

COMPILATION ON USE OF CLOSED AND OPEN SUCTION SYSTEMS IN MECHANICALLY VENTILATED PATIENTS

A. GUIDELINES

AARC Clinical Practice Guidelines. Endotracheal suctioning of mechanically ventilated patients with artificial airways 2010. *Respir Care.* 2010 Jun;55(6):758-64

B. LITERATURE REVIEWS

1. Lavigne MC. Comparing suctioning techniques used to assist mechanical ventilation: protecting you and your patients. *Int J Infect Control.* 2016;12:1-12.
2. Morrow BM, Argent AC. A comprehensive review of pediatric endotracheal suctioning: Effects, indications, and clinical practice. *Pediatr Crit Care Med.* 2008;9:465-477.

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3. Effects of open and closed suctioning systems on pain in newborns treated with mechanical ventilation. Acikgoz A, Yildiz S, et al, *Pain Manag Nurs.* 2015;16:653-663.
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6. Comparison of open and closed suction on safety, efficacy and nursing time in a paediatric intensive care unit. Evans J, Syddall S, Butt W, Kinney S. *Aust Crit Care.* 2014;27:70-74

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7. Lung volume changes during cleaning of closed endotracheal suction catheters: a randomized crossover study using electrical impedance tomography. Corley A, Sharpe N, Caruana LR, Spooner AJ, Fraser JF. *Respir Care.* 2014;59:497-503.
8. Closed versus open endotracheal suctioning: costs and physiologic consequences. Johnson KL, Kearney PA, Johnson SB, Niblett JB, MacMillan NL, McClain RE. *Crit Care Med.* 1994;22:658-666.
9. Closed suctioning system reduces cross-contamination between bronchial system and gastric juices. Rabitsch W, Köstler WJ, Fiebiger W, Dielacher C, Losert H, Sherif C, Staudinger T, Seper E, Koller W, Daxböck F, Schuster E, Knöbl P, Burgmann H, Frass M. *Anesth Analg.* 2004;99:886-892.
10. The impact of implementing multifaceted interventions on the prevention of ventilator-associated pneumonia. Khan R et al; *Am J Infect Control.* 2016 Mar.
11. Decreasing the adverse effects of endotracheal suctioning during mechanical ventilation by changing practice. Maggiore SM, Lellouche F, Pignataro C, Girou E, Maitre B, Richard JC, Lemaire F, Brun-Buisson C, Brochard L. *Respir Care.* 2013;58:1588-1597.
12. Effects of open and closed suction systems on the haemodynamic parameters in cardiac surgery patients. Özden D, Görgülü RS; *Nurs Crit Care.* 2015;20:118-125.
13. Influence of tracheal suctioning systems on health care workers' gloves and equipment contamination: a comparison of closed and open systems. Ricard JD, Eveillard M, Martin Y, Barnaud G, Branger C, Dreyfuss D; *Am J Infect Control.* 2011;39:605-607.
14. Nosocomial outbreak of carbapenem-resistant *Acinetobacter baumannii* in intensive care units and successful outbreak control program. Choi WS, Kim SH, Jeon EG, Son MH, Yoon YK, Kim JY, Kim MJ, Sohn JW, Kim MJ, Park DW. *J Korean Med Sci.* 2010;25:999-1004.

E. NON-CLINICAL STUDIES

15. The impact of closed endotracheal suctioning systems on mechanical ventilator performance. El Masry A, Williams PF, Chipman DW, Kratochvil JP, Kacmarek RM. *Respir Care.* 2005;50:345-353.

GUIDELINES

AARC Clinical Practice Guidelines. Endotracheal suctioning of mechanically ventilated patients with artificial airways 2010. *Respir Care.* 2010 Jun;55(6):758-64

An electronic literature search for articles published between January 1990 and October 2009 was conducted by using MEDLINE, CINAHL, and Cochrane Library databases. The update of this clinical practice guideline is the result of reviewing a total of 114 clinical trials, 62 reviews and 6 meta-analyses on endotracheal suctioning. The following recommendations are made following the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) criteria:

- (1) It is recommended that endotracheal suctioning should be performed only when secretions are present, and not routinely
- (2) It is suggested that pre-oxygenation be considered if the patient has a clinically important reduction in oxygen saturation with suctioning
- (3) Performing suctioning without disconnecting the patient from the ventilator is suggested;
- (4) Use of shallow suction is suggested instead of deep suction, based on evidence from infant and pediatric studies;
- (5) It is suggested that routine use of normal saline instillation prior to endotracheal suction should not be performed;
- (6) The use of closed suction is suggested for adults with high F(I)O₂, or PEEP, or at risk for lung de-recruitment, and for neonates;
- (7) Endotracheal suctioning without disconnection (closed system) is suggested in neonates;
- (8) Avoidance of disconnection and use of lung recruitment maneuvers are suggested if suctioning-induced lung de-recruitment occurs in patients with acute lung injury;
- (9) It is suggested that a suction catheter is used that occludes less than 50% the lumen of the endotracheal tube in children and adults, and less than 70% in infants;
- (10) It is suggested that the duration of the suctioning event be limited to less than 15 seconds.

LITERATURE REVIEWS

1. Comparing suctioning techniques used to assist mechanical ventilation: protecting you and your patients

Lavigne MC. *Int J Infect Control* 2016;12:1-12.

BACKGROUND:

Removal of airway secretions is an important aspect of providing efficient mechanical ventilation (MV) in critically-ill patients. Endotracheal suctioning (ES) may be achieved by open (OS) or closed (CS) methods. While both of these approaches are each capable of removing airway secretions effectively, fundamental differences in the two procedures have consequences for patient and caregiver safety.

OBJECTIVE:

To compare open and closed methods of ES in terms of patient and caregiver safety.

DESIGN, PATIENTS AND METHODS:

This report is based on published peer-reviewed articles, and clinical practice recommendations. First, an outline of topics about suctioning methods during MV was compiled. Second, MEDLINE was searched via PubMed using Boolean methods and search terms drawn from the topics of interest. Full publications revealed by PubMed searches, and identified as relevant from titles and article abstracts, were obtained and used as source information.

RESULTS:

A variety of studies have compared the effects of CS and OS on physiological and other parameters in neonates, older children, and adults. Nearly 20 years ago, a study in 11 premature infants found significantly greater decreases in both heart rate and arterial oxygen saturation during OS than during CS. More recent larger studies have also reported that CS maintains better physiologic stability in neonates than OS, and identified other benefits of CS, such as less procedure-related pain and risk of airway trauma or pneumonia. At least two studies in children have similarly found that unfavorable changes in respiratory and/or cardiovascular parameters occur more frequently or are more pronounced with OS than with CS. In adult patients, including those in the intensive care unit (ICU) following acute lung injury, brain injury or after cardiac surgery, greater and/or more frequent deleterious changes in all principal cardiorespiratory parameters with OS compared with CS have been reported. Guidelines for preventing transmission of infectious agents in healthcare settings note that OS can generate small particle aerosols, and have been associated with the transmission of infectious agents to healthcare workers (HCWs). Microbiological studies support this, and in at least three separate instances, have shown that adopting CS as part of outbreak control measures has contributed to the partial or complete containment of a microbial outbreak. The cost of equipment for CS is more than that of OS. However, CS has relatively protective effects on physiologic and other patient parameters, environmental contamination, and infection prevalence, in addition to lower costs of associated supplies, lower demand on staff time, and the potential for extended use in the ICU. These broader aspects of suctioning practice suggest that the higher cost of CS systems compared with OS equipment is justified.

CONCLUSION:

A variety of studies reported in peer-reviewed publications have compared the effects of OS to CS on patients and caregivers. Taken together, these studies show that CS has benefits over OS in limiting suctioning-related changes in patients' physiologic status, and protecting HCWs, other patients and the clinical environment from contamination by microbial pathogens.

2. A comprehensive review of pediatric endotracheal suctioning: Effects, indications, and clinical practice

Morrow BM, Argent AC. *Pediatr Crit Care Med* 2008;9:465-477.

BACKGROUND:

Infants and children with life-threatening conditions frequently require intubation and mechanical ventilation (MV) in pediatric ICU. Intubated patients are unable to clear secretions effectively. All infants and children with an artificial airway thus require endotracheal suctioning (ES) to remove secretions and prevent airway obstruction.

OBJECTIVE:

To provide a comprehensive evidence-based review of the effects, indications, and clinical practice of pediatric ES, and to develop clinical recommendations from these findings.

DESIGN, PATIENTS AND METHODS:

Electronic databases were searched for English language articles published between 1962 and June 2007. Searches were initially limited to randomized controlled trials (RCTs) but revealed a paucity of objective pediatric data. The scope of searches was subsequently extended to all reports of ES, including studies of lower evidence level, and adult, neonatal, in vitro and animal studies.

RESULTS:

One hundred eighteen references were included in the final review. Despite the widespread use of ES, very little high-level evidence dealing with pediatric ES was found. Specifically for clinical trials that evaluated ES, literature searches identified only 17 studies in neonates and eight studies in infants and children. Across all studies, ES was reported to cause a range of potentially serious complications, including adverse respiratory, cardiovascular, and neurologic effects and pain. Most reports point to the detrimental effect of the procedure on lung mechanics. In infants and young children where functional residual capacity is close to the closing volume, intubation prevents glottic closure, predisposing the patient to atelectasis. Therefore, even in intubated children with normal lungs, positive end-expiratory pressure may be necessary to maintain lung volume. Disconnection from the ventilator results in a decrease in airway pressure with loss of lung volume, which may be exacerbated by the application of a negative suction pressure.

ES practice guidelines are not currently based on evidence from controlled clinical trials. New or revised guidelines should incorporate the following recommendations.

- All patients receiving MV should receive analgesia for the duration of MV.
- ES should be performed when obstructive secretions are present rather than routinely.
- Closed suction systems appear to reduce lung volume loss and hypoxia. HCWs should use the suction method with which they are proficient.
- Patient's cardiorespiratory status should be monitored continuously during ES.
- Patients should be hyperoxygenated for ≤ 60 s before ES, and the preoxygenation level determined by the individual's clinical condition.
- The suction catheter size should be selected after considering both the ETT size and the secretion consistency. The catheter should be large enough to allow effective removal of secretions but not of a size that causes trauma or occlusion of the endotracheal tube.
- The vacuum pressure used should be the lowest that removes secretions with the least adverse effects, and specifically ≤ 360 mmHg.
- Sterile technique is not necessary but infection control measures should be used.
- Suction should only be applied on catheter withdrawal, not during insertion, and limited to ≤ 10 s. Patients receiving open ES should then be reconnected to the ventilator to allow recovery.
- The suction catheter should not be passed deeper than the end of the endotracheal tube, which can be determined by direct measurement.
- Routine saline instillation before ES should not be performed.
- ES should be discontinued if large airways have been cleared, if oxygen desaturation, cardiac arrhythmia or bradycardia, or if the child becomes extremely agitated.
- Recruitment maneuvers after ES should not be performed routinely.

CONCLUSIONS:

While ES is necessary to maintain patency of the airways, it is not a benign procedure. All HCWs performing the procedure should be aware of the positive and negative effects of ES, and methods to prevent or minimize its complications. Objective evidence in support of clinical practice recommendations is currently limited, particularly in the pediatric population. Further controlled clinical trials are necessary to develop an evidence-based protocol for ET suctioning of infants and children, as well as to examine the impact of different suctioning techniques on the duration of MV support, incidence of nosocomial infections and length of ICU and hospital stays.

PROSPECTIVE NEONATAL/ PEDIATRIC STUDIES

3. Effects of open and closed suctioning systems on pain in newborns treated with mechanical ventilation

Acikgoz A, Yildiz S. et al, *Pain Manag Nurs* 2015;16:653-663.

BACKGROUND:

Endotracheal suctioning (ES) is often necessary in newborn infants in intensive care, particularly those receiving mechanical ventilation. Pain experienced during ES is an important potential complication of this invasive procedure. Studies comparing the pain levels caused by the suctioning process according to the suction method used have not been reported.

OBJECTIVE:

To compare the effects of open (OSS) and closed (CSS) suctioning systems[†] on the level of pain suffered by newborns treated with mechanical ventilation during suctioning procedures.

DESIGN, PATIENTS AND METHODS:

In this open, prospective, randomized study, babies admitted to the neonatal intensive care unit who were receiving treatment with MV, required ES, had no paralysis and neuromuscular blockage, and were not administered analgesics were randomly assigned to ES with OSS ($n = 22$) or CSS ($n = 20$). All suctioning procedures were performed by the same nurse in the same way using a size 6 suction tube at maximum suction pressure 100 mmHg, avoiding aggressive and deep suctioning, and ensuring sterility of the suction tubes. Intervention was determined by the nurse according to suctioning implementation criteria in the Neonatal Therapeutic Intervention Scoring System. Two independent investigators evaluated babies' pain responses before and during suctioning using the Neonatal Pain, Agitation, and Sedation Scale (N-PASS). This validated assessment tool was developed to assess pain and sedation levels in neonates and infants and uses validated, clinical applicable and easy-to-use indicators: crying/irritability, behaviour/state, facial expression, extremities/tone and vital signs.

RESULTS:

Before ES, N-PASS scores in the OSS group and in the CSS group were similar; median (range) 1.0 (0-4) and 1.0 (0-3), respectively. N-PASS scores increase significantly ($p < 0.001$) in both groups during suctioning and while the increase was greater in the OSS group (4.0 (1-10)) than in the CSS group (3.0 (0-7)), this difference was not significant.

Analysis of vital signs showed no significant difference in changes in average heart rate and systolic blood pressure from before and during ES in the two groups. Average diastolic blood pressure (DBP), body temperature, and oxygen saturation did not change significantly during the procedure in the CSS group. In contrast, average DBP and body temperature increased and oxygen saturation decreased significantly during ES in OSS group.

CONCLUSIONS:

Babies feel pain during ES, and the level of pain experienced during suctioning by OSS appears to be slightly higher than during CSS, although the difference assessed by N-PASS was not statistically significant. Stress-induced changes in vital signs were consistent with this difference identified by pain assessment.

[†]Products from undisclosed suppliers were used in the study.

4. Closed versus open endotracheal suctioning in extremely low-birth-weight neonates: a randomized, crossover trial

Pirr SM, Lange M, Hartmann C, Bohnhorst B, Peter C. *Neonatology* 2013;103:124–130.

BACKGROUND:

Endotracheal suction (ES), while essential in patients who require mechanical ventilation (MV), can cause serious complications such as bradycardia, hypoxemia, atelectasis, arterial hypertension and cerebral hyperperfusion. These complications are more likely to occur in patients with compromised lung function such as extremely low-birth-weight (ELBW) neonates. ES can be performed by open (OS) or closed (CS) suctioning, but comparison of the two approaches in this patient group has not been reported.

OBJECTIVE:

To investigate whether CS has any advantages over OS in ELBW neonates.

DESIGN, PATIENTS AND METHODS:

This randomized, prospective, crossover study included 15 ELBW neonates admitted to the neonatal ICU. All patients were gestational age <32 weeks, birth weight <1000g, needed MV, had an arterial line in place, and written parental consent. Each patient was randomly assigned to OS or CS as the initial ES method. After a 4-hour period, the alternative method was used. ES was undertaken by specialist neonatal nurses using an OptFlo[†] CS system (Dahlhausen) for CS and a Müllen^{††} sterile Ch 6 catheter (Unomedical) following a defined protocol in which suctioning was performed three times. Data on oxygen saturation (SpO_2), heart rate (HR), arterial blood pressure, arterial blood gases, duration of the ES procedure and recovery time were collected.

RESULTS:

During CS the mean frequency of hypoxemia <85% was significantly decreased (0.5 vs 1.1, $p = 0.012$) compared with OS. The mean minimum SpO_2 was significantly higher (87% vs 84%, $p = 0.012$) and the drop in mean SpO_2 was less steep (-5% vs -8%, $p = 0.007$) during CS than during OS. Mean PaO_2 (59 mmHg vs 53 mmHg, $p = 0.035$) and mean oxygenation ratio (OR) (197 vs 171, $p = 0.016$) were significantly higher after CS. No significant differences between CS and OS were found in HR, incidence or duration of bradycardia, recovery time, arterial blood pressure, duration of suctioning, number of complications, or duration of hypoxemia.

CONCLUSION(S):

In ELBW neonates, CS provided superior oxygenation values (rate of SpO₂ decline, minimum SpO₂, mean PaO₂, and OR) and a significant reduction in the frequency of hypoxemia compared with OS. CS thus provides better physiologic stability and can safely be performed in these vulnerable patients. Further research is needed to confirm the superiority of CS over OS in ELBW neonates, especially considering the additional dead space and ventilation requirements of these patients. Until such evidence is reported, CS should be administered on an individual basis in ELBW neonates.

[†]OptoFlow is a registered trademark of Dahlhausen CZ spol. s r.o. Kurim, Czech Republic.

^{††}Müller is a registered trademark of Unomedical a/s, Birkerød, Denmark.

5. Comparison of the closed and open suctioning systems in the care of ventilated preterm infants

Wilińska M, Górný J, Świeciński J, Sobala W, Piotrowski A; *J Ped Neonatal 2005;2:NT29-35.*

BACKGROUND:

Mechanical ventilation (MV) is critically important in the management of neonates with severe respiratory failure. Intubation causes tissue irritation and increased secretions that require regular clearing to prevent discomfort and airway restriction. Endotracheal suction (ES) using a catheter connected to a closed suction system (CSS) may maintain physiologic stability better than a conventional open suction system (OSS).

OBJECTIVE:

To compare the immediate and long-term effects of suctioning with OSS and CSS in prematurely born infants requiring MV support.

DESIGN, PATIENTS AND METHODS:

This prospective, randomized study included 90 newborn infants of gestational age 23–36 weeks who required nasotracheal intubation and MV because of respiratory distress syndrome. ES in the OSS group used disposable catheters (Balton^a or Sherwood^b) with side opening and length marked in cm. In babies intubated with 2.5 mm ET tubes size 6 Fr suction catheters were used, and when wider tubes were used size 8 Fr catheters were employed. ES in the CSS group used the Trach Care^c system (Kendall, USA), with size 6 Fr and 30.5 cm long catheters. The suction tube sets were changed for new, if the catheter became blocked by secretions or when the colour of secretions changed. The depth of catheter insertion from the tip of the endotracheal tube depended on the baby's weight: <1 kg, 3 cm; 1–2 kg, 4 cm; and >2 kg, 5 cm. Suction pressures of 100–200 mm H₂O were used in OSS and CSS procedures were based on separate standard protocols. The immediate effects of suctioning on heart rate, respiratory rate, blood pressure and oxygen saturation were studied on the third day of treatment. The incidence of major complications, survival, and length of treatment with MV were also compared and the nurses' attitude towards both systems was evaluated.

RESULTS:

After exclusions, data were available for 40 infants in the CSS group and 38 infants in the OSS group. In procedures performed on day 3, there were significantly fewer episodes of O₂ desaturations ≥10% ($p < 0.001$) and respiratory rate decreases of ≥20% ($p = 0.006$) in the CSS group. The mean time for blood pressure ($p = 0.049$), respiratory rate ($p = 0.009$) and O₂ saturation ($p = 0.017$) values to return to baseline was significantly longer in the OSS group. In addition, infants treated by CSS had a lower incidence of patent ductus arteriosus and nosocomial pneumonia. There were no differences in the incidence of air-leak syndromes, intracranial hemorrhage, nosocomial sepsis, and in the duration of assisted ventilation and stay in the ICU. The majority of nurses (83%) considered the CSS to be a better technique than the OSS.

CONCLUSIONS:

ES with a CSS causes less severe respiratory disturbance during and after the procedure, maintains more stable hemodynamics, and has a lower risk of nosocomial pneumonia or PDA compared with an OSS. In addition, after an introductory period, nurses prefer using a CSS to an OSS.

^a Balton Sp. z o.o., Warsaw, Poland. ^b Sherwood, Ballymoney, Ireland. ^c Trach Care is a product of Avanos Medical

6. Comparison of open and closed suction on safety, efficacy and nursing time in a paediatric intensive care unit

Evans J, Syddall S, Butt W, Kinney S. *Aust Crit Care* 2014;27:70-74.

BACKGROUND:

Endotracheal suctioning (ES) is one of the most common procedures performed in pediatric intensive care. The procedure has specific significance and risk in paediatric and neonatal patients who are particularly prone to potential complications due to physiological and respiratory immaturity. ES can be performed using open (OSS) or closed (CSS) suction systems, but there is limited information comparing the two approaches to ES in neonates and children.

OBJECTIVE:

To compare the physiologic effects, safety and associated staff resource use of open and closed ES in a pediatric ICU.

DESIGN, PATIENTS AND METHODS:

This prospective open study included all pediatric patients in ICU with an endotracheal tube (ETT) between June and September 2011. In this study period, alternative months were nominated as 'open' or 'closed' suction months. For either method, ES was performed according to the pre-existing guideline within the unit. Staff were permitted to change the catheter type at any point after allocation if considered clinically necessary. The suction catheters used for open ES were Y-suction catheters (Unomedical^a or Pacific Hospital Supply Co.^b), and closed ES was performed with the AVANOS^{*} CSS^c for neonates/paediatrics. For each discrete episode of ES (ES event), data were collected regarding the event, staff involved, time taken, use of saline, and change from pre-suction baseline in heart rate (HR), mean arterial pressure (MAP) and oxygen saturation (SpO_2). Blocked or dislodged ETTs were recorded as adverse events.

RESULTS:

Over the 4-month study, 6691 ES events were documented from 229 individual patients admitted to the ICU. Open ES was used for 583 patient-days and closed ES for 441 patient-days. Closed ES resulted in more ES events per day compared with open ES (7.2 vs 6.0, $p < 0.01$). Adverse events occurred in 3 open ES events and 5 closed ES events ($p = 0.23$). The average ES time spent per day for each bedside nurse was significantly less for closed ES compared with open ES (23 min vs 38 min, $p < 0.01$). This reflected the lower average length of time for each closed ES event (2.6 min vs 3.2 min) and that fewer staff on average were needed to carry out the suction procedure using a CSS than with an OSS.

Open ES resulted in more ES events with decreased SpO_2 (6.3% vs 4.8%, $p = 0.01$), increased HR (4.6% vs 1.6%, $p < 0.01$) and increased MAP (9.2% vs 3.4%, $p < 0.01$) than closed ES. The proportion of ES events that resulted in decreases in MAP or HR was similar with the two suctioning methods. All patient subgroups experienced more physiologic disturbance following open ES than closed ES and this was more likely in patients with respiratory infection than other subgroups.

CONCLUSION:

Compared with open ES, closed ES could be performed with less physiologic disturbances to patients and a similar frequency of adverse events, and required less staffing time and fewer nurses. This clinical comparison supported a decision to change ES practice in the pediatric ICU to use a CSS as standard unless an OSS was clinically justified.

^aUnomedical, Mona Vale, New South Wales, Australia.

^bPacific Hospital Supply Co., Taipei, Taiwan.

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PROSPECTIVE STUDIES: ADULTS

7. Lung volume changes during cleaning of closed endotracheal suction catheters: a randomized crossover study using electrical impedance tomography

Corley A, Sharpe N, Caruana LR, Spooner AJ, Fraser JF. *Respir Care* 2014;59:497-503.

BACKGROUND:

Cleaning of the suction catheter is essential after airway suctioning in mechanically ventilated patients, but may lead to loss of lung volume.

OBJECTIVE:

The aim of this study was to compare the changes in end-expiratory lung volume that occurred during post-suction cleaning of the catheter in two closed suction systems, one with (AVANOS^{*} Turbo-Cleaning CSS with BALLARD^{*} Technology) and one without (Portex Steri-Cath DL[†], Smiths Medical) a valve between the patient's airway and catheter cleaning chamber.

DESIGN, PATIENTS AND METHODS:

This prospective, randomized crossover study included 10 patients mechanically ventilated via volume-controlled synchronised intermittent mandatory ventilation (SIMV-VC) and requiring manual hyperinflation (MHI). Lung volume changes were measured during SIMV-VC and MHI using impedance changes on electrical impedance tomography.

RESULTS:

Non-significant lung volume changes and maintenance of normal ventilation were recorded during MHI (188 impedance units (IU), 95% CI -136 to 511, $p = 0.22$) and SIMV-VC (22 IU, 95% CI -342 to 299, $p = 0.89$), respectively, during cleaning of the catheter in the valved closed suction system. In contrast, significant decreases in lung impedance during MHI (-2563 impedance units, 95% CI 2213-2913, $p < 0.001$) and significant increases in lung impedance during SIMV (762 impedance units, 95% CI 452-1072, $p < 0.001$) occurred during cleaning of the catheter in the valveless closed suction system.

CONCLUSION:

In mechanically ventilated patients, use of a closed suction system with a valve between the patient's airway and the catheter cleaning chamber prevents lung de-recruitment and maintains uninterrupted ventilation during cleaning of the catheter. The absence of such a valve results in significant lung volume loss during MHI and disruption to ventilation during SIMV-VC. Using a closed suctioning system with a valve should be considered the best practice for mechanically-ventilated patients.

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[†]Portex Steri-Cath DL is a registered trademark of Smiths Medical, Dublin, OH, USA.

8. Closed versus open endotracheal suctioning: costs and physiologic consequences

Johnson KL, Kearney PA, Johnson SB, Niblett JB, MacMillan NL, McClain RE. Crit Care Med 1994;22:658-666.

BACKGROUND:

In the conventional approach to endotracheal suctioning (ES), the patient is disconnected from the ventilator and receives pre- and post-suction hyperinflation and hyperoxygenation breaths. ES using a multiple use catheter incorporated in a closed suction system (CSS) eliminates the risk associated with disconnecting the patient from the ventilator. Few studies have compared the physiologic impact of the two suctioning methods.

OBJECTIVE:

To compare the physiologic consequences and costs associated with ES by CSS and open (OSS) suction systems.

DESIGN, PATIENTS AND METHODS:

This prospective, randomized, controlled study included 35 patients treated in a trauma ICU; 19 patients underwent 127 open ES procedures and 16 patients received closed ES (Trach Care CSS*) in 149 procedures. Mean arterial pressure (MAP), heart rate (HR) and rhythm, arterial oxygen saturation (SaO_2) and systemic venous O_2 saturation (SvO_2) were measured before ES (baseline), immediately after hyperoxygenation, immediately after ES, and 30 seconds after ES.

RESULTS:

MAP in both the OSS and CSS groups was increased from baseline at all three post-baseline measurements, with open ES resulting in significantly larger increases in MAP ($p < 0.001$) throughout the suctioning procedure than closed ES. Mean HR increased with ES and the HR increases were greater in the OSS group than in the CSS group; 30 seconds after the procedure, open ES was associated with a significantly higher mean HR ($p = 0.021$) than closed ES. Closed ES was associated with significantly fewer dysrhythmias than open ES (2% vs 14%, $p < 0.001$). SaO_2 and systemic SvO_2 decreased with open ES. In contrast, SaO_2 and systemic SvO_2 increased with the closed ES. At all three measurement points, the percent change in SaO_2 and SvO_2 was significantly different in the two groups. Ten patients in the OSS group and eight patients in the CSS group developed pneumonia. Open ES cost \$1.88 more per patient per day and required significantly more nursing time (average time /procedure 153 s vs 93 s, $p < 0.001$).

CONCLUSION:

ES using a CSS resulted in significantly fewer acute physiologic disturbances than open ES. Closed ES appears to be an effective and cost-efficient method of ES that is associated with fewer procedure-related complications.

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9. Closed suctioning system reduces cross-contamination between bronchial system and gastric juices

Rabitsch W, Köstler WJ, Fiebiger W, Dielacher C, Losert H, Sherif C, Staudinger T, Seper E, Koller W, Daxböck F, Schuster E, Knöbl P, Burgmann H, Frass M. Anesth Analg 2004;99:886-892.

BACKGROUND:

Avoidance of ventilator-associated pneumonia (VAP) is especially important in critically-ill patients. The major mechanism of lower respiratory tract colonization is aspiration of contaminated oropharyngeal, gastric, or tracheal secretions. Airway contamination may also occur during open endotracheal suctioning, which is necessary to prevent accumulation of secretions and airway blockage. In addition, contamination from exogenous sources may occur during conventional open suctioning (OS) by allowing direct communication between the surrounding air and the patient's airway. No previous studies have compared OS and closed suctioning (CS) in adults with respect to microbiological cross-contamination between the bronchial system and stomach.

OBJECTIVE:

The primary aim of this study was to evaluate whether the CS would decrease the risk of cross-contamination in intubated, critically ill patients receiving mechanical ventilation (MV). The secondary aims were to analyze the frequency of VAP and alterations in gas exchange.

DESIGN, PATIENTS AND METHODS:

This prospective, randomized study included 24 consecutive adult patients on MV who were randomly assigned to OS ($n = 12$) or CS ($n = 12$) using a Closed Suction system by Tyco Healthcare^{††}. Within 12 h of initial intubation, the endotracheal tube (ETT) was replaced by a visualized ETT (VETT; Pulmonx[†]) to allow fiberoptic control of ETT positioning and visual estimation of the amount of tracheobronchial secretions. In both groups, regular suctioning took place every 4 h, and additional suctioning was performed whenever clinically necessary. Oxygen saturation (SaO_2) was measured before and immediately after suctioning. Microbiological samples were obtained by aspiration via a tracheal catheter or the feeding tube and antibiograms were performed from tracheal secretions and gastric juice aspirates on Days 1 and 3 of intubation. Microbial genotypes were determined by random amplification of polymorphic DNA (RAPD) polymerase chain reaction (PCR).

RESULTS:

Antibiogram results showed cross contamination (bronchial-to-gastric or gastric-to-bronchial) had occurred in five patients in the OS group and none of the CS group ($p = 0.037$). In these five patients, the microbial strains isolated initially from gastric juice aspirates and subsequently from bronchial aspirates, or vice versa, were confirmed as cross-contaminants by matching common genotypes as determined by RAPD PCR. VAP occurred in the five patients of the OS group who had cross-contamination but in none of the CS group ($p = 0.037$). Patients in the OS group had significantly lower post-suctioning SaO_2 values compared with patients in the CS group on Day 1 ($89.6\% \pm 2.5\%$ vs $96.8\% \pm 1.0\%$, $p < 0.0001$) and Day 3 ($89.6\% \pm 1.9\%$ vs $96.4\% \pm 0.8\%$, $p < 0.0001$).

CONCLUSION:

Compared with OS, CS significantly reduced cross-contamination between the bronchial system and gastric juices, reduced the incidence of VAP, and reduced the risk of oxygen desaturation.

[†]The Visualized Endotracheal Tube System™ is a registered trademark of Pulmonx Inc., Palo Alto, CA, USA.

^{††}Closed Suction system by Tyco Healthcare.

10. The impact of implementing multifaceted interventions on the prevention of ventilator-associated pneumonia.

Khan R, Al-Dorzi HM, Al-Attas K, Ahmed FW, Marini AM, Mundekkadan S, Balkhy HH, Tannous J, Almesnad A, Mannion D, Tamim HM, Arabi YM. Am J Infect Control. 2016 Mar 1;44(3):320-6. doi: 10.1016/j.ajic.2015.09.025.

OBJECTIVE:

A. baumannii has been increasingly reported as a significant causative organism of various nosocomial infections, especially among critically ill patients in ICUs. Serious *A. baumannii* infections are usually treated with a carbapenem, but resistance to these compounds is increasing worldwide and is associated with high morbidity and mortality rates.

MATERIALS AND METHODS:

From 2008 to 2011, control phase of the study, hospital had implemented VAP control bundle. The VAP incidence was still high during this phase. An experimental phase from January 2011 to December 2013 was designed with evidence based revised VAP care bundle (7- element care: Nursing care: head-of-bed elevation 30°-45°, oral care with chlorhexidine (using Avanos Q4 Oral care kit), Physician care: daily sedation vacation and assessment for extubation, peptic ulcer disease prophylaxis, deep vein thrombosis prophylaxis, Respiratory Therapist Care: endotracheal intubation with in-line suction and subglottic suctioning (Closed suction with Avanos 72 hrs closed suction system and ET tube Taperguard), and maintenance of endotracheal tube cuff pressure at 20-30 mmHg) in order to bring down the VAP rates and increase the compliance to VAP bundle approach. During both the phases, all mechanically ventilated patients admitted to the intensive care unit between 2008 and 2013 were prospectively followed for VAP development according to the National Healthcare Safety Network criteria. Additionally the compliance rates were compared between two phases.

RESULTS:

A total of 3665 patients received mechanical ventilation, and there were 9445 monitored observations for bundle compliance. The patients in the experimental group (2011-2013) were sicker with higher APACHE III scores and more comorbidities. Total bundle compliance was 90.7% before initiation of the VAP team and 94.2% after ($P < .0001$). Bundle compliance remained above 90% after introduction of the VAP prevention team in 2011, and reached 97% in 2013. The number of patients observed for bundle compliance were almost double in experimental phase making it more robust. The number of VAP episodes decreased from 144 during 2008-2010 to only 14 during 2011-2013 ($P < .0001$). The rate of VAP decreased from 8.6 per 1000 ventilator-days to 2.0 per 1000 ventilator-days ($P < .0001$) after implementation of the care bundle. The ICU mortality in the experimental phase was also less. However the decrease in ICU length of stay and duration of Mechanical ventilation could not be demonstrated in experimental phase, possibly due to out of "VAP bundle" factors and the sample population in experimental group was more critical.

CONCLUSIONS:

This project demonstrates that a systematic implementation of a multidisciplinary team approach with high compliance to evidence based best practices adhered to as a bundle, can reduce the incidence of VAP.

*In this study Oral care and Closed Suction systems from Avanos were used.

11. Decreasing the adverse effects of endotracheal suctioning during mechanical ventilation by changing practice

Maggiore SM, Lellouche F, Pignataro C, Girou E, Maitre B, Richard JC, Lemaire F, Brun-Buisson C, Brochard L. *Respir Care* 2013;58:1588-1597.

BACKGROUND:

Few studies have reported the incidence of and risk factors for complications due to endotracheal suctioning (ES).

OBJECTIVE:

To evaluate the incidence of adverse effects from ES in general medical patients and the impact of clinical practice guidelines on this rate.

DESIGN, PATIENTS AND METHODS:

This before-and-after observational study followed consecutive adult patients needing mechanical ventilation during 3-month periods before ($n = 79$) and after ($n = 68$) intervention. Before implementation of the practice guidelines, ES was generally performed at least every 2 hours, with no standardized duration, depth, vacuum pressure, or size of suction catheter. Saline was instilled for dry, tenacious secretions. Patients, including those with acute respiratory distress syndrome (ARDS), were disconnected from the ventilator during suctioning, and closed suction systems were not used. During the pre-intervention period, ≥ 1 complication occurred in 47 patients (59.5%) and 559 procedures (12.4%) at a rate of 92.5 per 100 ventilator days. Specific adverse effects of ES were oxygen desaturation (46.8% of patients and 6.5% of suctionings), haemorrhagic secretions in (31.6% and 4%, respectively) blood pressure change (24.1% and 1.6%, respectively) and heart rate change (10.1% and 1.1%, respectively).

Suctioning practice guidelines developed between the two study periods provided the following recommendations:

1. suctioning was performed according to need rather than routinely, with evaluation of need based on expiratory flow and respiratory sounds;
2. to minimize mucosal trauma, suctioning was limited to the endotracheal tube and trachea instead of deep suctioning;
3. the duration of suctioning was limited to 10–15s;
4. the diameter of the suction catheter was <50% the inner diameter of the endotracheal tube;
5. suction pressure was set between 200 and 250 mmHg;
6. saline instillation was avoided;
7. ventilator connection was maintained by use of a closed suction system, particularly in patients with ARDS; otherwise, a suction port swivel adaptor could be used, although no other particular ventilator system details or types were specified.

RESULTS:

After guideline implementation, the frequency of all complications decreased to 29 patients (42.6%) and 4.9% of procedures at a rate of 39 per 100 ventilator days ($p < 0.05$, $p < 0.001$ and $p < 0.001$, respectively). Oxygen desaturation and haemorrhagic secretions decreased by 40% and 83%, respectively, after the guidelines were introduced, but remained the most frequent adverse effects. More than 6 suctionings/day, requirement for a positive end expiratory pressure (PEEP) > 5 cm H₂O, and the presence of ARDS were found to increase the risk of suctioning-related complications.

CONCLUSIONS:

The adverse effects of ES, particularly oxygen desaturation and haemorrhagic secretions, are common. Factors that increased the likelihood of suctioning complications, which include frequent suctioning, PEEP > 5 cm H₂O, and ARDS, can be used to identify patients at higher risk. Using a less invasive suctioning procedure standardized according to targeted clinical practice guidelines in conjunction with a closed suction system can reduce all ES-related complications.

[†]Products from undisclosed suppliers were used in the study.

12. Effects of open and closed suction systems on the haemodynamic parameters in cardiac surgery patients

Özden D, Görgülü RS; Nurs Crit Care 2015;20:118-125.

BACKGROUND:

In intubated patients, removal of airway secretions by endotracheal suction (ES) is essential to maintain stable respiration, and may be undertaken by open (OSS) or closed (CSS) suction systems. Various adverse effects of ES on cardiovascular and respiratory systems have been noted, but studies evaluating the effects of open and closed ES on patient haemodynamic status have reported conflicting results.

OBJECTIVE:

To determine the effects of ES by OSS and CSS on hemodynamic parameters in patients undergoing open-heart surgery.

DESIGN, PATIENTS AND METHODS:

This observational quasi-experimental study included adult patients who were admitted to the cardiovascular surgery ICU having undergone CABG surgery and open heart surgery. Patients were intubated, receiving mechanical ventilation (MV) and routine monitoring of haemodynamic and respiratory status. When ES was indicated, the patient was aspirated by a nurse according to a standard protocol, and haemodynamic data were collected. Heart rate (HR), mean arterial blood pressure (MAP), oxygen saturation (SpO_2) and arterial blood gases were measured immediately prior to and after ES, and at 5 min and 15 min post-ES. Of the 120 patients, 60 underwent open ES[†] and 60 underwent closed ES[†] during separate 3-4 week evaluation periods.

RESULTS:

In patients given open ES, mean HR, MAP, and mean PaCO_2 increased significantly immediately after the procedure and then decreased, reaching baseline values 15 min post-ES. Mean PaO_2 decreased significantly once the procedure terminated and remained below baseline at 15 min post-ES. Mean SaO_2 and mean SpO_2 also decreased immediately post-ES with values then recovering to approach but still be below baseline at 15 min post-ES.

In patients receiving closed ES, there were also significant increases in mean HR and MAP ($p < 0.05$), but the changes immediately post-procedure were less than observed in the open ES patient group. Mean PaO_2 increased immediately post-ES and continued to increase at 5 min and 15 min post-ES, although these changes from baseline were not significant. Mean PaCO_2 increased significantly as soon as ES ended, and returned to baseline level by 5 min post-ES. Mean SaO_2 decreased immediately post-ES then increased to levels above baseline at 5 min and 15 min post-ES. Mean SpO_2 increased during and after the procedure. When the OSS and CSS were compared, the changes in mean MAP and mean SpO_2 during ES were statistically significant.

CONCLUSIONS:

In patient intubated and receiving MV after cardiac surgery, open ES adversely affected HR, MAP and arterial blood gases, the levels of which took 15 min to recover after the procedure to near-baseline values. In patients undergoing closed ES, any changes in hemodynamic and respiratory parameters had resolved by 5 min after post-ES, and there was no significant change in mean PaO_2 and pH during the procedure. These data indicate that use of closed ES is more likely to prevent procedure-related complications, especially hemodynamic and respiratory disturbances such as hypoxemia, and is thus more suitable for ES in patients recovering from cardiac surgery.

[†]Products from undisclosed suppliers were used in the study.

13. Influence of tracheal suctioning systems on health care workers' gloves and equipment contamination: a comparison of closed and open systems

Ricard JD, Eveillard M, Martin Y, Barnaud G, Branger C, Dreyfuss D ; Am J Infect Control 2011;39:605-607.

BACKGROUND:

Health care-associated infections represent a major challenge for clinicians and medical centers. These infections often result from cross contamination, a major route of which is passage of pathogenic microorganisms from the hands of health care workers (HCWs) to patients or equipment. Direct patient contact, respiratory care, and handling of body fluid secretions are aspects of patient care associated with high levels of HCW hand contamination. The use of closed (CSS) rather than open (OSS) suction systems may reduce the microbial burden on HCW hands, but studies comparing CSS and OSS have not been reported.

OBJECTIVE:

To compare glove and airway equipment contamination during endotracheal suctioning (ES) with either OSS or CSS.

DESIGN, PATIENTS AND METHODS:

This before-after observational study investigated patients colonized with bacteria carrying multidrug resistance (MDR). Patients admitted to the ICU were routinely screened for MDR-positive bacterial strains by regular culture of tracheal aspirates. Before obtaining screening results, patients are suctioned with an OSS (Unomedical[†], Denmark). If screening showed tracheal colonization either with MDR or a high burden of other pathogens, the ES method was switched to CSS (Ty-Care^{††} exel, Covidien). Consecutive OSS and CSS ES procedures in 10 patients were studied. Swab samples were taken before and after ES from the respiratory care equipment for microbiologic culture. HCWs put on clean gloves before performing ES and just after the procedure. HCWs applied their gloved hands to agar culture plates and the gloves were then discarded. Microbial colonies on culture plates were systematically identified using routine microbiological methods.

RESULTS:

Data were available for 9 OSS and 10 CSS procedures. Glove contamination occurred during all 9 OSS procedures, but in only 3 of 10 ES with CSS ($p < 0.004$). Median glove contamination after ES using OSS was 40 (13-105) colony-forming units (CFUs) per plate and 0 with CSS ($p = 0.0002$). Maximum glove contamination was 240 CFU/plate with OSS compared with 15 CFU/plate with CSS. The median (range) level of contamination of respiratory equipment increased significantly from 0 (0-2) CFU before ES to 5 (0-30) CFU ($p < 0.01$) after ES with OSS. In contrast, the median level of contamination before and after ES with CSS was 0 ($p = 0.31$). After ES with OSS, contamination was found on 74% equipment samples up to a maximum level of 300 CFU/plate. In comparison, a significantly smaller proportion of samples taken after ES with CSS were contaminated (6%, $p < 0.0001$) and the maximum level of contamination was only 10 CFU/plate.

CONCLUSIONS:

ES by OSS of patients harbouring bacterial strains with MDR causes frequent and substantial bacterial contamination of HCW gloves and airway equipment. CSS significantly reduces the contamination associated with the procedure, thereby reducing the risk of patients and staff in the ICU developing treatment-resistant infections.

[†]Unomedical, Birkerod, Denmark. ^{††}Ty-Care™ exel is a registered trademark of Covidien, Elancourt, France.

14. Nosocomial outbreak of carbapenem-resistant *Acinetobacter baumannii* in intensive care units and successful outbreak control program

Choi WS, Kim SH, Jeon EG, Son MH, Yoon YK, Kim JY, Kim MJ, Sohn JW, Kim MJ, Park DW. J Korean Med Sci 2010;25:999-1004.

BACKGROUND:

A. baumannii has been increasingly reported as a significant causative organism of various nosocomial infections, especially among critically ill patients in ICUs. Serious *A. baumannii* infections are usually treated with a carbapenem, but resistance to these compounds is increasing worldwide and is associated with high morbidity and mortality rates.

OBJECTIVE:

To describe the outbreak of carbapenem-resistant *A. baumannii* (CRAB) in two ICUs and the infection control program that successfully reduced the spread of CRAB.

DESIGN, PATIENTS AND METHODS:

After noting an increase in CRAB strains, the investigators conducted a prospective before-after microbiological surveillance study in two ICUs from October 2007 through July 2008. Samples for culture were obtained from patients, their immediate surroundings and healthcare workers. All isolates underwent species identification and antibiotic susceptibility testing, and the genetic relationships of the CRAB isolates were analysed using pulse-field gel electrophoresis (PFGE). During the outbreak, control strategies were established and implemented beginning in April 2008. These strategies covered prevention of hand-borne transmission of CRAB via HCWs through strict contact precautions; reduction of environmental contamination by cleaning all areas of the ward environment and equipment; prevention of transmission and environmental contamination of CRAB during endotracheal suctioning. Because CRAB was isolated predominantly from the respiratory tract (see results), open suctioning was presumed to be the main cause of environmental contamination. Use of a CSS[†] was introduced for all patients receiving MV, and new guidelines were introduced for aseptic techniques of open suctioning patients not on MV. Education was provided for all staff, emphasizing the importance of hand hygiene and of controlling environmental contamination.

RESULTS:

During the outbreak period, a total of 204 specimens from 57 patients were positive for CRAB; 155 (76.0%) were recovered from the respiratory tract and 21 (10.3%) from blood. CRAB infection was diagnosed in 19 patients, 17 of whom (89.4%) had pneumonia. The incidence of CRAB colonization/infection was 38.6 cases/1000 ICU patients. The overall mortality rate, which was 8.2% before the outbreak occurred, increased to 9.9%. The number of newly diagnosed cases per month increased to a maximum of 17 in March 2008 and began to decrease after the introduction of outbreak control measures. By August 2008, there were no new cases of CRAB colonization or infection in either ICU. PFGE patterns showed that the isolates taken from patients, from the hands of HCWs, and from the ward environment were genetically related and likely to have been involved in the outbreak. The data suggested that type A1 CRAB was probably the major causative organism of the outbreak.

CONCLUSION:

There is a high probability that patient-to-patient cross transmission of CRAB is related to contact with contaminated environmental items and to transient colonization of HCWs' hands. Because open ES is likely to be a major contributor to environmental contamination, strict contact precautions, extensive environmental decontamination, and use of a CSS can be effective for the control of a CRAB outbreak.

[†]Products from undisclosed suppliers were used in the study.

NON-CLINICAL STUDIES

15. The impact of closed endotracheal suctioning systems on mechanical ventilator performance

El Masry A, Williams PF, Chipman DW, Kratochvil JP, Kacmarek RM. Respir Care 2005;50:345–353.

BACKGROUND:

Closed suction systems (CSS) allow uninterrupted ventilation during endotracheal suctioning (ES), thereby decreasing lung volume loss and impairment of gas exchange. The impact of closed ES on ventilator function has not, however, been studied in detail.

OBJECTIVE:

To compare the performance of 11 intensive care ventilators in various ventilation modes during closed endotracheal suctioning (ES).

DESIGN AND METHODS:

In this non-clinical experimental study, the performance of 11 intensive care ventilators was evaluated using a 2-chamber mechanical lung to simulate the respiratory system. The model incorporated a Trach Care^a (Avanos Medical) CSS to investigate the impact of ES on air flow and pressure. The ventilators were: Evita 4^b (Dräger Medical); Galileo^c; Raphael^c (Hamilton Medical); PB 840^d, PB 760^d, PB 7200^d (Puritan Bennett); Esprit^e (Respironics) Servo 900C^f, Servo 300^f, Servo-i^f (Siemens-Elema); and Avea^g (Viasys). All ventilators were set up according to the manufacturers' recommendations, but without a circuit humidifier, to avoid the problem of condensate in the ventilator circuit. Each ventilator was evaluated in pressure-assist/control (PA/C), volume-assist/control (VA/C) if available, continuous positive airway pressure (CPAP), and pressure support (PS) ventilation modes using 2 suctioning pressures (-120 mm Hg and approximately -200 mm Hg) and with 2 tidal volumes (450 mL and 900 mL). In the lung model, airway pressure, airway flow, and pressure distal to the suction catheter tip were measured, converted to electronic signals and digitized. The resulting flow and airway pressure waveforms were recorded continuously. All waveforms were analyzed 10 s before suctioning was performed, during a 15 s suctioning period, and for 30 s after cessation of suctioning. Ventilator malfunction was defined as an inability to continue gas delivery during closed ES and an inability of the ventilator to resume pre-suctioning gas delivery pattern within 5 breaths after suctioning.

RESULTS:

All ventilators continued to deliver gas in all modes during closed ES. All ventilators resumed the pre-suctioning gas delivery pattern within 1–2 breaths after suctioning ended. There were no significant differences in peak airway, end-expiratory pressure, peak flow, or respiratory rate before and after ES with any ventilator, regardless of mode or suction pressure. During suctioning, end-expiratory pressure decreased markedly in all modes, and peak flow increased in all modes except VA/C ($p < 0.001$). Respiratory rate increased during suctioning in PA/C and VA/C ($p < 0.001$) but not during PS or CPAP. Gas delivery was most altered during VA/C with the smaller tidal volume ($p < 0.05$) and least altered during PA/C with the larger tidal volume.

CONCLUSIONS:

Although closed ES alters the delivery of PA/C, VA/C, CPAP, and PS this procedure does not cause ventilator malfunction. All ventilators maintained gas delivery during closed ES in all ventilation modes and upon completion of suctioning and removal of the suction catheter, all ventilators tested returned to their pre-suctioning waveforms within 1-2 breaths. Closed ES suctioning does decrease end-expiratory pressure, but airway pressure is also re-established within 1-2 breaths after suction catheter removal.

^a Registered Trademark or Trademark of Avanos Medical, Inc. or its affiliates. ©2016 HYH. All rights reserved.;

^b Evita 4 is a registered trademark of Dräger Medical, Telford, PA, USA;

^c Galileo and Raphael are registered trademarks of Hamilton Medical, Reno, NV, USA;

^d PB 840, PB 760, PB 7200 is a registered trademark of Puritan Bennett, Pleasanton, CA, USA;

^e Esprit is a registered trademark of Respirationics, Pittsburgh, PA, USA;

^f Servo 900C6, Servo 3006, Servo-i are registered trademarks of Siemens-Elema, Danvers, MA, USA;

^g Avea is a registered trademark of Viasys Products, Palm Springs, CA, USA.

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