Lab #11: Respiratory Physiology

Background

The respiratory system enables the exchange of O_2 and CO_2 between the cells and the atmosphere, thus enabling the intake of O_2 into the body for aerobic respiration and the release of CO_2 for regulation of body fluid pH. In this exercise, we will examine ventilation of the lungs to enable the exchange of air between the alveoli and the atmosphere, and also explore the rate of CO_2 release from the lungs as a mechanism for controlling pH.

Mechanics of Lung Ventilation.

Air flow into and out of the lungs is driven by pressure differences between the atmospheric air and air in the lungs. When atmospheric pressure exceeds intrapulmonary pressure, air flows into the lungs, and when intrapulmonary pressure exceeds atmospheric pressure, air flows out of the lungs. Changes in intrapulmonary pressure are driven by changing the volume of the lungs—per Boyle's Law, the pressure exerted by a given amount of gas at a constant temperature is inversely proportional to the volume of that gas. Thus increasing the volume of the lungs will decrease intrapulmonary pressure, whereas decreasing lung volume will increase intrapulmonary pressure.

During tidal ventilation, air is inspired by contracting certain muscles in the walls and floor of the thoracic cavity (Fig 11.1). As the diaphragm contracts, it pulls downward and forward, whereas when the external intercostals contract, they lift the ribs upward and laterally.

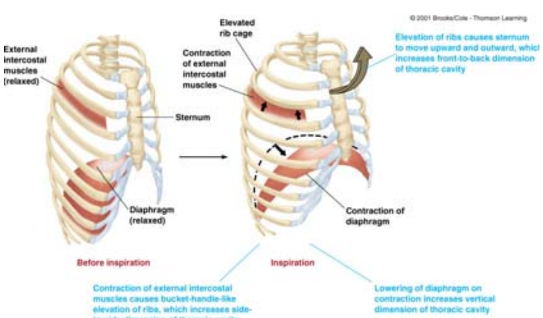

Fig 11.1. Muscle contractions that drive tidal inspiration. From L. Sherwood, *Fundamentals of Human Physiology.* Brooks Cole

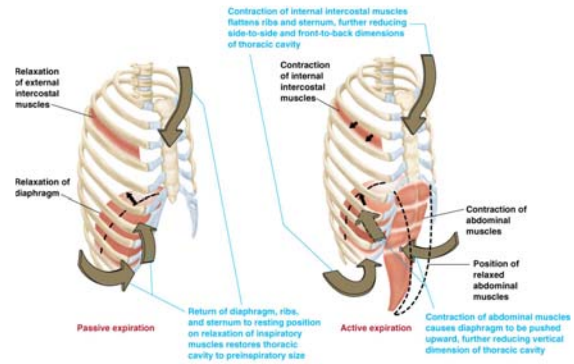

Fig 11.1. Relaxation of the inspiratory muscles drives tidal expiration (left), whereas forced expirations are driven by contraction of the expiratory muscles (right). From L. Sherwood, *Fundamentals of Human Physiology.* Brooks Cole.

The net result is an increase in the volume of the thoracic cavity. Since the lungs are adhered to the inner walls of the thoracic cavity, the lungs also expand. This decreases intrapulmonary pressure below atmospheric pressure, and air flows into the lungs along the pressure gradient.

Tidal expiration is driven by the relaxation of the muscles used to drive tidal inspiration (Fig 11.2). As the diaphragm moves upward and backward and the ribs move downward and inward the overall volume of the thoracic cavity is reduced. This compression of the thoracic cavity, in turn, elevates intrapulmonary pressure above atmospheric pressure, and air flows out of the lungs.

Additional amounts of air can be inspired or expired from the lungs with the contraction of additional muscles. Maximal inspirations are driven with contraction of muscles associated with the sternum and clavicle in addition to a full contraction of the diaphragm and external intercostals. Air can be forcibly expired from the lungs with contraction from the internal intercostals and a number of abdominal muscles (Fig 11.2).

Lung Volumes and Capacities.

The amount of air contained in the lungs during ventilation can change considerably depending on what muscles are driving air flow and how forcefully they contract. The different amounts of air drawn into or out of the lungs by

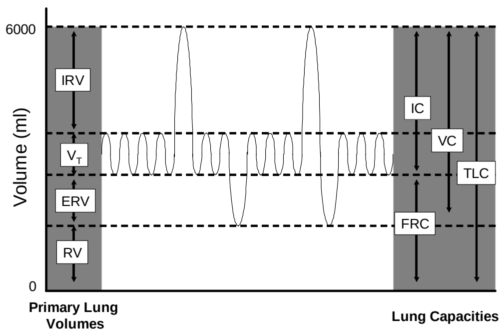

Fig. 11.3. Illustration of a spirometer recording depicting measurements of the primary lung volumes (left) and the lung capacities (right)

contracting different groups of muscles are called *primary lung volumes*. Different combinations of the primary lung volumes, in turn provide us with *lung capacities*, which define either how much air is present in the lungs or how much air can be moved by the lungs under specific situations.

There are four primary lung volumes (Fig 11.3), defined as follow.

- *Tidal volume (V_T).* The tidal volume is the amount of air inspired (or expired) during normal tidal breathing. At rest, tidal volume in healthy adult men is approximately 500 ml, and about 400 ml in women. Tidal volume increases with activity to accommodate increased need for gas exchange.
- *Inspiratory Reserve Volume (IRV).* The inspiratory reserve volume is the volume of air that can be maximally inspired above the volume inspired tidally. Average IRV measurements at rest for men and women are approximately 3100 ml and 2400 ml, respectively. IRV decreases with exercise.
- *Expiratory Reserve Volume (ERV).* The expiratory reserve volume is the maximum volume of air that can forcibly expired beyond a normal tidal expiration. Average ERV at rest is approximately 1200 ml for men and 900 ml for women at rest. Like IRV, the ERV decreases when exercising.
- *Residual Volume (RV).* The residual volume is the amount of air that remains in the lungs following a maximal expiration, and can only be forced out of the lungs by collapsing the lungs. The RV for men is approximately 1200 ml and approximately 900 ml in women.

There are also four lung capacities, each of which is the sum of two or more primary lung volumes.

- *Total Lung Capacity (TLC).* The total lung capacity is the maximum amount of air that can be held within the lungs at one time, and is the volume of air in the lungs following a maximal inspiration. TLC is the sum of all four primary volumes (TLC = IRV + V_T + ERV +RV).
- *Vital Capacity (VC).* The vital capacity is the maximum amount of air that can be exchanged between the lungs and atmosphere in a single breath, and is the volume of air that can be forcibly expired from the lungs following a maximal expiration. The vital capacity is the sum of the three primary volumes that can be directly exchanged with the atmosphere (VC = IRV + V_T + ERV).
- *Inspiratory Capcity (IC).* The inspiratory capacity is the maximum amount of air that can be inspired following a normal tidal expiration. It is the sum of the inspiratory reserve volume and the tidal volume (IC = IRV + V_T).
- Functional Residual Capacity (FRC). The functional residual capacity is the volume of air that remains in the lung following a normal tidal expiration. It is the sum of the expiratory reserve volume and the residual volume (FRC = ERV + RV).

Measurements of Tidal Ventilation.

The amount of air exchanged between the lungs and the atmosphere during tidal breathing is

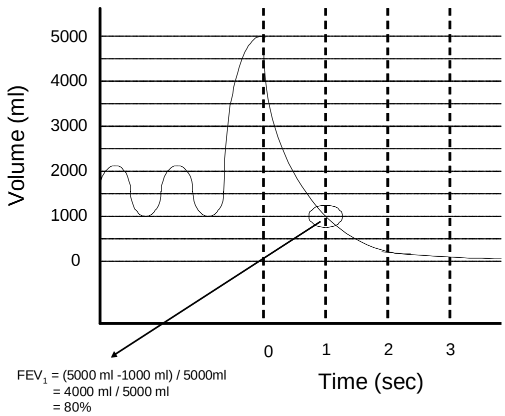

Fig 11.4. Illustration of a spirometer recording measuring forced expiratory volume.

determined influenced how much air is exchanged in each breath (the tidal volume) and how frequently breaths are take (the breathing rate). Measurements of tidal ventilation, therefore, must take both of these factors into account. One simple measurement of tidal ventilation is the *minute volume* (V_M), which is the volume of air inspired through tidal breathing during in a one minute period of time. Minute volume is simply the product of the tidal volume (V_T) and the breathing rate (f)

$$V_M = f \times V_T$$

The minute volume, however, overestimates the amount of air that is available for gas exchange. This is because not all of the air flowing into the lungs during inspiration flows into the alveoli; some of this air accommodates the increased volume of the respiratory passages during inspiration, and since these passages are not designed for gas exchange with the blood, they are considered to be physiological "dead space". A better measurement for the amount of air flowing over the respiratory surfaces during tidal ventilation is *alveolar ventilation* (V_A), sometimes called the minute alveolar volume, which is the amount of air entering the alveoli in a one minute period. Alveolar ventilation is calculated using a similar equation to that of the minute volume except that it corrects for the volume of the dead space:

$$V_A = f \times (V_T - V_{DS})$$

where V_{DS} is the volume of the dead space (estimated to be 1/3 of the resting tidal volume).

Air Flow Measurements.

Efficient air exchange between the lungs and the atmosphere requires a) that the lungs be able to change volume effectively and b) air can pass through the respiratory passageways with relative ease. The ability of a person's lungs to change in volume is reflected in their vital capacity measurement—individuals with larger vital capacities can change the volume of their lungs more that can those with smaller vital capacities. The ability of air to flow through the respiratory passages, in contrast is reflected in a measurement called the *forced expiratory volume* (FEV_t), which is the percentage of the vital capacity that, after a maximal inspiration, can be forcibly expired in *t* seconds (Fig 11.4). FEV_t can be calculated as the ratio of air forcibly expired in a designated time interval (V_t, not to be confused with tidal volume, V_T) divided by the vital capacity (VC) and converted into a percentage.

$$FEV_t = \frac{V_t}{VC} \times 100\%$$

A young adult can typically expire roughly 80% of their vital capacity within one second, 94% within two seconds, and 97% within three seconds.

Vital capacity and FEV_t measurements can be used to diagnose various types of air flow disorders. Abnormally low FEV_t measurements (less than 90% the value predicted for an individual based on their age) may be indicative of an *obstructive disorder*. In an obstructive disorder, air flow through the respiratory passages is impeded by a narrowing of those passages, thus increasing resistance to air flow. Bronchiolar secretions and constriction of air passageways (See Fig 11.5) are common causes of obstructive disorders. On the other hand, abnormally low vital capacity (less than 80% the predicted value based on age, sex, and body size) may be indicative of a *restrictive disorder*. In a restrictive disorder, the lungs are unable to

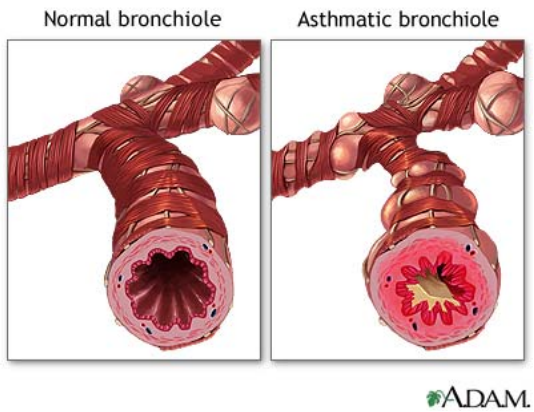

Fig 11.5. Asthma is an example of an obstructive lung disorder. Smooth muscle contraction in the respiratory passages reduce the diameter of the airways, increasing resistance to air flow through them. Image from http://www.drgreene.org/images/cg/19346.jpg

change volume enough to allow adequate air flow into and out of the alveoli. This could be caused by a loss of elasticity of the tissue, fluid within the alveoli, or an increase in the dead space of the lungs (see Fig 11.6). Note that a particular lung pathology could be both obstructive and restrictive. For example, in emphysema (Fig 11.7), the alveolar walls break down. This decreases the elasticity of the lungs, increases the dead space, and decreases the vital capacity, and is thus a restrictive disorder. The breakdown of the alveoli, however, also reduces structural supports for the bronchioles, thus the bronchioles may narrow or even collapse, creating obstruction to air flow.

Fig 11.6. X rays of normal lungs (left) and lungs with pulmonary fibrosis (right). Pulmonary fibrosis, or scarring of the lung tissue, is a restrictive disorder. Interstitial spaces between the alveoli are filled with fibrous tissue, thus restricting the ability of the alveoli to expand. Moreover, the alveoli are often inflamed, resulting in fluid within the alveoli that reduce alveolar volume and increase diffusion distances. Images from alice.ucdavis.edu/ IMD/420C/films/cxr4.htm

Fig. 11.7. Cross section of a lung with emphysema. Note the numerous cavities formed by the collapse of alveolar walls. The result is an elevation in residual volume, a decrease in vital capacity, and elevated resistance to air flow in the respiratory passages. Image from http://www.medicdirect.co.uk/ images/emphysema_large.jpg

Carbon Dioxide Exchange and pH Balance.

CO_2 is an important factor in the regulation of pH in the human body. This is because CO_2 in solution can reversibly react with water to form carbonic acid.

$$CO_2 + H_2O \leftrightarrow H_2CO_3$$

Carbonic acid, in turn, may dissociate into bicarbonate and free hydrogen ion, in turn elevating the $[H^+]$ of the solution and lowering pH.

$$H_2CO_3 \leftrightarrow H^+ + HCO_3^-$$

CO_2 is transported in the blood stream by three different means: as dissolved CO_2 gas in the plasma, by binding to hemoglobin in the erythrocytes, and in the form of bicarbonate in the blood plasma. Both methods of transporting CO_2 in the plasma can influence the pH of the plasma.

Most of the bicarbonate present in blood plasma is not a result of spontaneous reactions

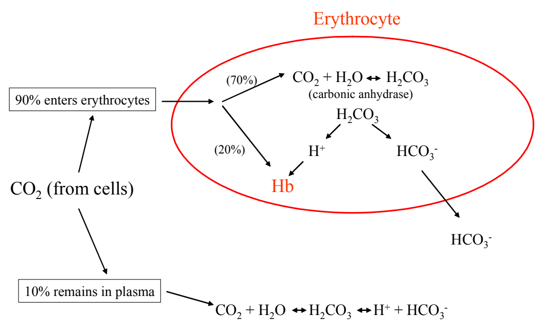

Fig 11.8. Diagram illustration the three means of CO_2 transport in the blood. Note that some of the CO_2 dissolved in the plasma can react spontaneously with water to form carbonic acid. Thus increased CO_2 in the plasma tend to decrease plasma pH through increased carbonic acid formation.

between CO_2 and H_2O, but is manufactured by the erythrocytes (Fig 11.8). Roughly 90% of the CO_2 released from the cells is absorbed by the erythrocytes. About 20% binds to hemoglobin, whereas the remaining 70% reacts with water to form carbonic acid in a reaction catalyzed by the enzyme carbonic anhydrase. The carbonic acid formed subsequently dissociates into H^+ and bicarbonate. H^+ binds to specific amino acid side chains on the hemoglobin, whereas the bicarbonate is transported out to the blood plasma. The bicarbonate formed can act as a buffer against pH changes due to the introduction of other acids, since increases in $[H^+]$ will tend to promote the binding of H^+ to bicarbonate.

The remaining 10% of the CO_2 released by the cells can also influence blood pH. Some of this dissolved CO_2 will spontaneously react with water to form carbonic acid, which in turn will dissociate into H^+ and bicarbonate. Note that in this case the H^+ is released into the plasma. The more dissolved CO_2 present in the blood, the more H^+ will be released into the plasma, and the lower the pH will be. Thus regulation of dissolved CO_2 levels in the plasma is an important component of body fluid pH regulation. By modifying tidal ventilation and subsequent CO_2 release into the atmosphere, dissolved CO_2 levels in the blood can be tightly regulated and thus blood pH can be tightly regulated.

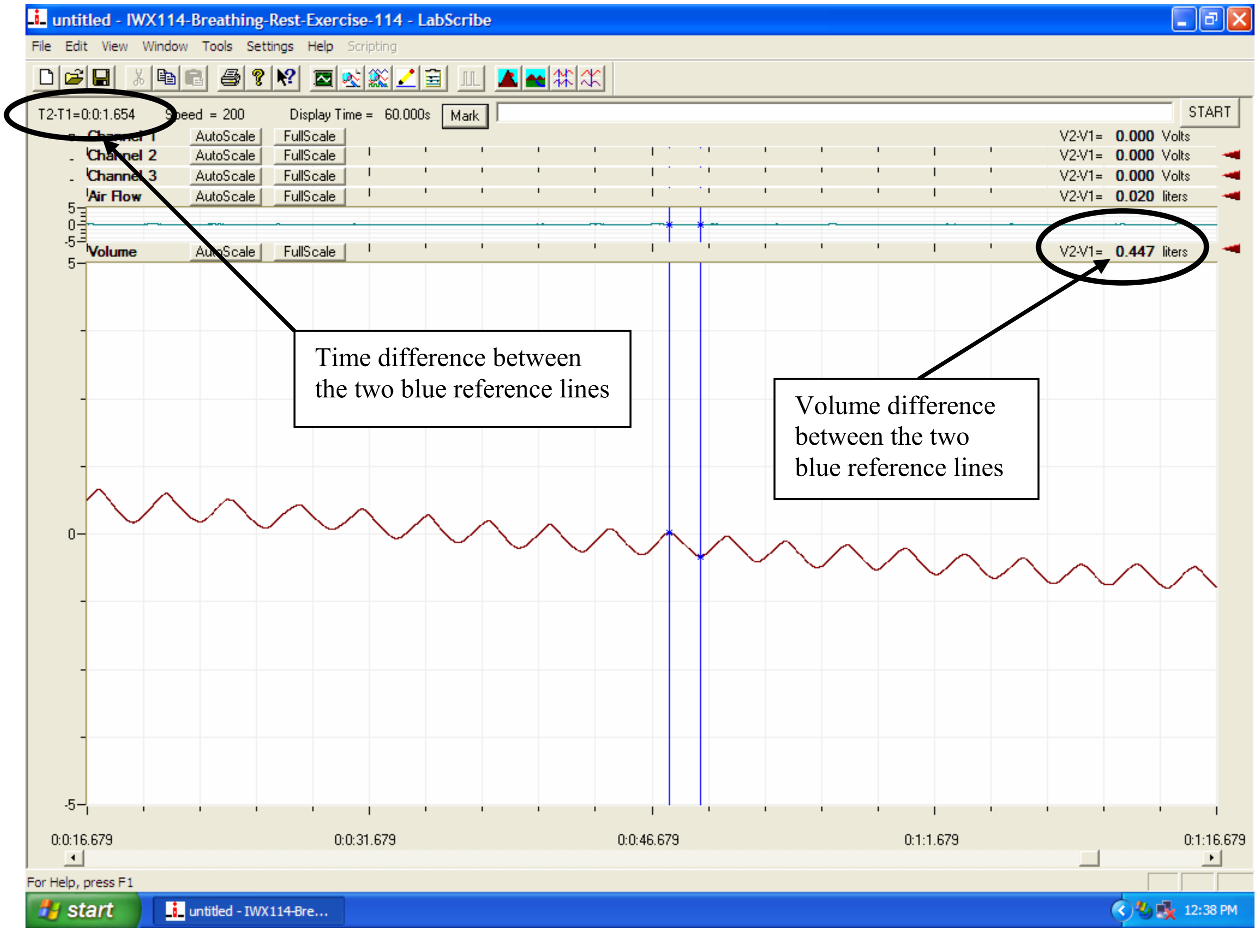

Fig 11.9. The Labscribe setup for measuring lung ventilation.

Experiment I: Lung Ventilation.

A. Tidal volume, breathing rate, and alveolar ventilation measurements

1. Place a disposable cardboard mouthpiece over one of the ends of the spirometer flow head attached to the iWorx unit.

2. Go to the computer screen, and be sure the software (LabScribe) is running (Fig 11.9). The top tracing will display voltage changes from the transducer—ignore it for our exercise. The lower tracing converts these changes in voltage into volume changes, and you will be using this tracing for all of your measurements. Change the display time to 60 sec by selecting the EDIT menu from the top, then PREFERENCES, then enter the desired display time in the middle box of the top line.

3. Click "START" in the top right corner of the screen.

4. **The subject should wait five seconds before beginning to breathe through the mouthpiece** so the instrument can equilibrate correctly. Have the subject place the mouthpiece fully in their mouth and

pinch their nostrils closed so that they breathe only through their mouth. The subject should breathe through the mouthpiece normally for ~70 seconds (your can keep track of this by the meter in the top left corner of the screen, then click "STOP" at the top right of the screen. If the tracing "stairclimbs" (i.e., keeps moving progressively up or down) during your recording ask your instructor for assistance.

5. If the tracing on the lower screen is reversed (i.e., the tracing dips when the person breathes in), right click on the lower screen and select "INVERT"

6. Count the number of inspirations made during the last 60 seconds of the recording (i.e., what is on the screen) to determine the ***respiratory frequency*** for this individual (see Fig 11.10).

7. Select a single tidal breath in the recording. Drag one of the blue lines at the far right edge of the tracing over to the low point of this tidal breath, and drag the other blue line over to the peak of the tracing (see Fig 11.10). The difference in volume between these to points, showing just above the tracing to the right, is the ***tidal volume*** (V_T). Measure the tidal volume for three separate breaths and record the average of these values.

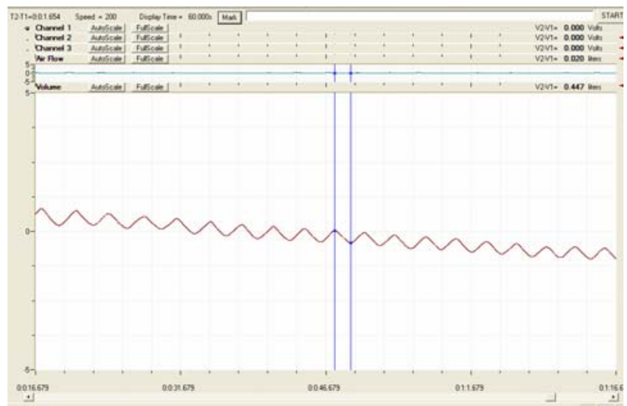

Fig. 11.10. Positioning Reference lines for determination of Tidal Volume (V_T)

8. Calculate the ***alveolar ventilation*** using the respiratory frequency, the average tidal volume, and assuming that the volume of the dead space (V_{DS}) = 1/3 the average resting tidal volume. Remember: $V_A = RF \times (V_T - V_{DS})$

9. Have the subject exercise moderately by having them run up and down a staircase 2-3 times then run back to the lab (they should be fairly winded when they return). As soon as they return to the lab, repeat the procedures above and determine the ***respiratory frequency***, ***tidal volume***, and ***alveolar ventilation*** during exercise. NOTE: use the estimate for V_{DS} calculated from <u>*resting*</u> tidal volume to calculate alveolar ventilation.

B. Lung volumes, capacities, and forced expiratory volume.

1. Click "START" in the top right corner of the screen.

2. After waiting five seconds, have the subject place the mouthpiece in their mouth and pinch their nostrils closed so that they breathe only through their mouth. The subject should take five normal tidal breaths through the mouthpiece with their noses pinched closed as you record. When they have expired their fifth tidal breath, they then should inspire as much air as they possibly can (the rest of the group should cheer them on), then **expire as much air as quickly and forcibly as they possibly can** (again, cheer them on as they are doing this). The subject must make sure their nostrils are pinched closed so that air escapes only through the mouthpiece. Only after the subject cannot force any more air out of their lungs should they remove the mouthpiece.

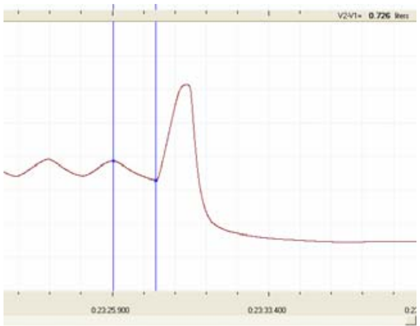

Fig. 11.11. Positioning Reference lines for determination of Tidal Volume (V_T)

3. If the tracing on the lower screen is reversed (i.e., the tracing dips when the person breathes in), right click on the lower screen and select “INVERT”. You may also want to change the display time to 30 sec instead of 60 seconds. You may do so by selecting the EDIT menu from the top, then PREFERENCES, then enter the desired display time in the middle box of the top line.

4. Using the blue lines, determine the ***tidal volume*** (V_T) for this tracing based on the tidal breath immediately before the maximal inspiration (see Fig. 11.11). It should be similar to the average tidal volume recorded for that individual earlier.

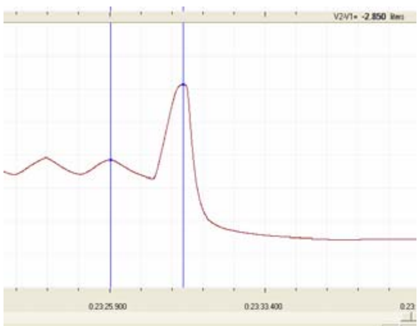

Fig. 11.12. Positioning Reference lines for determination of Inspiratory Reserve Volume (IRV) .

5. Determine the ***inspiratory reserve volume*** (IRV) by measuring the difference in volume from the peak of the tidal inspiration to the peak of the maximal inspiration (see Fig. 11.12).

6. Determine the ***expiratory reserve volume*** (ERV) by measuring the difference in volume from the base of the tidal expiration to the base of the maximal expiration, per Fig. 11.13.

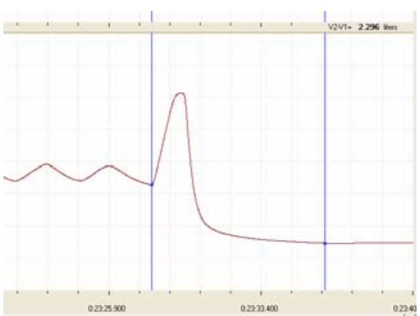

Fig. 11.13. Positioning Reference lines for determination of Expiratory Reserve Volume (ERV).

7. Measure the ***vital capacity*** (VC) by measuring the difference in volume from the peak of the maximal inspiration to the base of the maximal expiration, per Fig. 11.14. Compare this value with the subject’s predicted vital capacity (based on their age, sex and height, see Appendix).

8. Calculate the ***inspiratory capacity*** (IC) by either a) subtracting the expiratory reserve volume from the vital capacity or b) adding the tidal volume and inspiratory reserve volumes together.

9. Estimate the ***residual volume*** (RV) and ***total lung capacity*** (TLC) for the subject by multiplying the volume of the vital capacity by the values based upon age given in Table 11.1.

10. Calculate the ***functional residual capacity*** (FRC) by adding the residual volume and the expiratory reserve volume together.

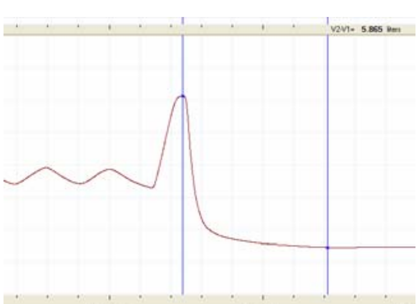

Fig. 11.14. Positioning reference lines for determination of Vital Capacity (VC).

Table 11.1. Equations for estimating residual volume (RV) and total lung capacity (TLC) from measured vital capacity.

Age	Estimated Residual Volume	Estimated Total Lung Capacity
16-34	0.250 × Vital Capacity	1.250 × Vital Capacity
35-49	0.305 × Vital Capacity	1.305 × Vital Capacity
50-69	0.445 × Vital Capacity	1.445 × Vital Capacity

From S.I. Fox, *Laboratory Guide to Human Physiology*, 9th ed, McGraw Hill

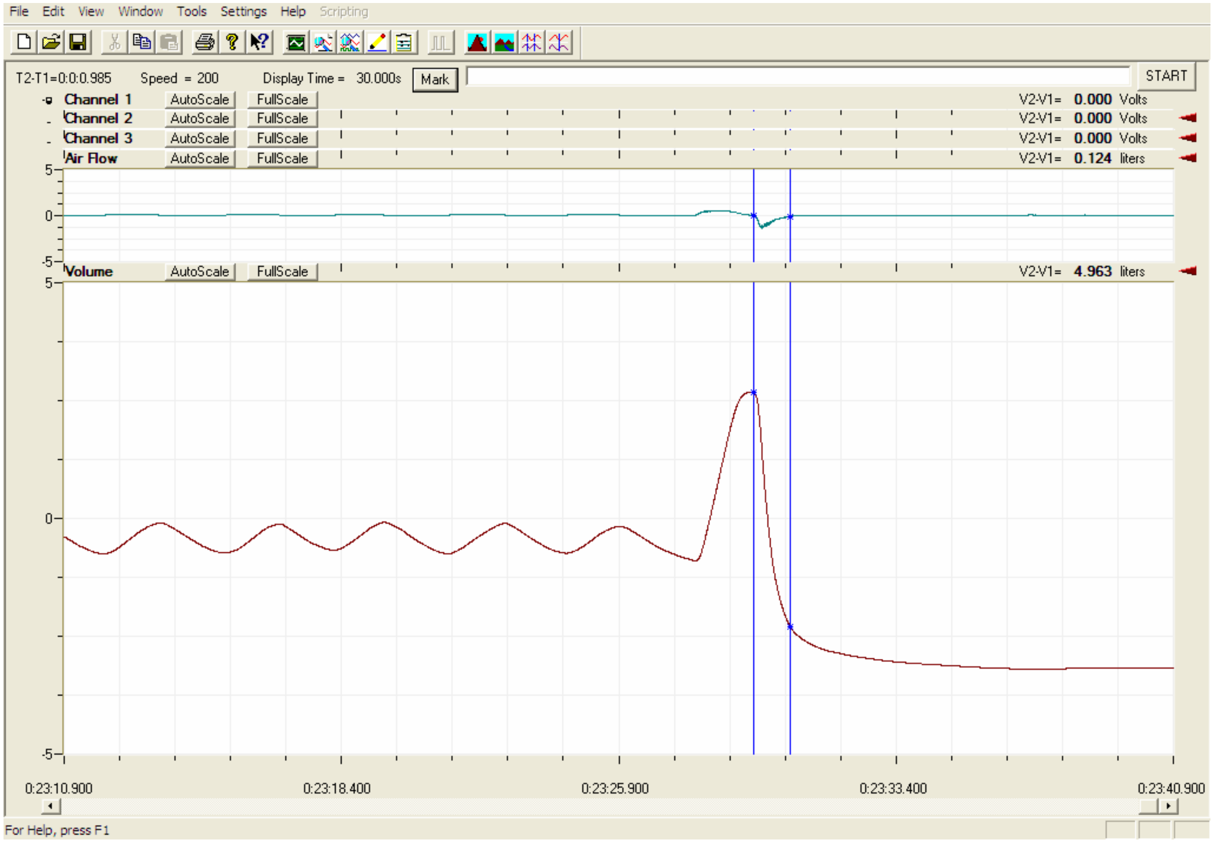

Figure11.15. Positioning reference lines for determination of the volume of air forcibly expired in 1 second (V_1). Note that the left-hand line needs to be positioned at the start of the forced expiration, then the right-hand line should be positioned as close to 1.000 sec after the left-hand line as possible (arrow).

C. Forced Expiratory Volume

To calculate the ***forced expiratory volume*** (FEV_1), return to the recording of the vital capacity from the previous experiment. Place one of the blue lines on the peak of the maximal expiration at the exact point at which the person begins to exhale (see figure below). Position the second line to the right of the first so that the time meter in the top left hand corner of the screen ("T2-T1") is as close to 0:0:1.000 (1 second) as possible (see Fig 11.15). Record the volume of air expired in 1 second (upper right hand of lower tracing), then divide this value by the vital capacity, and convert to a percentage per the following equation.

$$FEV_{1sec} = V_{1sec}/VC \times 100\%$$

Compare the value obtained with the subject's predicted FEV_1 values (based on age) in Table 11.2.

Table 11.2. Predicted FEV_{1sec} values.

Age	Predicted FEV1sec (%VC)
18-29	80-82%
30-39	77-78%
40-44	75.50%
45-49	74.50%
50-54	73.50%
55-64	70-72%

From S.I. Fox, *Laboratory Guide to Human Physiology*, 9th ed, McGraw Hill.

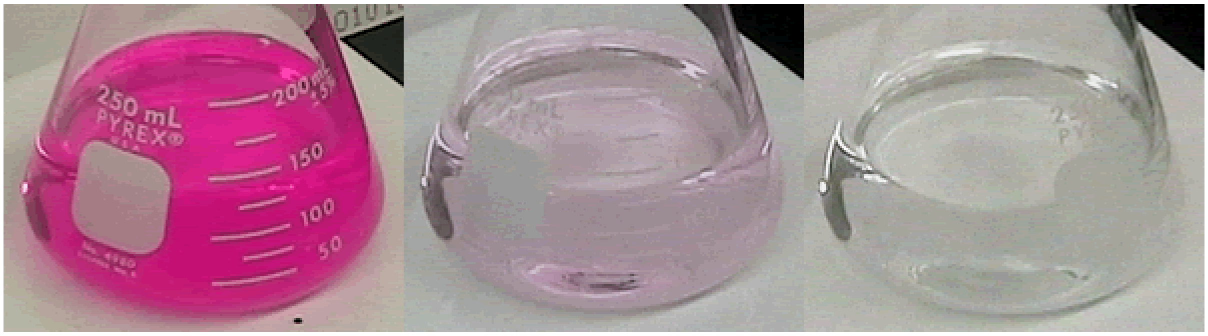

Fig 11.16. Progressive changes in the color of a phenolphthalein solution as CO_2 is added to the solution and pH decreases from alkaline to neutral pH. Images from http://www.chemistry.wustl.edu/~courses/genchem/Labs/AcidBase/phph.htm.

Experiment II: CO_2 Production and Acid-Base Balance.

A. Elevated Blood [CO_2] and its Effect on pH

Obtain a pair of beakers containing ~150-200 ml of our test solution, which consists of distilled water, a small amount of NaOH to generate a weakly alkaline pH, and a few drops of phenolphthalein. The color of phenolphthalein changes with pH; at a pH > 7.0, phenolphthalein is pink, but below pH 7.0 it is colorless. Place two straws into one of the two beakers. Have the subject place the straws in their mouth and start timing. The subject should breathe tidally inspiring through the nose then expiring through their mouth, blowing bubbles into the solution. Be sure to breathe as normally and tidally as possible (this is not a bubble-blowing contest!). Time how long it takes for the solution to lose all pink coloration (Fig 11.16). Once completed, have the person go for a quick run outside or up and down the staircase to elevate their respiration (they should be panting when they return). Immediately give them the second beaker of solution and repeat the procedure. Note any difference in the time it takes to turn the solution clear.

B. Reduced Blood [CO_2] and its Effect on Respiration

Have someone in your lab group sit quietly for one minute, then record their resting breathing rate for 30 sec. Multiply this value by two to obtain the breathing rate (breaths/min) and record. Then have them hyperventilate for 10 seconds, increasing both tidal volume and breathing frequency as much as possible. Once they have completed their hyperventilation, record their breathing rate once again for a period of 30 sec and record the breathing rate in breaths/min. Note any difference in breathing rate.

APPENDIX: Predicted Vital Capacity - Females

	HEIGHT (cm)																									
AGE	**146**	**148**	**150**	**152**	**154**	**156**	**158**	**160**	**162**	**164**	**166**	**168**	**170**	**172**	**174**	**176**	**178**	**180**	**182**	**184**	**186**	**188**	**190**	**192**	**194**
16	2950	2990	3030	3070	3110	3150	3190	3230	3270	3310	3350	3390	3430	3470	3510	3550	3590	3630	3670	3715	3755	3800	3840	3880	3920
17	2935	2975	3015	3055	3095	3135	3175	3215	3255	3295	3335	3375	3415	3455	3495	3535	3575	3615	3655	3695	3740	3780	3820	3860	3900
18	2920	2960	3000	3040	3080	3120	3160	3200	3240	3280	3320	3360	3400	3440	3480	3520	3560	3600	3640	3680	3720	3760	3800	3840	3880
20	2890	2930	2970	3010	3050	3090	3130	3170	3210	3250	3290	3330	3370	3410	3450	3490	3525	3565	3605	3645	3685	3720	3760	3800	3840
22	2860	2900	2940	2980	3020	3060	3095	3135	3175	3215	3255	3290	3330	3370	3410	3450	3490	3530	3570	3610	3650	3685	3725	3765	3800
24	2830	2870	2910	2950	2985	3025	3065	3100	3140	3180	3220	3260	3300	3335	3375	3415	3455	3490	3530	3570	3610	3650	3685	3725	3725
26	2800	2840	2880	2920	2960	3000	3035	3070	3110	3150	3190	3230	3265	3300	3340	3380	3420	3455	3495	3530	3570	3610	3650	3685	3725
28	2775	2810	2850	2890	2930	2965	3000	3040	3070	3115	3155	3190	3230	3270	3305	3345	3380	3420	3460	3495	3535	3570	3610	3650	3685
30	2745	2780	2820	2860	2895	2935	2970	3010	3045	3085	3120	3160	3195	3235	3270	3310	3345	3385	3420	3460	3495	3535	3570	3610	3645
32	2715	2750	2790	2825	2865	2900	2940	2975	3015	3050	3090	3125	3160	3200	3235	3275	3310	3350	3385	3425	3460	3495	3535	3570	3610
34	2685	2725	2760	2795	2835	2870	2910	2945	2980	3020	3055	3090	3130	3165	3200	3240	3275	3310	3350	3385	3425	3460	3495	3535	3570
36	2655	2695	2730	2765	2805	2840	2875	2910	2950	2985	3020	3060	3095	3130	3165	3205	3240	3275	3310	3350	3385	3420	3460	3495	3530
38	2630	2665	2700	2735	2770	2810	2845	2880	2915	2950	2990	3025	3060	3095	3130	3170	3205	3240	3275	3310	3350	3385	3420	3455	3490
40	2600	2635	2670	2705	2740	2775	2810	2850	2885	2920	2955	2990	3025	3060	3095	3135	3170	3205	3240	3275	3310	3345	3380	3420	3455
42	2570	2605	2640	2675	2710	2745	2870	2815	2850	2885	2920	2955	2990	3025	3060	3100	3135	3170	3205	3240	3275	3310	3345	3380	3415
44	2540	2575	2610	2645	2680	2715	2930	2785	2820	2855	2890	2925	2960	2995	3030	3060	3095	3130	3165	3200	3235	3270	3305	3340	3375
46	2510	2545	2580	2615	2650	2685	2715	2750	2785	2820	2855	2890	2925	2960	2995	3030	3060	3095	3130	3165	3200	3235	3270	3305	3340
48	2480	2515	2550	2585	2620	2650	2685	2715	2750	2785	2820	2855	2890	2925	2960	2995	3030	3060	3095	3130	3160	3195	3230	3265	3300
50	2455	2485	2520	2555	2590	2625	2655	2690	2720	2755	2785	2820	2855	2890	2925	2955	2990	3025	3060	3090	3125	3155	3190	3225	3260
52	2425	2455	2490	2525	2555	2590	2625	2655	2690	2720	2755	2790	2820	2855	2890	2925	2955	2990	3020	3055	3090	3125	3155	3190	3220
54	2395	2425	2460	2495	2530	2560	2590	2625	2655	2690	2720	2755	2790	2820	2855	2885	2920	2950	2985	3020	3050	3085	3115	3150	3180
56	2365	2400	2430	2460	2495	2525	2560	2590	2625	2655	2690	2720	2755	2790	2820	2855	2885	2920	2950	2980	3015	3045	3080	3110	3145
58	2335	2370	2400	2430	2460	2495	2525	2560	2590	2625	2655	2690	2720	2750	2785	2815	2850	2880	2920	2945	2975	3010	3040	3075	3105
60	2305	2340	2370	2400	2430	2460	2495	2525	2560	2590	2625	2655	2685	2720	2750	2780	2810	2845	2875	2915	2940	2970	3000	3035	3065
62	2280	2310	2340	2370	2405	2435	2465	2495	2525	2560	2590	2620	2655	2685	2715	2745	2775	2810	2840	2870	2900	2935	2965	2995	3025
64	2250	2280	2310	2340	2370	2400	2430	2465	2495	2525	2555	2585	2620	2650	2680	2710	2740	2770	2805	2835	2865	2895	2925	2955	2990
66	2220	2250	2280	2310	2340	2370	2400	2430	2465	2495	2525	2555	2585	2615	2645	2675	2705	2735	2765	2800	2825	2860	2890	2920	2950
68	2190	2220	2250	2280	2310	2340	2370	2400	2430	2460	2490	2520	2550	2580	2610	2640	2670	2700	2730	2760	2795	2820	2850	2880	2910
70	2160	2190	2220	2250	2280	2310	2340	2370	2400	2425	2455	2485	2515	2545	2575	2605	2635	2665	2695	2725	2755	2780	2810	2840	2870
72	2130	2160	2190	2220	2250	2280	2310	2335	2365	2395	2425	2455	2480	2510	2540	2570	2600	2630	2660	2685	2715	2745	2775	2805	2830
74	2100	2130	2160	2190	2220	2245	2275	2305	2335	2365	2390	2420	2450	2475	2505	2535	2565	2590	2620	2650	2680	2710	2740	2765	2795

1 inch = 2.54 cm

APPENDIX Predicted Vital Capacity - Males

	HEIGHT (cm)																								
AGE	**146**	**148**	**150**	**152**	**154**	**156**	**158**	**160**	**162**	**164**	**166**	**168**	**170**	**172**	**174**	**176**	**178**	**180**	**182**	**184**	**186**	**188**	**190**	**192**	**194**
16	3765	3820	3870	3920	3975	4025	4075	4130	4180	4230	4285	4335	4385	4440	4490	4540	4590	4645	4695	4745	4800	4850	4900	4955	5005
18	3740	3790	3840	3890	3940	3995	4045	4095	4145	4200	4250	4300	4350	4405	4455	4505	4555	4610	4660	4710	4760	4815	4865	4915	4965
20	3710	3760	3810	3860	3910	3960	4015	4065	4115	4165	4215	4265	4320	4370	4420	4470	4520	4570	4625	4675	4725	4775	4825	4875	4930
22	3680	3730	3780	3830	3880	3930	3980	4030	4080	4135	4185	4235	4285	4335	4385	4435	4485	4535	4585	4635	4685	4735	7490	4840	4890
24	3635	3685	3735	3785	3835	3885	3935	3985	4035	4085	4135	4185	4235	4285	4330	4380	4430	4480	4530	4580	4630	4680	4730	4780	4830
26	3605	3655	3705	3755	3805	3855	3905	3955	4000	4050	4100	4150	4200	4250	4300	4350	4395	4445	4495	4545	4595	4645	4695	4740	4790
28	3575	3625	3675	3725	3775	3820	3870	3920	3970	4020	4070	4115	4165	4215	4265	4310	4360	4410	4460	4510	4555	4605	4655	4705	4755
30	3550	3595	3645	3695	3740	3790	3840	3890	3935	398	4035	4080	4130	4180	4230	4275	4325	4375	4425	4470	4520	4570	4615	4665	4715
32	3520	3565	3615	3665	3710	3760	3810	3855	3905	3950	4000	4050	4095	4145	4195	4240	4290	4340	4385	4435	4485	4530	4580	4625	4675
34	3475	3525	3570	3620	3665	3715	3760	3810	3855	3905	3950	4000	4045	4095	4140	4190	4225	4285	4330	4380	4425	4475	4520	4570	4615
36	3445	3495	3540	3585	3635	3680	3730	3775	3825	3870	3920	3965	4010	4060	4105	4155	4200	4250	4295	4340	4390	4435	4485	4530	4580
38	3415	3465	3510	3555	3605	3650	3695	3745	3790	3840	3885	3930	3980	4025	4070	4120	4165	4210	4260	4305	4350	4400	4445	4495	4540
40	3385	3435	3480	3525	3575	3620	3665	3710	3760	3805	3850	3900	3945	3990	4035	4085	4130	4175	4220	4270	4315	4360	4410	4455	4500
42	3360	3405	3450	3495	3540	3590	3635	3680	3725	3770	3820	3865	3910	3955	4000	4050	4095	4140	4185	4230	4280	4325	4370	4415	4460
44	3315	3360	3405	3450	3495	3540	3585	3630	3675	3725	3770	3815	3860	3905	3950	3995	4040	4085	4130	4175	4220	4270	4315	4360	4405
46	325	3330	3375	3420	3465	3510	3555	3600	3645	3690	3735	3780	3825	3870	3915	3960	4005	4050	4095	4140	4185	4230	4275	4320	4365
48	3255	3300	3345	3390	3435	3480	3525	3570	3615	3655	3700	3745	3790	3835	3880	3925	3970	4015	4060	4105	4150	4190	4235	4280	4325
50	3210	3255	3300	3345	3390	3430	3475	3520	3565	3610	3650	3695	3740	3785	3830	3870	3915	3960	4005	4050	4090	4135	4180	4225	4270
52	3185	3225	3270	3315	3355	3400	3445	3490	3530	3575	3620	3660	3705	3750	3795	3835	3880	3925	3970	4010	4055	4100	4140	4185	4230
54	3155	3195	3240	3285	3325	3370	3415	3455	3500	3540	3585	3630	3670	3715	3760	3800	3845	3890	3930	3975	4020	4060	4105	4145	4190
56	3125	3165	3210	3255	3295	3340	3380	3425	3465	3510	3550	3595	3640	3680	3725	3765	3810	3850	3895	3940	3980	4025	4065	4110	4150
58	3080	3125	3165	3210	3250	3290	3335	3375	3420	3460	3500	3545	3585	3630	3670	3715	3755	3800	3840	3880	3925	3965	4010	4050	4095
60	3050	3095	3135	3175	3220	3260	3300	3345	3385	3430	3470	3500	3555	3595	3635	3680	3720	3760	3805	3845	3885	3930	3970	4015	4055
62	3020	3060	3110	3150	3190	3230	3270	3310	3350	3390	3440	3480	3520	3560	3600	3640	3680	3730	3770	3810	3850	3890	3930	3970	4020
64	2990	3030	3080	3120	3160	3200	3240	3280	3320	3360	3400	3440	3490	3530	3570	3610	3650	3690	3730	3770	3810	3850	3900	3940	3980
66	2950	2990	3030	3070	3110	3150	3190	3230	3270	3310	3350	3390	3440	3490	3510	3550	3600	3640	3680	3720	3760	3800	3840	3880	3920
68	2920	2960	3000	3040	3080	3120	3160	3200	3240	3280	3320	3360	3400	3440	3480	3520	3560	3600	3640	3680	3720	3760	3800	3840	3880
70	2890	2930	2970	3010	3050	3090	3130	3170	3210	3250	3290	3330	3370	3410	3450	3480	3520	3560	3600	3640	3680	3720	3760	3800	3840
72	2860	2900	2940	2980	3020	3060	3100	3140	3180	3210	3250	3290	3330	3370	3410	3450	3480	3520	3560	3600	3640	3680	3720	3760	3800
74	2820	2860	2900	2930	2970	3010	3050	3090	3130	3170	3200	3240	3280	3320	3360	3400	3440	3470	3510	3550	3590	3630	3670	3710	3740

1 inch = 2.54 cm