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REVIEW

Comparing suctioning techniques used to assist mechanical ventilation: Protecting you and your patients

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Abstract

Removal of patients' airway secretions is an important ancillary procedure for ensuring the effectiveness of mechanical ventilation (MV). Healthcare professionals may choose the closed suctioning (CS) or open suctioning (OS) method to remove airway secretions. While each procedure adequately achieves its primary purpose, caregivers may prefer CS due to the relative advantages it offers concerning patient and caregiver safety. To compare suctioning methods with respect to patient and caregiver safety, reviews of peer-reviewed literature and clinical practice recommendations were conducted. Safety concerns specifically for treated patients were accentuated by recurring emphasis on comparative effects of CS and OS on physiological and other parameters, which cited more robust disturbances in association with OS. The safety information for caregivers and neighboring patients pertained to an awareness of the potential for bacteria to be inadvertently distributed to caregivers and patient environments during OS, and the preferred choice of CS use to help contain microbial outbreaks in clinical settings. Compared to OS, CS appears to be a safer method for patients, and for caregivers to suction airway secretions during MV. The benefit of having potentially fewer complications associated with CS compared to OS suggests less overall deleterious impact of suctioning on patients and caregivers, thereby making CS worth the investment.

Key Words: mechanical ventilation, closed suctioning, open suctioning, adverse outcomes, healthcare-associated infection, environmental contamination, cost

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Introduction

The accumulation of airway secretions may block endotracheal tubes, and present a potential origin for patient infection if the tubes are colonized with microbial organisms and aspirated. Upon removal of secretions by vacuum suctioning, it is important to minimize infection spread through secretion scatter, and physiological disturbances in patients that are already critically ill. Here, the effects of closed (CS) and open airway suctioning (OS) methods on patient and caregiver safety are highlighted from peer-reviewed literature and clinical practice recommendations.

Background

Mechanical ventilation (MV) is a commonly used life-sustaining treatment modality for children and adults in intensive care units (ICUs). To ensure the best possible effectiveness of MV, endotracheal tube ventilation lines must be kept clear of airway secretions to primarily enable airflow, and to secondarily prevent infections. There are currently two suctioning procedures available to accompany MV, including closed and open techniques.

There are fundamental procedural differences that distinguish CS from OS. Closed suctioning involves a catheter that is encased in a protective, flexible transparent plastic sheath, and thus is "in-line" with the ventilator tubing. Thus, CS does not require disconnection of the ventilator from the patient. To complete OS, however, the ventilator must be disconnected from the patient, and the suctioning catheter is subsequently used in an unshielded manner to remove airway secretions from the patient. During CS, then, ventilation is continuous, and the caregiver and environment are shielded from patients' airway secretions.

These methods are each capable of removing airway secretions, however the ancillary aspects that accompany the fundamental purpose of each technique distinguish the two. While several reports have cited no difference in the incidence of ventilator-associated pneumonia (VAP) when performing either suctioning technique,[1-5] a 2015 review article by Kuriyama *et al.* indicated that closed suctioning (CS) was associated with reduced VAP incidence compared to open suctioning (OS).[6] David and colleagues described a trend for the occurrence of this same phenomenon pertaining to the general incidence of VAP at the Christian Medical College and Hospital in Tamil Nadu, India, but as a significant difference in favor of CS with respect specifically to late-onset VAP.[7] Despite these conflicting outcomes concerning VAP incidence, compared to OS, CS offers other clearer advantages for both patients and caregivers. As elaborated in this review, these include fewer physiological disturbances within treated patients, decreased caregiver and environmental exposure to infectious agents, and prevention of cross-contamination among patients. In contrast to the suctioning differentiation endpoints outlined immediately above, the evidence reviewed to compare CS to OS revealed a relative paucity of focus on longer-term outcomes such as duration of MV, length of hospital stay, and mortality, and thus was of inadequate volume to substantially contribute to this review.

Materials and Methods

Initially, an outline of topics about suctioning methods during MV was determined to construct the review article. Subsequently, PubMed was inspected without time-period restrictions using Boolean methods that generally used terms from the topics of interest, including "closed suctioning" AND "neonates" (47 articles); "closed suctioning" AND "pediatric" (42 articles); "closed suctioning" AND "open suctioning" AND "adult" AND "mechanical ventilation" (37 articles); "closed suctioning" AND "open suctioning" AND "cardiac" AND "surgery" (46 articles); "suctioning" AND "secretions" AND "contamination" (55 articles); "suctioning" AND "secretions" AND "dissemination" (2 articles), "closed suctioning" AND "open suctioning" and "cost" (24 articles). Reference selection criteria included: English language, abstract available, and CS versus (vs.) OS comparison with respect to the topics in this review. Full peer-reviewed publications having titles and abstracts related to the manuscript sub-topics of interest were accessed for further review and incorporation into this report.

Results

Protecting Patients

Patients that require MV are likely to be seriously incapacitated due to an illness such as acute lung injury (e.g., acute respiratory distress syndrome), chronic obstructive pulmonary disease, or congestive heart failure. Consequently, clinical processes performed in conjunction with MV should not introduce added stress to such already-compromised patients. A variety of studies have compared the effects of CS to OS with respect to changes in physiological and other parameters in neonates, older children, and adults that occur as a result of performing each method.

he physiological parameters measured in the studies presented in this review provide feedback concerning the immediate impact of CS or OS on patients. Suctioning-induced reductions in the amount of oxygen dissolved in arterial blood (partial pressure of oxygen; PaO_2), oxygen bound to hemoglobin (arterial oxygen saturation; SaO_2 or SpO_2), the percentage of oxygen bound to hemoglobin in blood entering the right atrium of the heart (mixed venous oxygen saturation; SvO_2), the measurement of oxygen partial pressure in blood through skin (transcutaneous partial pressure of oxygen; $TcPO_2$), and/or increases in the amount of carbon dioxide dissolved in arterial blood (partial pressure of carbon dioxide; $PaCO_2$), and/or alterations in blood pressure (BP), heart rate (HR), or heart rhythm (arrhythmia or dysrhythmia) likely indicate compromise of the stability (homeostasis) of the cardiovascular and/or respiratory systems. In patients who are already health-challenged and in respiratory distress, and thus need intensive care such as that provided by MV, it is especially critical that such added physiological stresses are prevented, or at least held to a minimum upon suctioning. Whereas extrinsically-applied positive-end expiratory pressure (PEEP) can be introduced during MV to help maintain proper lung alveolar function (exchange of oxygen and carbon dioxide), pulmonary distress promoted by suctioning in this context could require PEEP adjustments to correct a gas exchange disruption, and therefore alterations in PEEP would indicate an adverse effect of CS or OS. As a result of suctioning, if the PaO_2 dropped and/or the oxygen concentration in air that is breathed by a patient (fraction of inspired oxygen; FiO_2) needed to maintain a desired patient PaO_2 required elevation during MV, this would be reflected by a reduced oxygenation ratio (PaO_2/FiO_2), and would thus indicate an unfavorable effect of CS or OS. Other deleterious signs of patient health status that may be associated with suctioning include increased intracranial pressure (ICP) and reduced blood flow to the brain. Although the effects of changes in these physiological endpoints on long-term patient outcomes (e.g., duration of MV, length of hospital stay, and mortality) are unclear within each of the studies discussed in this report, the importance of avoiding their modification in such critically-ill patients underscores their roles in differentiating use of CS from OS.

Neonates

Eleven premature infants in Milan, Italy (median gestational age = 26 weeks; range = 25 - 36), who were alternately treated with OS or CS on a daily basis (33 of each procedure), were included in an analysis by Mosca and colleagues.[8] Decreases in both HR and SaO2 were significantly greater during OS compared to CS. Additionally, cerebral blood flow was reduced to a greater extent during OS than during CS.

This study was followed by a report from Cordero and colleagues that described a comparison made between CS (67 patients) and OS (66 patients) techniques in low birth weight infants at the Ohio State University Medical Center, Columbus, Ohio, United States of America (USA).[9] Closed suctioning catheters were changed daily, while OS catheters were discarded after each use, and OS involved disconnection of patients from ventilators. Significant differences between patient groups were not observed regarding the incidence of nosocomial pneumonia, blood stream infections, bronchopulmonary dysplasia, mortality, or overall airway bacterial colonization. However, 91% (40/44) of neonatal ICU (NICU) nurses favored CS vs. OS based on ease of use, less procedure time, and patient tolerance.

Kalyn and colleagues determined that CS maintains better physiologic stability than OS.[10] This randomized clinical trial occurred at a university-affiliated, level 3 NICU in Ontario, Canada, and compared CS to OS among 200 infants who were stratified into three different weight classes (< 100 grams (g), 1000 – 2000 g, > 2000 g). The OS method was associated with a significant decrease in HR, as patients < 1000 g had the most significant changes relative to the other weight classes. The changes from respective baselines in SaO_2 and $TcPO_2$ were significantly reduced in patients treated by OS compared to those treated by CS. The increase in systolic BP that occurred when OS was used was significantly greater than in the CS group, and there was a trend toward higher BP readings with the OS method. A significantly shorter time-period (2.1 minutes (CS) vs. 4.4 minutes (OS)) was needed for physiological parameters to recover (return to baseline) following CS completion. The CS and OS groups were associated with 12 and 35 complications (bradycardia and/or oxygen desaturation), respectively, which was a significant difference in frequency that further differentiated the two suctioning techniques.

In the NICU of the Al-Zahra Hospital in Isfahan, Iran, Taheri *et al.* explored the effects of CS and OS on various respiratory parameters through a cross-over study in 44 infants who underwent MV.[11] After randomization into CS or OS groups, patients that initially received CS were subsequently treated by OS and vice-versa. Overall, CS was associated with fewer changes in respiratory rate (RR) and SaO_2, which accounted for the authors' concluding recommendation to nurses to use CS in infants. Pirr et al. conducted a randomized, cross-over clinical trial to compare OS vs. CS in 15 extremely low-birth-weight neonates (mean birth weight = 655 grams) in Germany.[12] The physiological parameter measurements associated with CS were significantly different than those determined for OS, including less frequent hypoxemia (an abnormally low oxygen concentration in blood), higher mean minimum SpO_2 (87% vs. 84%), a milder drop in mean SpO_2 (-5% vs. -8%), and higher mean PaO_2 (59 millimeters (mm) Hg vs. 53 mm Hg) and oxygenation ratio (197 vs. 171).

Valizadeh and co-investigators reported that responses to a questionnaire distributed to 35 neonatal intensive care nurses in Taleghani and Al-Zahra teaching hospitals in Tabriz, Iran indicated CS to be statistically significantly better than OS in pre-term neonates with respect to reducing the risk of traumatizing the airway, developing pneumonia, increasing ICP, prolonging emergency suctioning, developing intraventricular hemorrhage, blood stream infection, physiological instability, and lowering PEEP.[13] In contrast, lower risk of extubation and comfort were considered advantages ascribed to OS.

Acikgoz and Yildiz studied pain experienced by newborns (mean birthweight = 1.82 ± 1.1 kilograms; mean gestational age = 31.9 ± 5.3 weeks) treated by MV in Turkey.[14] Based on the Neonatal Pain Agitation, and Sedation Scale (N-PASS), the babies endured more pain by OS than by CS.

Children

Evans and colleagues compared the effects of OS to CS on SpO_2, mean arterial (blood) pressure (MAP), and HR in pediatric patients (≤ 18 years-old; N = 258) who were alternately treated with CS or OS on a monthly basis during a four-month period in the pediatric ICU of The Royal Children's Hospital of Melbourne, Australia.[15] Closed suctioning had a nearly equivalent associated adverse event rate compared to OS (5 vs 3). However, OS was associated with a significantly higher frequency of suctioning events that decreased SpO_2 (6.3% vs 4.8%), increased HR (4.6% vs 1.6%), or increased MAP (9.2% vs 3.4%). Decreases in MAP or HR between methods were not different. These outcomes imply that CS is less burdensome on mechanically-ventilated (M-V) patients, and as such is advantageous compared to OS. Following these outcomes, the investigators changed their practice to using CS unless OS was clinically warranted.

Choong and colleagues compared lung volume loss in M-V children (ages 6 days to 13 years) who were alternately treated with CS and OS on a daily basis in the critical care unit of the Hospital for Sick Children in Toronto, Canada.[16] Both the absolute lung volume loss (133.3 milliliters (ml) ± 127.4 vs. 50.5 ± 49.3; p = 0.008), and volume loss normalized to tidal volume (83.7 ± 30.8 vs. 42.3 ± 34.6; p = 0.001), were statistically greater during OS. These differences were attributable to the unique OS requirement of disconnection of the endotracheal tube from the ventilator. The differences in absolute and relative lung volume losses were each more pronounced between CS and OS in patients who had restricted pulmonary compliance (< 0.8 ml/cm H_2O/kilogram and FiO_2 requirements of ≥ 0.4) secondary to lung disease. Moreover, OS reduced SpO_2 more than CS (4.1 ± 4.4% vs. 1.4 ± 1.8%). The authors favored CS compared to OS, primarily because of the differences in lung volume loss observed between suctioning methods.

Adults

In 1990, Clark and co-workers conducted a multi-site study to compare the effects of closed (62 patients) and open (127 patients) suctioning on physiological parameters.[17] Pre-hyperoxygenation breaths of 100% oxygen, one-pass intermittent suctioning for 10 or fewer seconds, and then post-hyperoxygenation (100% oxygen) constituted the sequence of interventions in this study. The SvO_2 decreased only in the OS group immediately after suctioning (66% to 62%), while no differences in HRs were observed between suctioning treatment groups.

A prospective, randomized cross-over investigation conducted by Lee *et al.* at Tan Tock Seng Hospital in Singapore revealed that, compared to CS, OS was associated with a significantly greater incidence of deleterious changes in cardiorespiratory parameters in 14 M-V patients.[18] Indeed, OS was more closely associated with elevated HR and MAP, and lower SpO_2. No difference in respiratory rate was noted between the groups, but cardiac arrhythmia occurred significantly more often when OS was implemented.

Johnson *et al.* conducted a prospective, randomized controlled study of the physiological consequences associated with OS or CS on adult (average age = 43 years-old) patients in a trauma ICU of the University of Kentucky Hospital in Lexington, KY.[19] There were 16 and 19 patients exclusively treated by OS and CS, respectively, and included 127 OS and 149 CS procedures. More trauma patients (81% vs. 68%) and more patients with chest trauma (eight vs. four patients) were in the CS group. Physiological parameters were measured at three different checkpoints, including after hyperoxygenation, immediately following suctioning, and 30 seconds post-suctioning. Increased MAP at each checkpoint, and HR elevation 30 seconds after suctioning, were significantly greater with OS than with CS. Additionally, while OS was associated with decreases in SaO_2 and systemic venous oxygen saturation at each checkpoint, CS was instead associated with increases in each of these physiologic endpoints at each measurement (all measurements between OS and CS were statistically significantly different). In addition, significantly more cardiac dysrhythmias were associated with OS compared to CS.

Blood gas levels and suctioning removal of secretions in the trachea (efficiency) were examined among 18 patients with acute lung injury in Paris, France by Lasocki *et al.*[20] Nine patients were alternately treated by CS and OS at a suctioning pressure of -200 mmHg, while the remaining nine patients underwent these suctioning methods at two different pressures, -200 mmHg and -400 mmHg. During OS, PaO_2 was significantly reduced (mean = 18%) and $PaCO_2$ increased by an average of 8%. In contrast, PaO_2 and $PaCO_2$ levels were not significantly affected by CS, with maximum reduced and elevated levels of change reaching 11% and 10%, respectively. At -200 mmHg suctioning pressure, tracheal secretion mass collected through CS was significantly less than that gathered by OS (0.6 ± 1 g vs. 3.2 ± 5.1 g), but was significantly enhanced at -400 mmHg (1.7 ± 1.6 g vs. 1 ± 1.3 g) without significantly disrupting PaO_2 or $PaCO_2$.

In their review of the effects of CS or OS on ICP and cerebral perfusion pressure (CPP) in adult patients (≤ 18 years-old) with severe brain injury, Galbiati and Paola concluded that CS is favorable to OS.[21] This determination was based on extraction of information from 14 different articles, including systematic reviews, and reports of nonrandomized prospective clinical trials and prospective double-blind clinical trials, which collectively indicated that CS is associated with less intense cerebral hemodynamic alterations than OS. For example, in Istanbul, Turkey, Uğraş and Aksoy found that ICP was higher during OS compared to during CS (OS: baseline = 13.41 ± 7.91 to 21.03 ± 8.81 mmHg during suctioning; CS: baseline = 13.63 ± 7.92 to 16.28 ± 8 mmHg during suctioning).[22] The ICP value associated with OS during suctioning exceeded the indicated limit of 20 mmHg.[23] Because conflicting results were reported among reviewed studies concerning the effects of each suctioning technique on CPP, it could not be determined whether CS or OS was better for maintaining this physiological parameter.

Cardiac Surgery Patients

Analyses of arterial blood gas values were performed by Faraji and colleagues on open-heart surgery patients treated in ICUs of Imam Ali Hospital in Kermanshah-west of Iran.[24] While the PaO_2 was significantly greater one minute following OS than following CS, trends of increased and decreased $PaCO_2$ were observed for OS and CS, respectively, and reductions in PaO_2 at five and fifteen minutes following OS were significantly greater than those for CS at these time-points. Overall, blood gas disturbances were less robust when CS was conducted compared to when OS was performed.

Mohammadpour *et al.* compared alterations in pain, oxygenation, and ventilation following OS or CS in 130 patients who had undergone coronary artery bypass grafting (CABG), at the cardiac surgery ICU of the Emam Reza Hospital in Mashhad, Iran.[25] Pain scores and SpO_2 values were not different between patient groups subjected to the two different suctioning methods, however CS was associated with significantly higher PaO_2 and PaO_2/FiO_2 five minutes post-suctioning. Also, OS patients had a significantly higher mean $PaCO_2$ than individuals in the CS group (40.54 ± 6.56 vs. 38.02 ± 6.10). Thus, although pain associated with OS and CS was similar, oxygenation and ventilation were less disturbed with use of CS in these CABG patients.

Özden and Görgülü studied the effects of CS or OS on 120 open heart surgery patients at a cardiac ICU of a state hospital in Turkey.[26] Modifications in HR, arterial BP, and arterial blood gases favored use of CS, and as such, the authors concluded that CS is preferable to OS to achieve safe suctioning in open-heart surgery patients.

A summary of physiological and other parameters having measurements that have distinguished CS from OS is provided in Table I.

Protecting Caregivers and Other Patients

In the "2007 Guideline for Isolation Precautions: Preventing Transmission of Infectious Agents in Healthcare Settings" from the Centers for Disease Control (CDC; Atlanta, Georgia, USA),[27] the following statement appears regarding advisory precautions during aerosol-generating procedures:

"The performance of procedures that can generate small particle aerosols (aerosol-generating procedures), such as bronchoscopy, endotracheal intubation, and open suctioning of the respiratory tract, have been associated with transmission of infectious agents to healthcare personnel, including M. tuberculosis,[a] *SARS-CoV*[b,c,d] *and N. meningitidis.*[e] *Protection of the eyes, nose and mouth, in addition to gown and gloves, is recommended during performance of these procedures in accordance with Standard Precautions. Use of a particulate respirator is recommended during aerosol-generating procedures when the aerosol is likely to contain M. tuberculosis, SARS-CoV, or avian or pandemic influenza viruses."*

a. *Catanzaro A. Nosocomial tuberculosis. Am Rev Respir Dis 1982;125:559-562.*
b. *Loeb M, McGeer A, Henry B, Ofner M, Rose D, Hlywka T, Levie J, McQueen J, Smith S, Moss L, Smith A, Green K, Walter SD. SARS among critical care nurses, Toronto. Emerg Infect Dis 2004;10:251-255.*
c. *Fowler RA, Guest CB, Lapinsky SE, Sibbald WJ, Louie M, Tang P, Simor AE, Stewart TE. Transmission of severe acute respiratory syndrome during intubation and mechanical ventilation. Am J Respir Crit Care Med 2004;169:1198-1202.*
d. Christian MD, Loutfy M, McDonald LC, Martinez KF, Ofner M, Wong T, Wallington T, Gold WL, Mederski B, Green K, Low DE; SARS Investigation Team. Possible SARS coronavirus transmission during cardiopulmonary resuscitation. Emerg Infect Dis 2004;10:287-293.
e. *Gehanno JF, Kohen-Couderc L, Lemeland JF, Leroy J. Nosocomial meningococcemia in a physician. Infect Control Hosp Epidemiol 1999;20:564-565.*

This statement from the CDC suggests that, by interacting with neighboring patients, fellow caregivers, family members, friends, and passers-by, primary caregivers who administer OS may become a vehicle for wide-spread infection. Moreover, the precautionary measures of donning protective equipment such as those recommended above by the CDC (gowns, gloves, etc.) are time-consuming, incur added expenses, and may be cumbersome for caregivers to adequately perform suctioning. Thus, an alternative to OS seems warranted for reducing the probability of promoting these infectious and practical challenges associated with this method.

Consistent with the implications of the statement from the CDC, Ng *et al.* discovered that visible droplets of airway secretions were scattered an average distance

Table I. ***Parameters measured that compare closed suctioning to open suctioning.***

Patient Population	Parameters	Reference
Neonates	• HR • SaO_2 • cerebral blood flow	8
	• bacterial colonization of airway • nosocomial pneumonia • blood stream infection • bronchopulmonary dysplasia • mortality	9
	• HR • SaO_2 • $TcPO_2$ • BP • complications	10
	• RR • SaO_2	11
	• hypoxemia • SpO_2 • PaO_2 • mean PaO_2/FiO_2	12
	• airway damage • pneumonia • ICP • IVH • blood infection • PEEP	13
	• pain	14
Children	• SpO_2 • MAP • HR • complications	15
	• lung volume • SpO_2	16

Table continued on next page

Patient Population	Parameters	Reference
Adults	• SvO_2 • HR	17
	• HR • MAP • SpO_2 • cardiac arrhythmia	18
	• MAP • HR • SaO_2 • systemic venous oxygen saturation • cardiac dysrhythmias	19
	• PaO_2 • $PaCO_2$	20
	• ICP • CPP	21
	• ICP	22
Cardiac Surgery Patients	• PaO_2 • $PaCO_2$	24
	• pain • SpO_2 • PaO_2 • PaO_2/FiO_2 • $PaCO_2$	25
	• HR • arterial BP • arterial blood gas	26

HR, heart rate; SaO_2, arterial oxygen saturation; $TcPO_2$, transcutaneous partial pressure of oxygen; BP, blood pressure; RR, respiratory rate; SpO_2, arterial oxygen saturation; PaO_2, arterial partial pressure of oxygen; PaO_2/FiO_2 (fraction of inspired oxygen), oxygenation ratio; ICP, intracranial pressure; IVH, intraventricular hemorrhage; PEEP, positive end-expiratory pressure; MAP, mean arterial (blood) pressure; SvO_2, mixed venous oxygen saturation; $PaCO_2$, arterial partial pressure of carbon dioxide; CPP, cerebral perfusion pressure. See text for further details about terms in table.

of 60 centimeters (cm) (range = 25 - 168 cm) from adult patients' (N = 14; 50 procedures) endotracheal tubes during OS, and some droplets contained bacteria derived from patients' airways.[28] Furthermore, Cobley and colleagues observed that contamination of an intensive therapy unit (ITU) in Cardiff, Wales was significantly less when CS was used compared to OS use to treat M-V patients infected with *Escherichia coli, Pseudomonas aeruginosa, Enterobacter cloacae,* and *Proteus species*.[29] By primarily protecting the environment from bacterial spread upon suctioning, CS compared to OS was more capable of secondarily protecting caregivers and neighboring patients from the infective organisms harbored by patients in the ITU.

In at least three separate instances, CS has been initiated in an effort to control microbial outbreak in a clinical setting.

El Shafie and colleagues reported that, beginning in January of 2002, an outbreak of multi-drug resistant *Acinetobacter baumannii* occurred in an ICU at the Hamad Medical Corporation in Qatar.[30] The outbreak involved 21 patients that developed nosocomial infection/colonization originating from the endotracheal tube of one patient. An *Acinetobacter baumannii* strain with an antibiogram similar to that of the patient was isolated from the environment, equipment, and caregiver hands. The authors indicated that OS for MV likely promoted microbial aerosolization and contamination of the patient environment, which facilitated contamination of caregivers' hands, and subsequent transmission to other patients and their immediate environments. Closed suctioning was implemented along with other outbreak control measures, including cleaning of the environment and respiratory equipment, and accentuated hand hygiene practices. Implementation of these containment activities ended the outbreak after June of 2002.

Wilks *et al.* conveyed in June 2002 that an 18-month outbreak of multi-drug resistant *Acinetobacter baumannii-calcoaceticus* (MDRABC) colonization and infection began in the ICU of The Royal London Hospital in London, England, with 15 cases recorded during one of the months.[31] More than 60% of patients had MDRABC in their airway secretions when the outbreak began. During the first 6-months of the outbreak, environmental surroundings, including curtains, slings from patient-lifting equipment, door handles, and computer keyboards, were contaminated with MDRABC. Seven months after outbreak initiation, CS was adopted to support MV of patients. Following this change in clinical practice, along with other outbreak control activities such as hand sanitation with alcohol, and revised strategies for cleaning ICU equipment and the patient environment, MDRABC infection prevalence decreased to a pre-outbreak rate of two cases per month with no signs of environmental contamination.

Choi and colleagues reported that CS was part of a three-pronged approach for reducing outbreaks of carbapenem-resistant *Acinetobacter baumannii* (CRAB) in two ICUs of the Korean University Ansan Hospital in Ansan, Korea.[32] Beginning in October 2007, nineteen patients were infected with CRAB, with an associated case-fatality rate of 21.1%. The bacterium was isolated from 24 (17.9%) of 135 environmental (ICU) samples and seven (10.9%) of 65 caregivers. The microbial outbreak was managed by enforcing contact precautions, reducing environmental contamination through massive cleaning, and use of a CS system. By August 2008 there were no new cases of CRAB in the ICUs. Importantly, CRAB was isolated from the respiratory tracts of most affected patients, and thus suggests this as the origin of environmental and caregiver contamination secondary to formerly employed OS. Whereas a multi-faceted effort was implemented to reduce microbial contamination, further analyses were required to understand to what extent CS could independently reduce such a microbial outbreak.

Table II summarizes instances in which suctioning practice modifications have been initiated to control microbial outbreaks in ICUs.

Cost

A number of analyses to compare the costs associated with CS and OS have been reported in the past two decades. While the cost of CS catheters is more than that of OS kits, ancillary aspects of suctioning implementation and use reveal that CS has been

Table II. *Suctioning practice changes to facilitate infection control in the intensive care unit.*

Infection Outbreak Microorganism	Suctioning Practice Implemented to Control Outbreak	Reference
MDR-*Acinetobacter baumannii*	OS to CS	30
MDR-*Acinetobacter baumannii-calcoaceticus* (MDRABC)	adoption of CS	31
Carbapenem-resistant *Acinetobacter baumannii* (CRAB)	OS to CS	32

MDR, multi-drug resistant; OS, open suctioning; CS, closed suctioning.

shown to be less expensive than OS. As such, an in-depth analysis of cost differences between CS and OS by DePew *et al*. demonstrated that suctioning supplies per month (considering the number of catheters/kits needed/month) were more costly with OS use ($203 (CS) vs. $2915 (OS)).[33] Nursing demands and costs, too, were less with CS use than with use of OS, as supported by shorter average nursing time for each suctioning procedure (1.5 minutes (CS) vs. 2.3 minutes (OS)), fewer nurses needed to provide hyperoxygenation for patients (1 (CS) vs. 2 (OS)), and a lesser nursing cost per suctioning episode ($0.42 (CS) vs. $0.64 (OS). Two other reports indicated that nursing time requirements associated with CS were significantly shorter compared to those for OS, including on per procedure (93 seconds vs. 153 seconds) 19 and per day (23 minutes vs. 38 minutes) 15 bases. Moreover, when at least nine suctioning events per patient were performed per 24-hour time-period (in order to normalize the differential costs of the CS catheters and OS kits), CS afforded a cost savings per month and year of $551 and $6612, respectively. These results are consistent with findings made by Johnson *et al*.[19] and Afshari *et al*.[34] in which suctioning procedure frequency was a factor in determining that OS was more expensive than CS. For example, when 16 procedures were performed per patient per day, CS was $1.88 cheaper per day than OS.19 In addition, the duration of MV appears to play a role in cost differences, as Lorente and colleagues observed that CS was more expensive than OS for patients M-V for < 4 days, but less expensive than OS when MV occurred for > 4 days.[35] An original investigation from David *et al*.7 and a meta-analysis conducted by Jongerden *et al*.[36] found OS to be less expensive than CS. However, the former study did not account for suctioning frequency as a factor, and the latter examination did not consider the potential for long-term cost savings associated with better environmental contamination and infection controls, which appear to be more closely linked to CS.[30-32] Taken together, the comparatively protective effects of CS on physiological and other parameters, environmental contamination and infection prevalence, and reduced associated expenses through supply cost savings, diminished personnel demand and time, and potential for extended use in the ICU to treat critically-ill patients, suggest its practical advantage and cost justification vs. OS.

Conclusions

Compared to OS, CS may be better for limiting changes in patients' physiological measurements, and protecting caregivers and patients from contamination by microorganisms.

The beneficial effects of CS compared to OS appear not to be restricted to particular patient populations, but instead have been demonstrated in patients of various ages and clinical backgrounds, such as cardiac disease. In pediatric M-V patients, CS has statistically significantly less impact on altering physiological parameters, such as SpO_2, HR, lung volume loss, and cerebral blood flow. In adult patients, increases in MAP and HR associated with CS were significantly less than when OS was performed, and OS, but not CS, was associated with ICP values > 20 mmHg. Furthermore, while reductions in both arterial and venous oxygen saturation were associated with OS, these measurements increased after CS. Significantly more dysrhythmias occurred as a result of OS compared to CS.

The fundamental technical differences that distinguish CS from OS specifically relate OS to greater opportunities for caregiver and environmental exposure to microbial contamination derived from patients' airway secretions. As such, primary caregivers, neighboring patients, and individuals that primary caregivers interact with may be at risk of infection. In clinical settings where MV is necessary, CS has been implemented to control microbial outbreak. The protective garb uniquely recommended for use with OS introduces time and monetary costs that are not linked to CS. Furthermore, by primarily having fewer episodes of environmental contamination associated with it,[30-32] relative to OS, CS may secondarily decrease the possibility for suctioning to cause infections in patients and caregivers, thus helping to restrict healthcare costs to treatments of primary illnesses that demanded patients' original requirement for MV and suctioning.

The data discussed here suggest that CS is preferable to OS. Compared to OS, CS may present less risk of complications that could impact both patients and caregivers. From physicians' perspective, this is important for the well-being of their patients, and the caregivers who need to remain healthy enough to care for their patients on a regular basis. From caregivers' perspective, it is in their best interest to keep themselves, and those that they regularly interact with, healthy. The possibility for a caregiver to "bring her/his work home with her/him" may be more likely to place her/his loved ones and acquaintances at risk of infection if she/he practices OS rather than CS in the clinic. Moreover, already health-compromised patients cannot afford to be further encumbered by significant changes in physiological parameters, or infection, which may be less likely to occur when CS is used. For these reasons, which are based on the evidence provided in this review, health professionals who manage or directly perform suctioning for M-V patients may adopt CS instead of OS as standard care, if not done already, to increase the likelihood of protecting their patients, themselves, and others from harm.

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