

Choosing the NIV ventilator: technical issues

Cesare Gregoretti
Cesare.gregoretti @unicamillus.org

COI

Received fees for presentations from:

- Philips
- Vivisol
- Airliquide

Agenda

- **Background**
- **Leaks compensation**
- **Tidal volume measurements**
- **CO2 rebreathing**
- **Patient-ventilator synchrony**
- **Variable PEEP**
- **Possible drawbacks**

Types of Ventilators: gas source

- ICU HIGH PRESSURE (4 atm.) DRIVEN VENTILATORS.

They always ensure stable FiO₂ (“blender”)



- TURBINE OR PISTON DRIVEN VENTILATORS WITH O₂ PROVIDED AT LOW PRESSURE

They do not ensure stable FiO₂ (“no blender”)



- TURBINE OR PISTON DRIVEN VENTILATORS WITH O₂ PROVIDED AT HIGH PRESSURE

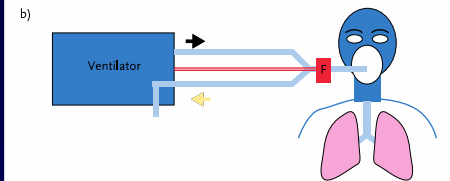
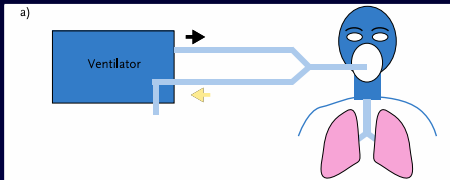
They always ensure stable FiO₂ (“blender”)



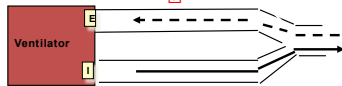
Severely hypoxemic patients need ventilators with high pressure O₂ inlet because:

- stable FiO₂ is provided
- PaO₂/FiO₂ ratio is computed

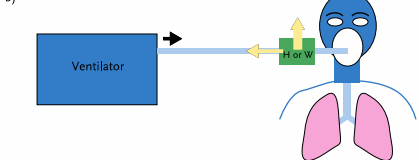
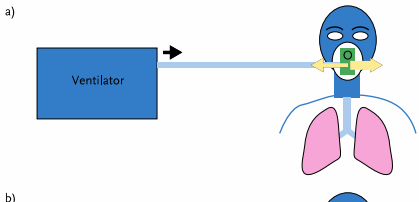
Types of Ventilators: circuits configuration



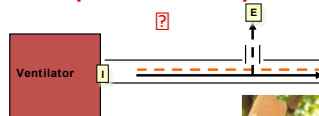
Double Limb Circuit (SC) with non-intentional leak (non-vented circuit)



— Inspiration
- - - Expiration

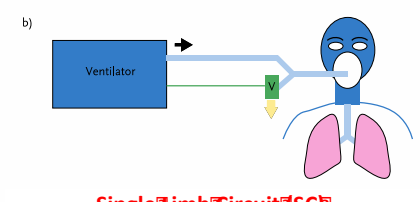
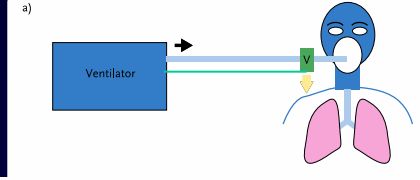


Single Limb Circuit (SC) with intentional leak (vented circuit)

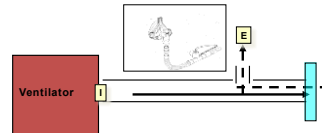


— Inspiration
- - - Expiration

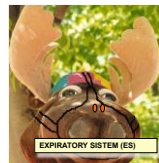
$VT_{insp} = \frac{Q_{turbine}}{f_{turbine}}$ (turbine flow / overall leak flow)



Single Limb Circuit (SC) with non-intentional leaks (non-vented circuit)



— Inspiration
- - - Expiration



EXPIRATORY SYSTEM (ES)

Types of Ventilators:performance

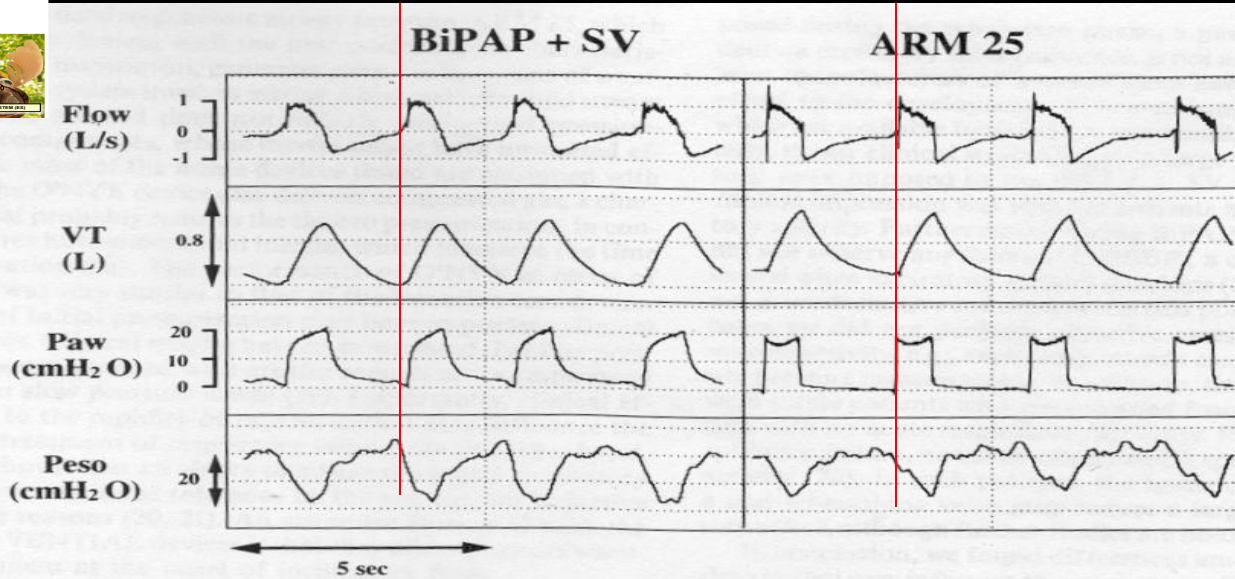
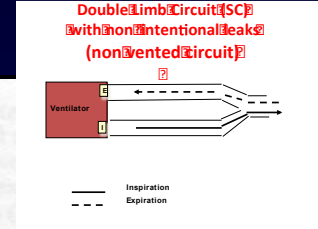
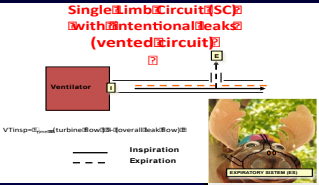


Figure 5. Tracing obtained in the representative Patient No. 3 during pressure support ventilation with the conventional intensive care pressure support ventilator (ARM 25) and with the BiPAP device equipped with the Sanders NRV-2 non-rebreathing valve (BiPAP-SV). Note that the BiPAP device was associated with larger esophageal pressure swings during the inspiratory phase despite similar values for pressure support level and tidal volume.

Lofaso F et al AJRCCM 1996; 153:1561-9

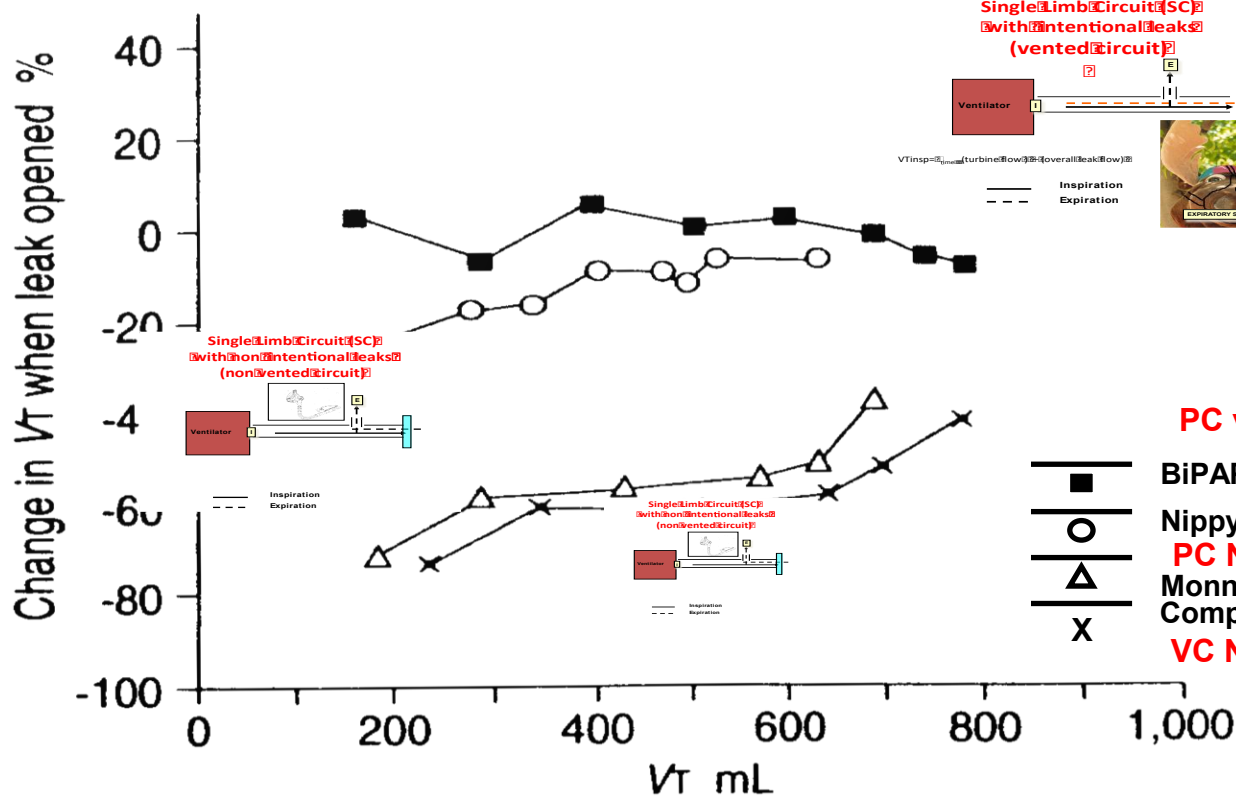
Arnaud W. Thille
Aissam Lyazidi
Jean-Christophe M. Richard
Fabrice Galia
Laurent Brochard

A bench study of intensive-care-unit ventilators: new versus old and turbine-based versus compressed gas-based ventilators

On average, turbine-based ventilators performed better than conventional ventilators, which showed no improvement compared to a bench comparison in 2000.



Leak compensation

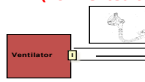
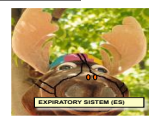


Single Limb Circuit (SC) with intentional leaks (vented circuit)

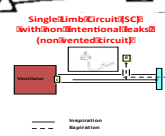


$V_{Tinsp} = \text{turbine flow} - \text{overall leak flow}$

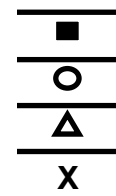
— Inspiration
- - - Expiration



— Inspiration
- - - Expiration



— Inspiration
- - - Expiration



PC vented (HOLES IN THE MASK)

■ BiPAP (Respironics)

○ Nippy (Friday Medical)

PC Non-Vented (NO HOLES IN THE MASK)

△ Monnal D (Taema)

× Companion 2801 (Puritan Bennet)

VC Non-Vented (NO HOLES IN THE MASK)

Pressure targeted NIPPV is able to compensate for circuit leaks, with under a 10% drop in tidal volume reported. **Vented configuration did better compared to nonvented**

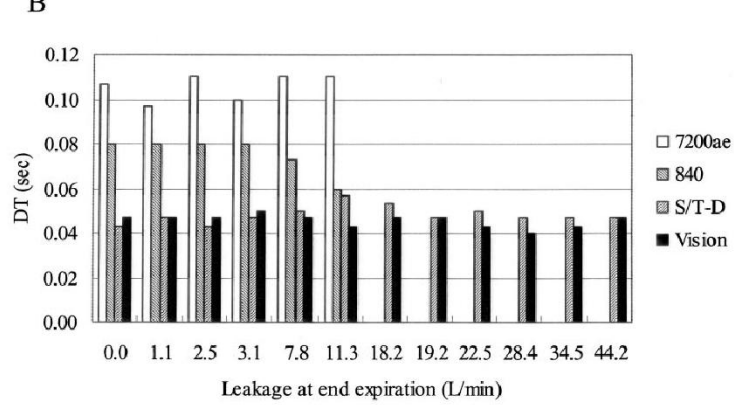
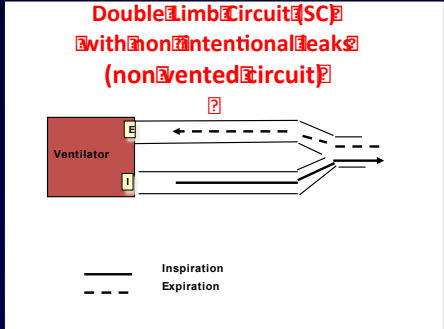
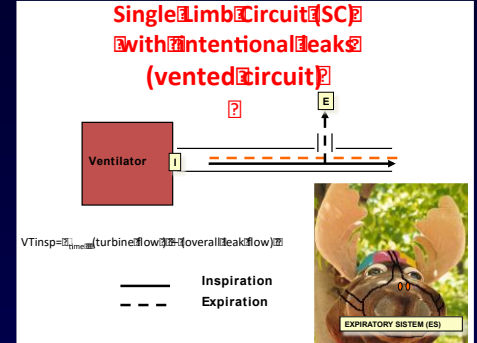


FIGURE 3. PI (top, A) and DT (bottom, B) at various levels of gas leak. With gas leaks > 18 L/min at PEEP of 5 cm H₂O, inspiratory triggering could not be properly titrated with the two ICU ventilators (Puritan-Bennett 7200ae and Puritan-Bennett 840). PI and DT were not affected by the amount of gas leak as long as titration of inspiratory trigger sensitivity was possible.



Abbreviations: AH = absolute humidity; DT = inspiratory delay time; FiO_2 = fraction of inspired oxygen; NPPV = noninvasive positive pressure ventilation; PEEP = positive end-expiratory pressure; PI = inspiratory trigger pressure; PIP = peak inspiratory pressure; RH = relative humidity; RR = respiratory rate

Leak compensation allows a shorter trigger delay and so a better patient-ventilator synchrony

Miyoschi Chest 2005

Tidal Volume measurements

In non vented circuit VT is measured by means of pneumotachograph

(Flow= $\Delta P/R$ and $V_T = \text{Flow} \times T_i$)

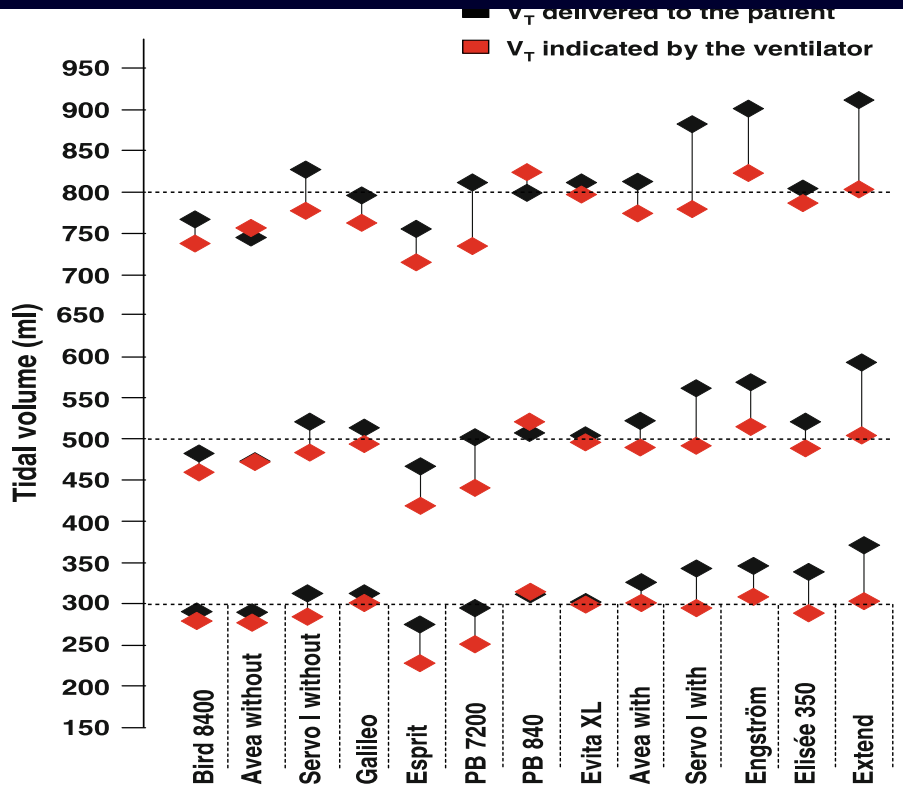
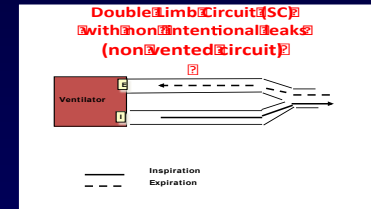


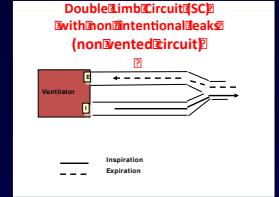
Fig. 3 Actually delivered tidal volume (V_T) under BTPS conditions in *black* and V_T indicated by the ventilator in *red* for all ventilators tested using three V_T values (800, 500, and 300 ml from top to bottom). V_T values are the means of six conditions: three respiratory system mechanics conditions with and without an inspiratory pause. The V_T indicated by the ventilator was lower than the actually delivered V_T , and the difference was often greater than 10% of the preset V_T .



In summary, despite the use of compensation algorithms, ventilators differ in their ability to deliver the preset V_T , and substantial differences may exist between the preset V_T and the V_T under BTPS conditions in the patient's lungs. When V_T was set at 6 ml/kg of predicted body weight, differences ranging from 1 to 2 ml/kg were common. Such differences may have clinical consequences in terms of both alveolar ventilation and the risk of ventilator-induced lung injury.

Monitoring expiratory V_{Ti}/V_{Te} in nonvented configuration

Volume delivered = insp V_T + Leaks



- In presence of leaks, insp V_t shown on the monitor increases while exp. V_t decreases.
- -Therefore watch the exp. V_t to determine the true V_t when allowed by the ventilator

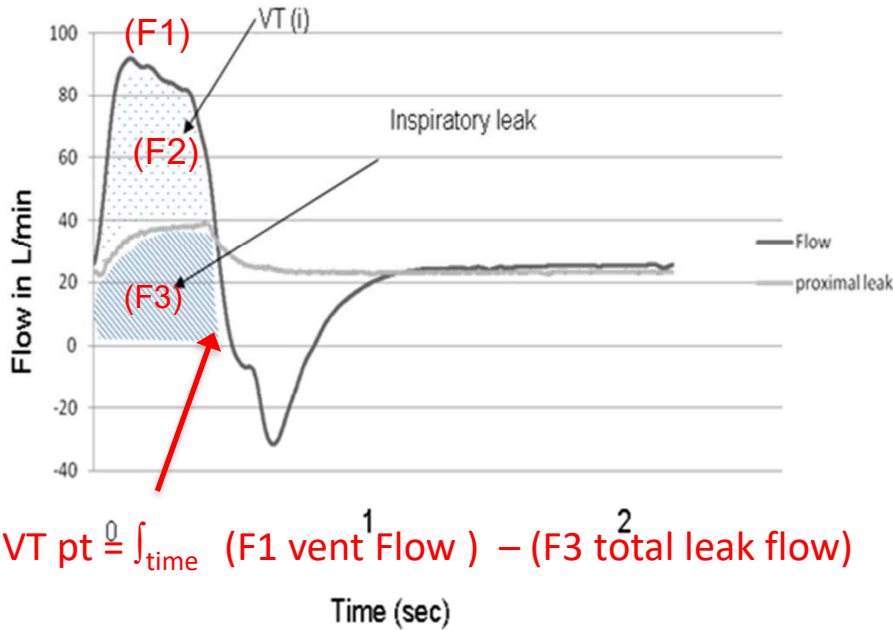
Exp $V_T = \text{insp } V_T - \text{Leaks}$

But...

- Often measuring expiratory V_t is also misleading because some of the expiratory V_t can be part of expiratory leaks
- So actual V_{te} could be lower of what the patient gets

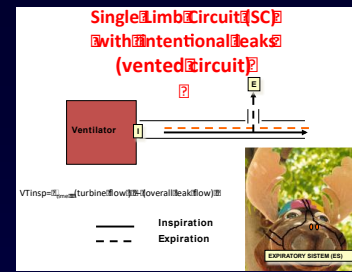
In vented circuit VT is estimated

$$VT_{insp} = \int_{time} (\text{turbine flow}) - (\text{overall leak flow})$$



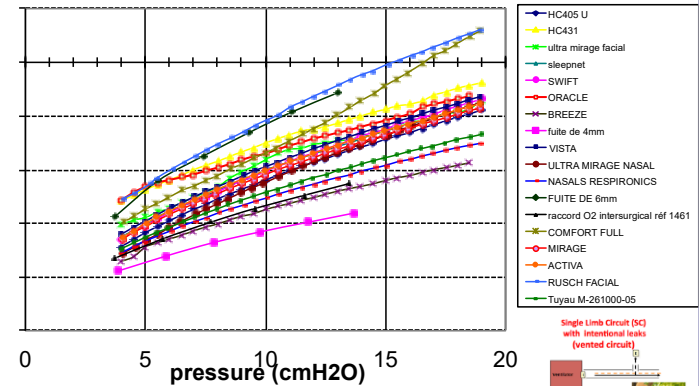
$$VT_{pt} = \int_{time} (F1 \text{ vent Flow}) - (F3 \text{ total leak flow})$$

Lujan et al Respiratory Care 2012



In vented circuit VT is estimated

Standard Vented-Mask: Pressure / Flow relationship



Annalisa Carlucci
Annia Schreiber
Alessio Mattei
Alberto Malovini
Jacopo Bellinati
Piero Ceriana
Cesare Gregoretti

The configuration of bi-level ventilator circuits may affect compensation for non-intentional leaks during volume-targeted ventilation

VTG modes

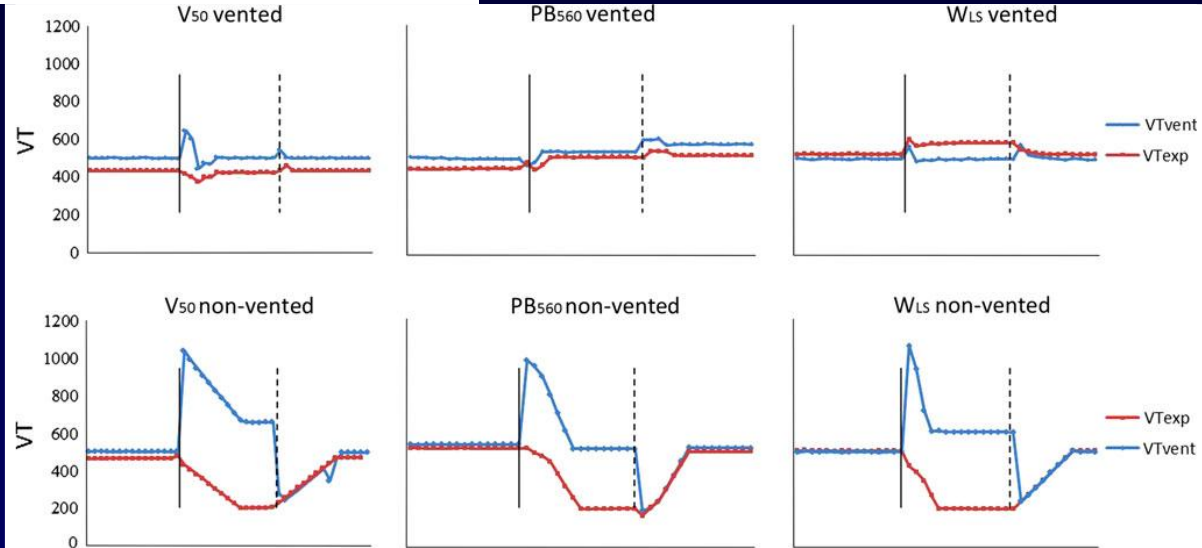
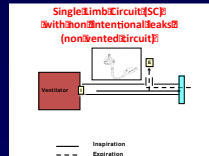
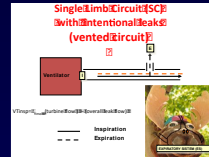


Fig. 3 Trend of expiratory tidal volume (V_{Texp}) and tidal volume displayed by the ventilator monitoring system (V_{Tvent}) at baseline, during a leak of 15 l/min and after the closure of the leak. The solid line indicates the opening of the leaks. The dotted line indicates the closure of the leaks

Minimal IPAP was first adjusted at 8 cmH₂O, EPAP at 4 cmH₂O and VTG at 500 and maximal IPAP at 30 cmH₂O. IPAP increased to about 15-20 achieve the target VT before a leak was generated

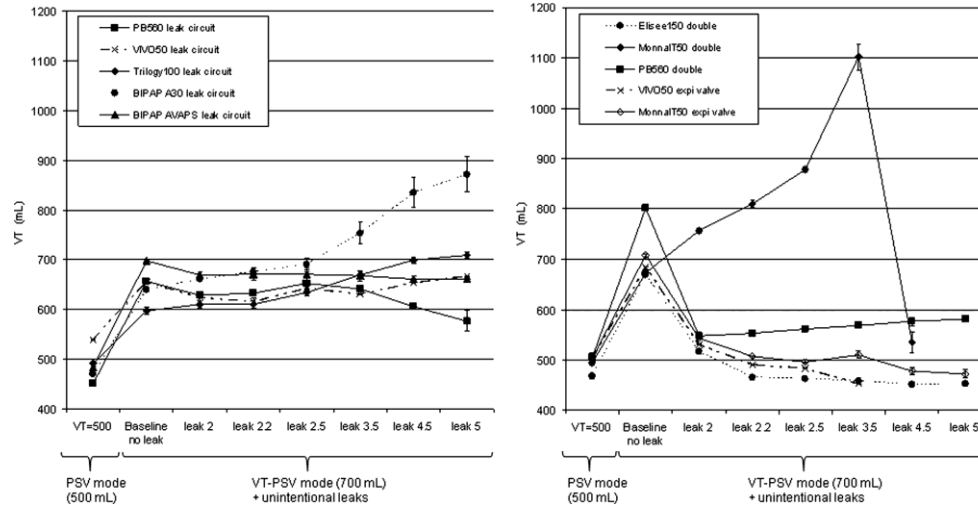


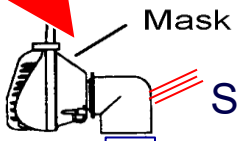
Figure 3 Variations in tidal volume (VT) during various levels of unintentional leakage. The left panel shows results with pressure-support ventilators and intentional right panel results with the pressure-support devices and a double-limb circuit or expiratory valve. The VIVO 50 with expiratory valve and the Monnal T50 with double-limb circuit were not able to cope with leaks over 3.5 and 4.5 mm, respectively. Each point represents the mean value of at least 10 stable cycles. Vertical bars represent the standard deviation.

Khirani S et al Harms of unintentional leaks during volume targeted pressure support ventilation *Respiratory Medicine* 2013

CO₂ rebreathing

EXHALATION PORT

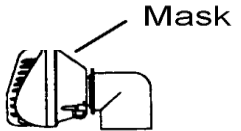
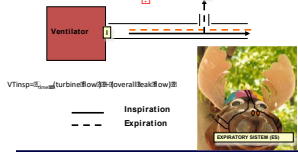
DEAD SPACE



SLOTS

Tubing

Single limb circuit with intentional leak (vented circuit)

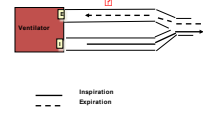


Whisper Swivel
SLOTS

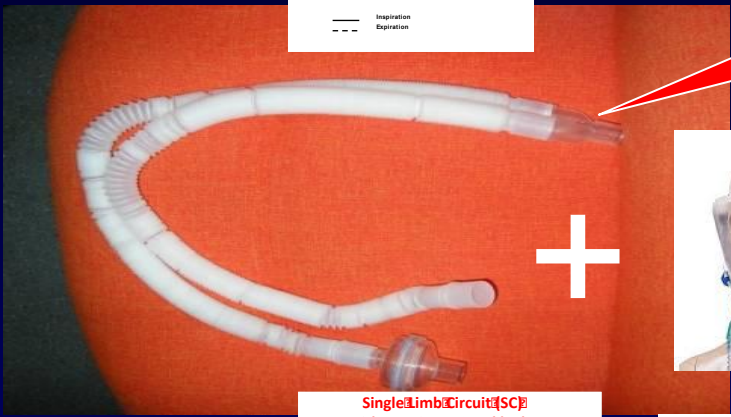
DEAD SPACE

Tubing

Double limb circuit with non-intentional leaks (non-vented circuit)



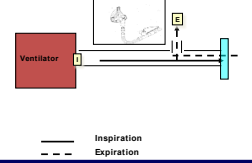
DEAD SPACE



+



Single limb circuit with non-intentional leaks (non-vented circuit)



DEAD SPACE,

$$VD_{dyn} = (VD_{phys}) + (VD_{app}).$$

V_t

Interface

Face mask and nasal plugs produced a greater fall in PaCO₂ than nasal mask

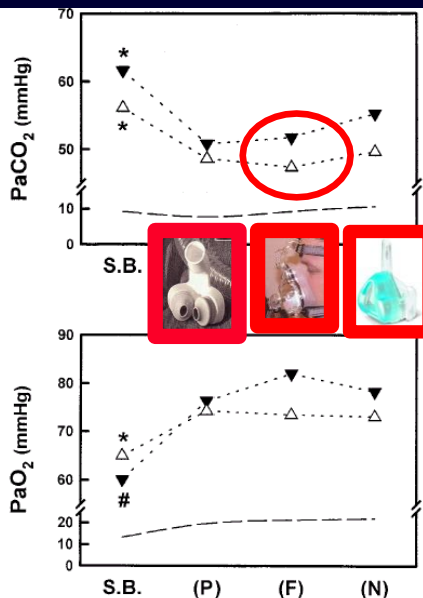
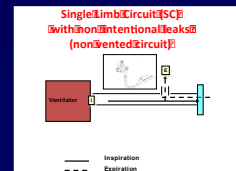
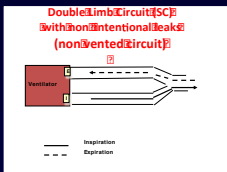


Figure 3. Mean values \pm SD of PaCO₂ and PaO₂ during the mask trials, when the patients were divided according to their underlying pathology. *Open triangles* represent restrictive thoracic diseases, *filled triangles* represent chronic obstructive pulmonary disease. *S.B.*, spontaneous breathing; *(P)*, nasal plugs; *(F)*, facial mask; *(N)*, nasal mask. **p* < .01 spontaneous breathing vs. nasal plugs, full-face mask and nasal mask. #*p* < .001 spontaneous breathing vs. nasal plugs, full-face mask.

Physiologic evaluation of noninvasive mechanical ventilation delivered with three types of masks in patients with chronic hypercapnic respiratory failure

Paolo Navalesi, MD; Francesco Fanfulla, MD; Pamela Frigerio, RT; Cesare Gregoretti, MO; Stefano Nava, MD

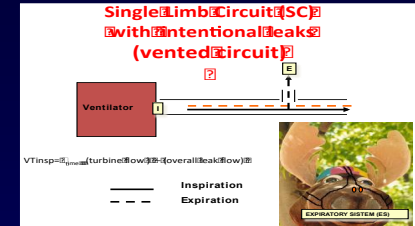
COPD 

RTD 

Conclusions: In this physiologic study, we have shown that in patients with hypercapnic respiratory failure, irrespective of the underlying pathology, the type of interface affects the NIMV outcome more than the ventilatory mode. (Crit Care Med 2000; 28: 1785–1790)

CO2 rebreathing

- The amount of CO2 rebreathing at given pressure depends on:
- The amount of CO2 *Szkulmowsky Intensive Care Med 2010*
- Respiratory Rate *Szkulmowsky Intensive Care Med 2010*
- Flow through the holes/slots
- PEEP level ($< 8 \text{ cmH}_2\text{O}$) *Ferguson GT et al AJRCCM 1995*
- Place of the holes/slots *Sattci E et al ERJ 04*
- Mask dead space and set pressure *Schettino GPP et al Crit Care Med 2003*
- Type of interfaces *Hill NS et al Chest 2003*



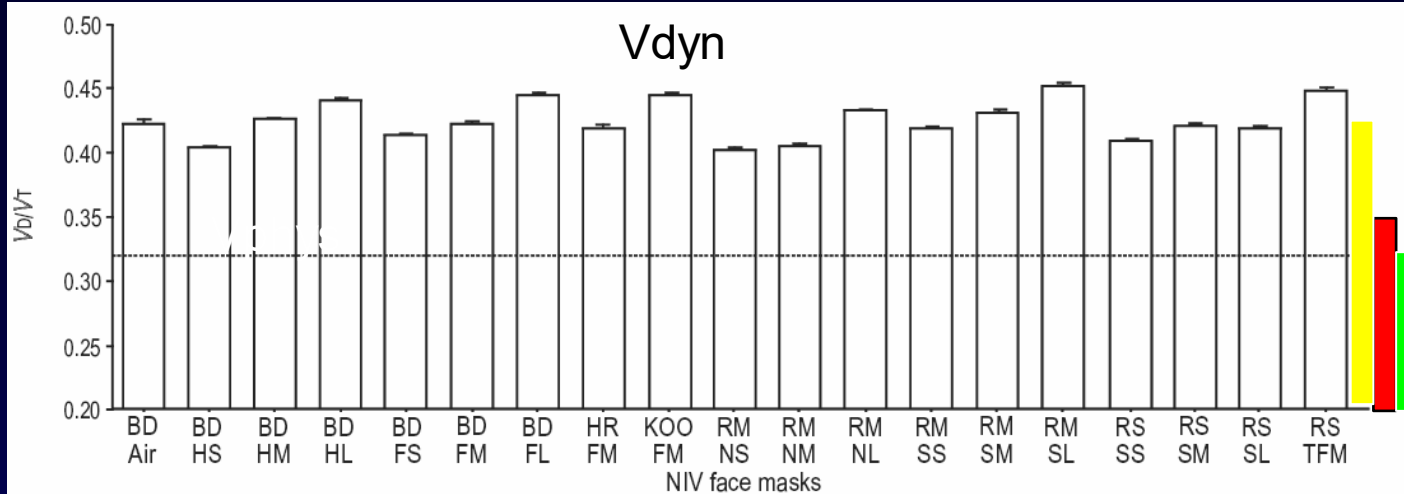


Fig. 4.- Total dynamic dead space (V_D/V_T) of noninvasive ventilation (NIV) face masks in spontaneous breathing. Refer to table 1 for abbreviations.

V_{dyn} SB

V_{dyn} IPAP16

V_{dyn} CPAP 4

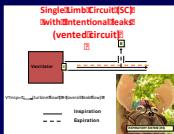
V_{dyn} BILEVEL 16/4

- PEEP ↓ V_Ddyn near to V_dphys in vented masks .
- PS without PEEP ↓ V_Ddyn to a lesser extent, from 42% to 39% of V_T, leaving V_Ddyn ↑ than V_Dphys.

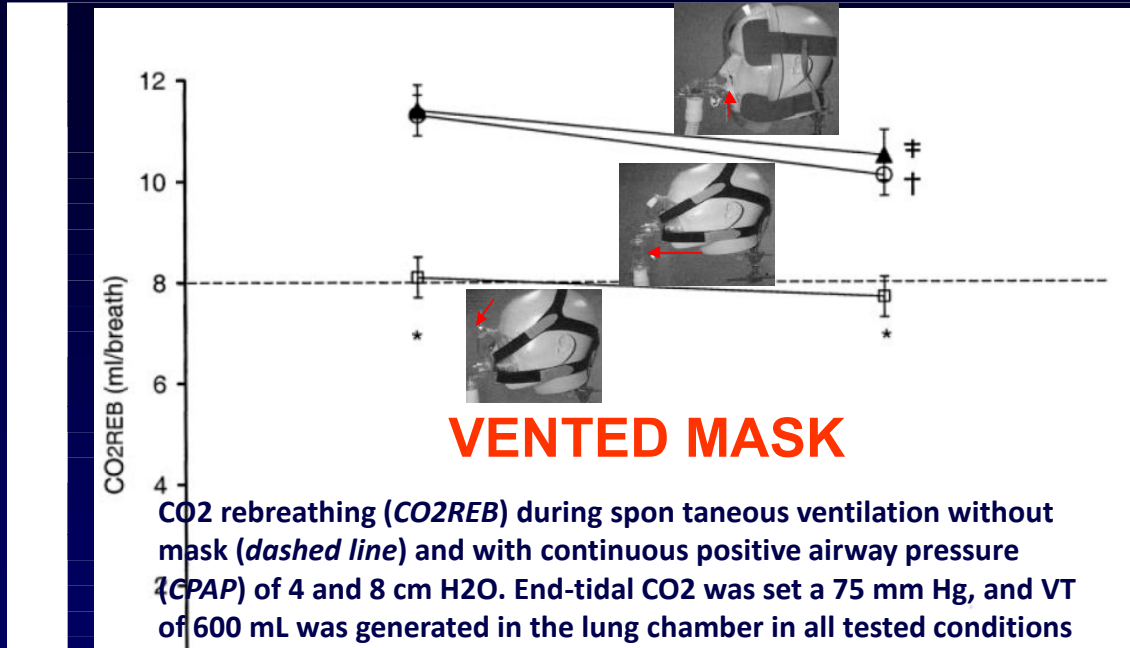
$$V_{D_{dyn}} = (V_{D_{phys}}) + (V_{D_{app}}).$$

V_t

Interface



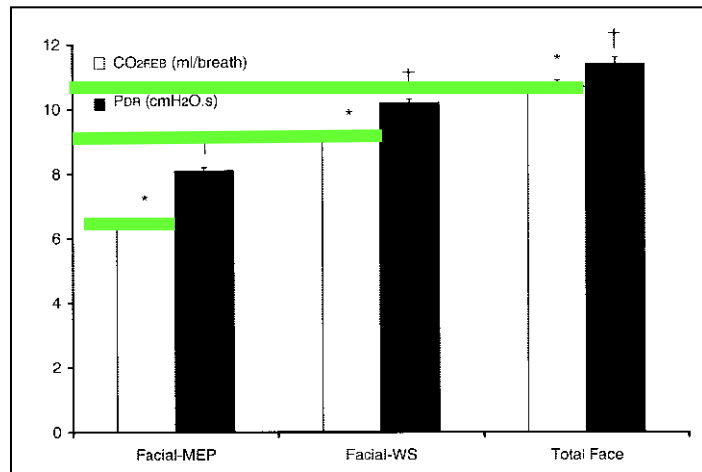
- The closer the EP to patient's airway the CO2 clearance



VENTED CIRCUIT

Table 1. CO₂ dynamics during pressure support ventilation

	Facial-MEP	Facial-WS	Total Face
P _{ET} CO ₂ mm Hg	72.4 ± 0.1 ^a	74.6 ± 0.9	75.7 ± 1.4
CO ₂ FEB mL/breath	7.0 ± 0.2 ^a	9.9 ± 0.5	10.4 ± 0.3
V _T mL	610 ± 5	611 ± 4	606 ± 9



Vented FFM
165ml
Leaks
24 L/m



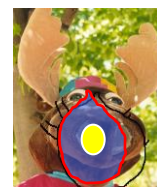
Vented system
in the circuit
165ml
Leaks 15 L/m



Vented TFM
875 ml
Leaks 30 L/m



Vented FFM



Vented system
in the circuit



Conclusion: Facial-MEP with its exhalation port within the mask and the smallest mask volume demonstrated less re-breathed CO₂ and a lower P_{DR} than either the Facial-WS or Total Face masks. Additional studies are necessary to confirm if mask design can clinically affect patient's inspiratory effort during noninvasive positive pressure ventilation. (Crit Care Med 2003; 31:2178–2182)

(P_{DR}) required to decrease end-tidal CO₂ by 20% (from 75 to 60 mm Hg).

“Vented ventilation” and CO₂ rebreathing

The likelihood of CO₂ rebreathing and V_{dyn} may be decreased by ventilator settings as well as by mask “vent” system configuration

Ferguson et al AJRCCM 1998; Schettino et al Crit Care Med 2003; Saatci et al Eur Respir J 2004; Skkumowsky et al Intensive Care Med 2010

Vented-mask



$$V_{D_{dyn}} = (V_{D_{phys}}) + (V_{D_{app}}).$$

V_t

Interface

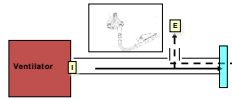
Vented-mask



Patient-ventilator synchrony

HC NON VENTED VENTILATORS

Single limb circuit
with non intentional leaks
(non vented circuit)



— Inspiration
- - - Expiration

Expiratory valves used for home devices: experimental and clinical comparison

F. Lofaso*, P. Aslanian*, J.C. Richard*, D. Isabey*, T. Hang**, E. Corriger**,
A. Harf*, L. Brochard*

Expiratory valves used for home devices: experimental and clinical comparison. F. Lofaso, P. Aslanian, J.C. Richard, D. Isabey, T. Hang, E. Corriger, A. Harf, L. Brochard. ©ERS Journals Ltd 1998.

ABSTRACT: A bench study followed by a clinical trial were performed to evaluate the mechanical characteristics of five (commercially available) expiratory valves used for home ventilators, as well as the potential clinical impact of differences between these valves.

In the *in vitro* study, expiratory valve resistance was evaluated under unvarying conditions, whereas dynamic behaviour was evaluated by calculating the imposed expiratory work of breathing during a simulated breath generated by a lung model. Differences in resistance and imposed expiratory work of up to twofold and 150%, respectively, were found across valves. We then conducted a randomized crossover clinical study to compare the effects of the least resistive (Bennett) and most resistive expiratory valves (Peters) in 10 intubated patients receiving pressure support ventilation.

There were no significant differences regarding blood gases or respiratory parameters except for the oesophageal pressure-time product (PTP_{oes}), which was significantly increased by the Peters valve ($236 \pm 113 \text{ cmH}_2\text{O} \cdot \text{s} \cdot \text{min}^{-1}$ versus $194 \pm 90 \text{ cmH}_2\text{O} \cdot \text{s} \cdot \text{min}^{-1}$). An analysis of individual responses found that the Peters valve induced substantial increases in intrinsic positive end-expiratory pressure (PEEP), PTP_{oes}, and expiratory activity in those patients with the greatest ventilatory demand.

In conclusion, differences between home expiratory valve resistances may have a clinically relevant impact on the respiratory effort of patients with a high ventilatory demand.

Eur Respir J 1998; 11: 1382–1388.

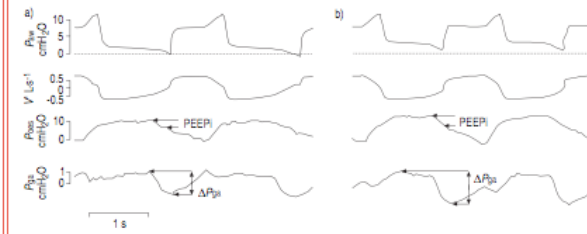
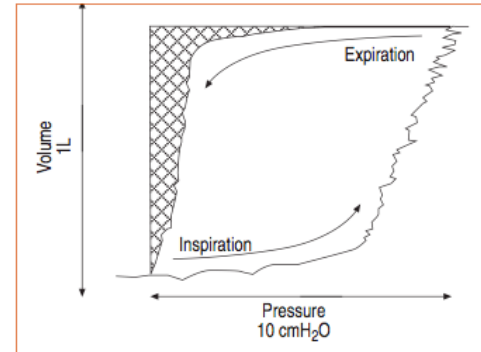


Fig. 5. – Representative recordings of airway pressure (P_{aw}), flow (V), oesophageal pressure (P_{oes}) and gastric pressure (P_{ga}) in patient 7. Tracings demonstrated increases in P_{aw} during expiration, intrinsic positive end-expiratory pressure (PEEP_i), and decline in P_{ga} (ΔP_{ga}) with: a) the expiratory Peters valve as compared to b) the expiratory Bennett valve.

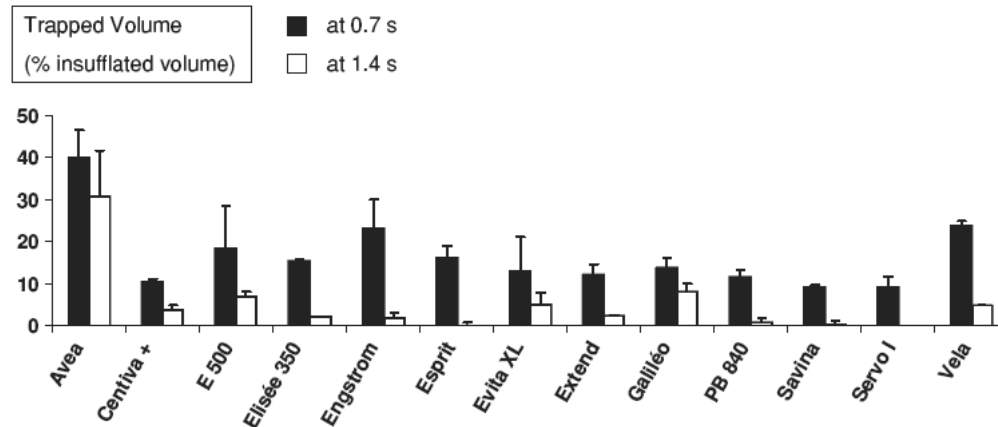


ICU NON VENTED VENTILATORS

Arnaud W. Thille
Aissam Lyazidi
Jean-Christophe M. Richard
Fabrice Galia
Laurent Brochard

A bench study of intensive-care-unit ventilators: new versus old and turbine-based versus compressed gas-based ventilators

Fig. 5 Expiratory resistance for each ventilator evaluated as the trapped volume at 0.7 and 1.4 s of expiratory time (expressed as percentage of insufflated volume). Lower trapped volumes indicate lower expiratory resistance and better performance



CHEST

Official publication of the American College of Chest Physicians



Patient-ventilator asynchrony during noninvasive ventilation: A bench and clinical study

Guillaume CARTEAUX, Aissam LYAZIDI, Ana CORDOBA-IZQUIERDO, Laurence VIGNAUX, Philippe JOLLIET, Arnaud W. THILLE, Jean-Christophe M. RICHARD and Laurent BROCHARD

Chest; Prepublished online March 8, 2012;
DOI 10.1378/chest.11-2279

The online version of this article, along with updated information and services can be found online on the World Wide Web at:
<http://chestjournal.chestpubs.org/content/early/2012/03/07/chest.11-2279>

VENTED VS NON VENTED VENTILATOR

Conclusion: Dedicated NIV ventilators allow better patient-ventilator synchrony than ICU and transport ventilators, even with their NIV algorithm. However the NIV algorithm improves, at least slightly and with a wide variation among ventilators, triggering and/or cycling off synchronization.

Table 3 Clinical study – Number of patients (%) presenting each type of asynchrony during a NIV session with a high incidence (>1/min) or an Asynchrony Index > 10%

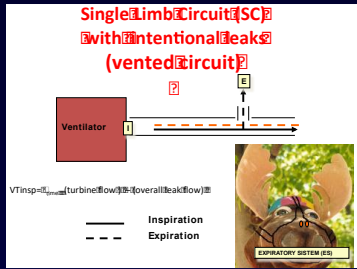


	<i>ICU_{NIV-}</i>	<i>ICU_{NIV+}</i>	<i>NIV_V</i>	<i>p</i>
Auto-triggering	5 (33)	5 (33)	0	.016
Double-triggering	0	1 (7)	0	-
Ineffective effort	0	0	0	-
“Delayed cycling”	0	0	0	-
“Premature cycling”	3 (20)	1 (7)	0	.097
At least one asynchrony	6 (40)	5 (33)	0	.012
Asynchrony Index > 10%	4 (27)	2 (13)	0	.091

Definition of abbreviations: *ICU_{NIV-}*: NIV session using an ICU ventilator whose NIV

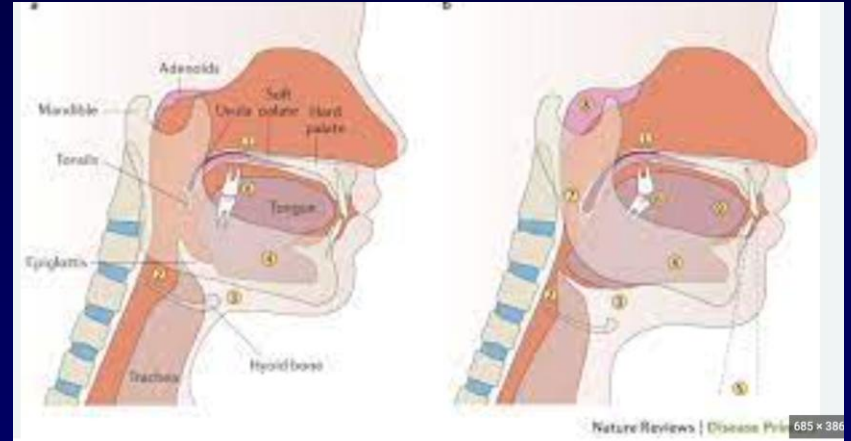
algorithm has been turned off; *ICU_{NIV+}*: NIV session using an ICU ventilator whose NIV

algorithm has been turned on; *NIV_V*: NIV session using a dedicated NIV ventilator.

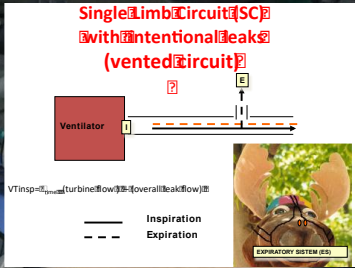


VARIABLE PEEP

- RATIONALE ?
- DO I NEED IT ?
- FOT
- FLOW CURVES analysis



$$P_{\text{musc}} = P_{\text{aw}} = P_0 + (P_{\text{el}_L} + P_{\text{el}_{\text{cw}}}) + (P_{\text{res}}_{\text{Upper Airway}} + P_{\text{res}}_{\text{Lower Airway}})$$





Possible drawbacks

O2 bleeding

Effects of Gas Leak on Triggering Function, Humidification, and Inspiratory Oxygen Fraction During Noninvasive Positive Airway Pressure Ventilation*

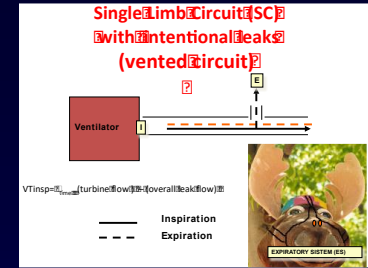
Eriko Miyoshi, MD; Yuji Fujino, MD; Akinori Uchiyama, MD;
Takashi Mashimo, MD; and Masaji Nishimura, MD

Objectives: During noninvasive positive pressure ventilation (NPPV), the gas leak that commonly occurs around the mask can render NPPV ineffective. We evaluated the effects of gas leak on inspiratory trigger function during NPPV with bilevel pressure and ICU ventilators. In addition, we evaluated the effects of gas leak on fraction of inspired oxygen (F_{iO_2}) and humidification.

Methods: Air leak was created at the airway opening of a model lung by establishing several different-size holes in the circuit. During simulated spontaneous breathing, we evaluated inspiratory trigger performance of two bilevel pressure ventilators (BiPAP Vision and BiPAP S/T-D; Respironics; Murrysville, PA) and two ICU ventilators (Puritan-Bennett 7200ae and Puritan-Bennett 840; Tyco Healthcare; Mansfield, MA). Inspiratory delay time and inspiratory trigger pressure were analyzed. F_{iO_2} at the airway opening and inside the model lung were evaluated during BiPAP S/T-D ventilation at supplemental oxygen flows of 3, 6, 9, 12 and 15 L/min. Measured oxygen concentration was compared to mathematically predicted levels. Finally, using two heated humidifiers, we evaluated the effect of gas leak on humidification.

Results: The bilevel pressure ventilators triggered properly at all levels of gas leak, and inspiratory triggering was more effective than with the ICU ventilators. Delivered F_{iO_2} with the BiPAP S/T-D ventilator was affected by gas leak and could be predicted mathematically unless the gas leak was large. With large gas leaks, although relative humidity was maintained, absolute humidity decreased.

Conclusion: Gas leak affected triggering of ICU ventilators, F_{iO_2} of the BiPAP S/T-D ventilator, and humidity with both types of humidifiers. (CHEST 2005; 128:3691–3698)



« Non-Vented Ventilation » and ventilator performance

The amount of intentional leaks may interfere with patient's triggering, expiratory flow threshold and ventilator performance

Louis et al Eur Respir J 2010; Borel et al Chest 2009

Loss in performance

Eur Respir J 2010; 35: 627–636

(CHEST 2009; 135:669–677)

