PULMONARY BAROTRAUMA

ESSAY

Submitted For Partial Fulfilment Of
The Master Degree In ANAESTHESIOLOGY

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1991

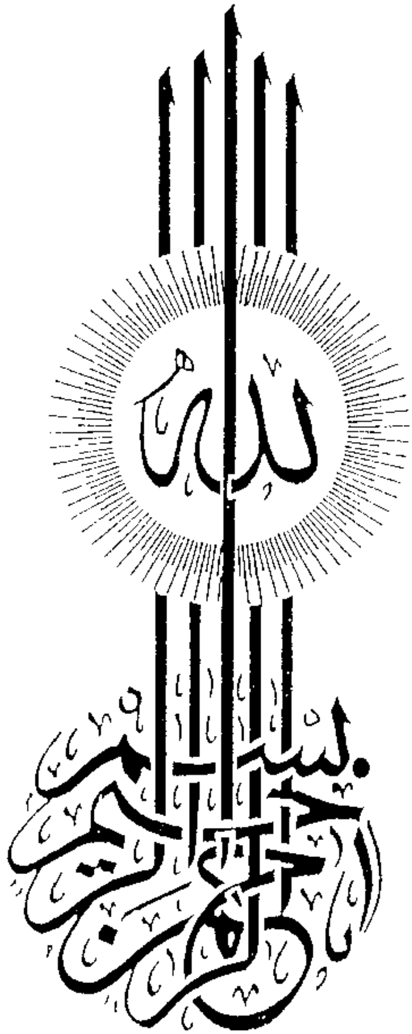
ACKNOWLEDGEMENT

First and foremost I thank God the beneficent and the merciful.

I would like to express my deepest gratitude and appreciation to **Prof. Dr. SAMIR Y. BASSILY,** *Professor of Anaesthesiology, Ain Shams University, for his kind supervision, valuable suggestions and constructive criticism.*

I am also grateful to **Dr. AMIR I. SALAH,** *lecturer of Anaesthesiology, Ain Shams University, for his meticulous guidance and sincere help throughout this work.*

Sincere thanks are also extended to the Senior Medical Staff and my Colleagues in the Anaesthesiology Department for their support, valuable remarks and cooperation.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conducting zone of the airways occupied by gas that does not exchange with blood in the pulmonary vessels.

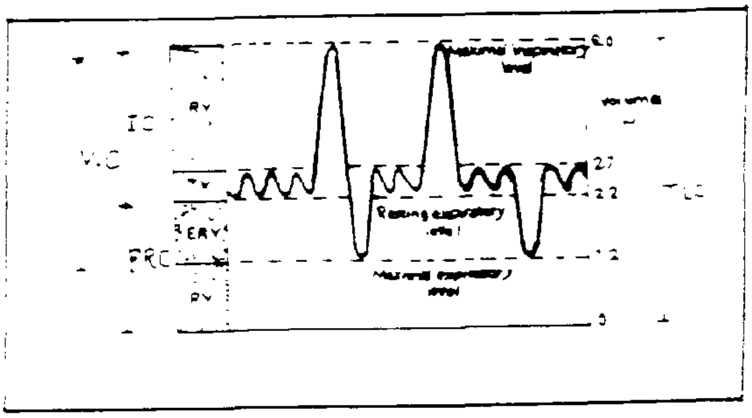

Figure (1) : Lung volumes and capacities (modified from Ganong, 1989)

ERV = expiratory reserve volume — TV = tidal volume

IRV = inspiratory reserve volume — RV = residual volume

VC = vital capacity — FRC = functional residual capacity

TLC = total lung capacity — IC = inspiratory capacity

12- Closing capacity (C.C.) (figure I) : is the lung volume at which the small airways in the dependent parts of the lung begin to close or it is the sum of closing volume and residual volume (R.V.). Closing volume (C.V.) is the gas volume expelled during phase IV of the single breath nitrogen test, which denotes the lung volume from the beginning of airway closure to the end of maximal expiration. Therefore ; C.V. = C.C. - R.V..

In normal young people, the closing volume is approximately 10% of the vital capacity, or 400 ml. to 500 ml.. The closing volume and the closing capacity increase bow out or expand (Figure 4). This means that the lungs collapse below residual volume (but not to a completely airless state) when they are excised from the intact thorax. The chest wall if unopposed by the lungs, would occupy a volume approximately 70% of the total lung capacity (TLC). Therefore, in the intact thorax the forces of contraction (lung tissue) and expansion (chest wall) differ in magnitude and direction throughout most of the ventilatory cycle (figure 5) (Spearman et al., 1982).

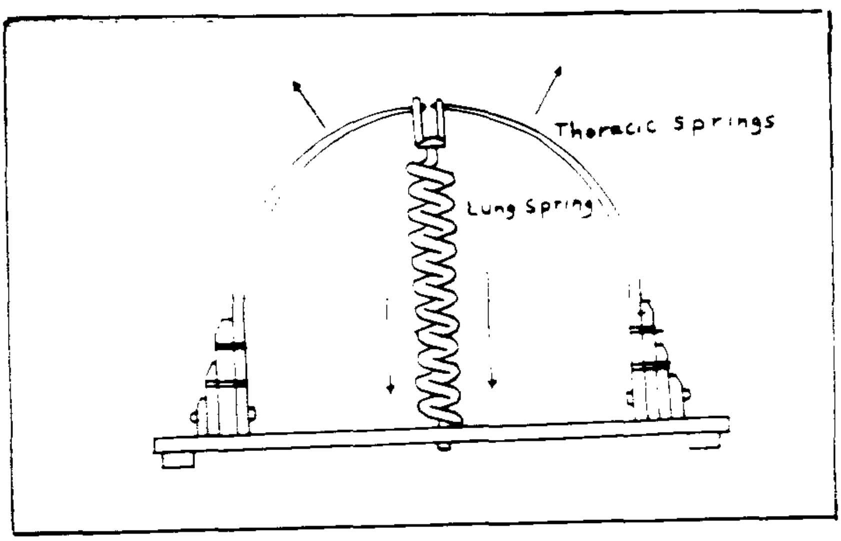

Figure (4) : Schematical illustration of lung contraction opposed by chest wall expansion. The coiled spring represents the natural tendency of the lung tissue to contract. The bowed springs depict the thorax tending to expand. The arrows indicate the direction in which each of these tissues seeks to move (after Spearman et al., 1982).

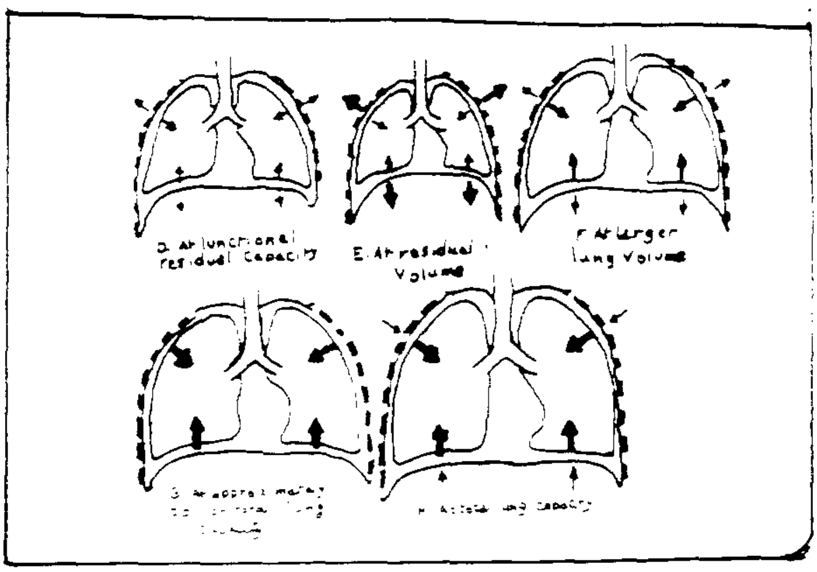

Figure (5) : The interaction of the two opposing forces of lung tissue recoil and chest wall expansion at five different ventilatory positions after Spearman et al., 1982):

1- At functional residual capacity (at normal end exhalation), the recoil forces of the lung parenchymal tissue are equal in magnitude but opposite in direction to expansion forces of chest wall tissue. Thus the two forces are in equilibrium.

2- At residual volume at this ventilatory position the contractile forces of the lung tissue are less than the expansile forces of the chest wall. Consequently the tendency of the lung chest wall system at this point favors lung filling (inspiration).

3- At a large lung volume more than functional residual capacity and less than 70% of total lung capacity, the contractile forces of the lung tissue are greater than those tending to expand the chest wall. Therefore, at this lung volume the tendency of the lung chest wall system is to favor lung emptying (exhalation).

4- At a lung volume equal to 70% of the total lung capacity : chest wall elastic recoil is zero. Consequently, the contractile forces of the lung tissue act unopposed and promote exhalation.

5- At total lung capacity. Both forces, lung and chest wall elastic recoil, act in the same direction. However, the magnitude of the lung parenchymal recoil forces exceeds those contributed by the chest wall.

During the inspiratory phase of the ventilatory cycle the muscles of inspiration provide the force required to produce a pressure change. Normal exhalation requires no muscle effort because the elastic recoil of the lung tissue accomplishes exhalation to the functional residual capacity (F.R.C.) level. To achieve residual volume (R.V), active contraction of certain abdominal and thoracic muscles is required. The normal expansile tendency of the chest wall prevents the passive accomplishment of this act (Spearman et al., 1982).

Because lung and chest wall tissues are elastic materials, Hooke's law has physiologic applications. However, due to the complexity of the respiratory apparatus, the application of Hooke's law to this physiologic model is not as straightforward as the length-force system of a spring. If we substitute pressure for force and volume for length, a pressure-volume curve can be plotted (Figure 6). This pressure-volume curve is actually a compliance curve. Compliance is defined as the volume change per unit of pressure change and represents the elastic behaviour of the respiratory apparatus.

$$\text{Compliance} = \frac{\text{Volume change (litre)}}{\text{Pressure change (cm } H_2O)} = \Delta \frac{V}{P}$$

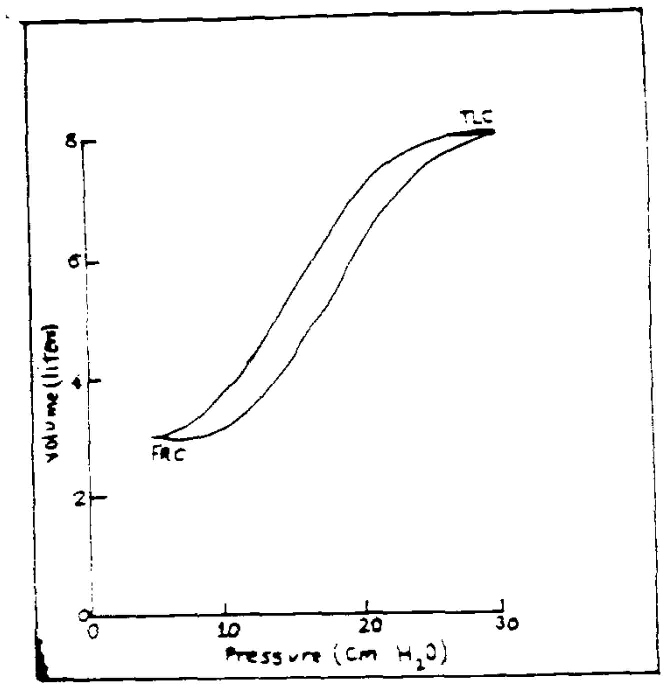

Figure (6) : The compliance curve is obtained by plotting lung pressure versus lung volume. This compliance curve indicates two plottings, inspiration (lower tracing) and expiration (upper tracing), between functional residual capacity and total lung capacity (after Kacmarek et al. 1979)

The shape of the compliance curve is sigmoid. Thus the relationship between lung volume and lung pressure charges throughout the ventilatory cycle is not linear. Because of the nonlinear nature of the lung pressure-volume curve, it should be evident that a single measurement derived from the curve will not accurately reflect the elastic properties of the lungs. The reason is that a given volume change (ΔV) on the steep portion of the curve requires a small pressure change (ΔP) than that required for the same volume change on the flat segment of the curve (Figure 7) (Kacmarek et al., 1979).

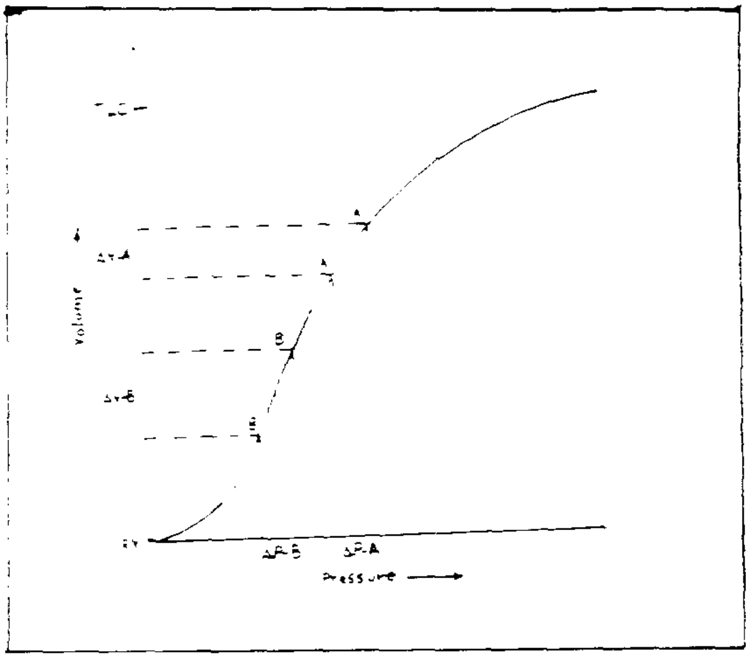

Figure (7) : Lung compliance curve showing differences at lung bases and apices. On the X axis ΔP-B represents the pressure change of the lung bases during normal tidal ventilation while ΔV-B Y axis refers to the corresponding volume change in the bases. The ΔP-A represents the pressure change in apices during normal tidal breathing, and ΔV-A represents the volume change in the apices. ΔP-B equals ΔP-A; however, corresponding volume change for each pressure change is not equal. The ΔV-A is less than ΔV-B for the same pressure change because the apices are situated close to the flat portion of the compliance curve, whereas the bases are located on the steep portion (after Kacmarek et al., 1979).

Three types of compliance exist within the respiratory system. They are :

1- Lung or pulmonary compliance (C_l).

2- Chest wall or thoracic compliance (C_{cw}).

3- Lung-chest wall or total compliance (C_t).

Each type of compliance can be obtained from the expression

$$\frac{1}{C_l} + \frac{1}{C_{cw}} = \frac{1}{C_t}$$

where : $1/C_l$ = the reciprocal of the compliance of the lung tissue.

$1/C_{cw}$ = the reciprocal of the compliance of the chest wall.

$1/C_t$ = the reciprocal of the compliance of the total respiratory apparatus (that is to say ; the lungs and chest wall combined).

It should be noted from the equation that the total compliance will always be less than the compliance of either the lungs or chest wall alone. Normally C_l and C_{cw} each equal 0.2 L/cm H_2O, thus C_t = 0.1 L/cm H_2O.

To determine C_l, ΔV and transpulmonary pressure gradient (P alveolar - P pleural, the ΔP for the lung) must be known. To determine C_{cw}, ΔV and transmural pressure gradient (P pleural - P ambient, the ΔP for the chest wall) must be known. To determine C_t, Δv and the transthoracic pressure gradient (P alveolar - P ambient, the ΔP for the lung and chest wall together) must be known. In clinical practice, only C_t is measured, which can be done dynamically or statically depending on whether a peak or plateau inspiratory pressure gradient (respectively) is used for the C_t calculation. During a positive or negative pressure inspiration of sufficient duration, the transthoracic pressure gradient first increases to peak value and then decreases to a somewhat lower plateau value. The peak transthoracic pressure value is due to pressure required to overcome both elastic and airway resistance. The transthoracic pressure decreases to a plateau value following the peak value, because, with time, gas redistributes from stiff alveoli (which expand only slightly and therefore have only a very short inspiratory period) into more compliant alveoli (which expand a great deal and therefore have a long inspiratory period). Since the gas redistributes into more compliant alveoli, less pressure is required to contain the same amount of gas, and this explains why the pressure decreases. In practical terms, dynamic compliance is the volume change divided by the peak inspiratory transthoracic pressure; static compliance is the volume change divided by the plateau inspiratory transthoracic pressure. Therefore, static C_t is usually greater than dynamic C_t, since the former calculation uses a smaller denominator (lower pressure) than the latter calculation (Benumof, 1990).

As compliance depends not only on the elasticity of the lung tissue but also on the initial volume of the lung before it is stretched. and as the compliance value changes with lung volume (for instance, a person with a small lung volume will have a lower compliance than someone with a high lung volume, despite the fact that both lungs may have identical elastic and distensible qualities). Therefore, it is necessary to determine whether an alteration in compliance represents a change in elasticity of the lung tissue itself or whether it is due to change in initial lung volume. It has been proposed that the best method of eliminating the effects of a change in lung volume is to determine the specific compliance which represents the elastic behaviour of the respiratory apparatus, and is used to indicate the volume at which the compliance measurement was made. Compliance measurement is often made at functional residual capacity (FRC) and thus

$$\text{specific compliance} = \frac{C_t \ (L/cm\ H_2O)}{FRC\ (L)},$$

thus the units are litre/ cm H_2O/ Litre FRC, the normal value is 0.05 and the range is 0.038 - 0.070 L/cm H_2O/L. FRC (Kacmarek et al., 1979).