The author provides an overview of the various postoperative therapeutic regimens for surgical patients recovering from anesthesia. Because anesthesia care begins preoperatively and continues well into the postoperative period, a thorough understanding of the altered pulmonary physiology caused by anesthesia, narcotics and surgery, as well as the appropriate implementation of postoperative respiratory maneuvers, is essential to ensure a successful anesthetic course for the patient.

After a successful surgical procedure, numerous complications may afflict a patient in the postoperative period. Despite the advances in surgical technique, anesthetic management and postoperative care, significant morbidity and mortality can and do occur postoperatively.

A postoperative complication may be defined as an untoward event which occurs in the patient within 30 days of the surgical procedure. Common postoperative complications include wound infection, hepatitis, nerve palsies, cardiac complications and respiratory complications.

Postoperative pulmonary complications are the largest single cause of morbidity and mortality in the postoperative period. Various investigators report an incidence of 4.5-76.0%. An average of 11% has been reported for pulmonary complications following abdominal operations.

Preoperative risk factors

When patients undergo anesthesia and surgery, certain risk factors predispose them to develop postoperative pulmonary complications. Patients at greatest risk are those with pre-existing pulmonary problems or those with abnormal pulmonary function prior to surgery. In patients with chronic respiratory disease, Wightman found pulmonary complications to occur in 26.4%, as compared to only 8.2% in patients without evidence of such disease.

Pulmonary function tests using expiratory flow rate measurements such as the forced vital capacity (FVC) or the ratio of the forced expiratory volume for one second to the forced vital capacity ratio ($FEV_1/FVC$) are valuable predictors of the patient's ability to generate an adequate cough, which is a pulmonary defense mechanism commonly rendered ineffective in the immediate postoperative period by anesthesia and surgery. If the cough reflex is ineffective in clearing secretions, this can lead to decreased lung volumes, decreased lung compliance, increased ventilation/perfusion inequality, increased venous admixture, hypoxemia, and increased work of breathing, ultimately leading to atelectasis. Another excellent indicator of postoperative pulmonary complications is an elevated $PaCO_2$ in excess of 50 torr.
Chronic cigarette smoking has been demonstrated to increase the incidence of postoperative pulmonary complications. Morton suggests that patients smoking only ten cigarettes a day have a sixfold increase in pulmonary morbidity in the postoperative period. The incidence of pulmonary embolism is higher in the smoker due to increased coagulability produced by chronic cigarette smoking.

Chronic cigarette smoking will damage the ciliated epithelium of the lungs. This damage leads to some blockage of the mucociliary transport system which can result in bronchiolar obstruction, infection, and atelectasis. Because smoking significantly increases the incidence of postoperative pulmonary complications, patients who smoke should be encouraged to refrain from smoking at least two weeks prior to surgery. Cessation of smoking two to three days before surgery does not appear to change the incidence of postoperative pulmonary complications in the chronic cigarette smoker.

Studies differ on the incidence of postoperative pulmonary complications in patients of advanced age. In such patients, there may be a slightly higher risk of developing postoperative pulmonary complications. It has been demonstrated that there is a greater decrease in the functional residual capacity (FRC) following surgery in patients of advanced age. Since the closing volume increases with age, significant airway closure can occur during tidal ventilation postoperatively. Because the overall risk factor of age is not too great, other risk factors should be given stronger consideration in determining possible postoperative pulmonary complications.

The markedly overweight patient has a very significant chance of developing postoperative pulmonary complications. This is due mainly to the altered pulmonary physiology caused by excess adipose tissue. The expansion of the lungs is hindered by an enlarged abdomen which elevates the diaphragm, and by increased weight on the chest wall. This leads to a decreased thoracic wall and lung compliance, low lung volumes to include a lowered FRC, airway closure during normal tidal ventilation, ventilation to perfusion imbalance, and finally, systemic arterial hypoxemia.

**Postoperative lung volumes**

The incidence of postoperative pulmonary complications is 40-50% in thoracic operations, 20-30% in upper abdominal procedures, 5-10% in lower abdominal cases, and less than 0.5% in peripheral surgery. The primary factor contributing to postoperative pulmonary complications is decreased lung volumes. Lung volumes reduced in the immediate postoperative period are the total lung capacity (TLC), expiratory reserve volume (ERV), vital capacity (VC), inspiratory capacity (IC), and functional residual capacity (FRC). The residual volume may remain the same or may decrease when compared to preoperative measurements.

**Causes of decreased lung volumes.** The major factor contributing to low lung volumes in the postoperative patient is a shallow, monotonous, sighless breathing pattern caused by general anesthesia, pain, and narcotics. General anesthesia, in the intraoperative and immediate postoperative period, appears to reduce the FRC which ultimately leads to a ventilation/perfusion (VA/Q) imbalance and hypoxemia.

Both pain, which restricts the thoracic expansion of the postoperative patient, and narcotics produce a shallow, sighless breathing pattern. Caro and associates demonstrated that lung volumes decrease after applying a tight strapping on the chest of unanesthetized subjects: the tight strapping prevents the normal sigh mechanism. Lung volumes reduced within less than one hour after application of the strapping were the TLC, FRC, and VC.

Normally, adults breathe regularly and rhythmically, spontaneously performing a maximal inspiration (sigh) that is held every 5-10 minutes. It has been hypothesized that this physiologic sigh is needed to maintain surfactant function. Surfactant, made up of carbohydrates, proteins, and lipids with a principal component of L-a-<dipalmitoyl lecithin, has a principal physiologic function of acting to reduce surface tension.

As alveoli with competent surfactant function become reduced in size, the surface tension is reduced by the surfactant, which stabilizes the alveoli. Ultimately, surfactant functions to prevent the collapse of the alveoli. Sighless ventilation may result in uneven distribution of surfactant and a loss of stability of the small airways and alveoli which ultimately leads to alveolar collapse.

Pain produces a sighless ventilatory pattern by causing the patient so much discomfort during a maximal inspiration maneuver that a shallow, sighless ventilatory pattern is usually adopted to reduce the amount of pain experienced. The closer the surgical incision is to the diaphragm, the greater is the impairment of pulmonary function.

It has been demonstrated that a patient who has undergone abdominal surgery and has a ver-
tical incision will have more severe arterial hypo-
xemia than the patient who has a transverse ab-
dominal incision. The sighless pattern of ventila-
tion produced by pain produces a lower chest wall compliance which leads to a reduction in the FRC and ultimately, to hypoxemia.

The physiology of postoperative lung volumes

When lung volumes decrease, lung recoil increases. Hence, with increased lung recoil, the lungs require significantly higher inflation pressures to achieve the same volume. The relationship between force (pressure) and stretch (volume) is termed compliance. Compliance of the lung (C.L.) is expressed as the volume increase in the lungs for each unit increase in transpulmonary pressure. The transpulmonary pressure reflects the pressure difference between the alveoli and the pressure surrounding the lungs (pleural pressure). In the immediate postoperative period, a high lung recoil and low transpulmonary pressure at resting lung volumes result in a low lung compliance and a stiffer lung. The ultimate consequence is lower lung volumes.

As the lung volumes diminish, the small airways become narrower and may become totally obstructed, resulting in airway closure. In the normal lung at residual volume, the pleural pressure in the dependent lung zones exceeds the airway pressure leading to airway closure. The result is the trapping of gas behind closed airways. The absolute lung volume where airways begin to close is the closing capacity (CC).

In normal lungs, the closing capacity is less than the resting lung volume (FRC) and airways remain open during tidal breathing. In the immediate postoperative period, patients who have a sighless, monotonous, low tidal volume ventilatory pattern usually have a reduced FRC. When the FRC plus tidal volume falls below the closing capacity, the airways leading to dependent lung zones may be effectively closed throughout tidal breathing (Figure 1). Inspired gas is then distributed mainly to the upper or nondependent lung zones. Perfusion continues to follow the normal gradient with higher flows to the dependent areas of the lung.

Postoperatively, as airway closure occurs, gas is trapped in significant amounts behind closed airways. Over a period of time, this sequestered air is absorbed and the alveoli become airless (atelectasis). Also, at lower lung volumes, surfactant function is altered, ultimately leading to alveolar collapse and atelectasis. Atelectasis leads to decreased ventilation as compared to perfusion (low $V_A/Q$) resulting in a widening of the alveolar-oxygen gradient and hypoxemia. Atelectasis also provides an excellent culture medium which facilitates the development of pneumonia.

Clinical investigations

Various investigators have demonstrated a decrease in lung volumes in the immediate postoperative period. Ali measured the FRC on the day of surgery at 4, 10, and 16 hours postoperatively. In the 11 patients studied on the day of surgery who had undergone an upper abdominal procedure, the FRC did not change significantly from preoperative values at 4 and 10 hours into the postoperative period, but there was a significant fall in the FRC by hour 16. In a study by this author of 14 patients who had undergone upper abdominal surgery, the FRC at one and two postoperative hours was lower than the findings of Ali. A possible explanation for the differences in data is that there may be an immediate fall in FRC or a sustained reduced FRC from the intraoperative period, which then returns to near baseline by the fourth postoperative hour. A second subsequent fall of the FRC...
does not return to baseline values for five to seven days postoperatively (Figure 2).

These studies suggest that two different mechanisms may be involved in the production of a decreased FRC. In patients receiving a general inhalational anesthetic, the FRC has been shown to be below preoperative values, and continues to be below these values while the inhalation agents are being dissipated during the first two postoperative hours. However, the FRC returns to near normal values by the fourth through tenth hours. Then, possibly by a different mechanism associated with the major effects of upper abdominal surgery, the FRC is reduced again.

The first mechanism in decreasing the FRC may be associated with anesthesia and the latter mechanism may be due to postoperative pain and narcotic administration which serve to reduce the number and magnitude of the physiologic sigh mechanism.

Figure 2
Composite curve of the mean values of the Functional Residual Capacity (FRC) in the postoperative period

![Graph showing the mean values of Functional Residual Capacity (FRC) over the postoperative period from Hour 1 to Day 5. The graph shows a trend where FRC is below baseline values initially, then returns close to baseline by Day 5.]
Anesthesia care

Postanesthesia lung volumes are critically important and should be monitored by the nurse anesthetist. In particular, patients identified as at risk or those who undergo thoracic or upper abdominal surgical procedures may be regarded as "critical" patients during the postoperative period. The anesthesia management of these patients begins preoperatively with a focus on secretion clearance and the improvement of pulmonary function. The intent is to improve the patient's condition and outcome in the critical postoperative period.

Preoperative anesthesia care. Patients who have an ongoing or have had a recent upper respiratory tract infection should have their surgery postponed for at least one week, preferably two weeks, after the upper respiratory infection has subsided. Percussion and postural drainage should be instituted preoperatively to enhance secretion clearance in patients who have chronic or acute problems in secretion clearance such as is found in bronchitis or bronchiectasis. The amount of secretions may also be reduced with antibiotic therapy after the organism has been identified.

Pulmonary function testing, emphasizing expiratory flow measurements and arterial blood gas determinations, should be obtained for baseline information so as to serve as predictors for the type and degree of postoperative care. Also, in patients with obstructive lung disease, the reversible component should be treated with bronchodilators. The goal is to facilitate optimal preoperative lung function for the individual patient.

Intraoperative anesthesia care. Intraoperative management of the patient at risk for decreased lung volumes in the postoperative period should include avoidance of Mendelson's syndrome, fluid overload, and prolonged emergence from anesthesia (to include neuromuscular blockade).

Postoperative anesthesia care. Patients who have undergone thoracic or upper abdominal surgical procedures will present themselves at the post-anesthesia recovery room with a reduced FRC. VA/Q imbalance, and probable microatelectasis. The objectives in the postoperative anesthetic management of these patients are to expand the lung volumes so as to increase the FRC and aid the patient in secretion clearance.

Postoperative respiratory maneuvers

The recovery room stir-up regimen of turn-cough-and-deep-breathe is effective in reducing the incidence of postoperative pulmonary complications. More specifically, this stir-up regimen involves positioning, coughing, and ventilation. Recent studies indicate that some methodology of the original stir-up regimen may need to be modified.

Positioning. The patient's position should be changed every 15 minutes during the immediate postoperative period. The change in position alters the most dependent portion of the lungs, which aids in matching of ventilation to perfusion. This change in position also facilitates secretion clearance.

Besides being encouraged to change position in bed, the patient should be assisted to get out of bed and sit in a chair at some time during the first 24 hours after the surgical procedure. Additionally, early ambulation should be instituted as soon as possible. Such activity should increase lung volumes, improve matching of ventilation to perfusion, and aid in secretion clearance.

Coughing. Various researchers have demonstrated that the forced vital capacity in one second (FEV1) is reduced in the immediate postoperative period. A normal FEV1 is an important factor in the production of high velocities necessary to clear retained secretions during the cough maneuver. The driving pressure for the flow of air out of the lungs during expiration, such as a cough maneuver, is equal to the lung recoil (Pst) and the pleural pressure (Ppl). Consequently, the driving pressure is highest in the alveoli and distal airways and declines progressively to the mouth.

The position where the inside of the airway lumen pressure is equal to the Ppl is the equal pressure point (EPP). From the EPP toward the mouth (downstream segment), the Ppl exceeds the airway intraluminal pressure and dynamic compression occurs. Dynamic compression does not occur from the EPP toward the alveoli or upstream segment because the airway intraluminal pressure exceeds the Ppl.

Coughing is most effective in the downstream segment because the dynamic compression decreases the cross-sectional area of the airways, ultimately increasing the velocity of airflow toward the mouth. In the healthy individual, the EPP is located in the area of the lobar or segmental bronchi at lung volumes above FRC. The EPP moves toward the alveoli when the volume of air in the lungs is below FRC. When this occurs, a longer segment of airways is exposed to dynamic compression.

Anesthesia, surgery, immobility, and the absence of an intraoperative cough maneuver are factors which cause the patient to retain some
secretions in the immediate postoperative period. Hence, it is important to begin the cough maneuver when the patient is emerging from the anesthetic experience. This therapeutic regimen should be continued several days into the postoperative period to facilitate secretion clearance.

For the patient recovering from anesthesia who has a low FEV₁, the cascade cough is believed to increase the effectiveness of the cough maneuver. The patient should be taught to take a rapid, deep inspiration to increase the volume of air in the lungs which will in turn dilate the airways, allowing air to pass beyond the retained secretions. Upon exhalation, the patient should perform multiple coughs at succeedingly lower lung volumes. With each cough during exhalation, the length of the airways undergoing dynamic compression will increase, enhancing cough effectiveness.

Between cascade cough maneuvers, the patient should be encouraged to inhale and close his glottis. This dilates the airways and, by increasing the P_pl, further compresses the airways so as to "milk" secretions toward the larger airways where they can be removed in succeeding cough maneuvers. Patients with preoperative pulmonary pathophysiology involving retained secretions benefit from chest percussion and postural drainage because these maneuvers facilitate the movement of secretions to the larger airways, where they can be removed by coughing.

Ventilation. For many years the voluntary deep breathing maneuver has been used to increase lung volumes in the postoperative period. Many gadgets and maneuvers have been designed to improve the voluntary deep breathing maneuver. The ideal maneuver promotes a high inflation pressure and volume with a long alveolar inflation time (Table 1).

The expiratory maneuver using blow bottles has been marginally effective in slightly increasing the FRC, provided the patient takes a sustained deep breath before performing the expiratory maneuver. Because the pleural pressure exceeds the airway pressure, airway closure occurs during expiration, especially when the patient exhales into his closing capacity range. Hence, if the patient does not take a deep breath and just performs an exhalation, the FRC may indeed be driven down.

The positive end-expiratory pressure (PEEP) effect of exhaling into a device that provides some resistance is likely to be extremely transitory. This PEEP effect is probably not effective in maintaining or improving the PaO₂. Because the alveolar inflating pressures and times are minimal, coupled with a variable alveolar inflating volume, this maneuver is only marginally successful in enhancing postoperative lung volumes.

Carbon dioxide rebreathing, or dead space rebreathing, is a maneuver that increases the PaCO₂ by the rebreathing of carbon dioxide. Provided there is no blunting of the patient's physiologic response to an increased inspired concentration of carbon dioxide, rebreathing carbon dioxide leads to hyperventilation. Hyperventilation greatly increases the minute ventilation, but because the tidal volume is not increased to total lung capacity, alveolar inflation pressure and volume are moderate and the alveolar inflation is short (Table 1). Hypoxemia is also produced with dead space rebreathing.

The clinical usefulness of intermittent positive pressure breathing (IPPB) in the prevention of postoperative pulmonary complications has been questioned in many studies. Only one study indicated that IPPB was able to demonstrate its usefulness. Another investigator found that during routine postoperative IPPB treatments, the pressures employed do not produce a tidal volume as large as the patient can produce voluntarily.

Most problems associated with the usefulness of IPPB are in the techniques of administration. Often times, IPPB treatments are too short and the patients are not coached to ensure achievement of an appropriate tidal volume. Although the

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alveolar inflating pressure is present, the alveolar inflating volume is unknown and the alveolar inflation can be long (Table 1).

Another difficulty with the use of IPPB is that when administered without a bronchodilator, it can increase airway resistance which can lead to bronchospasm. If the inspiratory pressure on the IPPB device exceeds the esophageal pressure, gastric distension can result which can be harmful in patients with an ileus.

The sustained maximal inspiration (SMI) maneuver has been introduced recently as a method to enhance lung volumes of postoperative patients, thus improving on the incidence of postoperative pulmonary complications and in particular, the atelectasis-pneumonia sequelae. The SMI maneuver consists of the patient inhaling as close to total lung capacity as possible and, at the peak of inspiration, holding that volume of air in the lung for 5-3 sec. before exhaling it.

The SMI maneuver produces maximal alveolar inflating pressure, time, and volume. In a study by this author, the decrease in the FRC in subjects who had undergone upper abdominal surgery, using the SMI maneuver as compared to subjects using the voluntary deep breathing maneuver, was significantly less from one to two hours postoperatively.

Although not statistically significant, a trend was seen for a steady increase and no further fall in the inspiratory capacity (IC), expiratory reserve volume (ERV), vital capacity (VC), and FEV1 measurements from one to two hours postoperatively in the SMI group. A trend toward a further fall in the same measurements in the deep breathing maneuver group was also noted. Consequently, the SMI maneuver may be more effective than the voluntary deep breathing maneuver in preventing a further reduction in lung volumes in the immediate postoperative period.

Both the deep breathing and the SMI maneuvers generate a high transpulmonary pressure gradient. However, the alveolar inflating time, which is utilized in the SMI maneuver but not in the deep breathing maneuver, may be of critical importance in enhancing pulmonary function and consequently, in reducing the postoperative pulmonary complications in the patient who has undergone upper abdominal surgery. (Table I).

The incentive spirometer and the deep breathing exerciser are comparable to the performance of the SMI maneuver. The incentive spirometer is a device so designed that the patient must take a prolonged inspiration at a flow rate and depth sufficient enough to trigger a battery-operated light. The main objective of the incentive spirometer is to provide positive feedback, therefore encouraging the patient to create a maximum transpulmonary pressure. Hence, the incentive spirometer is designed to encourage the patient to perform the sustained maximal inspiration maneuver.

The deep breathing exerciser is a semiquantitative flow measuring device that uses visual feedback. This device, although predicated on flow measurement, is designed to encourage the patient to take a sustained maximal inspiration. The SMI maneuver can be performed with or without these devices. Optimally, the patient should be monitored and coached to ensure the correct performance of the maneuver.

During the immediate postoperative period, the patient recovering from general anesthesia will usually be unable to use a SMI-producing mechanical device. This is due to the patient's inability to achieve a tight fit on the mouthpiece of the device. Consequently, the patient should be encouraged with verbal and tactile (hands on chest) stimuli to perform the SMI maneuver independently of the mechanical device.

REFERENCES


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It should be noted that the opinions stated in this article are those of the author and are not reflective of the official opinions of the Department of Defense and U.S. Army.