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A journal for both independent clinical research and bench studies in the field of respiratory care.

Published by the respiratory research class of Lone Star College-Kingwood Associate Degree respiratory care department.

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Editor-in-chief comments

One of the ongoing requirements of LSC: Kingwood Associate in Applied Science Degree includes participation in the creation of this magazine for *RSPT 2243 Research in Respiratory Care*. Students formed teams that designed research projects for application during the semester. Some of the requirements of this course were membership in a weekly journal club of current articles from AARC's *Journal of Respiratory Care* as well as active participation in writing the four papers in our journal based on their independent research. Students were also expected to provide peer-review of other teams' papers.

The summer 2012 editing board consisted of the following: Jovanna Mejia, S.R.T., Anna Dunahoe, S.R.T., Joyce Bukut, SRT, Jennifer McMurtrey, SRT, Shaun Jones, SRT Darshane L. Miller SRT, April Anderson B.S., S.R.T., Ray Managbanag B.S., S.R.T., Frederick Johnson B.S. L.C.C.A. S.R.T., Kimberly Gonzalez, L.V.N., S.R.T., Ana Vela, S.R.T., Juanita Robinson, S.R.T, and Stella Ekewenu, S.R.T., Jennifer Hua S.R.T., Kim Frie S.R.T., Cynthia Young S.R.T., and Julissa Webb S.R.T.

All research this semester was in the form of bench studies. Half the class concentrated on exploring the Metaneb™ IPV machine our program acquired this year. One team collected flow, volume and pressure graphics on the Metaneb™ in various modes then compared these graphs to those created by the Vortran ™ IPV machine. Another group filled a cadaver cow lung with artificial secretions then attached the Metaneb™ in an attempt to mobilize secretions.

The other foci of LSC: Kingwood College Respiratory Care Department's investigation included bench studies of endotracheal tubes. One team measured the time it took for cuff pressures to stabilize at body temperature, while another team compared various methods of endotracheal cuff inflation and their ability to prevent material from above the cuff to contaminate the lower airways in a cadaver cow trachea.

This year found several Kingwood College respiratory care research teams using cadaver cow lung donated by a local meat processing plant. Due to the extremely large trachea of the cows and the not quite human anatomy of these lungs, the team had their work cut out for them just finding a central airway that would fit the human-sized endotracheal tubes. The first team to dissect their cow lungs forged the trail for the rest of the teams. Isolating appropriate airways and working with fresh tissue that has not been preserved was more time-consuming than anyone expected. The program facilitator learned that kitchen shears are not only faster than scalpels on lung tissue, but safer. Although the tissue was from cattle deemed safe for human consumption, great efforts were taken to utilize personal protective gear and dispose of the material after. This was to my mind, one of the most frustrating and yet most enjoyable research classes I've ever conducted.

We would like to take this occasion to thank Maribeth Stitt RDH Med. program director of the LSC: Kingwood College dental hygiene department who x-rayed the lungs. We thank the Garza Meat Processing Plant for donation of the cow lungs.

Once again, LSC: Kingwood's Graphic department lead by Shawn Sedoff provided a talented student-graphic designer via their annual Design-A-Thon. The student-graphic designer, Dominic Zotti, managed (in spite of my rather contradictory instructions) to design two wonderful covers for both 2012 volumes based on airway morphology and electron microscope views of the alveoli.

As always, we thank Kenny McCowen program director for his foresight in creating the course and his continued support of this Associate degree research class as it moves closer to a second decade of existence.

Elizabeth Kelley Buzbee A.A.S., R.R.T.- N.P.S., R.C.P.

Airway Clearance: The Effectiveness of the MetaNeb© using Two Cadaver Cow Lungs.

Jovanna Mejia, SRT, Anna Dunahoe, SRT, Joyce Bukut, SRT, Jennifer McMurtrey, SRT, Shaun Jones, SRT
Faculty facilitator: Elizabeth Kelley Buzbee A.A.S., R.R.T.-N.P.S., R.C.P.

Abstract

INTRODUCTION: The MetaNeb© a version of intrapulmonary percussion ventilation is designed to increase the mucociliary clearance, improve gas exchange, humidify the airway, stabilize airway patency, and improve the lung mechanics. OBJECTIVE: To mobilize secretions from all lobes of the lungs with the use of the MetaNeb© machine. METHODS: Artificial secretions were verified for mobility in both trials. Conducted two trials; one cow cadaver lung was intubated and placed on Bi-level Positive airway Pressure mode and 30cc of synthetic secretions was instilled followed by positive pressure to send secretions into the lung. The lung was x-rayed. After 15 minutes on MetaNeb© at manufacturer's recommended treatment settings, secretions were suctioned into sputum trap and the lung was x-rayed. The other lung was placed on Continuous Positive airway Pressure mode and metal shavings were added to the secretion. Lung was x-rayed. After 15 minutes on MetaNeb©, secretions were suctioned and x-ray repeated. Volumes and weights of secretions obtained with both methods were recorded. RESULTS: 3.21grams of secretions were removed from the lung on bi-level positive airway pressure; 1.45 grams were removed on continuous positive airway pressure. CONCLUSION: Significantly more secretions were removed from the lung during bi- level positive airway pressure than from continuous positive airway pressure. The total amount of secretions instilled was not recovered possibly due to the evaporation or absorption of the synthetic secretions into the lung tissue.

Background

The MetaNeb© was a version of intrapulmonary percussive ventilation (IPV). The first form of IPV, the Percussionaire ™, was introduced in 1979 by Dr. Forrest Bird (Cairo & Pilbeam, 2010). According to the manufacturer, the MetaNeb© system was originally designed to increase the mucociliary clearance, improve the gas exchange, humidify the airway, stabilize airway patency, and improve the lung mechanics (Reychler, et al., 2004).

Theoretically, the advantage of IPV had "been described as a 2-fold effect in airway clearance" (Myers, 2007); the percussive motion or oscillations reportedly decreased the viscoelastic properties of the mucus and increased expiratory airflow, thus making it easier to mobilize secretions up and through the airways by means of short bursts airflow (Myers, 2007). The MetaNeb© is meant to be utilized in three different ways including lung expansion therapy, airway clearance, and aerosolized medication delivery.

For the purpose of this research, lung hyperinflation is defined as increasing lung volume by increasing the transpulmonary pressure gradient (Wilkins, Stoller, & Kacmarek, 2009). Through a sliding Venturi with added continuous aerosol generation, the MetaNeb© device delivers rapid minibursts of gas mixture at 200 to 300 cycles per minute (Natale, Pfeifle, & Homnick, 1994).

The technique of lung expansion was used to help mobilize and remove excessive bronchial secretions, help with lung expansion, and improve oxygenation (Berney & Denehyl, 2002). Medication aerosolized through an intrapulmonary percussive device results in a smaller particle size of 0.2 micrometers with an increased tidal volume and decreased respiratory rate causing greater deposition of the medication in the lungs when compared to small volume nebulizers of 1.89 micrometers (Reychler, et al., 2004).

The background research used in this study was based on previous research of similar IPV systems, because there was limited resources on the MetaNeb© system.

This investigation was designed to test the MetaNeb©'s ability to mobilize secretions in deceased animal lungs, thus answering the question: Can the MetaNeb© effectively mobilize secretions? The expectations are that the MetaNeb©, when applied with proper technique at recommended settings, will effectively mobilize secretions in all lung regions.

For the purpose of the study two calf lungs were utilized. Both animal lungs were received within 12 hours of death and placed on ice for 72 hours. Inclusion criteria contained that the lungs were appropriately sized for intubation, fully intact, and the lungs could be harvested from pig, calf, or

goat, also in addition, the lungs needed to be obtained or donated within 12 hours of death.

Exclusion criteria included anything not the size of a pig, calf, or goat, past 12 hours of death and not intact.

The animal lungs were thoroughly cleaned inside and out with water and soap prior to starting the experiment. The excess tissue, which would not harm the integrity of the lung, was cut away. The lungs were then kept flat on a cardboard box covered in plastic.

The universal precautions were used, which included the standard gloves, gown, goggles, and mask. After the experiment, the lungs were discarded in the proper manner; wrapped, sealed, and double-bagged in an industrial grade garbage bag. The equipment that was used is stated in the addendum.

All equipment was calibrated prior to starting the experiment. For this study the utilization of the resources available on campus were used, which for this case instead of a chest x-ray a dental x-ray unit ultra oral number three size film Kodak's speed D was used.

Equipment Calibration

Scale Calibration

1. Power on the balance
2. Press calibration button and obtain calibration number after pressing "Cal" button
3. Power off and restart the balance
4. Place calibration weights located on the side of the machine
5. Allow time to calibrate
6. Confirm 200g

MetaNeb© Calibration

The MetaNeb© was calibrated by performing the Function Test according to the manufacture's manual. Because of the added bacteria filter to the circuit, which is not mentioned in the manufacture's recommendations, a waveform test was performed showing the difference between the manufacture's recommendations versus the circuit with the added bacteria filter; the waveform findings showed no major changes between the two tests.

Preparation of Secretions

The synthetic secretions were prepared using six tablespoons of lime gelatin mix which was mixed with one cup of boiling water, left to return to room temperature, and stirred occasionally with a fork. One cup of corn syrup was then added, stirred gently with the fork, and the mixture was put in a freezer for 30 minutes. The mixture was removed from the freezer, stirred with a fork, and left sitting at room temperature for an additional 30 minutes. Two tablespoons of warm water was added and mixed in with a fork before each test to restore the original viscosity.

Perform Viscosity Test

For the viscosity test, the foam poster board was marked in centimeters to determine the length of the board. This particular board was 51 centimeters long. The board was then propped on top of a table with an incline of 30^{o} and a 2x6 clear plastic wrap was placed at the bottom of the board to catch the secretions.

A batch of synthetic secretions was mixed and 5cc of the secretions were drawn up in a 30cc syringe. At the top of the board, the secretions were slowly released from the syringe and the stopwatch was started at the same time. The trial was repeated once more, to get two trial runs for each lung.

Protocol of experiment

Step 1. the lungs were modified by cutting away any excess tissue in order to find an appropriately sized airway to use an endotracheal tube size 8.

Step 2. animal lung was set flat on cardboard that was wrapped in plastic. Both of the test subjects were intubated in a lobe with a smaller airway that could support the size of the endotracheal tube; the cuff was inflated to maintain a good seal.

Step 3. the endotracheal tube was then attached to a Portex self inflating manual resuscitator bag and the lungs were then manually bagged. This was done to recruit alveoli.

Step 4. the lungs were then connected to a Respironics V60 Ventilator to apply BiPAP/CPAP and maintained the inflation of lung.

Step 5. perform viscosity test for secretions. (Refer to *How to Perform Viscosity Test* subheading.)

Step 6. the M-PROVE top-loading balance scale was zeroed, the empty syringe, and empty sputum trap were weighed. This was done to adjust for the weight of the containers in the results.

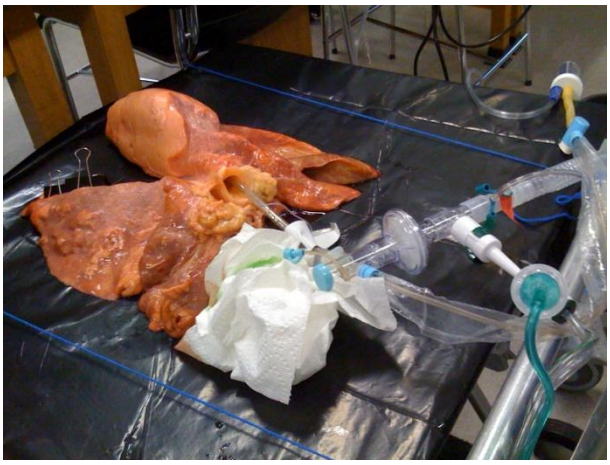
Step 7. the synthetic secretions were weighed in the syringe.

Step 8. then 30cc of synthetic secretions was administered into the airway via syringe.

Step 9. the lung was placed back on BiPAP and the secretions were manually massaged into the distal airways.

Step 10. The BiPAP settings were set at: Ipap 40cmH_2O/Epap 12cmH_2O, respiratory rate 20 breaths per minute.
Step 11. the lung was transported to obtain pretreatment x-rays. This was done in order to see the density of the secretions for the purpose of the post-treatment comparison.
Step 12. researchers then switched from the BiPAP setting to CPAP setting 40cmH_2O. This kept the lungs inflated and stationary during the x-ray.
Step 13. x-ray of the lung was done. Three different density films were used for the x-ray; this was done in order to obtain which density gave the better observation of the secretions.
Step 14. researchers resumed BiPAP and transported the lung back to the respiratory department.
Step 15.lungs were then connected to the MetaNeb© at the standard setting for a treatment. Times on the MetaNeb© were according to the manufacture manual. The 15 minute treatment shifted between lung expansion CPEP (Continuous Positive Expiratory Pressure) for 2 ½ minutes and then airway clearance CHFO (Continuous High Frequency Oscillation) for 2 ½ minutes until 15 minutes was reached. While against the manufacture's settings, the cuff was kept inflated so inflation was not lost.
Step 16. promptly after the treatment, the lung was suctioned twice with a suction catheter inserted 2 cm past the ET tube, 5ml normal saline was administered, and a -120mmHg suction pressure was applied.
Step 17. all synthetic secretions acquired from suctioning was collected in a sputum trap connected to the in-line suction catheter.
Step 18. the synthetic secretions were measured in volume using milliliters (cc) and weighed with the scale.
Step 19. repeat steps 10 - 13 for post-treatment assessment.
Step 20. post x-ray of the same area of the lung was performed after secretions were removed.
Step 21. findings were evaluated.

The same procedure was repeated with the other lung, except this lung was kept on CPAP as the secretions were being inserted, and metal aluminum pieces were inserted. All equipment was kept clean between each experiment per manufacturer's instructions.



The setup used for the procedure: ET-tube, in-line suction catheter, sputum trap, suction tubing, bacteria filter, T-piece/adapter, MetaNeb©, corrugated tubing, BiPAP/CPAP

Results

Trial One

Viscosity test

A viscosity test was performed on lung one to show that the secretions were mobile. Two trials were performed using 5mL of secretion that traveled 51 centimeters (cm); the mean time for both trials was 12.45 seconds (SD .49 sec). The test was measured in cm per second, to demonstrate how fast the secretions moved. For the calculation of speed at which the secretions traveled the equation, distance divided by time was utilized. The mean speed was 4.09 cm/second (SD 0.163 cm/sec).

Table 1

Initial settings: BiPAP

EPAP	**12 cmH_2O**
IPAP	40 cmH_2O
RR	20
FIO2	21 %
Vt	157 mL
PIP	40 cmH_2O

Table 1 illustrates the initial settings used when the lung was placed on BiPAP.

Table 2

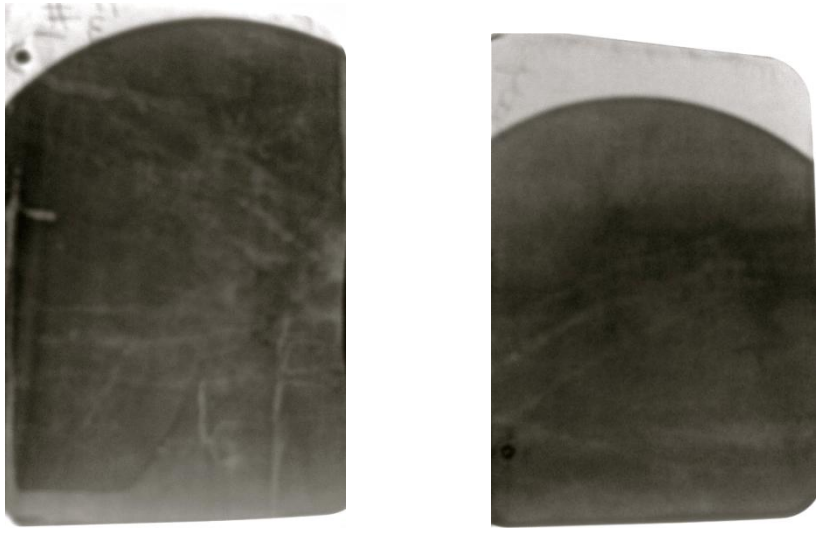
Ventilator parameters during treatment: Airway Clearance (CHFO) & Lung Expansion (CPEP)

Parameters	CHFO	CPEP
EPAP	12 cmH_2O	12 cmH_2O
IPAP	36 cmH_2O	36 cmH_2O
Respiratory Rate	20 bpm	20 bpm
FIO2	21 %	21 %
Vt	1193 mL	1218 mL
PIP	36 cmH_2O	N/A
Ve	23.9 L/min	24.4 L/min

Table 2 shows the ventilator setting during the treatment, while the lung was attached to the MetNeb© during CHFO and CPEP. The ventilator setting during the treatment was attached to the MetNeb© (CPEP), which was set on lung expansion.

Figure 1 X-rays

Lung One: **Pretreatment X-Ray** **Post-treatment X-Ray**



Trial Two

Viscosity test

A viscosity test was performed on lung two to show that the secretions were mobile and constant. Two trials were performed using 5mL of secretion that traveled 51cm; the mean time for both trials was 11.40 seconds (SD .70 sec). The test was measured meter per second, to demonstrate how fast the secretions moved. Speed was derived from the equation; distance divided by time. The mean speed was 4.48cm/second (SD 0.278 cm/sec).

Table 3

Initial setting: CPAP

CPAP	**25 cmH_2O**
Patient Leak	17 L/min
Respiratory Rate	0
FIO2	21 %
Vt	18 mL
PIP	25 cmH_2O
Ti/T_{ToT}	17%
Ve	0 L/min

Table 3 illustrates the initial settings used when the lung was placed on CPAP.

Table 4

Ventilator parameters during treatment: Airway Clearance CHFO & Lung Expansion CPEP

Parameters	**CHFO**	**CPEP**
CPAP	25 cmH2O	25 cmH_2O
Patient Leak	17 L/min	17 L/min
Respiratory Rate	0 bpm	0 bpm
FIO2	21 %	21 %
Vt	3387 mL	3387 mL
PIP	43 cmH_2O	43 cmH_2O
Ve	1.1 L/min	24.4 L/min

Table 4 shows, the ventilator setting during the treatment, while the lung was attached to the MetNeb© while on CHFO and CPEP.

Figure 2 X-ray

Lung Two: **Pretreatment X-Ray** **Post-treatment X-Ray**

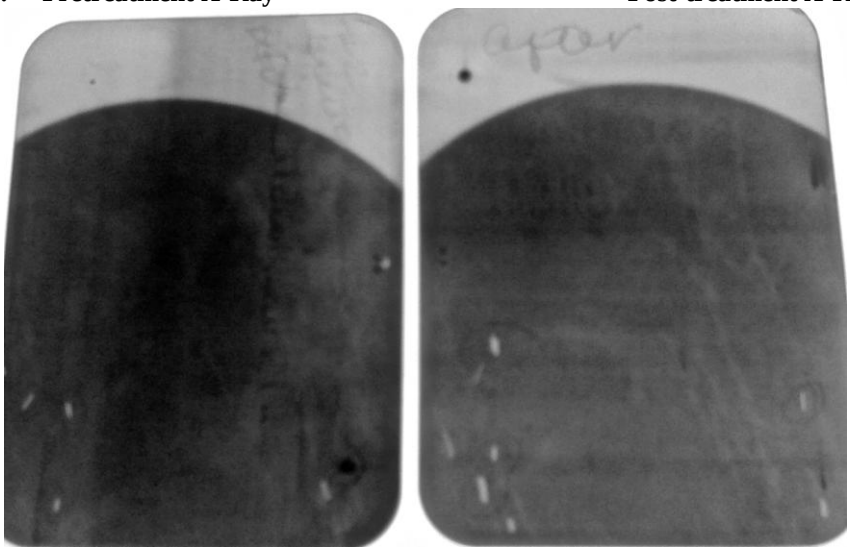


Figure 3

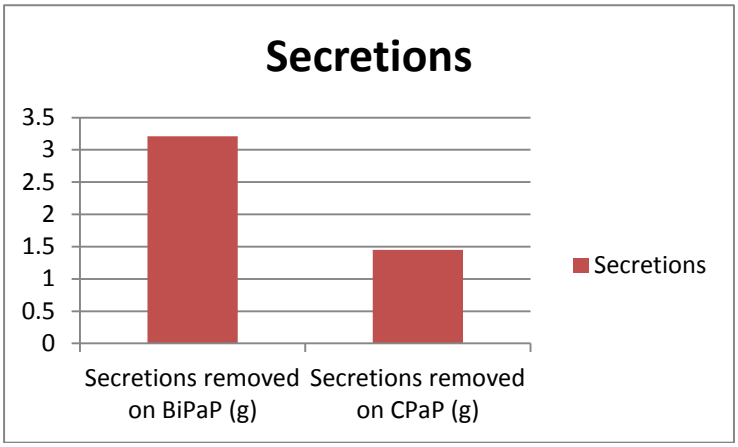
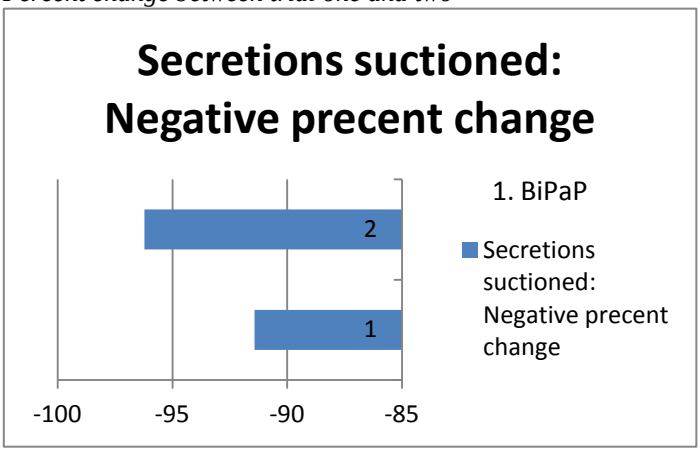


Figure 3 demonstrates the amount of secretions that was removed while on BiPAP (3.21grams) and CPAP (1.45grams), after the 15 minute treatment on MetaNeb©. While suctioning out the secretion, 5mL of normal saline was added to dilute the secretions.

Figure 4

Percent change between trial one and two



This figure compared secretions removal at different settings. The equation was derived from post-value subtracted from pre-value divided by pre-value times 100. The post-value was the amount of secretions after suction, and pre-value was the amount of secretion that was inserted into the lung.

Discussion and Conclusion

In using manufacturer recommended technique and settings, the researchers believed the MetaNeb© would effectively mobilize secretions in all lung regions. When performing the experiment, there were some limitations and other factors that should be further investigated to perhaps improve patient care. The results of the trials did not support the hypothesis due to unexpected limitations, however many questions arose that should be further investigated.

Trial One

Trial one was performed with 37.46 grams of synthetic secretions with an average viscosity of 4.09cm/sec. The lung was ventilated using the BiPAP mode for the duration of trial; using settings that would maintain inflation (see Table 1). BiPAP was also used throughout the duration of the MetaNeb© treatment which was performed according to manufacturer's specifications (see Table 2). Treatment was administering for 15 minutes, and then the lung was suctioned and returned 3.21 grams of synthetic secretions after instilling 5mL of normal saline (see Figure 3).

Trial Two

Trial two was performed by instilling 38.35 grams of synthetic secretions with an average

viscosity of 4.48 cm/sec. The lung was ventilated with CPAP throughout the trial with settings that achieved lung inflation (see Table 4), and was also used during the MetaNeb© treatment. The parameters of the ventilator during the MetaNeb© treatment can be found in Table 5. After the 15 minute MetaNeb© treatment the lung was suctioned and 1.45 grams of synthetic secretions were retrieved (see Figure 3).

Comparison between Trial One and Trial Two

These trials were designed to show the effectiveness of the treatment but proved inconclusive most likely because of some major limitations and other factors. The time allotted to conduct these trials limited the research to only two trials instead of the ideal three trials. Also the two trials that were performed were using two different modes of ventilation. These two trials returned different amounts of secretions Figure 4 shows the two trials compared in percentage. The researchers found it interesting that BiPAP returned more secretions than CPAP mode. This requires further investigated. During the first trial it was believed that BiPAP was necessary to maintain cadaver lung inflation, however during the second trial it was discovered that CPAP could be used to maintain the same inflation if lung recruitment maneuver was performed prior to placing lungs on CPAP. The x-rays taken during the two trials did not indicate any change in secretions; however the x-ray was taken with dental equipment which limited to clarity and quality. Another factor that may have affected the trials is evaporation or absorption of the synthetic secretions into the lung tissue; researchers believed that the absorption or evaporation could have been changed by heating and humidifying the ventilator circuit.

Limitations

Due to the fact that the lung being used was not a viable lung, there was no cilia activity and muscle action which caused may have limited clearance of the airways. The lung was not at body temperature it possibly affected the delivered volumes. When ventilating the lung, positive pressure was used instead of negative pressure to allow the lung to stay inflated when examining under x-ray. This allowed the lung to dry out causing the secretions that were inserted in the lung to be absorbed and/or evaporated. The purpose of the MetaNeb© is to mobilize the secretions from the upper airways, the cow lung trachea was too large for a human endotracheal tube therefore smaller airways were intubated in both trials; the MetaNeb© is made to mobilize secretions in the central airways and the area distal to the endotracheal tube that was placed was more peripheral than if the cow lung had been intubated in the tracheal.

Conclusion

The MetaNeb© is still a new product that may be an effective means of mobilizing secretions, but there is little literature about it and it should be further studied to assess the effectiveness. The researchers believed that the MetaNeb© would mobilize secretions from all lung regions but the results of these trials do not support this hypothesis. Researchers were surprised by the minimal amount of secretions that were returned leading the researchers to believe that the trials were hindered by possible evaporation and absorption of the synthetic secretions; it would be interesting to study this further. Other possible research stemming from questions that arose in these trials is to study the possible effect that heating and humidifying the ventilator circuit would have on secretion mobilization in patients with secretion buildup.

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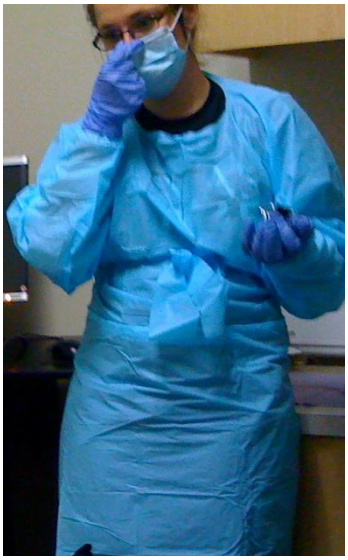
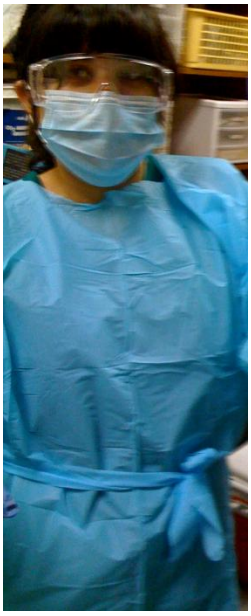
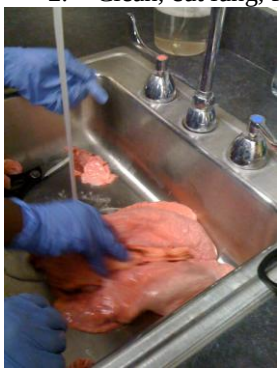
Addendum

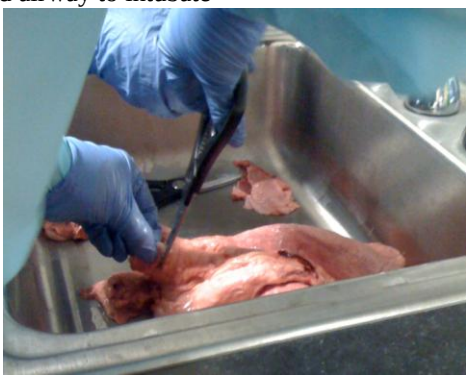
1. Outfit in gown, glove, mask and goggles

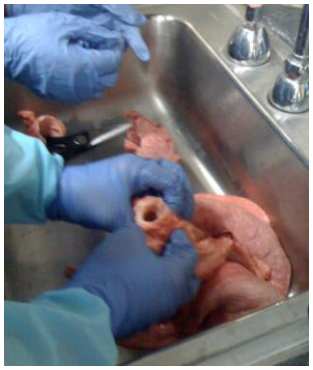




2. Clean, cut lung, find airway to intubate



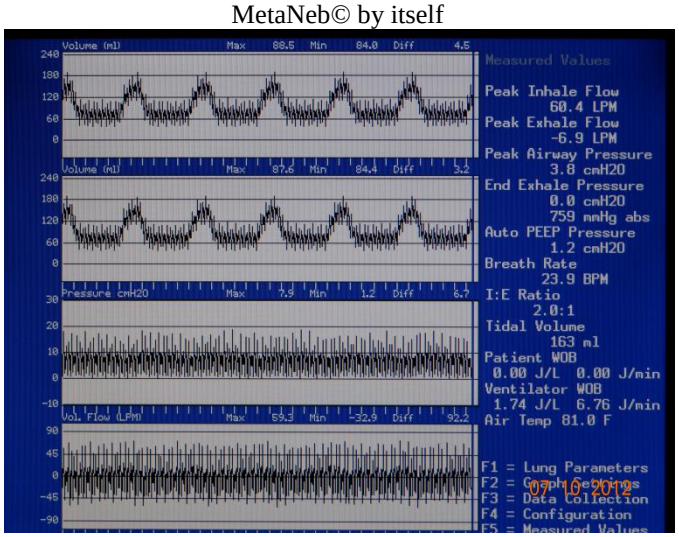




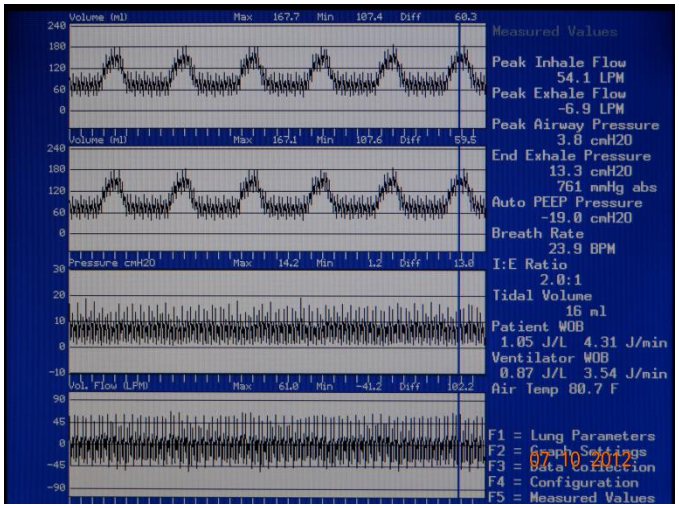
3. At same time perform function test for the MetaNeb©

Waveforms to check for effect of bacterial filter

MetaNeb© by itself



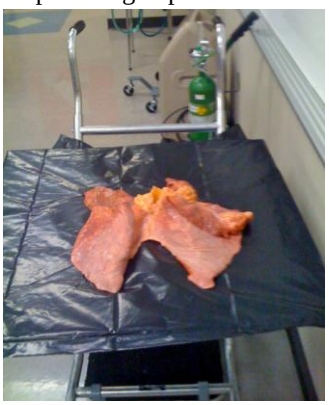
MetaNeb© with bacteria filter



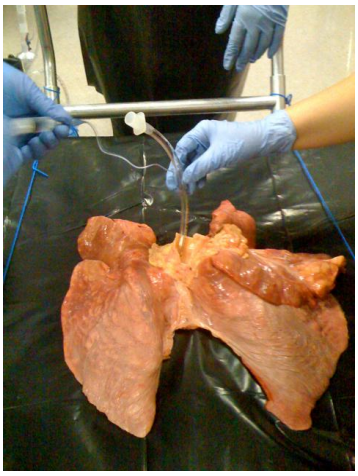
Calibrate scale – then weigh syringe & trap to zero out

Viscosity test with <u>synthetic secretions</u>

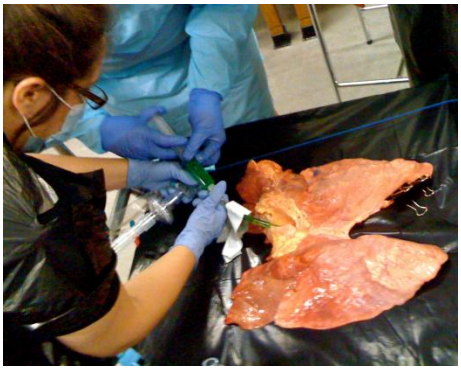
Prepare lungs - place on cardboard



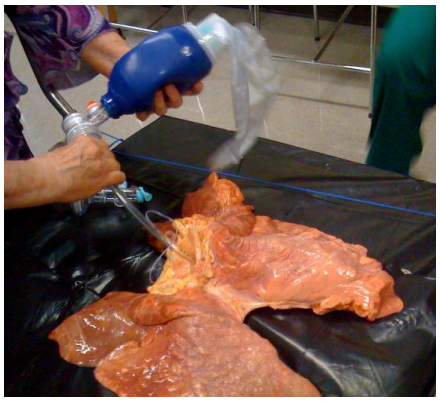
Intubate lung lobe



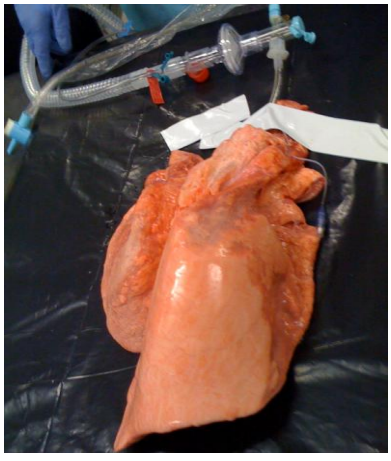
instillation of mock secretion



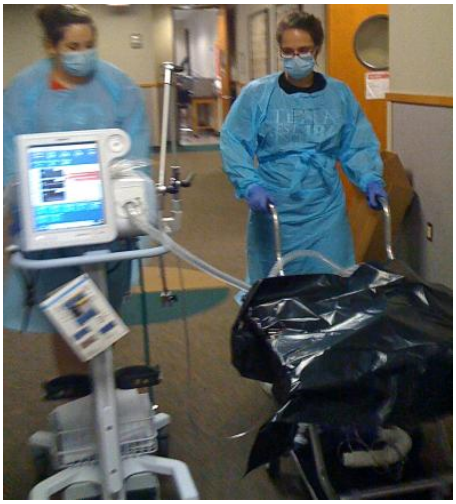
alveolar recruitment



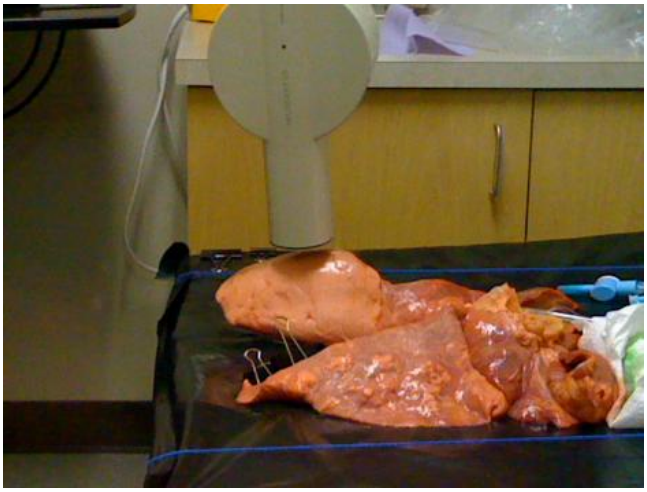
Place Lung on BiPAP/CPAP



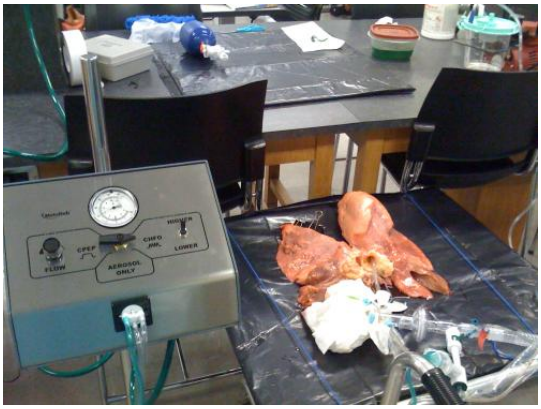
Transport to dental hygiene

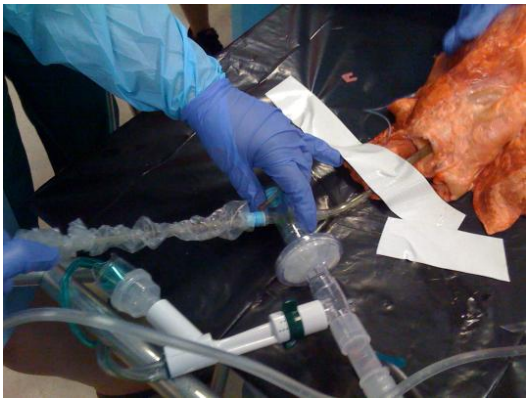


Pretreatment X-ray



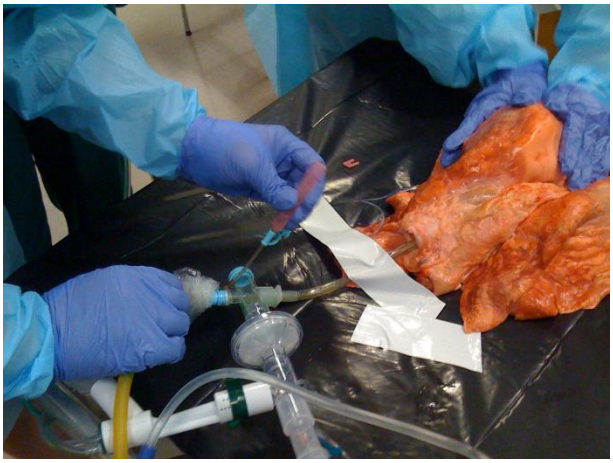
treatment with MetaNeb© (15 min.)

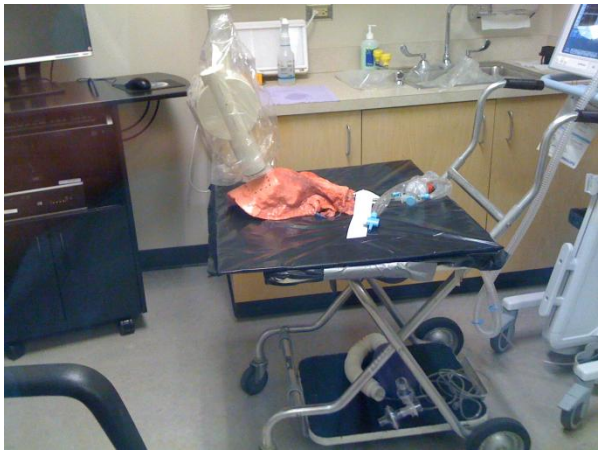




Suction afterwards

Added normal saline and massaged into lower lung to mimic forceful cough.





Post-treatment X-ray

Personal Protective Equipment
Hospital grade gown, glove, mask and goggles
Kitchen shears
MetaNeb©
Manufacturer Hil-Rom
Address From Manufacturer: Singapore (Equipment made in USA)
serial # 10-01911
item # C20130
Standard MetaNeb© circuit

Waveform machine
Manufacturer HANS RUDOLPH, Inc
Series 1101
Breathing Simulator
Address from Manufacturer: 7200 Wyandotte, Kansas City, Missouri 64114 USA

Scale
Company name: Santorius
Model Name: M-prove
Serial No: 27355093
Stock No: 3

Syringe
30cc, 12cc, 3cc

Endotracheal Tube
Size ID (Inner Diameter) 8.0
Cuff Diameter: 27.5mm
Tube OD (Outer Diameter) MM 9.3mm
Reference: 112082070
Serial Number: (01)04026704300402
Lot No. 08LE49
Made by: Teleflex
Address: Research Triangle Park, NC.

Bacterial Filter
Guardian (Disposable Bacterial/Viral Filter)
Record #FH 603003
22mm OD/15 mm ID x 22mm ID/15 mm OD
Manufactured By:
Ventlab Corporation
155 Boyce Drive
Mocksville, HC 27028
Lot: 02452

Self Inflating Manual Resuscitator
Portex
BiPAP/CPAP
Manufacturer Phillips
Brand name: Respironics
Model: V60
Manufacture address: Respironics CA Inc. 2271 Cosmos Court, Carlsbad, CA 92011

Xray machine
- Attached to the Wall

Intraoral Xray unit
By: Sirona
Model No.: 4684606-D3302
Serial No.: 23652
Manufactured: 2003
- Arm piece – exposure tube

Model No.: 4681263
Serial No: 31820

Suction Connector Tubing
72 in length with 3/16 diameter
made in Mundelein, IL,
lot # 9905081
Date 2004/05
reorder # DYND50216

Inline suction catheter
Closed suction system for adults (AKA Inline suction)
Size: 14 French
Length: 54cm
Reference: 2205
Manufactured by: Ballard Medical Products – Draper, UT
Distributed by: Kimberly-Clark Global Sales Inc. – Roswell, GA

Sputum trap
Sherwood medical
Address given: St. Louis, MO. 63103 USA
Assembled in Mexico.
Re-Order No.: 8884-724500 074-0490
40cc (or ml)

Bench Study: Comparison of Cuff Management Techniques in the Prevention of Ventilator Associated Pneumonia

Darshane L. Miller SRT, April Anderson BS SRT, Ray Managbanag BS SRT, and Frederick Johnson BS LCCA SRT

Abstract

PURPOSE: This research compared current cuff management techniques to determine which was most effective in the prevention of ventilator associated pneumonia. OBJECTIVE: To determine if using a manometer will prevent the most amount of simulated oronphrynegeal secretions from falling below the cuff of a well lubricated ET tube. METHODS: Each cuff management technique was performed once using 8.5 mm and 9.0 mm lubricated endotracheal tubes inserted into the tracheae of cow cadavers. Dyed egg white solution was placed above the cuff. A tracheal lavage was performed after three minutes of manual ventilation to determine the amount of dyed egg white solution that fell below the cuff after ventilation. RESULTS: Based on volume, weight, and color changes, the trial using a manometer to manage cuff pressure was the most effective technique in preventing simulated secretions from falling below the cuff during ventilation. The minimal leak technique was determined to be the least effective cuff management technique. CONCLUSION: Using a manometer to manage cuff pressure prevented the most simulated secretions from falling below the cuff of a well lubricated ET tube during ventilation.

Keywords: manometer; minimal leak technique; minimal occluding volume; ventilator associated pneumonia; lubrication; cuff pressure.

Background

When a patient is unable to maintain or protect the upper airway mechanical ventilation is often required. The initial airway used for mechanical ventilation is an appropriately sized endotracheal (ET) tube which consists of a 15-mm adapter, polyvinyl chloride (PVC) tube, permanently bonded cuff, small filling tube, and a pilot balloon (Wilkins, Stoller, & Kacmarek, Fundamentals of Respiratory Care, 2009). The purpose of the cuff is to prevent the transfer of secretions from the upper airway into the lower airway and to allow positive pressure ventilation to be administered to the patient. Cuff status and pressure are managed and adjusted using the pilot balloon. Artificial airway cuff pressure is recommended to be within the range of 20 – 30 centimeters of water (cm H_2O) (Howard, 2011). Higher cuff pressures can cause damage to the tracheal tissue such as necrosis, stenosis, or tracheomalacia. Lower cuff pressures can cause secretions from the oral cavity and upper airway to migrate below the cuff into the lower airway. This is the leading contributor to ventilator associated pneumonia (VAP) (Wilkins, Stoller, & Kacmarek, 2009).

Ventilator associated pneumonia (VAP) accounts for 80-90% of nosocomial pneumonias in intensive care unit (ICU) patients (Deem & Treggiari, 2010). It prolongs the length of hospital stay, increases healthcare costs, and increases the risk of death within the critically ill adult population (O'Keefe-McCarthy, Santiago, & Lau, 2008). The risk of ventilator associated pneumonia (VAP) is greatest during the first five days of intubation but can occur at any time during the intubation period. Bacteria contaminated secretions from the oropharynx slide down the longitudinal folds of the inflated cuff, created when the cuff pushes against the wall of the trachea, into the lower airway (Blunt, Young, Patil, & Haddock, 2001). Once in the lower airway, the bacteria colonize and signs and symptoms of ventilator associated pneumonia (VAP) begin to present.

Current strategies used to prevent ventilator associated pneumonia (VAP) include hand washing, routine suctioning and oral care, patient isolation, patient positioning, lubrication of the endotracheal (ET) tube cuff with a water-based gel, and maintaining endotracheal (ET) tube cuff pressure above 20 centimeters of water (cm H_2O) to prevent oropharyngeal secretions from falling below the cuff.

Methods used to manage cuff pressure include attaching a calibrated manometer, performing the minimal occluding volume technique, and performing the minimal leak technique. The technique of using a manometer to manage cuff pressure involves inserting a calibrated manometer into the spring loaded end of the pilot balloon. The pressure inside of the cuff is displayed on the screen and air can be added or withdrawn to maintain a cuff pressure of 20-30 centimeters of water (cm H_2O). The minimal occluding volume technique involves completely deflating the cuff with a 10 milliliter

(mL) syringe attached to the pilot balloon until airflow is heard around the cuff during a positive pressure breath. Once airflow is heard, the cuff is slowly inflated until airflow is no longer heard. The minimal leak technique is performed the same way as the minimal occluding volume technique; however a small amount of air is removed once no airflow is heard around the cuff (Wilkins, Stoller, & Kacmarek, 2009).

Our research will compare the ability of the above cuff pressure management techniques to prevent leakage of oropharyngeal secretions below the cuff of an endotracheal (ET) tube placed inside the trachea of an animal cadaver. Our research will also explore the role cuff lubrication plays in preventing upper airway secretions from entering into the lower airway. It is expected that using a manometer will be the most effective method of cuff management and that lubricating the cuff will play a key role in preventing VAP.

Methodology

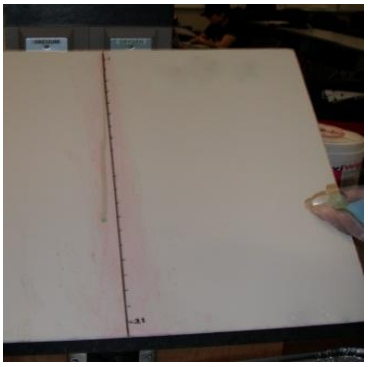
Materials

To test the effectiveness of the three cuff management techniques on lubricated endotracheal (ET) tube cuffs, the following materials were used:

1. 22 inch x 28 inch White Poster Board for Testing of Egg Whites Viscosity
2. CPE Plastic Isolation Gowns (disposable)
   Manufactured by: Wuhan Vanjoin Light Industrial Products Co., Ltd - Hubei, China
3. Dynarex Ear Loop Procedure Mask w/Splash Face Visor (disposable)
   Manufactured by: Dynarex Corporation - 10 Glenshaw Street, Orangeburg, NY 10962
4. Defender Examination Gloves (disposable)
   Manufactured by: Digitcare Corp. - 2999 Overland Ave., Los Angeles, CA 90064
5. Staples® Economy Rubber Bands Size #18
6. Cow Tracheae and Lungs
   Donated by Garza Processing Market - 4519 Theiss Rd # 1Humble, TX 77338
7. Disposable Surgical Scalpel
   Manufactured by: Med Pro Corporation Shandong, China
8. Ultra Concentrated Dawn Dishwashing Liquid Detergent
   Size: 709 milliliter (mL) bottle
   Distributed by: Procter & Gamble – Cincinnati, OH 45202
9. Napkins
10. Scotch® Packing Tape Premium Heavy Duty 3770RD. Clear
    Size: 1.88 inches x 54.6 yards
11. Velcro® Sticky Back™ Hook & Loop Fastener General Purpose Tape, Black
    Size: ¾ inch (in.) x 15 feet (ft.) Roll
12. Wooden Yard Stick
13. Makeshift Aluminum Foil-Covered 45° Angle Cardboard Ramp
14. Craftsman 12-inch Stainless Combination Square
15. PDI Sterile Lubricating Jelly
    Size: 5.0 grams (g.)/0.17 ounce (oz.) packets
    Manufactured by: Professional Disposables International, Inc. Orangeburg, NY 10962
16. Parker Flex-Tip PFHV (High Volume Low Pressure Cuff) Tracheal Tube-Cuffed
    Size: 8.5 millimeter (mm) and 9.0 millimeter (mm)
    Cat no.: 86453
    Lot no.: 090300-0686
    Date: 2010/05
    Manufactured by: Well Lead Medical Guangzhou, China
    Manufactured for: Parker Medical 7275 S. Revere Pkwy. Suite 804, Englewood, CO 80112
17. 10-milliliter (mL) Disposable Syringes
    Model: 10mL Luer Lock Tip
    Lot no.: 070823
    Manufactured by: Exelint International Co. 5840 W Centinela Ave. Los Angeles, CA 90045
18. Posey Cufflator Endotracheal Tube Inflator and Manometer
    Manufactured by: J.T. Posey Company 5635 Peck Road, Arcadia, CA 91006-0020
19. Bag and Peep Valve-
    Anesthesia Breathing Bag
    Lot no.: 97272-6494
    Cat no.: N7905
    Manufactured by: Owens-Brigam Medical - Newland, NC
    Description: 0.5 Liter (L) hyperinflation set, hyperinflation elbow with plug, 84 inch (in.) star lumen tubing with connectors.
20. Precision Medical® Flowmeter, 0-15LPM Model 1MFA
    Manufactured by: Precision Medical® 300 Held Drive, Northhampton, PA 18067
21. MicroGard Microbial Filter
    Manufactured by CareFusion, 22745 Savi Ranch Pkwy., Yorba Linda, CA 92887
22. Crystal Farms AllWhites® 100% Liquid Egg Whites
    Size: 32 ounce (oz.) carton
    Manufactured by: Crystal Farms, a Michael Foods Company
23. Great Value™ Green Food Color & Egg Dye 0.25 ounce (oz.) bottle
    Size: 0.25 ounce (oz.) bottle
    Distributed by Wal-Mart Stores, Inc., Bentonville, AR 72716-1100
24. 40-cubic centimeter (cc) specimen trap
    Re-Order No.: 8884-724500
    Assembled in Mexico

Manufactured for: Sherwood Medical, St. Louis, MO 63103

25. McGaw Sterile Water for Irrigation USP
    Size: 1000 milliliter (mL)
    Expiration Date 08/02
    Lot no.: J9K187
    Manufactured by: McGaw, Inc. Irvine, CA 92714-5895
26. Inline Suction Catheter
    Ballard® Adult Trach Care® T-Piece
    Size: 14 French/4.6 mm
    Length: 54cm
    Reference: 2205
    Manufactured by: Ballard Medical Products – Draper, UT
    Distributed by: Kimberly-Clark Global Sales, Inc. – Roswell, GA
27. Medical Industries America, Inc. Portable Suction Machine 120 VAC/60 Hz.
    Serial No.: 55644
    Manufactured by: Medical Industries America, Inc. 26378 289th Pl., Adel, IA 50003
28. Suction Connection Tubing
    Length: 72 inches (in.)
    Diameter: 3/16 inches (in.)
    Lot No.: 0501141
    Date: 2010/01
    Manufactured by: ConMed Corporation – 310 Broad St., Utica, NY 13501
29. Precision Weighing Scale
    Model: M-Prove
    Serial No: 27355093
    Manufactured by: Sartorius AG - Weender Landstr. 94-108, 37075 Goettingen, Germany
30. Contractor's Choice 42-Gallon Contractor Clean-up Bags
    Size: 42 gallon x 12 bag box
    Manufactured by: Poly-America, 2000 West Marshall Drive, Grand Prairie, Texas 75051

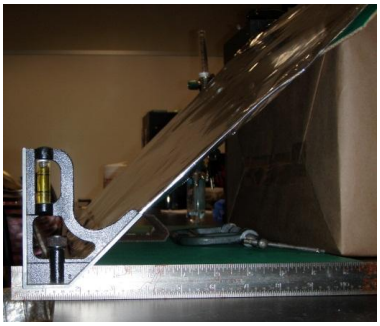


Egg whites were used to represent oropharyngeal secretions for this experiment and were colored using green food dye to increase visibility. Viscosity of the dyed egg white solution was tested by placing 2.5 milliliters (mL) of ambient room temperature solution on one end of a single vertical line drawn on a poster board. The vertical line was previously marked in one inch (in.) increments up to a total of 22 inches. The poster board was raised to a 45° angle to allow the solution to flow from top to bottom and traveled at a rate of 22 inches in 2.6 seconds.

Due to the bio hazardous nature of the materials used, universal precautions were taken. Personal protective equipment worn during the experiment included: disposable barrier gowns, examination gloves, and surgical masks with face shields.

Three cow tracheae were prepared by first removing the visceral pleura and cutting off the lungs two inches above the carina using a disposable surgical scalpel. The tracheae were then washed using regular dishwashing detergent and tap water. These were rinsed again to remove any detergent residue.

The distal ends of each trachea were wrapped with paper napkins and taped to reduce diameter. Velcro® Sticky Back™ Loop Fastener Tape was attached 3 inches from the end of each trachea. Prior to preparation, cow tracheae were removed from three calves and kept on ice in a large ice chest for less than 72 hours.



A ramp was used to simulate a patient's bed set at a 45° angle. It was created by covering an illustration board with aluminum foil and taping it to a manila paper-covered large cardboard box. A 12-inch Stainless Combination Square was used to ensure the ramp was set at a 45° angle. Four inch strips of Velcro® Sticky Back™ Hook Fastener Tape were placed 8 inches apart along the top of the ramp.

The scale used for this experiment was not calibrated, but was zeroed prior to each use by clearing the base plate and pressing the "Zero" button located in the lower right hand corner.

Statistics

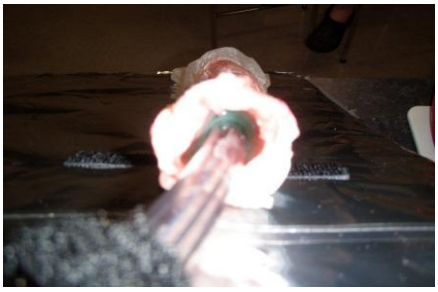
Microsoft® Excel™ was used to compile data for this experiment. Tables were created using Microsoft® Word™.

Procedure

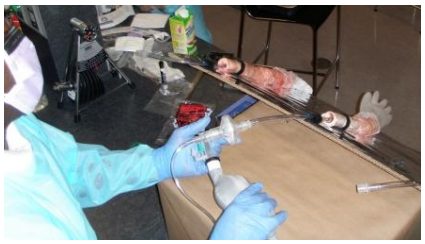
The following steps were taken to test Trial #1: Using a Manometer to Manage Cuff Pressure.

Trial #1:

1. Attached disposable examination glove on the distal end of cow trachea with rubber band.
2. Secured cow trachea to ramp using Velcro® Sticky Back™ tape with proximal end pointing upward.
3. Liberally squeezed 1 packet of lubricating jelly onto the outside of the ET tube cuff.
4. Inserted lubricated ET tube into the distal end of the calf trachea up to the point where the edge of the trachea was between "Parker" and "Medical" on the ET tube (12 cm on 9.0 mm ET tube and 11.5 cm on 8.0 mm ET tube).
5. Secured ET tube to ramp using Velcro® Sticky Back™ tape.
6. Inflated cuff with a 10-milliliter (mL) disposable syringe until trachea expansion can be seen from the outside of the trachea.
7. Attached a manometer to the pilot balloon of the ET tube and adjusted cuff pressure to 120 centimeters of water (cm H_2O) pressure.
8. Connected flow inflating anesthesia breathing bag to wall oxygen source and set flowmeter to 15 liters per minute (lpm). An antimicrobial filter was attached to the end of the resuscitation bag to protect equipment.
9. Anesthesia breathing bag was tested for leaks by placing a gloved hand over the open end of the antimicrobial filter and allowing the bag to inflate. After testing the bag, it and the filter were connected to the ET tube at the patient port.



10. Injected 2.5 milliliter (mL) of room temperature dyed egg white solution into trachea above the cuff using a 10-milliliter (mL) disposable syringe.
11. Pumped anesthesia breathing bag at a rate of 20 times per minute to simulate breathing.
12. While manual ventilation took place, a specimen trap containing 10 milliliters (mL) of sterile water was weighed on a calibrated scale. The sterile water was then removed from the specimen trap using a 10 milliliter (mL) disposable syringe. The empty specimen trap was connected to an inline suction catheter and a portable suction device.



13. After three minutes of manual ventilation, the anesthesia breathing bag and filter were removed and the inline suction catheter was connected to the ET tube at the patient port.
14. The 10 milliliters (mL) of sterile water from step 12 was injected into the instillation port of the inline suction catheter.
15. Set suction device to -20 millimeters of mercury (mmHg) and passed entire length of suction catheter down ET tube three times. Remaining fluid in glove was extracted by puncturing/cutting off glove fingers and/or squeezing out the solution into the specimen trap.
16. The specimen trap with sterile water and dyed egg white solution was reweighed. Volume and color of solution were recorded.
17. Double bagged used cow trachea and ET tube for disposal.

The following steps were taken to test Trial #2: Using Minimal Leak Technique to Manage Cuff Pressure.

Trial # 2:

1. Repeated steps 1 through 5 of Trial # 1.

2. Attached flow inflating anesthesia breathing bag and antimicrobial filter to ET tube at patient port and manually ventilated at a rate of 20 breaths a minute.
3. Slowly inflated cuff with a 10 milliliter (mL) disposable syringe until airflow heard escaping around the cuff during a positive-pressure breaths ceased. Once a seal was obtained, a small amount of air was removed, allowing a slight leak at peak inflation pressure.
4. Connected flow inflating anesthesia breathing bag to wall oxygen source and set flowmeter to 4 liters per minute (lpm). An antimicrobial filter was attached to the end of the resuscitation bag to protect equipment.
5. Repeated Steps 9 through 17 of Trial # 1.

The following steps were taken to test Trial #3: Using Minimal Occluding Volume Technique to Manage Cuff Pressure.

Trial # 3:

1. Repeated Steps 1 through 5 of Trial # 1.
2. Attached flow inflating resuscitation bag and antimicrobial filter to ET tube at patient port and manually ventilated at a rate of 20 breaths a minute.
3. Slowly inflated cuff with a 10 milliliter (mL) disposable syringe until airflow heard escaping around the cuff during a positive-pressure breaths ceased.
4. Connected flow inflating anesthesia breathing bag to wall oxygen source and set flowmeter to 4 liters per minute (lpm). An antimicrobial filter was attached to the end of the resuscitation bag to protect equipment.
5. Repeated Steps 9 through 17 of Trial # 1.

Results

Volume

Table 1 lists all recorded volumes for each trial. Mean volume loss (n = 3) for all three trials was 0.667 mL (SD = 1). Trials #1 and #3 each had a volume loss of 1 mL sterile water solution after the tracheal lavage.

Table 1

Recorded Volumes of Sterile Water Solution Before and After Tracheal Lavage

	Trial #1 MAN	Trial #2 MLT	Trial #3 MOV
Volume of Instilled Water for Tracheal Lavage (mL)	10	10	10
Volume of Suctioned Water from Tracheal Lavage (mL)	9	10	9
Difference in Water Volume Before & After Tracheal Lavage (mL)	-1	0	-1
Percent Change	-10	0	-10

MAN = manometer, MLT = minimal leak technique, MOV = minimal occluding volume

Weight

Weight loss for all three trials ranged from 1.40 g to 2.03 g. Mean (n = 3) weight loss for all three trials was 1.73 g (SD = 0.316069613) with a median of -1.76 g. Trial #1 had the most weight loss with a 2.03 g difference from its pre-experiment weight. Trial #2 had the least amount of weight loss. See Table 2 for all recorded weights for each trial.

Table 2

	Trial #1 MAN	Trial #2 MLT	Trial #3 MOV
Weight of Specimen Trap and Sterile Water Before Tracheal Lavage (g)	38.40	40.80	37.71
Weight of Specimen Trap and Sterile Water Solution After Tracheal Lavage (g)	36.37	39.40	35.95
Difference in Weight of Specimen Trap and Sterile Water or Solution Before & After Tracheal Lavage (g)	-2.03	-1.40	-1.76
Percent Change	-5.29	-3.43	-4.67

Weights of Specimen Trap and Sterile Water Solution Before and After Tracheal Lavage

Visible Characteristics of Sterile Water Solution

Figure 1

Sterile Water Solution After Tracheal Lavage for Trials 1-3

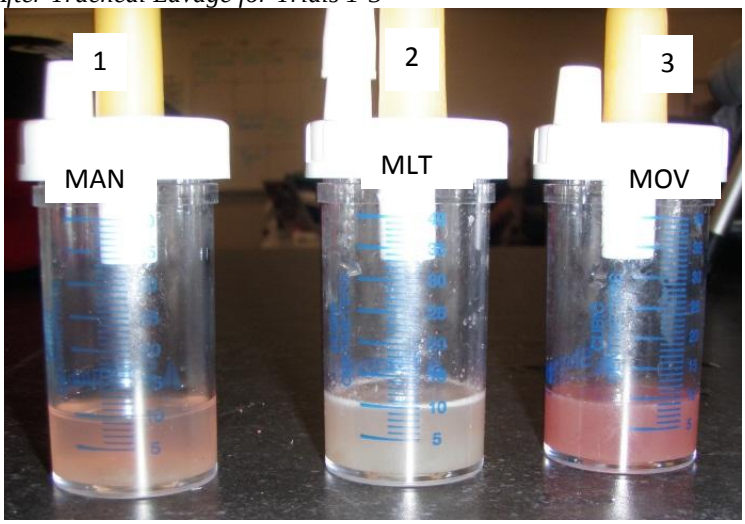


Table 3
Descriptions of Sterile Water Solution after Tracheal Lavage

Trial #1 MAN	Cloudy but still translucent, Light pink, No visible bubbles/foam on surface
Trial #2 MLT	Cloudy, Opaque, Tan with Greenish Tint, Significant amount of visible bubbles/foam on surface
Trial #3 MOV	Cloudy and opaque, Pink, Slightly visible bubbles/foam on surface

Discussion

Categories used to determine the effectiveness of each cuff management technique were volume, weight, and visible characteristics of the sterile water solution after tracheal lavage. Data collected from the experiment supports the hypothesis that using a manometer is the most effective cuff management technique and prevents the most amount of dyed egg white solution from leaking below the cuff of a well lubricated ET tube.

The trial that involved using a manometer to manage cuff pressure (trial #1) had the least amount of dyed egg white solution fall below the cuff during positive pressure ventilation. This was demonstrated in all three categories. One milliliter of sterile water solution was lost during the tracheal lavage. This was the assumed baseline for each trial due to tracheal tissue absorption of the sterile water solution. This absorption also caused a decrease in weight in all three trials. The manometer method had the greatest weight loss of the three methods indicating no significant addition of dyed egg white solution to the sterile water for the lavage. Contents of the specimen trap after the lavage showed no significant signs of dyed egg white solution.

The minimal leak technique (trial #2) had the most dyed egg white solution fall below the cuff during ventilation and was demonstrated in all three categories. The volume of the sterile water solution remained the same before and after the tracheal lavage. Assuming that about 1 mL of the 10 mL sterile water solution was absorbed by tracheal tissue, any additional volume was attributed to dyed egg white solution that managed to fall below the cuff of the ET tube. Weight loss post tracheal lavage was considerably less when compared to technique involving using a manometer. Dyed egg white solution that managed to fall below the cuff made up the difference in weight (0.63 g). Sterile water used for the lavage went from clear and translucent to cloudy, opaque and khaki colored.

The minimal occluding volume technique (trial #3) was seen to be less effective than using a manometer, but more effective than the minimal leak technique. This was demonstrated in only two of the three categories. The volume of sterile water lost during the lavage with this technique was the same as the volume lost using a manometer (1 mL).

Though they were the same, it was assumed that some dyed egg white solution did fall below the cuff based on the other categories. The weight loss of sterile water solution after the lavage for this technique was not as much as with using a manometer but greater than using the minimal leak technique. This along with the change in translucency and the presence of foam on the surface of the solution in the specimen trap indicated that some dyed egg white solution did fall below the cuff of the ET tube.

Research performed by Blunt et al, determined that water soluble lubrication on the cuff of an ET tube reduced the amount of oropharyngeal secretions from falling below the cuff during the first

48 hours of intubation; a key timeframe in the prevention of VAP bacteria colonization (Blunt, Young, Patil, & Haddock, 2001). Lubricating the ET tube and using a manometer to manage cuff pressure should significantly reduce the incidence of VAP in a hospital setting when compared to other cuff management techniques.

Limitations of this study

Due to time constraints, each trial was performed only once. The research should be repeated with a minimum of three runs per trial to provide more conclusive results.

Some volume of sterile water solution was lost due to absorption into dried tracheal tissue. It was assumed that this value is about 1 mL based on the results. A test run was not performed to determine how much sterile water solution would be lost and what factors affected the amount of solution lost. Another suggestion in correcting this requires the tracheae to be soaked in water until ready to use for the experiment. Also, the precision of the instrument used to measure volume was to the nearest whole number. Repeating the experiment with an instrument that measures to the thousandths would provide more accurate results especially when comparing using a manometer and minimal occluding volume.

Despite manipulation of the tracheae, they were too big for the 8.5 mm and 9.0 mm tubes used for the experiment. This required cuff pressures to be higher than the normal 20 – 30 centimeters of water (cm H_2O) range in order to ensure a good cuff seal against tracheal wall. Using a pressure of 120 cm H_2O in a human would cause tracheal damage.

Conclusion

This research demonstrated that using a manometer to manage cuff pressure was the most effective technique in preventing oropharyngeal secretions from falling below the cuff of a well lubricated ET tube. The minimal leak technique had the most dyed egg white solution fall below the cuff and proved to be the least effective in the prevention of VAP. It is suggested that this technique be discontinued in patient care because more proficient methods are available. Future studies on this topic should explore how ineffective manometer cleaning in between patients affects the prevalence of VAP when compared to the other techniques using a disposable syringe.

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Bench Study: Time Needed for Cuff Pressure Stabilization At Body Temperature After Intubation

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Abstract

BACKGROUND: The purpose of this study is to determine the time it would take for cuff pressure to stabilize once the cuff is subjected to body temperature. OBJECTIVE: To determine how many minutes for the cuff pressures to increase after intubation. METHOD: Inflate size 7mm endotracheal tube and size 8mm endotracheal tube with 8 ml of air and place in 37 degree Celsius water bath. Check and record cuff pressure immediately, at 30 second intervals for 5 minutes. RESULTS: Immediately after submersion the size 7 endotracheal tubes cuff mean pressure (n =3) was 24.0 cm H_20 (SD 2.00) ; at 30 seconds the mean pressure was 32.67 cm H_20 (SD 3.05), at 150 seconds the mean pressure was 33.33 cm H_20 (SD 3.05) , and at 300 seconds the mean pressure was 34.33 cm (SD 3.51). Immediately after submersion the size 8 endotracheal tubes mean pressure (n=3) was 22.67 cm H_20 (SD 1.15) ; at 30 seconds the mean pressure was 24.67 cm H_20 (SD 1.15); at 150 seconds the mean pressure was 26.67 cm H_20 (SD 1.15); and at 300 seconds the mean was calculated to be 28.67 cm H_20 (SD 1.15). Conclusion: As this study was conducted it was shown that ETT cuff pressure took an average of three minutes to stabilize.

Background

Approximately 900 years have passed between the first intubation and the development of a cuffed endotracheal tube (Bouvier, 1981). The Arabian doctor Avicenna (980-1037) described the first use of orotracheal intubation in dyspnea (Bouvier, 1981). The history of oral endotracheal intubation actually began in the 18th century. At that time obstetricians and lifesavers used breathing tubes (Bouvier, 1981). Regular oral intubation to keep the respiratory tract clear during narcosis was first applied by Franz Kuhn in 1900; unfortunately, the pioneer himself did not live to see his method become a routine procedure. In 1928, Ralph M. Waters, M.D. and Arthur E. Guedel, M.D. introduced an adult endotracheal tube with an inflatable rubber cuff that could seal the trachea from gas and water when inflated for anesthetic purposes (Bouvier, 1981). It was only as late as 1945, that endotracheal intubation became part of hospital practice (Bouvier, 1981).

Today, cuffed endotracheal tubes are used in children (> 5-6 years old) and adults to 'seal-off' the lower airway. This seal allows application of positive pressure ventilation to the lungs without extensive gas leaks (Bouvier, 1981). The seal provided by the cuff helps prevent and minimize aspiration of oropharyngeal or supraglottic secretions into the lungs (Bouvier).

The process of endotracheal intubation has had approximately 1000 years to evolve into a safe practice (Bouvier, 1981). Unfortunately, the pressures used to inflate tracheal tube cuffs continue to be a cause of concern. Irreversible damage to the tracheal mucosa can occur if the cuff pressure is too high (Braz, Navarro, Takata, Nascimento, 1999). Undetected over-inflation of the endotracheal cuff balloon may disrupt the capillary blood supply leading to ischemia, inflammation, ulceration, granulation, nerve and vocal damage, as well as, stenosis at the site of contact between the cuff and trachea (Braz et al., 1999). Endoscopic studies show a correlation between elevated cuff pressures and tracheal lesions (Braz et al., 1999). Post-operative sore throat is also associated with elevated endotracheal cuff pressure (Stewart, Secrest, Norwood & Zachary, 2003).

Patients also can be at risk if the cuff pressure is too low. To prevent aspiration during positive pressure ventilation, pressure must be approximately 27cm H_2O. Aspiration has been shown to occur with intracuff pressures of approximately 20 cm H_2O (Stewart et al., 2003). Underinflation of the endotracheal tube cuff is associated with inadequate delivery of prescribed tidal volume and aspiration of secretions. When the cuff pressure was maintained at less than 20 cm H_2O, the risk for ventilator associated pneumonia (VAP) was 4 times higher than when pressure was maintained at higher values (Ben, Cooper, Drummond & Morello, 2012).

In the trachea, capillary blood flow becomes obstructed when the pressure in an endotracheal tube cuff exceeds the capillary perfusion pressure of the tracheal mucosa. Reports suggest that 25 cm H_2O is a "safe" pressure, although the precise pressure at

which capillary perfusion is impaired certainly will vary from patient to patient (Bouvier, 1981). The acceptable cuff pressures range from 25 to 30 mmHg, which equates to 20 to 25 cmH_2O (Stewart et al., 2003). The precise pressure at which any individual will experience impaired or obstructed tracheal mucosal blood flow will depend upon numerous factors, most important their blood pressure (Bouvier, 1981).

Standardized instruments to measure cuff pressures might help decrease the possibility of injury resulting from endotracheal intubation (Braz et al., 1999). There are currently four methods for monitoring cuff inflation.

In the minimal occlusive volume (MOV) technique, air is added to the cuff to create a seal and abolish air leak on inspiration. In the minimum leak technique (MLT), air is removed from the cuff to allow a small leak on inspiration. Cuff pressure measurement (CPM) is performed with a manometer during the inspiratory phase provides objective measurement of intracuff pressure that does not involve cuff deflation. A fourth technique, the palpation method, involves subjective estimation of cuff inflation based on gentle palpation of the pilot balloon (Braz et al., 1999).

In 2012, Ben et al measured cuff pressures as the cuff was heated to 37 degrees. The main finding of their research was that cuff pressures did not stabilize at 30 seconds, cuff pressures continued to increase up to three minutes (Secrest et al., 2012).

The purpose of this study is to determine the time it would take for the cuff pressures to stabilize once the cuff is subjected to body temperature. The cuff pressure should increase as the cuff moves from room temperature to body temperature. Gay-Lussac's Law states that when volume is constant, as the temperature rises, the pressure also rises (Ben et al., 2012). The biological question is how long will it take for the cuff pressure to stabilize after intubation. It is anticipated that it will take longer than three minutes for cuff pressures to stabilize.

Methology

To determine the time it will take to stabilize cuff pressures the following materials were used:

*Equipment Needed

1) Poly Pro Bath:
    a. Serial number = 111908C
    b. Model number = RS-PB-100
    c. Manufacturer = REVSCI
2) Posey 8199 standard cufflator Endotracheal Tube Inflator and Manometer
3) 5- inch flex hose (trachea substitute)
4) Endotracheal Tube Size 7 mm
    a. Lot number = 1005HV0834K
    b. Manufacturer = Well Lead Medical
5) Endotracheal Tube Size 8 mm
    a. Lot number = 1003HV0337M
    b. Manufacturer = Well Lead Medical
6) Syringe
    a. Model 10 ml Luer Lock Tip
    b. Lot number = 070823
    c. Manufacturer = Exelint International
7) 76 mm glass thermometer (measured in Celsius)
8) Gallon of distilled water
9) Stopwatch (apple I Phone)

Procedure

The following steps were taken to test trial #1: Cuff Pressure Stabilization

Trial #1

1. Filled the water bath with 3 liters distilled water
2. Set temperature on Poly Pro Bath at 37 degree Celsius
3. Covered the water bath (maintained for 1 hour)
4. Inserted 76mm glass thermometer and checked accuracy of temperature (if temperature is off more than 0.5 Celsius, recalibrate)
5. Instilled 10ml air into 10ml Luer Lock syringe
6. Placed 10ml Luer Lock syringe into pilot balloon of the 7mm endotracheal tube, instilled air into pilot balloon to check for leaks
7. Withdrew air placed into pilot balloon using the same 10ml Luer Lock syringe
8. Removed 10ml Luer Lock syringe from pilot balloon
9. Inserted size 7mm endotracheal tube into 5- inch flex hose
10. Inflated pilot balloon of size 7mm endotracheal tube cuff with 8ml of air
11. Connected the manometer (do not detach during each run) to the pilot balloon
12. Recorded the pressure
13. Submerged the endotracheal tube cuff completely in water bath
14. Recorded pressure using the manometer immediately after inserting endotracheal tube into bath water
15. Recorded pressures at 30 second intervals until pressures stabilized
16. Repeated and recorded results for steps 1 through 15 for three trial runs

The following steps were taken to test Trial #2: Cuff Pressure Stabilization

Trial #2

1. Repeated steps 1 through
2. Placed 10ml Luer Lock syringe into pilot balloon of the 8mm endotracheal tube, instilled air into pilot balloon to check for leaks
3. Withdrew air placed into pilot balloon using the same 10ml Luer Lock syringe
4. Removed 10ml Luer Lock syringe from pilot balloon
5. Inserted size 8mm endotracheal tube into 5- inch flex hose
6. Inflated pilot balloon of size 8mm endotracheal tube cuff with 8 ml of air
7. Repeated steps 11 through 15 of Trial #1
8. Repeated and recorded results for steps 1 through 7 for three trial runs

Statistics

Collected data was incorporated on Microsoft™ Word allowing us to create tables to substantiate the pressure change as time elapsed. MS Excel ™ was utilized to generate graphs exhibiting the change in pressure for both tube sizes. Data collected from research trials were entered in MS Excel ™ to compute mean, range, percentage change, median, and standard deviation.

Results

Table 1 – 7.0 ETT			
	Trial 1	*Trial 2*	*Trial 3*
Time (seconds)	**Pressure (cmH_2O)**	**Pressure (cmH_2O)**	**Pressure (cmH_2O)**
Baseline	20 cmH_2O	20 cmH_2O	20 cmH_2O
Immediately after submerging	24 cmH_2O	26 cmH_2O	22 cmH_2O
30	36 cmH_2O	32 cmH_2O	30 cmH_2O
60	36 cmH_2O	34cmH_2O	30 cmH_2O
90	36 cmH_2O	34cmH_2O	30 cmH_2O
120	36 cmH_2O	34cmH_2O	30 cmH_2O
150	36 cmH_2O	34cmH_2O	30 cmH_2O
180	38 cmH_2O	34cmH_2O	31 cmH_2O
210	38 cmH_2O	34cmH_2O	31 cmH_2O
240	38 cmH_2O	34cmH_2O	31 cmH_2O
270	38 cmH_2O	34cmH_2O	31 cmH_2O
300	38 cmH_2O	34cmH_2O	31 cmH_2O

Immediately after submersion it was found that the mean pressure (n=3) was 24.0 cm H_2O (SD 2.00); at 30 seconds the mean pressure was 32.67 cm H_2O (SD 3.05); at 150 seconds the mean average pressure was 33.33 cm H_2O (SD 3.05); and at 300 seconds the mean pressure was calculated to be 34.33 cm H_2O (SD 3.51). The range of pressure was 30 to 38 cm H_2O. The percentage % change between the initial cuff pressure and the final cuff pressure of trial 1 was 90%, trial 2 was 70% and trial 3 was 55%.

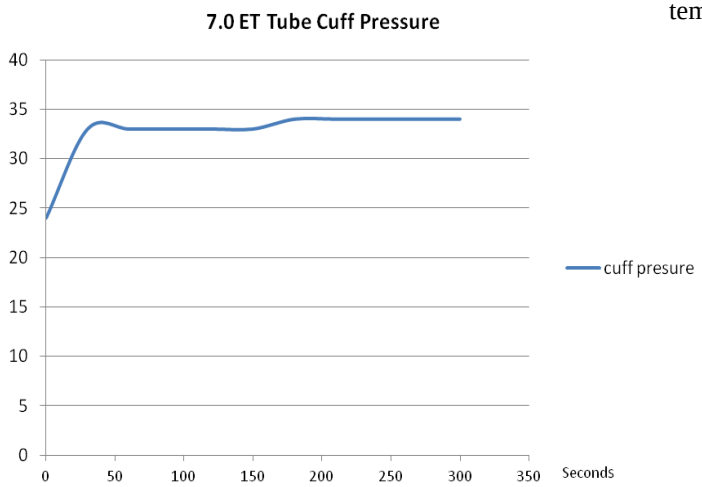
Table 2 – 8.0 ETT			
	Trial 1	*Trial 2*	*Trial 3*
Time (seconds)	**Pressure (cmH_2O)**	**Pressure (cmH_2O)**	**Pressure (cmH_2O)**
Baseline	20 cmH_2O	20 cmH_2O	20 cmH_2O
Immediately after submerging	22 cmH_2O	24 cmH_2O	22 cmH_2O
30	24 cmH_2O	26 cmH_2O	24 cmH_2O
60	24 cmH_2O	26cmH_2O	24 cmH_2O
90	26 cmH_2O	26cmH_2O	26 cmH_2O
120	26 cmH_2O	28cmH_2O	26 cmH_2O
150	26 cmH_2O	28cmH_2O	26 cmH_2O
180	26 cmH_2O	28cmH_2O	26 cmH_2O
210	28 cmH_2O	30cmH_2O	28 cmH_2O
240	28 cmH_2O	30cmH_2O	28 cmH_2O
270	28 cmH_2O	30cmH_2O	28 cmH_2O
300	28 cmH_2O	30cmH_2O	28 cmH_2O

The same sequence and time intervals previously used for *Table 1* were incorporated to calculate data for *Table 2*. After submersion the mean pressure (n=3) was 22.67 cm H_2O (SD 1.15); at 30 seconds the mean pressure was 24.67 cm H_2O (SD 1.15); at 150 seconds the mean pressure was 26.67 cm H_2O (SD 1.15); and at 300 seconds the mean was calculated to be 28.67 cm H_2O (SD 1.15). The range

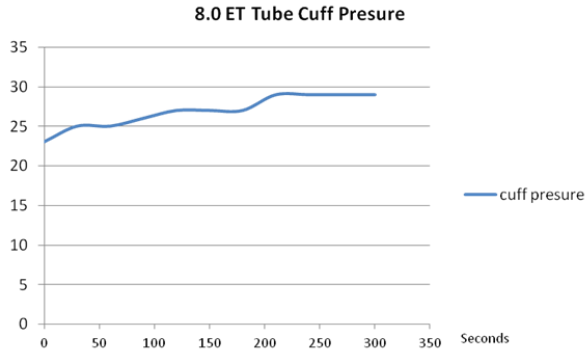
of pressure was 24 to 30 cm H_2O. The percentage % change between the initial cuff pressure and the final cuff pressure of trial 1 was 40%, trial 2 was 50% and trial 3 was 40%.

The three trials were performed on ETT size 7.0 mm and 8.0 mm at a temperature of 37 degree Celsius, a baseline pressure of 20 cmH_2O, and a volume of 8 cc's of air.

Cuff pressures presented for each trial on *Table 1* (n-3) were averaged based on 30 second intervals starting immediately after submersion. The average plotted on the 7.0 and 8.0 tube cuff pressure graphs in order to demonstrate the cuff pressure changes once the ETT is exposed to body temperature.



Same strategy used to plot the 7.0 tube cuff pressure graph was implied on the 8.0 tube cuff pressure graph using the data from *Table 2*.



When the time frame was separated for 7.0 tube cuff pressures the percent change in the early stage (baseline-60 sec.) was found to be 65%; intermediate stage (90-180 sec.) was a 3% change; and in the late stage (210-300 sec.) there was a 0% change.

Percent change for the 8.0 ET tube during the early stage was 25%; intermediate stage was 4%; and in the late stage there was a 0% change.

Discussion

Previous studies suggest that the time it takes for cuff pressures to stabilize is usually underestimated. For example, Ben *et al.* observed that the size 7 and size 8 ETT cuff pressures exceeded 30 cm H_2O after 3 minutes. Their research shows that immediately after the insertion of the size 7 ETT the average pressure was below the suggested range. At 30 seconds it rose to within the range of cuff pressures and at 3 minutes it continued to rise above the suggested cuff pressures. Immediately after inserting the size 9 ETT the average pressure was below normal, at 30 seconds it reached suggested range and at 3 minutes it was above normal range.

Our results are consistent in that measured cuff pressures exceeded 30 cm H_2O after 3 minutes. Cuff pressures were thus less likely to be within the recommended range (20–30 cm H_2O) if measured before three minutes. This result suggests that clinicians should wait at least three minutes post

intubation before performing cuff pressure readings to encourage accuracy.

A limitation of this study is that ETT cuff pressures were not tested on the human trachea but by substitution of corrugated ventilator tubing (artificial trachea). Our research showed that the volume of air required to inflate the endotracheal tube cuff did not vary as a function of tube size and type. But interestingly, the volume required to inflate the cuff to a particular pressure was much smaller when the cuff was inflated inside an artificial trachea. Also, the inner surface of the 5 inch flex hose is corrugated which is not typical of the human or even animal lung.

Our research as well as Ben *et al*. found that another drawback of these studies was that the inferior border of the ETT cuff was not exposed to positive pressure ventilation. It may also be effective to repeat this experiment with the 5 inch flex hose attached to a rubber test lung. The rubber test lung could then be bagged to identify the impact of positive pressure ventilation on these cuff pressures.

Conclusion

As this study was conducted it was shown that ETT cuff pressures took an average of three minutes to stabilize. Establishing a secure airway via endotracheal intubation is a critical clinical skill and lifesaving technique. The procedure, however, can cause complications even long after the endotracheal tube (ETT) is placed past the vocal cords and secured. Tracheal necrosis, rupture, stenosis, laryngeal nerve palsy and tracheo-esophageal fistulas are all potential risks when the pressure in ETT cuffs is excessively high.

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Waveform Comparisons: The MetaNeb® and Vortran™

Jennifer Hua, Kim Frie, Cynthia Young, Julissa Webb

Abstract

BACKGROUND: The MetaNeb® and Vortran™ are both forms of intrapulmonary percussive ventilation (IPV). The MetaNeb® proposed three methods of operation: continuous positive expiratory pressure (CPEP) for lung expansion, continuous high frequency oscillation (CHFO) for secretion mobilization, and aerosol for delivery of medication. The Vortran™ provides high frequency oscillation at two levels, soft and hard. The aim of this study was to compare the waveforms produced by the MetaNeb® and the Vortran™. METHODS: Rudolph Breathing Simulator displayed the waveforms of both devices via pressure, volume, and flow rates. Both devices operated on 50 psig, and waveforms of the Rudolph Breathing Simulator alone were collected for baseline graphs. All graphs were recorded using digital camera images. The MetaNeb® was set on oscillation (CHFO) at both high and low oscillation. On continuous positive expiratory pressure (CPEP) started with no flow, and then maintained pressure of 20 cmH_20. The Vortran was set on soft and hard modes. RESULT: The MetaNeb® displayed oscillation waveforms varying slightly between high and low oscillation, with 1.8 cmH_2O peak airway pressure in both modes. Auto PEEP of 9.8 cmH_20 on high and 11.8 cmH_20 on low. The same mode, with no flow, had a peak airway pressure of 0.4 cmH_2O, auto PEEP pressure 0.0 cm H_2O, and tidal volume 72 ml. When 20 cmH_2O was added, peak airway pressure increased to 18.2 cmH_2O, auto PEEP pressure -0.4 cm H_2O, and tidal volume decreased to 64 ml. The Vortran™ had a peak airway pressure 0.5 cmH_2O, auto PEEP pressure 0.0 cm H_2O, and tidal volume 72 ml on hard. In soft mode, there was peak pressure of 0.4 cmH_2O, auto PEEP pressure 0.0 cm H_2O, and tidal volume 71 ml. Waveforms in both hard and soft modes were similar to the baseline graphs. CONCLUSIONS: The MetaNeb®, on the 20 cmH_2O setting, resulted in the most increased functional residual capacity (FRC). However, the Vortran™ running on 50 psig on both hard and soft settings did not raise the FRC. Vibration was seen in both devices.

Background

The MetaNeb® (Comedica, Inc., Dallas, TX) is a form of intrapulmonary percussive ventilation (IPV) that was introduced in August 2010, and was one of many recently developed devices that incorporate high frequency oscillator ventilation. MetaNeb® was effectively used for the mobilization of secretions, lung expansion therapy, and the treatment and prevention of atelectasis by combining continuous lung expansion therapy through the delivery of aerosolized nebulized medication, continuous positive pressure ventilation, and high frequency positive pressure ventilation (Barton, 2008; Faram, 2009). It required a 50-psi gas source, circuits that connect to a power box, and pressure limits maintained between 15-20 cm H_2O. The MetaNeb® offered three different selections consisting of two modes that could both be used with or without aerosol; continuous positive expiratory pressure (CPEP) and continuous high frequency oscillation (CHFO). Continuous positive expiratory pressure (CPEP) treatment delivered lung expansion by providing constant airway pressure during both inhalation and exhalation, using continuous flow through a venturi, and a fixed orifice resistor (Bocci, Garcia, Timon, Wolff, Hargett, & Thornton, 2006). Continuous high frequency oscillation (CHFO) was an airway clearance therapy, which used a systematic method to improve normal mucus clearance, and managed atelectasis by delivering aerosolized therapy to relax bronchial smooth muscle to decrease airway resistance and hydrate thickened secretions. Continuous high frequency oscillation (CHFO) was precisely calibrated frequency and I:E ratio to generate airway pressure in order to sustain airway ability, to prevent early closure of the airway and increase the collapsed lung field (Metaneb). Continuous high frequency oscillation (CHFO) was maintained during both inspiration and expiration to form a pressure gradient to the small airways where secretions are trapped. This created a faster expiratory airflow that could be controlled to assist in moving the secretions to the upper airways (Metaneb). Caution should be taken when using MetaNeb®. The MetaNeb® is a single patient use only, and entrainment orifices should not be occluded when in use. Contraindications of MetaNeb® are

similar to IPPB, such as high intracranial pressure (ICP), an absolute contraindication of all airway clearance devices. Other contraindications included untreated pneumothorax, head or neck injury that has not been stabilized, and active hemorrhage with hemodynamics instability (Application of HFCO). Other devices similar to MetaNeb® include the Bird IPV, which offers the same modes as MetaNeb®, but is not indicated for lung expansion therapy, and is a non-disposable and reusable interface circuit. The Vortran™ is another airway clearance device, also similar to MetaNeb®. It is a high frequency intrapulmonary percussive nebulizer that is designed to oscillate at higher frequencies to mobilize mucus from the lungs in patients with retained secretions. It offers intrapulmonary percussive aerosol ventilation, high frequency oscillation, mucus clearance, and high aerosol output (Faram, 2005).

Since the MetaNeb® only came on the market in 2010, little research is available as to the effectiveness and comparability of this equipment to other IPV (intrapulmonary percussive ventilation) devices (Comedica, Inc., Dallas, TX). It would stand to reason that comparable waveforms would indicate a similar function and effectiveness of like equipment. The purpose of this study is to compare the waveforms created during the three different modes of operation of the MetaNeb® and compare them to the waveforms created by the Vortran™ Percussive Neb thus observing any similarities between the IPV (intrapulmonary percussive ventilation) devices, and determining if the devices are truly similar, as well as if their therapeutic function is equal. Our hypothesis is that the waveforms produced during the three different modes of operation of the MetaNeb® will be the same as those produced by similar IPV (intrapulmonary percussive ventilation) devices, specifically the Vortran™ Percussive Neb.

Methodology

Method

This study was performed at Lone Star College Kingwood, in the Respiratory Department Laboratory, Kingwood, Texas, US.

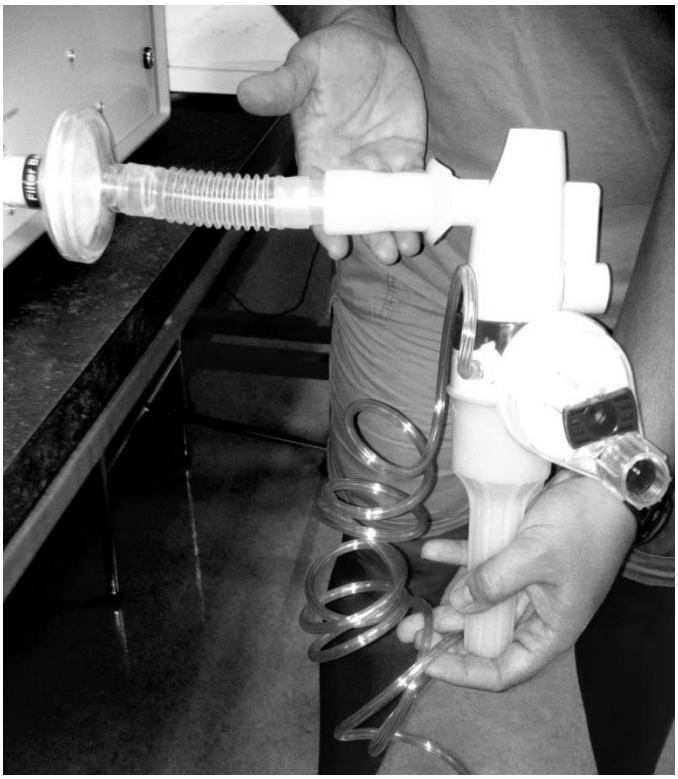
Equipment

- MetaNeb® (Comedica, Inc., Dallas, TX) serial number: 10-01911, item number C20130, product No. PMN3
- Vortran™ Percussive Neb medical technology Inc. (Sacramento, CA)
- Series 1101 Breathing stimulator manufacture by Hans Rudolph, Inc. (Kansas City, Missouri)
- Sony brand Cyber-shot digital still camera with a 30X optical zoom

Description of Use

The MetaNeb® circuit included a mouthpiece, selector ring, hand-set, circuit connector, nebulizer, orifice indicator, adapter size 22 mm x 15 mm, occlusion ring, and adapter size 22 mm x 22 mm, following user manual guide to assemble parts. The component of the Vortran™ Percussive Neb included a nebulizer top, mouthpiece, nebulizer reservoir with baffle inside, main column, amplitude dial, modulator, and gas flow that can support 60 L/min. The last equipment was the Series 1101 Breathing stimulator.

In order to make the Vortran™ connect to the Rudolph Breathing Simulator, a rubber pulmonary function mouth interface was placed on the Vortran™ patient inhalation port, and a six inch section of 22 mm corrugated bore tubing was attached to the rubber mouthpiece and the Rudolph Breathing Simulator. See Photograph 1.



Photograph 1: Vortran™ Percussive Neb with Connection to Rudolph Breathing Simulator

Testing and Calibration

MetaNeb®

The equipment was checked for leaks and proper function before use. The MetaNeb® was connected to a 50 psig gas source, and the knob turned to continuous high frequency oscillation (CHFO) mode with higher setting selected. The selector ring on handset was placed on the three dots, indicating high resistance. The device was switched to the ON position, and the continuous high frequency oscillation (CHFO) rate was observed for a period of five seconds. Continuous high frequency oscillation (CHFO) was +17/- 8 pulses in 5 seconds. The knob was then turned counter clockwise to full flow to check for leaks in continuous positive expiratory pressure (CPEP) mode. With the selector ring at three dots, the patient opening of the handset was occluded and the manometer was observed showing peak pressure between 15 and 30 cmH_2O, indicating no leaks in the MetaNeb®.

Vortran™ Percussive Neb

A function check was also performed on the Vortran™ Percussive Neb by occluding the mouthpiece and adjusting the flow until oscillation began. According to the manual, the Vortran™ Percussive Neb requires an 80 psig to generate a flow of 60 l/min. For this study, 80 psig was not available; therefore a 50 psig was used to perform a function check.

Series 1101 Breathing Simulator

A system leak and calibration was performed on the Series 1101 Rudolph Breathing Simulator, by a calibration laboratory AJD on 02-21-2007 and recalibrated on 02-22-2008. According to the manual, the unit should be calibrated at least once per year. For this study, we were unable to calibrate the Rudolph Breathing Simulator; therefore a pressure check was conducted to validate the accuracy of the pressure and volumes, using the Phillips Respironics V60 mechanical ventilator.

The Respironics V60 was set in the pressure control (PC) mode with IPAP 20 cm H_2O, EPAP 10 cm H_2O, peak inspiratory flow 39 L/min, and tidal volume 184 L/min. When connected to the Rudolph breathing simulator using a standard bipap circuit, the Rudolph Breathing Simulator had a peak pressure of 20.4 cm H_2O and an end expiratory pressure of 10.2 cmH_2O, peak inspiratory of 37.1 cmH_2O, and tidal volume of 173 L/min, showing that the pressure and volume were very close to accurate, thus validating that the pressures and volumes are correct on the Rudolph breathing stimulator.

As can be seen, the Respironics V60 gave an IPAP of 20 cmH_2O, and the Rudolph Breathing Simulator measured 20.4 cm H_2O. The EPAP given by the V60 ventilator was 10 cmH_2O and the EPAP measured by the Rudolph was 10.2 cmH_2O. The peak inspiratory flow measured was 1.9 L/min lower

than what was delivered, and the measured tidal volume was 11 L/min lower than what was delivered.

Additional Equipment

In addition to the respiratory equipment used for this study, a Sony brand Cyber-shot digital still camera with a 30X optical zoom was used to capture images of various waveforms. The camera was placed on a standard camera tripod to maintain stability.

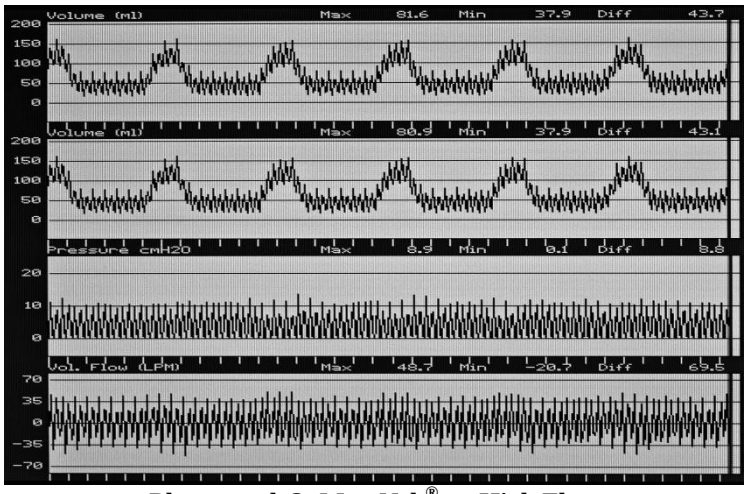
Patient Set Parameter

The set parameters for the Breathing Simulator used in the entire experiment were based on the manufacturer's recommended mean of the normal values. According to these recommendations, settings included a set airway resistance of 12 cmH_2O/lps, compliance of 35 ml/cmH_2O, breath rate of 6 bpm, amplitude of -5 cmH_2O, effort slope waveform profiles set at 12, percent inhale 30% to create a 1:2 I:E ratio, and a set target volume of 3000 ml. These parameters are from the breathing simulator manual and represent the parameters that would be found in a normal lung.

Protocol

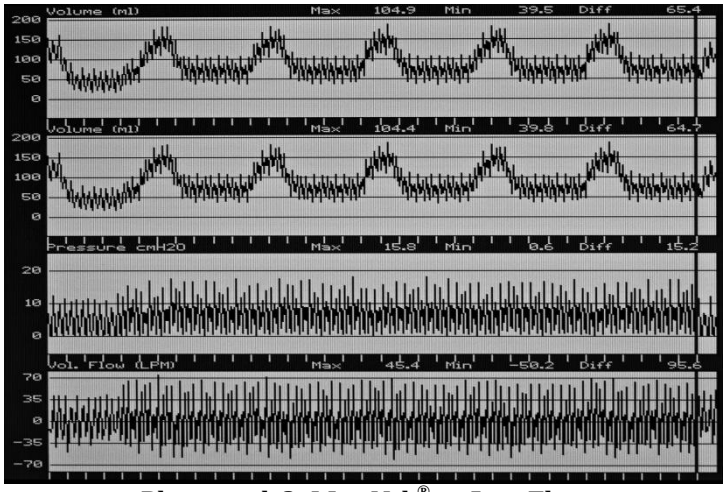
1. The waveforms on the breathing machine were photographed with the preset parameters, without any additional machines attached to it. This gave us a baseline to compare future waveforms. *It was necessary to allow the adjusted waveforms to populate the screen after each change, and before the photograph was taken. This took approximately 15 seconds. It was understood from here forward that this time frame was necessary after each subsequent change before the photograph of the affected waveform could be taken.
2. The MetaNeb® was attached to the breathing simulator, the frequency set on low on the MetaNeb® and the waveforms were then photographed.
3. The frequency was then changed to high and the waveforms were photographed.
4. The mode on the MetaNeb® was then changed to continuous positive expiratory pressure (CPEP) and the waveforms were photographed.
5. The mode was then changed to continuous positive expiratory pressure (CPEP) low/no flow and the waveforms were photographed.
6. The mode was then changed to continuous positive expiratory pressure (CPEP) high 19 cmH_2O and the waveforms were photographed.
7. The mode was then changed from continuous positive expiratory pressure (CPEP) to aerosol on the MetaNeb®, with the first setting in this mode being low flow. The waveforms were then photographed.
8. The aerosol mode was then changed from the low flow setting to the high flow setting, reaching approximately 20 cm H_2O, and the waveforms was then photographed. *The MetaNeb® unit is a solely contained unit that can be moved around on wheels. It is therefore considered stable enough to be attached to the breathing simulator and requires no additional manipulation during the testing, other than changing modes.
9. After testing of the MetaNeb® was complete, the MetaNeb® was removed from the breathing simulator.
10. The Vortran™ Percussive Neb was then attached to the breathing simulator, was set on the hard setting and the waveforms were photographed.
11. The Vortran™ was then set on the soft setting and the waveforms were photographed. This concluded the experiment portion of our study. *The Vortran™ was designed to be hand held by patient, therefore the Vortran™ needs to be held by a member of the research team to be attached to the breathing simulator.

Results



Photograph 2: MetaNeb® on High Flow

MetaNeb® on High Flow had a peak inhaled flow of 43.5 LPM, peak exhaled flow of -6.9 LPM, peak airway pressure of 1.8 cmH_2O, end exhaled pressure of 1.0 cmH_2O, auto PEEP pressure of 9.8 cm H_2O, and tidal volume of 59 ml.



Photograph 3: MetaNeb® on Low Flow

MetaNeb® on Low Flow, had a peak inhaled flow of 47.1 LPM, peak exhaled flow of -6.9 LPM, peak airway pressure of 1.8 cmH_2O, end exhaled pressure of 1.3 cmH_2O, auto PEEP pressure of 11.4 cm H_2O, and a tidal volume of 59 ml.

Moving from MetaNeb® on Low Flow to high showed an 8.3% change in peak inhaled flow, no change in peak exhaled flow and peak airway pressure, a 30% change in end exhaled pressure, a 16% change in auto peep, and no change in tidal volume.

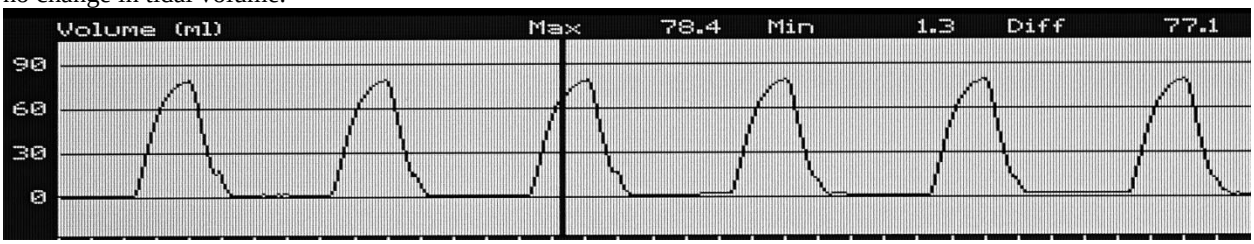


Figure 1: Baseline Volume

The baseline graphs had a peak inhaled flow of 5.4 LPM, peak exhaled flow of -6.9 LPM, peak airway pressure of 0.3 cmH_2O, end exhaled pressure of 0.0 cmH_2O, auto PEEP pressure of 0.0 cm H_2O, and tidal volume of 70 ml.

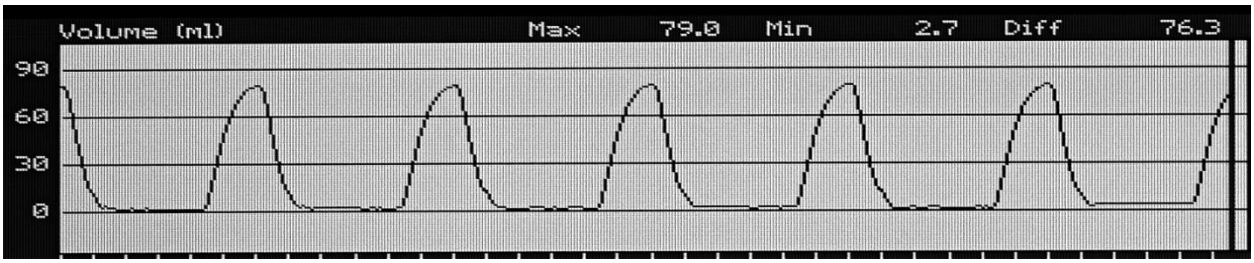


Figure 1.2: CPEP with no Flow

During CPEP without flow, one saw peak inhaled flow of 5.6 LPM, peak exhaled flow of -7.0 LPM, peak airway pressure of 0.4 cmH_2O, end exhaled pressure of 0.0 cmH_2O, auto PEEP pressure of 0.0 cm H_2O, and tidal volume of 72 ml.

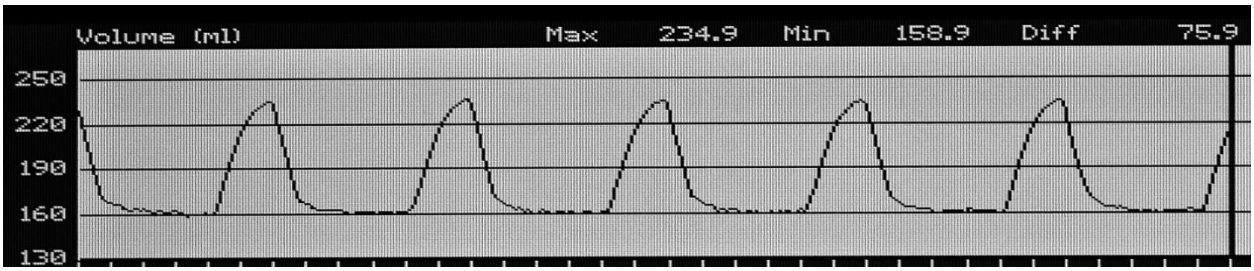


Figure 1.3: CPEP Volume with 20 cmH_2O

CPEP Volume with 20 cmH_2O displayed peak inhaled flow of 6.0 LPM, peak exhaled flow of -6.8 LPM, peak airway pressure of 18.2 cmH_2O, end exhaled pressure of 16.0 cmH_2O, auto PEEP pressure of 0.4 cm H_2O, and tidal volume of 64 ml. Figure 1.3 showed that the volume did not return to baseline on high flow, but maintained 160 ml of functional residual capacity (FRC).

When moving from CPEP with no Flow & CPEP Volume with 20 cmH_2O one saw a 7% change in peak inhaled flow, 3% change in peak exhaled flow, 45% change in peak airway pressure, 160% change in peak exhaled pressure, 4% change in auto peep, 12.5% change in tidal volume, and 160% change in functional residual capacity (FRC).

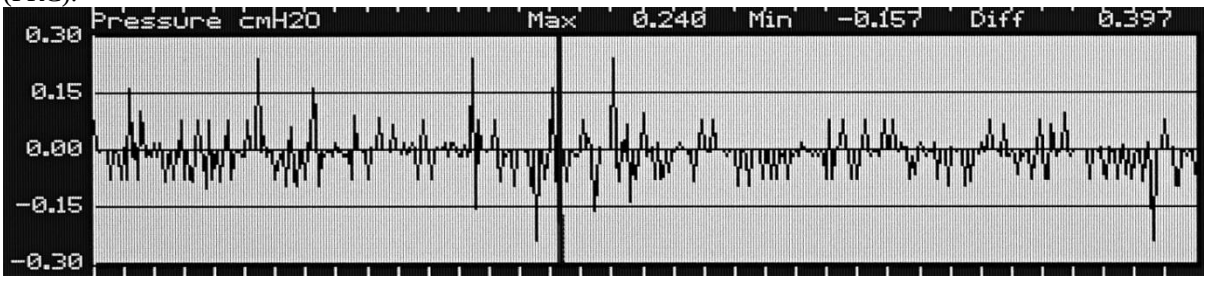


Figure 2: Pressure Baseline

During baseline readings one saw peak inhaled flow of 5.4 LPM, peak exhaled flow of -6.9 LPM, peak airway pressure of 0.3 cmH_2O, end exhaled pressure of 0.0 cmH_2O, auto PEEP pressure of 0.0 cm H_2O, and tidal volume of 70 ml.

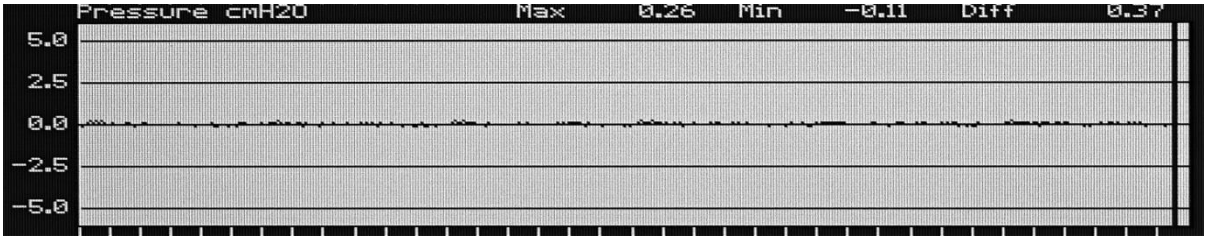


Figure 2.1: CPEP Pressure with No Flow

CPEP Pressure with No Flow showed peak inhaled flow of 5.6 LPM, peak exhaled flow of -7.0 LPM, peak airway pressure of 0.4 cmH_2O, end exhaled pressure of 0.0 cmH_2O, auto PEEP pressure of 0.0 cm H_2O, and tidal volume of 72 ml.

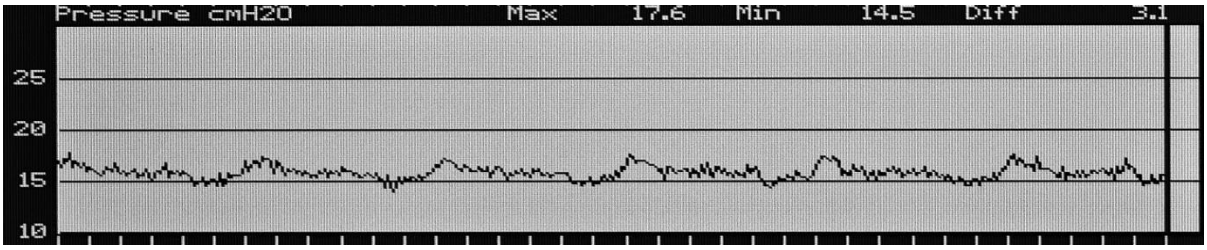


Figure 2.2: CPEP Pressure High Flow on 20 cmH_2O

CPEP Pressure High Flow on 20 cmH_2O resulted in a peak inhaled flow of 6.0 LPM, peak exhaled flow of -6.8 LPM, peak airway pressure of 18.2 cmH_2O, end exhaled pressure of 16.0 cmH_2O, auto PEEP pressure of -0.1 cm H_2O, and tidal volume of 64 ml.

When going from CPEP Pressure with No Flow to CPEP Pressure High Flow on 20 cmH_2O, a 7% rise in peak inhaled flow, 3% change in peak exhaled flow, 45% change in peak airway pressure, 160% change in peak exhaled pressure, 1% change in auto peep, and 12.5% change in tidal volume.

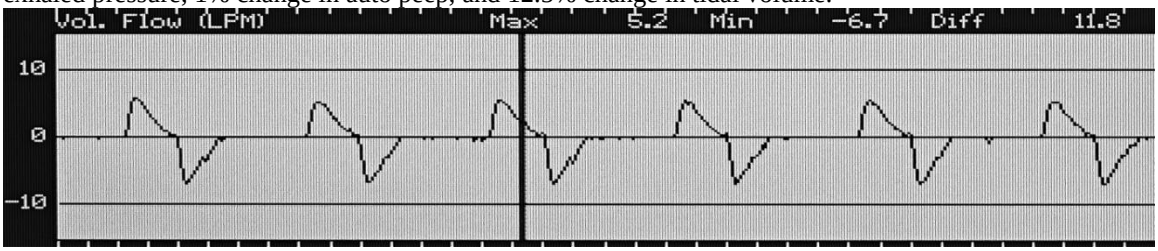


Figure 3: Flow Baseline

Baseline graphs showed peak inhaled flow of 5.4 LPM, peak exhaled flow of -6.9 LPM, peak airway pressure of 0.3 cmH_2O, end exhaled pressure of 0.0 cmH_2O, auto PEEP pressure of 0.0 cm H_2O, and tidal volume of 70 ml.

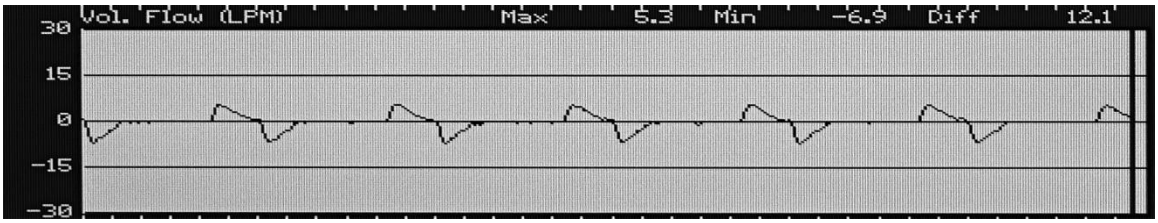


Figure 3.1: CPEP no Flow

CPEP no Flow showed peak inhaled flow of 5.6 LPM, peak exhaled flow of -7.0 LPM, peak airway pressure of 0.4 cmH_2O, end exhaled pressure of 0.0 cmH_2O, auto PEEP pressure of 0.0 cm H_2O, and tidal volume of 72 ml.

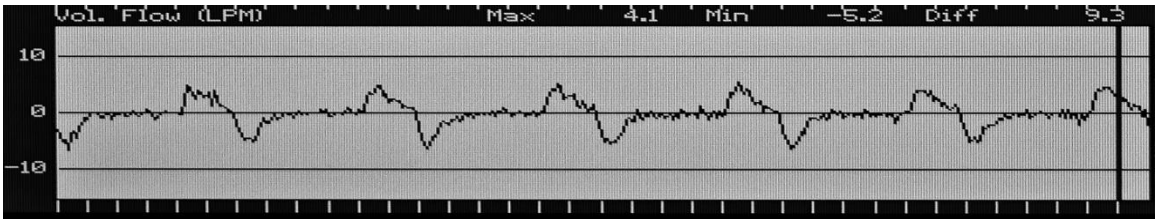


Figure 3.2. CPEP High Flow with 20 cmH_2O

CPEP High Flow with 20 cmH_2O showed peak inhaled flow of 6.0 LPM, peak exhaled flow of -6.8 LPM, peak airway pressure of 18.2 cmH_2O, end exhaled pressure of 16.0 cmH_2O, auto PEEP pressure of -0.4 cm H_2O, and tidal volume of 64 ml.

After moving between CPEP no Flow and CPEP with High Flow with 20 cmH_2O, one saw a 7% change in peak inhaled flow, 3% change in peak exhaled flow, 45% change in peak airway pressure, 160% change in peak exhaled pressure, 4% change in auto peep, and 12.5% change in tidal volume.

Vortran™

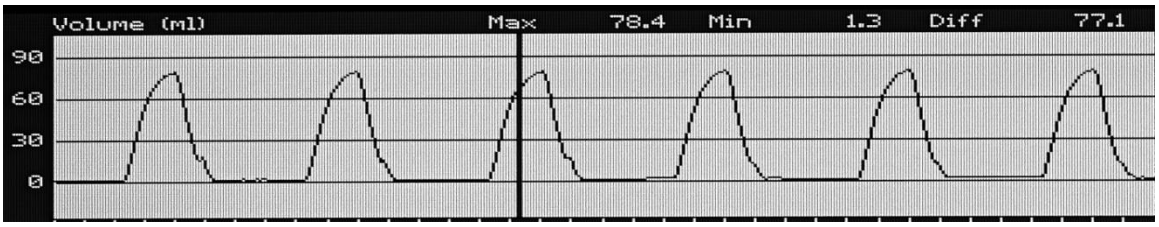


Figure 4: Volume Baseline

During baseline readings before Vortran™ was attached, one saw peak inhaled flow of 5.4 LPM, peak exhaled flow of -6.9 LPM, peak airway pressure of 0.3 cmH_2O, end exhaled pressure of 0.0 cmH_2O, auto PEEP pressure of 0.0 cm H_2O, and tidal volume of 70 ml.

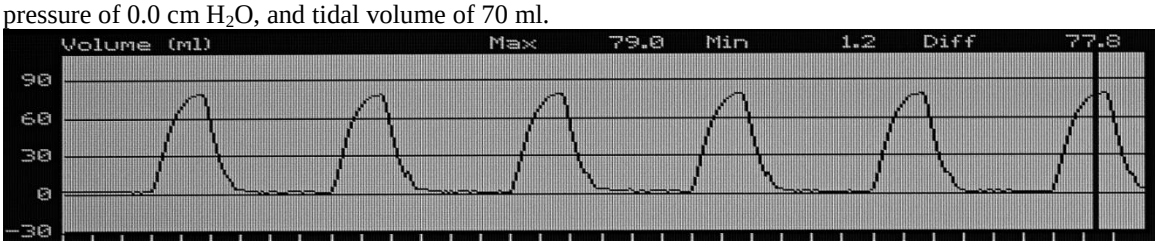


Figure 4.1: Vortran™ Hard Volumes

Vortran™ Hard mode showed peak inhaled flow of 6.1 LPM, peak exhaled flow of -7.1 LPM, peak airway pressure of 0.5 cmH_2O, end exhaled pressure of -0.1 cmH_2O, auto PEEP pressure of 0.0 cm H_2O, and tidal volume of 72 ml.

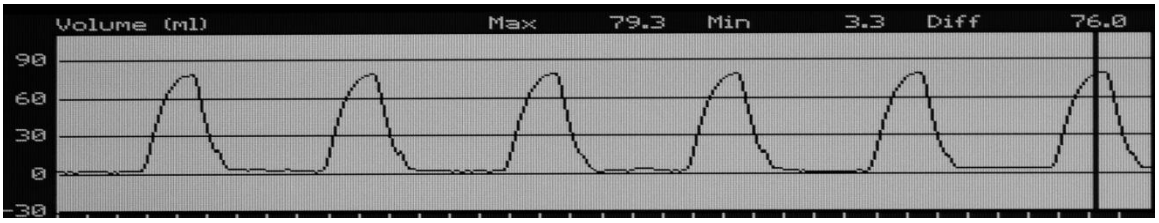


Figure 4.2: Vortran™ Soft Volume

Vortran™ Soft showed peak inhaled flow of 5.8 LPM, peak exhaled flow of -7.0 LPM, peak airway pressure of 0.4 cmH_2O, end exhaled pressure of 0.0 cmH_2O, auto PEEP pressure of 0.0 cm H_2O, and tidal volume of 71 ml.

When moving from Vortran™ Soft to Hard mode one saw 5% rise in peak inhaled flow, 1% change in peak exhaled flow, 25% change in peak airway pressure, 10% change in end exhaled pressure, no change in auto peep, and 1% change in tidal volume.

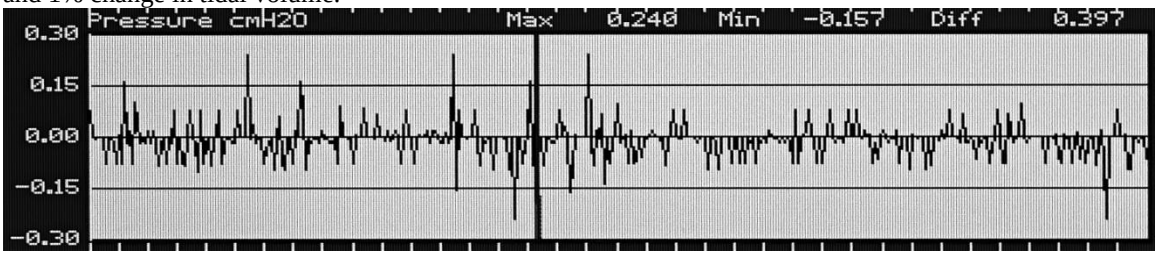


Figure 5: Pressure Baseline

Baseline readings showed peak inhaled flow of 5.4 LPM, peak exhaled flow of -6.9 LPM, peak airway pressure of 0.3 cmH_2O, end exhaled pressure of 0.0 cmH_2O, auto PEEP pressure of 0.0 cm H_2O, and tidal volume of 70 ml.

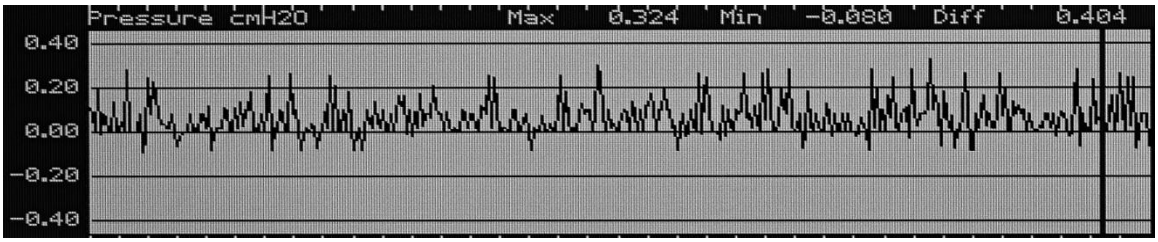


Figure 5.1. Vortran™ Hard Pressure

Vortran™ Hard showed peak inhaled flow of 6.1 LPM, peak exhaled flow of -7.1 LPM, peak airway pressure of 0.5 cmH_2O, end exhaled pressure of -0.1 cmH_2O, auto PEEP pressure of 0.0 cm H_2O, and tidal volume of 72 ml.

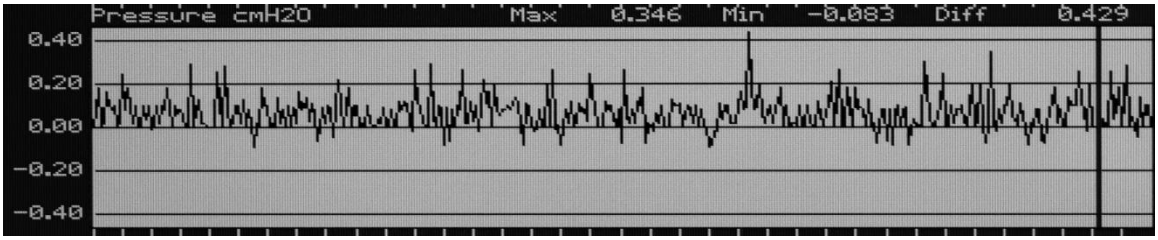
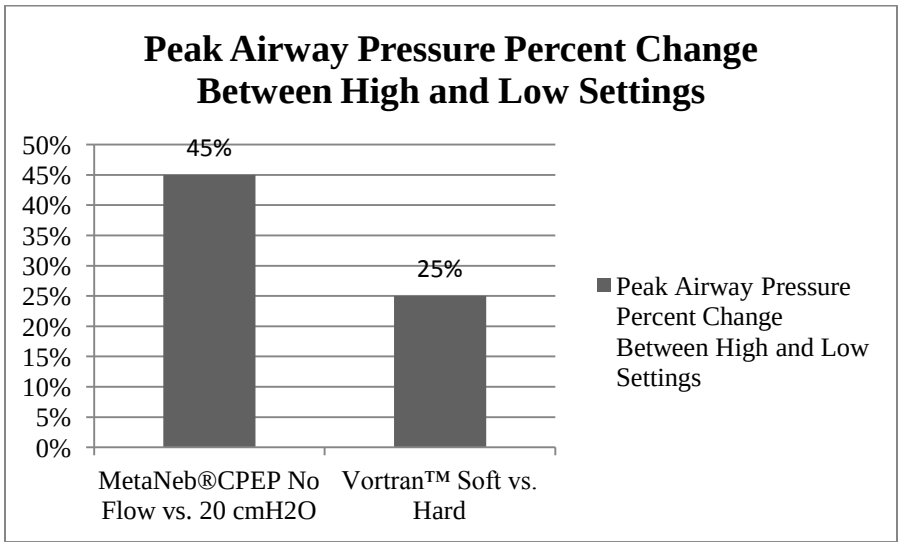


Figure 5.2. Vortran™ Soft Pressure

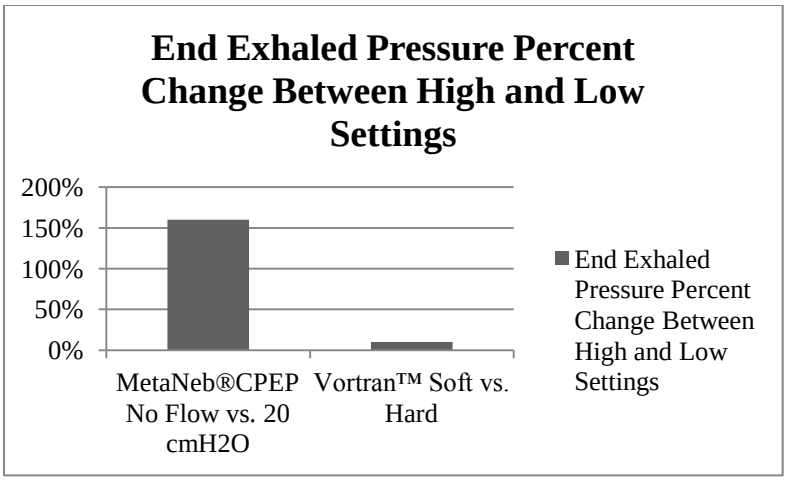
Vortran™ Soft showed peak inhaled flow of 5.8 LPM, peak exhaled flow of -7.0 LPM, peak airway pressure of 0.4 cmH_2O, end exhaled pressure of 0.0 cmH_2O, auto PEEP pressure of 0.0 cm H_2O, and tidal volume of 71 ml.

When going from Vortran™ Soft to Hard modes there was a 5% change in peak inhaled flow, 1% change in peak exhaled flow, 25% change in peak airway pressure, 10% change in end exhaled pressure, no change in auto peep, and 1% change in tidal volume.



Graph 1: Peak Airway Pressure Change Between High and Low Settings

In Graph 1, there was a 45% change in the peak airway pressure between the no flow setting on the MetaNeb® and the high flow, or 20 cmH_20, setting. There was a 25% change in the peak airway pressure between the Vortran™ soft and hard settings. The MetaNeb® had a 20% greater change in the peak airway pressure between settings than the Vortran™.



Graph 2: End Exhaled Pressure Percent Change Between and Low Setting

In Graph 2, there was a 160% change in the end exhaled pressure from the no flow setting on the MetaNeb® and the high, or 20 cmH_20, setting. There was only a 10% change in the end exhaled pressure between the soft and hard settings on the Vortran™. The MetaNeb® had a 150% greater change in end exhaled pressure than the Vortran™.

Discussion

The research team hypothesized that the waveforms produced during the three different modes of operation of the Metaneb® would be the same as those produced by similar IPV (intrapulmonary percussive ventilation) devices, specifically the Vortran™ Percussive Neb. It was discovered that two of the three settings on the MetaNeb® were not truly comparable to either setting on the Vortran™. The MetaNeb® had a mode for delivering aerosol at low or high flow, as well as a mode for just delivering low or high flow.

After attaching the MetaNeb® and then the Vortran™ Percussive devices to the Rudolph lung simulator we found that the MetaNeb®, on high or low oscillatory settings, produced a waveform indicating an elevation in the functional residual capacity. The functional residual capacity (FRC) was elevated to 160 mL on the high setting of the MetaNeb®, and it never rose on the low setting of the MetaNeb®.

The researchers were able to compare the MetaNeb® in the CPEP mode, with no flow and 20 cmH_2O, to the Vortran™ soft and hard settings, because of the similar nature of these two oscillatory modes. The MetaNeb® baseline waveform and the CPEP low flow setting showed no auto PEEP. The MetaNeb® CPEP setting with high flow (pressure kept at 20 cmH_2O) showed an increase of 160 mL of functional residual capacity.

One of the more significant findings of this study was the change in the peak airway pressure between settings in the comparable modes of the MetaNeb® and the Vortran™. The MetaNeb® showed a 45% change in the peak airway pressure from no flow to 20 cmH_2O. The Vortran™ showed a 25% change in peak airway pressure between the soft and hard setting. This is also the setting where the FRC was noted on the MetaNeb®.

Another notable variance between the MetaNeb® and the Vortran™ was in the end exhaled pressure. There was a 160% change in the end exhaled pressure when the MetaNeb® was switched from no flow to 20 cmH_2O. The Votran™ only exhibited a 10% change when it was switched from the soft to hard setting. This would show that the MetaNeb® has a much greater continuous positive expiratory pressure than the Vortran™.

Limitations

Although this study demonstrated that there were similar waveforms produced by the MetaNeb® and the Vortran™, there were also some differences. Some of these differences may be attributed to the limitations of our study. The manufacturer of the Vortran™ recommends that it be used with its own 80 psig compressor. The 80 psig compressor was not available for our study, so 50 psig was used. The off label use of the Vortran™ altered the data collection of the waveforms produced by the Vortran™. Another limitation may have been the connection of the Vortran™ to the Randolph Breathing Simulator. In order to effectively connect the Vortran™ to the Randolph, a rubber pulmonary function mouth interface had to be connected. Being made of rubber, it is possible that it absorbed some of the percussiveness, therefore altering the data. It at 80

psig and we used a 50 psig. It is a recommendation of this team that this study be reproduced in the future using the 80 psig compressor.

Clinical Significance

The results of this study would indicate that using the MetaNeb® on the high oscillatory setting on a patient with consolidation, such as pneumonia, would give that patient a level of functional residual capacity (FRC) that could be beneficial to that patient. In a patient with COPD, who does not need an elevated FRC as they already air trap, we suggest the MetaNeb® on low. This particular type of patient could benefit from the percussion of the lower setting, without the elevation to their functional residual capacity (FRC). We were unable to locate any prior studies of this nature to compare our study to. It is possible this is the first study comparing waveforms produced by the different settings on the MetaNeb® and the Vortran™.

Conclusion

The purpose of this study was to compare the waveforms created during the three different modes of operation of the MetaNeb®, and compare them to the waveforms created by the Vortran™ Percussive Neb to determine if there are similarities between IPV (interpulmonary percussive ventilation) devices. We hypothesized that the waveforms produced during the three different modes of operation of the MetaNeb® would be the same as those produced by similar IPV devices.

We discovered that two of the three MetaNeb® modes were actually not comparable to the one mode of the Vortran™. We were able to compare the no flow and 20 cmH_2O settings of the CPEP mode on the MetaNeb® to the soft and hard settings on the Vortran™.

What we found was that the MetaNeb® provided a greater end exhaled pressure than the Vortran™, as well as higher peak airway pressure. The most significant finding of our study was the MetaNeb® on the 20 cmH_2O setting resulting in a sustained functional residual capacity. This is significant because it could benefit patients in need of alveolar recruitment. This form of air trapping would maintain alveolar expansion while still allowing ventilation on top of this FRC. The Vortran™ on the high setting, which is comparable to the MetaNeb® 20 cmH_2O setting, did not retain any FRC, but returned to baseline. However, this poor result may be the result of not using the recommended working pressure.

Although our hypothesis was not confirmed, it can be seen that the newer equipment is an improvement over the older equipment, because of the additional FRC.

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