High-Frequency Chest Compression: A Practical Intervention for Secretion Retention in the ICU

Jane Braverman, PhD

In a sweeping Medicare policy change, Bush administration officials announced in August, 2007 that the program will no longer reimburse medical institutions for the extra costs of treating conditions identified as hospital-acquired illnesses or injuries ... "that could reasonably have been prevented."[1] Despite the government's approach to reduce excess expenditure by mandating improvements in care practices, healthcare professionals know that adverse outcomes persist even with the most rigorously applied preventative programs. Inevitably, complications occur as a natural consequence of treating seriously ill patients for prolonged periods of time. No professional healthcare team member knowingly neglects evidence-based care guidelines. Unfortunately, complex realities are not easily communicated to policy makers. No matter how unfairly some poor outcomes may be labeled as "preventable," budget-strapped hospitals now must even more aggressively identify cost-effective ways to prevent and/or manage complications associated with suboptimal recovery.

Pulmonary Complications: An ICU Nemesis

Pulmonary complications (PC) are an ever-present threat in acute care medicine. Mild problems may delay recovery. More severe PC may progress and worsen until they pose serious, even life-threatening challenges. Clinically important PC include atelectasis, interstitial and alveolar edema, pneumonia, hypoventilation, aspiration and respiratory failure.[2-4] In patients undergoing thoracic or upper abdominal surgery, PC are a major cause of postoperative mortality.[1-7] Even after uncomplicated procedures, 30-60% of patients experience hypoxemia and some go on to develop respiratory failure.[8] Depending upon severity, mortality following respiratory failure ranges from 10-60%.[8] Moreover, the costs incurred for extended ICU stays are substantial. Additional expenditures for complication-related interventions including reintubation, mechanical ventilatory support, treatment of infections or nosocomial pneumonia account for a significant proportion of Medicare dollars. Laboratory services and specialized nursing care further increase total costs.

The Economic Cost of PC: Current Estimates

Although PC are a significant source of ICU morbidity and mortality, until recently few studies have attempted to quantify their impact on health care resource utilization. The data are striking:

- Khan, et al [2006] assessed costs associated with clinically important PC with total hospital costs and length of stay (LOS) in patients undergoing noncardiac surgery.[9] After adjusting total hospital costs and LOS for preoperative and surgical characteristics, data showed:
  - » Of 7,457 eligible surgical patients, 6.9% (514/7,457) developed at least one clinically important PC
  - » These complications increased hospital costs by 78% and LOS by 114%
  - » Postoperative pneumonia was the most common complication (3%) and was associated with a 55% increase in hospital costs and an 89% increase in LOS.

When mechanical ventilation is part of the clinical picture, costs skyrocket:

- Warren, et al [2003] found that patients with ventilator-associated pneumonia had significantly longer ICU and hospital LOS, with higher crude hospital costs and mortality rates compared with uninfected patients.[10] After adjusting for underlying severity of illness, the attributable cost of ventilator-associated pneumonia (VAP) was approximately $11,897. Data from 819 intensive care patients in a suburban medical center followed prospectively for the occurrence of VAP showed an overall incidence of 15.5% (127/819). Compared with uninfected ventilated patients, patients with VAP:
  - » Had higher *Acute Physiology and Chronic Health Evaluation II* scores on admission ($p<.001$);
  - » Were more likely to require multiple intubations ($p<.001$), hemodialysis ($p<.001$), tracheostomy ($p<.001$), central

Jane Braverman is Director: Clinical Programs, RespirTech. This article is provided by RespirTech.

venous catheters (p<.001), and corticosteroids (p<.001).
  - » Were more likely to be bacteremic during their ICU stay (36 [28%] vs. 22 [3%]; p<.001).
  - » Had significantly higher unadjusted...
    - ICU LOS (26 vs. 4 days; p<.001)
    - Hospital LOS (38 vs. 13 days; p<.001)
    - Mortality rates (64 [50%] vs. 237 [34%]; p<.001)
    - Hospital costs ($70,568 vs. $21,620, p<.001).
    - Estimated attributable cost of ventilator-associated pneumonia ($11,897 – [range $5,265 – $26,214] p<.001].

- Dasta, et al [2005] studied intensive care costs of 51,009 adult ICU patients treated in 2002 at 253 US hospitals and found...[11]
  - » 36% received mechanical ventilation (MV) during their stay
  - » Mean MV duration: 5.6 days ±9.6.
  - » Mean intensive care unit cost and length of stay: $31,574 ±$42,570 and 14.4 days ±15.8 for patients requiring MV
  - » $12,931 ±20,569 dollars and 8.5 days ±10.5 for those not requiring mechanical ventilation.
  - » Mean incremental cost of MV in intensive care unit patients was $1,522 per day (p<.001).

The Status Quo

Inadequate removal of tracheobronchial secretions is well-recognized as a common and potentially lethal problem associated with major surgery, serious acute illness or significant trauma. Nevertheless, despite advances in both surgical technique and emergency/acute care medicine, the prevalence of serious PC remains stubbornly high. A rapidly aging population, together with increased access to advanced medical care among a growing population of medically complex, higher-risk individuals, accounts for a large part of this persistent problem. Other patients with few or no obvious risk factors are also affected. An abundance of recent medical literature reflects the magnitude of the problem. Editorial pieces and review articles examine current practices and seek to identify institutional or systemic weaknesses that may contribute to high PC rates.[12-15] Several studies identify patients with a predisposition to PC, stratify risk factors and suggest interventions to modify those risks.[1,2,5-7,16] Numerous protocols outline steps to help recognize and manage developing signs and symptoms of PC.[17-20] However, few papers address identification of risk for the single factor both necessary and sufficient for PC to occur: a breakdown of the mucociliary clearance system.

Secretion Retention: A Proximate Cause of Acute PC

Lung health is impossible to maintain without effective mucociliary clearance (MCC). MCC plays an essential role in the defense of the respiratory system by entrapping inhaled particles, including bacteria, in a layer of mucus and then moving it forward via coordinated structures and mechanisms aptly called the mucociliary escalator.[21] When sufficient mucus is accumulated in the central bronchus, it is easily cleared by coughing and/or swallowing. Normal MCC may be disrupted by one or more factors that arrest or delay mobilization of mucus from distal lung regions to central airways. These factors include 1) increased mucus production; 2) abnormal mucus rheology; 3) abnormal ciliary activity and; 4) loss of ciliated cells.[21] Most acutely ill patients present with some degree of one or more of these anomalies. Measurements of tracheal mucus veleocity (TMV) in acutely ill patients establish the presence of impaired MCC definitively.[22-24] Closer scrutiny of this fact provides new insight into the high susceptibility for PC among ICU patients.[25] Impaired TMV appears to be the common denominator in development of secretion retention and pneumonia.

- MV patients are disproportionately at-risk for developing serious PC-especially nosocomial pneumonia. Konrad, et al [1994] measured tracheal mucus veleocity (TMV) with technetium 99-labeled albumin microspheres during the first three days of MV in 34 ICU surgical patients and found significantly reduced TMV and a correspondingly high incidence of PC:[22]
  - » Average TMV in healthy subjects is about 10 mm/min.[21]
  - » Median TMV in MV subject's right primary bronchus was 0.8 mm/min and 1.4 mm/min in the left
  - » No measurable particle movement occurred in 9/34 subjects
  - » 14/34 subjects experienced 19 PC (10x secretion retention; 9x pneumonia)
  - » One or more PC occurred in 8/9 patients with no measureable TMV
  - » Subjects with PCs had significantly lower TMV than those without [median with range] – left bronchus: 0 (0 to 6.5) mm/min vs 3.5 (0 to 10.5) mm/min 9 p<0.01); right bronchus: 0 (0 to 3.0) mm/min vs 4.7 (0.11.7) mm/min (p<0.01)

- Patients with COPD are shown to be at significant risk for serious exacerbation of existing pulmonary problems during ICU admissions; Morgan, et al [2004]: [23]
  - » Scintographic measurements of TMV in 32 normal subjects [20 young (<50 years) and 12 older (>50)] and 34 subjects with COPD showed significantly decreased TMV in older individuals and markedly impaired TMV in COPD subjects.
  - » TMV (mean ±SD) in young normal subjects: $10.7 \pm 3.5 mm/min^{-1}$
  - » MV in older normal subjects: $6.6 \pm 2.6 mm/min^{-1}$
  - » TMV in COPD subjects: $2.1 \pm 2.7 mm/min^{-1}$

- Nakagawa, et al [2005] reported that markedly impaired MCC occurred even in stable acutely ill patients without any form of airway manipulation (i.e. tracheostomy, intubation, MV or gastric or enteral tubes).[24] Contributing factors may be drug effects and type/length of anesthesia.

- Bonde, et al [2002] showed a strong correlation between impaired MCC (p<0.01) and the incidence of atelectasis, pneumonia and respiratory failure that occurred in 30% (108/361) consecutive thoracotomy patients. Seventeen patients died; nine deaths were caused by pneumonia attributed to secretion retention.[25]

Clinical Implications

TMV is a reliable measure of ineffective MCC.[23,26] Decreased TMV is common and frequently predictable in a subset of acute care patients. Studies in various patient populations confirm that patients at high risk for decreased TMV are the same as those at high risk for PC.[22-25] Patient-related high risk factors include chronic lung or systemic disease, a significant smoking history, immunodeficiency, obesity and advanced age.[3] Procedure-related risk factors include type of surgery-especially upper abdominal and cardiothoracic-and kind and duration of anesthesia.[3] When TMV is significantly slowed, secretion retention inevitably follows. Stagnant secretions not only cause airway obstruction, atelectasis and suboptimal gas exchange; prolonged exposure to entrapped bacteria and viruses promotes

development of pneumonia. ICU pneumonias are frequently antibiotic-resistant; respiratory failure, re-intubation, need for MV and, all too often, death may follow. The impact of preventable PC on patients, institutional resources and the healthcare dollar is unacceptable. Effective interventions are urgently needed.

Treatment

In theory, use of routine prophylactic and therapeutic airway clearance therapy (ACT) to prevent or relieve secretion retention is both intuitive and logical.[17-19] In practice, technique-related, patient-related, and institutional barriers limit both systematic implementation and fair assessment ACT outcomes.[27-29]

Most ICUs utilize a graduated array of ACT methods; few stand out as notably effective.[30] With the exception of a recently introduced therapy, high-frequency chest compression (HFCC), none of these modalities adequately address the primary cause of secretion retention: decreased TMV secondary to ineffective MCC. Each ACT technique used in the ICU has advantages and disadvantages. Post surgical patients and those with severe acute illness or injury may be weak, in pain and attached to sensitive or invasive equipment; many are disoriented or comatose. Such factors must be considered in choosing a therapy. ACTs used in the ICU:

- *Incentive spirometry*: Promotes lung expansion and cough; requires patient effort and cooperation
- *Nebulizers and brochodilators*: Humidify and loosen secretions and open airways; do not significantly mobilize tenacious secretions
- *Deep breathing and post-exhalation cough maneuvers*: Help expel secretions from primarily central airways; require effort and compliance
- *Nasal CPAP*: May improve functional residual capacity; does not affect refractory secretion stasis; suitable for severely ill patients and/or comatose patients
- *Minitracheostomy*: Permits secretion suctioning; invasive, labor-intensive, risk for infection
- *Rigid or flexible bronchoscopy*: invasive and expensive: works well to clear accumulated secretions; risk for infection; requires sedation and sometimes anesthesia
- *Chest physiotherapy (CPT)*: Works well to mobilize retained secretions; reduces atelectasis; improves peak expiratory flow rates; labor-intensive, technique-dependent and poorly tolerated by acutely ill patients. Moreover, it is difficult for RT departments to provide therapeutically effective doses of CPT. In a series of 361 lung surgery patients....196 required two CPT sessions per post-op day; 118 needed more than two but fewer than four; 35 needed more than four but fewer than six; 12 required more than six sessions/day.[25]

High-Frequency Chest Compression Therapy

High-frequency chest compression therapy (HFCC) is rapidly gaining acceptance as an ideal therapy for ICU patients. It is safe, easy to use, requires no active participation from the patient and only minimal staff effort. Equipment consists of 1) an inflatable jacket or wrap; 2) two interconnecting hoses and; 3) a pulsating therapy unit (PTU). The therapy works by administering rapid but gentle compressive forces via the inflatable jacket/wrap to the chest. These forces produce increased airflow and oscillatory effects within the airways, thus enhancing mucus mobilization and clearance. HFCC is the only secretion clearance modality shown to mimic all the mucokinetic and mucolytic effects of a normal MCC system: HFCC....

- » Increases TMV up to 340x that of spontaneous breathing[31,32]
- » Reduces the viscoelastic and cohesive properties of mucus[33]
- » Promotes mucus clearability by the air-liquid interactions associated with cephalad airflow bias[34-35]
- » Mobilizes secretions from peripheral towards central airways for removal by cough, swallowing or suctioning.[36]

HFCC: Safety and Tolerance in the Acute Care Setting

Clinical studies and twenty years of experience have established HFCC as a safe and effective therapy for home use in diverse patient populations. A series of studies suggest that, with appropriate care, HFCC is safe and well-tolerated in the ICU as well.

- Allen, et al [2003] assessed HFCC safety and tolerance in 25 elective thoracic surgical patients receiving HFCC as soon as 24 hours after surgery. Pre and post HFCC treatment, hemodynamic and pulse oximetric values remained stable; 84% of patients tolerated and accepted the therapy; no major adverse events were observed.[37]
- Brierly et al [2003] observed HFCC safety and tolerance in 73 critical care/post-surgical patients treated with HFCC concurrently with therapies or equipment including 1) sternal incision/sternal wires (n=48); 2) chest tubes (n=24); 3) external pacer wires (n=30) ; 4) swan-ganz catheters (n=27); 5) penrose drains (n=23); 6) central venous pressure lines (n=21); 7) implanted cardiac pacemakers (n=11); 8); CPAP (n= 5); 9) mechanical ventilation (n=1); 10) internal cardiac defibrillator (n=1).[38] In an evaluation of a total of 179 therapy days HFCC was well tolerated by 84% of users; 16% discontinued citing discomfort. No significant adverse events were reported.
- Ndukwu et al [1999] conducted a randomized, controlled study comparing chest physiotherapy (CPT) with high frequency chest compression (HFCC) in 54 long-term acute care patients who had been ventilator-dependent for a median of 84 days.[39] Subjects were randomized to receive either CPT or HFCC 4 x daily for 15 minutes for 40 days. After 21 days, the HFCC group....
  - » Produced larger volumes of sputum
  - » After 40 days, 38 % were weaned from ventilator dependence compared with 15% in the CPT group
  - » No adverse events occurred

Summary

Removal of static airway secretions is a critical component of pulmonary care in the ICU. HFCC is an established "standard of care" therapy used widely for out-patients with chronic lung disease. HFCC clears mucus from distal lung regions and significantly accelerates TMV. These effects minimize exposure of lung tissue and airways to bacteria and byproducts of inflammation. By controlling the proximate cause of secretion-related PC, the prevalence of preventable PC may be reduced and patient outcomes improved. Substantial reductions in total inpatient costs may be inferred.

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