

Summary of Key Features:

The PV Loop Module is a LabChart Module used for pressure-volume studies.

PV Loop Module provides equal functionality of the PVAN Ultra software and includes a number of additional features:

- **Unlimited sample size** PVAN Ultra is limited to a maximum 25,000 data points.
- **Online analysis in real-time** PVAN Ultra is limited to Offline analysis.
- **Dynamic and linked data display** Reanalysis of selected data is instantly updated in all views.
- **New Analysis Manager** Data can be saved and restored from within the same file.

Overview of PV Loop Module:

- Data can be analyzed and displayed both Online and Offline.
- Loop View. An analysis view where individual loops can be reviewed and selected for inclusion/exclusion in analyses. Loop View plots and displays the key cardiac parameters:
 - ESPVR (End Systolic Pressure-Volume Relationship). The slope of the ESPVR curve as an index of myocardial contractility; the steeper the ESPVR curve, the greater the cardiac contractility.
 - EDPVR (End Diastolic Pressure-Volume Relationship). The slope of the EDPVR curve is an indicator of ventricular compliance; the steeper the curve, the greater the ventricular stiffness.
- The Hemodynamics Table. This reports 29 parameters for each individual loop including:
 - Stroke Work.
 - Cardiac Output.
 - Ejection Fraction.
 - Tau (the Isovolumic Relaxation Constant).
- Data in the Hemodynamics Table can be exported to file or copied into Data Pad by a single click
- Four different analysis plots are provided by PV Loop.
 - PRSW View. Preload-Recrutable Stroke Work is used as an index of contractility.
 - dP/dt Max vs. EDV View shows the steepest slope during the upstroke of the pressure curve versus end diastolic volume. This is used as an index of contractility.
 - PVA vs. EDV Plot. PVA is the mechanical energy generated by contraction of the ventricle.
 - PVA vs. ESP Plot.
- Easy automated Calibration:
 - Cuvette calibration - for calculating absolute volume units using calibration cuvettes.
 - Saline calibration - for determining parallel conductance of ventricular wall (V_p).
- Note that LabChart 7.1.1 or later is required for PV Loop.
- PV Loop Module is included in LabChart Pro. LabChart Pro provides access to all Modules and all subsequent releases of LabChart and Module software for five years from the date of purchase.

Analysis Manager:

- The PV Loop Module includes a new Analysis Manager feature. This provides investigators with the ability to quickly save and compare different data selections and their respective analyses.

Introduction:

PV Loop Module is a convenient and powerful tool for the detection and analysis of left ventricular pressure and volume data. PV Loop seamlessly processes data acquired using MPVS Ultra and pressure-volume Mikro-Tip catheters.

Uses:

Pressure-Volume analyses are used in various Hemodynamic Assessment applications:

- Baseline and Occlusion Analysis.
- Heart Hypertrophy and Failure Models.
- Effects of Specific Gene Manipulation.
- Pharmacology/Toxicology Studies.

Features:

- Automatic calculation and display of the end-systolic pressure-volume relationship (ESPVR) and the end-diastolic pressure-volume relationship (EDPVR) and their associated regression values.
- The advanced plotting options of PV Loop include four analysis plots: PRSW Plot, dP/dT Max vs. EDV Plot, PVA vs. EDV Plot and PVA vs. ESP Plot.
- The reporting of 29 different hemodynamic parameters and associated statistics in the Hemodynamic Table. Full user control over selection of data for inclusion in analyses.
- All parameters available in the Hemodynamics Table can also be plotted in Chart View in real time using Channel Calculations.
- Results can be reported in Volts, Relative Volume Units or absolute volume units.
- Cuvette and Saline calibration functions enable easy calibration of raw data.
- Analysis Manager enables instant review, editing and reprocessing of analyses.

PV Loop Module compared to PVAN Ultra:

With the PV Loop Module the use of the PVAN Ultra or other software for analysis and reporting of pressure-volume data is optional. PV Loop Module has equivalent functionality to PVAN Ultra.

- PV Loop Module can present data in real-time.
- PV Loop does not limit the sample size to 25,000 points of data (e.g., 25 s at 1 kHz). When using PV Loop, the sample size is limited by the processing capacity of the machine on which PV Loop is running. Note that with very large data sets (of several million data points), drawing of Loop View and the calibration graphs has been known to time out. However, this had no effects on the accuracy of the results displayed in the Hemodynamics Table. This feature of PV Loop allows different data types (namely occlusion, steady state, and saline data) to be saved and analyzed from within the same channel and in the same file. The Analysis Manager in PV Loop makes saving, finding and reanalyzing these data selections very easy.
- Note that when recording pressure-volume data from rats and mice, the data should be sampled at a minimum rate of 1 kHz. For animals with comparatively slow heart rates the sampling rate can be adjusted accordingly, if necessary.
- PV Loop provides the Weiss calculation method for Tau. PVAN Ultra also provides the Tau (Glantz) and Tau (Logistic) calculations. In practice the three methods can differ in the results obtained.

Documentation Files:

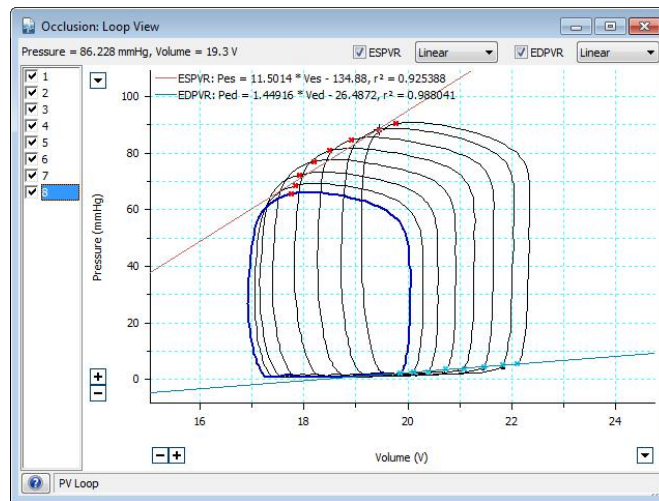
PV Loop Module includes a Demo file of Baseline and Occlusion data used for demonstrating the detection and analysis of left ventricular pressure and volume data. Also included is a Tutorial data file used in conjunction with the supplied "Getting Started with PV Loop" tutorial to help new users familiarize themselves with the PV Loop Module.

Loop View:

Loop View is central to the PV Loop Module. Loop View is able to present and analyse data both dynamically in real-time (when Online mode is selected) and statically (when Offline mode is selected). Loop View calculates and reports the key hemodynamic regression equations for the End Systolic Pressure Volume Relationship (**ESPVR**) and the End Diastolic Pressure Volume Relationship (**EDPVR**). EDPVR and ESPVR are derived from series of loops obtained by gradual aortic occlusion. EDPVR and ESPVR are valued by researchers because, compared to other indices, they are relatively insensitive to changes in preload, afterload and heart rate. ESPVR defines the maximum pressure that can be developed by the ventricle at any given left ventricular volume. The pressure-volume loop cannot cross over the ESPVR because the ESPVR defines the maximum pressure that can be generated under a given contractility (inotropic) state. The slope of the EDPVR is the reciprocal of ventricular compliance. The filling phase moves along the EDPVR or passive filling curve for the ventricle.

In addition to the regression equations, the associated R^2 coefficient constants are provided. Another useful feature of Loop View is that it allows the user to select whether either a linear, quadratic (for ESPVR) or linear, exponential (EDPVR) equations are used to model ESPVR and EDPVR. The choice of linear or quadratic will normally depend on the shape of the data and which line of best fit has higher R^2 values, if the latter differ significantly. The ESPVR and EDPVR equations are plotted over the data. This allows the user to intuitively assess the data in real-time. These lines are colored red and blue, respectively, in the following figures. If the user does not want the regression data plotted, the ESPVR and EDVPR options can be simply deselected with the Loop View window.

Individual loops can be added or removed from the analysis in the left hand region of the Loop View. When a numbered row is selected, the corresponding loop changes from black to blue color within Loop View. Individual loops in Loop View can also be selected by clicking the end systolic or diastolic point. In keeping with other LabChart Modules, data is cross linked between the various analysis windows. Thus highlighting a particular loop in the Hemodynamics Table will center the loop within Chart View as well as select the same loop within Loop View. This allows the user to quickly cross check the various data in all PV Loop windows.



Loop View - The ESPVR and EDPVR functions are plotted red and blue respectively. The equations and the corresponding regression information is reported in the upper left corner. In this example, number eight loop has been selected and shows as the blue colored loop. Deselection of any particular loop removes it from the analyses provided both in Loop View, the Hemodynamics Table and other views.

Hemodynamics Table:

The Hemodynamics Table displays the calculated parameters for each detected loop. To open this view, choose PV Loop→Hemodynamics Table. As with Loop View, the analysis can be updated and displayed in real-time or in offline mode. The Hemodynamics Table reports up to 29 parameters for each individual loop as selected by the user. Summary statistical information can also be updated and displayed in the Hemodynamics Table. All information available in the Hemodynamics Table can be exported in both text (*.txt) and comma delimited (*.csv) formats. Transfer of all data into Data Pad is done simply by clicking the **Add to Data Pad** tab.

1	214.0	1273	2.181	9.445	7.544	8.625	9.097	145.4	-3.028	48.50	148.9	144.8	1.486	606.1	22.11	68.90	372.5	104.5	0.5748	4.008
2	194.4	1223	2.018	9.547	7.529	8.578	8.829	142.1	-2.872	46.56	144.9	141.9	1.186	606.1	21.58	70.32	348.7	154.3	0.5576	3.842
3	202.9	1251	2.043	9.588	7.515	8.572	8.972	143.2	-3.059	47.87	146.3	142.7	1.020	612.2	21.77	69.82	358.8	155.7	0.5658	3.861
4	213.5	1211	1.998	9.506	7.509	8.521	9.285	140.5	-3.560	46.20	143.0	140.2	1.238	606.1	21.06	70.18	364.0	150.5	0.5867	4.159
5	204.0	1224	2.020	9.510	7.490	8.548	9.031	142.1	-3.091	46.67	145.2	140.6	1.249	606.1	21.45	70.13	355.7	151.7	0.5794	4.077
6	176.5	1122	1.852	9.338	7.487	8.478	8.718	137.4	-2.830	44.16	140.2	137.5	0.5307	606.1	20.11	74.35	323.5	147.0	0.5457	4.112
7	189.8	1170	1.931	9.416	7.483	8.484	8.843	140.9	-3.028	46.17	143.9	140.4	0.6244	606.1	20.89	72.68	341.9	152.1	0.5551	3.986
8	192.5	1130	1.864	9.304	7.440	8.372	9.125	137.0	-2.498	44.38	139.5	136.0	1.499	606.1	20.07	72.94	338.5	146.0	0.5687	4.425
9	181.7	1099	1.797	9.250	7.453	8.407	8.970	137.1	-3.028	43.92	140.2	136.9	1.811	606.1	19.58	76.38	325.6	143.9	0.5581	4.256
10	157.5	990.8	1.635	9.093	7.408	8.297	8.680	133.1	-3.059	41.95	136.1	132.6	0.4038	606.1	18.13	81.14	301.3	143.8	0.5227	4.148
11	171.9	1065	1.767	9.243	7.485	8.388	8.749	138.0	-3.203	45.02	140.9	137.3	0.9990	606.1	19.27	78.38	320.9	148.1	0.5355	4.200
12	188.2	1114	1.819	9.243	7.424	8.372	9.114	135.9	-3.310	44.36	138.2	135.2	1.717	612.2	19.71	74.32	328.3	140.1	0.5733	4.403
13	181.6	1067	1.760	9.192	7.432	8.379	9.057	135.6	-2.747	43.43	138.0	135.4	1.623	606.1	19.19	76.94	321.2	139.6	0.5654	4.270
14	195.3	1070	1.832	9.071	7.439	8.278	8.660	133.3	-3.053	42.00	136.2	132.9	0.4843	600.0	18.17	81.45	300.9	141.6	0.5293	4.167
15	162.8	1002	1.653	9.099	7.447	8.313	8.698	135.6	-2.935	43.78	138.6	135.2	1.061	606.1	18.37	81.84	305.4	142.6	0.5330	4.059
16	180.0	1073	1.752	9.138	7.386	8.275	9.027	132.7	-2.375	43.04	135.1	132.1	1.155	612.2	19.20	79.40	315.2	135.2	0.5712	4.292
17	176.6	1038	1.713	9.120	7.407	8.292	9.093	131.4	-2.726	41.23	134.1	131.1	1.592	600.0	18.78	76.96	310.5	133.9	0.5687	4.476
18	155.4	955.3	1.576	8.989	7.412	8.216	8.649	130.9	-3.122	41.04	134.0	130.6	0.9366	606.1	17.64	82.83	290.5	135.0	0.5351	4.211
Avg	155.8	959.9	1.588	8.986	7.398	8.165	8.740	127.2	-2.824	40.29	130.1	128.8	0.9891	604.3	17.72	81.06	287.2	131.4	0.5389	4.293
Min	95.27	624.8	1.058	8.379	7.270	7.738	8.126	106.0	-3.497	32.73	108.0	105.3	0.0000	600.0	12.69	68.90	211.6	106.7	0.4807	3.842
Max	214.0	1273	2.181	9.445	7.544	8.625	9.285	145.4	-3.280	48.50	148.9	144.8	1.484	612.2	22.11	105.0	372.5	158.5	0.5867	4.260
Count	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47

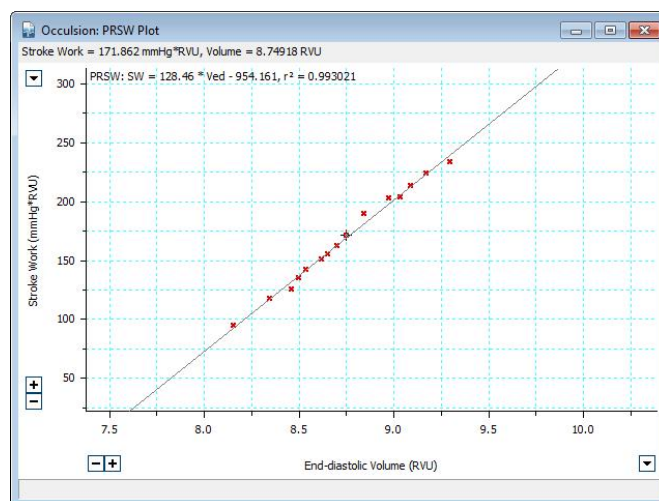
Hemodynamics Table - The Hemodynamics Table displays calculated cardiac parameters. Note that the table can be exported using the **Export** button. Parameters displayed in the Hemodynamics Table can be selected by choosing the **Options** button. Data can also be copied to Data Pad by choosing **Add to Data Pad** button.

Parameters reported in the Hemodynamics Table are configured after selecting the **Options** button in the lower left corner of the Hemodynamics Table.

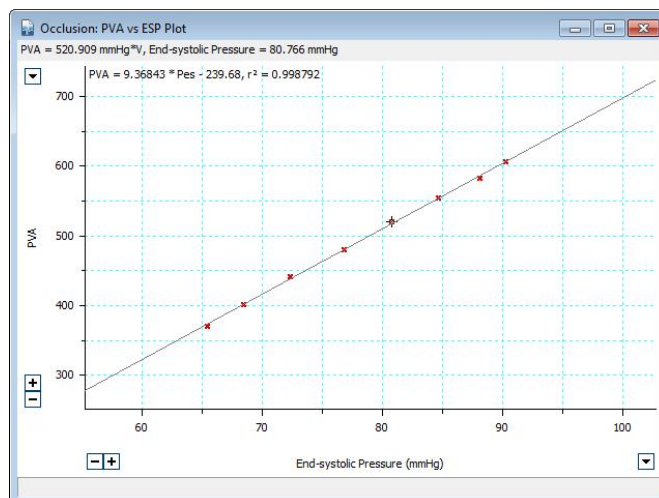


Hemodynamics Options – Parameters that can be reported in the Hemodynamics Table include Cardiac Output, Stroke Work, Stroke Volume and Tau. The display of summary information can also be turned off within the **Options...** button.

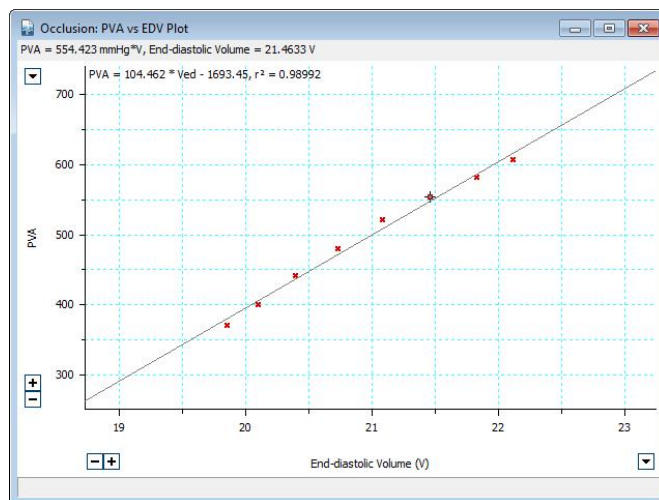
Analysis Plots:



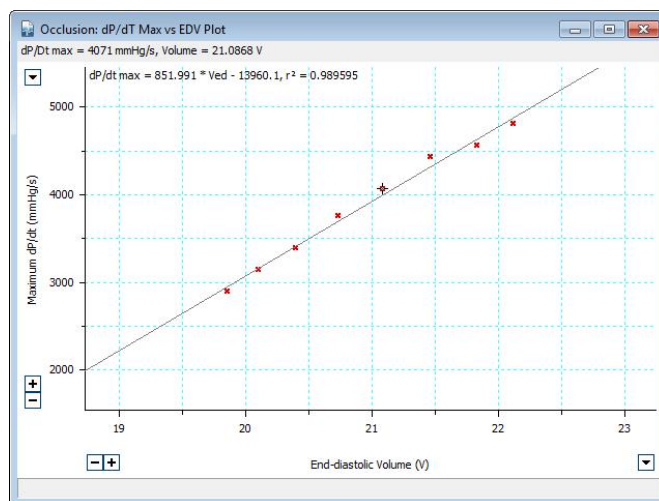
PRSW Plot – The PRSW View displays a plot showing the Preload-Recrutable Stroke Work. Investigators use this as an index of contractility. PRSW View plots a scatter graph of Stroke Work versus End Diastolic Volume. As with other plots in the PV Loop Module, regression information is displayed in the plot and instantaneous values are displayed above the plot by moving the tracking cursor on a point in the plot. Clicking on a data point similarly highlights the associated loop in Loop View, the Hemodynamics Table and Chart View.



PVA vs. ESP Plot - Pressure Volume Area plotted against End Systolic Pressure. PVA represents the total mechanical energy generated by ventricular contraction and is used to calculate cardiac efficiency.



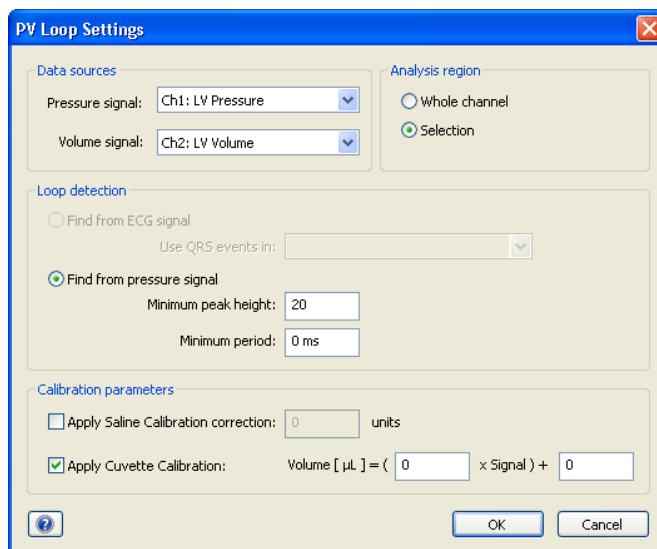
PVA vs. EDV Plot - Pressure Volume Area plotted against End Diastolic Volume. Both PVA vs. EDV and PVA vs. ESP plots include the standard features available in PV Loop plots such as regression information, copy and paste capability and dynamic linking in real-time with the other analysis views and the Hemodynamic Table in PV Loop Module.



dP/dt Max vs. EDP Plot - PV Loop also provides a dP/dt Max vs. EDP plot. The plot is an XY scatter graph of maximum change in pressure versus end diastolic volume for the currently analyzed data and is valuable to researchers as an index of cardiac contractility.

How to use PV Loop:

PV Loop Settings dialog box: The PV Loop Module is accessed from the PV Loop toolbar menu (as per other Modules). The Settings box enables selection of Data Source and the Analysis region (Whole channel or Selection).



PV Loop - Settings Dialog Box.

Selection of data: The PV Loop Module requires two sets of data; pressure and volume. The Chart View channel data corresponding to these measures are in PV Loop Settings box. The analysis region can be the entire channel data or limited to a user selected subset; for example during a user defined occlusion event.

Loop Detection: PV Loop Module offers two methods for detecting the end of diastole when analyzing a ventricular pressure signal. Loops can be detected from either the pressure signal or from an ECG signal.

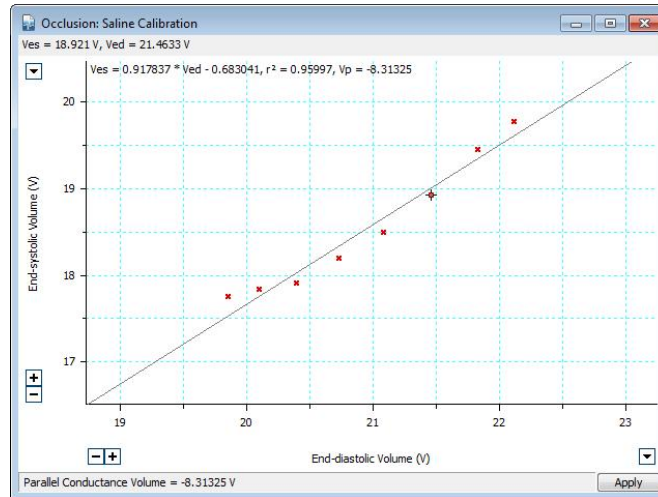
- Minimum peak height can be defined for the cycle to be recognized. Note that this is not an absolute threshold level for cycle detection but rather a net amplitude. A Minimum period can also be defined so that any secondary peak occurring within this period will not be recognized as an event. The Minimum period can be entered as seconds (s) or milliseconds (ms).
- If an ECG signal has been recorded synchronously with the pressure signal, the user can trigger EDP detection at the time of the QRS complex. The signal trigger at the largest peak of the QRS complex.

Calibration: There are essentially four aspects to calibrating PV Loop data. One of these concerns the pressure data. The other three are concerned with volume calibration.

- **Pressure Calibration:** Calibration of the pressure channel data from Volts to mmHg is simply done using the **Units Conversion...** feature, similar to how it's done for any pressure signal.
 - The Settings dialog box is not relevant to calibrating the pressure data.
- **RVU Calibration:** Relative Volume Unit calibration is where voltage signal output from the MPVS Ultra is used to calibrate the signal into arbitrary relative volume units (RVUs).
 - RVUs are widely used when researchers only require an estimation of ventricular volume rather than an absolute measure. It is ideal for studies where changes in relative ventricular volume changes are important rather than absolute volume.
 - RVUs are calibrated using the **Units Conversion...** When set to 5.0 RVU the MPVS outputs an approximately -8 V and approximately +9 V when set to 50.0 RVU.

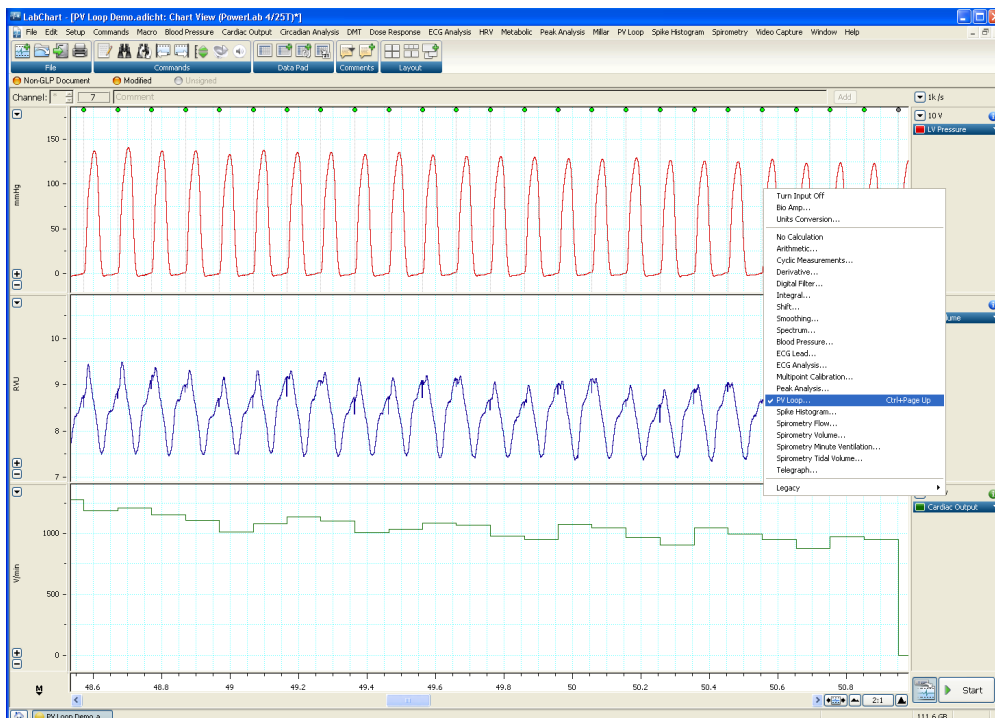
shows the regression information in the upper left corner of the window and includes the key parameter of Vp.

- The Vp parameter value is also displayed along the bottom of the plot as shown in the following figure.
- By clicking Apply, the Vp value will be automatically entered into the Settings field and can then be subsequently applied as a correction factor to other selected data.



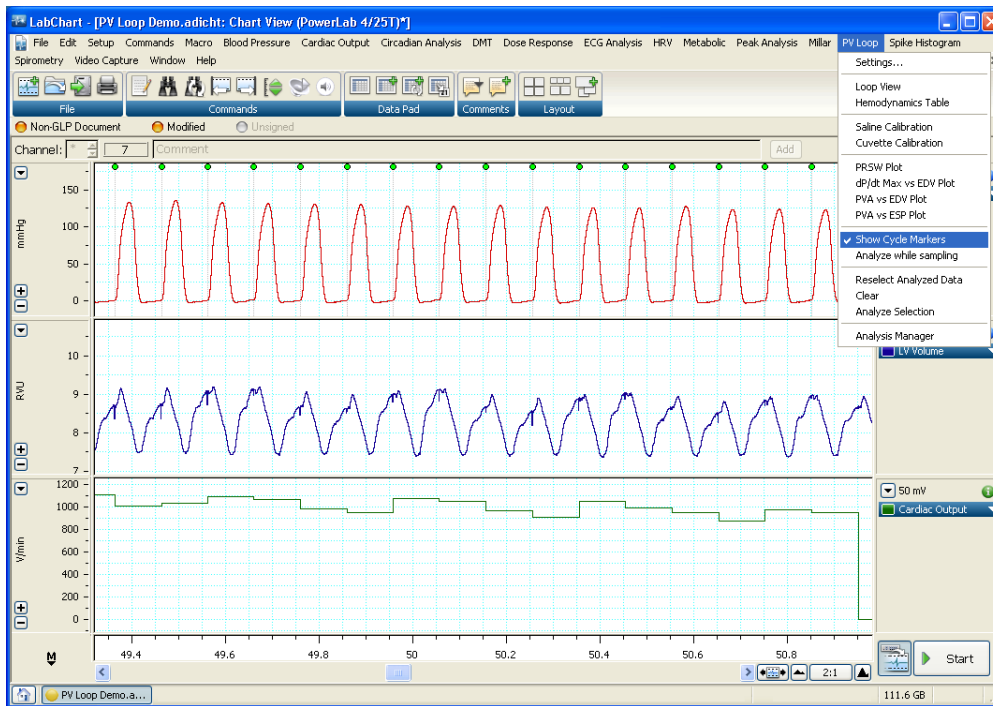
Saline Calibration – Select via PV Loop → Saline Calibration. The plot is an XY scatter graph of End Systolic Volume versus End Diastolic Volume for the currently analyzed data. The intersection between the regression line and a second line representing $V_{ed} = V_{es}$ (equal end-systolic and end-diastolic volumes) represents the parallel conductance. This value is Vp. The value of Vp is displayed at the top and bottom of the graph.

Channel Calculations: PV Loop parameters are also available as Channel Calculations within Chart View.



Channel Calculations - Select Channel Calculations→PV Loop→Cardiac Output. This is enabled in Channel 3 above. All 29 PV Loop parameters available in the Hemodynamics Table can be displayed as channel calculations. Event markers indicate the position of detected and selected cycles in Channel 1, configured through the Settings dialog box.

Cycle Markers: PV Loop Hemodynamics Table parameters are also provided as as Channel Calculations within Chart View. Enabling Cycle Markers allows users to identify loops being detected in real-time.



Cycle Markers - The display of Event Markers for detected cycles can be turned on or off through the PV Loop menu.

Analysis Manager:

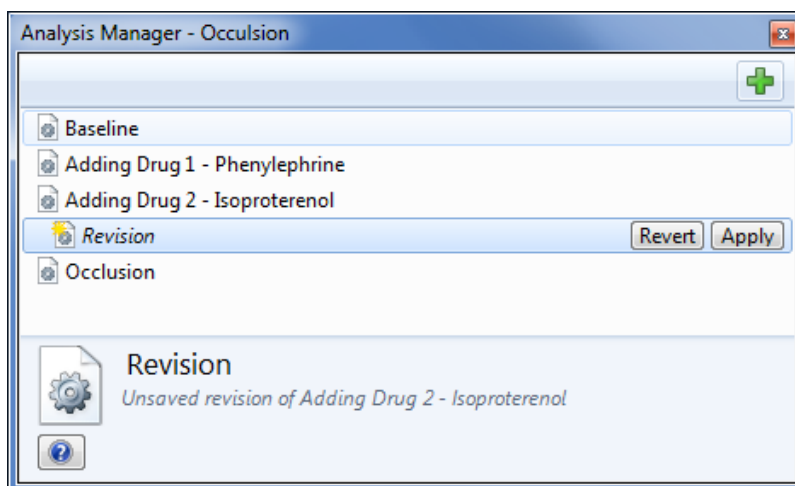
In PV Loop Module a new feature has been added called Analysis Manager. When doing PV studies it is often necessary to select different regions of data for analysis. For example, data acquired during the saline bolus needs to be selected and analyzed to calculate V_p . Selected data such as this can be saved and quickly restored using the Analysis Manager. Similarly, data selections acquired during steady state, for example, may require recalibration using the calculated V_p value.

The Analysis Manager can be used to save the settings associated with an analysis. This allows separate data regions within a data file to be analyzed, results of the complete analysis state to be saved and each saved analysis set to be recalled. By clicking on a region saved within Analysis Manager automatically restores:

- the settings in the Settings dialog

- the parameters selected for analysis
- the selection in Chart View and selections made in the menu options (e.g., show cycle markers)
- the selections made in the views (e.g., regression information, loop exclusion etc..)

Using the Analysis Manager previously saved analyses can be reviewed and if required reselected and analyzed by the PV Loop Module. A new analysis can then be reviewed and saved as a revision (overwrite) of the named region, or the original analysis can be restored by clicking the **Revert** button.



Analysis Manager - Analysis Manager is opened by selecting PV Loop→Analysis Manager. Detailed information on using Analysis Manager is available in the PV Loop Help section in LabChart.

In Summary

- Analyses done with PV Loop can be saved and restored so that two analyses can be easily compared.
- Calibration or other values derived from one data selection can be saved and applied to other data selections.
- Saved analyses can be uniquely named and have comments recorded with them.
- Saved data regions can be reselected and reanalyzed. The resulting region can be applied or discarded by clicking the Revert button. This allows users to optimize data analysis without having to discard previously saved analyses.