PREOPERATIVE AND POSTOPERATIVE RESPIRATORY STUDIES * †

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THE increasing interest in the study of pulmonary function makes it imperative that the anesthesiologist become conversant with this additional method for preoperative evaluation of the patient. Knowledge of the respiratory pattern and of the underlying alterations in pulmonary capacity and mechanism of ventilation is essential prior to surgical treatment of disease of the lungs. Frequently, the risk of a surgical procedure remote from the chest is complicated by a disorder of pulmonary function. In either instance, a careful study of the respiratory status may have a decided influence on the choice of anesthetic agents and methods, on the planning and extent of operation and on the prognosis.

Pulmonary function may be considered as the sum of two interrelated activities, ventilation and alveolorespiration (1, 2). Ventilation is the mechanical act of movement of air into and out of the lungs; ventilatory insufficiency is characterized chiefly by dyspnea. Alveolorespiration is, in essence, the distribution of inspired air to the alveolocapillary membrane and the diffusion of the respiratory gases across it; inadequacy of these functions is denoted by anoxia and by an increase in ventilation.

The determination of the factors producing abnormalities of alveolorespiration is time-consuming and requires both specially trained personnel and excellent laboratory facilities. The relationship of dyspnea to reduction of ventilatory capacity provides a basis for estimation of the degree of pulmonary insufficiency from a study of the ventilation alone.

The respiratory pattern can be recorded graphically by means of a closed circuit spirometer designed for use in studies of pulmonary function (3). The tidal volume, inspiratory capacity,§ expiratory reserve volume,‖ vital capacity and maximal breathing capacity are measured

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§ Inspiratory Capacity (complemental air): the volume of air inspired from the resting end-expiratory level to the point of maximum voluntary inspiration.

‖ Expiratory Reserve Volume (reserve air): the volume of air expired from the resting end-expiratory level to the point of maximum voluntary expiration.

and computed. Observation of the resting end-expiratory level ¶ is important; marked variations in this level during the breathing study may indicate trapping of air, providing visual evidence of underlying obstruction of air passages. If this obstruction is due in part to bronchospasm and mucosal edema, the inhalation of a suitable bronchodilator will usually be followed by increased ease of emptying of the lungs and by a more uniform resting position. The relationship of the combined vital capacity to the observed vital capacity is informative. The inspiratory capacity and expiratory reserve volume are measured separately from the resting end-expiratory level. The combined vital capacity obtained by adding these two volumes is normally larger than the vital capacity obtained by a single maximal expiration; this difference may be large in the presence of significant obstruction to the flow of air (for example, asthma). A smaller combined vital capacity usually represents lack of understanding of the test or of fullest cooperation by the subject.

The maximal breathing capacity is the greatest amount of air which can be moved into and out of the lungs per unit of time by voluntary effort; it is calculated in liters per minute. This capacity represents a dynamic test of function with emphasis on the rate and amplitude of breathing; it is a test of ability to ventilate during stress. The maximal ventilation is more indicative of ventilatory efficiency than is the vital capacity. The latter is a single phase of forced respiration without regard for the time elapsed. The vital capacity may be small; the ability to increase the rate of ventilation, however, may maintain the maximal breathing capacity within acceptable limits. Conversely, the maximal ventilation may be markedly reduced in the presence of a large vital capacity where significant obstruction to the flow of air exists. The maximal breathing capacity reflects the efficiency of the chest bellows and its supporting parts, the amount of aerated pulmonary tissue, the distensibility and elasticity of the lungs, the degree of patency of the air passages and the general physical fitness of the subject. Close scrutiny of the manner in which the patient performs the test helps considerably in recognizing deviations from the normal pattern. There is a poor correlation between the vital capacity and maximal breathing capacity on the basis of the units employed in expressing them. Some correlation does exist when the variations of either or both capacities from the predicted values are compared. This relationship is known as the "air velocity index" (4). The air velocity index is the ratio of the maximal breathing capacity in percentage of the predicted value to the vital capacity in percentage of the predicted value. The ratio is less than 1.0 in the presence of significant obstruction to the flow of air. The vital capacity can be performed at the expense of time and increased effort during the expiratory phase; however, lack of ability to

¶ Resting End-expiratory Level (pulmonary mid-position): the position at which the chest and lungs come to rest at the end of a normal expiration.

effect a rapid exchange of air per unit of time results in reduction of the maximal breathing capacity. The degree of obstruction due to bronchospasm can be estimated by employing a bronchodilator. There is usually an appreciable increase in maximal ventilation with little or no change in vital capacity; the index rises accordingly. The ratio will usually be greater than 1.0 following the loss of aerated pulmonary tissue when there is no important reduction of velocity of air flow. In this instance, the vital capacity is restricted but the rapidity of exchange may be unaffected. A like reduction of both volumes will also yield a ratio of 1.0. The usefulness of this index is based on first-hand observation of the component tests and knowledge of the actual figures employed in computing it.

An estimation of the breathing reserve is helpful in determining operability and in predicting the postoperative ventilatory status. The breathing reserve equals the maximal breathing capacity minus the ventilation at the moment. The latter is also expressed as the minute volume of ventilation; it should be determined both under resting conditions and during standard exercise. The breathing reserve is usually considered in percentage of the maximal breathing capacity (BR/MBC $\times$ 100). The reserve at rest can be determined from the tracing obtained during a test of basal metabolism or by the collection of the expired air in a Douglas bag through suitable one-way valves. The reserve during exercise can be estimated by employing a simple test, for example, the walking ventilation (5). The expired air is collected in a Douglas bag during the last three minutes of a four minute test in which the subject walks slowly at a constant rate of 180 feet per minute. The ventilation is expressed in liters per minute.

The breathing reserve is determined largely by the maximal breathing capacity. Major lesions of the lungs may cause no marked deviation from the expected values for ventilation at rest and during exercise. The patient with severe pulmonary emphysema may be unable to hyperventilate during exercise. The maximal breathing capacity will be reduced according to the extent of pulmonary involvement, to the degree of obstruction to the flow of air and to other factors previously mentioned. The maximal ventilation alone, therefore, provides a valuable clue to the breathing reserve. More important than the calculated value for ventilation during exercise is the level at which dyspnea occurs. The complaint of shortness of breath during or at the conclusion of a simple exercise test, such as the walking ventilation, is sufficient evidence of a low reserve; the maximal ventilation will be severely reduced. The normal subject may experience dyspnea only at high levels of ventilation; the maximal breathing capacity is high and provides a satisfactory reserve. Careful observation of the subject during the tests is more informative than the calculated results.

The residual volume is that amount of air which remains in the lungs at the end of maximal voluntary expiration. It cannot be re-

corded on the closed circuit spirometer ordinarily employed. Simple clinical methods for its determination are not available. Careful differential fluoroscopy, however, will yield much information about underlying factors influencing the residual volume. Attention should be directed to the following: the position of the mediastinum on quiet respiration; motion of the mediastinum on both quiet and forced expiration; changes in position and direction of the ribs on both maximal inspiration and expiration; the time and pattern of decrease in radiolucency of the lung fields on both quiet and forced expiration and the level and contour of the diaphragm on both maximal inspiration and expiration. In advanced emphysema, the ribs will remain in the position of hyperinflation, exhibiting little excursion on forced respiration; the diaphragm is flat and low, with markedly restricted motion; highlighting of the lung fields is predominant throughout the respiratory cycle, with little tendency toward fading during expiration. Localized obstructive emphysema is readily observed. The trapping of air indicates a reduction of air flow velocity and may be associated with an increase in residual volume. On the spirogram, trapping will appear as lengthening of the expiratory time, as the exhalation of air in spurts and as changes in the resting end-expiratory level; the maximal breathing capacity is usually performed well above the resting level.

Differential fluoroscopy also provides an indication of the percentage of the total ventilation performed by each lung (6). The motion of the ribs and hemidiaphragm on each side is estimated in percentage of normal motion. The sum of motion on each side is then divided by the sum total for the two sides to calculate the differential ventilation. For example, the motion of the ribs on the right is 100 per cent of normal and on the left, 75 per cent; the motion of the right hemidiaphragm is 100 per cent of normal and the left, 25 per cent. The sum for the right side is 200 and for the left, 100. The sum total for the two sides is 300. The differential ventilation is then approximately 67 per cent for the right lung and 33 per cent for the left lung. This method requires experience in fluoroscopy of the chest. The estimates of two independent observers accustomed to the procedure will be in close agreement.

In clinical practice, the major portion of the problems of preoperative evaluation involving disorders of pulmonary function can be resolved by means of the foregoing procedures. In the occasional instance in which the ventilatory studies are inconclusive, bronchospirometry may be performed. The method is useful mainly before excision or collapse of pulmonary parenchyma in the presence of diminished function of the contralateral lung. For example, the capacity of the opposite lung to absorb oxygen may be decreased although its ventilation is adequate. A major loss of functioning pulmonary tissue on the side of operation (the "good" side) might seriously jeopardize the patient's chances for survival. Bronchospirometry, however, requires additional expensive apparatus. It imposes an extra burden upon the

patient. The personnel conducting the test must be well grounded in the procedure and must function efficiently as a team. The respiratory pattern during the test is not physiologic. The chief advantage of the test is the differential and simultaneous determination of absorption of oxygen by each lung. Careful and detailed fluoroscopy will provide an approximate estimate of differential function, with less disturbance to the patient.

SUMMARY AND CONCLUSIONS

The preoperative evaluation of the patient with decreased pulmonary reserve is incomplete without knowledge of the factors underlying the deficiency. Much of the necessary information can be secured from external spirometry and from simple tests of ventilation at rest and under mild stress. Inspection by fluoroscopy of the movements of the thoracic cage and of the appearance of the lungs during ventilation should be a standard part of the study. The anesthesiologist who can provide this information or assist intelligently in applying it is benefited by an increased understanding of the mechanics of ventilation in the normal individual, by recognition of deviations from the normal in the presence of disease, by an additional aid in the choice of anesthetic agents and methods best suited to the problem at hand and by a keener insight into the relation of abnormal pulmonary function to complications occurring in the postoperative period. His contribution to the management of the patient is thereby substantially increased.

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