ASSESSMENT OF VENTILATOR DATA PRIOR TO AND DURING ENDOTRACHEAL TUBE OBSTRUCTION.
Case: adult male patient, intubated and receiving mechanical ventilatory support.

Patient was placed on a spontaneous breathing trial (SBT) in the am.

Approximately 45 minutes into the SBT the patient’s saturation decreased and the patient appeared to be in distress.

The therapist attempted to pass the suction catheter without success.

Prior to removal of the ETT the patient coded

CPR was started and the ETT was removed.

Bag-valve-mask ventilation started until a new ETT was inserted.

Patient saturation, heart rate and respiratory rate returned to normal once effective ventilation was restored.

Patient was placed back on ventilatory support.

Inspection of the original ETT revealed a near complete obstruction of the internal diameter with mucus
Although this patient was receiving mechanical ventilatory support at the time of the incident, there was no alarm alerting the healthcare providers of the impending occlusion.

The mode/type of support from the ventilator contributed to the event.

Traditionally we would monitor tidal volume and peak inspiratory pressure to ensure effective ventilation.

We theorized that ventilatory parameters, other than PIP and VT, may provide valuable information during an airway occlusion.

Sentinel events are those that cause serious injury or death to a patient. Artificial airway complications have been implicated in sentinel event monitoring throughout the US and Europe. Identification of early warning signs to partial and complete airway obstruction could reduce the likelihood of future events.
Maintaining patency of the artificial airway is a required component to achieving alveolar ventilation.

The structural design of the airway creates multiple limitations when attempting to clear the lungs.

Practitioners rely on the mechanical ventilator and its monitored parameters to provide useful and meaningful information on the status of the patient.

It is likely that current mechanical ventilation parameters offer a limited amount of information.

This project investigated the relationship between airway obstruction and uncommon ventilatory parameters.
METHODOLOGY

- Texas State IRB exemption
- Bench evaluation of airway obstruction
- We used the IngMar parabolic resistance ring (PRR), an 8.0 mm artificial airway, the ASL5000 with software version 3.3, and a IngMar test lung.
- PRR is capable of producing a resistance within a breathing tube
- Ingmar Medical’s ASL5000 Breathing Simulator with updated software (Virtual Ventilator Software 3.3) behaved as the ventilator and recorded all data parameters.
  - The ASL5000 records and displays over 50 data items for review and analysis.
- 8.0 mm ETT is the most common adult artificial airway used
- IngMar Test Tung served as the patient’s lungs
The items listed above were connected in series:
- ASL to the ETT to the PRR to the test lung
- Started with the lowest resistance setting on the PRR
- ASL was set to ventilate using a pump strategy
- We set the respiratory rate at 12 breaths per minute
- Data was recorded for 10 ventilator breaths for each PRR setting.
- Following the completion of all PRR settings, data was downloaded and analyzed using Bivariate Correlation in SPSS (Version 20, Statistical Package for the Social Science, IBM, Inc.).
Grant purchased software upgrade for the ASL 5000.

Grant also purchased virtual ventilator software.

- Allows real-time changes in ventilatory parameters
- Also, we purchased additional virtual ventilator software. Software allows uploading to a standard PC/IMB computer.
EXPERIMENTAL SET-UP

- Grant purchased a parabolic resistor ring
- Extra funds allowed the purchase of an extra PRR for the department
The following ventilatory parameters demonstrated a significant correlation to airway obstruction:

- inspiratory time,
- inspiratory percent,
- expiratory time,
- pause time
- inspiratory tidal volume,
- expiratory tidal volume,
- peak pressure,
- mean pressure,
- peak flow rate,
- median flow rate
- time to trigger,
- inspiratory work,
- inspiratory resistive work,
- expiratory resistive work,
- patient inspiratory work,
- patient inspiratory resistive work,
- patient inspiratory elastic work
- patient expiratory work,
- patient expiratory resistive work,
- patient expiratory muscle work,
- patient total resistive work
- patient trigger work above PEEP,
- time to pressure minimum,
- work between the start of expiration and pressure minimum.
The following ventilatory parameters demonstrated a strong correlation (+/- .7) with airway obstruction:

- Expiratory Resistive Work (-.832)
- Peak Flow Rate (-.815)
- Inspiratory Resistive Work (-.766)
- Peak Airway Pressure (.753)
- Pressure Time Product (.707)
Work of breathing

- Quiet work of breathing consumes only about 5% of the body’s oxygen content.
- Increased WOB can consume as much as 25-30% of the body’s oxygen content.
- The diaphragm does the majority of the work
- Diaphragm contraction is responsible for lung inflation

Resistive WOB:
- Airway resistance accounts for the majority of the increased WOB
- Function of the airflow traveling down the airway
- Turbulent airflow increases resistive WOB
- Airway obstruction will increase turbulent airflow
- Resistive WOB increases as the obstruction increases
DISCUSSION

- **Peak Flow Rate**
  - The flow rate is determined by the ASL and the formula:
    - Flow $\times$ inspiratory time = tidal volume
    - We held tidal volume relatively constant
    - the obstruction limited the amount of flow that could pass
    - Therefore, the peak flow decreased with each increase in obstruction

- **Pressure time product**
  - An indicator of energy expenditure of the respiratory muscles and WOB
  - Linked increased Inspiratory effort
  - Normally requires measurement of pleural pressure
  - Newer non-invasive techniques are available
  - As the obstruction increased the pressure time product increased
PEAK PRESSURE
INSPIRATORY RESISTIVE WORK
The goal of this project was to determine the ventilator parameters that strongly correlate to a progressively worsening airway obstruction.

Mechanical ventilators do not provide direct evidence to the patency of the endotracheal tube.

Therefore, clinicians rely on surrogate information to prevent partial and complete obstruction.

Traditionally, peak airway pressure is the primary parameter that signals an obstruction.

In addition to peak airway pressure, we identified multiple parameters that hold a strong correlation, defined as .7 or greater, to airway obstruction.

These parameters may provide an additional warning sign to airway obstruction.
Previously published research supports our hypothesis that PIP and exhaled tidal volume may be insensitive to signaling impending airway obstruction.

Some of these parameters are not available to bedside clinicians when monitoring mechanical ventilator data.

The inclusion of this data as part of the monitored information is possible given the sophistication of current critical care machines.

We still haven’t found one ideal parameter.

Although this was a bench-top study we believe the results have value with practicing clinicians.

Limitations:
- Patient application
- Type of occlusion
Continuing the project to the pediatric and neonatal artificial airways

Testing PAV technology using the PRR

Recognition of airway resistance during manual bag-valve-mask ventilation

Occlusion location and severity determination using sound wave technology

Using the virtual ventilator to teach mechanical ventilation properties to RC students
REFERENCES

QUESTIONS