TREATMENT

Preventive

1) Careful preanesthetic examination to determine the type of risk; and to guide in the selection of preanesthetic medication and the anesthetic.

2) Adequate preliminary medication to prevent fright, minimize struggle and suppress sympathetic hyperactivity.

3) The selection of anesthetic agent or agents best suited for the particular case.

4) Do not rush the induction period.

5) Avoid external stimuli during the induction period.

6) The anesthetic level should be varied to conform to the progress of the surgical procedures and continued deep narcosis should be avoided.

7) Airway should be open and efficient breathing maintained at all times.

8) Accurate record of blood pressure, pulse and respiration at all times.

9) The time factor in surgery is a vital factor that is frequently overlooked. The degree of depression varies directly with the operating time and the depth of narcosis.

Active

Be prepared to deal with any anesthetic emergencies or complications that may occur, such as vomiting, convulsions, shock, etcetera. Stimulants, oxygen under pressure, and suction equipment should be available for emergency treatment at all times during anesthesia.

In conclusion, I wish to say that teamwork between the surgeon, the anesthetist and the nurses is extremely essential to the success of every operation. Neither should make unreasonable demands upon the other, but should coordinate their efforts in the best interest of the patient.

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DEPARTMENT OF EDUCATION

ANATOMY OF THE RESPIRATORY SYSTEM

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THE BRONCHIAL TREE

In man the respiratory system consisting of nose, mouth, pharynx, larynx, trachea, bronchi, bronchioles, terminal bronchioles, respiratory bronchioles, alveolar ducts, alveolar sacs and their eventual alveoli; a huge number of these bronchioles, air spaces and alveoli being grouped within a closed serous membrane sac (pleura) to constitute a lung.

Air entering through the nose or mouth passes down the pharynx, through the larynx and into the trachea (a cylindrical structure composed of cartilaginous rings, situated in the center of the upper thorax). The trachea at its lower end bifurcates into two main bronchi, one proceeding to and within the right lung, the other proceeding to and within the left lung. Each of these main bronchi divides in-
to bronchioles, and these in turn into many progressively smaller bronchioles, all terminating eventually in minute alveoli. Thus, air passing down the trachea is conducted through an ever increasing number of progressively smaller air passages until it reaches the final alveoli, within the structures of which the actual exchange of gases takes place between the respired air within the alveoli and the circulatory blood as it courses through the tiny capillaries which so bountifully invest the walls of each alveolus.

While the alveoli themselves are individually exceedingly small in size, they exist in huge numbers (something like four hundred million in an adult lung). As a result of this, there is exposed to respiratory air an alveolar surface equal to something like one hundred times the surface of the entire external body. Because of this tremendous alveolar area with which the pulmonary circulation is brought into contact, a very effective exchange of gases takes place between the alveolar air and the blood flowing through the pulmonary capillaries, even during the brief period of transit of that circulatory blood through the lungs.

It is to be noted that the trachea, bronchi, bronchioles and air sacs are merely conductors of respiration air, and that while the bronchi by alterations in their caliber (alterations in the size of their lumen) contribute to the physical effectiveness of inspiration and

Fig. 1. Bronchi and Bronchioles: Lobes and Lobules. The lungs have been widely separated and tissue cut away to expose the air tubes. (Gray’s Anatomy, courtesy Lea & Febiger.)
expiration, these air conductors do not of themselves enter into the act of actual respiration; as that exchange of gases between (a) respiratory air and (b) pulmonary circulation, takes place only in the respiratory bronchioles and in the alveoli themselves.

Illustrative of the above, Macklin proposes considering the bronchial tree as consisting of two parts:—the first part to embrace the mere air conduits, which extend from the trachea to and including the terminal bronchioles; (these "branches" and "twigs" of the "tree" possessing no respiratory function) (Fig. 1)—the second part, to embrace the actual respiratory structures, which lie distal to the terminal bronchioles, (these "leaves" of the bronchial tree constituting the structures in which the actual respiratory function takes place). Each of these individual leaves of the respiratory tree embraces a cluster of basic structures (respiratory bronchioles, alveolar ducts, alveolar sacs and alveoli; together with their arteries, veins and lymphatics), this basic group constituting the anatomical and physiological primary respiratory unit of the lung (Fig. 2). It is the distensible or "belows" part of the lung structure.

In the foregoing outline, the modern conception is presented of "terminal bronchioles" emptying air into "respiratory bronchioles"—these respiratory bronchioles dividing into "alveolar ducts" and "alveolar sacs," from the walls of which evacuate the final minute sacculations called "alveoli"; this "assembly" (of a terminal bronchiole, with its own little group of attendant ducts, sacs and eventual alveoli, together with their vessels, nerves, muscular tissue and connective tissue), constituting the structural and physio-
logical unit of the lung. The older terms “atria” and “infundibula” which have caused considerable confusion in the past (and being without particular physiological significance, according to Starling) have been purposely discarded from these present notes, in favor of the more modern terminology.

**THE LUNGS (PULMONES).**

The lungs themselves may be considered as two large closed membranous sacs, completely enveloping their enclosed bronchi, bronchioles, air sacs, alveoli, et cetera, and occupying the greater part of the thoracic cavity.

Each lung is divided by deep fissures into lobes; the right lung into three lobes, the left lung into two lobes.

Each lobe is made up of a great number of lobules. The outlines of the peripheral layer of these lobules are visible on the external surface of the lungs in the form of clearly defined pigmented lines identifying their polyhedral boundaries.

The right and left lung are separated from each other by an area called the mediastinum, which area contains the heart, trachea, esophagus and other structures. By reason of the fact that the heart encroaches upon the left lung, the left lung is smaller than the right.

The root of the lung is the term applied to that area of the lung through which a number of structures both enter it and leave it at the wedge-shaped depression called the hilum that indents its mesial surface. These structures which pass into and out of the lung at its hilum, and which constitute its root, are notably (1) the pulmonary arteries and veins coming from, and returning to the heart, (2) bronchi from the trachea, (3) pulmonary nerves, lymphatic vessels, bronchial glands and aerolar tissue. This group of structures is held together by an investment of pleura which is a continuation of the mediastinal pleura described on page 172. The root of the lung constitutes a pedicle by which each lung is attached to the mediastinum.

**THE PLEURAE.**

The pleurae are two serous membranes, one right and one left, each of

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![Diagram](image-url)

**Fig. 3. The pleurae and their reflexions, from behind.**

*(A Method of Anatomy, J. Boileau Grant, courtesy Wm. Wood & Co.)*
which constitutes the covering for the lung which lies within it. After completely investing the entire lung structure itself, each pleura reflects mesially as a continuation of itself to cover first the root of the lung, then to cover the mediastinum, and finally from the sternal and vertebral reflexions, to line the walls of the thoracic cavity (Fig. 3).

The inner layer of pleural membrane, which is inseparably fused with the lung that it covers, (extending into the interlobar fissure) is called the visceral pleura or pulmonary pleura.

The outer layer of pleural membrane, which is fixed to and which lines the thoracic cavity in its various dimensions, is called the parietal pleura. Its various areas are named descriptively as follows according to the precise structures with which they are associated:

Superiorly, that portion of the parietal pleura which rises up into the neck over the apex of the lung, is called the cervical pleura or “cupola of the pleura.” Laterally, that portion of the parietal pleura which lines and is affixed to the internal surfaces of the ribs and intercostal spaces, is called the costal pleura. Inferiorly, that portion of the parietal pleura which invests and is affixed to the diaphragm, is called the diaphragmatic pleura. Mesially, that portion of the parietal pleura which reflects posteriorly from the sternum (sternal reflexion) to pass over and cover the pericardium and other anterior mediastinal structures, is called the mediastinal pleura. Likewise, that portion of the parietal pleura which reflects anteriorly from the vertebral column (vertebral reflexion) to pass over and cover the esophagus and other posterior mediastinal structures, is also called the mediastinal pleura (Fig. 4).

While the foregoing several areas of the pleurae are for purposes of identification described by the names noted, it is to be remembered that the various portions of each pleural membrane are actually continuous with each other; each constitutes a continuous unbroken membranous sac.

**Fig. 4.** The pleurae; cervical, costal, diaphragmatic, mediastinal. The lung is represented as a balloon with a stalk. (A Method of Anatomy, J. Boileau Grant, courtesy Wm. Wood & Co.)

**THE PLEURAL CAVITY.**

Where the pulmonary pleurae and the costal pleurae lie in apposition to each other, their surfaces are separated by only a thin layer of lymph which lies between them, which is secreted there for lubricating the slippage of their surfaces over each other. While in the normal state these surfaces are in actual contact with each other, the space between them constitutes a potential cavity, which becomes an actual cavity when air or liquid is introduced between them, either through the chest wall, or through a lesion in the lung, or as a result of pathological exudation; (pneumothorax, hydrothorax, empyema, et cetera). The space (potential or actual) existing between the visceral pleura and the parietal pleura, is called the pleural cavity (Fig. 5).
THE SIMPLE MECHANICS OF BREATHING

The thorax may be defined as that part of the body cavity enclosed within the bony cage which is formed by the ribs, the sternum and the thoracic vertebrae, extending from the neck to the abdomen. It is a closed cavity, entirely shut off from contact with the outside.

Together with the other thoracic viscera, the lungs completely fill the closed thoracic cavity. Their membranous covering of pulmonary pleura lies laterally in intimate contact with the costal-pleura-lined walls of the thorax.

This close apposition of the structural lung covering, to its opposed pleural-lined thoracic walls, is caused and maintained by the negative pressure which during life is normally present in the potential cavity that exists between that lung covering and the thoracic walls. Accordingly, when a mechanical enlargement in size and volume of the thoracic cavity takes place, it is accompanied by a corresponding enlargement in the size and volume of the lungs. The normal size of the thorax and of its contained lungs, is regarded as that which exists at the end of an ordinary expiratory movement—when all of the respiratory muscles are at rest. Normal breathing is regarded as consisting of an active inspiration, followed by a passive expiration.

Inspiration. The act of inspiration results from a mechanical enlargement
of the thoracic cavity, which is effected in the following manner:—

(1) Contraction of the muscles of the diaphragm pull that structure markedly downward, thus enlarging the size of the thorax in its superior-inferior dimension. Accompanying this descent of the diaphragm, the abdominal viscera are compressed downward and force the abdominal wall outward.

(2) Contraction of inspiratory muscles attached to various ribs, vertebrae, the sternum, et cetera, pulls the ribs upward and outward, thus increasing the size of the thorax in that dimension.

These enlargements in size of the thorax in its various dimensions, create an increased negative pressure within the pleural cavity which lies between the thoracic walls and the lung covering—this "suction" effect keeping the pulmonary pleura in continued close apposition to the chest wall during the enlargement in volume which necessarily accompanies the thoracic expansion. As this mechanically induced enlargement in volume of the lung takes place, air is drawn into it from the outside atmosphere, through the freely open respiratory tract; and the air so taken into the lungs in this mechanistic way, constitutes an inspiration.

Expiration. The act of normal expiration is a more passive procedure, being accomplished chiefly by merely physical forces. As the inspiratory muscles relax, the following sequence of events transpires:—

(1) The diaphragm returns upward to its normal, relaxed, arched position. It is assisted in this return by upward pressure from the abdominal viscera which were forced downward during inspiration, but which now return to their normal positions, assisted by the contractive elasticity of the stretched abdominal wall.

(2) The weight and torsion of the ribs cause their portion of the thorax to sink back to resting position.

(3) During these diminutions in size of the thoracic cavity in its various dimensions, the elastic tissues of the lungs are enabled to correspondingly contract from their expanded "inspiratory" volume. As they do so, they force their air out into the atmosphere, through the open respiratory tract. When the thorax and lungs have reached their normal "resting" position, an expiration has been effected.

Note: While during expiration the intercostal muscles do contract to pull the ribs together, and the bronchial wall muscles do shorten and narrow the bronchi, these forces are not sufficiently great to change the designation of the normal expiratory act from an essentially passive function, to that of an active one.

Discussion. As a matter of record, it is to be noted that the foregoing classical description of the mechanics involved in the act of inspiration is at slight technical variance with a contention which has been urged, that "atmospheric positive pressure," and not "intrapleural negative pressure" causes the lung expansion to parallel thoracic-cavity expansion during the inspiratory phase. Both factors are involved; but avoiding many argumentative details, it would seem that an inclusive summing up of the salient controversial features is achieved,
by stating that the act of normal inspiration results from changes in the pressures which are presented to the surfaces of the pulmonary pleurae, during, and as a result of, inspiratory enlargement of the thoracic cavity. As intrapleural negative pressure is increased by the expanding thorax, its outward pull on the external surface of the pulmonary pleura is “accommodated” by the degree of positive pressure which is communicated to the internal surface of that pulmonary pleura from the atmosphere, with which it is in communication through the open respiratory tract. As Graham has aptly stated, the passage of air down the trachea and into the lungs, is essentially a suction action.

**PULMONARY VENTILATION.**

If at the end of an ordinary inspiration, a further forcible inspiratory effort is made, it will be found that an additional amount of air can be breathed in. The average amount of this additional volume, in normal adults, is approximately 1,500 to 2,000 cc. The air which can be so added to the lungs through this additional available volume of inspiration, is called complemental air.

The air which is inhaled and exhaled during ordinary breathing is called tidal air. Tidal volume for the average adult during quiet breathing is about 500 cc. per inspiration.

If at the end of an ordinary expiration, a further forcible expiratory effort is made, it will be found that an additional approximately 1,500 cc. of air may be exhaled. The air which can be so expelled from the lungs through this additional available volume of expiration, is called supplemental air.

The combined volumes of:—complemental air, tidal air, and supplemental air (the total amount of air which can be exhaled after a maximal inspiration, or that can be inhaled after a maximal expiration) is called the Vital Capacity. This maximum possible amount of an individual’s forced respiratory exchange, averages in a normal adult about 4,000 cc.

But even by means of the most forceful expiratory movement, it is not possible to exhale all of the air from the lungs, an approximately 1,500 cc. of air remaining. This air which remains in the lungs after such maximal forced exhalation is called residual air.

- 2,000 cc. Complemental air
- 500 cc. Tidal air
- 1,500 cc. Supplemental air
- 1,500 cc. Residual air

5,500 cc. Total Capacity of the respiratory organs.

Obviously the total capacity of the respiratory organs will vary considerably among different sized individuals...and corresponding variations in the volume of residual air, supplemental air, complemental air, tidal volume and dead space in various individuals will result.

Not all authors adopt the same “average” figure for these several volumes. The table herein used is that of Waller, as published by Graham, Williams and others.

**Dead Space Air.** Not all of the air which is breathed in during an inspiration reaches the actual pulmonary alveoli, as a portion of it is contained within the merely conductive “branches” and “twigs” of the bronchial tree at the completion of the inspiration. This air which remains within the lumen of this non-respiratory portion of the bronchial tree at the end of a respiratory phase, is called dead space air. Since, as already stated, the
size of this “dead space” varies with individuals, so does the volume of dead space air vary with the individual, but in an average adult, during quiet breathing, the average volume of dead space air is about 150 cc.

From the foregoing it will be seen that while tidal volume of breathing may average 500 cc., only about 350 cc. of that inspired air reaches the actual respiratory areas, to mix with the approximately 3,000 cc. of “stationary air” already there.

At the end of an inspiration, the dead space air consists of the atmosphere that has just been breathed in, practically uncontaminated by respiratory products of blood oxidation. It also naturally represents, at the same time, the first fraction of air that will be expired. At the end of expiration, the then dead space air has come from the alveolar areas and is accordingly laden with carbon dioxide.

EXPLANATION OF PRESSURE TERMINOLOGY

Intrapulmonic Pressure (Intrapulmonary Pressure) relates to the conditions of pressure existing within the lung structure itself (the distensible and collapsible structure enclosed within the pulmonary pleura). When the lungs are at rest, at the end of an inspiration or at the end of an expiration, intrapulmonic (intrapulmonary) pressure equals that of the outside atmosphere with which it is in free communication through the open respiratory tract. It is therefore at that resting phase, neither positive nor negative.

During the act of inspiration, intrapulmonic (intrapulmonary) pressure becomes “negative,” or less than that of the outside atmosphere. This is brought about by the already described active enlargement of the thorax, whose outward pull expands the lungs faster than their air can be drawn in without frictional resistance from the mechanical constrictions that are interposed by the glottis (which is normally the narrowest part) and other portions of the respiratory tract. The extent of this intrapulmonic negative pressure during inspiration, depends upon (a) the rapidity and amplitude of the muscular inspiratory enlargement and (b) the size and degree of resistive constrictions that may exist between the lungs and the outside atmosphere. During quiet, normal inspiration, intrapulmonic negative pressure averagely registers approximately minus 2 millimeters of mercury (—2 mm. Hg).

During the act of expiration, intrapulmonic (intrapulmonary) pressure becomes “positive” or greater than that of the outside atmosphere. This is due to the fact that the speed of contraction in size of the thorax is such that it permits the contractile lungs to reduce their volume faster than their air can be expelled through the conductive respiratory tract without frictional resistance from the glottis and other portions of the tract through which it must pass in exhalation. Hence, pulmonic air is “compressed” somewhat and positive pressure is thereby created within its area. During quiet, normal expiration, intrapulmonic positive pressure averagely registers approximately plus 3 or plus 4 millimeters of mercury (+3 or +4 mm. Hg).

Intrapleural Pressure (Intrathoracic Pressure) relates to the conditions of pressure existing within the thorax, but outside of the lungs. It embraces the pleural cavity and the mediastinum (the mediastinal spaces). This intrapleural or intrathoracic pressure denotes the condition of pressure under which the heart, the great vessels, the thoracic duct and other structures
within the mediastinum function. Normally, intrathoracic pressure is negative and therefore the vital mediastinal structures carry on their work at a pressure that is lower than that of the outside atmosphere. This intrathoracic negative pressure facilitates the drawing of blood up into the large venous trunks and into the auricles of the heart, due largely to a “sucking” effect. It also plays an important rôle in maintenance of normal lymph flow through the thoracic duct which empties into the venous stream to the heart. Conversely, positive pressure introduced to the intrathoracic area inhibits these actions.

The intrapleural (intrathoracic) negative pressure under which the lungs, heart, great vessels and other thoracic organs normally carry on their work, is caused by the counterplay of two opposed forces, (1) the already described inspiratory pull by the diaphragm and thoracic cage as they expand the cavity downward, upward and outward acting against (2) the tonic, contractile counter pull inward of the elastic lung structure, which continuously acts to contract the pleural lung covering away from the thoracic walls and from the diaphragm. While the degree of the resultant negative pressure within the intrapleural cavity varies markedly with different individuals, and even in the same individual at different times, it is stated (by Aaron and others) to average in adults “minus 4.5 to minus 9 millimeters of mercury during quiet inspiration” and “minus 3 to minus 6 millimeters of mercury during quiet expiration.” The chest service at Barnes Hospital has noted during inspiration “minus 2 to minus 18 millimeters of mercury, according to the phase at which the reading were taken” and has noted during expiration “from almost zero to minus 8 millimeters of mercury, according to the phase at which it was taken.”

It is to be noted that intrapleural (intrathoracic) pressure does not equal atmospheric pressure, but instead continues to be “negative,” even during expiration. This is due to the fact that during expiration the constant contractile tension of the elastic lung structure continually acts to pull its closed covering (pleura) away from the thoracic walls, in an effort to deflate itself to an “unstretched” state. This contractive effort the lung structure continues even at the end of expiration, when each lung is still “expanded” to the extent of the supplemental air and of the residual air which it contains at the end of the expiratory phase.

While intrapleural pressure does not reach atmospheric pressure during expiration, both intrapulmonic pressure and intratracheal pressure do reach, and exceed, atmospheric pressure during the expiratory phase, due to the fact that both of these latter areas (intrapulmonic and intratracheal) lie between the actuating compressor force of the contracting lung covering (pulmonary pleura) and the frictionally resistant narrowed opening of the glottis.

**THE MEDIASTINUM.**

As has been noted (page 171), the space between the lungs is occupied by a group of structures which includes the trachea, esophagus, heart, great arteries, great veins, thoracic duct, et cetera. This median space, within which these structures lie, is called the mediastinum. The structures within its boundaries are called the mediastinal contents (Fig. 5). While for convenience in description, the mediastinum is divided anatomically into several areas, we will for our purpose here consider it in its entirety, as
a single structure composed of the mediastinal contents "walled in" by, and lying between, the right and left mediastinal pleurae.

**Normal Mobile Mediastinum:** Normally the mediastinum is somewhat mobile, moving slightly forward and backward with inspiration and expiration. When positive pressure is presented to one side of it, as in the creation of an artificial pneumothorax in that side of the chest, the mobile mediastinum shifts (is forced) over toward the other side of the thorax, thereby encroaching upon the unoperated lung and consequently decreasing its respiratory capacity. The practical significance of this physical phenomenon, to the anesthetist, lies in its indication for administering the anesthesia under sufficient positive pressure to counterbalance the contralateral pressure that has been introduced by the pneumothorax, and to thereby prevent encroachment of the mobile mediastinum upon the unoperated lung at a time when its fullest respiratory integrity is vitally needed.

**Fixed Mediastinum.** Under certain circumstances, such as pleural adhesions, induration in empyema, et cetera, the normally mobile mediastinal tissues become somewhat stabilized, and a condition termed "fixed mediastinum" exists, in which the anchored or stiffened mediastinal structure resists the positive pressure of pneumothorax and thereby prevents the increased (atmospheric) pressure of the pneumothorax from forcing the mediastinum over into the unaffected lung.

Whether a patient's mediastinum is "mobile" or "fixed," and therefore whether the anesthesia during pneumothorax is to be conducted under increased positive pressure or at merely atmospheric pressure, is determined by the surgeon's findings at the operative field. It is important that the anesthetist understand the significance of the physiological functions and mechanics involved.

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