

Recording Blood Pressure

This application note describes the use of PowerLab transducers and front-ends, together with Chart software, to record intravascular blood pressure, and discusses optimal sampling speed and filter settings.

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Introduction

Invasive recording of arterial or venous blood pressure in animals is required in a wide range of research and teaching applications. A cannula is attached to a pressure transducer (both being prefilled with heparinised saline), inserted into the blood vessel of interest, and tied in place. Pressure fluctuations in the vessel are then transmitted along the cannula to the transducer's diaphragm, which moves very slightly in response. The diaphragm movements are converted into a varying electrical signal.

Equipment needed

Any PowerLab unit connected to a computer with Chart software can be used to record the data. Three different PowerLab transducers, and two front-ends, are suitable for recording blood pressure.

Transducers

- MLT 1050 blood-pressure transducer. This small unit has a convenient brass mounting bar. It is supplied with an 8-pin DIN connector for use with a PowerLab Bridge Amp, and has two Luer fittings.
- MLT 0380 blood-pressure transducer. This unit has a removable cap for cleaning and sterilisation. It is supplied with an 8-pin DIN connector for use with a ML110 Bridge Amp, and has two Luer fittings.
- MLT 0698 low-cost disposable blood-pressure transducer. This is supplied with a Tronomed lead (MLCBP1) for connection to the PowerLab BP Amp. The combination is precalibrated. Alternatively, an adaptor cable allows the transducer to be used with a Bridge Amp. The transducer has three Luer fittings, one of which includes a three-way tap.

Front Ends

- The ML 110 Bridge Amp is a versatile non-isolated bridge amplifier with a range of low-pass filter settings (2 kHz down to 1 Hz).

- The ML117 BP Amp is electrically isolated for safe human use (to IEC standard 601.1 CF), and has a fixed 55 Hz low-pass filter. It is precalibrated for the MLT 0698 transducer.

Setting up

Plug the pressure transducer into the front panel socket of the front-end (Bridge Amp or BP Amp), and connect the latter to the PowerLab unit in the usual way. Start the Chart program, and select the Bridge Amp... or BP Amp... command from the appropriate Channel Function pop-up menu.

Ensure that the transducer has a connection open to the air, so that there is no applied pressure, and click the Zero button in the dialog box (Fig. 1).

Recommended filter settings for the Bridge Amp are shown in Fig. 1.

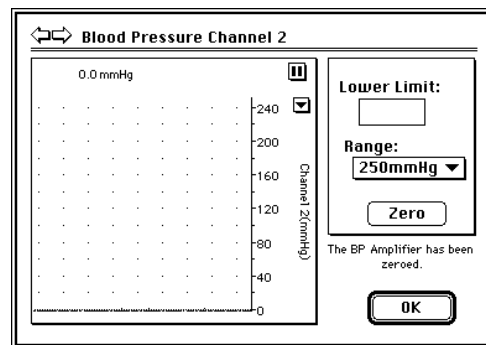
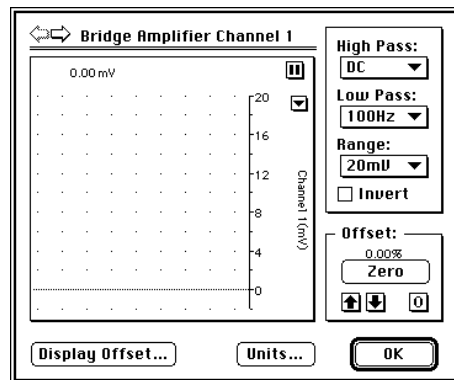


Figure 1. Bridge Amplifier and Blood Pressure Amplifier dialog boxes, after zeroing.

Calibration

Calibration requires a temporary connection of the transducer to a known pressure (commonly a clinical BP manometer with rubber inflating bulb). A short Chart recording of the transducer output at the known pressure can be used for Units Conversion (Figs. 2 and 3). Many workers also record a transition to zero pressure after opening the connection; this allows a check on the accuracy of the zeroing.

Cannula connection

Details of connection and filling methods differ greatly from laboratory to laboratory, and so only an outline is given here. The cannula is connected to one of the Luer fittings ('cannula port') on the transducer, with or without an intervening pressure line. Heparinised saline is then introduced through the other Luer fitting ('filling port') so as to fill the transducer and backfill the cannula, care being taken to avoid bubbles. Lastly a stopcock on the filling port is closed off, leaving the cannula as the only hydraulic connection from the transducer.

After the cannula has been tied into a blood vessel it is necessary from time to time to inject small additional quantities of heparinised saline via the filling port, in order to prevent clotting of blood in the cannula.

Direct waveform data recording

If the low-pass filter frequency and the sampling speed are both set high enough, most or all of the information in the transduced pressure waveform will be retained in the digitised recording. This is the usual goal.

The 'Spectrum' Chart extension is a useful tool for investigation of frequency components of the recorded signal (Figs. 4 and 5). For the example shown, in spite of fast sampling and a high filter frequency, no pulse-related frequency components above 42 Hz are evident. Thus we would expect that essentially all information will be retained with a filter frequency of 100 Hz and sampling speed of 200 samples per second (200/s) or faster. Experiment confirms this (Figs 6 and 7).

As a minimum, the low-pass filter frequency (if adjustable) should be at least 10 times the heart rate. In general the sampling speed (that is, frequency) should be at least twice the filter frequency. For accurate reproduction of dicrotic notches and diastolic and systolic extremes, high sampling speeds are desirable, perhaps up to 50 or 100 times the heart rate.

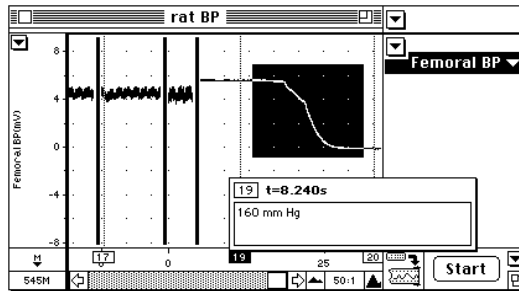


Figure 2. Calibration data. The selected part of the Chart trace includes a calibrated pressure change from 160 mmHg down to 0 mmHg, shown by the comment that is 'popped up' for viewing.

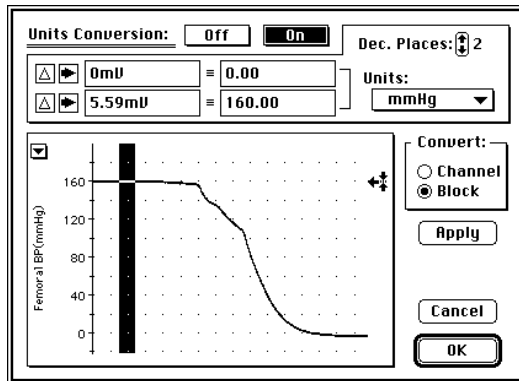


Figure 3. The Units Conversion dialog box, showing the data of Fig. 2, and the calibration in mmHg. If the Bridge Amp has been correctly zeroed, one conversion equation can be entered as 0 mV = 0 mmHg. Full instructions for Units Conversion are given in the *Chart User's Guide*.

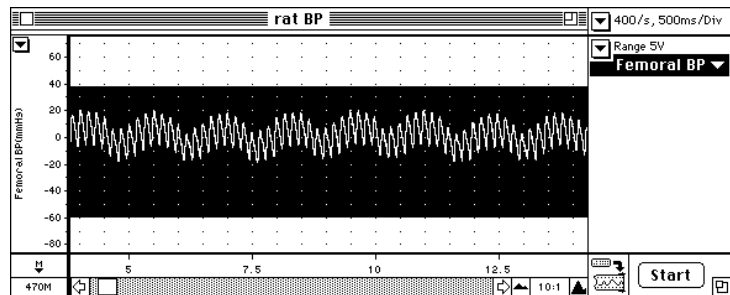


Figure 4. Rat blood pressure, sampled at 400/s, with the Bridge Amp low-pass filter at 200 Hz. To allow better display in Fig. 5 of spectral frequencies greater than 0, the mean value of the selected data has been set to zero with Chart's Set Baseline command.

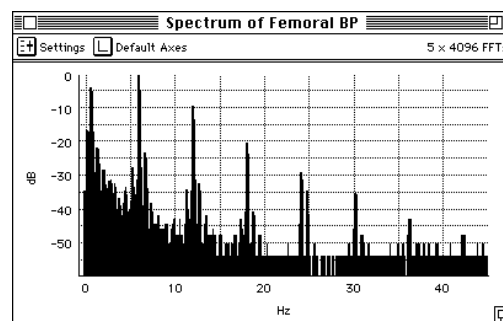


Figure 5. Spectrum of data in Fig. 4, showing a respiratory component at 0.7 Hz, the fundamental pulse at 6 Hz, and diminishing harmonics at 12, 18, 24, 30, 36 and 42 Hz. Note the vertical dB scale.

Figure 6. Waveform recording of rat's blood pressure at different sampling speeds. The Bridge Amp's low-pass filter frequency was 200 Hz. Each record is 1 s long; heart rate is approximately 360 BPM (6 Hz). Traces (a) and (b) are grossly under-sampled.

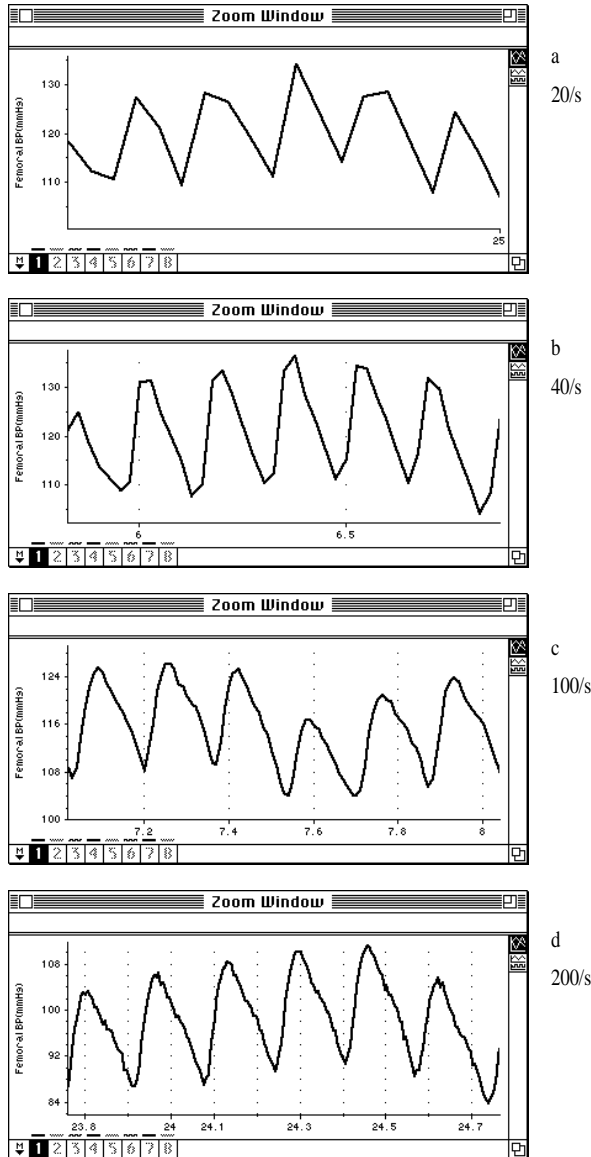


Figure 7. Waveform recording of rat's blood pressure sampled at 400/s, with different low-pass filter frequencies set in the Bridge Amp. Each record is 1s long. In trace (a), only a respiratory variation in mean BP is evident; trace (b) shows pulsatile variations, but they are grossly distorted.

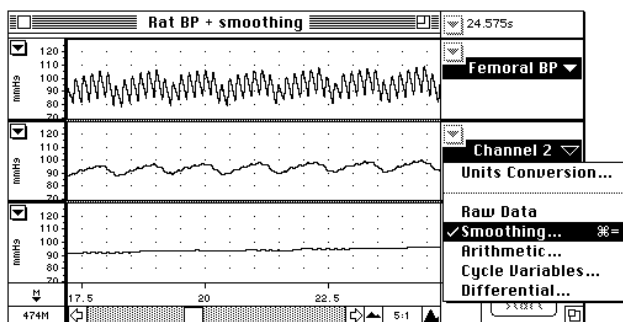
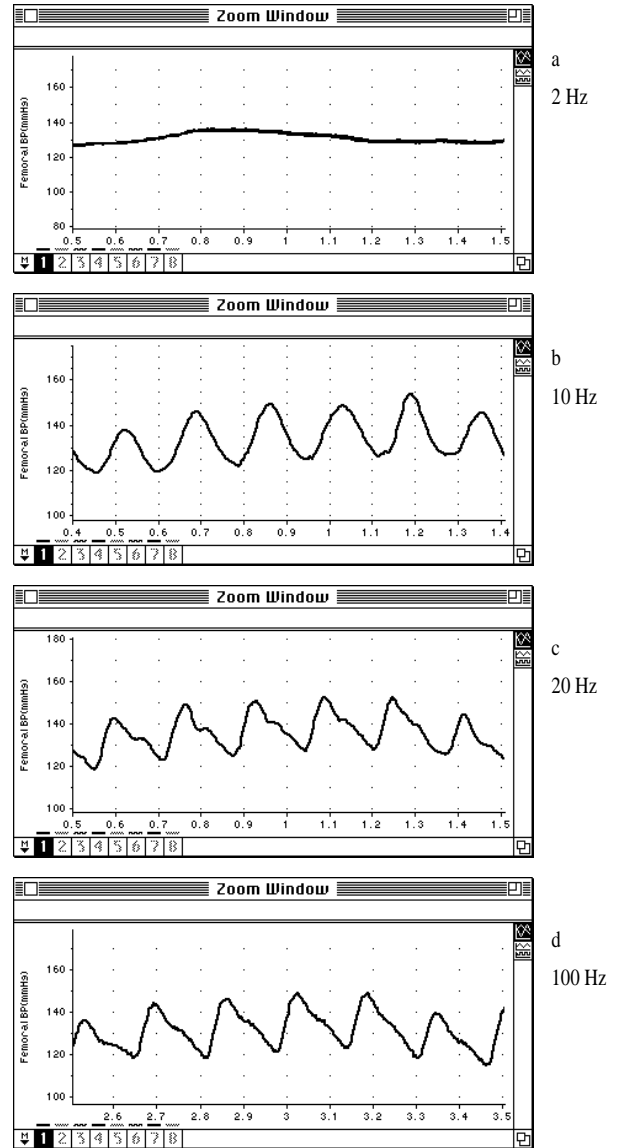


Figure 8. Off-line smoothing for mean BP. Top trace: raw data, sampled at 200/s. Middle trace: smoothing with amount 30 removes cardiac cycle-related pressure changes. Bottom trace: smoothing with amount 100 removes respiratory variations as well.

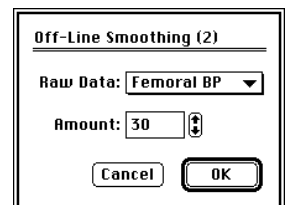


Figure 9. Off-line smoothing dialog box for Channel 2. Note that you can choose any channel in the Raw Data pop-up menu.

Off-line calculations

The most commonly required derived signal is the mean blood pressure, from which pulsatile variations have been removed. This can be obtained most simply by smoothing the raw data (Figs 8 and 9). Alternatively, the Cycle Variables Chart extension (supplied as standard) can be set up to display cyclic mean — the pressure averaged over one cardiac cycle, and updated after each cycle (Figs 10 and 11). These off-line calculations are done after data recording is completed. Triggering threshold settings and baseline tracking can be adjusted by trial and error, so as to avoid the two commonest problems: false triggering on dicrotic waves, and temporary loss of triggering.

Cycle Variables can also display cyclic minimum (representing diastolic pressure), cyclic maximum (representing systolic pressure), and heart rate or period. More detailed examination of heart rate can be made with the Heart Rate Variability (HRV) Chart extension.

Recording with reduced information

In certain circumstances, particularly when recording over long periods of time, it may be desirable to sample at a much lower speed than that needed in direct waveform recording. The advantage is that the resulting disk file is smaller, and therefore easier and quicker to review or analyse. The PowerLab system offers several alternatives.

Restricted bandwidth of BP signal

If the animal's heart rate is well above 2 Hz, the Bridge Amp's low-pass filter may be set at 2 Hz to suppress fluctuations during the cardiac cycle (see top trace in Fig. 7). With a suitable sampling speed such as 4 samples per second (4/s), the recording represents mean BP.

Computed Input — cyclic parameters

Chart's Computed Input offers a range of 'cyclic' parameters that duplicate those in the Cycle Variables extension (Figs 12 and 13). One difference is that these calculations are on-line: the computed function *replaces* the raw data. The raw data itself is lost (unless it is recorded separately on a different channel). Another, less important, difference is that raw data for computed inputs is sampled internally at 2000/s. The computed cyclic parameters maintain a steady value during each heart beat, and can therefore be sampled at a low speed (2/s – 10/s).

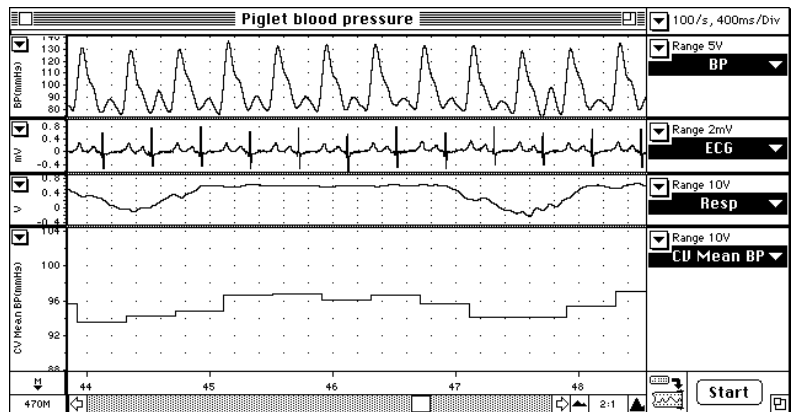


Figure 10. Arterial pressure, ECG, respiratory movements and cyclic mean pressure in a piglet. The bottom trace (cyclic mean) was calculated by the Cycle Variables Chart extension from the raw data in the top trace. It shows a respiratory variation in mean pressure.

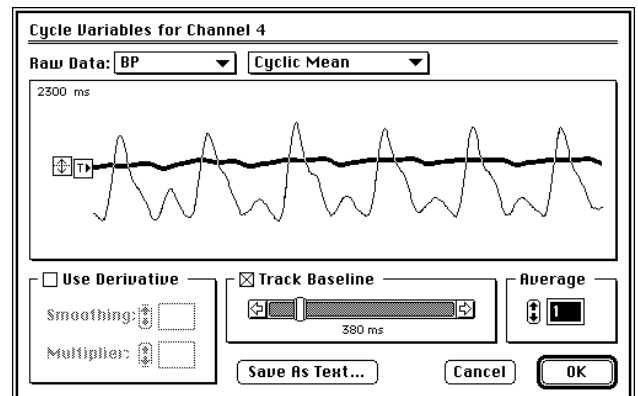


Figure 11. The Cycle Variables dialog box for cyclic mean, showing suggested settings for baseline tracking and triggering. In this example, care is needed to avoid false triggering on the dicrotic wave.

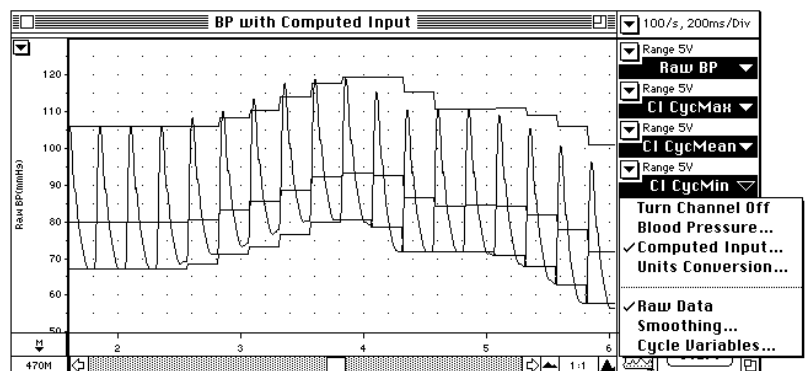


Figure 12. Waveform recording of pressure sampled at 100/s, together with the Computed Inputs cyclic maximum, cyclic mean, and cyclic minimum. The four traces are overlaid at the same vertical scale. The cyclic computed inputs change their values after each heartbeat, and no additional information is obtained by sampling them more often than once per beat.

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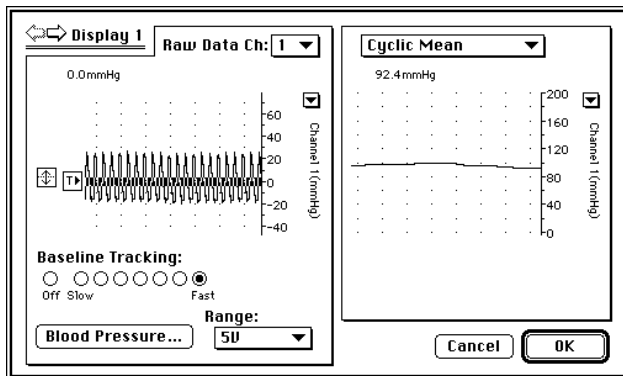


Figure 13. The Computed Input dialog box for a cyclic parameter (in this case Cyclic Mean), showing suggested settings for baseline tracking (fast) and triggering. Some manipulation of the drag-scale in the left pane is required to get correct display and triggering.

A serious disadvantage of this technique is that even if you have set up for correct triggering initially, a change in the pressure waveform during the experiment may produce the triggering problems mentioned above. In this case all information about the pressure signal is lost.

Computed Input — envelope

There are two envelope computed functions: Envelope Max and Envelope Min. The computed values are the maximum or minimum value attained by the raw data in each sampling interval. (Internally, and unseen by the user, the raw data is sampled at 2000/s). Thus for example if you set a sampling speed of 2/s, the computed values that are returned every 0.5 s are the maximum or minimum of 1000 internal samples.

In envelope recording, the sampling speed should be set *less than* the heart rate, to ensure that each sampling interval includes at least one pressure minimum and maximum. Then Envelope Max returns the systolic pressure and Envelope Min returns the diastolic pressure.

The advantage of the envelope functions is that there is no cycle detection; the functions work reliably and automatically regardless of the input waveform. The disadvantage is that the mean pressure cannot be obtained.

Frequency response

If the precise details of a pulse waveform are of interest, it will be necessary to pay attention to the frequency response of the transducer^{1,2}. The inertia of the liquid in the cannula combines with the compliance of the transducer (and pressure line) to form a second-order system, damped by hydraulic resistance (viscosity) in the cannula. A pop test² (Fig. 14) gives a measure of the response speed of the transducer/cannula combination. The resonant frequency should be greater than any components of the pulse waveform.

To increase resonant frequency:

- if possible, connect the cannula directly to the transducer with no intervening pressure line
- if a pressure line is used, it should be made of stiff material and be as short as possible
- de-gas the saline by boiling or applying a low vacuum, to reduce bubble formation
- remove visible bubbles in the transducer or cannula
- choose a cannula of the maximum diameter that will fit the blood vessel
- take care that the cannula tip is unobstructed.

References

1. L.A. Geddes, *The Direct and Indirect Measurement of Blood Pressure*, (Year Book Medical Publishers, Chicago, 1970).
2. I.T. Gabe, 'Pressure Measurement in Experimental Physiology', in *Cardiovascular Fluid Dynamics*, vol. 1, ed. D.H. Bergel (Academic Press, London, 1972), pp. 11–50.

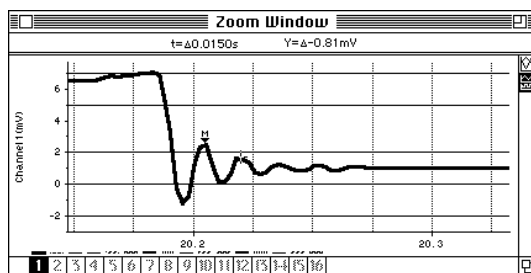


Figure 14. Pressure transient recorded during pop test of MLT 0380 transducer. The cannula was 38 mm long with an internal diameter of 0.9 mm. The marker and cursor have been placed over adjacent peaks of the damped oscillation, so that the time read-out shows the period (0.015 s), corresponding to a resonant frequency of 67 Hz.