RESPIRATORY CARE Paper in Press. Published on September 17, 2013 as DOI: 10.4187/respcare.02601

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

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Conflicts of Interest Statement and Source of funding

Kimberly-Clark supported this study by supplying 10 Ballard Trach Care-72™ closed suction catheters. A Corley and J F Fraser have also received an unrestricted grant from Kimberly-Clark for partial funding of the study. Kimberly-Clark had no part in study design, data collection, data analysis, or creation of the manuscript. For the remaining authors, there are no financial or other potential conflicts of interest to declare.

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ABSTRACT

Background Airway suctioning in mechanically ventilated patients is required to maintain airway patency. Closed suction catheters (CSC) minimise lung volume loss during suctioning but require cleaning post-suction. Despite their widespread use, there is no published evidence examining lung volumes during CSC cleaning. The study objectives were to quantify lung volume changes during CSC cleaning; and to determine if these changes were preventable using a CSC with a valve *insitu* between the airway and catheter-cleaning chamber.

Methods This prospective randomised crossover study was conducted in a metropolitan tertiary intensive care unit. Ten patients mechanically ventilated with Synchronised Intermittent Mandatory Ventilation – volume control (SIMV-VC) and requiring manual hyperinflation (MHI) were included in this study. CSC cleaning was performed using two different brands of CSC (one with a valve [Ballard Trach Care-72™, Kimberly-Clark] and one without [Portex® Steri-Cath® DL, Smiths Medical]). The manoeuvres were performed in both SIMV-VC and MHI. Lung volume change was measured via impedance change using electrical impedance tomography (EIT). A mixed model was used to compare the estimated means.

Results During cleaning of the valveless CSC, significant decreases in lung impedance occurred during MHI (-2563 impedance units; 95%CI 2213, 2913; p<0.001) and significant increases in lung impedance occurred during SIMV (762; 95%CI 452, 1072; p<0.001). In contrast, cleaning of the CSC with a valve *insitu* resulted in non-significant lung volume changes, and maintenance of normal ventilation during MHI and SIMV-VC respectively (188, 95%CI -136, 511, p=0.22; and 22, 95%CI -342, 299, p=0.89).

Conclusions When there is no valve between the airway and suction catheter, cleaning of the CSC results in significant derangements in lung volume. Therefore, the presence of such a valve should be considered essential in preserving lung volumes and uninterrupted ventilation in mechanically ventilated patients.

Key words

Suctioning; lung volume; lung volume measurement; alveolar derecruitment; electrical impedance tomography; mechanical ventilation

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INTRODUCTION

The goal of protective ventilation strategies is to minimise the shear forces associated with repeated derecruitment and re-expansion of alveoli in an attempt to prevent the development of ventilator induced lung injury [1]. Endotracheal suctioning leads to significant lung derecruitment [2-4] however, it is essential in maintaining a patent airway in mechanically ventilated patients. It has been demonstrated that closed suctioning minimises loss of lung volume when compared to open suctioning, largely due to the fact that disconnection from the ventilator circuit is not required [2,4,5]. This has lead to its increased use particularly in patients requiring long term ventilation.

Closed suction catheters (CSC) sit within a sterile sleeve, in-line with the ventilator circuit and the patient's airway. During airway suctioning, the catheter is manually advanced into the airway and suction is applied whilst the catheter is being withdrawn. After each suction, the CSC requires flushing with normal saline whilst, simultaneously, applying suction. This cleaning process is necessary to prevent the build-up of secretions within the catheter but can involve a prolonged period of suction being applied to adequately clean thick tenacious secretions from the lumen of the catheter. During the cleaning of a CSC in a mechanically ventilated patient in our Intensive Care Unit (ICU), the investigators made an incidental finding while measuring the effects of suctioning on lung volume loss. It was observed that, after airway suctioning was complete and during cleaning of the CSC, there was a marked loss of lung volume.

We hypothesized that the observed loss of lung volume during CSC cleaning was due to the absence of a valve between the CSC and the patient's airway in the product that was used for closed airway suctioning at the time (Portex® Steri-Cath® DL, Smiths Medical, Ashford, Kent, UK). The Ballard Trach Care-72™ closed suction catheter (Kimberly-Clark Health Care, Roswell, GA) has a separate cleaning chamber which is isolated from the patient's airway and ventilator circuit by a valve that closes once the catheter has been withdrawn into the sterility sleeve (Figure 1). One unpublished bench top study examined ventilator volume loss during CSC cleaning by attaching a ventilator to a test lung [6]. This study demonstrated that almost all volume was removed from the test lung during cleaning of the CSC without a valve. In contrast, when there was a valve in place between the ventilator circuit and the CSC, very little volume was lost during CSC cleaning. We were interested in

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exploring these findings further in the clinical in vivo situation, removed from the standardised conditions of a bench top experiment.

Loss of lung volume can be safely and accurately measured at the bedside using Electrical Impedance Tomography (EIT) [6-8]. A relatively new tool EIT measures change in resistance or biological impedance to current flow [9, 10]. An array of electrodes placed circumferentially around the thorax records the changes of impedance caused by the changes of air volume within the thorax during inspiration and expiration [10, 11]. The recorded changes can be used to create images of ventilation within the lungs both globally and regionally [10, 12, 13]. Due to the strong linear relationship between impedance change and volume change [14, 15], changes in lung volume can be accurately measured. In particular, this measurement technique has been shown to reliably and accurately detect changes in lung volume during and after endotracheal suctioning [2,6,7] .

In this study we aimed to compare the loss of end-expiratory lung volume (EELV) during CSC cleaning when using a CSC with a valve and without a valve to determine if the valve's presence preserved lung volume during manual hyperinflation (MHI) and volume controlled synchronised intermittent mandatory ventilation (SIMV-VC).

METHODS

Prior to study commencement, ethical approval was obtained from our institution's Human Ethics and Research Committee (EC27105). Written informed consent was obtained from each participant prior to their scheduled cardiac surgery and the study was conducted in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki.

Each consented patient was then screened on return to ICU. Patients were deemed eligible if they met all of the following inclusion criteria:

- ≥ 18 years
- post cardiac surgery
- ventilated in SIMV-VC mode
- required MHI as part of their standard treatment.

Patients were excluded if they:

- required ongoing cardiac pacing,
- had an open sternum
- had a positive end-expiratory pressure (PEEP) ≥ 10cmH_2O
- were unlikely to be able to tolerate MHI due to desaturation or haemodynamic instability (defined as: SaO_2≤90%, MAP<55mmHg, PaO_2<70mmHg, and/or active bleeding with drain loss of >100mls in last hour)
- required any change in ventilator settings between cleaning manoeuvres.

Cleaning of closed suction catheter protocol

All cleaning procedures were performed by two critical care nurses (NS and AC). Patients were positioned in a supine position. CSC cleaning was tested during two modes of ventilation (MHI and SIMV-VC); and using two types of CSC (Portex® Steri-Cath® DL, Smiths Medical, Ashford, Kent, UK; and the Ballard Trach Care-72™, Kimberly-Clark Health Care, Roswell, GA). The order of catheter testing and mode of ventilation was randomised using a sequentially numbered opaque envelope system so that, for each patient, four catheter cleaning episodes were performed, each of five seconds in duration.

Whilst assessing the effects of CSC cleaning during SIMV-VC, ventilator settings (Puritan Bennett 840; Covidien, Mansfield, Mass) were standardised to the following:

- SIMV-VC mode with a tidal volume of 6 to 8 mL/kg
- inspiratory flow trigger of 1.5 L/min
- peak flow of 50 L/min
- PEEP of 5 cm H_2O
- FiO_2 set by the intensive care specialist to maintain an oxygen saturation value via pulse oximetry of 95% or greater.

While performing CSC cleaning during MHI:

- breaths were delivered at 15 breaths per minute using a Mapleson C modified circuit (Mayo Healthcare, Rosebury, Australia)

- a manometer was placed inline with the circuit to maintain PEEP at between 4 - 6 cm H_2O and a peak inspiratory pressure of 25 - 30 cm H_2O.

Each CSC cleaning was performed in the following manner:

1. The suction catheter was fully retracted and contained within the sterility sleeve (ie. outside the patient's endotracheal tube)
2. Suction (standardised to -150 mmHg) was applied for 5 seconds by depressing the suction button on the closed suction device and, simultaneously, 10mls of Normal Saline was instilled to clean the suction catheter
3. Twenty minutes was allowed to elapse between each CSC cleaning to negate any washout effect
4. The suction catheter was not introduced into the patient's airway during the study

Lung volume measurement

EELV change was assessed using the EIT Evaluation Kit 2 (Drager, Lubeck, Germany). After self test of the device as per the manufacturer's instructions, end-expiratory lung impedance (EELI) was measured at baseline (immediately prior to each of the cleaning manoeuvres) and during each of the cleaning episodes performed. The linear relationship between impedance change and volume change has previously been established [14, 15] such that the change in EELI is seen as an accurate reflection of change in EELV.

Statistical analysis

To account for the repeated results from the same subject, a mixed model was used to analyse the data. The model included a random intercept for each subject with a factor of ventilation type (MHI or SIMV) or catheter type (valve or no valve). A pair-wise comparison of the estimated marginal means was performed to ascertain the change in EELI during CSC cleaning compared to baseline. Data were normally distributed. Ten subjects were required for a power of 80% at 5% significance.

RESULTS

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Nineteen patients were consented to the study. Two patients did not meet inclusion criteria after their surgery due to haemodynamic instability and seven patients had their surgery cancelled. Therefore, ten patients were randomised and studied, eight of whom were male, with a mean age of 55.8 years (± 10.5). Five patients underwent coronary artery bypass graft surgery, four underwent valve replacement and one patient had a myomectomy. Table 1 summarises the study findings.

Manual hyperinflation

When ventilating with MHI, cleaning of the CSC with a valve *insitu* was not associated with a significant difference in mean EELI from baseline (188 impedance units; 95% CI -136, 511; p=0.22). However, when cleaning the CSC was performed with no valve between the airway and the sterility sleeve in the same mode of ventilation, there was a statistically significantly decrease in mean EELI from baseline (-2563; 95% CI 2213, 2913; p<0.001) indicating a significant loss of EELV during cleaning. Figure 2 provides an example of these findings.

Synchronised Intermittent Mandatory Ventilation

During SIMV-VC, there was no significant changes in EELI during CSC cleaning when using a CSC with a valve (+22; 95% CI -342, 299; p=0.89). In contrast, there were large increases in EELI observed during CSC cleaning when using a CSC without a valve (+762; 95% CI 452, 1072; p<0.001) indicating significant increases in EELV and interruption to delivered ventilation. Figure 3 provides an example of these findings.

DISCUSSION

The results of this study demonstrate that when ventilating with MHI and SIMV-VC, the presence of a valve between the patient's airway and the CSC protects lung volumes and maintains uninterrupted ventilation during cleaning of the CSC. CSC cleaning without such a valve results in significant lung derecruitment during MHI, and significant increases in lung volume and derangements to normal ventilation during SIMV-VC. Although not supported by any evidence, there is a presumption by clinicians that the application of suction during CSC cleaning has minimal or negligible effect on lung volume and ventilation. This study clearly establishes that this is not the case and that end-expiratory lung volume is significantly affected by cleaning of a CSC without a valve.

Cleaning of the CSC is essential after airway suctioning as, without adequate cleaning of the CSC after suctioning, colonised bacteria from the catheter may spread to the ventilator circuit and lower respiratory tract, increasing the chance of ventilator associated pneumonia [16-19]. Whilst it is critical that cleaning of the CSC is performed after suctioning, it is evident from this data that there must be a valve present between the patient's airway and the cleaning chamber to prevent interruption to ventilation and loss of lung volume during this procedure. For the purposes of this study, catheter cleaning time was standardised to 5 seconds. In clinical practice, this period may be much longer dependent on how thick and tenacious the patient's secretions are and how difficult they are to remove from the catheter. Therefore, the actual period of derecruitment and ventilation interruption may be far longer, resulting in greater loss of lung volume and longer interruptions to ventilation.

Significant lung derecruitment was observed during MHI when using the CSC without a valve. It is interesting that extensive research has been conducted examining strategies to minimise lung derecruitment during suctioning [3-5, 20] however there is minimal data examining the effects of CSC cleaning on lung volumes and decrecruitment. This study clearly shows that, when using a CSC without a valve in MHI, lung derecruitment during CSC cleaning is a significant contributor to suctioning-induced lung derecruitment. This repeated alveolar collapse and reopening has been shown to be harmful to the lung [21-22] and should be avoided. This lung derecruitment was entirely avoided when using a CSC with a valve therefore the use of this type of suction catheter should be advocated in clinical practice to avoid the negative effects of derecruitment.

In contrast to the changes seen with CSC cleaning during MHI, EELV was seen to markedly increase with CSC cleaning in the absence a valve during SIMV-VC. During CSC cleaning without a valve, the suction applied to clean the CSC was observed to continuously trigger the ventilator to deliver a breath due to flow trigger activation. The complex interaction between the suction, peak flow and the inspiratory flow trigger leads to this constant ventilator cycling and interruption to delivered ventilation. Breath stacking and the resultant increase in lung volume on a sustained and repeated basis could possibly contribute to alveolar damage and volutrauma [23], particularly in vulnerable patients with

acute lung injury or acute respiratory distress syndrome [24]. The lung volume changes that may result in these negative effects proved to be completely preventable by using a CSC with a valve.

The one previous study in this area [25] examined the effects of CSC cleaning during volume-controlled ventilation in a bench top experiment. This study tested a CSC with a valve against a CSC without a valve and measured the effect on ventilator circuit volume loss. It was found that when cleaning the CSC without a valve the entire delivered volume was lost. In contrast to this finding, the present study actually found an increase in the volume delivered. The differences in these two findings can be attributed to different ventilator trigger settings between the studies. Van Hooser et al [25] set a pressure trigger of -20cm H_2O to avoid auto-triggering of the ventilator by the negative pressure generated by the suction. Therefore, with the ventilator not triggered to deliver a breath, no extra volume was delivered into the circuit and thus volume was lost as a result of the suction applied during CSC cleaning.

However, we chose a more clinically relevant flow trigger of -1.5 litres per minute and, as such, observed the auto-triggering during SIMV-VC that the previously mentioned study were trying to avoid. This resulted in the increase in EELV during CSC cleaning without a valve observed in the present study. It is evident, then, that despite the ventilator trigger setting, CSC cleaning without a valve results in unintended and uncontrolled consequences to delivered ventilator breaths and the lung. In both studies, the presence of a valve between the patient's airway and the catheter cleaning chamber either minimised or completed~~l~~y negated the deleterious effects of suction on the functioning of the ventilator and on the lung.

The severity of adverse events associated with suctioning appear to be dependent on the duration of the suctioning procedure [26], therefore there are firm recommendations regarding limiting the period of airway suctioning to no more than 15 seconds [27]. However, there are no time limits recommended for cleaning of CSC largely due to the fact that there has previously been no evidence regarding the effects of CSC cleaning on lung volume. If using a CSC without a valve, clinicians and nurses must be mindful of the effects of CSC cleaning on lung volume. Guidelines should be put in place when using a CSC without a valve limiting the cleaning time. Alternatively, CSCs with a valve should be

routinely used particularly in patients who are vulnerable to the adverse effects associated with lung derecruitment and barotrauma. At the time of this study, our ICU used a CSC with no valve *insitu* between the patient's airway and the sterility sleeve. The study findings have led us to change to the CSC with a valve and this change has been cost neutral to the ICU. Based on these findings, the investigators believe that the use of CSC without valve can no longer be justified due to the obvious lung derecruitment and failure to maintain uninterrupted ventilation during the cleaning of the catheters.

This study has a number of limitations. A small sample of patients were studied, however we were able to demonstrate statistically and clinically relevant differences between the two catheter types. Although post-operative cardiac surgical patients were recruited to ensure a homogenous group was studied, further investigation of other mechanically ventilated patient groups is required. Additionally, no long term outcomes were assessed due to the randomised crossover design of the study. As only SIMV and MHI were assessed in this study, further work needs to be done investigating the effects of CSC cleaning in different ventilation modes.

CONCLUSIONS

In mechanically ventilated patients, using a CSC with a valve in place between the patient's airway and the catheter cleaning chamber prevents lung derecruitment and ventilation interruption 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. Utilising a closed suctioning catheter with a valve should be considered best practice for mechanically ventilated patients, particularly for patients with acute lung injury or acute respiratory distress syndrome.

RESPIRATORY CARE Paper in Press. Published on September 17, 2013 as DOI: 10.4187/respcare.02601

REFERENCES

1. Lachmann B. Open up the lung and keep the lung open. Intensive Care Med 1992;18(6):319-321.
2. Corley A, Spooner AJ, Barnett AG, Caruana LR, Hammond NE, Fraser JF. End-expiratory lung volume recovers more slowly after closed endotracheal suctioning than after open suctioning: a randomized crossover study. J Crit Care 2012;27(6): 742.e1–742.e7.
3. Fernandez MD, Piacentini E, Blanch L, Fernandez R. Changes in lung volume with three systems of endotracheal suctioning with and without pre-oxygenation in patients with mild-to-moderate lung failure. Intensive Care Med 2004;30(12):2210-2215.
4. Maggiore SM, Lellouche F, Pigeot J, Taille S, Deye N, Durrmeyer X, et al. Prevention of endotracheal suctioning-induced alveolar derecruitment in acute lung injury. Am J Respir Crit Care Med 2003;167(9):1215-1224.
5. Cereda M, Villa F, Colombo E, Greco G, Nacoti M, Pesenti A. Closed system endotracheal suctioning maintains lung volume during volume-controlled mechanical ventilation. Intensive Care Med 2001;27(4):648-654.
6. Grant CA, Fraser JF, Dunster KR, Schibler A. The assessment of regional lung mechanics with electrical impedance tomography: a pilot study during recruitment manoeuvres. Intensive Care Med 2009;35(1):166-170.
7. Lindgren S, Odenstedt H, Olegard C, Sondergaard S, Lundin S, Stenqvist O. Regional lung derecruitment after endotracheal suction during volume- or pressure-controlled ventilation: a study using electric impedance tomography. Intensive Care Med 2007;33(1):172-180.
8. Tingay DG, Copnell B, Grant CA, Dargaville PA, Dunster KR, Schibler A. The effect of endotracheal suction on regional tidal ventilation and end-expiratory lung volume. Intensive Care Med 2010;36(5):888-896.
9. Brown B, Barber D, Seagar A. Applied potential tomography: possible clinical applications. Clin Phys Pysiol Meas 1985;6(2):109-121.
10. Caruana LR, Paratz J, Chang AT, Fraser JF. Electrical impedance tomography in the clinical assessment of lung volumes following recruitment manoeuvres. Physical Therapies Review 2011;16(1):66-74.

11. Bodenstein M, David M, Markstaller K. Principles of electrical impedance tomography and its clinical application. Crit Care Med, 2009;37(2):713-724.

12. Costa ELV, Lima RG, Amato MBP. Electrical impedance tomography. Curr Opin Crit Care, 2009;15(1):18-24.

13. Putenson P, Wrigge H, Zinserling Z. Electrical impedance tomography guided ventilation. Curr Opin Crit Care 2007;13:344-350.

14. Hinz J, Hahn G, Neumann P, Sydow M, Mohrenweiser P, Hellige G, et al. End-expiratory lung impedance change enables bedside monitoring of end-expiratory lung volume change. Intensive Care Med 2003;29(1):37-43.

15. van Genderingen HR, van Vught AJ, Jansen JR. Estimation of regional lung volume changes by electrical impedance pressures tomography during a pressure-volume maneuver. Intensive Care Med 2003;29(2):233-240.

16. Freytag CC, Thies FL, Konig W, Welte T. Prolonged application of closed in-line suction catheters increases microbial colonization of the lower respiratory tract and bacterial growth on catheter surface. Infection 2003;31(1):31-37.

17. Hagler DA, Traver GA: Endotracheal saline and suction catheters: sources of lower airway contamination. Am J Crit Care 1994;3(6):444-447.

18. Inglis TJ, Lim TM, Ng ML, Tang EK, Hui KP. Structural features of tracheal tube biofilm formed during prolonged mechanical ventilation. Chest 1995;108(4):1049-1052.

19. Sottile FD, Marrie TJ, Prough DS, Hobgood CD, Gower DJ, Webb LX, Costerton JW, et al. Nosocomial pulmonary infection: possible etiologic significance of bacterial adhesion to endotracheal tubes. Crit Care Med 1986;14(4):265-270.

20. Dyhr T, Bonde J, Larsson A: Lung recruitment manoeuvres are effective in regaining lung volume and oxygenation after open endotracheal suctioning in acute respiratory distress syndrome. Crit Care 2003;7(1):55-62.

21. Amato MB, Barbas CS, Medeiros DM, Maqaldi RB, Schettino GP, Lorenzi-Filho G, et al. Effect of a protective-ventilation strategy on mortality in the acute respiratory distress syndrome. N Engl J Med 1998;338(6):347-354.

22. Muscedere JG, Mullen JB, Gan K, Slutsky AS. Tidal ventilation at low airway pressures can augment lung injury. Am J Respir Crit Care Med 1994;149(5):1327-1334.

23. The Acute Respiratory Distress Syndrome Network: Ventilation with lower tidal volumes as compared with traditional tidal volumes for acute lung injury and the acute respiratory distress syndrome. New England Journal of Medicine 2000;342(18):1301-1308.

24. Bernard GR, Artigas A, Brigham KL, Carlet J, Falke K, Hudson L, et al. Report of the American-European consensus conference on ARDS: definitions, mechanisms, relevant outcomes and clinical trial coordination. The Consensus Committee. Intensive Care Med 1994;9(1):72-81.

25. Van Hooser T, Madsen E, Flood T. New closed suction catheter design reduces ventilator volume loss during simulated suction events. Abstract presented at American Association for Respiratory Care International Respiratory Congress, 2002.

26. Pedersen CM, Rosendahl-Nielsen M, Hjermind J, Egerod I. Endotracheal suctioning of the adult intubated patient--what is the evidence? Intensive Crit Care Nurs 2009;25(1):21-30.

27. Restrepo RD: AARC Clinical Practice Guidelines: from "reference-based" to "evidence-based". Respir Care 2010;55(6):787-789.

RESPIRATORY CARE Paper in Press. Published on September 17, 2013 as DOI: 10.4187/respcare.02601

ACKNOWLEDGEMENTS

We would like to thank Assoc Prof Adrian Barnett for his statistical support.

Professor John Fraser wishes to also acknowledge the funding provided in support of this research by the Office of Health and Medical Research, Queensland Health, through his current Health Research Fellowship.

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FIGURE LEGENDS

Figure 1 Closed suction catheter with a valve between the patient's airway and sterility sleeve

Figure 2 Electrical impedance tomography ventilation waveforms during manual hyperinflation. The grey shaded areas denote the catheter cleaning periods.

(A) Cleaning of closed suction catheter with a valve, showing no interruption to ventilation during cleaning

(B) Cleaning of closed suction catheter without a valve, showing loss of lung volume during cleaning

Figure 3 Electrical impedance tomography ventilation waveforms during synchronised intermittent mandatory ventilation – volume control. The grey shaded areas denote the catheter cleaning periods.

(A) Cleaning of CSC with a valve, showing no interruption to ventilation during cleaning

(B) Cleaning of CSC without a valve, showing increased of lung volume and interruption to ventilation during cleaning

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Table 1 Mean differences in end-expiratory lung impedance (EELI) by ventilation mode (manual hyperinflation [MHI] and synchronised intermittent mandatory ventilation – volume control [SIMV-VC] and catheter type)

Ventilation mode/ Catheter type	**Mean EELI at baseline (Impedance units)**	**Mean EELI during cleaning (Impedance units)**	**Difference (Impedance units)**	**95% CI**	**p-value**
MHI with valve	979	1166	188	-136, 511	0.22
MHI without valve	930	-1633	-2563	2213, 2913	<0.001
SIMV-VC with valve	286	308	+22	-342, 299	0.89
SIMV-VC without valve	292	1054	762	452, 1072	<0.001

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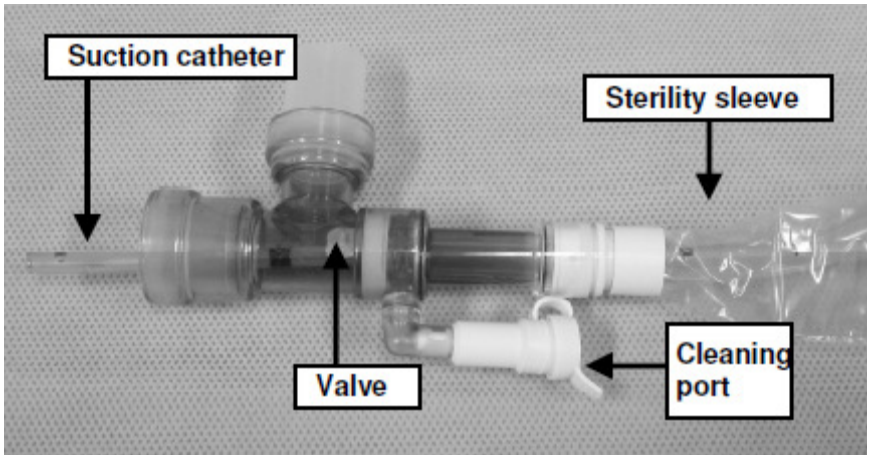

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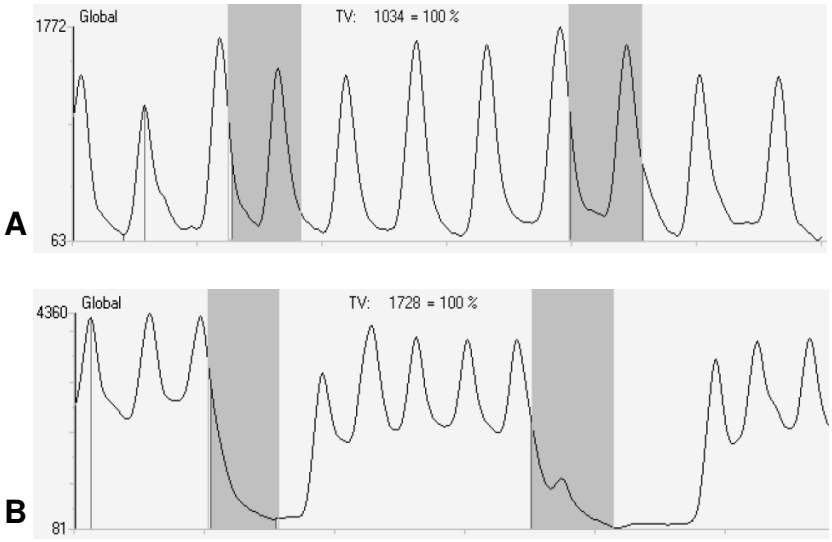

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