Review

Clinical review: Airway hygiene in the intensive care unit

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Abstract

Maintenance of airway secretion clearance, or airway hygiene, is important for the preservation of airway patency and the prevention of respiratory tract infection. Impaired airway clearance often prompts admission to the intensive care unit (ICU) and can be a cause and/or contributor to acute respiratory failure. Physical methods to augment airway clearance are often used in the ICU but few are substantiated by clinical data. This review focuses on the impact of oral hygiene, tracheal suctioning, bronchoscopy, mucus-controlling agents, and kinetic therapy on the incidence of hospital-acquired respiratory infections, length of stay in the hospital and the ICU, and mortality in critically ill patients. Available data are distilled into recommendations for the maintenance of airway hygiene in ICU patients.

Introduction

Clearance of airway secretions, or airway hygiene, is a normal physiological process needed for the preservation of airway patency and the prevention of respiratory tract infection. Impaired clearance of airway secretions can result in atelectasis and pneumonia, and may contribute to respiratory failure prompting admission to an intensive care unit (ICU).

Physical methods to augment the clearance of secretions are often used in the ICU. This review focuses on mechanical methods and pharmacological agents commonly used to maintain airway hygiene in the ICU, and their effect on clinical outcomes of critically ill patients. The impact of oral hygiene, tracheal suctioning, bronchoscopy, mucus-controlling agents, and kinetic therapy on the incidence of nosocomial respiratory infections, length of stay in the hospital and the ICU, and mortality will be discussed. Where possible, we have distilled available data into recommendations for airway hygiene in ICU patients.

Methods

Literature for this article was identified by searching the PubMed database (1966 to present). English-language articles of relevance were selected and reviewed. Additional resources were obtained through the bibliographies of reviewed articles. The following search terms were used: airway hygiene, oral hygiene, mucociliary clearance, tracheal suctioning, bronchoscopy, mucolytics, chest physiotherapy, kinetic therapy, continuous lateral rotational therapy, selective digestive decontamination, nosocomial pneumonia, hospital-acquired pneumonia, ventilator-associated pneumonia, and pneumonia.

A summary of recommendations and associated strength of supporting evidence for strategies used in the reduction of nosocomial pneumonia is shown in Table 1. The following grading system described by Kollef [1] was used to assess strength of evidence: A, supported by at least two randomized, controlled investigations; B, supported by at least one randomized, controlled investigation; C, supported by nonrandomized, concurrent-cohort investigations, historical-cohort investigations, or case series; U, undetermined or not yet studied in clinical investigations.

Oral/pharyngeal hygiene

A general tenet of hospital-acquired pneumonia and ventilator-associated pneumonia (VAP) is that infections of the lower respiratory tract are preceded by colonization or infection of the upper airway. Thus, most hospital-acquired pneumonias stem from micro- or macro-aspiration of infected secretions from the upper airway. Methods that reduce oropharyngeal colonization have been postulated to reduce infections of the lower respiratory tract in the critically ill. Surprisingly, nasopharyngeal and oropharyngeal hygiene often receives little attention from intensivists.

Many risk factors have been linked to airway colonization, including severity of illness, length of hospitalization, prior or concomitant antibiotic use, malnutrition, endotracheal intubation, azotemia, underlying pulmonary disease, inadequate

CLRT = continuous lateral rotation therapy; CPAP = continuous positive airway pressure; ICU = intensive care unit; IS = incentive spirometry; NAC = *N*-acetylcysteine; SDD = selective digestive decontamination; VAP = ventilator-associated pneumonia.

Table 1

Recommendations for airway hygiene in critically ill patients for reduction in health-care-associated pneumonia

Strategies	Recommended for clinical use	Grade	Reduction in HCAP	Reduction in mortality	Refs
Effective strategies					
Chlorhexidine gluconate oral rinse	Yes	A	Yes	No	11–14
Endotracheal suctioning on 'as needed' basis (compared with routine suctioning)	Yes	A	No increased incidence of HCAP	No	45,57,58
Kinetic therapy	Yes[a]	A	Inconclusive	No	105–111
Ineffective strategies					
Selective digestive decontamination	No	A	Inconclusive	No	15–33
Oral topical iseganan	No	B	No	No	35
Aerosolized mucus-controlling agents	No	U	N/A	N/A	85–88
Endotracheal instillation of saline	No	C	N/A	N/A	52,53
Chest physiotherapy	No	A	Inconclusive	No	114, 117–125
Strategies of equivocal or undetermined effectiveness					
Continuous subglottic suctioning	Yes[b]	A	Yes	No	70–75
Bronchoscopy	Yes[c]	B	N/A	N/A	114
Closed (in-line) endotracheal suctioning (compared with open suctioning)	Yes[d]	A	Inconclusive	No	59–68

The grading scheme used is as follows: A, supported by at least two randomized, controlled investigations; B, supported by at least one randomized, controlled investigation; C, supported by nonrandomized, concurrent-cohort investigations, historical-cohort investigations, or case series; U, undetermined or not yet studied in clinical investigations. HCAP, healthcare-associated pneumonia; N/A, not applicable. [a]The increased cost of kinetic beds is offset by the decreased length of stay; [b]this strategy is recommended for patients expected to require more than 72 hours of mechanical ventilation; [c]this strategy is recommended for patients with acute atelectasis involving more than a single lung segment in the absence of air bronchograms who remain symptomatic after 24 hours of chest physiotherapy; [d]this strategy is recommended for patients requiring mechanical ventilation for more than four days.

oral hygiene, substandard infection control practises during bathing, tracheal suctioning, enteral feeding, and endotracheal tube manipulation. Furthermore, critical illness is associated with alterations in oral mucosal-cell-surface fibronectin and carbohydrate expression patterns, disruption of the mucosa by endotracheal tubes and suction catheters, and increased secretion of mucus, all of which provide binding sites for pathogenic bacteria [2-5]. Gram-negative bacteria and *Staphylococcus aureus* replace the normal upper-airway flora of patients hospitalized for more than 5 days [6]. Not surprisingly, many patients (50%) have pathogenic bacteria in their oropharynx on admission to the ICU [7]. The periodontal areas, oropharynx, sinuses, stomach, and trachea are colonized by the end of the first week in most mechanically ventilated patients [7-9]. Tracheal and oropharyngeal colonization is associated with VAP, whereas gastric colonization in the setting of acid suppression therapy may not be [7,8,10].

Oral antiseptic rinses such as chlorhexidine gluconate reduce the rate of nosocomial pneumonia in critically ill patients [11-13]. The twice-daily use of chlorhexidine gluconate 0.12% oral rinse reduced respiratory tract infections by 69% and antibiotic use by 43% in cardiac surgical patients postoperatively without affecting antibiotic resistance patterns [11]. The impact was greatest in patients intubated for more than 24 hours and who had the highest degree of bacterial colonization [13]. The cost of nursing care did not significantly increase with the use of chlorhexidine oral rinse, and the liquid form was easier and quicker to apply than an antibiotic paste [11,13]. Despite the reduction in bacterial colonization and/or nosocomial pneumonia, the use of oral antiseptic rinses has not been shown to affect the duration of mechanical ventilation or survival, although it may modestly reduce the length of stay in the hospital [12,14].

Selective decontamination of the oropharynx, and gastric and subglottic area, or selective digestive tract decontamination (SDD) with several different regimens have been proposed as a method for decreasing VAP. These SDD regimens have included one or more of the following antibiotics: polymixin, tobramycin/gentamycin, vancomycin, and amphotericin B suspension. More than 50 randomized controlled trials and 12 meta-analyses evaluating the SDD prophylaxis have been

published [15-29]. These trials were conducted in unselected medical and surgical patients who required 2 days or more of mechanical ventilation and in selected patients including liver transplant, cardiac surgical, and burn patients. Most randomized control trials found a beneficial effect in reduction of bacterial colonization and/or VAP; however, effects on length of stay in the ICU and mortality are inconsistent. Although some analyses suggest a reduction in mortality in selected patients [24,27], others have demonstrated only a modest effect with the use of combined (topical and systemic) SDD therapy [18,19,23]. Survival advantage seems to be limited to surgical ICU patients treated with a combination of parenteral and topical prophylactic antibiotics [18,24,30]. A modified SDD regimen that includes oral vancomycin reduces the rate at which isolates of methicillin-resistant *Staphylococcus aureus* are found [31,32]. The impact of this regimen on the incidence of nosocomial pneumonia is less clear [31,32]. Furthermore, a transient increase in isolation of vancomycin-resistant *Enterococcus* has been observed with this regimen [32]. Failure of SDD strategies to reduce morbidity and mortality consistently in critically ill patients may be related to suboptimal study design, the emergence of antibiotic-resistant bacteria, and an alteration in hosts' normal bacteriologic flora [33]. Additional toxicity and increased healthcare costs related to SDD [17,27,34] have further dampened the enthusiasm for this preventive strategy. On the basis of available evidence, SDD with topical antibiotics should not be routinely used in the ICU. If combined parenteral and topical SDD is used in surgical/trauma patients, clinicians should be vigilant in monitoring for the emergence of new multidrug-resistant organisms.

A recent randomized controlled trial of oral topical iseganan, an antimicrobial peptide with a broad *in vitro* activity against aerobic and anaerobic Gram-positive and Gram-negative bacteria and yeasts, was stopped early because of a higher, although not statistically significant, rate of VAP and death among mechanically ventilated ICU patients in the iseganan arm [35]. The widespread use of biocides such as chlorhexidine in hospital, domiciliary, industrial, and other settings raises concern for the development of antibiotic-resistant infection. Fortunately, no clinically significant alteration of antibiotic resistance patterns has been noted in epidemiologic studies [36,37]. Therefore, chlorhexidine gluconate oral rinse, an inexpensive and easily applied agent, should be a routine aspect of care of the critically ill patient.

Tracheal suctioning

Airway hygiene is impaired in critically ill patients as a result of depressed cough reflex and ineffective mucociliary clearance from sedation, high inspired oxygen concentrations, elevated endotracheal tube cuff pressure, and tracheal mucosal inflammation and damage [38-40]. Accordingly, care of intubated patients includes tracheal suctioning to facilitate the removal of airway secretions. Routine suctioning via endotracheal tubes is often performed on the basis of the assumption that it maintains airway patency and prevents pulmonary infection. However, tracheal suctioning induces mucosal injury, exposing the basement membrane and thereby facilitating bacterial adhesion *in vitro* [41] and in low-birthweight babies [42]. Suctioning has also been associated with many deleterious effects including decreased arterial oxygen tension (12 to 20 mmHg) [43-45], which may be more pronounced in cardiac surgical patients [43] and in patients with hypoxemic respiratory failure requiring high levels of positive end-expiratory pressure [46], in patients with cardiac arrhythmias (7 to 81%) [45,47], and in cardiac arrest in patients with acute spinal cord injury [48]. These detrimental effects of tracheal suctioning, however, may be mimimized through the use of manual hyperinflation, preoxygenation, sedation, and optimal suctioning technique [49-51]. Normal saline is frequently instilled into the trachea before endotracheal suctioning under the assumption that it may help dislodge secretions and facilitate airway clearance. However, Ackerman and colleagues have shown that intratracheal instillation of 5 ml of normal saline adversely effects oxygen hemoglobin saturation and has no effect on the clearance of secretions [52,53]. In addition, a 5 ml saline instillation dislodges fivefold more viable bacterial colonies from the endotracheal tube than does the insertion of a tracheal suction catheter alone [54] and is associated with prolonged deoxygenation [55,56]. Limiting the frequency and duration of tracheal suctioning and limiting the use of saline instillation may prevent its adverse effects without affecting the duration of mechanical ventilation, length of stay in the ICU, mortality in the ICU, and incidence of pulmonary infection [45,57,58]. Thus, tracheal suctioning of intubated patients should be performed on an as-needed basis that is defined by the quantity of secretions obtained, not at prescribed, set intervals.

Closed (in-line), repeated-use endotracheal suction devices have become commonplace in ICUs. These devices eliminate the need for disconnection from mechanical ventilation and do not require single-hand sterile technique of open suction methods. Available data on the effect of these catheters on tracheal colonization are conflicting [59,60]. A single study has reported that in-line suction systems are associated with a reduction in the incidence of VAP [61], but most studies and a recent meta-analysis find no beneficial effect on nosocomial pneumonia [59,62-64]. Their cost-effectiveness, however, is questionable, with some studies demonstrating cost savings [65,66] and others suggesting higher costs associated with closed systems [62,63,67,68]. Despite the failure of closed endotracheal suctioning systems to reduce VAP or mortality, these devices may be preferable because of their efficiency and smaller number of suction-induced complications [65] and cost-effectiveness among patients requiring more than 4 days of mechanical ventilation [66]. Routine changes of these devices are not required [69].

A more recent development is the use of endotracheal tubes with a dorsal suction channel that opens immediately before

the inflatable cuff in the subglottic area. Suction can be applied via this port continuously or intermittently for purposes of removing secretions from the subglottic space. A recent meta-analysis reported that these endotracheal tubes reduce early-onset VAP in patients expected to require more than 72 hours of mechanical ventilation. Early-onset VAP was defined as pneumonia occurring 5 to 7 days after intubation. Duration of mechanical ventilation, the length of ICU stay, and mortality were not different when intention-to-treat data were summarized [70]. However, subglottic suctioning does not alter oropharyngeal or tracheal bacterial loads [71], nor does it significantly reduce the duration of mechanical ventilation, length of ICU stay, or mortality [70,72-75]. Furthermore, continuous aspiration of subglottic secretions can cause severe tracheal mucosal damage [76]. Endotracheal tubes with a dorsal suction channel are significantly more expensive than standard endotracheal tubes, increase nursing workload, and therefore have the potential to increase ICU costs [77]. A case cost analysis model suggests a potential cost-saving associated with the use of subglottic suctioning primarily if these tubes decrease the length of the ICU stay [77], which has not been observed [72-75]. The use of endotracheal tubes that allow subglottic suctioning outside populations with a high incidence of early-onset VAP cannot be recommended at present.

Mucus-controlling agents

Distilled water, normal saline, hypertonic and hypotonic saline have long been used to 'loosen' thick airway secretions and promote airway hygiene. However, formed mucus does not readily incorporate topically applied water [78]. Increased sputum production and clearance attributed to bland aerosols, especially hypertonic saline, may be due to the irritant nature of the aerosol, which may cause bronchoconstriction rather than mucolysis [79-81].

N-Acetylcysteine (NAC) is a mucolytic agent that breaks disulfide bonds of mucus, reducing its viscosity and elasticity, and has anti-inflammatory properties in experimental models [79,82]. As a result of its mucolytic properties, many practioners advocate its use in the ICU for assistance in the clearance of airway secretions. Although there are limited data on the use of NAC in ICU patients, it is important for clinicians to recognize the potential deleterious effects of this practice. *In vitro*, NAC may antagonize aminoglycoside and β-lactam antibiotics [83,84]. Additionally, NAC at concentrations less than 10% inhibits the growth of *Pseudomonas* strains *in vitro* [84], potentially causing false-negative sputum cultures. Delivery via aerosol thins airway secretions but does not change pulmonary function or sputum volume in patients with stable chronic bronchitis [85,86]. Furthermore, aerosolized NAC can cause bronchoconstriction and inhibit ciliary function [87,88]. Concomitant administration of a bronchodilator partly ameliorates NAC-induced bronchospasm [89]. Gas exchange may worsen acutely after NAC administration, possibly because liquefied secretions gravitate into smaller airways [90]. Tracheal instillation of NAC through an endotracheal tube or bronchoscope may induce the rapid accumulation of liquefied secretions that must be suctioned immediately to prevent asphyxia [91]. Direct tracheal instillation of NAC is more effective than aerosol inhalation in the treatment of atelectasis caused by mucoid impaction [92,93]; however, it remains unclear whether undirected instillation of NAC results in delivery to areas of mucus accumulation. Thus, despite its widespread use, few data are available to support NAC as a mucolytic agent. Dornase alfa (recombinant human DNase) is used as a mucolytic in cystic fibrosis and other bronchiectatic conditions [94,95]. Case reports of its use in status asthmaticus [96], acute respiratory distress syndrome [97], and mechanically ventilated pediatric patients [94,98] have been published but no prospective efficacy studies are available to support its use in adult ICU patients for airway hygiene.

β_2-Adrenergic agonists increase ciliary beat frequency in experimental models, raising the possibility that they may be useful for airway hygiene [99]. Salbutamol increases large-airway mucociliary clearance, both in stable patients with chronic obstructive pulmonary disease and in healthy subjects [100], although this may not be true for smaller airways [101]. There are no data from ICU patients. Thus, despite the simplicity and attractiveness of this approach, there are no data to support the use of inhaled β_2-adrenergic agonists as adjuncts for airway hygiene in ICU patients.

Kinetic therapy

Immobility impairs cough and mucociliary clearance in patients receiving mechanical ventilation, thereby promoting retention of secretions [102,103]. Kinetic therapy with beds that intermittently or continuously rotate patients along their longitudinal axis by 40° or more have gained acceptance in the care of the critically ill patients [104].

A modest body of data regarding the effect of kinetic beds for continuous lateral rotation therapy (CLRT) to facilitate airway hygiene is available. Some of these studies found that CLRT reduced the incidence of pneumonia and decreased the length of stay in the ICU in heterogeneous groups of critically ill patients receiving mechanical ventilation [105-109]. Conversely, other studies detected no meaningful effect on measures of care in the ICU [110,111]. Differences in diagnostic criteria for nosocomial pneumonia and variable use of broad-spectrum antibiotics in treatment and control groups may be responsible for the diametrically opposed results of these studies. Importantly, three of the five studies demonstrating benefit from CLRT were supported by kinetic bed manufacturers [105-107]. Data from these studies support the use of CLRT in critically ill patients. The increased cost of CLRT is offset by reduced nosocomial pneumonia and antibiotic use and a decreased length of stay in the hospital and the ICU [106,108,109,112].

Chest physiotherapy

Chest physiotherapy, including gravity-assisted drainage, chest wall percussion, chest wall vibrations, and manual lung hyperinflation, aids in the re-expansion of atelectatic lung [113-115] and increases peak expiratory flow rates [116]. Chest physiotherapy treatment is as effective as early bronchoscopy in patients with acute atelectasis [114]. A single study examined the role of chest physiotherapy in patients at high risk for post-operative respiratory failure. Hall and colleagues randomized 301 spontaneously breathing patients at high risk for respiratory complications to receive incentive spirometry (IS) or IS plus chest physiotherapy after abdominal surgery [117]. The incidence of respiratory complications was not significantly different between two study groups. The inclusion of physiotherapy, however, required 30 minutes of staff time per patient. A recent meta-analysis examined the role of various chest physiotherapy techniques including IS, deep breathing exercise, chest physical therapy (cough, postural drainage, percussion/vibration, suction, and ambulation), intermittent positive-pressure breathing, and continuous positive airway pressure (CPAP) [118]. In patients who underwent abdominal surgery, any type of lung expansion technique was better than no intervention in the prevention of pulmonary complications. Although no particular intervention seemed superior, IS may require the least staff time, while CPAP may be particularly beneficial in patients who have limited ability to participate with other physiotherapy techniques [118]. In contrast, others reported poor adherence to an independent use of IS among patients recovering from surgery and superiority of encouragement by hospital personnel to the use of IS [119,120]. Current evidence does not support the use of IS in the prevention of complications after cardiac or abdominal surgery [121,122]. When nosocomial pneumonia is used as a specific endpoint, only one study showed the beneficial effect of physiotherapy [123]. Routine chest physiotherapy therefore cannot be recommended for prophylaxis against respiratory complications in spontaneously breathing patients.

There are mixed data about chest physiotherapy in mechanically ventilated patients. A single study of patients receiving mechanical ventilation for 48 hours or more showed a reduced incidence of VAP [124], whereas a second trial in trauma patients was unable to detect an effect on nosocomial pneumonia rates [125]. Furthermore, chest physiotherapy may cause cardiac arrhythmias, bronchospasm, and transient hypoxemia, and may prolong the duration of mechanical ventilation [126-128]. These complications, as well as increased staff use and cost, combined with a paucity of data regarding beneficial effects on the prevention of nosocomial pneumonia, should limit the use of chest physiotherapy to the ICU patients with acute atelectasis, exacerbations of bronchiectasis, and conditions that are characterized by excessive sputum production and impaired cough.

Limited data are available about flutter valves, cornet type devices, or intrapulmonary percussive ventilation in ICU patients. Cough assist devices, which generate a strong expiratory flow through the application of positive pressure followed by the application of negative pressure, have been shown to aid in the removal of secretions [129,130] and may avoid intubation in patients with neuromuscular disease [131]. However, the long-term benefit of these devices in other ICU populations is unclear. A small study of pneumatic high-frequency chest compression in long-term mechanically ventilated patients found it to be just as efficacious as percussion and postural drainage [132], and another study of patients immediately after cardiopulmonary bypass surgery reported reduced sternotomy pain with cough [133].

Bronchoscopy for atelectasis

Atelectasis occurs when alveolar closing volume rises above functional residual capacity and is rarely due to proximal airway obstruction by mucus. Critically ill patients have elevated closing volumes as a result of increased lung water, advanced age, and low functional residual capacity due to respiratory muscle weakness, sedation, and supine positioning [134]. Fiberoptic bronchoscopy is frequently requested and often performed for 'pulmonary toilet' or treatment of atelectasis in critically ill patients; however, its utility in improving gas exchange and preventing nosocomial pneumonia is limited. Only one randomized study compared the efficacy of fiberoptic bronchoscopy with chest physiotherapy for the treatment of acute atelectasis [114]. Thirty-one consecutive patients with acute lobar atelectasis were randomly assigned to receive immediate fiberoptic bronchoscopy with airway lavage followed by chest physiotherapy every 4 hours for 48 hours or to receive chest physiotherapy alone. Patients who were assigned to chest physiotherapy alone underwent 'delayed fiberoptic bronchoscopy' if their atelectasis persisted at 24 hours. Radiographic resolution of lung volume loss with bronchoscopy was similar to that after the first chest physiotherapy treatment in the control group (38% versus 37%). Although half of the patients who were randomized to chest physiotherapy alone underwent 'delayed' bronchoscopy, this study provided the impetus for teaching pulmonologists-in-training that there is rarely a role for bronchoscopy for atelectasis. In addition, bronchoscopy in patients with acute or incipient respiratory failure is not without adverse effects. Deterioration of gas exchange, barotrauma from elevated airway pressures, increased myocardial oxygen demand, and intracranial pressure have been reported [135-138]. Nevertheless, subgroup analysis [114], case series [137,139-143], and clinical experience support a role for bronchoscopy for some patients with atelectasis: specifically, critically ill patients with acute whole-lung, lobar, or segmental atelectasis without air bronchograms [114] who are unable to maintain airway hygiene independently and remain symptomatic after 24 hours of aggressive chest physiotherapy (every 4 hours). Clinical experience indicates that atelectasis recurs frequently after

bronchoscopy because the cause of compromised airway hygiene continues. Thus, failure to resolve the primary problem should not be an indication for repeated invasive intervention in the airways. There is no role for empiric 'cleaning of the airways' with a bronchoscope.

Conclusion

The rationale for airway hygiene is the prevention of pneumonia and respiratory failure. Current practice reflects clinical experience and expert opinion and not the results of controlled clinical trials. Several evidence-based recommendations can now be made about airway hygiene in critically ill patients. First, oropharyngeal decontamination with oral biocide rinses reduces the incidence of nosocomial pneumonia and should be part of the routine care of the mechanically ventilated patient. Careful monitoring of antibiotic resistance patterns after the initiation of routine biocide use is prudent at this time. Second, tracheal suctioning should be performed only on an 'as needed' basis. Closed (in-line) suction catheter devices should be used and routine changes of these devices are not necessary. Third, aerosolized mucus-controlling agents, such as NAC, and routine instillation of saline have no demonstrable effect on the clearance of airway secretions and should not be routinely used in critically ill patients. Fourth, kinetic therapy decreases the rate of nosocomial pneumonia, and may reduce the length of stay in the ICU and the hospital. The high cost of kinetic beds may be offset by a shortening of stay and a decreased use of systemic antibiotics. Fifth, chest physiotherapy should be limited to patients with acute atelectasis and/or excessive sputum production who are unable to conduct airway hygiene independently. Sixth, the therapeutic role of bronchoscopy in acute atelectasis is limited and transient, and should be reserved primarily for patients with acute atelectasis involving more than a single lung segment in the absence of air bronchograms who remain symptomatic after 24 hours of chest physiotherapy.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

All authors participated in literature review and manuscript preparation.

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