Diaphragmatic Breathing Maneuvers and Movement of the Diaphragm After Cholecystectomy*

Timothy A. M. Chuter, B.M. B.S.; Charles Weissman, M.D.; Donald M. Mathews, M.D.; and Paul M. Starker, M.D.

Coached efforts at diaphragmatic breathing were assessed as a means of increasing diaphragmatic movement in postoperative patients. Inductive plethysmography was used to measure compartmental tidal volumes of the abdomen (Vab) and the chest (Vc) in eight women (aged 41 ± 16 years) who had no history of cardiovascular or pulmonary disease. These patients were studied before and after (POD1,3) elective cholecystectomy. In preoperative studies, DB increased the supine value of Vab. The corresponding increase on POD1 represents a similar proportion of the resting value. The postoperative fall in resting and stimulated values of Vab is attributed to the known effects of abdominal surgery on diaphragmatic movement. Hence, DB warrants investigation as a method of prophylaxis against the pulmonary complications of surgery, because diaphragmatic movement is largely responsible for ventilation of the lower lung fields, where atelectasis and infection occur most often. *(Chest 1990; 97:1110-14)*

> DB = diaphragmatic breathing; POD = postoperative day; Vab = tidal volume of the abdominal compartment; Vc = tidal volume of the chest compartment; VT = overall tidal volume

The pulmonary complications of upper abdominal surgery remain an enormous cause of morbidity, despite the widespread use of various respiratory maneuvers.[1-7] Recent studies suggest that impaired diaphragmatic movement may be an important factor in the pathogenesis of postoperative pulmonary dysfunction.[8-14] Postsurgical patients not only exhibit poor diaphragmatic movement at rest,[8-14] but they also fail to recruit diaphragmatic movement in response to incentive spirometry.[9] This may contribute to the frequent occurrence of atelectasis and infection in the lower lung fields, which depend largely on diaphragmatic movement for ventilation.[10,15] The benefits of intermittent maximal inspiration[16] would probably be greater with an exercise which recruits diaphragmatic movement.

Although postsurgical patients have poor baseline diaphragmatic function, their response to phrenic nerve stimulation is normal.[12] The potential for voluntary movement of the diaphragm therefore exists. Indeed, there are several anecdotal reports that patients recovering from upper abdominal surgery are able to produce normal voluntary diaphragmatic movements[8,10,13] and that such efforts improve the ventilation of their lower lung zones.[10] The aim of this study was to quantitate the degree of voluntary diaphragmatic motion, before and after upper abdominal surgery.

METHOD

Respiratory inductive plethysmography (Fig 1) was used to study the tidal volumes of the thoracic and abdominal compartments (Vc and Vab respectively) in eight women, aged 41 ± 16 years, none of whom gave any history of pulmonary or cardiovascular disease. A series of measurements was performed preoperatively and on the first and third days after cholecystectomy. Incentive spirometry was performed routinely throughout the postoperative period, in addition to diaphragmatic breathing maneuvers. Measurements were made at noon, before patients received lunch. Narcotic analgesia was administered 20 minutes prior to each postoperative study. Patients were not allowed to fall asleep during the measurement period, because sleep affects the pattern of ventilation.[17] Each series of measurements was comprised of the following phases:

1. Supine, at rest.
2. Supine, during coached diaphragmatic breathing.
3. Semirecumbent (with the hips flexed and the head of the bed elevated at 30° to the horizontal), at rest.
4. Semirecumbent, during coached diaphragmatic breathing.

Resting measurements followed a 3-minute equilibration period and continued for a further 3 to 5 minutes. The tidal volumes of the
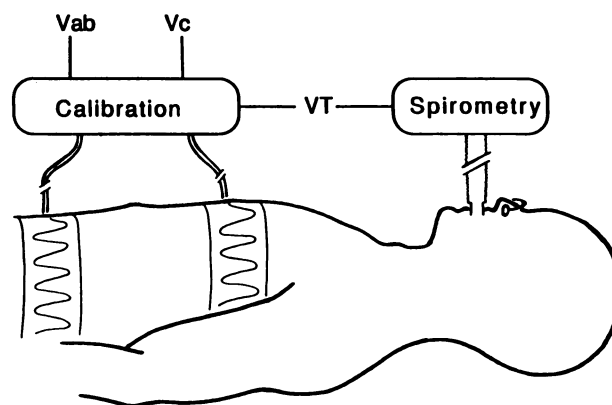

FIGURE 1. The technique of inductive plethysmography.

two compartments (Vab and Vc) were calculated for each breath. The mean values for all breaths in the measurement period were recorded. For the coached breathing, the mean compartmental volumes were calculated from the values for five to eight breaths, recorded after the tidal volumes had reached a plateau of maximum volume.

During diaphragmatic breathing, patients were instructed to restrict the movement of their chest wall and attempt to maximize the movement of their anterior abdominal wall. Feedback was provided through the instructions of a study physician, who assessed performance by reference to the tidal volumes of the chest and abdominal compartments; the object being to maximize Vab, regardless of the effect on Vc. Most patients were able to modify breathing patterns to achieve this effect after 10 to 15 breaths.

The measurement of compartmental tidal volumes depends on the assumption that the behavior of the respiratory system can be approximated to two degrees of freedom of motion,[18] such that the sum of the tidal volume of the rib cage (Vc) and the tidal volume of the abdomen (Vab) is equal to the tidal volume of the whole (VT). Details of the technical and physical characteristics of inductive plethysmography have been described previously.[19] Inductance coils were positioned at the umbilicus and halfway between the angle of Louis and the xiphoid process. Respiratory movements produced changes in the cross sectional areas of the rib cage and abdomen, which generated a current by self inductance of the coils. The resulting signals were calibrated by reference to the output of a spirometer using the method of least squares.[20] Before and after each series of measurements, a validation procedure was used to compare the values of tidal volume derived from spirometry with those derived by the summation of compartmental tidal volumes. If the two values of tidal volume differed by more than 10 percent, the calibration was repeated. Calibration and validation of the inductance coils were repeated after each change in posture. The calibration procedure required spirometric measurements of the tidal volume of five breaths. Once calibration factors had been calculated and validated, the spirometer mouthpiece and nose-clip were removed.

The study was approved by the Institutional Review Board of the Columbia-Presbyterian Medical Center and full informed consent was obtained.

Statistical Methods

The effects of surgery, posture, and diaphragmatic breathing were assessed by analysis of variance. The strength of any association between the values of Vab obtained in different parts of the study was measured by linear regression analysis.

RESULTS

In the supine position, the effects of surgery were maximal on POD 1, with some return to baseline on POD 3. The most notable effect was a fall in the tidal volume of the abdominal compartment (Vab from 240 ± 56 ml(SD) on POD -1, to 131 ± 77 ml on POD 1, $p<0.0001$) and in the relative contribution of abdominal excursion to breathing (Vab/VT, 0.63 ± 0.15 on POD -1, 0.38 ± 0.20 ml on POD 1, $p<0.0001$). Overall tidal volume also fell (389 ± 73 ml on POD -1, $347 + 72$ ml on POD 1, $p<0.0001$), despite a concomitant increase in the tidal volume of the chest compartment (Vc, 149 ± 86 ml on POD -1, 216 ± 102 ml on POD 1, NS). The effect of surgery on resting Vab showed little variation between individuals, in the supine position, so that values on POD -1 correlated
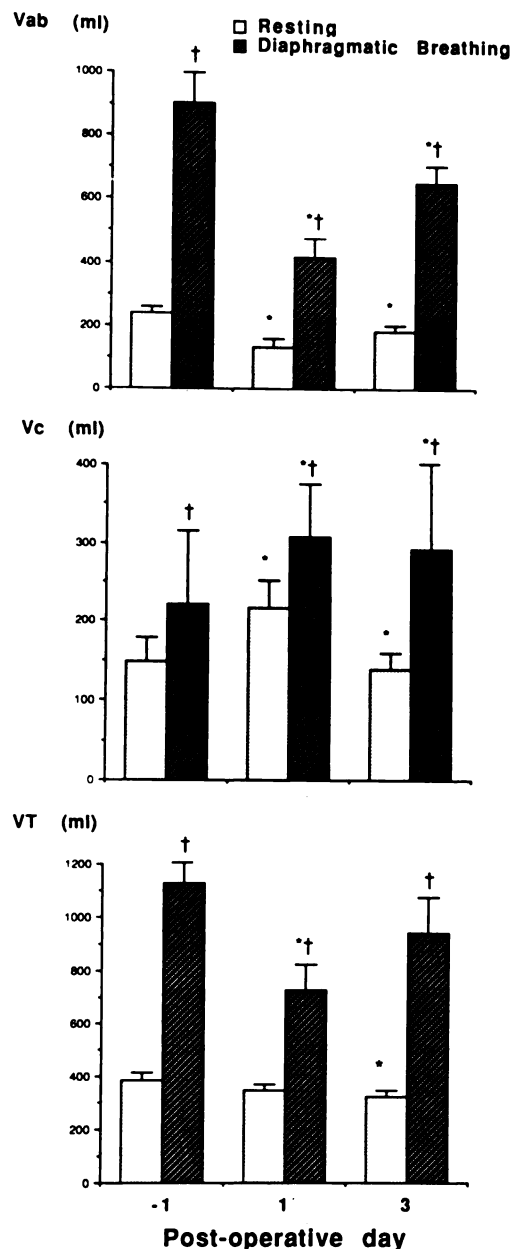

FIGURE 2. Compartmental tidal volumes of the abdomen (Vab,ml), chest (Vc,ml) and their sum (tidal volume, VT,ml); at rest and during diaphragmatic breathing, in the supine position. *Asterisk* indicates $p<0.05$, from POD-1; *dagger*, $p<0.05$, from resting value. *Bars* indicate SE.

well with corresponding values on POD 1 ($r=0.765$).

Voluntary diaphragmatic breathing increased the tidal volumes of all compartments on all days, with Vab increasing the most (Fig 2). Changes in the magnitude of the response to diaphragmatic breathing paralleled changes in the resting value. Thus, diaphragmatic breathing was associated with the highest value of Vab on POD -1 (908 ± 257) and the smallest value of Vab on POD 1 (418 ± 173). There was no correlation between individual values of Vab at rest and during diaphragmatic breathing, on any day.
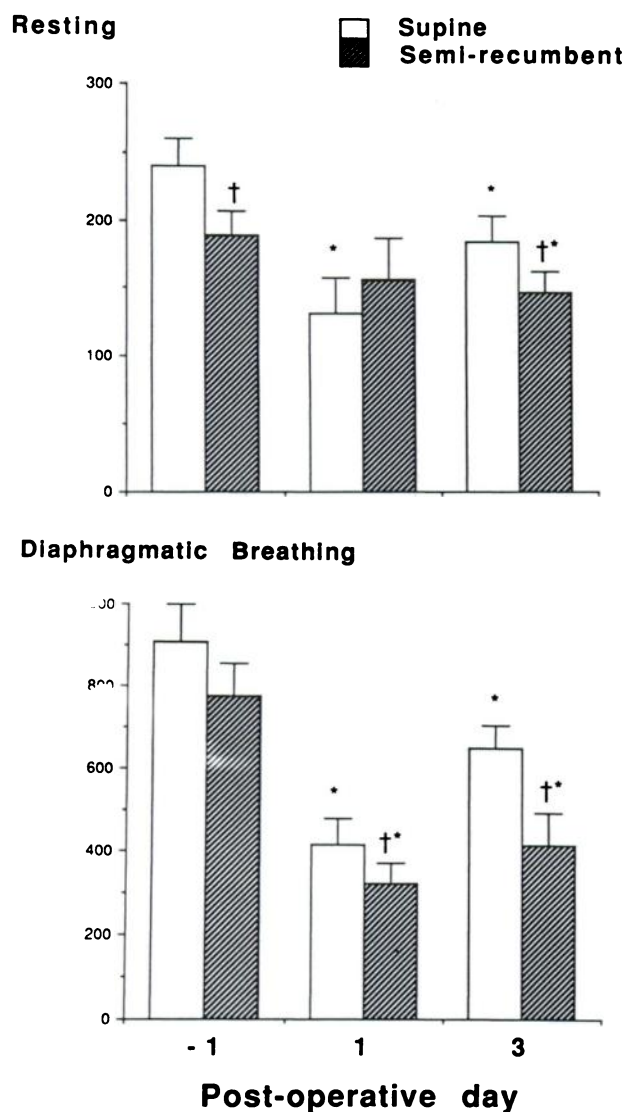
Resting and diaphragmatic breathing values of Vab

FIGURE 3. Compartmental tidal volumes of the abdomen (Vab,ml), in the semirecumbent and supine positions, at rest and during diaphragmatic breathing. *Asterisk* indicates p<0.05, from POD – 1; *dagger*, p<0.05, from supine. *Bars* indicate SE.

were generally lower in the semirecumbent position than supine (Fig 3). The effect of posture was most apparent during diaphragmatic breathing and was notably absent in resting patients on POD 1.

There were no cases of postoperative pneumonia, and none of the patients required supplemental oxygen.

DISCUSSION

We have shown that, with suitable instruction, the postoperative patient is able to increase the tidal excursion of the diaphragm. The effect of surgery is to reduce the absolute magnitude of this response, just as it reduces resting diaphragmatic function.

The tidal volume of the abdominal compartment (Vab) is used here as an index of diaphragmatic descent, and the postoperative fall in Vab is interpreted to be the result of diaphragmatic dysfunction. Several other

observers, using such diverse methods as magnetometry, fluoroscopy, plethysmography, and transdiaphragmatic pressure measurement, have reported a profound fall in the activity of the diaphragm following upper abdominal surgery.[8-14]

The partitioning of tidal volume into these two compartments depends upon the assumption that overall ventilation can be approximated by measuring movements of the chest and abdominal walls.[18] This does not imply that the two compartments are mechanically independent.[21,22] The diaphragm takes origin from the lower rib cage as well as the spine. Any displacement of the abdominal viscera, resulting from diaphragmatic contraction, is accompanied by an elevation of the rib cage. Nor can it be assumed that the force of diaphragmatic contraction is the sole determinant of diaphragmatic descent. Other influences include the relative compliance of the chest and abdomen[22] and the expiratory position of the diaphragm.[23] But, these considerations do not necessarily invalidate the use of abdominal volume changes as an index of diaphragmatic movement. Moreover, in studies where measurements of abdominothoracic configuration were combined with transdiaphragmatic pressure measurements, a postoperative fall in Vab/Vt was found to be due primarily to a reduction in the force of diaphragmatic contraction.[11,14]

In the postoperative period, the effects of surgery on thoracoabdominal configuration are superimposed upon the effects of narcotic analgesics, which were administered shortly before each of the postoperative studies. Narcotic analgesics are known to produce a fall in Vc and an increase in Vab.[24] The observed fall in Vab occurred despite the use of narcotics. It is attributed to the effects of surgery on diaphragmatic movement.

Surgery is known to depress the transdiaphragmatic pressure and diaphragmatic descent measured during maximal inspiratory effort against a closed shutter.[11] Diaphragmatic descent under these conditions depends upon the degree to which the patient can isolate diaphragmatic breathing, because the resulting increase in the volume of the abdominal compartment can only occur in association with a concomitant fall in the volume of the chest compartment. This contrasts with the current study, in which compartmental tidal volumes were measured during unimpeded breathing and maximal results were compared with baseline function.

The observed increases in the diaphragmatic movement of postoperative patients are attributable to preoperative instruction and continuing feedback (from an informed observer referring to compartmental volume measurements), directed specifically to that goal. Routine incentive spirometry has been found to produce no increase in diaphragmatic move-

ment after cholecystectomy.[9] The overall tidal volumes achieved during incentive spirometry and diaphragmatic coaching were very similar, but that associated with incentive spirometry was achieved solely through an increment in Vc.

These findings confirm anecdotal reports that patients recovering from upper abdominal surgery are able to enhance diaphragmatic movement through voluntary effort.[8,10,13] Postsurgical patients, with resting diaphragmatic dysfunction, have also been shown to respond normally to phrenic nerve stimulation.[12] The defect in resting diaphragmatic movement is attributed to the influence of visceral afferents on central control.[25-27] After surgery, an unimpaired phrenic nerve and diaphragm might be expected to respond normally to voluntary effort, but the response of Vab to diaphragmatic breathing fell markedly after surgery. This may reflect the effects of surgery on maximal transdiaphragmatic pressure.[11] Other factors which might limit diaphragmatic movement after surgery include the incisional pain and decreased abdominal compliance.

The constancy of the ratio between mean supine values of Vab during resting and diaphragmatic breathing does not imply that the relationship between the two was unaltered by surgery. There was no correlation between individual values of Vab at rest and those during diaphragmatic breathing; either before or after surgery. Nor did individual values for this ratio correlate with those found after surgery; the mean value just happened to be the same.

There is an accumulating body of evidence that diaphragmatic dysfunction is a major factor in the etiology of postoperative pulmonary complications. The frequency of atelectasis, infection, and hypoxemia parallel differences between operations in the severity of diaphragmatic dysfunction, with upper abdominal procedures being the most affected.[1,4,10,28] Restrictive defects in lung function have also been shown to be associated with diaphragmatic dysfunction.[8,10,14] The role of incisional pain, which was once thought to be a major factor, has come into question, because effective relief of pain (by narcotic epidural anesthesia) is not associated with any reduction in complication rates;[29] possibly because this form of anesthesia is not associated with any change in the level of diaphragmatic function,[11] or major improvements in static lung function.

In the postoperative patient, poor ventilation of the lungs leads to the development of small airways collapse. The preponderance of lower lung field involvement in atelectasis and infection has been attributed to a postural gradient in intrapleural pressure.[30] Only late in inspiration do pleural pressures surrounding the lower lung fall sufficiently to permit alveolar expansion. Postoperative respiration is characterized by low lung volumes and a loss of variability of tidal volume, which most affect ventilation of the lower lung fields.[31] A more important factor may be the dependence of lower lung field ventilation on diaphragmatic movement. In dogs, pleural pressures over the lower lobes are reduced by electrophrenic stimulation and increased by phrenicotomy.[32,33] Xenon distribution experiments, in normal human subjects show that voluntary isolated diaphragmatic breathing enhances lower lung ventilation in all postures.[15] Patients recovering from upper abdominal surgery, who have markedly imparied diaphragmatic movement, also show reduced ventilation of the lower lung fields.[10]

The importance of diaphragm movement in lower lung field ventilation may explain the association between postoperative diaphragmatic dysfunction and the pulmonary complications of surgery. Inspiratory maneuvers, such as incentive spirometry (which does not recruit diaphragmatic movement), probably fail to produce as great an enhancement of ventilation in the areas of lung most at risk. This may explain the paucity of data from controlled clinical trials that complication rates (in low risk patients) are reduced by incentive spirometry,[3,5,7] despite the sound rationale for its use as a means of intermittent ventilation to total lung capacity.[16] Coached diaphragmatic breathing, which enhances diaphragmatic movement, may provide more effective prophylaxis against the pulmonary complications of surgery. The question remains whether the modest increments in Vab, seen in this study, would enhance regional ventilation sufficiently to be of benefit.

The change in posture, from supine to semirecumbent, reduced Vab in preoperative studies, both at rest and during coached breathing. This reflects changes in the relative compliance of the chest and abdomen,[23] more effective coupling between the chest wall and diaphragm, and less efficient length-tension relationships in the semirecumbent posture.[34] The effects of posture were not seen in resting studies on POD1 but were apparent (in postoperative patients) during coached breathing. The explanation for the postoperative loss of the postural change in resting values may lie in the postoperative weakening of the diaphragm, or the effect of surgery on baseline abdominal wall compliance. Notwithstanding these effects of surgery, coached breathing was found to be less effective, as a means of enhancing diaphragmatic movement, for postoperative patients in the semirecumbent posture. The effects of posture on the diaphragmatic response to coached breathing are probably also reflected in extent of the resulting enhancement of lower lung field ventilation. Similar effects of posture on regional ventilation have been observed in normal subjects.[15] These presumably result from the known effects of posture on diaphragmatic movement. The supine

position may thereby enhance the efficacy of diaphragmatic breathing exercises, but the semirecumbent position is generally preferred for the care of resting patients because it is associated with increased FRC and improved arterial oxygenation.[34]

We conclude that through focused instruction, the movement of the diaphragm may be increased, even in postoperative patients who have much reduced diaphragmatic activity during resting breathing. This physiotherapeutic approach warrants investigation as a method of prophylaxis against the pulmonary complications of abdominal surgery because the technique of diaphragmatic breathing is easy to learn and has been shown to enhance ventilation of the lower lung fields,[15] where atelectasis and infection occur most often.

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