Ventilatory Circuit Management (from airway humidification to cuff pressure)

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Introduction

- Normal breathing: nasopharynx warms, filters and humidifies inspired gas
- Mechanical ventilation: normal structures are bypassed and function of nasopharynx was lost

Introduction

- Gas supplied from cylinders or pipelines are very dry in order to reduce the risk of corrosion, condensation and frost formation

- Therefore, gas delivered to patient's trachea should be artificially humidified, warmed and filtered to prevent damage to the airway

Introduction

1. Filters
2. Humidifiers
3. Endotracheal tube (cuff pressure)

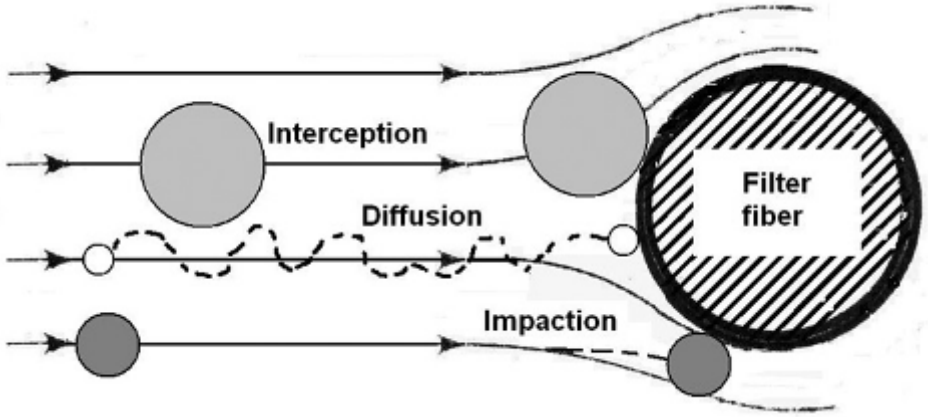
Filters

Filters

- Remove particles from gases delivered and to prevent microbes from patients cross-infecting other patients and staff, to reduce contamination of equipment

Mechanisms for Filtration

1. Interception
2. Inertial impaction
3. Gravitational settling
4. Diffusion
5. Electrostatic attraction



Types of Filter

1. Glass fibre filter

2. Electrostatic filter

Glass Fibre Filters

- Filter material consists of a sheet of resin-bonded glass fibres
- Fibres are densely packed and has a high resistance to gas flow per unit area
- A sheet with large surface area is used to reduce the resistance to gas flow to an acceptable level

Electrostatic Filters

- Fibre density is lower than that in glass fibre filters and hence the resistance to gas flow is lower per unit area

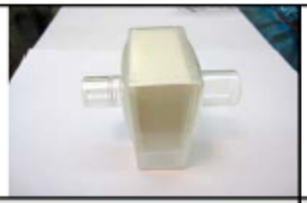
- Filtration performance is enhanced by using electrostatically- charged material

Efficiency of Filters

- Filtration efficiency of a filter is determined by measuring the number of particles passing through the filter as a percentage of the number of particles in an aerosol challenge to the filter

- Can increase dead space and air flow resistance (overestimate peak inspiratory pressure and underestimate PEEP)
- Adding filters in series: increase efficiency but also increase dead space and air flow resistance

Know more about breathing filters in ICU

					
Brand	DAR Sterivent 'S'	MAQUET Servo Duo Guard	MAQUET Servo Guard	INTERSURGICAL Clear-Guard 3	(GTS) HME – Flex / (GGM) HME-S
Filtration efficiency (*BFE/ VFE)	99.99999%	99.9999%	>99.99%	99.997%	Heat & moisture exchanger only
ICU stock	Yes	Will replace Servo Guard	No more after present stock	Yes	Yes
Place before Y-connector	Yes	No	No	Yes	Yes
Recommended Tidal Volume (TV) Range	200-1500 ml	Not mentioned	Not mentioned	150-1500 ml Minimum TV (filter only)=200 ml	300-1500 ml
Resistance to flow	1.9 cm H2O @ 60 I/min	Max. 30 KPa	Max. 15 KPa	0.9 cm H20 @30 I/min	90 (Pa) @ 30 L/min 210 (Pa) @ 60 L/min
Internal /Compressive Volume	69 ml	170 ml	190 ml includes 42 ml water trap (Dead space= 150ml)	49 ml	Dead space = 90 ml / 80 ml
Weight (approx.)	39 g	<55 g	<75g	28 g	
Others					May consider to change to heated humidifier in patient with low expiratory TV or restrictive lung condition. Not for use with nebulizers or heated humidifiers.

*BFE (Bacterial Filtration Efficiency)

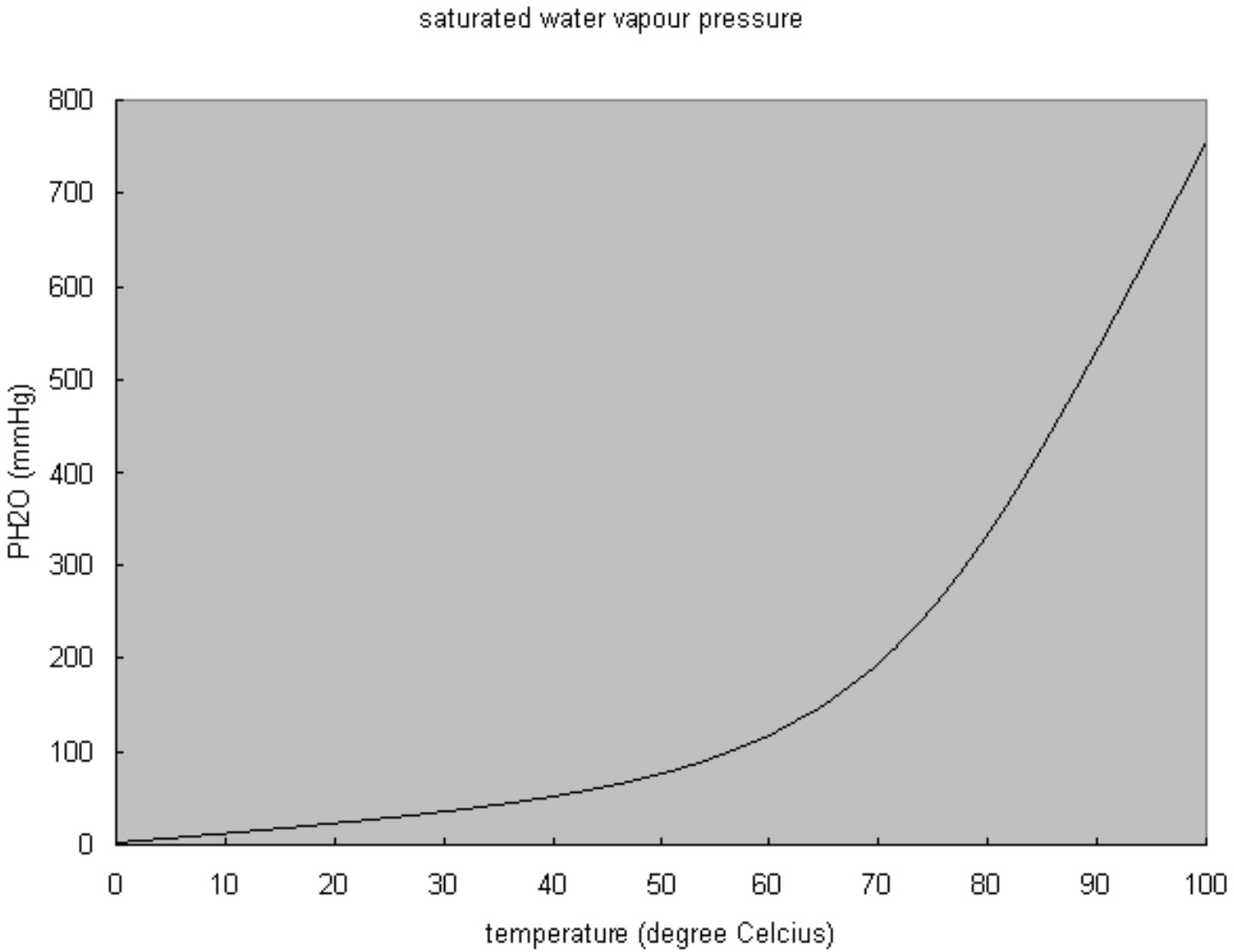
*VFE (Viral Filtration Efficiency)

Humidifiers

Humidification

- Humidity: amount of water vapour in a gas

- Absolute humidity: total mass of water in a given volume of gas at a given temp (g/m^3)
- Relative humidity: ratio of mass of water in a given volume of gas to mass of water required to saturate the same volume of gas at a given temp


saturated water vapour pressure
PH2O (mmHg)
800
700
600
500
400
300
200
100
0
0
10
20
30
40
50
60
70
80
90
100
temperature (degree Celcius)

Clinical Applications of Humidification

- To overcome problem of tracheal intubation:

1. Increased mucus viscosity
2. Depressed ciliary function
3. Cytological damage to the tracheobronchial epithelium, including mucosal ulceration, tracheal inflammation and necrotising tracheobronchitis
4. Microatelectasis from obstruction of small airways, and reduced surfactant leading to reduced lung compliance
5. Airway obstruction due to viscous sputum with increased airway resistance

Ideal Humidification

- Set temp remains constant and does not fluctuate
- Humidification and temp remain unaffected by a large range of fresh gas flows, esp high flows
- Device is simple to use
- Humidification can be provided for air, oxygen or any mixture of inspired gas, including anaesthetic agent

Ideal Humidification

- Can be used with spontaneous or controlled ventilation
- Safety mechanisms, with alarms against overheating and overhydration
- Resistance, compliance and dead-space do not adversely affect spontaneously breathing modes
- Sterility of inspired gas is not compromised

Characteristics of Humidifier

- Moisture output
  - The amount of heat and humidity provided
  - Will change with the duration of use and application
  - Moisture output reported in the package insert is based on a certain tidal volume, inspiratory time, respiratory rate and temp; deviations from these values cause moisture output to change

- Resistance
  - May adversely affect the patient's work of breathing
  - Increase during use as the media absorbs water; after prolonged use, the increase in resistance to expiratory flow may cause airtrapping and autoPEEP

Characterisitcs of Humidifier

- Dead space
- Additives
- Calcium chloride or lithium chloride as hygroscopic additives to increase moisture output
- Some manufacturers also add chlorhexidine as a bacteriostatic treatment
- Cost

Humidifiers

1. Passive: rely on patient's ability to add moisture to the inspired gas

2. Active: add water vapour to a flow of gas independently of the patient

3. Combined passive and active devices

Passive Humidifiers

Heat and Moisture Exchanger (HME)

Heat and Moisture Exchanger

- HMEs return a portion of the exhaled heat and moisture to the next inspiration
- Consists of a transparent plastic housing so that any obstructions or secretions can be readily seen
- Housing contains a layer of either foam or paper that is commonly coated with a hygroscopic salt such as calcium chloride

Active Humidifiers

1. Water bath humidifiers

2. Active HME

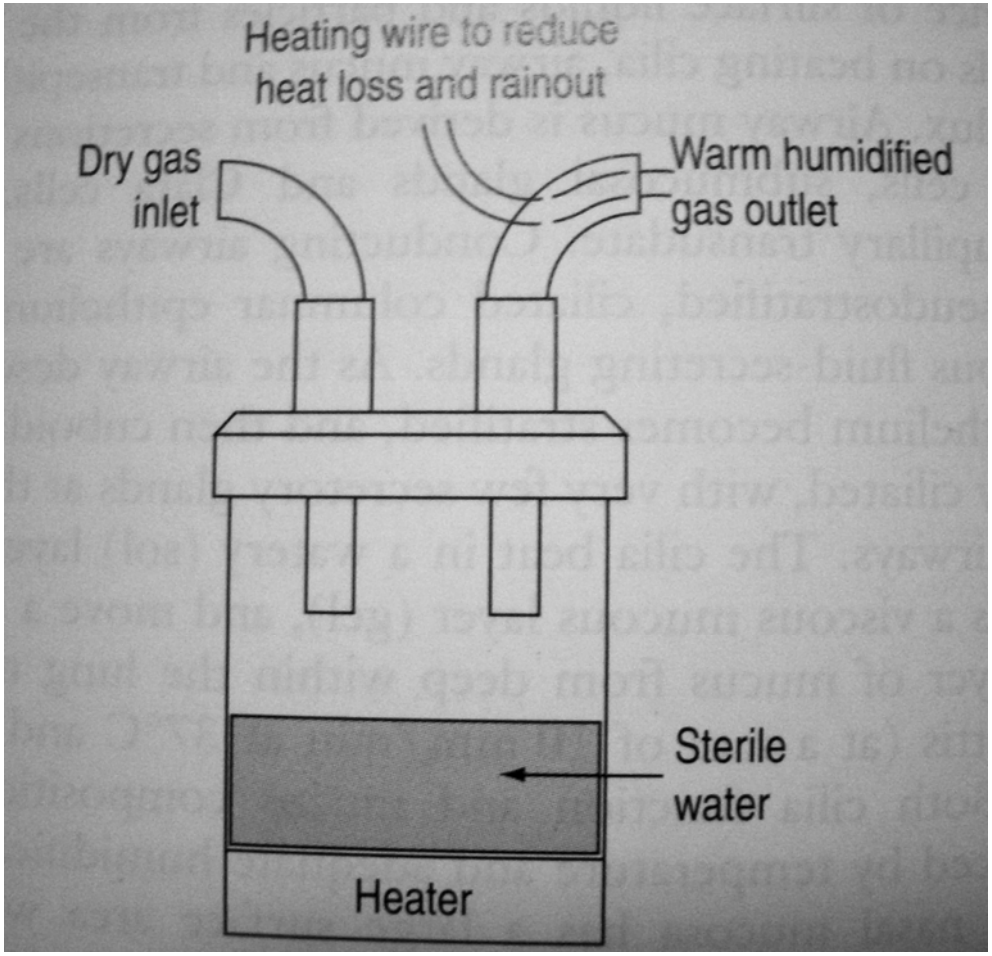
Water Bath Humidifier

- Cold water: ineffective
- Hot water: inspired gas is passed over (blow-by humidifier) or through (bubble or cascade humidifier) a heated water reservoir

Blow-by (Fisher and Paykel)

- Inspired gas is passed over a heated water reservoir
- Commonly used blow-by humidifier
- Delivery hose is heated by an insulated heating wire to achieve a manual preset inspired temp

Blow-by


Heating wire to reduce
heat loss and rainout
Dry gas
inlet
Warm humidified
gas outlet
Sterile
water
Heater

Bubble/ Cascade

- Inspired gas is passed through a heated water reservoir

- It is commonly believed that hot-water humidifiers do not produce aerosols, but microdroplets (usually less than 5 microgram in diameter) have been reported with bubble humidifier, and this may be a potential source of infection

Active HME

- HME + additional water vapour can be added to the inspiratory gases
- Filter can also be added

Other Information

- Another way of giving moisture to patient with tracheostomy: administering water nebuliser around patient's tracheostomy opening
- Heated wire in ventilatory circuit to reduce condensate

Complications of Humidification

- Inadequate humidification
- Overheating: water intoxications, impaired ciliary clearance and airway burns
- Imposed work of breathing
- Infection: although water reservoirs represent a good culture medium for bacteria, it is rare to culture bacteria from humidifiers; positive finding is usually preceded by colonization of the circuit by the patient’s own flora within the first 24 hrs of use

Endotracheal Tubes

Endotracheal Tube

Endotracheal Tube

- The distal end is cut obliquely (bevelled)
- The bevel facilitates insertion and allows the tip of the tube to be seen passing between the vocal cords
- A hole (Murphy eye) may be present at the wall opposite to the bevel; designed to provide secondary port for gas movement in and out of the tube if the bevel become blocked or wedged against the tracheal wall

Construction Material

- Red rubber or natural latex is used traditionally as the construction material since they can be cleaned and sterilized for reuse

- However these materials are opaque, occlusion of the lumen by foreign objects and dried mucus is not readily visible

Construction Material

- Currently, plastics (PVC) and to a lesser extent, silicone rubber, have replaced red rubber and natural latex:

1. Non-irritant
2. Inexpensive for single use
3. Blockages can be visible as the material is usually clear
4. Cuffs of rubber tubes are usually thick and require high pneumatic pressures to inflate, may cause mucosal ischaemia and necrosis if used for prolonged periods

Drawbacks of Plastic Tubes

- Plastic tubes do not have the elasticity of rubber and therefore may be more difficult to insert
- Because of their relative rigidity at room temperature compared with rubber ones, appear to cause more trauma when inserted via nasal route
- Can be softened pre-insertion by immersing in warm water, esp for nasal intubation

Silicone Tubes

- Silicone rubber is entirely synthetic containing no latex derivatives
- Soft and can withstand autoclaving and hence can be reused
- More expensive and is not generally used for disposable airway products

Implant Testing

- The type of plastic used is tested to make sure that it is non-irritant
- Marking of ‘Z79-IT’ over the tube body
- Z79 Toxicity Subcommittee of the ANSI (American National Standards Institute) set up in 1968 in the USA
- Implant 4 samples of plastic into the paravertebral muscle of anaesthetized rabbits, then examine the implant sites for signs of inflammation

Size of ETT

- Conventionally, tube with the widest diameter that would pass easily through the narrowest part of the airway should always be used in order to minimize the resistance to gas flow within it, and also to reduce the work of breathing

Size of ETT

- Recent approaches consider using smaller diameter tubes:

1. Ventilator does the work of breathing when a patient is ventilated, so the diameter of the tube does not dictate the airway pressure distal to it
2. Small tubes are easier to insert and reduce the trauma of intubation

- However smaller diameter tubes can be too short or have cuffs that are too small to achieve a good seal

ETT Cuffs

1. High pressure and low volume cuffs
2. Low pressure and high volume cuffs
3. Medium pressure cuffs

High Pressure and Low Volume Cuffs

- Requires a high pressure to distend it
- Tends to inflate in a circular shape and when a seal is just achieved, only the widest circumference touches the tracheal wall
- Overdistension increases the area of contact but will cause the high pressure to be transmitted to the tracheal wall
- Cuts off the blood flow to the underlying mucosa which can cause ischaemic damage (capillary perfusion pressure is about 35 mmHg)

Low Pressure and High Volume Cuffs

- Made of thin inelastic material (PVC) which when fully inflated would have a larger volume than that required to effect a seal

- The material is not fully unfolded when a seal is achieved, a number of small channels may form running the length of the cuff; these channels may contribute to VAP by allowing transmission of potentially infective pharyngeal contents

Medium Pressure Cuffs

- Made of thinner elastic material such as latex rubber
- Requires some degree of pressure for inflation and achieve a seal with an intracuff pressure below that in the capillaries supplying the tracheal mucosa
- These materials are less resistant to tearing but are more easily damaged by snagging on teeth and instruments or passage through the nose

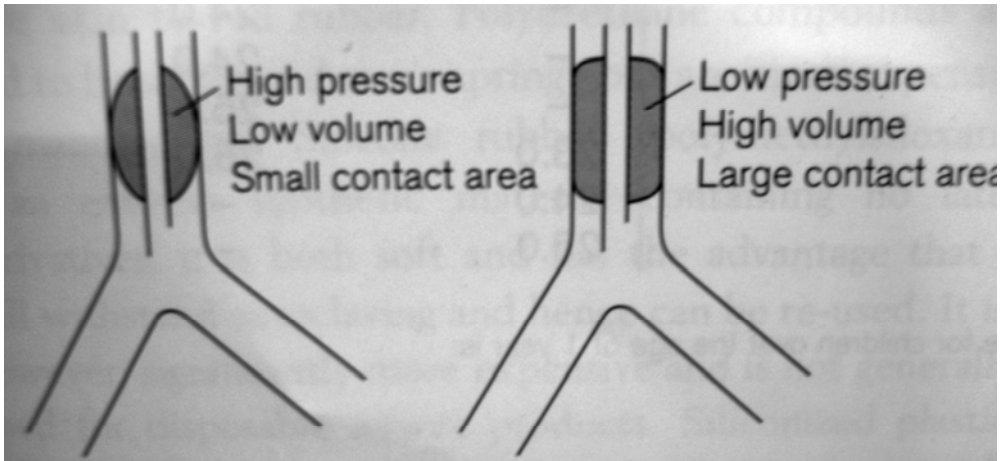


Figure 8.22 High and low pressure tracheal cuffs. Medium pressure cuffs have a profile between these extremes.

- Is cuff pressure = pressure exerted on tracheal wall mucosa ?

Study: Low volume, low pressure tracheal tube cuff reduces pulmonary aspiration
(Critical Care Medicine, 2006)

- Leakage of fluid from subglottic space to the lungs occurs along the longitudinal folds within the wall of an inflated high-volume low-pressure (HVLP) cuff

- Low-volume low-pressure (LVLP) cuff does not have these folds yet allows for convenient and reliable control of tracheal wall pressure

Study: Low volume, low pressure tracheal tube cuff reduces pulmonary aspiration
(Critical Care Medicine, 2006)

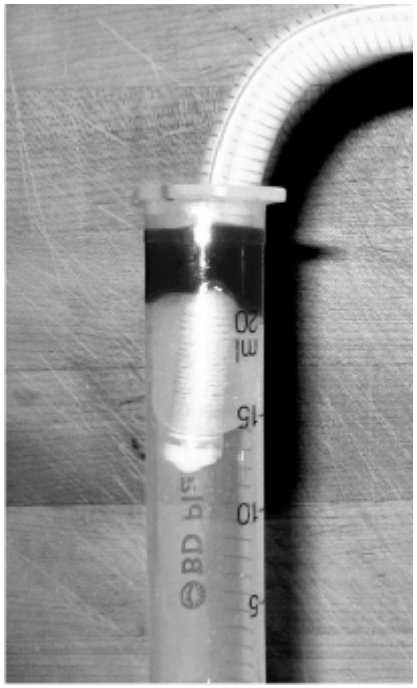
- Anaesthetized (n=38) and critically ill patients with either a LVLP or HVLP cuffed tracheostomy tube following swallowing assessment (n=67)

- The LVLP cuff was compared with HVLP cuff for leakage of dye placed in the subglottic space to the tracheobronchial tree in a rigid tracheal model and a benchtop pig trachea model (before and after a standardized cuff movement).

Study: Low volume, low pressure tracheal tube cuff reduces pulmonary aspiration

(Critical Care Medicine, 2006)

- In the rigid lung model, the incidence of leakage was 0% in the LVLP group and 100% in the HVLP group ($p<0.01$)



Study: Low volume, low pressure tracheal tube cuff reduces pulmonary aspiration
(Critical Care Medicine, 2006)

- Dye leakage in the pig tracheal model with HVLP cuffs was 44% before tube movement, increasing to 79% afterward. The LVLP cuff did not leak in the pig tracheal model

- Axial rotation of 90 degree left and right, and proximal to distal movement through 5-7cm; try to simulate the inevitable tracheal tube movement that occur in the critically ill during routine clinical care

Table 1. Static test in pig tracheas

	Trachea A (2.45 cm)	Trachea B (2.0 cm)	Trachea C (1.7 cm)	Trachea D (1.6 cm)	Trachea E (1.5 cm)	Total Leakage, %
Sheridan CF (8-mm ID)	1/3	3/3	1/3	0/3	0/3	33
Mallincrodt Lanz (8-mm ID)	2/3	2/3	3/3	3/3	3/3	87
Portex Soft Seal (8-mm ID)	2/3	2/3	1/3	0/3	1/3	40
Portex Profile (8-mm ID)	0/3	3/3	3/3	0/3	1/3	47
Bivona Aircuf (8-mm ID)	3/3	2/3	3/3	0/3	0/3	53
Bivona Fomecuf (7-mm ID)	3/3	1/3	0/3	0/3	0/3	27
Shiley (no. 4)	3/3	3/3	0/3	0/3	0/3	40
Shiley (no. 6)	0/3	1/3	1/3	0/3	1/3	20
Shiley (no. 8)	2/3	3/3	1/3	0/3	2/3	53
LVLP (8-mm ID)	0/3	0/3	0/3	0/3	0/3	0

ID, inner diameter; LVLP, low volume, low pressure.

Table 2. Standardized movement test in pig tracheas

	Trachea A (2.45 cm)	Trachea B (2.0 cm)	Trachea C (1.7 cm)	Trachea D (1.6 cm)	Trachea E (1.5 cm)	Total Leakage, %
Sheridan CF (8-mm ID)	3/3	3/3	3/3	2/3	1/3	80
Mallincrodt Lanz (8-mm ID)	3/3	3/3	3/3	3/3	3/3	100
Portex Soft Seal (8-mm ID)	3/3	3/3	2/3	3/3	3/3	93
Portex Profile (8-mm ID)	3/3	3/3	3/3	3/3	3/3	100
Bivona Aircuff (8-mm ID)	3/3	3/3	3/3	2/3	1/3	80
Bivona Fomecuf (7-mm ID)	3/3	3/3	0/3	0/3	0/3	40
Shiley (no. 4)	3/3	3/3	0/3	0/3	0/3	40
Shiley (no. 6)	2/3	3/3	3/3	2/3	2/3	80
Shiley (no. 8)	3/3	3/3	3/3	3/3	3/3	100
LVLP (8-mm ID)	0/3	0/3	0/3	0/3	0/3	0

ID, inner diameter; LVLP, low volume, low pressure.

Study: Low volume, low pressure tracheal tube cuff reduces pulmonary aspiration

(Critical Care Medicine, 2006)

- Dye leakage in anesthetized patients was 0% before movement and 5% after in the LVLP group and in the HVLP group 22% increasing to 67% after movement ($p < .001$).

Table 3. Anesthesia study

	Static Test	Standard Movement Test
Sheridan HVLP cuff (n = 18)	4	12[a]
Silicone LVLP cuff (n = 20)	0	1[a]

Leakage past the cuff in anesthetized patients with high-volume, low-pressure (HVLP) and low-volume, low-pressure (LVLP) cuffed endotracheal tubes.

[a] $p = .0001$.

Study: Low volume, low pressure tracheal tube cuff reduces pulmonary aspiration
(Critical Care Medicine, 2006)

- Forty-nine percent of swallow assessments were scored as failed in the critical care patients with HVLP tracheostomy tube cuffs, and there were no episodes of aspiration following swallow assessment in the LVLP group ($p < .05$).

Table 4. Critical care study

	Portex Soft Seal (HVLP) Cuff (n = 39)	Silicone (LVLP) Cuff (n = 28)
Aspiration	19[a]	0[a]
No aspiration	20	28

Episodes of aspiration in critically ill patients with high-volume, low-pressure (HVLP) and low-volume, low-pressure (LVLP) cuffed tracheostomy tubes.

[a] $p = .01$.

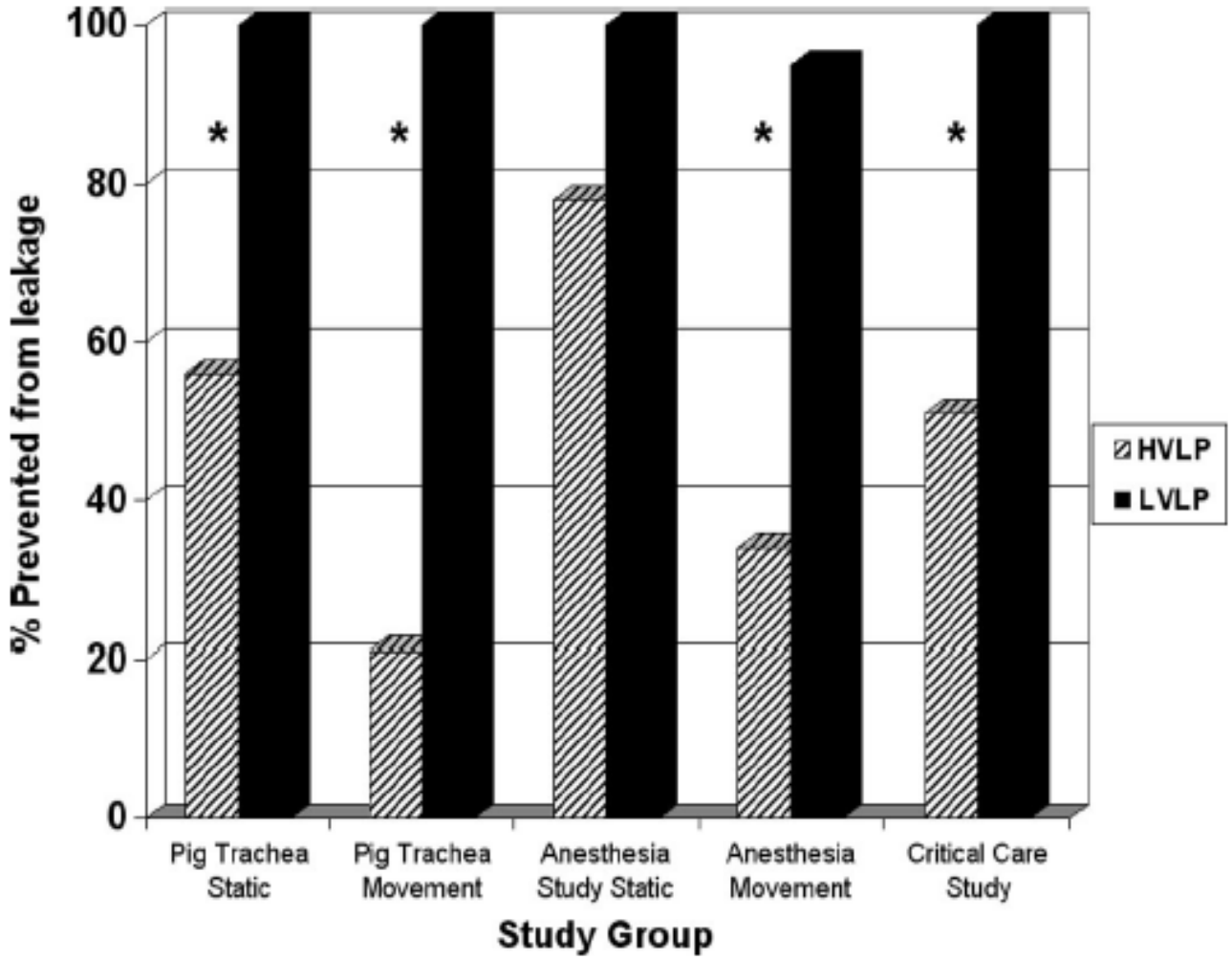


Figure 2. Summary of results. *$p < .05$. *HVLP*, high-volume, low-pressure tube; *LVLP*, low-volume, low-pressure tube.

Study: Low volume, low pressure tracheal tube cuff reduces pulmonary aspiration

(Critical Care Medicine, 2006)

- Pulmonary aspiration can be prevented by the LVLP cuff if it is continuously and corrected inflated
- In contrast, pulmonary aspiration commonly occurs in the critically ill patient with a correctly inflated HVLP cuff in place, which causes VAP and increases morbidity and mortality
- The likely higher cost of the LVLP tube might indicate its selection for use in those patients at high risk of VAP such as the critically ill and high-risk emergency and elective surgical patients

Summary

- Ventilatory circuit management

1. Filters
2. Humidifiers
3. Endotracheal tubes (cuff pressure)

The End

Thank you