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Endotracheal Tube Cuff Design and the Impact on Aspirations

Aryeh Shander, MD

Post-intubation pulmonary complications (PPC) remain one of the leading causes of morbidity and mortality and result in delayed discharge of post surgical patients. While several patient- and procedure-related factors have been linked to increased risk of PPCs, aspiration of upper airway secretions into the respiratory tract is a major etiologic factor. To prevent this from happening and to allow positive pressure ventilation, endotracheal tubes are equipped with inflatable cuffs that are filled after the tube is in place to provide a seal. These are either “low-volume, high-pressure” (LVHP) or “high-volume, low-pressure” (HVLP) cuffs. A problem with these cuffs is that folded cuff material often creates small longitudinal ducts and channels that permit leakage of fluids past the cuff into the respiratory tract. This leakage can result in microaspiration and plays an important role in PPC complications, including pneumonia. Several strategies to reduce and prevent microaspiration or attenuate its detrimental effects have been proposed including newer cuff designs and materials that provide a better seal, and suctioning of subglottic secretions. These and other strategies are undergoing active investigation.

Panel Discussion: Postoperative Pulmonary Complications: What are they and What are the Perioperative Risks?

Moderator: *Aryeh Shander, MD*

Panelists: *Gerald W. Smetana, MD*
Garry Brydges, DNP, CRNA, ACNP-BC
Steven Lisco, MD
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Postoperative pulmonary complications are well-understood and documented, but opinions vary as to the definition of PCCs, their causes, who is at risk, and how to prevent them. In this panel discussion, several experts were asked to answer questions related to the definition of PCCs, their frequency, and implications for hospital length of stay and costs. Panelists discuss the risk factors for PPCs, both modifiable and non-modifiable, and present strategies to address the latter. Finally, suggestions on how to prevent microaspiration are also discussed.



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Endotracheal Tube Cuff Design and the Impact on Aspirations

Aryeh Shander, MD

Postintubation pulmonary complications remain one of the leading causes of morbidity and mortality and result in delayed discharge of hospitalized patients, particularly those who have had surgery.¹ These complications have also been a main reason for readmission of surgical patients, imposing substantial financial burden on the health care system.² A large study of patients undergoing major noncardiac surgery indicated that the 30-day postoperative mortality rate in patients who developed pneumonia was 21% versus 2% in those who did not develop a postoperative pneumonia.³ Another study confirmed that postoperative hospital-acquired pneumonia was associated with a nearly 10-fold increase in mortality among patients undergoing intra-abdominal surgery.⁴ Depending on the definitions and patient- or procedure-related risk factors, the incidence of pulmonary complications varies but reported rates are as high as 25% in abdominal aortic aneurysm surgery, 19% in esophagectomy, 14% in abdominal surgery and 10% in head and neck surgery.⁵ Another study identified pneumonia as the

most common postoperative complication in patients undergoing noncardiac surgery, associated with a 55% increase in hospital costs and an 89% increase in length of stay.⁶ Similarly, pulmonary complications were the most common postoperative complication and the second most expensive of all complications in trauma patients at a level I trauma center.⁷ Interestingly, while serious postoperative pulmonary complications rival serious cardiac complications in terms of frequency and associated mortality, the former do not often receive as much recognition or attention from clinicians.^{5,8}

Significance of Cuff Design and Microaspiration

While several patient- and procedure-related factors have been linked to increased risk of post-intubation respiratory complications, aspiration of upper airway secretions into the respiratory tract is a major etiologic factor. To prevent this from happening and to allow positive pressure ventilation, endotracheal tubes are equipped with inflatable cuffs that are filled after the tube is in place to provide a seal. Generally, the cuffs are either “low-volume, high-pressure” (LVHP; so-called “red-rubber” tube cuffs) or “high-volume, low-pressure” (HVLP). LVHP cuffs have a smaller contact area with the trachea, which results in higher pressure on the tracheal wall and a more effective seal. However, the higher-pressure seal is also associated with higher risk of tracheal ischemia and necrosis (ultimately resulting in tracheal stenosis, and tracheoesophageal fistula), particularly during prolonged intubation. Conversely, HVLP cuffs provide a larger contact area and lower pressure onto the tracheal wall, which effectively reduces the risk of necrosis. The trade-off is a less effective seal and increased likelihood of fluid leakage past the cuff.

Due to the higher risk of injury to the tra-

cheal wall associated with the use of LVHP endotracheal tubes, HVLPs have been used more frequently since the 1970s, and have largely replaced the LVHP endotracheal tubes.⁹ It should be noted that even HVLP cuffs may be improperly overinflated in which case they can interfere with mucosal blood flow and cause tracheal damage, similar to LVHP tubes.⁹ The HVLP tubes have been designed so that the diameter of the fully inflated cuff is larger than the internal diameter of the trachea. Following inflation, the excess cuff material folds into the cuff to provide a seal without damaging the trachea. However, the folded cuff material often creates small longitudinal ducts and channels that could possibly permit leakage of fluids past the cuff into the respiratory tract, and result in microaspiration (Figure 1).^{10,11}

It is interesting to note that microaspiration is commonly reported (100% of cases in some studies) in all pressure ranges in patients intubated with conventional HVLP endotracheal tubes.^{9,12} However, these reports become alarming when the adverse implications of microaspiration are considered. Entrance of aspirated materials into the tracheobronchial tree can cause serious irritation and injury to the mucus membrane of the respiratory tracts and lung parenchyma, resulting in conditions such as bronchospasm, atelectasis, aspiration pneumonia and bacterial infections.¹³ Several independent studies have demonstrated that microaspiration can cause ventilator-associated pneumonia (VAP) and postoperative pneumonia which result in substantial morbidity and mortality.¹⁴⁻¹⁹

Strategies to Limit Microaspiration

Given the unfavorable outcomes associated with microaspiration of fluids and other materials past the cuff of endotracheal tubes, a number of strategies have been suggested to limit microaspiration. These include redesigning cuffs for a better seal, constructing cuffs of materials with better sealing characteristics, adjusting the cuff pressure, suction and removal of accumulated fluids above the cuff, and use of lubricants. A number of endotracheal tubes with features specifically designed to reduce microaspiration and/or prevent VAP are listed in Table 1.

Various design modifications of the cuff have been made with the intent to reduce

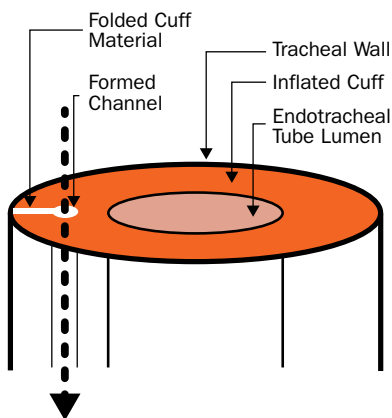


Figure 1. Formation of a small channel by internal folding of the extra cuff material in an HVLP endotracheal tube. The dotted arrow indicates the fluid leakage through the formed channel. (Image reproduced by permission of the author.)

leakage, and studies comparing endotracheal tubes made by different manufacturers often provide data in support of some tubes over others. However, given the often limited data and rapid progress in the field, it is difficult to recommend a particular endotracheal tube over others.

Recently, use of a “tapered” cuff versus conventional cylindrical cuffs has shown promising results in a number of studies.^{30,31} Unlike the conventional HVLP cuffs that are barrel-shaped and have a similar diameter throughout their length, tapered cuffs have a larger diameter at one end which tapers toward the other end, or are tapered at both ends. As a result, longitudinal channels spanning the whole length of the cuff are largely eliminated. Endotracheal tubes incorporating this design are emerging and while more data are needed to validate their safety and efficacy, preliminary data supports their effectiveness in preventing microaspiration.^{30,31}

An aspect related to the cuff design is the material used to make the cuff. While HVLP cuffs have been traditionally made from polyvinylchloride plastics, the use of other materials such as polyurethane and silicone has been explored and some *in vitro* and *in vivo* studies support the effectiveness of these materials in reducing leakage through the cuff.^{10,28,32,33} The available evidence on the polyurethane cuffs is more extensive.

A number of studies indicate that ultra-thin cuffs made of polyurethane provide a better sealing. One study showed reduction in early postoperative pneumonia with polyurethane cuffs and another found reduction in VAP using tubes incorporating both polyurethane cuffs and subglottic secretions drainage.^{22,23,30,34} No remarkable safety concerns currently have been noted with the use of polyurethane in making endotracheal tube cuffs.

Variations in cuff pressure are common and can adversely affect cuff performance. Overinflated cuffs are associated with increased risk of damage to the underlying mucosa and tracheal wall, while underinflated cuffs are associated with increased leakage and microaspiration. Even properly inflated cuffs tend to lose pressure over time (albeit not necessarily in a uniform and predictable fashion), and they should be regularly monitored.³⁵ Alarming, it has been reported that even experienced clinicians may often be unable to inflate cuffs to the proper pressure or accurately estimate the cuff pressure by palpation.³⁶⁻³⁸ While these observations support more accurate methods of monitoring the cuff pressure, a study of an automatic cuff pressure control device did not show better clinical outcomes despite closer control of the cuff pressure.³⁹ More investigation is needed.

The issue of cuff pressure becomes more complicated when various ventilator set-

tings and pressures are considered. For example, increased airway pressure has been shown to result in increased cuff inflation pressure, possibly to the point of damaging the tracheal wall.⁴⁰ In another study, positive expiratory pressure was shown to reduce fluid leakage through the cuff.⁴¹

Coating of endotracheal tubes with anti-bacterial agents does not quantitatively affect microaspiration but has been proposed as an effective strategy to reduce bacterial colonization and biofilm formation on the tube. Silver compounds (e.g. silver sulfadiazine) are commonly used for this purpose. While clinical studies support reduced bacterial colonization,⁴²⁻⁴⁴ reported effectiveness in terms of VAP reduction and other clinical outcomes has been marginal.²⁵ Use of a water-soluble gel to lubricate the cuff with the goal of plugging the formed folds and channels has also been reported to reduce leakage, but the effect on pneumonia and other outcomes, as well as long-term effectiveness, remains to be determined.⁴⁵

The inflated cuff of an endotracheal tube is expected to provide a seal between the cuff and trachea and prevent secretions and other fluids and particles from entering the lower respiratory tracts. This results in accumulation of fluids in the subglottic space before the cuff, which as discussed above, can still leak past a cuff. Removal of the accumulated fluids by continuous or intermittent suctioning can be an effective strategy to prevent this from happening. Suction lumens that open just before the cuff have been integrated into endotracheal tubes and such tubes are commercially available.²⁰ A meta-analysis of randomized trials concluded that suction of subglottic secretions reduced the incidence of VAP by half and delayed its onset by nearly 7 days, shortening the duration of mechanical ventilation by 2 days and length of stay in the intensive care unit by 3 days.²¹ Nonetheless, two studies of cardiac surgery patients did not show significant reduction in VAP incidence, length of stay, or mortality, although patients ventilated >48 hours in larger trials did show significant reductions in VAP incidence, ICU length of stay, and antibiotic usage.^{23,46-48} On the other hand, concerns have been raised regarding the adverse effects of continuous suctioning of the subglottic space (e.g. mucosal damage due to mechanical damage or increased dryness) as well as issues related to the increased thick-

Table 1. Some endotracheal tubes with features to reduce microaspiration and/or prevent ventilator-associated pneumonia (Modified from Deem and Treggiari, 2010).²⁰

Device	Mechanism of Prevention
Hi-Lo Evac	Extra lumen allows continuous suctioning of subglottic secretions to prevent microaspiration
Microcuff	Polyurethane cuff for better seal
SealGuard	Polyurethane cuff for better seal
SealGuard Evac	Combination of continuous suctioning of subglottic secretions plus polyurethane cuff for better seal
TaperGuard Evac	Combination of continuous suctioning of subglottic secretions plus tapered cuff to prevent microaspiration
LoTrach	Combination of low-volume, low-pressure cuff and continuous suctioning of subglottic secretions to prevent microaspiration
Agento IC	Silver-coated lumen to prevent biofilm formation
Mucus Slurper	Extra lumen allows suctioning of secretions from tip of endotracheal tube

RCT, randomized controlled trial

VAP, ventilator-associated pneumonia

ness and reduced flexibility of these tubes. Cautious use of such devices seems to be effective in preventing microaspiration and related complications.^{20,49,50}

As seen in Table 1, some endotracheal tubes combine various strategies to prevent respiratory complications. Increased complexity of the tubes often results in a higher price tag. Additionally, potential risks and complications associated with each strategy should be considered. Nonetheless, continuous research and development in this field is expected to provide more effective and safe products that combine features such as tapered design, ultrathin cuff materials, antibacterial coats and integrated suctioning capability.

Considerations and Limitations of *in vitro* Models

Investigators commonly use various *in vitro* methods to test and quantify leakage through the cuffs of endotracheal tubes. An *in vitro* model can be as simple as a tube representing the trachea, with the endotracheal tube placed inside the tube and its cuff inflated. Liquids are added above the cuff and leakage is quantified. Various other devices can be added to the model to simulate lung function and mechanical ventilation among other details. To better simulate the physical properties of human trachea, *ex vivo* animal models (e.g. animal cadaver tracheae) have also been used in lieu of a synthetic tube in such models.

There is no doubt that these models provide easily available yet highly valuable methods to test endotracheal tubes. However, fundamental differences between these models and real patients must be considered when interpreting the data from these experiments. Often, *in vitro/ex vivo* experiments are conducted with single-size endotracheal tubes placed in a single-size test tube, while in clinical practice, tubes with various sizes are placed in patients with various trachea conditions and diameters, and hence, reproducibility of the results may be limited. Of note, the diameter of trachea in healthy adults varies greatly and can range from 10 and 13 mm to 21 and 25 mm in women and men, respectively.⁵¹ More importantly, *in vitro/ex vivo* models (no matter how complex) are bound to lack the full complexities of living systems. For example, the potential issue with mucosa dryness noted above in the case of continuous suction of subglot-

tic secretion may not be easily detected or reproduced in an *in vitro* model.

This example and studies cited here highlight the importance of clinical studies in evaluating various designs of endotracheal tubes and related strategies. When satisfactory results are observed in *in vitro/ex vivo* experiments, clinical (and possibly animal) studies should follow to ensure that the expected functions (e.g. prevention of leakage and microaspiration here) are effectively reproduced *in vivo*, and importantly, translate into fewer complications and better patient outcomes, the ultimately important measures. Ideally, the clinical studies should plan for adequate follow-up period to allow the detection of delayed side effects.

Conclusions

Microaspiration plays an important role in post-intubation respiratory complications such as pneumonia, and are associated with substantial morbidity, mortality, and costs. Avoidance of tracheal injury has been the driving force behind the wider use of endotracheal tubes with HVLP cuffs. However, such cuff designs are prone to forming longitudinal channels by internal folding of excess cuff material, and studies have indicated high levels of microaspiration with these endotracheal tubes. Several strategies to reduce and prevent microaspiration and/or attenuate its detrimental effects have been proposed including newer cuff designs and materials that provide a better seal, use of antibacterial coatings, and suctioning of subglottic secretions. These and other strategies used alone or in combination are undergoing active investigation, however, combining data from *in vitro* models with data from clinical studies, with an emphasis on clinically important outcome measures, is important.

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Panel Discussion

Postoperative Pulmonary Complications:

What are they and what are the perioperative risks?

Moderator: Ayreh Shander, MD

Panelists: Gerald W. Smetana, MD
Garry Brydges, DNP, CRNA, ACNP-BC
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How do you define postoperative pulmonary complications (PPCs)?

Smetana: PPCs contribute to morbidity or prolonged length of stay (LOS). It is important not to include minor complications that are self-limited and do not contribute to morbidity. For example, in the earlier literature, investigators often considered cough with low grade fever, or any cough with sputum production, to be PPCs. Using the more restrictive definition, the most important PPCs are pneumonia, atelectasis, respiratory failure, and exacerbation of pre-existing COPD or asthma. Most authors define respiratory failure as the need for mechanical ventilation for more than 48 hours or unplanned reintubation.

Brydges: PPCs are a result of interrupted pulmonary anatomy or physiology, defined by reduced integrity of the tracheobronchial tree and accessory structures requiring some form of intervention. Without medical intervention, PPCs can lead to prolonged hospitalization, and significant morbidity and mortality. McAlister and colleagues identify clinically significant symptomatic pulmonary complications as respiratory failure requiring mechanical ventilation, atelectasis requiring bronchoscopic evaluation, pneumonia, pulmonary embolus, pneumothorax or pleural effusion requiring percutaneous intervention.¹

Lisco: PPCs can be divided into major and minor categories. Major complications are those mentioned above by Gerald Smetana and Garry Brydges. Minor pulmonary com-

Pulmonary complications are common after surgical procedures, accounting for nearly 1 of every 4 deaths that occur in the first postoperative week.

– Kollef –

plications include abnormalities such as atelectasis, bronchospasm, laryngospasm, and the unanticipated need for supplemental oxygen beyond the immediate postoperative period.²

Restrepo: It is anticipated that almost every patient undergoing a major surgical procedure will experience some degree of physiological alterations in lung function. However, only patients with risks typically develop major PPCs as a result of decreased vital capacity, postsurgical mucus hypersecretion, or retention. Major PPCs result in prolonged LOS or the need for additional intervention and range from atelectasis to respiratory failure.³ All PPCs are considered major postoperative complications.³

Kollef: PPCs are any respiratory complication that occurs within 48 to 72 hours following a surgical procedure. Pulmonary complications are common after surgical

procedures, accounting for nearly 1 of every 4 deaths that occur in the first postoperative week.⁴ Overall, pneumonia is the third most common postoperative infection, after urinary tract infection and surgical site infection.⁵ In critically ill patients, however, the respiratory tract is the most common site of nosocomial infection accounting for 28% to 47% of all nosocomial infections.⁶ In discussing pneumonia in postsurgical patients, it is useful to distinguish between postoperative pneumonia (POP) and ventilator-associated pneumonia (VAP).

What is the frequency of PPCs and what are the implications with regard to hospital stays and costs?

Smetana: PPCs are among the most common clinically important medical complications after surgery. In studies that have determined the frequency of both pulmonary and cardiac complications after surgery, the frequency is generally similar. The absolute risk estimates depend primarily on surgical site. PPC rates range from 5-10% for lower abdominal surgery to as high as 20-25% for upper abdominal, aortic, or esophageal surgeries.⁷ When a major medical complication occurs after surgery, medical costs rise and LOS increases. Pulmonary complications cause more morbidity than cardiac or venous thromboembolic complications after surgery. For example, in a study of the consequences of medical complications derived from the NSQIP database, patients who developed a pulmonary complication had average LOS of 19 days and incurred average costs of \$63,000.⁸ This compared to \$18,000 and 4 days for cardiac complications and \$34,000 and 20 days for venous thromboembolic complications.

Brydges: According to Wynne, for every US dollar spent on surgical intervention, one US dollar is spent managing complications, accounting for approximately \$2 billion annually.⁹ Furthermore, average length of hospital stay is increased by 6 days with a 3% associated mortality. Cost is primarily associated with increased length of hospitalization requiring intensive therapeutic intervention, pharmacological intervention, diagnostics, and increased use of health disciplines.¹⁰ One quarter of postoperative deaths result from PPCs.¹¹

Lisco: The frequency of significant PPCs occurs at a rate similar to or greater than postoperative cardiac complications and

similar cardiac complications. They prolong overall hospitalization possibly by as much as 6-fold (27.9 vs. 4.5 days).¹ In a veteran cohort undergoing laparotomy, PPCs were approximately one-and-a-half times more frequent than postoperative cardiac complications (9.6% vs. 5.7%).¹² In that study, the patients experiencing a PPC also had a significantly longer hospitalization (24 vs 10 days) than their cohorts only experiencing cardiac complications.¹² Regardless of event rate, patients experiencing a PPC have a significant increase in hospital LOS and significantly decreased short-term and long-term survival when compared with patients of similar age and comorbid conditions who experience an uncomplicated hospital course.^{13,14}

Restrepo: A recent industry-sponsored analysis revealed that more than 1 million US patients experienced a PPC in 2008, and these cases were associated with 46,200 deaths, 2.9 million added days on the hospital floor, 1.9 million added ICU days and \$11.9 billion in additional costs.¹⁵ The median hospital cost associated with patients with PPC may be near \$23,000 higher than those without complications and \$14,000 higher than those with minor postoperative complications. (See Table 2.)

Can we identify patients at risk for PPCs? What are the risk factors? Which risk factors are modifiable and which are non-modifiable?

Smetana: It is helpful to consider two broad categories of PPC risk factors: patient-related and procedure-related. In contrast to risk factors for cardiac complications, procedure-related risk factors dom-

In contrast to risk factors for cardiac complications, procedure-related risk factors dominate the risk assessment for PPC.

– Smetana –

inate the risk assessment for PPC. Therefore, even healthy individuals may be at risk if important procedure-related risk factors are present.

The major patient-related risk factors are advanced age, American Society of Anesthesiologists (ASA) Physical Status >2, COPD, functional dependence, and congestive heart failure.⁷ Cigarette smoking, in the absence of COPD, is only a minor factor. Emerging risk factors based on recent trials are obstructive sleep apnea and pulmonary hypertension. Obesity and well controlled asthma are not PPC risk factors. Among procedure-related risk factors, the surgical site dominates. The risk increases as the surgical site is closer to the diaphragm. So, for example, the highest risk procedures are aortic, esophageal, and upper abdominal. Lower abdominal and orthopedic procedures carry lower risk. Other high-risk procedures include neurosurgery and head and neck surgery.

Other procedure related risk factors include surgery lasting more than 3 hours, emergency surgery, and the use of long-acting neuromuscular blockers such as pancuronium. General anesthesia, in comparison to neuraxial blockade (spinal or epidural anesthesia), is probably a risk factor, but this remains an area of controversy and active study. Unfortunately, most risk factors are nonmodifiable. Therefore, strategies to reduce tend to be generic, and not tailored to particular risk factors.

Brydges: Patient comorbidities and indicators which increase risk of PPC include COPD, sputum production, elevated scores in the Goldman Risk Indexes, Charlson Classifications, ASA score, and abnormal chest radiograph. Risk factors demonstrating statistical significance in multivariate analysis include number of procedures, age >50, BMI >30, upper or lower abdominal incision site, head and neck surgery, duration of anesthesia, gastric tube placement, health status, comorbid conditions such as COPD, history of smoking, and pulmonary functions test.^{16,17} The majority of these may be identified during clinical assessment and patient interview.¹⁶ The only diagnostic test able to identify a statistically significant risk factor for PPC was an abnormal chest radiograph.¹⁶

Lisco: Identification of the patient who may be at risk for PPCs begins preoperatively with history and physical examination. Intraoperative risk factors must also be included as every patient's risk must be assessed in context. Additionally, postoperative factors such as the quality, quantity, and duration of postoperative pain, anticipated analgesic requirements and analgesic techniques, and length of time at bed rest all need to be considered. It is simplest to divide risk factors first into patient-specific and surgery-specific and then to consider which factors are modifiable and which are not modifiable.^{2,3}

Restrepo: A good evaluation of preoperative pulmonary risks is the main priority in determining the potential for PPC as their presence may predict long-term mortality after surgery.¹⁸ While patient-related factors are predictive of postoperative cardiac complications, procedure-related factors appear to be critical to the incidence and severity of PPC. The surgical site is considered the

Table 2. Median total hospital costs and LOS for patients with and without Postoperative Complications (PC)

	PC	Without PC	p-value
Complication	Median total hospital costs (dollars)		
Respiratory	62,704	5,015	<.001
Thromboembolic	33,589	5,233	<.001
Cardiovascular	18,496	5,236	.001
Infectious	13,083	5,044	<.001
	Median LOS (days)		
Thromboembolic	20	5	<.001
Respiratory	19	5	<.001
Infectious	9	5	<.001
Cardiovascular	4	5	.17

PC: Postoperative complications. Adapted from: Warner DO. *Mayo Clin Proc* 2005; 80:252.

most important predictor of risk for post-operative pulmonary complications.³ My colleagues have categorized other risk factors well.

Kollef: Multivariate analysis identified several risk factors that led to an increased risk of post-operative pneumonia (POP), including type of surgery, age, functional status, recent weight loss, COPD, type of anesthesia, impaired sensorium, history of a cerebrovascular accident, blood urea nitrogen (BUN) level, blood transfusion, emergency surgical intervention, long-term steroid use, recent smoking, and significant recent alcohol use. In contrast to POP, VAP can occur in any patient undergoing mechanical ventilation, however it is substantially more common in surgical ICU patients than in medical ICU patients, reaching its highest prevalence in trauma and burn ICUs.¹⁹ As an example of how VAP disproportionately affects surgical patients, ventilator usage in surgical ICUs is lower than that in respiratory ICUs (0.39 versus 0.46 ventilator days/patient days), but VAP develops nearly ten times as often in the former as in the latter (4.9 versus 0.5 cases per 1,000 ventilator days). Patients in surgical ICUs with burns are especially susceptible to developing VAP, especially the 10-20% of burn patients who are victims of inhalation injury.²⁰

The single greatest risk factor for VAP is related to the duration of mechanical ventilation. The risk peaks at day 5 on the ventilator, plateaus after day 15, and then declines significantly, with the result that VAP is uncommon in patients on long-term mechanical ventilation.²¹

In terms of modifiable risk factors, can we identify strategies to modulate or prevent PPC?

Smetana: Cigarette cessation reduces PPC risk for smokers; the controversy has been the optimal duration of cessation. Earlier reports that recent quitters have a higher PPC risk have not been born out by more recent trials. While any duration is likely beneficial, a duration of at least 8 weeks is optimal when there is ample time to prepare for surgery. For patients with COPD or asthma, treatment to optimally reduce airflow obstruction and return the patient to his or her best possible state will reduce PPC risk. The goal is for a peak flow of >80% predicted or of personal best (when known).

Use of neuroaxial block as the primary anesthetic avoids airway instrumentation and use of general anesthesia.

– Lisco –

Patients should be free of wheezing. The treatment of such patients is identical to the treatment of similar patients who are not preparing for surgery; corticosteroids can be used safely if medically indicated.

The remaining intervention strategies can be applied to any high-risk patient and are not dependent on the particular risk factor profile of the patients. Lung expansion maneuvers are the best studied intervention. The results from the literature have not been consistent; some trials have failed to show a benefit. However the predominance of the literature indicates that these are among the most important strategies. For example, in the 2006 American College of Physicians position statement on PPC prevention, lung expansion maneuvers were the only intervention to earn a grade “A” recommendation.²² These include postoperative chest physical therapy, deep breathing exercises, incentive spirometry, and in selected patients, continuous positive airway pressure (CPAP). All of these interventions work best when the patient is instructed in their use before surgery. It is best to reserve postoperative CPAP for patients who cannot cooperate with effort dependent strategies. A particular strategy, inspiratory muscle training, has been shown to be beneficial when begun before surgery in patients undergoing coronary bypass surgery.²³

Postoperative pain may prevent deep breaths, cause splinting, reduce postoperative lung volumes, and increase PPC risk. Adequate pain control reduces PPC risk. In particular, postoperative epidural analgesia reduces risk in high-risk patients.²⁴ Laparoscopic surgery may confer lower risk than

open abdominal surgery, but the studies on this question have yielded mixed results.

Lisco: Modification of perioperative risk begins by employing best evidence strategies for prevention of postoperative complications in a coordinated and timely fashion. This is often a difficult task and one that evidence suggests is unlikely to be performed. Assuming that the task or need to reduce PPC is appropriately identified and resourced at an organizational level, successful performance will depend upon the coordinated care of the entire perioperative team. In this paradigm, if one element of the clinician team fails to perform adequately, it is unlikely a significant effect will be seen.

Before elective surgery, high-risk patients must have pulmonary function assessed and optimized. New underlying lung infections should be identified and treated and any new lung findings or exacerbation of baseline symptoms investigated. Worsening symptoms may justify delay or cancellation of elective procedures. Increased pulmonary secretions or a change in secretions may merit a course of antibiotics or a short course of steroids. If symptoms are progressive and an infectious etiology is ruled out, a short course of oral corticosteroids may be beneficial. If it is unclear whether the patient is on optimal medications, spirometry may provide helpful information.²⁵ Pulmonary rehabilitation may benefit selected patients by improving functional capacity, but it is unclear whether PPC rates subsequently decrease. Smoking cessation should be strongly encouraged. Although the optimal duration of abstinence before elective surgery is not clear, 2 months likely provides maximal benefit while minimizing risk of increased secretions.^{25,26,28}

Pulmonary patients who are calm and pain free may not require standard premedication with benzodiazepines or narcotics. Patients with preexisting pulmonary impairment display increased sensitivity to the respiratory depressant effects of benzodiazepines and narcotics.²⁷ Administration of even small doses of sedatives combined with narcotic may result in apnea. Anxious patients or patients complaining of pain preoperatively require careful titration of benzodiazepines and short-acting narcotics, respectively.

Several intraoperative techniques have been

evaluated to determine efficacy in decreasing the incidence of PPC. Use of intraoperative neuroaxial anesthesia would seem to offer benefit in the management of patients with pulmonary disease undergoing non-thoracic surgery. Use of neuroaxial block as the primary anesthetic avoids airway instrumentation and use of general anesthesia. However, patients with severe pulmonary disease may not tolerate loss of accessory muscles of respiration or the supine position.²⁸ Evidence is mixed regarding whether intraoperative neuroaxial anesthesia decreases PPC. One large and somewhat heterogeneous meta-analysis reviewed 141 trials of neuroaxial blockade with or without general anesthesia versus general anesthesia alone and found small but statistically decreased rates of pneumonia and respiratory depression in the group who received neuroaxial blockade.²⁹ A systematic review of 15 randomized or quasi-randomized trials found no significant difference in postoperative pneumonia rates between patients who received general anesthesia and those who received intraoperative neuroaxial blockade for hip surgery.³⁰ The literature does not clearly show improved outcomes, intraoperative neuroaxial block may offer some benefit in patients with severe pulmonary disease or in those undergoing high-risk surgeries.³¹

Restrepo: A mere recognition of the risk factors does not impact the incidence of PPC unless some strategies are designed to modify or eliminate some of the risk factors prior, during, and after the surgical procedure.

Preoperative strategies: It is suggested that patients who stop smoking at least for a period of at least eight weeks before surgery may significantly reduce the risk of PPC.^{32,33} Warner et al reported that patients who had stopped smoking for more than six months prior to surgery had rates of PPC similar to those who had never smoked.³⁴ More recently, Lindström et al found a reduction of PPC in patients undergoing low-risk procedures after perioperative smoking intervention programs were in place.³⁵ The improvement on the baseline level of pulmonary function in patients with COPD aggressively treated before surgery with combinations of bronchodilators, antibiotics, and systemic corticosteroids has been associated with a significant reduction of PPC.³⁶ On the other hand, while poorly

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– Restrepo –

controlled asthma is a definite risk factor for the development of PPC,^{37,38} well controlled asthma appears to confer little additional risk.³⁹ Although a step-up therapy with a brief course of systemic corticosteroids in asthmatic patients with important flow limitations is advised before surgery, good evidence to support this strategy is lacking. If endotracheal intubation is required for the procedure, the use of short-acting beta agonists is recommended in the perioperative period.

Intraoperative strategies: If the surgical procedure requires the use of muscle relaxants, Intermediate-active neuromuscular blocking agents (NMBA) such as atracurium and vecuronium should be preferred over long-acting NMBA such as pancuronium if possible as they may considerably reduce the risk of PPC.^{40,41} Regarding the duration of the procedure, Olsén and colleagues found that abdominal surgeries lasting more than

two hours were associated with a fivefold increase in the incidence of PPC.⁴² Whenever possible, alternatives to open surgical procedures should be considered. Laparoscopic rather than open bariatric surgery has been found to be effective strategies to reduce PPC, since they are associated with less postoperative pain.^{4,43} Weller and Rosati recently found that laparoscopic surgery was associated with a 50% reduction in the rate of PPC.⁴⁴ Although patients who receive intraoperative positive end-expiratory pressure (PEEP) have a lower incidence of postoperative atelectasis, there is currently insufficient evidence to make conclusions about whether intraoperative PEEP alters the risk of postoperative mortality and respiratory complications among surgical patients.⁴⁵

Postoperative strategies: In the postoperative stage, lung expansion techniques, postoperative thoracic epidural analgesia to obtain adequate pain control, and selective rather than routine use of nasogastric tubes for decompression may contribute to a lower incidence of PPC. When CPAP is administered to selected patients unable to perform IS, it needs to be remembered that continuous (at least 6 hours) rather than intermittent (10 minutes every four to six hours)⁴⁶ CPAP is associated with improvement of oxygenation and reduction of PPC such as pneumonia, atelectasis, and the rate of reintubation.⁴⁷⁻⁵⁰ Early ambulation and ability to take deep breaths are strongly associated with optimal postoperative pain control, particularly after thoracic and upper abdominal surgery. While the use of epidural analgesia and regional anesthesia via nerve blocks may be preferred over parenteral opioids, results have been mixed with regard to reduction in PPC.⁵¹⁻⁵⁴ Routine decompression of the stomach after abdominal surgery should be avoided since it has been shown to significantly increase the incidence of PPC, especially pneumonia and atelectasis.^{55,56} It should be reserved for those patients with symptomatic abdominal distension or nausea.

While some of the strategies may be directed to the specific duties of physicians, nurses, and respiratory therapists, only a multidisciplinary approach may significantly reduce the incidence of PPC. In a similar fashion to the prevention of VAP, efforts should be made to the creation of a protocol that effectively addresses PPC from the quality im-

provement perspective. Several institutions have effectively implemented such efforts and dramatically reduced the incidence of PPC.⁵⁷⁻⁶⁰

What can be done to prevent microaspiration?

Smetana: Microaspiration is a particular concern for patients undergoing abdominal surgery. It is customary practice for many surgeons to routinely place postoperative nasogastric tubes for patients after abdominal surgery. The presence of the tube can theoretically cause microaspiration that would then be the basis for clinically overt and morbid PPC. A robust body of evidence has now shown the selective use of NG tubes after abdominal surgery, rather than routine use, reduces PPC risk.⁵⁶ Selective means restricting their use to symptoms such as nausea or abdominal distension.

Another potential strategy is to use short-acting neuromuscular blockers during the intraoperative period. Long-acting neuromuscular blockers cause more residual neuromuscular blockade after surgery than short-acting ones. These patients are at risk for hypoventilation in the postoperative period and carry risk for microaspiration. Clinically significant PPC may follow. Short-acting neuromuscular blockers, such as vecuronium, lower this risk.

Brydges: Prevention of microaspiration is multidisciplinary and multimodal. Such preventive techniques include positioning, supraglottic and subglottic suctioning, enhanced endotracheal cuff designs (cuff geometry and material), minimizing pharmacological agents interrupting tracheobronchial mucociliary function (i.e. inhaled anesthetic agents), minimized gastric tube insertions (increases the incidence of PPC), gastric alkalization, management of comorbidities (insulin-dependent diabetes, COPD), optimized nutritional status (avoid hypoalbuminemia), immunological status (minimize steroid use), deep vein prophylaxis, appropriate mechanical ventilation parameters (avoid high peak airway pressures and hyperinflation), fluid volume status (maintain euolemia), minimize long-acting neuromuscular blockade, reduce stress response through regional anesthesia, pain management, and duration of anesthesia (<2 hours).⁶¹⁻⁶³ Furthermore, a multidisciplinary approach to prevention, surveillance, and management of micro-

aspiration must be maintained through the entire continuum of care. Such strategies are achieved through rigorous evidence-based development of recommendations and/or guidelines.

Lisco: In the ICU, the aspiration of upper airway secretions in the presence of colonization of the upper respiratory tract is a prerequisite for the development of VAP. Multiple strategies to reduce the incidence of this occurrence are routinely employed with success in the critical care environment some more proven than others. Maintaining the patient in a semi erect position as well as oropharyngeal decolonization with topical antibiotics or chlorhexidine has been proven effective and is both low cost and low-risk.⁶⁴⁻⁶⁷ Subglottic suctioning has been shown effective in reducing VAP in the ICU but not in changing mortality, LOS, or duration of mechanical ventilation.⁶⁷ Even newer technologies such as tapered cuff designs and cuffs made from ultrathin and less redundant materials designed to minimize the creation of microchannels which may facilitate microaspiration are currently available. There is minimal randomized outcome data to support efficacy in prevention of VAP in the ICU or the perioperative period and there is no human data evaluating possible long-term adverse effects on tracheal injury. More human studies will need to be done before this technology can be recommended.

Restrepo: Inadequate sealing endotracheal tubes are greatly responsible for the rate of microaspiration that happens in the perioperative period. New designs of cuffs have been able to minimize microaspiration and may dramatically decrease the incidence of postoperative pneumonia.⁶² However, more clinical trials and cost analyses are required to make this the standard of care.

Kollef: Maneuvers to reduce aspiration of orogastric secretions have the potential to decrease the incidence of POP and VAP. Because the supine position is associated with an increased risk of aspiration (especially if the patient is receiving tube feedings via a nasogastric tube), placing the patient in a semirecumbent position—by raising the head of the bed to an angle of 30° to 45° or greater—is recommended as a means of possibly preventing VAP (if not medically contraindicated).^{68,69} Secretions that pool above an inflated endotracheal cuff may also be an important source of aspirated

material that results in POP or VAP. Specially designed endotracheal tubes are available that have a separate opening above the cuff of the tube to allow either continuous suctioning or intermittent irrigation and drainage of secretions that accumulate in the subglottic space.

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For Nurses and RT's. You may take this test online at www.saxetesting.com

- PPCs lead to prolonged hospitalization and significant morbidity and mortality.
 - True
 - False
- PPCs are defined as those complications that typically happen after how many hours following a surgical procedure?
 - 24-48 hours
 - 48-72 hours
 - 78-96 hours
 - >96 hours
- What is the estimated incidence of PPC following upper abdominal surgical procedures?
 - 5-10%
 - 10-15%
 - 20-25%
 - 30-35%
- Respiratory conditions are associated with the highest median total hospital cost for patients with postoperative complications.
 - True
 - False
- Which of the following are considered the most important risk factors for PPCs?
 - Patient-related
 - Procedure-related
- Which of the following is not considered a risk factor for PPC?
 - Obesity
 - Congestive heart failure
 - COPD
 - Functional dependence
- Which of the following procedure-related factors is considered the most important?
 - Duration of the surgical procedure
 - Type of anesthesia
 - Surgical site
 - Use of neuromuscular blockers
- For at least how long should patients remain "smoke-free" prior to the surgical procedure in order to reduce the incidence of PPCs?
 - 2 weeks
 - 4 weeks
 - 8 weeks
 - 16 weeks
- Which of the following postoperative strategies IS NOT associated with a lower incidence of PPCs?
 - Lung expansion techniques
 - Selective use of nasogastric tube for decompression
 - Thoracic epidural analgesia to obtain adequate pain control
 - Antibiotics
- The use of strategies to prevent VAP is associated with a reduction of the microaspiration associated with the incidence of PPCs.
 - True
 - False

Participant's Evaluation

This program has been approved for 2.0 contact hours of continuing education (CRCE) by the American Association for Respiratory Care (AARC). AARC is accredited as an approver of continuing education in respiratory care.

Saxe Communications is approved as a provider by the Vermont State Nurses Association Inc. (VSNA) which is accredited as an approver by the American Nurses Credentialing Center's Commission on Accreditation. *

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1. What is the highest degree you have earned? Circle one. 1. Diploma 2. Associate 3. Bachelor 4. Masters 5. Doctorate

2. Indicate to what degree the program met the objectives:

Strongly Agree	Strongly Disagree
1 2 3	4 5 6

Objectives

Upon completion of the course, the reader was able to:

- To describe the significance of microaspiration and the reason it happens

Strongly Agree	Strongly Disagree
1 2 3	4 5 6
- To list various strategies to reduce or prevent microaspiration through the cuffs

Strongly Agree	Strongly Disagree
1 2 3	4 5 6
- To explain the limitations of *in vitro* models and importance of clinical studies to determine the safety and efficacy of new endotracheal tubes

Strongly Agree	Strongly Disagree
1 2 3	4 5 6
- Please indicate your agreement with the following statement. "The content of this course was presented without bias of any product or drug."

Strongly Agree	Strongly Disagree
1 2 3	4 5 6

Answers

1	A B C D <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	9	A B C D <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>
2	A B C D <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	10	A B C D <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>
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