THE CONTROL OF RESPIRATION IN ANESTHESIA

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Received for publication October 20, 1949

IN anesthesia the application of pressure to the inspired gases may be necessary to maintain adequate pulmonary ventilation. The technics for applying this pressure are classified under supplemental and complemental respiration.

SUPPLEMENTAL RESPIRATION

Supplemental respiration classifies the conditions of respiration whereby the respiratory center of the patient is temporarily without function and the anesthesiologist provides pulmonary ventilation by mechanical means. (Chart 1.)

CHART 1

Supplemental Respiration

(Inactive Respiratory Center)

1. *Controlled—Passive*
   Stage IV anesthesia
   Passive respiration
2. *Controlled—Active*
   Third plane anesthesia
   Decreased CO_2
   Overstimulation of pulmonary vagal endorgans
   (Block of neuromuscular mechanism, curare)

1. *Controlled Respiration.*—Passive as described by Guedel (1) is produced by artificial or passive respiration by manipulation of the breathing bag after the patient has been placed in the respiratory arrest of stage IV anesthesia. Guedel describes this apnea technic as the variations of the threshold of the respiratory center in two ways: elevation of the threshold of response to stimulus present within the body to such a degree that stimuli no longer activate the respiratory neuromechanism or the physiologic stimulus may be depleted to such an extent that it is incapable of activating the function.

2. *Controlled Respiration.*—Active is produced by a combination of factors which include:

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a. Elevation of the respiratory threshold by basal narcosis and anesthetic drugs.

b. Decrease of the normal stimulus to the respiratory mechanism by reducing the carbon dioxide concentration through overventilation.

c. The overstimulation of the vagal end organs in the pulmonary bed causing fatigue of the respiratory center, thereby temporarily cutting out impulses which initiate respiration.

d. Respirations may be abolished also with the use of large doses of curare which tend to paralyze skeletal muscle thereby eliminating the neuromuscular response to impulses from the respiratory center.

Since control of pulmonary respiration depends upon the relationship between threshold and stimuli, this technic of producing controlled respiration eliminates the necessity of stage IV anesthesia. As the respiratory threshold is elevated to a proper degree by suitable basal narcosis, controlled respiration is readily assumed during upper or middle third plane anesthesia by the simple expedient of overextending the inspiratory phase of respiration. In so doing, mild hyperventilation is established wherein the carbon dioxide is removed from the respiratory system by the soda lime. The mechanical effects upon the vagal end organs in the pulmonary bed tend to fatigue the respiratory center which already has an elevated threshold. The resulting apnea is maintained by pressure on the breathing bag during the inspiratory phase only. The expiratory phase is without pressure and completely passive. It has been found that 7 to 10 cm. of water pressure against the pulmonary bed is sufficient to maintain adequate ventilation. The technic by which the positive pressure is applied determines the efficiency of the control respiration. Rapid, forceful inflation builds up the interbronchial pressure to 10 cm. of water before the lung can expand. Slow gentle application of pressure to the pulmonary bed, 12 to 14 times per minute, will inflate the lungs efficiently before the peak pressure of 10 cm. of water is attained. Excess pressures on the pulmonary bed may cause rupture of the alveoli. Air may then dissect along the sheaths of the pulmonary blood vessels, resulting in mediastinal emphysema (2).

Many of the criticisms of controlled respiration arise from the application of positive pressure against the pulmonary bed. It is claimed that pressure above 7 cm. of water increases the intrabronchial pressure and the intrapleural pressure to a point where the venous return to the heart is inhibited, filling time of the heart is increased and stroke volume is decreased with the resultant decrease of cardiac output (3, 4, 5, 6, 7). Schwerma and Ivy (8) claimed there is no lung damage or significant interference with venous return to the heart if pressures varying from + 14 mm. to — 9 mm. of mercury are applied to the pulmonary bed briefly and intermittently. Clinically, it may be demonstrated that excess intrabronchial pressure will cause a marked fall of blood pressure and in some instances the peripheral pulse be-

comes imperceptible. In contrast to this, a marked increase in blood pressure may be demonstrated by permitting inadequate pulmonary ventilation with resultant accumulation of carbon dioxide. This circumstance may be demonstrated even though the patient remains in a state of apnea.

COMPLEMENTAL RESPIRATION

Complemental respiration includes the variations in pulmonary ventilation produced by the anesthesiologist whereby the respiratory center of the patient remains within functional limits. (Chart 2.)

CHART 2

Complemental Respiration

(Active Respiratory Center)

1. *Positive Pressure:* 2–4 Cm. HOH, Constant on both inspiratory and expiratory phases.
2. *Step-Up:* 7–10 cm. HOH Intermittent at peak of inspiration to inhibit expiration.
3. *Assisted:* Over inflation with each third or fourth inspiration.
4. *Compensated:* 7–10 cm. HOH, Intermittent on inspiratory phase, expiration passive.

1. *Positive pressure respiration* augments the respiratory exchange of the patient by forcing him to inhale and exhale against a positive pressure variable of 2 to 4 cm. of water. By limiting the positive pressure in this instance to a maximum of 4 cm. of water, the pressure mechanism of the cardiorespiratory system remains within normal limits and thus pulmonary circulation and cardiac output are relatively unchanged (9).

2. *Step-up respiration* may be described as positive pressure applied to the expiratory phase of respiration. The inspiratory phase occurs without abnormal pressure being applied. A positive pressure check is placed against the pulmonary bed at the end of the inspiratory phase and prevents expiration. As soon as the respiratory center passes through the normal phase of expiration a subsequent inspiration is initiated and the patient inspires from the breathing bag, adding the volume of the second inspiration to that of the first which has been withheld in the lung. A positive pressure check may be applied in a similar manner at the end of the second inspiratory phase withholding the inspired volume of the first and second inspirations until the respiratory center initiates the third inspiratory phase. At the end of the third inspiratory phase all pressure is released from the breathing bag and passive expiration is permitted, emptying the lung of the accumulated volume of three inspirations. (Chart 3.) When this technic is applied, maximum pressure varies from 7 to 10 cm. of water and if it is used in instances in which the respiratory rate is rapid and shallow, the period of time over which the pressure is permitted to build up intermittently is very brief. The principal application of this technic is to reduce a rapid inadequate respiratory exchange of

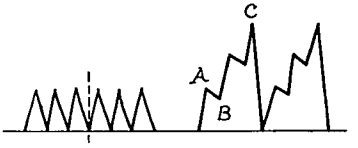
36 per minute or more into a more effective volume exchange of approximately 12 deep respirations (see Chart 3).

3. *Assisted respiration* exists when the anesthesiologist applies positive pressure up to a maximum of 10 cm. of water to the pulmonary bed on the inspiratory phase in order to increase any one respiratory exchange. This technic is frequently applied to every third or fourth respiration if there is some doubt as to the adequacy of ventilation.

4. *Compensated respiration* as described by Burstein and Alexander (10) makes use of approximately the same principles as are concerned in the active type of controlled respiration. The inspiratory phase of each respiration is moderately extended to a point just short of that at which fatigue of the respiratory center in the presence of an elevated threshold would produce apnea. A pressure of 7 to 10 cm. of water is applied just before the initiation of the inspiratory impulses.

Chart 3

STEP-UP RESPIRATION



A. 7 - 10 cm. HOH pressure applied at peak of inspiration to check expiration.

B. Pressure released.

C. Passive expiration after three inspirations.

As in controlled respiration the expiratory phase is passive. The efficiency of this technic can be maintained only by applying suitable pressure to each and every inspiratory phase of respiration.

General Surgery

In general surgery the various types of supplemental and complemental respiration are applied to produce a quiet, relaxed abdomen. Individuals using cyclopropane or cyclopropane-ether anesthesia may employ the technics of controlled respiration to produce relaxation of the abdominal musculature in preference to maintaining third or fourth plane anesthesia.

During controlled respiration intercostal function is completely abolished. As the lower six intercostal nerves innervate the abdominal wall and peritoneum there is a possibility that increased abdominal relaxation may result. When the respiratory center is depressed by heavy basal narcosis, pulmonary ventilation may become inadequate

as soon as the patient loses consciousness. Respiratory arrest with all the signs of stage IV anesthesia may occur before tissue saturation with the anesthetic gases and muscle relaxation are sufficient for the proper exposure of the surgical field. Oxygen intake and carbon dioxide output are depreciated and by the same token the transport of anesthetic gases to the tissues is incomplete. If respiratory function is depressed to a point where it cannot be stimulated to efficiency by the addition of ether to the inspired gases, then either supplemental or complemental respiration must be instituted. Inadequate oxygenation not only tends to minimize the efficiency of cardiac output but tends to increase the degree of muscle tension and in some instances initiates laryngospasm, thus defeating the attempts to produce skeletal muscle relaxation. It may be considered a serious error in technic to initiate controlled respiration in the depressed or unrelaxed patient by attempting to "pump" anesthetic gases into the patient by manipulation of the breathing bag. This technic will easily produce an overdose of anesthetic gases with a resulting concentration of the drug in the blood stream which may have a serious effect upon the myocardium and circulatory balance.

Stimulation in the abdomen during light anesthesia may cause respiratory function to become overactive and the abdominal contents are pushed out through the incision by increased interabdominal pressure. At this point the anesthesiologist may attempt to gain control of the situation by increasing the concentration of the anesthetic gases and initiating controlled respiration at the same time. In light anesthesia the respiratory threshold is not elevated sufficiently to be easily depressed and is low enough to permit stimuli to affect it. The application of positive pressure to the pulmonary bed necessarily must be increased far beyond the safe limits in order to fatigue the vagal end organs of the lung tissue and produce apnea. This excess pressure may immediately produce an acute circulatory depression or collapse. In elderly people this misapplication of pressure may eliminate signs of life such as respiration, pulse and blood pressure. If the pupil is small or reacts to light, discontinuance of the anesthetic and gentle inflation of the lung with 100 per cent oxygen may prevent death on the table.

THORACIC SURGERY—EXTRAPLEURAL

The use of supplemental or complemental respiration does not depend upon the use of endotracheal or endobronchial technics. The endotracheal tube may insure a patent airway and prevent bouts of respiratory obstruction due to laryngeal reflexes. Bronchospasm may be initiated through the carina reflex if the tube touches the bifurcation of the "uncocainized" trachea. Fourth plane anesthesia is usually necessary to obtund this highly specialized reflex.

Thoracoplasties involve the destruction of the bony cage of the

chest and in so doing may produce paradoxical respiration with a swinging mediastinum. In this instance positive pressure applied to the pulmonary bed is indicated to prevent the shifting of atmospheres from one lung to the other. As both lungs are brought into synchronous rhythm the swinging of the mediastinum is checked. For this purpose compensated or positive pressure respiration with a variable of 2 to 4 cm. of water may be effective.

Many thoracic surgeons object to the use of positive pressure as well as endotracheal tubes in patients with tuberculosis. The threat of contralateral spread of the disease is always imminent. For this reason basal narcosis should be light so that adequate respiratory exchange may be maintained. During anesthesia if ventilation is not adequate, some form of complemental respiration is indicated. Owing to periosteal or other stimulation in light anesthesia laryngospasm of various degrees may occur. A deeper plane of anesthesia is indicated and usually the spasm can be relieved by permitting the patient to exhale against 4 to 8 cm. of water. No pressure is used during the inhalation phase unless the obstruction is severe. It is generally recommended that only patients having first stage thoracoplasty be intubated.

Thoracic Surgery—Transpleural

Transpleural operations may include decortication of pleura, lobectomy, pneumonectomy, tumors of the esophagus and mediastinum, surgery of the heart and great vessels, repair of diaphragmatic hernias, and thoracoabdominal resection of the stomach.

Anesthesia for these various transpleural operations may be accomplished by using a closed absorption system, endotracheal or endobronchial technics and supplemental or complemental respiration as indicated. Various anesthesiologists use combinations of gases, ether, pentothal, curare, spinal and nonvolatile drugs as may suit their purpose. Our preference is a cyclopropane-ether sequence. Anesthesia is stabilized by saturation with ether in light second plane anesthesia. When this balance is attained the saturation of the tissues by ether is maintained throughout the operation until the resection is complete and the bronchial stump is pleuralized. If at any time a deeper plane of anesthesia is required to depress movement of a lung field or the diaphragm small amounts of cyclopropane are added. By using this technic it is possible to maintain continuous suction of bronchial secretions which are extremely prevalent in wet lung cases. Small or large volumes of air and oxygen are bypassed over ether to satisfy the volume of gases removed by a suction catheter which is inserted beyond the end of the endotracheal tube. In this manner any type of supplemental or complemental respiration may be maintained without a break in respiratory rhythm. Using this technic it is not necessary to cocainize the laryngeal or tracheobronchial structures. Although cardiac arrhythmias occur as frequently under ether anesthesia as they

do under cyclopropane anesthesia they are not of a dangerous character (11). If oxygenation is adequate these arrhythmias are not of clinical significance. Bronchiolarspasm may occur during induction of anesthesia regardless of the combination of anesthetic drugs that are used. The occurrence of bronchiolarspasm at this time is very significant in its warning of difficulties yet to come. In these instances such drugs as pentothal, curare and cyclopropane are eliminated and ether substituted. Intravenous procaine is introduced and maintained at a continuous drip throughout that portion of the operation during which the essential reflexes are encountered.

It is only logical that controlled respiration or some type of complemental respiration be used during open chest procedures. The choice of respiratory assistance must be suited to the anesthetic technic chosen for the procedure, to the variations of surgical procedures within the chest, and to the physiologic demands of the individual patient for adequate oxygenation. The anesthesiologist who plans to use controlled respiration sometimes uses an induction to anesthesia of pentothal and curare or nembutal and curare. Either combination produces an apnea for intubation at which time the larynx and tracheobronchial structures are "cocainized." Maintenance of controlled respiration is accomplished by addition of small amounts of the barbiturates and curare. Pressure ventilation is maintained with nitrous oxide and oxygen. As long as the patient is apneic from the effects of the barbiturates, controlled respiration of the passive type is necessary. If compensated or some other type of complemental respiration is desired, the respiratory center must be permitted to recover its function. During this process of recovery the patient may undergo spastic gyrations of the respiratory musculature referred to as "bucking." This can be overcome by the intermittent application of positive pressure in the form of compensated respiration.

In many instances the surgeon cannot decide the extent of the surgical procedure until the pleura has been opened and the degree of involvement of the lung field has been determined. This means that lobectomy or pneumonectomy may be decided upon. In our clinic it is not our purpose to use controlled respiration on all open chest cases but to maintain adequate oxygenation by the technic most suited to the circumstances. After the pleura is opened under cyclopropane-ether anesthesia and a lobectomy has been decided upon, the patient may be given a second dose of morphine and scopolamine which further elevates the respiratory threshold and further obtunds reflex irritability. Controlled respiration will insure a quite lung field. Movement of the diaphragm is stopped. The lungs are inflated and deflated rhythmically except at moments when the surgeon wishes to use sharp dissection or clamp a bleeding blood vessel in a difficult area. Segmental resection of a lobe or dissection of a lobe from the diaphragm can be accomplished without undue trauma. Although many surgeons prefer

to pack away the lobes of the lung with which they are not concerned it must be remembered that it is important to aerate at approximately fifteen minute intervals the lobes of the lung which are to remain functional. This prevents complete absorption of the alveolar gases and atelectasis. It may be noted that the lung field in partial collapse has a tendency to initiate a central respiratory response with return of diaphragmatic function. If the lung field is rhythmically expanded or left completely collapsed this does not seem to hold true. The functional lobes which are left completely collapsed tend to permit circulation of blood through unaerated alveoli with a resultant reduction of the total volume of oxyhemoglobin.

For upper lobe lobectomy positive pressure or compensated respiration may be applied if sufficient anesthesia is used to depress diaphragmatic movement. In some instances if oxygenation is adequate the patient may be permitted to maintain his own respiratory rate and rhythm. If the motion of the mediastinum seems to be overactive then a form of positive pressure must be used to stabilize it. When positive pressure respiration of 2 to 4 cm. of water is used to augment ventilation it is necessary that the respiratory center be active enough to maintain good respiratory exchange. Observation shows that if there is not at least 2 cm. of pressure variation in the water column the respiratory exchange is inadequate and this technic must be abandoned.

Controlled respiration is usually recommended for repair of diaphragmatic hernias and thoracoabdominal resection of the stomach.

For operations on the pleura, heart and great vessels, tumors of the esophagus and mediastinum, and pneumonectomy a type of complemental respiration is preferred to controlled respiration. For patients in this last group anesthetized with cyclopropane and ether the activity of the respiratory center is very carefully protected against depression. Additional doses of nonvolatile drugs to elevate the respiratory threshold are omitted. After the pleura is opened the patient is permitted a brief period of respiration without positive pressure to determine the activity of the lung field, diaphragm and mediastinum. If paradoxical respiration is not present and oxygenation is adequate, positive pressure is not indicated. If the lung field and diaphragm are overactive a deeper plane of anesthesia may be instituted. If the lung field and diaphragm are relatively quiet but oxygenation is not adequate then pressure is applied to the pulmonary bed. If the respiration is rapid and shallow, step-up respiration with determination of positive pressure at the end of two successive inspirations and passive expiration may be used. If ventilation is slightly subnormal assisted respiration with overinflation of each third or fourth inspiration may be satisfactory. If there seems to be excessive movement of the mediastinum or evidence of paradoxical respiration then positive pressure respiration may be used. If the variable between inspiration and expiration is unsatisfactory with the positive pressure technic due to central respira-

tory depression then compensated respiration will produce a more efficient result.

A valid criticism of controlled respiration is that some individuals have difficulty in evaluating the depth of anesthesia in the absence of respiratory function initiated by the respiratory center. Compensated respiration may be the answer for those who have this difficulty. It is always a mistake to initiate controlled respiration before a definite evaluation of the patient's condition is made. The plane of anesthesia, the effect of central depression upon respiration and circulation, and stabilization of the processes of anesthesia must be established. Just before controlled respiration is initiated, blood pressure, pulse pressure, pulse rate, volume and depth of respiration, position of the eyeball, size of the pupil, degree of relaxation, peripheral vascular effects such as capillary filling following pressure, condition of the skin as to color, warmth and moisture, and any evidence of cyanosis are noted. With the anesthesia completely stabilized and with an inventory of these factors as a standard, the respiratory center may be deprived of its function without harm to the patient. The anesthesiologist provides adequate exchange while at the same time maintaining a circulatory and autonomic balance which at all times approaches the previously established level.

If the technic of controlled respiration is not abused by the use of excessive amounts of pressure or anesthetic drugs the respiratory center is maintained in a state where it will take over its own function on thirty to sixty seconds notice. Return of central control of respiration is accomplished by stopping the manipulation of the breathing bag. Controlled respiration may be maintained continuously for six hours or more if the respiratory center is checked about every fifteen minutes to make sure that it is immediately ready to function. Experimentally it has been shown that impulses from the center through the phrenic nerves are coincident with the rhythm of pressure inflation and if central depression is not too acute these impulses will initiate respiration and at approximately the same rate (12). It is extremely important to maintain control of respiration on this borderline basis when there is a possibility of opening a sectioned bronchus. With an open bronchus, pressure respiration of any type may be futile and the respiratory center must be ready to take over its function immediately until a closed system has been reestablished. If the respiratory center does not take over, then respiration without respiratory movement must be established using a very high flow of gases through the bronchial tree.

SUMMARY

An arbitrary classification of the various types of supplemental and complemental respiration has been outlined. The clinical application of these various types of pressure breathing has been discussed.

We believe that the control of respiration should be accomplished by the application of the type of pressure breathing that is most suited to the prevailing physiologic conditions.

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The Secretary-Treasurer, Curtis B. Hickcox, M.D., has announced that Harvey B. Slocum of Galveston, Texas, was elected a Director of the American Board of Anesthesiology, Inc., at its meeting in Philadelphia on April 27, 1950. Dr. Slocum replaces John W. Winter, M.D., of San Antonio, Texas, on the Board. At a more recent meeting, Scott M. Smith, M.D., of Salt Lake City, Utah, was elected as an additional Director of the Board.