Stacked Inspiratory Spirometry Reduces Pulmonary Shunt in Patients After Coronary Artery Bypass*

David Strider, R.N., M.S.N.; Doug Turner, R.N., M.S.N.; Mary Beth Egloff, R.N., M.S.N.; Suzanne M. Burns, R.N., M.S.N., R.R.T.; and Jonathon D. Truwit, M.D., F.C.C.P.

Atelectasis is a major factor in postoperative morbidity for patients undergoing cardiopulmonary surgery. We evaluated the effectiveness of stacked inspiratory spirometry (STIS) in 17 patients status postcoronary artery bypass graft in a nonrandomized fashion. We measured pulmonary shunt as an endpoint, and compared the magnitudes before and after the STIS maneuver. Our results showed an 8.66 percent reduction in pulmonary shunt (p<0.05). The reduction in shunt was modest; however, repetitive maneuvers might result in greater improvement. (Chest 1994; 106:391-95)

Key words: atelectasis; incentive spirometry; postoperative; pulmonary shunt

Atelectasis contributes significantly to postoperative morbidity and mortality in cardiothoracic patients with an incidence ranging between 40 and 90 percent.1-7 Regions of collapsed lung may result in increased work of breathing, pneumonia, and impaired oxygenation.8-10 Efforts to reduce the incidence of and resolve atelectasis have been largely directed at sustaining inspiration at high absolute lung volumes and secretion clearance.

Recently, Baker et al11 found that postoperative patients using a new incentive spirometry technique devised by Marini et al1 were able to inspire greater volumes and maintain inspiration for longer periods of time than they could with deep breath incentive spirometry (DBIS). With the new technique, patients performed stacked inspiratory spirometry (STIS) by inspiring through a one-way valve that permitted inhalation and summation of successive volumes while prohibiting exhalation. Since STIS was more effective in stretching the lung (higher inspiratory volumes) and maintaining the stretch (longer periods of time), Baker et al11 reasoned that STIS might be more effective than DBIS in preventing atelectasis and hence improving gas exchange in the postoperative patient.

Our study assessed the effectiveness of STIS in reducing the pulmonary shunt fraction in postoperative thoracic surgery patients and tested the hypothesis of Baker et al11 that inspiratory efforts of greater duration and volume result in greater improvements in gas exchange. We chose to examine the pulmonary shunt fraction as an index of atelectasis as chest radiographs will not detect microatelectasis,9 nor would small changes in gross atelectasis be appreciated. The correlation between pulmonary shunt and atelectasis has been established by a computer-assisted tomography study by Hachenberg et al.12

METHODS

The study was performed on 17 patients status post coronary artery bypass surgery after preoperatively obtaining written consent for an Institutional Review Board approved protocol. After the protocol was explained preoperatively, patients had ample opportunity to practice the respiratory maneuver that was to be performed postoperatively.

The study was initiated in the postoperative period when the patient was capable of lifting his/her head 7.5 cm above the bed and inspiring a deep breath on command. Patients remained intubated and supported with synchronized intermittent mechanical ventilation (SIMV) at a rate of 9.18 ± 1.54 breaths per minute. To assess ability to cooperate, all patients correctly answered the following questions: (1) Is your name (correct name provided)? (2) Are you at home or in the hospital? (3) Is the sky green? (4) Is snow hot?

Next, the FlO2 was raised to 1.0 and after 15 min blood samples were withdrawn from the systemic and pulmonary arterial catheters (baseline 1, B1). Pulmonary shunt was then calculated: QH/QT=(CaO2−CaO2)/[CaO2−PvO2], where CaO2 is an estimate of pulmonary capillary oxygen content (hemoglobin [Hgb]*SaO2*1.36+PaO2*0.0031), CaO2 is arterial oxygen content (Hgb*SaO2*1.36+PaO2*0.0031) and CvO2 is mixed venous oxygen content (Hgb*SvO2*1.36+PvO2*0.0031). Oxygen tension and saturations were determined on a pH/blood analyzer (Corning 178) and a co-oximeter (Instrumentation Laboratories CO-Oximeter), respectively. Ten minutes later, while still inspirng 100 percent oxygen, repeated specimens were obtained and pulmonary shunt was recalculated (baseline 2, B2).

Patients were then asked to inspire through a one-way valve that prohibited exhalation. Patients were encouraged to make

*From the University of Virginia Health Sciences Center, Charlottesville.
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successive inspirations and rest against the one-way valve between efforts. The one-way valve was applied until the patient requested to exhale, appeared agitated, or until a change in cardiac or respiratory status was noted. Specimens were then withdrawn from the systemic and pulmonary arterial catheters, within 2 to 4 min of the completion of the maneuver (STIS), and pulmonary shunt was calculated. The maneuver’s duration and resultant inhaled volume were recorded by a hand-held pocket stopwatch and spirometer (model VM-90, Bear Ventilator Monitor), respectively.

RESULTS

Of the 17 patients, 11 were men. The sample ranged in age from 45 to 78 years (mean, 61.8 years). All were status post coronary artery bypass with internal mammary artery and saphenous vein grafts. Prior to study initiation, all patients successfully an-

swered the questions assessing ability to cooperate outlined above. Patients tolerated the procedure well without evidence of arterial desaturation or significant arrhythmias.

Pulmonary shunts of 25.32 ± 5.57 percent (mean ± SD) were found at B1 and did not differ significantly at B2 (25.14 ± 5.29, p = 0.207). However, pulmonary shunt was reduced an average of 8.66 ± 8.32 percent from B2 values, after the STIS maneuver; Q5/QT Post-STIS = 22.98 ± 5.66, p = 0.001, Fig 1).

Mixed venous saturations did not differ between B1 and B2 (74.42 ± 7.57 vs 73.44 ± 7.66, p = 0.575). However, SVO2 values declined between B2 and post-STIS maneuver (72.04 ± 7.26 post-STIS; p = 0.015). The variability in the magnitude of reduction in pulmonary shunt is not well explained by changes in SVO2, r2 = 0.007 (Fig 2).

The alveolar-arterial oxygen gradient and ratios were calculated. The gradient was reduced, but not significantly, from 336.40 ± 96.03 (B2) to 318.95 ± 94.45 (STIS) (p = 0.06). The alveolar-arterial oxygen ratio was reduced, but not significantly, from 2.22 ± 0.83 (B2) to 2.09 ± 0.77 (STIS) (p = 0.08).

The average duration and inhaled volume for the STIS were 32.0 ± 6.5 s and 1618.2 ± 369.4 ml, respectively. The variability in pulmonary shunt reduction was not well described by either the maneuver’s duration or resultant inhaled volume (r2 = 0.012 and 0.054, respectively) (Fig 2).

All patients were successfully extubated within 24 h and did not require reintubation. We were not able to detect phrenic nerve dysfunction, as we did not examine serial chest radiographs.

DISCUSSION

Atelectasis in the postoperative period most likely results from decreased distending forces, localized airway obstruction (mucus), or insufficient surfactant.13 To date, clinical practice has been directed toward sustaining high absolute lung volumes, secretion clearance, and sustaining surfactant levels.

After upper abdominal surgery, patients fail to make periodic deep breaths (sighs).14,15 Zikria et al14

![Figure 1](http://journal.publications.chestnet.org/pdfaccess.ashx?url=/data/journals/chest/21698/) Stacked inspiratory spirometry (STIS) decreases pulmonary shunt.

![Figure 2](http://journal.publications.chestnet.org/pdfaccess.ashx?url=/data/journals/chest/21698/) Reduction in pulmonary shunt is not well correlated with change in SVO2 (left), duration of STIS (center), and volume inhaled during STIS (right).
demonstrated the abolition of sighs equal to 200 and 300 percent of tidal volumes during the postoperative period in these patients. Bendixen et al. demonstrated progressive hypoxemia in anesthetized patients supported with constant volume-positive pressure ventilation without sighs. Deep breathing maneuvers led to reversal of hypoxemia.

In an effort to intermittently increase lung volume, Vrachtiu and Vrachtiu had patients perform deep breathing maneuvers twice daily (with a physical therapist present) and encouraged them to cough spontaneously throughout the day. The study showed a reduction in pulmonary complications, as defined by temperature >38.5°C, radiologic evidence of atelectasis or pneumonia, or abnormal breath sounds. The protocol, although successful, required trained personnel and was time consuming. Alternatively, the yawn may be an effective means to prevent atelectasis. This physiologic maneuver does result in sustained inspiration at high absolute lung volumes. Poorly cooperative patients, however, cannot be counted on to perform such a maneuver regularly.

Since the application of positive pressure to the airway increases functional residual capacity, some have reasoned it would result in a reduction in atelectasis. Iverson et al. examined the effectiveness of intermittent positive pressure breathing (IPPB), incentive spirometry, and blow-bottles in reducing atelectasis in patients postcardiomyotomy on postoperative day 3. The incidence of atelectasis was 55 percent with IPPB, 60 percent with incentive spirometry, and 40 percent with blow-bottles. Significant postoperative hypoxemia was identified in 52 percent of IPPB-treated patients, compared with 33 percent and 24 percent of patients treated with incentive spirometry and blow-bottles, respectively. Oikkonen et al. compared IPPB with the combination of incentive spirometry and chest physiotherapy (CPT) and found no difference in oxygenation or the incidence of atelectasis.

Celli et al. conducted a randomized study evaluating IPPB vs incentive spirometry vs deep breathing exercises vs no intervention in postoperative (abdominal surgery) patients. Pulmonary complications were significantly reduced in the treatment groups (48 percent vs 21 to 22 percent). The treatment groups were equivalent concerning frequency of pulmonary complications. However, in the more expensive treatment, IPPB, 18 percent of patients were intolerant to therapy that had to be discontinued.

Nasally applied continuous positive airway pressure (nasal CPAP) and positive end-expiratory pressure have also been examined in patients after coronary artery bypass graft. In two studies, neither the application of nasal CPAP nor positive end-expiratory pressure resulted in decreases in postoperative atelectasis. Nasal CPAP did result in improved oxygenation while applied. A prospective randomized study evaluating the addition of mask CPAP to aggressive respiratory therapy in patients after abdominal surgery revealed improved oxygenation and reduced incidence of atelectasis.

The application of positive pressure by selective insufflation through a balloon-tipped catheter may resolve lobar atelectasis. The catheter can be introduced under fiberoptic visualization through a bronchoscope or guided by fluoroscopy after traversing anesthetized vocal cords from a trnasnasal approach.

Atelectasis may also result from endobronchial mucus obstruction. The common practice of CPT, postural drainage, bronchodilators, and deep breathing exercises has been shown to reduce postoperative pulmonary complications. This regimen was not effective in children after cardiac surgery. Hammon et al. noted a high incidence of arrhythmias during chest percussion and postural drainage in critically ill patients. Major rhythm disturbances were noted in 11 percent of the patients and minor arrhythmias were noted in 25 percent. Risk factors included increased age and the presence of an acute cardiac disorder.

The combined therapy of CPT and bronchodilators does appear effective in reversing acute lobar collapse and may obviate the need for bronchoscopy. However, at times bronchoscopy is required for secretion removal. Mucolytic therapy with N-acetylcysteine failed to show a reduction in postoperative atelectasis.

Loss of surfactant in the postoperative patient may result from inhalational anesthesia, high inspired oxygen fraction, or lack of periodic deep ventilation. In a double-blinded multicenter trial, Fegiz et al. evaluated the effectiveness of ambroxol, an agent that promotes surfactant synthesis, in reducing bronchopulmonary complications in patients with chronic obstructive lung disease undergoing upper abdominal surgery. They noted a reduction in postoperative atelectasis (ambroxol: 10.6 percent vs control: 23.9 percent) and a smaller decrease in arterial oxygen tension (ambroxol: 80.4 to 76.6 mm Hg vs control: 81.4 to 72.5 mm Hg).

The new incentive spirometry technique devised by Marini et al. is attractive, as it could be performed by patients alone (after initial instruction) with little distress. Our study was designed to test two hypotheses: (1) pulmonary shunt is reduced after patients perform the STIS maneuver and (2) reductions in pulmonary shunts post-STIS maneuver were correlated with the maneuver's duration and resultant inhaled volume. We chose to examine patients after coronary artery bypass graft, as atelectasis is known.
to be a significant and frequent complication.\textsuperscript{2-7} These patients have large pulmonary shunts in the postoperative period. In addition, our institution routinely monitors these patients with indwelling right heart catheters postoperatively, making pulmonary shunt measurements possible.

**Conclusion**

Our results indicate that the performance of the stacked inspiratory maneuver results in a modest reduction in pulmonary shunt in patients after coronary artery bypass and they are assessed approximately 12 h after leaving the operating room. The magnitude of pulmonary shunt reductions does not correlate with the duration of inspiratory effort, resultant tidal volume, or percent change in mixed venous oxygen saturation. If elimination of atelectasis results in reduced shunt, then it appears that the maneuver itself eliminates atelectasis and not the maneuver's duration or inhaled volume. An increase in cardiac output resulting in shunt reduction seems unlikely as mixed venous oxygen saturations fell after the maneuver.

A trend in reduction of alveolar-arterial gradients and ratios was noted after the STIS maneuver. However, these trends did not achieve significance. Had our sample size been larger or comprised of intubated patients, we might have observed a significant difference. Such a finding would be valuable if the STIS is to be assessed in patients without indwelling right heart catheters.

The reduction in shunt was modest. However, repetitive maneuvers might result in further reductions as increased alveolar-arterial $P_{O_2}$ gradients in postoperative cardiopulmonary bypass patients have been attributed to atelectasis and not pulmonary capillary permeability.\textsuperscript{31} Furthermore, we do not know if STIS reduces pulmonary shunt in patients during spontaneous breathing or days later in the postoperative recovery period. Our study addressed patients still being supported by SIMV at a rate of 9.18 breaths/min. Greater reduction in shunt might be seen in spontaneously breathing unsupported patients or those with phrenic nerve dysfunction.

Finally, this study has not examined the impact of the maneuver on outcome (pulmonary complications, length of stay, or hospitalization costs). Since atelectasis is a major cause of postoperative morbidity in cardiothoracic patients, clinicians should continue to investigate simple, cost-effective interventions such as STIS.

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