MANAGEMENT OF POSITIVE PRESSURE IN ENDOTRACHEAL ANESTHESIA *

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The management of positive pressure, using the closed system endotraheal anesthesia, employing a tracheal tube that is attached to the carbon dioxide absorption machine, will be considered in this paper. The clearest understanding of the processes to be discussed may be obtained by focusing attention on the respired gases. These gases are confined to a system comprising the lungs,‡ bronchioles, tracheobronchial tree of the patient and the tracheal tube, tubes, adapters, valves, carbon dioxide absorber and breathing bag of the machine. Within this system there is a back and forth movement of gases between the two end points of the system, namely the lungs and the breathing bag. These parts, at the opposite ends, act as reservoirs for the gases and all other parts in between them have the rôle of connecting channels. The movement of gases is produced by the alternating changes in the capacity of the two reservoirs, that is, during the inspiratory phase the lungs are expanding while the breathing bag is partially collapsing, and during the expiratory phase the lungs are becoming smaller while the breathing bag is expanding. Normally, the activity of the lungs produces the movements, the breathing bag merely following passively. Under certain circumstances, however, the movements may originate in the breathing bag and the lungs play the passive rôle.

When flowing through certain points of the connecting channels, the gases meet resistance and transitory pressure changes develop. These amount to several centimeters of water when the gases pass through the tracheal tube, tracheobronchial tree and bronchioles, and a few millimeters of water when passing through various parts of the machine. These pressure changes are transitory fluctuations around

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‡ The term "lungs" includes: respiratory bronchioles, atria, air sacs, alveoli and interstitial structures.

For the sake of simplicity the system to which the rebreathed atmosphere is confined, comprising the reservoirs and connecting channels, will be called briefly the "system." The pressure of gases within the system will be termed "systemic pressure."

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the existing mean pressure, and depend on the phase and depth of respiration as well as on the particular part of the system where the pressure is measured. Although under certain conditions they may become very important, they have little significance in this presentation. Therefore, these pressure fluctuations will be disregarded and only the mean pressures will be considered. These mean pressures are measured by a manometer on the machine. The manometer readings correspond to the transitory fluctuations. The arithmetic mean of the maximum and minimum readings is the mean systemic pressure. For example, when the maximum and minimum readings are 8 and 4 cm. of water during expiration and inspiration respectively, the mean pressure is 6, the arithmetic mean of 8 and 4.

The mean systemic pressure depends on the relation between the capacity of the system and the volume of gases present therein. If the volume of gases does not exceed the capacity of the system, the systemic pressure equals the atmospheric pressure. If the volume of gases is larger than the capacity, the gases will be under greater pressure than atmospheric, and positive pressure will exist in the system. Positive pressure can be produced either by allowing a gas to flow into the system in excess, or by squeezing the breathing bag, that is, reducing its capacity. Constant positive pressure is pressure maintained evenly and uninterruptedly over a period of time. Intermittent positive pressure is pressure produced intermittently with a frequency equal to the rate of respiration. These two types of positive pressures can be administered in combination; in this case the intermittent pressure is superimposed on the constant pressure.

Intrathoracic or intrapleural pressure, which exists within the pleural cavities and mediastinum is not identical with the systemic pressure. Usually it runs parallel with it, but is about 5 to 6 cm. of water less. This difference in pressure corresponds to the force exerted by the elastic recoil of the lungs. On account of this difference the intrathoracic pressure is negative under normal circumstances when the systemic pressure is atmospheric. This is significant because of its support to the circulation, that is, to the venous return to the heart. The filling of the large veins in the mediastinum and the right auricle is facilitated by the sucking effect of the intrathoracic negative pressure. If the systemic pressure is raised above 5 to 6 cm. of water the intrathoracic pressure becomes positive. Whereas the negative intrathoracic pressure aids the circulation, positive intrathoracic pressure has an adverse effect; it obstructs the venous return to the heart, thereby reducing cardiac output (1). These circulatory changes are proportional to the extent and duration of the intrathoracic positive pressure, and they are of increased significance in patients whose circulation is already handicapped (2).

If there is a wide opening in the thoracic wall the circulatory effect of positive systemic pressure is changed. In this case the intrathoracic
pressure no longer parallels the systemic pressure but remains close to atmospheric even though the systemic pressure may be highly elevated. The venous return to the heart is not retarded appreciably when the intrathoracic pressure is equal to atmospheric pressure. Consequently, positive systemic pressures above 5 to 6 cm. of water are better tolerated if there is a wide opening in the thoracic wall than with an intact thorax.

Four distinct conditions requiring the administration of positive pressure will be discussed.

I. Insufficient Respiratory Exchange Owing to Decreased or Absent Lung Movements

The cause of this condition may be insufficient or absent thoracic and diaphragmatic excursions owing to central respiratory depression (cyclopropane), weakened, paralyzed respiratory musculature (curare), or a position which prevents effective thoracic and diaphragmatic movements. Another cause may be an opening in the pleura, in which case the lungs do not always follow the thoracic and diaphragmatic excursions although the latter may be sufficient or even increased.

The management of this condition aims to restore the respiratory exchange to normal by the administration of intermittent positive pressure.

If the respiratory exchange is insufficient, intermittent positive pressure of a few centimeters of water is required. This pressure must be synchronized with the inspiratory phase of the patient’s breathing. During this phase the flow of gases will be accomplished by both the actively moving lungs and the actively moving breathing bag. During the expiratory phase, when no compression is applied on the breathing bag, the lungs will contract partly because of the expiratory movements of the thorax and diaphragm and partly because of the elastic recoil; this will produce a flow of gases in the opposite direction. This type of exchange, accomplished by the patient’s own efforts and with the help of the anesthesiologist, is called assisted or compensated breathing (3).

If spontaneous respiratory exchange is absent, which is the case in apnea or respiratory paralysis, intermittent positive pressure of 5 to 12 cm. of water is required. In this instance the flow of gases is produced as follows: during the inspiratory phase solely by the actively moving breathing bag, with the lungs passively expanding, and during the expiratory phase by the contraction of the lungs owing to their elastic recoil. This type of exchange, depending mainly on the action of the anesthesiologist who controls the flow of gases in the system, is called controlled breathing (4, 5).

It requires considerable skill and experience on the part of the anesthesiologist to apply these intermittent pressures properly, that is, in such a manner that the flow of gases in the system and the alveolar
gas concentrations produced approximate ideal normal conditions, and at the same time undesirable intrathoracic pressure changes are kept at a minimum.

II. Insufficient Respiratory Exchange Owing to Bronchospasm

This condition is caused by the continuous spasm of the bronchioles. This spasm usually persists through both inspiration and expiration. It is unrelated to the depth of breathing; it may be present in cases in which the patient is making strenuous respiratory efforts (asthma), or when there is apnea because of paralysis of the respiratory musculature (curare). The depth of anesthesia has little effect on it, except in the case of deep ether.

As a result of this spasm not only the alveolar gas concentrations may become abnormal, leading to hypoxia and carbon dioxide retention, but other pathologic conditions may develop, such as excessive intrathoracic negative pressure, pulmonary edema, and so forth (6). Factors, such as allergic background in the patient's history, insufficient depth of anesthesia during intubation, the use of parasympathomimetic drugs, namely cyclopropane and pentothal, as well as the use of curare, predispose to the development of this complication.

The employment of positive pressure is one of the helpful measures in relieving this condition. The administration of a constant pressure of 2 to 4 cm. of water, preferably with helium as diluent, may be sufficient to open up the constricted bronchioles in cases in which the spasm is of mild or moderate degree. If there is a severe spasm, in which case the exchange remains insufficient in the presence of this constant pressure, it will be necessary to administer intermittent pressure in addition. This should be synchronized with the inspiratory phase and frequently must be of considerable magnitude to produce the desired exchange; sometimes as high as 10 to 15 cm. of water pressure is required in addition to the constant pressure.

Needless to say, measures that aim to eliminate the causative factors of the bronchospasm should be given prime attention in the management of this complication.

III. Altered Intrathoracic Conditions Owing to the Opening of One or Both Pleural Cavities

This condition has several variations.

Variation 1. There is a small opening into one pleural cavity

The small opening usually allows free entrance of air with each inspiration, but little escape during expiration. The result of this will be gradual collapse of the lung on the side of the opening, development of a pressure pneumothorax on the same side and mediastinal shift toward the other side. These changes have a grave effect upon the circulation. Often if such a small opening is made in the pleura and goes unnoticed, a severe circulatory collapse, that is, unobtainable
blood pressure and hardly palpable pulse, may be the first sign of its presence.

A small opening in one pleura may occur in any operation in which the procedure is performed in the close vicinity of the pleura, for example, splanchnicectomy, thoracoplasty, and so forth.

In the management of this complication it is important that measures should be taken promptly after the opening has been made. Since it is the surgeon who is likely to see the opening first, it is his duty to notify the anesthesiologist as soon as he discovers such an opening or even only suspects one. From then on constant pressure must be administered in order to prevent the gradual collapse of the lung and the development of other sequelae. This pressure, however, which often has to be administered over a long period time, must not be greater than 5 to 6 cm. of water, since higher systemic pressures convert intrathoracic pressure from negative to positive with its known adverse circulatory effect. This precaution applies here since we are dealing with a small opening in the pleura. It has been found that a constant pressure of 3 to 6 cm. of water is well tolerated and enough, in most cases, to keep the lung sufficiently, although not completely, expanded. This pressure should be maintained until the surgeon begins to close the wound. Then, in order to produce complete expansion, the pressure must be increased.

If the expanding lung can be seen through the opening, the pressure should be increased gradually until the lung is firmly pressing against the opening. If the opening cannot be seen or if the existence of such an opening is only suspected, the pressure should be increased gradually until the lung can be seen pressing firmly against the transparent pleura. It is good practice in the latter case as well as in those cases in which the pleura is not sufficiently transparent to make an opening, measuring $\frac{1}{2}$ to 1 inch, in the pleura just before the wound is closed. This will permit visible control of complete expansion. The possibility of trapping air in the pleural cavity is minimized by this procedure. A catheter, introduced into the pleural cavity and removed at the end of the closure while suction is applied through it, is an alternative measure to remove trapped air. Usually a pressure of 10 to 14 cm. of water is required for complete expansion. This pressure should be maintained until the wound is closed airtight. Often, however, a drop in the patient’s blood pressure during the closure indicates that the positive intrathoracic pressure so produced is poorly tolerated. If this occurs the systemic positive pressure must be reduced as soon as possible, preferably when the wound is airtight to some extent, to a point below 5 to 6 cm. of water.

Variation 2. There is a wide opening into one pleural cavity

The wide opening permits the lung on the same side to collapse completely. The mediastinum is shifted somewhat toward the other side. The lung of the contralateral side will be the only functioning
one. In many instances with just this one lung functioning the ventilation is sufficient without outside support. Quite often, however, it is necessary to supplement the spontaneous breathing, that is, to establish assisted or controlled breathing when the minute volume exchange becomes insufficient.

Such wide openings are usually employed in most intrathoracic and transthoracic operations. During these procedures administration of positive pressure is required on several occasions. In each of these cases the anesthesiologist should always watch the expanding or collapsing lung. This direct visual observation, possible through the wide opening, is the best guide to the proper administration of positive pressure.

The administration of constant positive pressure is required on the following occasions:

(a) *When the pleura is being opened.*

At the time of the opening the patient’s circulation and respiration are markedly altered owing to the collapse of the lung and the shift of the mediastinum. In order to make these alterations gradual the sudden collapse of the lung must be prevented. For that purpose 3 to 6 cm. of water pressure is administered, starting just before the pleura is opened until such a time, usually five to ten minutes later, when respiratory and circulatory adjustments are attained. Then the pressure should be reduced gradually.

(b) *Every twenty to thirty minutes throughout the operation.*

The collapsed lung or any portion of it, which is not operated on and which is expected to resume normal function postoperatively, should be periodically re-expanded. This will prevent to a great extent the development of edema and postoperative atelectasis in these parts.

Each expansion should be preceded by aspiration with a urethral catheter through the endotracheal tube. Then positive pressure is administered in such a manner that the lung will gradually expand to a point somewhat less than full expansion. Usually this requires 8 to 12 cm. of water pressure. This state of expansion should be maintained for one or two minutes, then the lung should be allowed to collapse gradually.

(c) *When it is required by the surgical procedure.*

Partial expansion aids the surgeon in the identification of the boundaries of the lobes (lobectomy, lingulectomy) and in the delineation of the lung (decortication). Another occasion requiring positive pressure occurs when the bronchial stump is tested to determine whether it is airtight. In the former cases the degree of expansion depends on the needs of the surgeon, in the latter case 10 to 14 cm. of water pressure is required.
(d) *When mediastinal flutter, “pulmonary decompensation” and paroxysmal breathing develop* (3).

The exchange between the functioning lung and the breathing bag is insufficient in these complications for various reasons; 2 to 4 cm. of water pressure will improve these conditions. Burstein recommends compensated breathing in addition to the constant pressure (3).

(e) *When the pleura is being closed.*

If the lung or part of it is to resume function at the end of the operation, the recommended procedure is as follows: the tracheobronchial tree is first aspirated through the endotracheal tube. Then, the lung or part of it is expanded to the point which is just below complete expansion. The expansion should be very gradual, taking about ten to fifteen minutes. During this time the surgeon may place the sutures in the pleural edges without danger of puncturing the lung. When he is ready to pull the edges together the positive pressure is increased until the lung presses firmly against the wound. Usually 12 to 16 cm. of water pressure is required for this purpose. Only after this is accomplished should the surgeon pull the edges together and continue working on the closure of the various layers of the wound. It is desirable that this same pressure be maintained until the wound is airtight. Sometimes, however, the pressure must be lowered sooner, as discussed in Variation 1.

If pneumonectomy is the operation, in which case there is no lung or lobe to be expanded, the administration of 8 to 10 cm. of water pressure during the closure is recommended. This administration should start about three to five minutes before the pleural edges are pulled together, the purpose being to correct the shift of the mediastinum.

*Variation 3. There is a wide opening into one pleural cavity and a small opening into the other*

In this condition, which may accidentally occur during intrathoracic or transthoracic operations, the lung on the side of the wide opening is collapsed and there is a possibility that the other lung, which is the only functioning one, may collapse too. This could gradually take place if the small opening remains unnoticed. If this is the case, there will be an obvious discrepancy between the exaggerated respiratory efforts and the slight respiratory exchange, and, in addition, the blood pressure will drop. This should not be allowed to happen. The surgeon should promptly notify the anesthesiologist if he notices or suspects an opening on the contralateral pleura and seal off the opening as tightly as possible with a compress for the remaining time of the intrathoracic procedure. The anesthesiologist should maintain a
constant pressure of 4 to 8 cm. of water for the same period of time, starting when the surgeon notifies him. In addition to this, pressure procedures as elaborated for the previous variation should be carried out as indicated. It is desirable that any necessary aspiration, which should always precede the expansion of the collapsed lung, be done as rapidly as possible.

At the time of closure the collapsed lung on the side of the wide opening is expanded as described in the previous variation. Before proceeding with this, the state of expansion of the lung on the contralateral side must be checked. If it can be seen pressing against the small opening no additional measures need be taken. If, however, it does not come up to the opening, it is necessary to keep the opening free from any structures that may cover it over while the ipsilateral lung is expanded. This will make the expansion of the contralateral lung possible at the same time. During the closure it is a good practice to place a catheter in the small opening and bring it out through the chest wound. Air that could have been trapped in the contralateral pleural cavity may be aspirated through this catheter.

Variation 4. There are wide openings into both pleural cavities

In this condition, which may be the result of extensive injury or rare pathology, both lungs tend to collapse and neither follows the movements of the thorax and diaphragm. A constant pressure of 5 to 10 cm. of water is required to keep the lungs in a state of midexpansion. In addition to this, controlled breathing is required for respiratory exchange. For the closure the same procedure as described for the previous variation should be carried out.

IV. Operations for Mitral Stenosis

Pulmonary edema may develop readily during operations for mitral stenosis. Owing to the impediment to the blood flow through the stenosed mitral valve the left side of the heart will not be able to handle the amount of blood which is discharged by the right ventricle, the function of which is not impaired. Therefore, blood will accumulate in the pulmonary vessels under steadily increasing pressure, leading to pulmonary edema (6). Positive pressure may prevent or clear this condition. This is accomplished probably by its effect on the venous return to the heart with the resulting reduction of the amount of blood which flows into the lungs, and by the direct physical force it exerts on the external wall of the capillaries counteracting the increased intracapillary pressure (7).

The administration of constant positive pressure of 2 to 4 cm. of water is recommended throughout the operations for mitral stenosis (8).
COMMENT

Although the four conditions were discussed as distinct entities, frequently they occur in combination. It is not rare that simultaneously two, three or even four indications are present for the administration of positive pressure. In such instances only the proper recognition and understanding of each of these conditions will enable the anesthesiologist to combine and commix the required pressures into the correct resultant.

The significance of proper management of positive pressure lies not only in its obvious immediate effects, that is, improving respiratory exchange, relieving bronchospasm, expanding lungs, and so forth, but in a factor not always fully appreciated—its effect on the general condition of the patient.

Reactions to surgery and anesthesia may be favorable or unfavorable. Patients may withstand the anesthetic and the operation well or sometimes show unexpected poor tolerance. It is well to remember that among other factors that may lead to such responses, the management of positive pressure may be an important one. Often there is no immediate sign which would warn the anesthesiologist of the improper administration of positive pressure, but adverse late effects will develop. These however, can hardly be traced to any particular specific cause. This fact should serve as a constant stimulus to the anesthesiologist when administering positive pressure and trying to produce the best results that up-to-date anesthesia can offer.

SUMMARY

The various pressures of gases moving back and forth between patient and machine during endotracheal anesthesia are discussed. Constant and intermittent positive pressures are described. The role of intrathoracic pressure in connection with the administration of positive pressure is elaborated.

The underlying physiology and the correct application of positive pressure is discussed in the following conditions: insufficient respiratory exchange owing to decreased or absent lung movements, insufficient respiratory exchange owing to bronchospasm, altered intrathoracic conditions owing to the opening of one or both pleural cavities and operations for mitral stenosis.

The significance of clear understanding and proper management of positive pressure in endotracheal anesthesia is pointed out.

REFERENCES

an Army General Hospital Overseas, Anesthesiology 8: 36–52 (Jan.) 1947.
Dec.) 1934.
1878.
7. Barach, A. L.: Physiologic Therapy in Respiratory Diseases, J. B. Lippincott Company,
1948.
8. Harken, D. E.; Ellis, L. B.; Ware, P. F., and Norman, L. R.: The Surgical Treatment
1948.

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AFTERNOON
North Ballroom
12:30 P.M.
Round Table Luncheon (Subjects to be announced)
Main Ballroom
2:00 P.M. to 4:30 P.M.
"Recent Studies on the Cerebral Circulation in Man"
Carl F. Schmidt, M.D., Chairman, Professor of Pharmacology, University of
Pennsylvania
Seymour S. Ketty, M.D., Professor of Clinical Physiology, University of Penn-
sylvania
John P. Holt, M.D., Associate Professor of Roentgenology, University of
Michigan
Benedict E. Abreu, Ph.D., M.D., Pharmacologist, Pittman-Moore Company
Merd H. Harmel, M.D., Associate Professor of Anesthesiology, Albany Medical
College
North Ballroom
2:00 P.M. to 3:30 P.M.
"Surgical Treatment for Congenital Cardiovascular Disease"
Robert E. Gross, M.D., Laud Professor of Children’s Surgery, Harvard Uni-
versity
"Problems of Anesthesia During the Surgical Treatment for
Congenital Cardiovascular Disease"
Robert M. Smith, M.D., Director of Anesthesia, Children’s Hospital, Boston,
Massachusetts
North Ballroom
4:00 P.M.
Second Session, House of Delegates, A. S. A.

EVENING
Main Ballroom
7:30 P.M.
Annual Banquet of the American Society of Anesthesiologists
H. Boyd Stewart, M.D., President, Presiding
Guest Speaker:
Anton J. Carlson, Ph.D., M.D., John P. Hixon Distinguished Service Professor
of Physiology (Emeritus), University of Chicago
Address of Retiring President, H. Boyd Stewart, M.D., Tulsa
Introduction of Newly Elected Officers
Address of Incoming President, Rolland J. Whitmore, M.D., Cleveland

Saturday, December 10th
RESIDENT’S PROGRAM
Main Ballroom
9:00 A.M.