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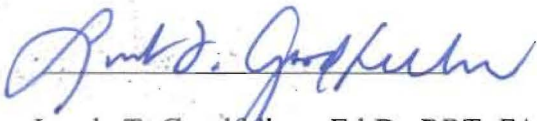
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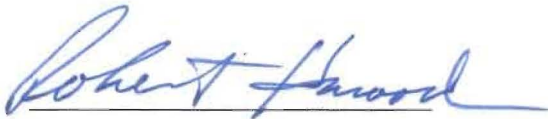
ACCEPTANCE:

This thesis, *The Independent Effect of Three Inline Suction Adapters and Lung Compliance change on Amplitude and delivered Tidal Volume during High Frequency Oscillatory Ventilation in an adult patient with ARDS: Bench Model*, by Shreya J. Thacker was prepared under the direction of the Master's Thesis Advisory Committee of Respiratory Therapy department at Georgia State University. It is accepted by the committee in partial fulfillment of requirements for the Master's of Science degree in Respiratory Therapy at Byrdine F. Lewis School of Nursing and Health Professions, Georgia State University.

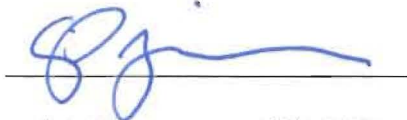
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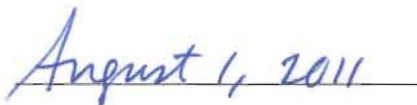
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AUTHOR'S STATEMENT

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A handwritten signature in blue ink that reads "Shreya J. Thacker". The signature is written in a cursive style and is underlined with two parallel lines.

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ABSTRACT

The Independent Effect of Three Inline Suction Adapters and Lung Compliance change on Amplitude and delivered Tidal Volume during High Frequency Oscillatory Ventilation in an adult patient with ARDS: Bench Model

By

Shreya J. Thacker

Introduction: The use of high frequency oscillatory ventilation is increasing in treatment of acute respiratory distress syndrome over the past decade. The technique of HFOV of ventilating the lungs at volumes less than the anatomical dead space calms the clinical concerns surrounding ventilating stiff ARDS lungs with high pressures and volumes. This largely reduces the probability of barotraumas and/or atelectrauma.

Purpose: The study was on an in vitro bench model that answered the following research questions: 1. The effect of three inline closed suction adapters on delivered tidal volume during HFOV with varying lung compliance 2. The effect of varying compliance on the amplitude delivered by HFOV; and 3. The effect of compliance on tidal volume delivered by HFOV.

Method: An in vitro bench model using high fidelity breathing simulator (ASL 5000, IngMar Medical) simulating an adult patient with ARDS was set up with 3100B SensorMedic high frequency ventilator. The simulation included varying the compliance for each lung at 50, 40, 30 and 20cmH₂O while maintaining fixed resistance of 15 cmH₂O/L/sec. The ventilator was set to the following parameters: power of 6, frequency (f) of 5, inspiratory time (Ti) of 33%, bias flow (BF) of 30 LPM and oxygen concentration of 50%. The breathing simulator was connected with the high frequency ventilator using a standard HFOV circuit and a size 8.0mm of endotracheal tube. Fourteen French Kimberly Clark suction catheters (with T and Elbow adapters) and Air-Life suction catheters (Y adapter) were placed in-line with the circuit successively to carry out the study. Each run lasted for 1 minute after achieving stable state conditions. This approximated to 300 breaths. The data was collected from the stimulator and stored by the host computer.

Data Analysis: The data was analyzed using SPSS v.11 to determine the statistical significance. A probability value (P value) of ≤ 0.001 was considered to be statistically significant.

Results: The data analysis showed that Air-Life Y-adapter suction catheters caused the least lost in tidal volume when placed in line with HFOV and hence proved to be the most efficient. The

study also showed a direct relationship between amplitude and lung compliance i.e. an increase in lung compliance caused an associated increase in amplitude (power setting remaining unaltered). Lastly, the study did not show a statistically significant change in tidal volume with changes in lung compliance. Future studies may be required to further evaluate the clinical significance of the same.

Conclusion:

1. Many factors affect delivery of tidal volume during high frequency ventilation and thus it is not constant. Choice of in-line suction system to be placed in line is one of the determinants of the same.
 2. Lung compliance changes lead to associated changes in amplitude delivery by HFOV. This should be adjusted as patient condition improves by altering the power settings to ensure optimal ventilation and to avoid trauma to the lungs.
-

THE INDEPENDENT EFFECT OF THREE INLINE SUCTION ADAPTERS
AND
LUNG COMPLIANCE CHANGE ON
AMPLITUDE AND DELIVERED TIDAL VOLUME DURING
HIGH FREQUENCY OSCILLATORY VENTILATION IN AN ADULT PATIENT WITH
ARDS:

BENCH MODEL

By

Shreya J. Thacker

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In

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Atlanta, Georgia

2011

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I am eternally grateful to my parents Mrs and Mr Thacker and my brother Ankit for their love, support and personal sacrifices. May god continue to abundantly bless you all and may he give me the chance to be the source of your happiness always.

Finally, I thank my friends for their encouragement, you guys rock!

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Chapter 1

INTRODUCTION

Mechanical ventilation forms the foundation of intensive care treatment for acute respiratory diseases. For the majority of patients requiring assistance, conventional mechanical ventilation (CMV) ensures adequate gas exchange by typically delivering tidal volumes that approximate 1 to 1.5 times the spontaneous tidal volume for a given patient. However, often high pressures and larger tidal volumes are required that culminate in undesirable effects of cardiac depression, hemodynamic instability and pulmonary air leaks. Thus to overcome the deleterious effects of high pressure and larger tidal volumes, high frequency oscillatory ventilation (HFOV) was developed. Apart from instituting HFOV to avoid high alveolar pressures, pulmonary hygiene is equally important and forms the cornerstone in maintaining appropriate pulmonary pressures. Suctioning has been studied extensively to cause loss of tidal volume on patients receiving mechanical ventilation (Fernandez, Piacentini et al. 2004). This can be partly owed to the dead space added by the suctioning apparatus to the ventilatory circuit. Since HFOV ventilates the lungs at tidal volumes that are lesser than the anatomical dead space, suctioning procedures have been avoided for long periods of time in these patients to prevent derecruitment of alveoli. This often culminates into secretion retention and high alveolar pressures (Pillow 2005). Thus to maintain adequate tidal volumes and to prevent the suboptimal use of suctioning during HFOV, research is required to understand the mechanics between the ventilator and the ventilatory circuit. In lieu of this, the presenting thesis studied *The Independent Effect of Three Inline Suction Adapters and Lung Compliance change on Amplitude and delivered Tidal Volume during High Frequency Oscillatory Ventilation: Bench model.*

After an initial enthusiasm for use of HFOV in the 1970's and 1980's, many clinical studies failed to prove the advantages of HFOV usage over CMV. However recently there has

been a renewed interest in use of HFOV because of two main reasons: (1) the literature supports the finding that CMV can intensify lung injury in patients with acute lung injury (ALI) or acute respiratory distress syndrome (ARDS); (2) Modification of ventilation techniques in terms of manipulating tidal volumes and airway pressure can provide a safer method of treating patients with ALI/ARDS (Krishnan and Brower 2000).

HFOV was developed to treat refractory hypoxemia in patients with ARDS/ALI. Hence HFOV works mainly for oxygenation rather than ventilation. The major advantage that HFOV provides is that it works at a respiratory rate (RR) of 60 – 900 breaths/min but at low tidal volumes which are often smaller than the anatomical dead space. This allows the maintenance of high mean airway pressures (mPaw). Therefore, when high respiratory rates maintain efficient gas exchange, alveolar derecruitment and overdistension are prevented by higher mPaw and lower tidal volumes respectively (Chan, Stewart et al. 2007).

Technique of HFOV:

While using HFOV in adults, a piston pump oscillates to maintain the frequency between 3-10Hz i.e. 180 – 600 breaths/min. mPaw is maintained via a resistance valve and the bias flow of gas between 30L – 60L/min present within the circuit. A distinctive feature of HFOV is that the back stroke of the piston brings about active expiration of gas. This is debatably thought to reduce air trapping. Another distinctive feature of HFOV is that it provides separate controls for oxygenation and ventilation. Fraction of inspired oxygen (FiO_2) and mPaw dictate the oxygenation status whereas ventilation is dictated by pressure amplitude (ΔP) and respiratory frequency, with the latter being inversely proportional (Chan, Stewart et al. 2007).

Mechanisms of Gas exchange during HFOV:

There are seven plausible mechanisms thought to enhance gas exchange during HFOV. These include: turbulence in large airways; direct ventilation of closed alveoli; turbulent flow with lateral convective mixing; pendelluft; gas mixing due to velocity profiles that are axially asymmetric; laminar flow with lateral transport by diffusion (Taylor dispersion); collateral ventilation through non-airway connection between adjacent alveoli (Slutsky and Drazen 2002).

A short description is given on these mechanisms:

Direct bulk flow: direct flow of inspired gas is received by the alveoli in the proximal tracheobronchial which leads to gas exchange by convective or *bulk flow*. *Taylor dispersion:* when diffusion is overlapped by convective flow, turbulent eddies and swirling occurs thereby increasing the amount of gas exchange that would occur from simple bulk flow. *Pendelluft:* variation in the resistance and compliance causes a difference in the pattern of airflow between lung regions and within these regions. Thus gas flows occurs between regions if these regions with variations in flow pattern are in close proximity. *Asymmetric velocity profiles:* air in the peripheral regions of the airway has a velocity lower than that in the center of the tracheobronchial tree. Owing to the difference in the flow rates, this parabolic velocity profile is pronounced during inspiration. With repetition of such cycles, air in the central part tends to move deep in the alveoli while that in the periphery moves out towards the mouth. *Cardiogenic mixing:* heart beats lead to mechanical stirring which is more evident in the lung units close to the heart. *Molecular diffusion:* this mechanism is similar to the other modes of ventilation which plays an important role in mixing of gas near the alveolar-capillary membrane (Chang 1984; Krishnan and Brower 2000).

Acute Respiratory Distress Syndrome

ALI and ARDS are defined by the American-European consensus committee. They describe ALI and ARDS as acute onset respiratory distress that presents clinically as refractory arterial hypoxemia and radiologically as diffuse pulmonary infiltrates. Both these diseases have pulmonary capillary wedge pressure of ≤ 18 mmHg with absence of clinical evidence of left atrial hypertension. The difference between the two diseases can be given by the difference in the PaO₂/FiO₂ ratio, which when ≤ 300 signifies ALI and when ≤ 200 signifies ARDS.

Etiologically, the risk factors for ARDS can be categorized into direct and indirect categories. Direct risk factors include pulmonary contusions, diffuse pulmonary infections, near drowning, inhalation of toxic fumes and aspirations. Indirect risk factors includes sepsis syndrome, severe non-thoracic trauma and cardio-pulmonary bypass (Kane and Galanes 2004).

Pathophysiologically, patients with ARDS present with acute inflammation of the lung parenchyma. Inflammation causes increased capillary permeability leading to extravasation of proteinaceous fluid into the alveoli. Protein molecules thus released inactivate the already existing surfactant. More so, the production of surfactant by type II pneumocytes is also reduced. The effect of same is an increase in surface tension and microatelectasis of alveoli. Worsening arterial oxygenation ensues due to increased dead space, pulmonary shunting and altered ventilation-perfusion mismatch. Minute ventilation is increased as a compensation to maintain the desired PaCO₂ and pH. Mechanical ventilation is generally required to support the respiratory system (Krishnan and Brower 2000).

To summarize, this chapter covered the need to introduce HFOV in management of patients with ARDS. It also briefed the importance of maintaining optimal pulmonary hygiene to

avoid deleterious effects of secretion retention. Thus the following research questions were intended to be answered:

1. The effect of three inline closed suction adapters on delivered tidal volume during HFOV with varying lung compliance
2. The effect of varying compliance on the amplitude delivered by HFOV
3. The effect of compliance on tidal volume delivered by HFOV

The answers to these questions would help prevent suboptimal use of suctioning in patients placed on HFOV and would also enhance the understanding of mechanics between ventilator and the ventilatory circuits. The study would help identify the most efficient suction adapter in terms of the amount of loss of tidal volume caused by its placement in-line with the ventilatory circuit.

Chapter 2

REVIEW OF LITERATURE

The articles for literature review were collected by using the online database system provided by the Georgia State University's library services. The databases that were used were: CINAHL plus with full text, PubMed, Health source: Nursing, Nursing and Allied Health Source and Web of Science. The articles presented in this chapter would highlight the use of HFOV in the treatment of patients with ARDS. The chapter would also present the very few studies relating to evaluating the effects of placement of inline suction catheters on the tidal volume delivered via HFOV.

The research questions intended to be answered at the end of the study were:

1. The effect of three inline closed suction adapters on delivered tidal volume during HFOV with varying lung compliance
2. The effect of varying compliance on the amplitude delivered by HFOV
3. The effect of compliance on tidal volume delivered by HFOV

High Frequency Oscillatory Ventilation in ARDS

Derak and colleagues carried out a multicenter randomized controlled trial on 148 adult patients suffering from ARDS with the aim to compare the efficiency and safety of employing HFOV with conventional mechanical ventilation (CMV). ARDS was defined as a PaO₂/FiO₂ (P/F) ratio of ≤ 200 on 10 or more cmH₂O of positive end-expiratory pressure (PEEP). All patients included in the study had a mean age of 48 years, mean PaO₂/FiO₂ ratio of 112.5, mean oxygenation index (OI) of 25.2 and a mean Acute Physiology and Chronic Health Evaluation (APACHE) II score of 22. Significant findings documented were that HFOV group showed an

early improvement in PaO₂/FiO₂ ratio but this improvement waned after the first 24 hours ($P = 0.008$). Both the groups showed an improvement in oxygenation index over the first 3 days. When 30-day mortality was assessed, HFOV had a mortality rate of 37% against 52% in CMV ($P = 0.102$). Nevertheless, there was no significant difference between these groups in causation of adverse reactions like hemodynamic instability, ventilation or oxygenation failure, mucus plugging and barotraumas. Conclusions revealed that HFOV was safe and efficient but showed no difference in incidence and intensity of complication compared to CMV (Derdak, Mehta et al. 2002).

Another randomized controlled trial was carried out by Bollen and colleagues on 61 patients with a mean OI of 22 and APACHE II score of 21 comparing the effects of HFOV vs. CMV. The study was mainly focused on the complications and mortality rate associated with HFOV. The study documented that of the 37 patients receiving HFOV, four patients (10.8%) developed pneumothorax, and one patient (2.7%) had an air leak. Of the 24 patients receiving CMV, one (4.2%) developed an air leak and one (4.2%) developed hypotension. However, baseline OI was higher in HFOV (25 vs. 18) than CMV. The 30-day mortality revealed a higher mortality in HFOV (43%) and a lower mortality in CMV (33%). The results of this study were contradicting the belief that HFOV has an effect in reducing mortality rates (Bollen, van Well et al. 2005).

On the other hand, a study conducted by Finkielman and colleagues showed somewhat different results. The retrospective study was carried out on 14 patients suffering for ARDS with a mean age of 56-years, APACHE II score of 35 and Sequential Organ Failure Assessment score (SOFA score) of 11.5. The authors reported that the data analysis showed an improvement in P/F ratio (82 to 107, $P < 0.05$) and OI (42 to 29; $P < 0.05$) only after the first 24 hours. The mortality

rate was documented to be 57%. No mention was made of complications after implementation of HFOV except in one patient in whom HFOV was discontinued due to development of refractory severe hypotension. The authors concluded that HFOV is an acceptable alternative to CMV in treatment of ARDS when protective lung strategies are required (Finkielman, Gajic et al. 2006). Since the sample size of this study was comparatively less and the authors mentioned the lack of use of a standardized protocol, the findings of the study are arguable.

Unlike the results of these studies, Mehta and colleagues reported a significant improvement in P/F ratio and OI which lasted for 72-hour in patients with ARDS receiving HFOV. They conducted a retrospective study on 156 patients with a mean age of 47.8 years, P/F ratio of 91, OI of 31.2 and APACHE II score of 21. Apart from the findings mentioned, other important findings presented were that HFOV was discontinued in 19 patients within four hours due to difficulty with maintaining oxygenation and ventilation; or deleterious hemodynamic changes like a significant rise in central venous pressure (CVP), reduced cardiac output and/or increase in pulmonary artery occlusion pressure. Additionally, 21.8% of the patients developed pneumothorax. Thirty-day mortality was assessed to be 61.7% and is highest amongst the studies mentioned (Mehta, Granton et al. 2004).

Another novel comparison was made to assess the effects of normocapnic HFOV in pulmonary (ARDS_p) and extra-pulmonary (ARDS_{exp}) forms of ARDS. It was a prospective study on 30 adult patients with mean age of 56 years, P/F ratio of 121 and SOFA score of 9.6. Assessments were made at six hours to evaluate improvements in P/F ratio. ARDS_{exp} showed significant improvement in P/F ratio (114 to 200 torr, $P < 0.01$) against no significant improvement in ARDS_p. It was also mentioned that a higher continuous distending pressure was required for the ARDS_{exp} group compared to ARDS_p (2.0 vs. 2.8 kPa, $P < 0.01$). Mortality rate

was documented to be 46% overall. It was inferred that these findings were suggestive of HFOV being more effective in extra-pulmonary ARDS compared to the pulmonary forms of ARDS (Pachl, Roubík et al. 2006).

Closed suction systems and High Frequency Oscillatory Ventilation

A bench model study was carried out in a neonatal lung model to assess for the loss of tidal volume and change in pressures associated with insertion of closed tracheal suction system (CTSS) with and without suctioning. An 8-Fr and a 6-Fr catheter were tested with a 4.5, 4.0 and 3.5 and a 3.5, 3.0 and 2.5mm ID ETT respectively. Measurements of pressures were done proximal and distal to the ETT along with measurements for inspiratory and expiratory tidal volumes. When 8-Fr catheter was inserted without the application of suctioning, no change was seen in proximal airway pressures but a decrease in distal peak inspiratory pressure was noted and no change in distal end-expiratory pressure with an increasing ratio of suction catheter to ETT size. Tidal volumes were also documented to be reduced. With the use of a 6-Fr catheter, though the proximal pressures continued to remain unchanged, a decrease in both distal pressures was seen owing to the reduction in size of the ETT. Thus, it was concluded that CTSS neither maintains the constant flow of gas nor does it maintain adequate pressures with its mere presence in the circuit even when the suction pressures are not applied (Monaco 1992).

The recommendation that with the use of HFOV, it is vital to maintain a smooth circuit with minimal interference between patient and the ventilator lead to the study that tested for pressure changes during HFOV with presence of inline suction catheters. Gaudet, et al. performed a bench model study on neonatal test lung using 3100A ventilators testing for 6-Fr sized catheters with an ETT size of 2.5, 3.0, and 3.5 mm ID. A 'Y' (45°), an elbow (90°) or no catheter inline was the scenario used to take ten repetitive measurements. With each

measurement mean airway pressure and amplitude were measured at distal ETT. Data analysis revealed a statistically significant but clinically insignificant difference in pressure changes with the use of the different catheters. Thus, the study gives further scope for research to ascertain if placement of inline catheters effect the pressure as well as tidal volumes in HFOV (Gaudet, Branconnier et al. 2005).

Thus from the above presented literature, one can conclude that studies conducted to evaluate the use of HFOV in treatment of patients with ARDS does show promising results. It is also evident that the placement of inline suction catheters alters the delivered tidal volume and amplitude by HFOV. This gives scope of further studies in the same arena.

Chapter 3

RESEARCH METHODOLOGY

This chapter describes the method used to answer the following research questions:

1. The effect of three inline closed suction adapters on delivered tidal volume during HFOV with varying lung compliance
2. The effect of varying compliance on the amplitude delivered by HFOV
3. The effect of compliance on tidal volume delivered by HFOV

Lung Model

An adult patient with ARDS was simulated using an in-vitro test lung model with high fidelity breathing stimulator Active Servo Lung (ASL) 5000, {Ingmar Medical, Pittsburgh, PA (USA)}. The ASL 5000 is digitally controlled, piston driven and simulates real time breathing. The following research question would be answered: the effect of three inline closed suction systems on delivered tidal volume with varying lung compliance (20, 30, 40 and 50 mL/cmH₂O) at predetermined airway resistance (Raw) of 15 cmH₂O/L/sec.

Ventilator Settings

A standard HFOV adult ventilator circuit and a size 8.0mm internal diameter (I.D) (Portex) cuffed endotracheal tube was used with the SensorMedics 3100B ventilator. Fourteen French Ballard suction systems (Kimberly Clark Roswell, Georgia (USA)) with Ballard T (T adapter), Ballard Elbow (E adapter) and AirLife-Y adapters (Y adapter) were used in-line with the ventilator. The ventilator was set to the following parameters: power of 6, frequency (f) of 5, inspiratory time (Ti) of 33%, bias flow (BF) of 30 LPM and oxygen concentration of 50%. The

mean airway pressure was variable reflecting the change in compliance set on ASL 5000 software (Fessler and Hess 2007). The above mentioned settings were used in accordance to the guidelines dictated by Fessler et al., (2007).

Dead Space Measurement

Each of the T, Elbow and Air-Life Y adapters were filled with water. The water was then aspirated with a syringe and measurements were made to denote the dead space volume.

Protocol

The scenario of an adult passive patient was selected on the ASL 5000 software to simulate an adult patient on HFOV with ARDS. The scenario allowed the resistance to be fixed while allowing compliance change throughout the study. The resistance of 15 cmH₂O/L/sec was maintained with a changing compliance of 20, 30, 40 and 50 mL/cmH₂O (protocol is included in the Appendix A). Ballard suction catheters sized 14-Fr with T/Elbow/Y adapters were used in-line with the circuit with each of the above mentioned permutations to measure the tidal volumes inside the ASL 5000 test lung.

The 3100B ventilator was set at the previously mentioned settings after an initial calibration performed as per the company manual. The test lung was connected to the ventilator using a standard adult HFOV circuit, 8.0 mm I.D endotracheal tube and an inline suction catheter. The test lung was then connected to the ASL 5000 software in the host computer using the RS-232 cable. The run time for each reading was 90 seconds that approximated to 450 breaths. The tidal volumes were measured in the test lung by the ASL 5000 software in the host computer.

Data Collection

Tidal volume was measured and recorded for each change in compliance with each of the three different suction systems. The tidal volume and number of breaths was measured and recorded by the ASL 5000 on the previously mentioned ventilatory settings. A run time of 90 seconds was used with the first 30 seconds used to achieve steady state and the next 60 seconds for recording of the relevant data. Approximately 450 breaths were used over the period of 90 seconds to measure an averaged expired tidal volume.

Data analysis

Statistical analysis was carried out using SPSS v.11. A three by four factorial analysis was done. Post hoc Bonferroni and descriptive statistic was also carried out to answer the following research questions: 1. the effect of three inline closed suction adapters on delivered tidal volume during HFOV with varying lung compliance; 2. The effect of varying compliance on the amplitude delivered by HFOV; and 3. The effect of change of compliance on tidal volume delivered by HFOV. A probability value ($P \leq 0.001$) was accepted as statistically significant.

To summarize, this chapter described the methods used to answer the research questions listed above. Data was collected using a 3100B HFOV on adult lungs simulating ARDS. SPSS v.11 was used to carry out the data analysis.

Chapter 4

RESULTS

The results and tables presented in this chapter are provided to help answer the following research questions:

1. The effect of three inline closed suction adapters on delivered tidal volume during HFOV with varying lung compliance
2. The effect of varying compliance on the amplitude delivered by HFOV
3. The effect of compliance on tidal volume delivered by HFOV

Dead Space Measurements of Suction Adapters

Ballard T-adapter: 19.4 mL

Ballard Elbow-adapter: 7.0 mL

AirLife Y-adapter: 11.0 mL

Tidal volumes as it relates to Adapter changes (T, Elbow and Y adapters)

Table 1 and 2 show the statistical analysis carried out to ascertain the effect of different adapters on tidal volume change while placing suction catheters in-line with HFOV circuit. The analysis shows a significant change in tidal volume between each adapter change.

Table 1: Descriptive Statistics – tidal volume and compliance changes as related to adapter changes

Compliance	Adapter	Mean	Standard Deviation (SD)	N (runs)
50	No adapter	139.0883	2.388	6
	T	128.8967	6.386	6
	Elbow	131.5550	6.624	6
	AirLife Y	133.4383	5.540	6
40	No adapter	125.2800	2.710	6
	T	117.3117	3.991	6
	Elbow	113.2800	5.193	6
	AirLife Y	118.7383	4.799	6
30	No adapter	110.8500	3.356	6
	T	106.0550	3.333	6
	Elbow	105.0017	3.381	6
	AirLife Y	108.1267	2.774	6
20	No adapter	99.47	3.213	6
	T	95.5300	4.723	6
	Elbow	94.9733	5.059	6
	AirLife Y	97.8050	2.426	6

Table 2: Multiple comparisons dependent variable: Bonferroni analysis

(I) ADAPTER	(J)ADAPTER	Std. Error	Sig.*
No adapter	T	.447	.000
	Elbow	.914	.000
	Y	.674	.000
T adapter	No adapter	.447	.000
	Elbow	.542	.000
	Y	.338	.000
Elbow Adapter	No adapter	.914	.000
	T	.542	.000
	Y	.345	.000
Y adapter	No adapter	.674	.000
	T	.338	.000
	Elbow	.345	.000

. * P value of ≤ 0.001 is significant

Tidal volumes as it relates to Compliance changes

Tables 1 and 3 show the tidal volume changes as it relates to the changes in compliance (20, 30, 40 and 50 cmH₂O). The analysis showed that the changes in tidal volumes were statistically insignificant with the changes in compliance.

Table 3: Multiple Comparisons Dependent variable: Bonferroni Analysis

(I)COMP	(J)COMP	Std. Error	Sig.*
50	40	.882	.004
	30	.975	.004
	20	.575	.005
40	50	.882	.004
	30	.619	1.000
	20	.568	.037
30	50	.975	.004
	40	.619	1.000
	20	.601	.016
20	50	.575	.005
	40	.568	.037
	30	.601	.016

Amplitude as related to compliance changes

Table 4 shows the changes in amplitude as related to the changes in compliance. The analysis of data showed that the changes in amplitude were statistically significant when compared to the change in the compliance.

Table 4: Amplitude changes as related to compliances changes

(I)AMP for compliance	(J)AMP for compliance	Std. Error	Sig.*
50	40	.120	.001
	30	.120	.000
	20	.072	.000
40	50	.120	.001
	30	.102	.000
	20	.188	.000
30	50	.120	.000
	40	.102	.000
	20	.188	.001
20	50	.072	.000
	40	.188	.000
	30	.188	.001

* P value of ≤ 0.001 is significant

In summary, there was a statistically significant decrease in tidal volumes as compared to the suction adapter changes. A statistically significant increase in amplitude was also seen as the lung compliance improved. There was no significant change seen in tidal volume as compared to changes in lung compliance.

Chapter 5

DISCUSSION

This chapter discusses the results presented in the preceding section for the following research questions:

1. The effect of three inline closed suction adapters on delivered tidal volume during HFOV with varying lung compliance
2. The effect of varying compliance on the amplitude delivered by HFOV
3. The effect of compliance on tidal volume delivered by HFOV

In clinical practice, efforts have been directed towards maintaining a circuit between ventilator and patient with minimal angulations so as to prevent its interference with transmission of oscillatory waves and pressure during HFOV. This ensures the maintenance of optimal ventilation. In this respect, the combined impedance of the ventilator, the ventilatory circuit, endotracheal tube and patient's respiratory system plays prime importance in deciding the efficiency of ventilation during HFOV. Impedance is described as mechanical barrier to flow of gas (Pillow 2005). With the use of suction adapters that have larger angles and bends, larger mechanical interference with the oscillatory waves is caused creating a dampening effect on the same. Additionally, angulations cause hindrance in the flow of gas through the circuit. Dampening of the oscillatory waves combined with the hindrance to the flow of gas leads to an associated loss of tidal volume. Larger pressure swings are thus required to restore the flow of gas and generate an equivalent tidal volume. Pressure swings are transmitted to the lung tissue causing it to distend thus increasing the chances of barotrauma and/or pneumothoraces. This negates one of the main advantages of HFOV of ventilating the lungs at low tidal volumes and low alveolar pressures to enhance the healing of lung tissues.

This thesis used three different adapters namely the T, Elbow and Air-life Y adapters to test for the loss of tidal volume during HFOV due to dampening of the oscillatory waves. The results revealed that the Air-Life Y adapter caused the least loss of tidal volume. The T and the Elbow adapters have 90° angulations between the ports for the ETT and the suction catheters. On the other hand, the Air-Life Y adapter has 45° angulations between these ports. Based on these facts, the lesser degree of bend leads to a decreased intensity of dampening effect and hence lesser loss of pressure and tidal volume.

Another important observation was the differences in dead space each of these adapters added when placed in-line with the ventilatory circuit. The T, the Elbow and the Air-Life Y adapters added 19.4, 7.0 and 11.0 mL respectively of dead space respectively. It is undeniable that the greater the dead space the greater the loss of tidal volume and hence greater the dead space ventilation. It should be noted that these changes in tidal volume cause exponential changes in minute volume owing to minute volume during HFOV being the product of respiratory rate and squared tidal volume. Hence efforts should be taken to choose a closed suction system adapter that has minimal dead space to minimize the loss of volumes while placing suction systems in-line with HFOV circuit.

Additionally these Y-adapters offer an advantage of providing a versatile port that allows performance of multiple procedures like mini- broncho-alveolar lavage (BAL), closed suctioning, bronchoscopic procedures and instilled drug delivery without disconnecting the circuit. This helps prevent lung derecruitment, loss of oxygenation and cross contamination during these procedures. There is no doubt that a suction system which is placed in-line that prevents patient disconnection from the ventilator provides a distinct advantage over a suction system that requires patient to be disconnected from the ventilator for various purposes.

This study also observed the changes in amplitude with changes in lung compliance. It was seen that as lung compliance improved, there was a statistically significant decrease in amplitude with no statistically significant change in tidal volume. It should be understood that these changes are normal. With an improvement in lung compliance, less pressure is required to deliver the set tidal volume and hence the piston moves less of a distance. This in turn correlates to the decreased amplitude with improved lung compliance. Clinicians should understand that the power settings should not be altered at this point to increase the amplitude as this leads to an increase in the delivered tidal volume to the lungs which inadvertently causes increase in alveolar pressures and increased risk of barotraumas. Further, as explained previously, a small increase in tidal volume due to altered power settings will lead to an exponential increase in minute volume creating mismatched ventilation. Modifying the tidal volume and power settings abrogates the low tidal volume, high PEEP and low alveolar pressure benefit of HFOV(England 2009).

Limitations: the study did not look for the effects of the procedure of suctioning i.e. the application of negative pressure. This can be a potential for further studies.

Clinical Applications: the study would help prevent suboptimal use of suctioning in patients placed on HFOV and would also enhance the understanding of mechanics between ventilator and the ventilatory circuits. The study would help identify the most efficient suction adapter in terms of the amount of loss of tidal volume caused by its placement in-line with the ventilatory circuit.

In conclusion, this study revealed that:

1. The AirLife closed suction adapters caused the least loss of tidal volume when placed in-line with a HFOV circuit and hence were the most appropriate for use with the same.

2. The study also showed that as lung compliance improves, amplitude decreases (without a manual change made in the power settings).
3. The study did not show any significant change in tidal volumes correlating to improvement in lung compliance.

LIST OF TABLES

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ABBREVIATIONS

ALI: Acute Lung Injury

APACHE II: Acute Physiology and Chronic Health Evaluation II

ARDS: Acute Respiratory Distress Syndrome

ASL: Active Servo Lung

BAL: Broncho - Alveolar Lavage

BF: Bias Flow

CMV: Conventional Mechanical Ventilation

CTSS: Closed Tracheal Suction System

CVP: Central Venous Pressure

ETT: Endo Tracheal Tube

F_iO₂: Fraction of Inspired Oxygen

HFOV: High Frequency Oscillatory Ventilation

I.D: Internal Diameter

OI: Oxygen Index

PEEP: Positive End Expiratory Pressure

P/F ratio: P_aO₂/F_iO₂ ratio, partial pressure of arterial oxygen/fraction of inspired oxygen

SOFA Score: Sequential Organ Failure Assessment score

Ti: Inspiratory time

Vt: Tidal Volume

APPENDIX
Protocol
High Frequency and Tidal Volume

Goals:

1. The effect of three inline closed suction adapters on delivered tidal volume during HFOV with varying lung compliance
2. The effect of varying compliance on the amplitude delivered by HFOV
3. The effect of compliance on tidal volume delivered by HFOV

Methods:

1. Dead space (V_D) was measured for each of the adapters of suction catheters i.e. for the Ballard elbow adapter, the Ballard T-adapter and the AirLife Y-adapter.
2. Initiation, calibration and setup of the equipment is as follows:
 - a. Test Lung:
 - i. Use ASL 5000 breathing stimulator
 - ii. Connect the ASL 5000 stimulator to line power and switch it “on”
 1. The motor red light is enabled
 2. Wait for the motor red light to turn “off”
 3. ASL 5000 is calibrated and ready to be connected to the ventilator and computer
 - iii. Connect the ASL 5000 to the host Ethernet via networking cable
 - iv. Connect ASL 5000 to high frequency oscillatory ventilator (HFOV) through standard high frequency breathing circuit and sized 8.0 I.D cuffed endotracheal tube (ETT)
 - b. Ventilator:

- i. Use sensor medics 3100B ventilator
- ii. Calibrate the 3100B with capped standard high frequency breathing circuit in the following way:
 1. Set the bias flow at 30 L/min
 2. Mean Airway Pressure (mPaw) to maximum
 3. Pressure amplitude (delta-P) to 60 cmH₂O
 4. Set the inspiratory time (I-time) to 33%
 5. Start the 3100B ventilator and wait for the mPaw to reach between 40 & 45 cm H₂O
- iii. Set the 3100B ventilator to the following:
 1. Set the power to 6.0. The pressure amplitude reading will be variable
 2. Frequency to 5Hz
 3. Mean airway pressure will be variable
 4. The bias flow will be set at 30 L/min
 5. I-time would be 33%
 6. Oxygen to 50%
- iv. Connect the Ballard suction system (with T-adaptor) to the 8.0 mm I.D cuffed ETT (Portex, Hythe Kent, England) and to the standard high frequency breathing circuit. This assembly is then connected to the ASL 5000

c. Computer:

- i. After all the cable connections have been completed, launch the lab view software on the host PC
- ii. Working page (welcome window) is presented
 1. From the welcome window choose run the software with Ethernet mode
 2. Welcome window will disappear and several screens will stack up on computer screen
 3. Host computer will attempt to synchronize with ASL 5000
 4. Wait for the ASL 5000 to respond (stimulator piston will start moving)
- iii. From the script editor window choose (Adult_apnea.sct) file to edit its lung model parameter files
- iv. From the script file box, double click on the file name (Adult_apnea.sct)
- v. A window titled “Step 1: select simulation parameter set” will open
 1. Click “edit” to proceed to next step
- vi. A window titled “step 2: choose a lung model” will open
 1. Choose the two compartment lung model
 2. Set the resistance (Raw 1) to 15 cm H₂O/L/sec
 3. Set the resistance (Raw 2) to 15 cm H₂O/L/sec
 4. Set compliance (CL 1) to 20 mL/cm H₂O
 5. Set compliance (CL 2) to 20 mL/cm H₂O
 6. Click “next”
- vii. A window titled “Step 3: chest wall model” will open

1. From the pop-up menu of the chest wall model, choose passive model
 2. Set the passive cycle to 12 breaths/min
 3. Click next
- viii. A window titled “step 4: save stimulation parameter set” will open
1. Click “save” to save the new variables in the file
- ix. From the “central run time” window do the following while the ventilator is running and connected to ASL 5000
1. Start the simulation by moving the slide switch from “off to on” position.
 2. From the file window choose a name for the data file path to store the data
 3. Click OK
- x. Go to breath detection/real-time analysis window
1. Check the “save data to high resolution file” checkbox
 2. Wait for the data of 300 breaths to be collected
- xi. Turn “off” the simulation by moving the slide switch from “on to off” position
- d. Data collection:
- i. Launch the Lab VIEW software on the host computer
 - ii. Go to post-run window
 1. Choose the file to be displayed and double click it

2. Open the “multi parameter trend” from the “green box” under the display data list
 - iii. Check the tidal volume waveform to establish steady state
 - iv. Record the tidal volume and use it in data analysis
3. With a compliance of 20 mL/cm H₂O, do three trails for Ballard suction systems with T - adapter as described above but at step (c-vi) set the compliance settings to 20 mL/cm H₂O.
4. With a compliance of 30 mL/cm H₂O, do three trails for Ballard suction systems with T - adapter as described above but at step (c-vi) change the compliance settings to 30 mL/cm H₂O.
5. With a compliance of 40 mL/cm H₂O, do three trials for Ballard suction systems with T - adapter as described above but at step (c-vi) change the compliance settings to 40 mL/cm H₂O
6. With a compliance of 50 mL/cm H₂O, do three trials for Ballard suction systems with T - adapter as described above but at step (c-vi) change the compliance settings to 50 mL/cm H₂O (the readings obtained from this settings would act as a ‘control’ against which the other reading would be compared)
7. Similar procedure will be repeated while testing for tidal volume changes with inline Ballard suction systems with Elbow-adapters or Air Life suction systems along with each compliance change of 20 ml/cm H₂O, 30 mL/cm H₂O and 40 mL/cm H₂O and 50mL/cmH₂O.

The layout of the data table:

Compliance (mL/cmH₂O)	Tidal Volume (V_t) in mL															
	No Catheter				Ballard with “T” adapter				Ballard with “Elbow” adapter				AirLife with “Y” adapter			
50	1	2	3	Mean	1	2	3	Mean	1	2	3	Mean	1	2	3	Mean
20	1	2	3	Mean	1	2	3	Mean	1	2	3	Mean	1	2	3	Mean
30	1	2	3	Mean	1	2	3	Mean	1	2	3	Mean	1	2	3	Mean
40	1	2	3	Mean	1	2	3	Mean	1	2	3	Mean	1	2	3	Mean

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