

Respiratory Airflow and Volume

In this experiment, you will be introduced to spirometry as a technique for recording respiratory variables and you will analyze a recording to derive respiratory parameters. You will examine lung volumes and capacities, as well as basic tests of pulmonary function.

Written by staff of ADI Instruments.

Background

Gas exchange between air and blood occurs in the alveolar air sacs. The efficiency of gas exchange is dependent on ventilation; cyclical breathing movements alternately inflate and deflate the alveolar air sacs. Inspiration fills the alveoli with fresh atmospheric air and expiration removes stale air, which has reduced oxygen and increased carbon dioxide concentrations.

Many important aspects of lung function can be determined by measuring airflow and the corresponding changes in lung volume. In the past, this was commonly done by breathing into a bell spirometer, in which the level of a floating bell tank gave a measure of lung volume changes. Flow, F , was then calculated from the slope (rate of change) of the volume, V :

$$F = \frac{dV}{dt} \quad \text{Equation 1}$$

More conveniently, airflow can be measured directly with a pneumotachometer (from Greek roots meaning "breath speed measuring device"). The PowerLab pneumotachometer arrangement is shown in Figure 2. The flow head contains a fine mesh. Air breathed through the mesh gives rise to a small pressure difference proportional to flow rate. Two small plastic tubes transmit this pressure difference to the Spirometer Pod, where a transducer converts the pressure signal into a changing voltage that is recorded by the PowerLab and displayed with the Chart software. The volume, V , is then calculated as the integral of flow:

$$V = \int F dt \quad \text{Equation 2}$$

This integration represents a summation over time; the volume traces that you will see in the Chart View during the experiment are obtained by adding successive sampled values of the flow signal and scaling the sum appropriately. The integral is initialized to zero every time a recording is started. A complication in the volume measurement is caused by the difference in air temperature between the Spirometer Pod (at ambient temperature) and the air exhaled from the lungs (at body temperature). The volume of gas expands with warming, therefore the air volume expired from the lungs will be slightly greater than that inspired. Thus a volume trace, as calculated by integration of flow, drifts in the expiratory direction. To reduce the drift, the flow has to be integrated separately during inspiration and expiration, with the inspiratory volume being corrected by a factor related to the BTPS factor (body temperature, atmospheric pressure, saturated with water vapor). The Chart extension "Spirometry" can make this correction.

Spirometry allows many components of pulmonary function (Figure 1) to be visualized, measured and calculated. Respiration consists of repeating cycles of inspiration followed by expiration. During the respiratory cycle, a specific volume of air is drawn into and then expired out of the lungs; this volume is the Tidal Volume (V_T). In normal ventilation, the breathing frequency (f) is approximately 15 respiratory cycles per minute. This value varies with the level of activity. The product of f and V_T is the Expired Minute Volume (\dot{V}_E), the amount of air exhaled in one minute of breathing. This parameter also changes according to the level of activity.

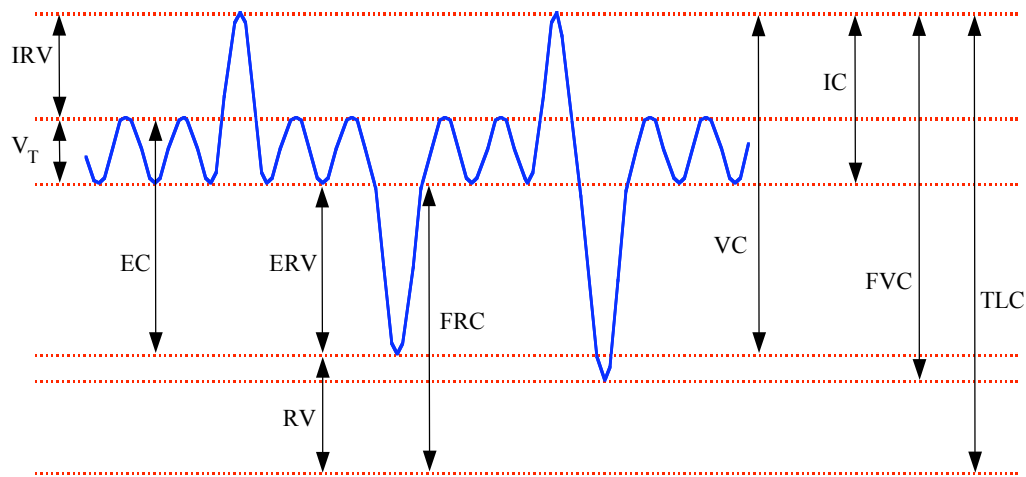


Figure 1. Lung volumes and capacities.

Required Equipment

A computer system
 Chart software
 Spirometry extension
 PowerLab
 Spirometer Pod
 Respiratory flow head (1000 L/min) with connection tubes
 Clean bore tubing
 Disposable filters
 Disposable vinyl mouthpieces
 Nose clip
 Tape measure or wall chart for measuring height
 Vital capacity prediction tables

Procedures

Set up and equipment calibration

Connecting the equipment

1. Connect the Spirometer Pod to the Pod Port for Input 1 on the PowerLab.
2. Since the Spirometer Pod is sensitive to temperature and tends to drift during warm-up, we recommend that the PowerLab and Spirometer Pod be turned on for at least 5-10 minutes before use. To prevent temperature drift, place the Spirometer Pod on a shelf or beside the PowerLab, away from the PowerLab power supply to avoid heating.
3. Connect the two plastic tubes from the respiratory flow head to the short pipes on the back of the Spirometer Pod, as shown in Figure 2
4. Attach clean bore tubing, a filter and mouthpiece to the flow head.

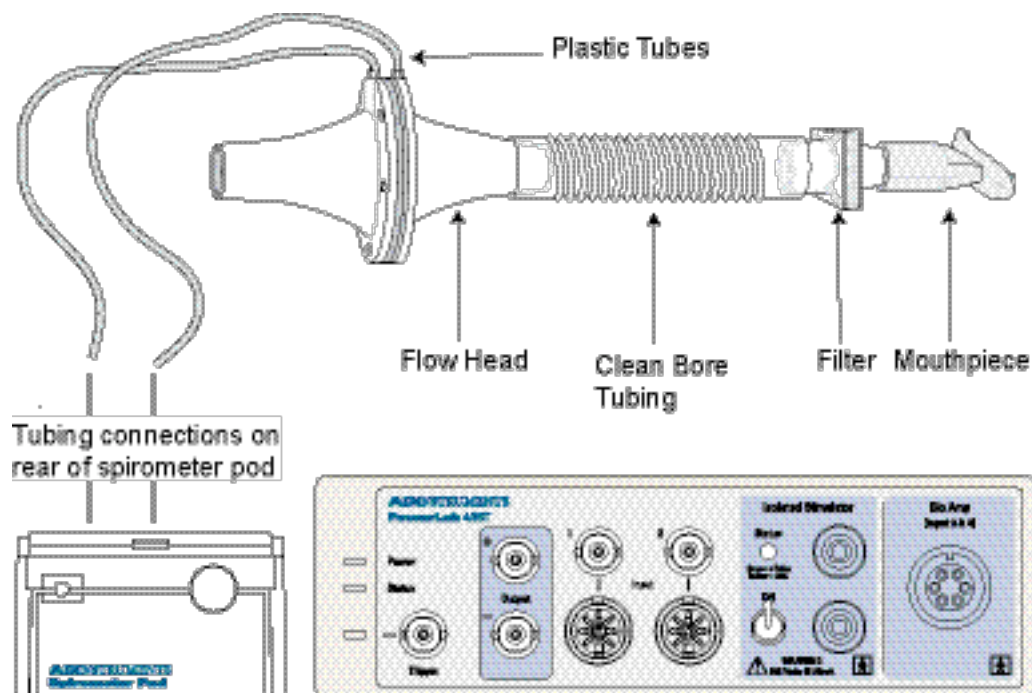


Figure 2. Setting up the spirometry experiment: connecting the flow head and attachments to the Spirometer Pod (The cable from the back of the Spirometer Pod to the Pod Port for Input 1 on the front of the PowerLab is not shown in this figure).

Hygiene

A clean mouthpiece and air filter should be supplied for each volunteer. The vinyl mouthpiece can be cleaned between uses by soaking it in boiling water or a suitable disinfectant. If you are suffering from a respiratory infection, we suggest that you do not volunteer for this experiment.

Starting the software

1. Locate Chart on the computer and start the software.
2. In the Experiments Gallery dialog, select "Respiratory" from the left-hand list. Select "Respiratory Settings" from the right-hand list, and click the Open button to apply those settings. If the Experiments Gallery dialog does not appear in front of the Chart View, choose the **Experiments Gallery...** command from the File menu.
3. After a short time, the Chart View on the computer screen should be set up for the experiment. Channels 1 and 2 are visible, with Channel 2 turned off; Channel 1 labeled "Flow" and Channel 2 "Volume".

Calibrating the Spirometer Pod and Flow head

1. The flow head must be left undisturbed on the bench during the zeroing process.
2. Choose **Spirometer...** from the Flow Channel Function pop-up menu. The Spirometer Pod dialog appears, as shown in Figure 3. Click the Zero button.
3. When zeroing has finished, have the volunteer breathe out gently through the flow head, and note the recorded signal in the data display area (Figures 3 and 4). If the signal shows a downward deflection (that is, negative), proceed to Step 5.
4. If the signal deflects upward, invert it. Click the Invert checkbox once to toggle its state.
5. Click OK to close the dialog window and return to the Chart View.
6. Now begin the exercises.

Note: the signal can also be inverted by reversing the orientation of the flow head, or by swapping the tubular connections to the Spirometer Pod. The Invert checkbox is simply more convenient.

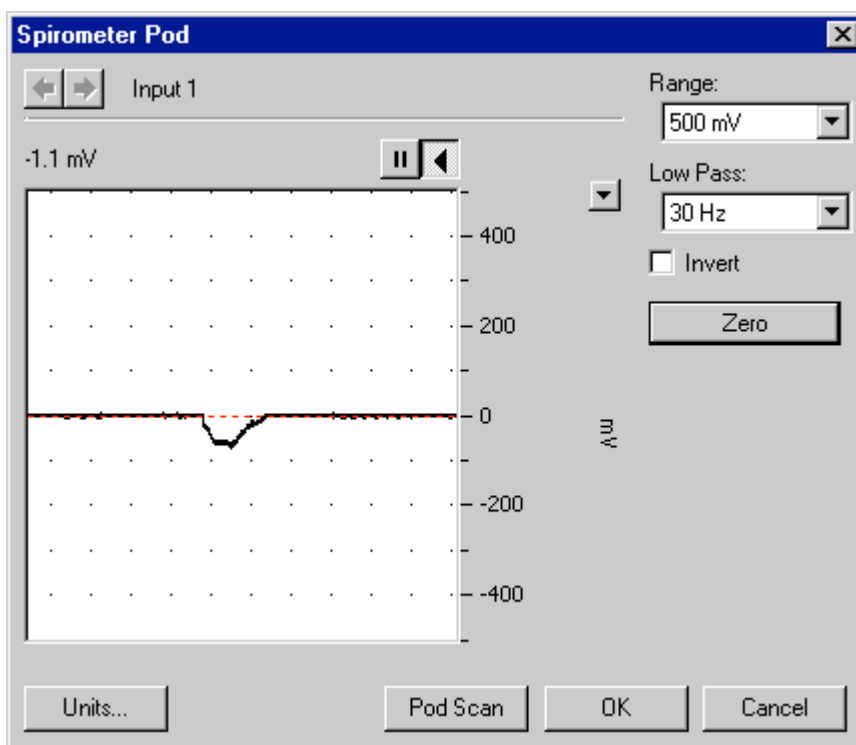


Figure 3. The dialog for the Spirometer Pod, showing an exhaled breath.

Exercise 1: Becoming familiar with the equipment

Objectives

In this exercise, the principles of spirometry will be described as well as how integration of the flow signal gives a volume.

Procedure

1. The volunteer should put the mouthpiece in their mouth and hold the flow head carefully with both hands. The two plastic tubes should be pointing upwards.
2. Put the nose clip on the volunteer's nose. This ensures that all air breathed passes through the mouthpiece, filter and flow head (Figure 4).
3. After the volunteer becomes accustomed to the apparatus and begins breathing normally, begin.
4. Click the Start button to begin recording.
5. Have the volunteer perform a full expiration and then breathe normally. Record the volunteer's tidal breathing for one minute. At the end of one minute, have the volunteer perform another full expiration. Data should be seen recorded in the Flow channel, but not in the Volume channel.
6. Click Stop to end the recording. The volunteer can stop breathing through the flow head and remove the nose clip.

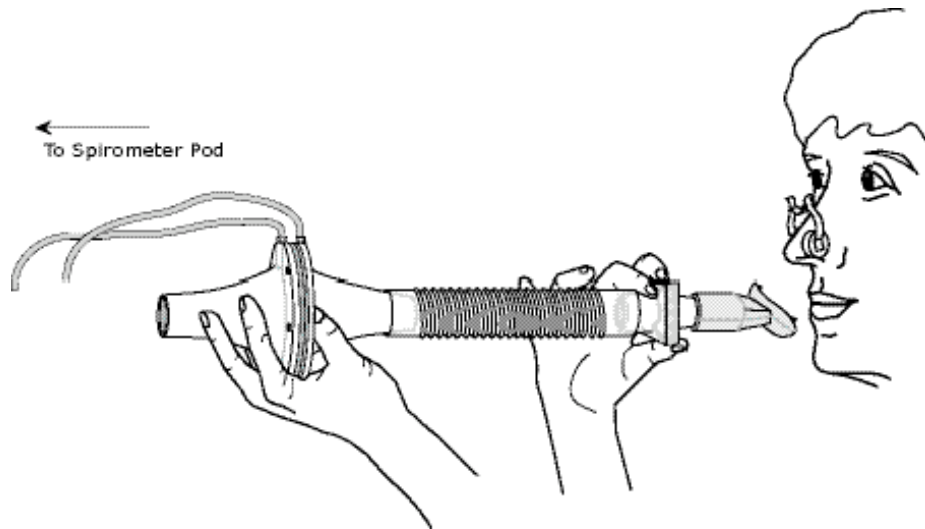


Figure 4. The volunteer should hold the flow head as shown here.

Setting up the Spirometry Extension

The Spirometry Extension processes the raw voltage signal from the Spirometer Pod, applies a volume correction factor to improve accuracy and displays calibrated Flow (L/s) and Volume (L) traces. The trace recorded in this exercise will provide reference points for the Spirometry Extension that allow it to calculate and perform corrections on the trace.

1. **Select** the entire recording of tidal breathing data including the two forced expirations by double-clicking in the Time axis beneath the trace (which selects a block of data).
2. Choose **Spirometry Flow...** from the Flow (Channel 1) Channel Function pop-up menu. The Spirometry Flow dialog appears (Figure 5).

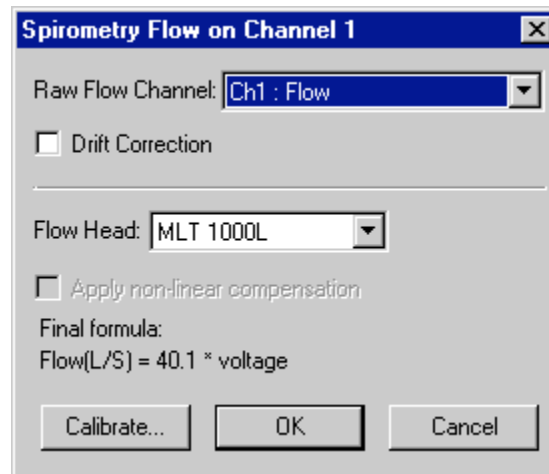


Figure 5. The Spirometry Flow dialog.

3. Flow (Channel 1) should be selected in the Raw Flow Channel pop-up menu; MLT 1000L should be selected in the Flow Head Calibration pop-up menu. When finished and the settings are the same as in Figure 5, click the OK button to close the dialog.
4. Choose **Spirometry Volume...** from the Volume (Channel 2) Channel Function pop-up menu. The Spirometry Volume dialog appears (Figure 6).

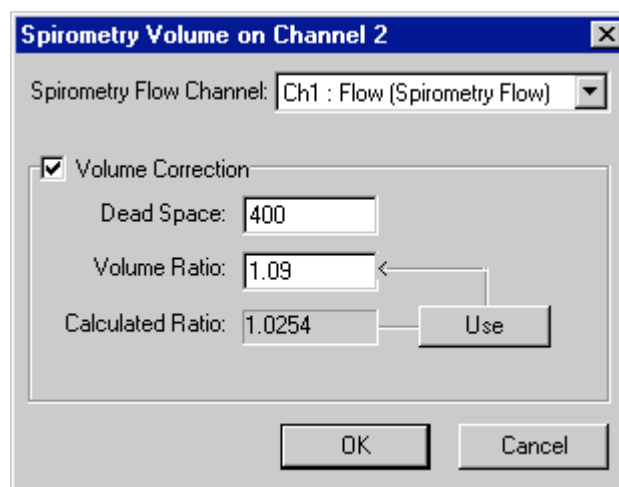


Figure 6. The Spirometry Volume dialog.

5. Flow (Channel 1) should be selected in the Spirometry Flow Channel pop-up menu. Ensure that Volume Correction is on. Click the Use button to allow the extension to use the volume correction ratio that it has calculated from the data.

6. When finished, click the OK button to close the dialog. The Chart View should now appear with calculated volume data on Channel 2.
7. Choose **Set Scale...** from the **Scale** pop-up menu in the Amplitude axis for the Flow channel. Make the top value 15 L/s and the bottom value -15 L/s, and click OK.
8. Choose **Set Scale...** from the **Scale** pop-up menu in the Amplitude axis for the Volume channel. Make the top value 5 L and the bottom value -5 L, and click OK.
9. Complete the Analysis section for Exercise 1 before continuing to Exercise 2.

Exercise 2: Lung volumes and capacities

Objectives

In this exercise, the respiratory cycle and measure changes in flow and volume will be examined.

Procedure

Note: It is important when recording normal respiration that the volunteer is facing away from the computer screen, and is not consciously controlling breathing. The volunteer may have to stare out a window or read a book to avoid conscious control of respiration.

1. The flow head must be left undisturbed on the bench during the zeroing process.
2. Choose the **Spirometer Pod...** item from the Flow channel Function pop-up menu. Click the Zero button to re-zero the Spirometer Pod. When zeroing has finished, click the OK button to return to the Chart View.
3. Note the time and click Start to begin recording. Ask the volunteer to replace the nose clip and breathe normally through the flow head. Record normal tidal breathing for at least 20 seconds. Add the **comment** "Normal tidal breathing" to the Chart trace.
4. Click Stop to end the recording.
5. Click Start to restart the recording.
6. Prepare the **comment** "IRV procedure", but do not press the Return/Enter key. At the end of a normal tidal inspiration ask the volunteer to breathe in as deeply as possible and then to breathe normally. Press the Return/Enter key to add the comment to the Chart trace.
7. Prepare the **comment** "ERV procedure". At the end of a normal tidal expiration ask the volunteer to exhale as deeply as possible and then to breathe normally. Press the Return/Enter key to add the comment.

Exercise 3: Pulmonary function tests

Objectives

In this exercise, parameters of forced expiration that are used in evaluating pulmonary function will be measured. Note that the Spirometry Extension is not intended for clinical evaluation of lung function.

Procedure

1. Re-zero the flow head using steps 1-2 from the procedures in Exercise 2.
2. Click the Start button to begin recording.
3. Prepare the **comment** "Forced Breathing".
4. Have the volunteer breathe normally for 30 seconds.
5. Ask the volunteer to inhale maximally and then exhale as forcefully and fully as possible (that is, inhale as much as possible and then exhale until no more air can be expired). Press the Return/Enter key to add the comment. After a few seconds, the volunteer should let their breathing return to normal.
6. Click Stop to end recording.
7. Repeat steps 2–6 twice more, so that there are three separate forced breath recordings. The recording should resemble Figure 7.

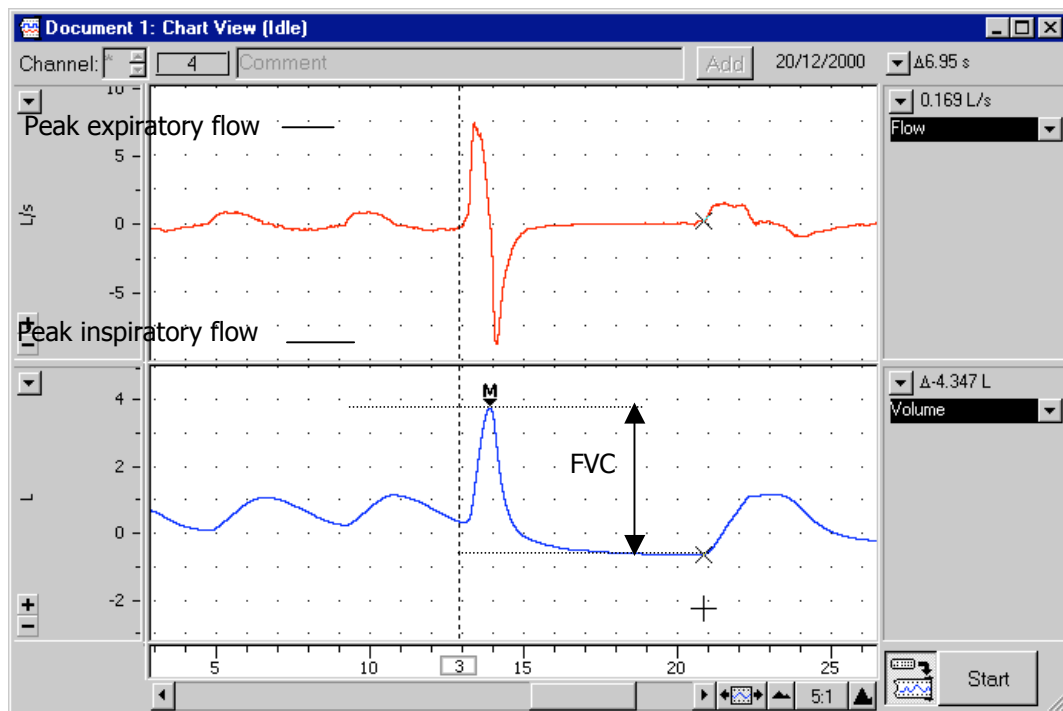


Figure 7. A spirometry recording showing where to find PIF and PEF, and how to determine FVC.

Exercise 4: Forced expiration in different volunteers

Objectives

In this exercise, parameters of forced expiration measured in different volunteers will be compared.

Procedure

1. Replace the disposable filter and mouthpiece.
2. Re-zero the Spirometer Pod; follow the procedures in steps 1-2 from Exercise 2.
3. Repeat the procedures in Exercise 3 for the new volunteer.
4. Repeat steps 1–3 until the forced expiration parameters (PIF, PEF, FVC and FEV₁) have been measured for all volunteers.

Analysis

Exercise 1: Becoming familiar with the equipment

1. When examining the data, use the scroll buttons as necessary to view parts of the trace that have scrolled out of sight.
2. Drag in the Time axis to **select** data from both channels and open the **Zoom View**. Note the relation between Flow and Volume. When the flow signal is positive (inspiration), the Volume trace rises; when the flow is negative (expiration), the Volume trace falls.
3. In the **Zoom View**, find a part of the recording where the flow is zero. Note that at this time the Volume trace does not change (it is horizontal) because integrating a zero signal does not add anything to the integral.
4. The volume trace is calculated by the extension in such a way that the displayed volumes at the end of the two full expirations are equal. In subsequent recordings, the volume correction is unlikely to be exact: you will notice a tendency for the volume to drift, typically by 1–2 L over 1–2 minutes. To see the effect of having no correction, turn off the Volume Correction checkbox in the Spirometry Volume dialog window (Figure 6), and examine the volume trace. Remember to turn Volume Correction back on again afterwards.

Exercise 2: Lung volumes and capacities

1. Examine the first part of the data trace. Observe the number of times the volunteer breathes over 15–20 seconds. Calculate how many breaths there would be in a one-minute period (f). Record f (/min) in the table provided in the Data Notebook. Also record f in the units of Hz (divide the number of breaths in one minute by 60).
2. Drag the **Marker** from its box at the bottom left of the Chart View to the Volume trace at the start of a quiet inspiration (Figure 8). Move the **Waveform Cursor** to the next peak of the Volume trace (this should be 0.5 to 1.5 s to the right of the **Marker**). Read off the numerical value of Volume from the Range/Amplitude display at the right.
3. The number in the Range/Amplitude display should have a “ Δ ” symbol in front of it, indicating that it is the difference between the volume at the **Waveform Cursor** position and the volume at the **Marker** position. If both the **Marker** and the pointer are in the right places, the value shown is the Tidal Volume (V_T) for that breath. Record this value in the table in the Data Notebook.

- Return the **Marker** to its box at bottom left of the Chart View, by double-clicking the **Marker**, dragging it back, or clicking its box.
- Using the value for V_T and the number of breaths, f (/min), observed over a one-minute period, calculate the Minute Volume () using Equation 3. Record your value in the table.

$$\dot{V}_E = V_T \times f \quad (\text{L/min}) \quad \text{Equation 3}$$

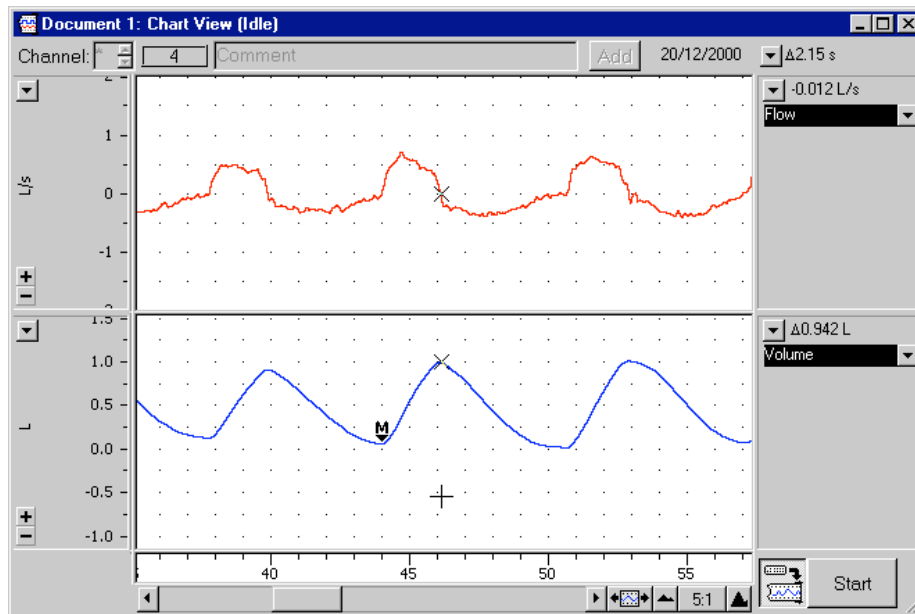


Figure 8. A typical tidal breathing record, displayed at 5:1 horizontal compression. The Marker and Waveform Cursor are positioned to measure the Tidal Volume of a single breath.

- Find the "IRV procedure" comment in the data trace. Place the **Marker** on the peak of the inspiratory volume of the previous tidal breath and move the **Waveform Cursor** along to the peak of the volume trace from the full-deep breath (Figure 9). The difference displayed in the Range/Amplitude display is the Inspiratory Reserve Volume (IRV). Record this value in the Data Notebook.

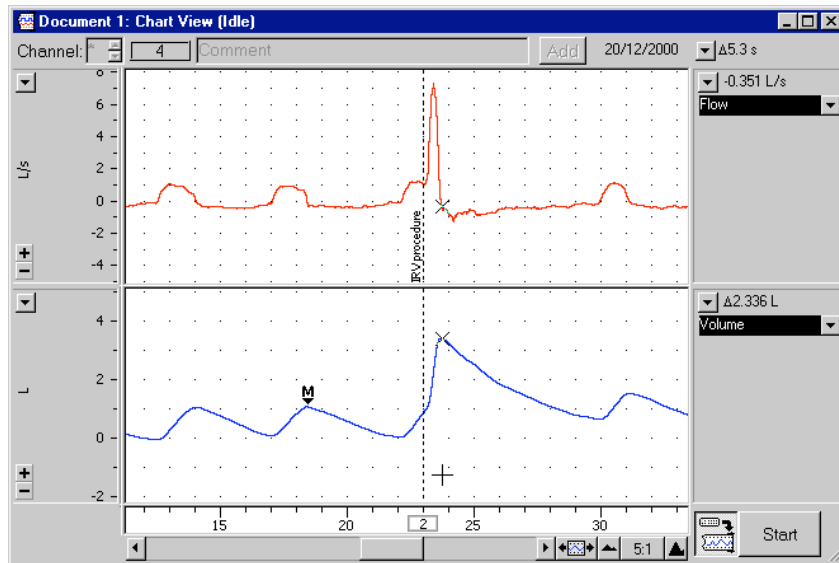


Figure 9. Record of full inhalation, with the Marker and Waveform Cursor positioned to measure IRV.

6. Calculate the Inspiratory Capacity (IC) using Equation 4.

$$IC = V_T + IRV \quad (L) \quad \text{Equation 4}$$

7. Return the **Marker** to its box at bottom left, by double-clicking the **Marker**, dragging it back, or clicking its box.
8. Find the comment containing "ERV procedure". Place the **Marker** on the trough of the expiratory volume of the previous tidal breath and move the **Waveform Cursor** along to the trough of the volume from the forceful exhalation. Figure 10 shows where to make the measurement. The difference that will be displayed in the Range/Amplitude display is the Expiratory Reserve Volume (ERV). Disregard the delta symbol and the negative sign.

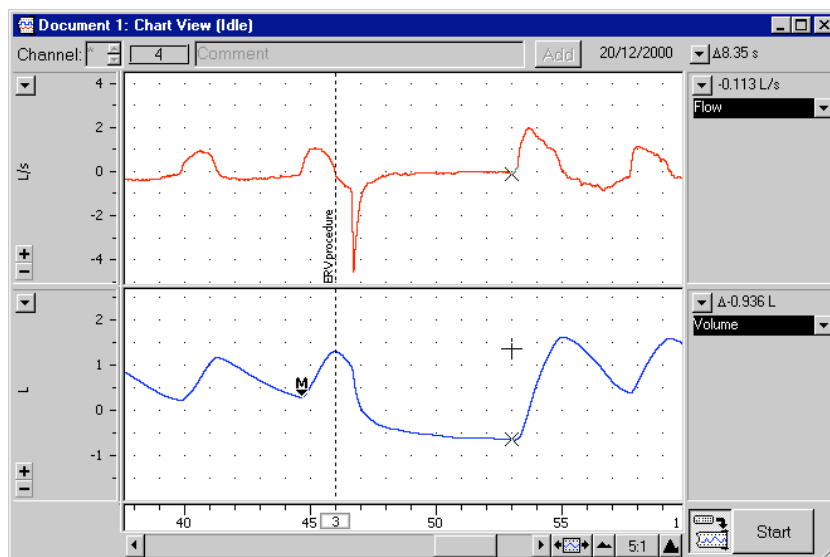


Figure 10. Record of full exhalation, with the Marker and Waveform Cursor positioned to measure ERV.

9. Calculate the Expiratory Capacity (EC) using Equation 5.

$$EC = V_T + ERV \quad (L) \quad \text{Equation 5}$$

10. Use the table provided to determine the volunteer's predicted Vital Capacity (VC). The predicted value varies according to the volunteer's sex, height and age.
11. Calculate the volunteer's measured VC using the experimentally derived values for IRV, ERV and V_T (Equation 6).

$$VC = IRV + ERV + V_T \quad (L) \quad \text{Equation 6}$$

12. Residual Volume (RV) is the volume of gas remaining in the lungs after a maximal expiration. The RV cannot be determined by spirometric recording. Using Equation 7, determine the predicted RV value for the volunteer. This equation predicts RV for 16–34 year-old subjects of either sex (Gaensler and Wright, 1966).

$$RV = \text{predicted VC} \times 0.25 \quad (L) \quad \text{Equation 7}$$

13. The Total Lung Capacity (TLC) is the sum of the vital capacity and residual volume. Calculate the predicted TLC for the volunteer (Equation 8) using the predicted values for VC and RV.

$$TLC = VC + RV \quad (L) \quad \text{Equation 8}$$

14. Functional Residual Capacity (FRC) is the volume of gas remaining in the lungs at the end of a normal tidal expiration (the sum of the RV and ERV). Calculate the FRC value for the volunteer using Equation 9.

$$FRC = ERV + RV \quad (L) \quad \text{Equation 9}$$

15. **Select** an area of the Chart View that contains normal breathing, making sure to select across complete respiratory cycles. Choose the **Report** command from the Spirometry menu. The Spirometry Report window contains various parameters calculated by the Spirometry Extension from the data selection (Figure 11). Copy the results for \dot{V}_E , V_T and f into the table in the Data Notebook.

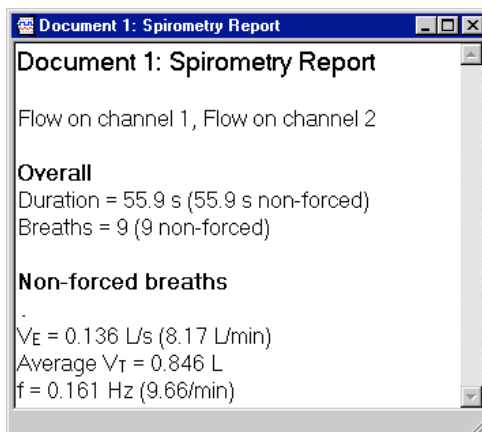


Figure 11. The Spirometry Report window, listing the parameters calculated from the data selection.

Exercise 3: Pulmonary function test

1. In the last data block of the Chart recording, move the **Waveform Cursor** to the maximal forced inspiration on the Flow trace. The absolute value displayed in the Range/Amplitude display is the Peak Inspiratory Flow (PIF). Multiply the value by 60 to convert from L/s to L/min.
2. From the Flow trace, measure the Peak Expiratory Flow (PEF) for the forced expiration. Multiply the value by 60 to convert from L/s to L/min. (Disregard the negative sign.)
3. To calculate the Forced Vital Capacity (FVC), place the **Marker** on the peak inhalation of the Volume trace and move the **Waveform Cursor** to the maximal expiration (Figure 12). Read off the result from the Range/Amplitude display. (Disregard the delta symbol and the negative sign.)
4. Return the **Marker** to its box at bottom left, by double-clicking the **Marker**, dragging it back, or clicking its box.
5. To measure Forced Expired Volume in 1 second (FEV₁), place the **Marker** on the peak of the Volume trace, move the pointer to a time 1.0 s from the peak, and read off the volume value. If it is hard to adjust the mouse position with enough precision, a time value anywhere from 0.96 to 1.04 s gives enough accuracy. (Disregard the delta symbol and the negative sign.)
6. Return the **Marker** to its box at bottom left, by double-clicking the **Marker**, dragging it back, or clicking the box.
7. Make a **selection** from the last recorded data block that includes a couple of normal breaths, the forced breath, then a few more normal breaths (Figure 12). Choose **Spirometry Data** from the Spirometry menu. The Spirometry Data window opens, showing the locations of PIF, PEF, FVC and FEV₁ (Figure 12). If the values aren't displayed, check that a forced breath is included in the selection. If the selection is correct but the parameters are still not displayed, ask for assistance.

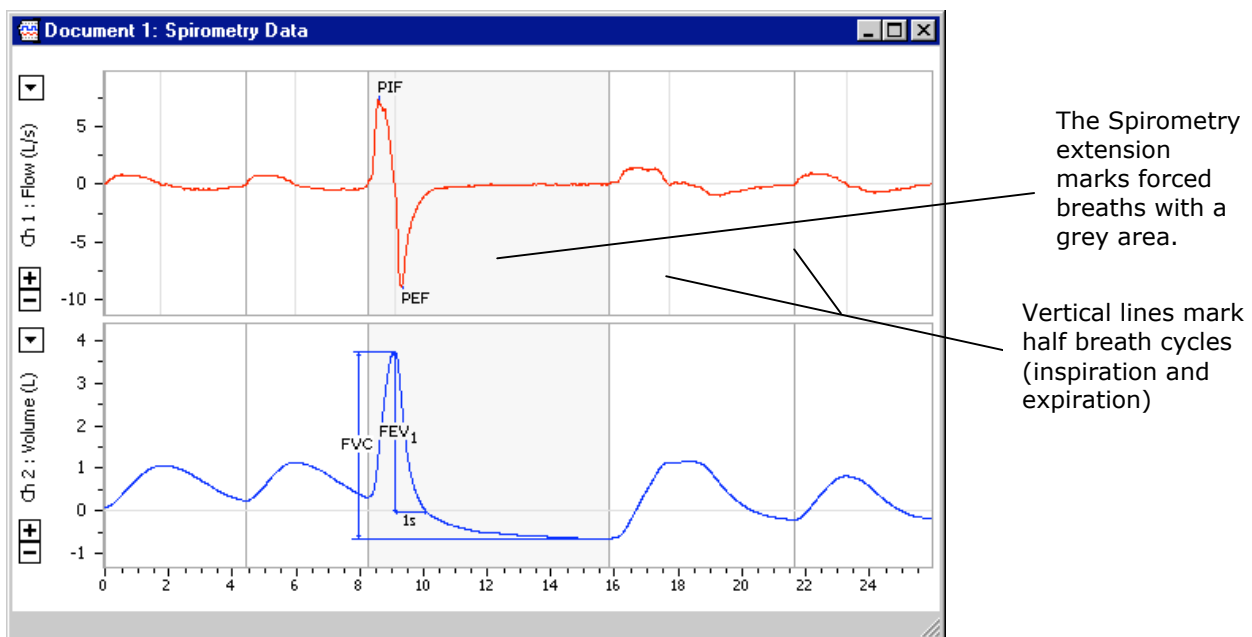


Figure 12. The Spirometry Data window, with the locations of the forced expiration parameters indicated.

8. Open the Spirometry Report window. The report lists the values calculated for those parameters. Add the report values to the Data Notebook table.
9. Repeat the analysis until all three forced breaths have been analyzed, both manually and with the Spirometry Extension.
10. Calculate the percentage ratio of FEV₁ to FVC for your experimental and Spirometry Extension results using Equation 10. Use the maximum values of FEV₁ and FVC.

$$\frac{(\text{FEV}_1/\text{FVC})}{100} \quad (\%) \quad \text{Equation 10}$$

Exercise 4: Forced expiration in different volunteers

1. Repeat the analysis procedures from Exercise 3 on the recordings from each volunteer. Have each member of the group record their data in their own Data Notebook. Give a copy of the data to each member of the group.

Data Notebook

Table 1. Respiratory parameters

Respiratory parameter	Abbreviation	Units	Experimental & calculated value	Spirometry Extension value
Frequency	f	(breaths/min)		
	f	Hz		
Tidal Volume	V_T	L		
Expired Minute Volume	$\dot{V}_E = V_T \times f$	L/min		
Inspiratory Reserve Volume	IRV	L		
Inspiratory Capacity	IC= $V_T + IRV$	L		
Expiratory Reserve Volume	ERV	L		
Expiratory Capacity	EC= $V_T + ERV$	L		
Vital Capacity	VC (from table)	L		
	$VC = IRV + ERV + V_T$	L		
Residual Volume	$RV = \text{pred. VC} \times 0.25$	L		
Total Lung Capacity	TLC = $VC + RV$	L		
Functional Residual Capacity	FRC = $ERV + RV$	L		
Peak Inspiratory Flow	PIF	L/min		
		L/min		
		L/min		
Peak Expiratory Flow	PEF	L/min		
		L/min		
		L/min		
Forced Vital Capacity	FVC	L		
		L		
		L		
Forced Expired Volume in one second	FEV ₁	L		
		L		
		L		
	FEV ₁ /FVC x 100	L		

Study Questions

1. Examine the Flow trace from Exercise 1, using the scroll buttons as required to show parts of the trace that have scrolled out of sight. In quiet spontaneous breathing, inspiration is normally followed immediately by expiration, but there is a clear interval before the next inspiration. Does the volunteer show this pattern?
2. In quiet breathing, muscular effort is used mainly in inspiration, and expiration is largely passive, due to elastic recoil of the lung. Can you relate this fact to the pattern of expiratory and inspiratory flow mentioned in Question 1? (Hint: the normal pattern of breathing is efficient in that it requires muscular effort for only a short time.)
3. Compare your experimental findings with your predicted results and those of the Spirometry Extension. Do any of the parameters differ significantly?
4. If so, what factors do you think influenced the results? How could you improve the accuracy of the measurements?
5. Why can RV not be determined by ordinary spirometry? What methods can be used to measure RV?

References

Gaensler, E.A., and G.W. Wright. 1966. Evaluation of respiratory impairment. *Archives of Environmental Health* **12**:146–189.

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