UNIVERSITY OF TORONTO

St. Michael's
Inspired Care.
Inspiring Science.

Physiology of Non-Invasive NAVA

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Disclosure

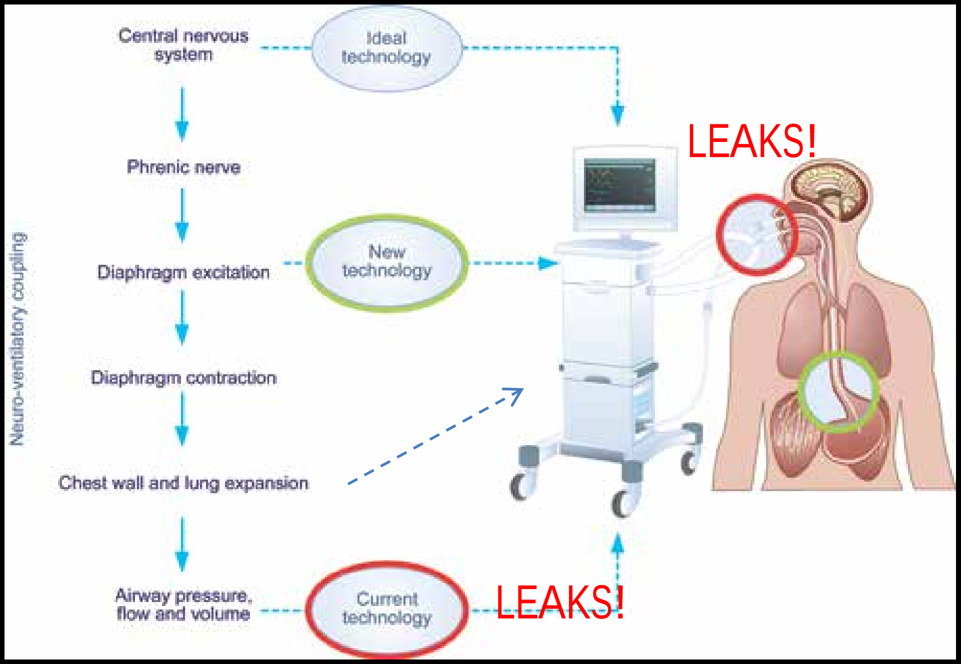
- Consultant: Maquet Critical Care
- Speakers Bureau: Maquet Critical Care
- Stock Shareholder: Nothing to disclose
- Employee: Nothing to disclose
- Other (identify): Royalties on patents

The following disclosure was approved by University of Toronto and St-Michael's Hospital:
Dr. Beck has made inventions related to neural control of mechanical ventilation that are patented. The license for these patents belongs to Maquet Critical Care. Future commercial uses of this technology may provide financial benefit to Dr. Beck through royalties. Dr Beck owns 50% of Neurovent Research Inc (NVR). NVR is a research and development company that builds the equipment and catheters for research studies. NVR has a consulting agreement with Maquet Critical Care.

Definition and goals of NIPPV

- NIV, just like INV, is mechanical ventilation delivered with intermittent inflations, usually with PEEP, to the airways, via a non-invasive interface
- The goal of NIV is to maintain adequate oxygenation and adequate ventilation, reduce the work of breathing, and to keep the lung open without overdistension.
- In order to avoid complications, NIV should be synchronized to the patient's breathing effort

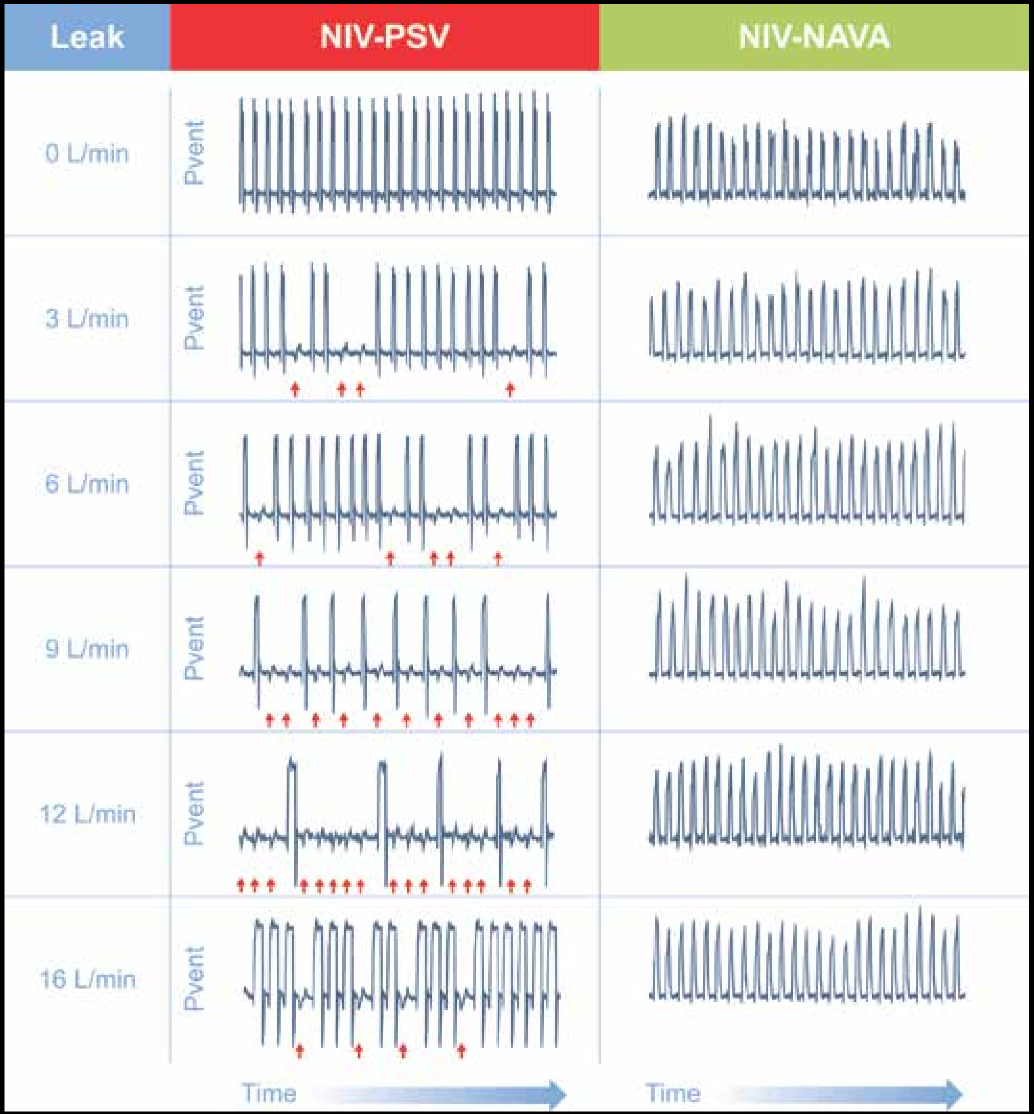
Factors Affecting NIV



- Controller signal for patient-ventilator synchrony
- Inadequate (pneumatic) monitoring
- Properties of interface
  - Masks and prongs (leaks)
  - Prongs (resistance)
  - Helmet (compliance)
- Leaks and pressure delivery
- Upper airways (protection and control of FRC)

From Principles and Practice of Mechanical Ventilation, ed. M Tobin, In Press, 2012

Leaks (“bench”)



Sinderby & Beck, Neurally Adjusted Ventilatory Assist in Principles and Practice of Mechanical Ventilation, Third Edition Editor: Tobin MJ, McGraw-Hill Medical 2013

Intensive Care Med
DOI 10.1007/s00134-007-0882-x

ORIGINAL

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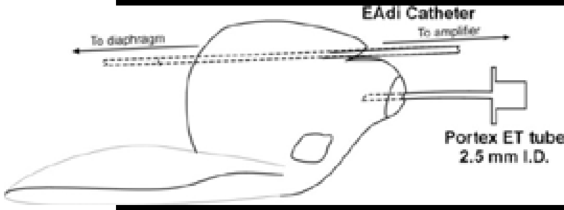
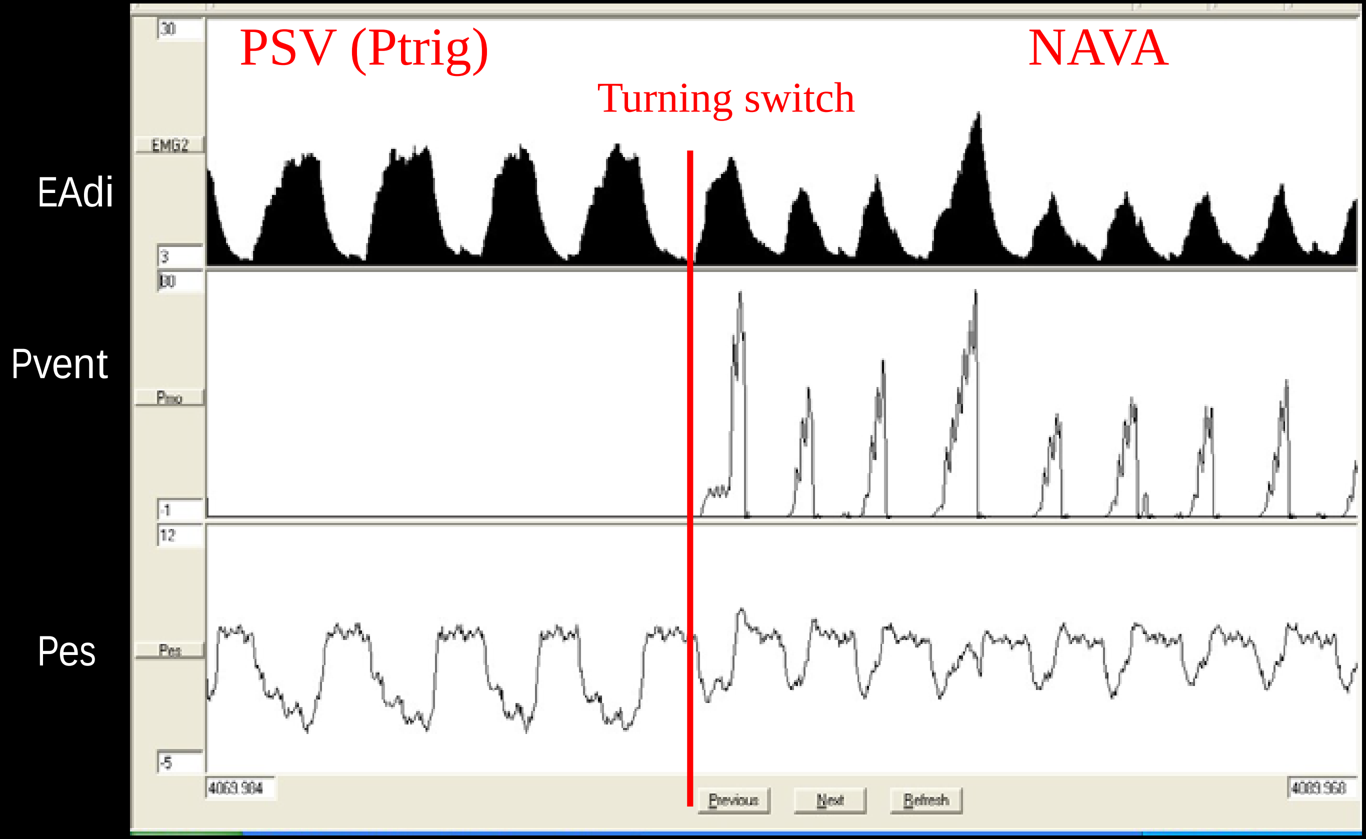
Non-invasive neurally adjusted ventilatory assist in rabbits with acute lung injury



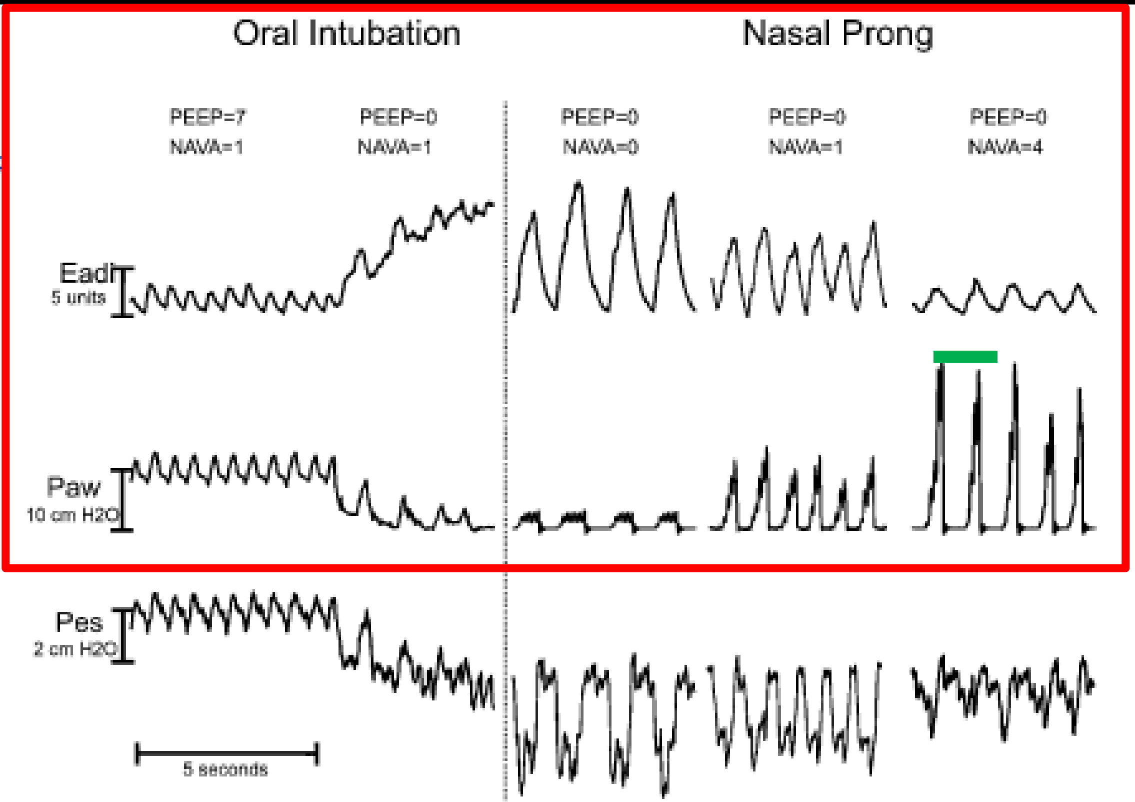


PO2 = 46.6 mmHg
PCO2 = 62.9 mm Hg

PO2 = 129.8 mmHg
PCO2 = 43.1 mm Hg

Monitoring of respiratory muscle unloading during NAVA-NIV

Fig. 2 Examples of tracings from one representative lung-injured animal breathing on NAVA. From left to right: orally intubated with titrated PEEP, NAVA level 1; removal of PEEP; extubation (indicated by *vertical line*); NAVA with nasal prong at level 0; NAVA level 1; and NAVA level 4. *Eadi*, Diaphragm electrical activity; *Paw*, airway pressure; *Pes*, esophageal pressure



Beck et al, 2008 ICM

Increased Risk of Gastrointestinal Perforations in Neonates Mechanically Ventilated with Either Face Mask or Nasal Prongs

Jeffery S. Garland, MD, David B. Nelson, MD, MSc, Thomas Rice, MD, and Josef Neu, MD

From the Medical College of Wisconsin, Department of Pediatrics, Milwaukee Children's Hospital, Milwaukee

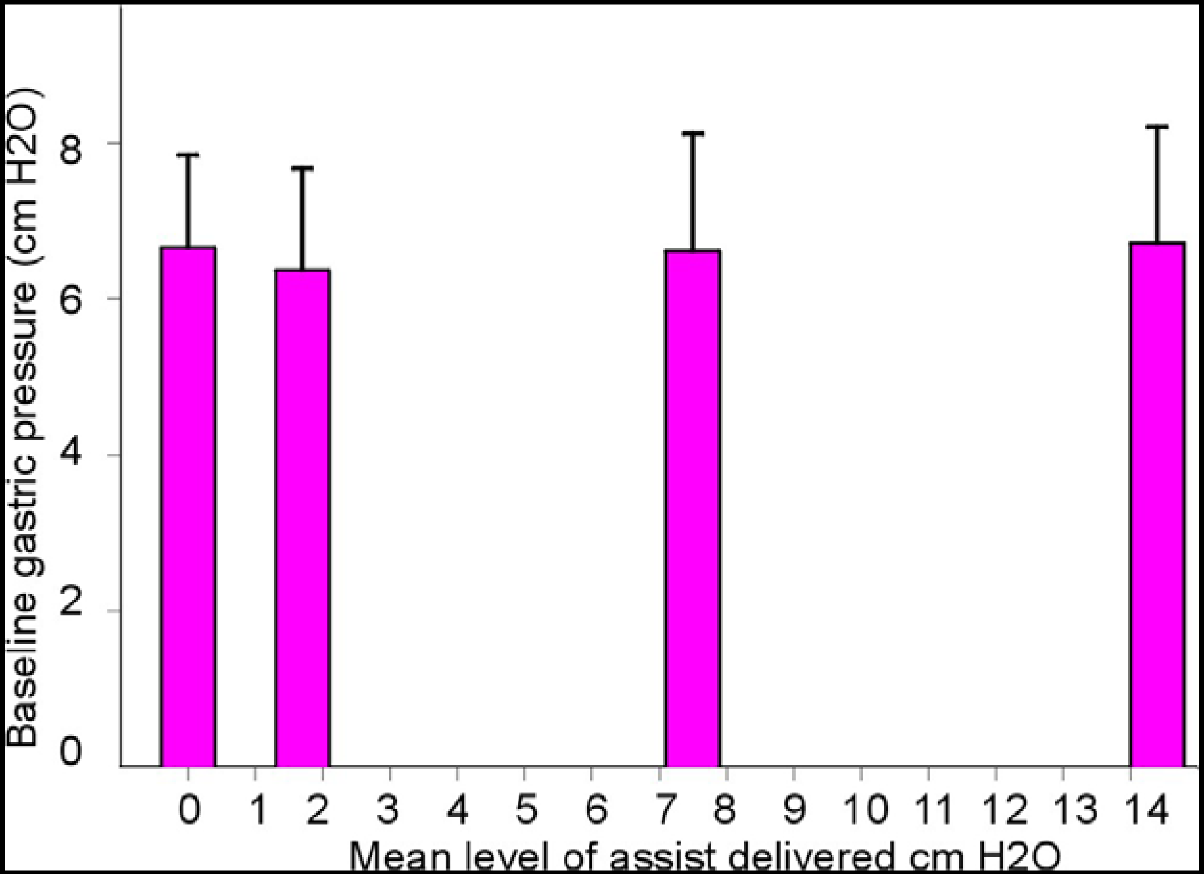
TABLE 1. Clinical and Ventilatory Data Pertaining to Infants with GPNN* and Control Infants

	Infants with GPNN (N = 15)	Control Infants (N = 60)	Significance
Gestational age (wk)†	30.0 ± 3.5	30.1 ± 4.1	NS
5-Min Apgar score			
0–4	5	19	
5–7	6	25	NS
8–10	4	16	
Birth weight (g)†	1,383 ± 552	1,355.8 ± 908.4	NS
Sex (M/F)	12/3	39/21	NS
Primary reason for ventilation			
Hyaline membrane disease	13	52	
Other	2	8	NS
Length of time of ventilation before perforation (d)†	6.8 ± 10.2	NA	NS
Peak inspiratory pressure setting at time of perforation (cm)†	18.6 ± 5.7	23.4 ± 7.39	NS

* Abbreviations used are: GPNN, gastrointestinal perforations not associated with necrotizing enterocolitis or bowel obstruction; NA, not applicable.
† Values are means ± SD.

No Evidence for Abdominal Distension with NIV NAVA (n=10)

(rabbits with single nasal prong)

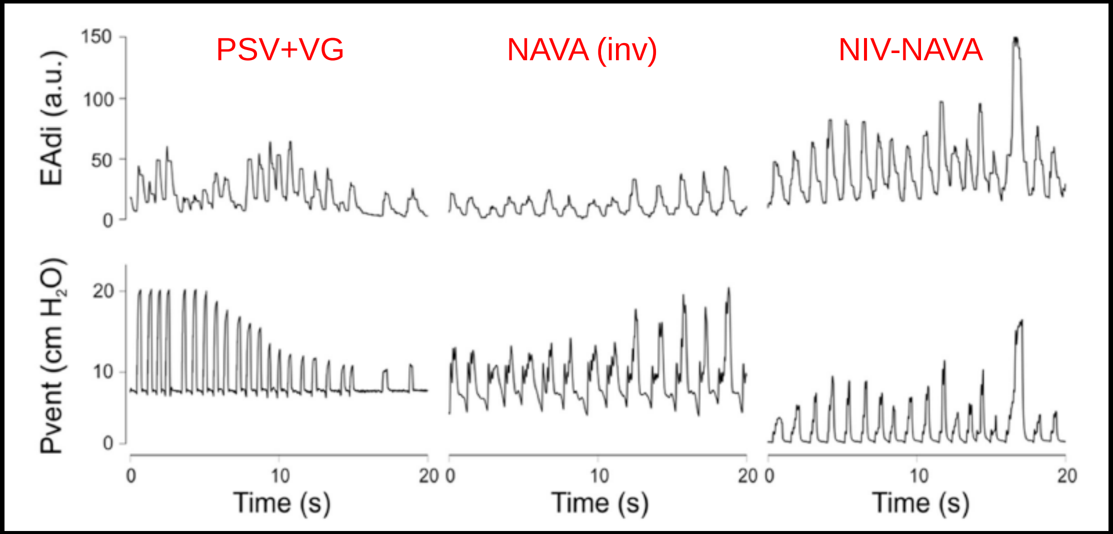


Beck et al, PATS 2005

Patient-Ventilator Interaction During Neurally Adjusted Ventilatory Assist in Low Birth Weight Infants

JENNIFER BECK, MAUREEN REILLY, GIACOMO GRASSELLI, LUCIA MIRABELLA, ARTHUR S. SLUTSKY, MICHAEL S. DUNN, AND CHRISTER SINDERBY

(*Pediatr Res* 65: 663–668, 2009)



N = 7
Mean weight = 976 g
Mean age = 12 days
GA at birth: 26 wks

0031-3998/09/6506-0663
PEDIATRIC RESEARCH

Vol. 65, No. 6, 2009
Printed in U.S.A.

Patient-Ventilator Interaction During Neurally Adjusted Ventilatory Assist in Low Birth Weight Infants

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Table 2. *Vital signs, ventilator parameters, neural breathing pattern, and patient-ventilator interaction*

	Conventional ventilation	NAVA-intubated	NAVA-extubated	*p*
	n = 7	*n* = 7	*n* = 5	
F_{IO_2} (%)	25.1 (5.8)†	26.4 (5.9)*	38.0 (19.1)	0.0034
S_{AO_2} (%)	94.6 (2.7)	94.1 (3.5)	95.4 (6.5)	0.961
T_{CO_2} (mm hg)	53.4 (14.6)	52.6 (13.0)	60.6 (12.5)	0.787
Heart rate (per min)	160 (15)	159 (11)	166 (11)	0.868
	n = 5	*n* = 7	*n* = 5	
MAPi (cm H_2O)	12.5 (1.5)*	9.6 (1.8)*	5.5 (1.6)	0.002
ΔPi (cm H_2O)	9.3 (1.3)	9.9 (1.3)	9.4 (3.1)	0.710
EAdi phasic (au)	27.9 (19.5)	43.6 (18.7)	44.8 (32.4)	0.333
EAdi tonic (au)	5.5 (2.0)	4.7 (3.0)	4.7 (1.4)	0.157
Nti (msec)	258 (43)	406 (131)	436 (198)	0.09
Nte (msec)	712 (139)	875 (237)†	1001 (256)	0.044
Nrr (per min)	74 (7)	54 (14)†	51 (14)†	0.004
EAdi-time product (au*s/min)	556.4 (421.2)	823.4 (444.3)	670.2 (524.5)	0.504
Trigger delay (ms)	74 (17)	72 (23)	76 (33)	0.698
Cycling-off delay (ms)	−120 (66)	32 (34)†	28 (11)†	<0.001
R^2 for EAdi *vs* Pvent	0.08 (0.1)	0.80 (0.06)†	0.73 (22)†	<0.001
Slope EAdi *vs* Pvent (cm H_2O per au)	0 (0.01)	0.19 (0.1)†	0.2 (0.1)†	0.007

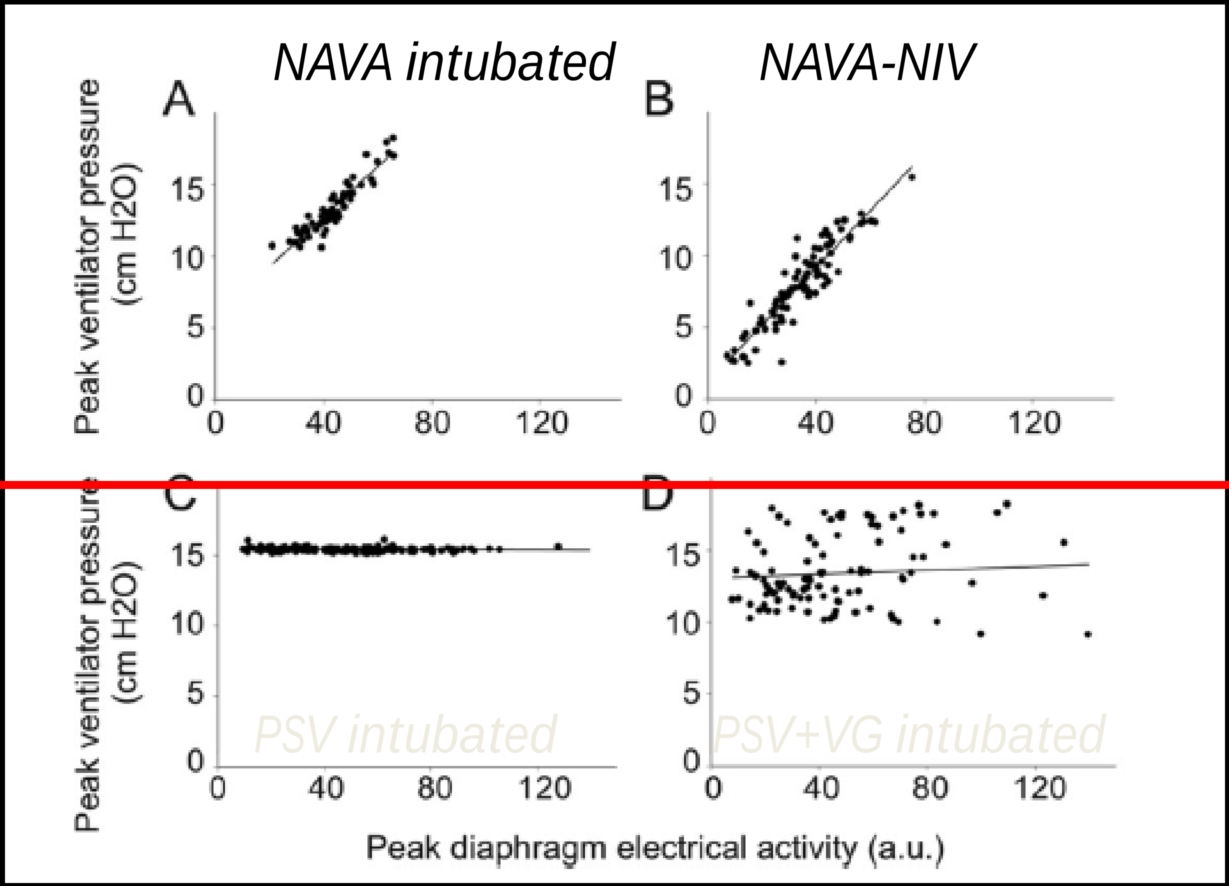
* Statistically different from NAVA-ext.

† Statistically different from Conv.

F_{IO_2}, fraction of inspired oxygen; S_{AO_2}, oxygen saturation; T_{CO_2}, transcutaneous carbon dioxide; MAPi, mean inspiratory airway pressure; ΔPi, delta inspiratory pressure above PEEP; EAdi, electrical activity of the diaphragm; Nti, neural inspiratory time; Nte, neural expiratory time; Nrr, neural respiratory rate; R^2, determination coefficient; Pvent, ventilator delivered pressure.

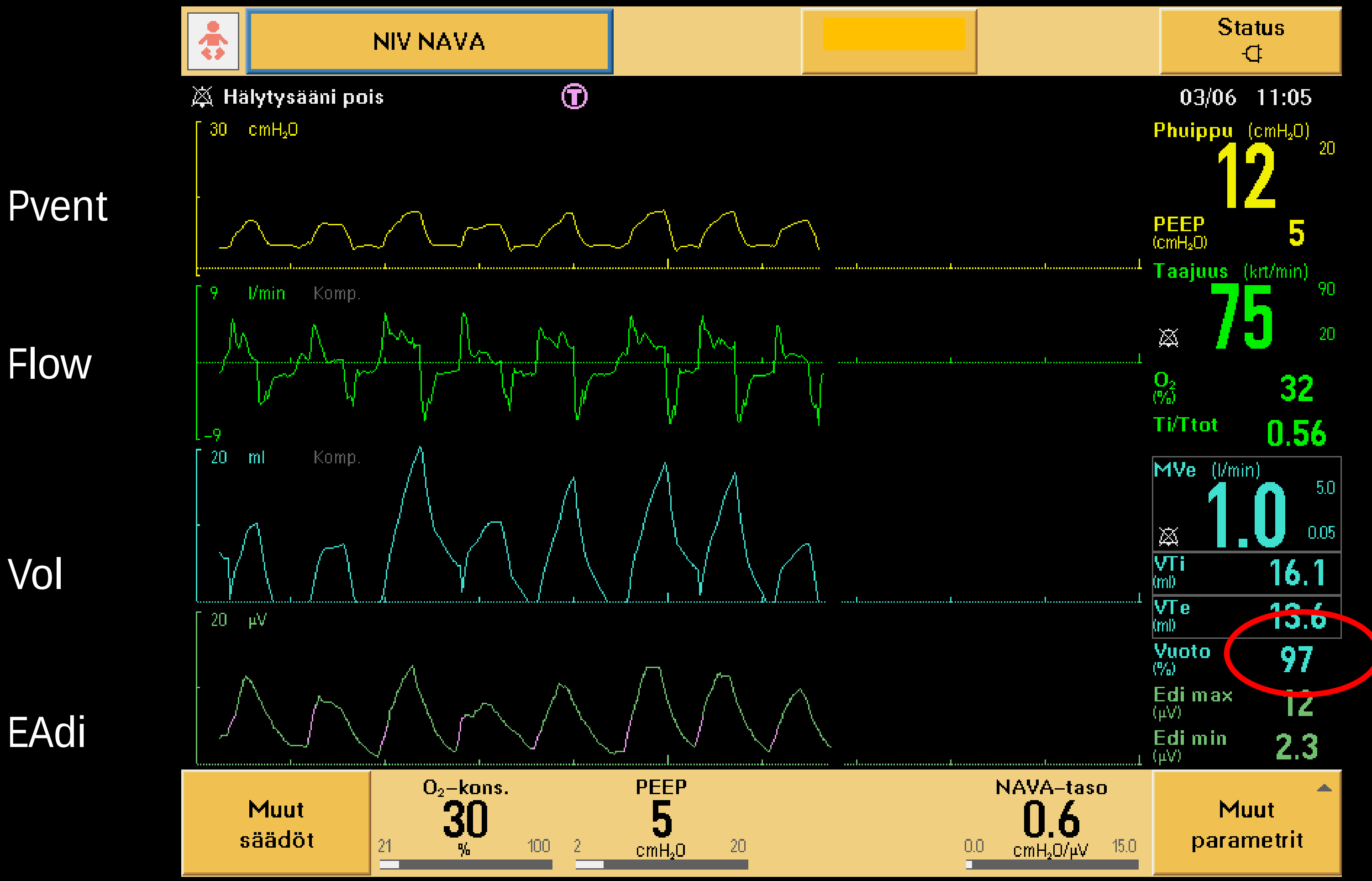
Beck et al, 2009 Ped Res

Proportionality between patient effort and ventilatory assist



Beck et al, Ped Res 2009

NIV-NAVA in the preterm



Slide courtesy of Dr. Lehtonen (Turku University Hospital)

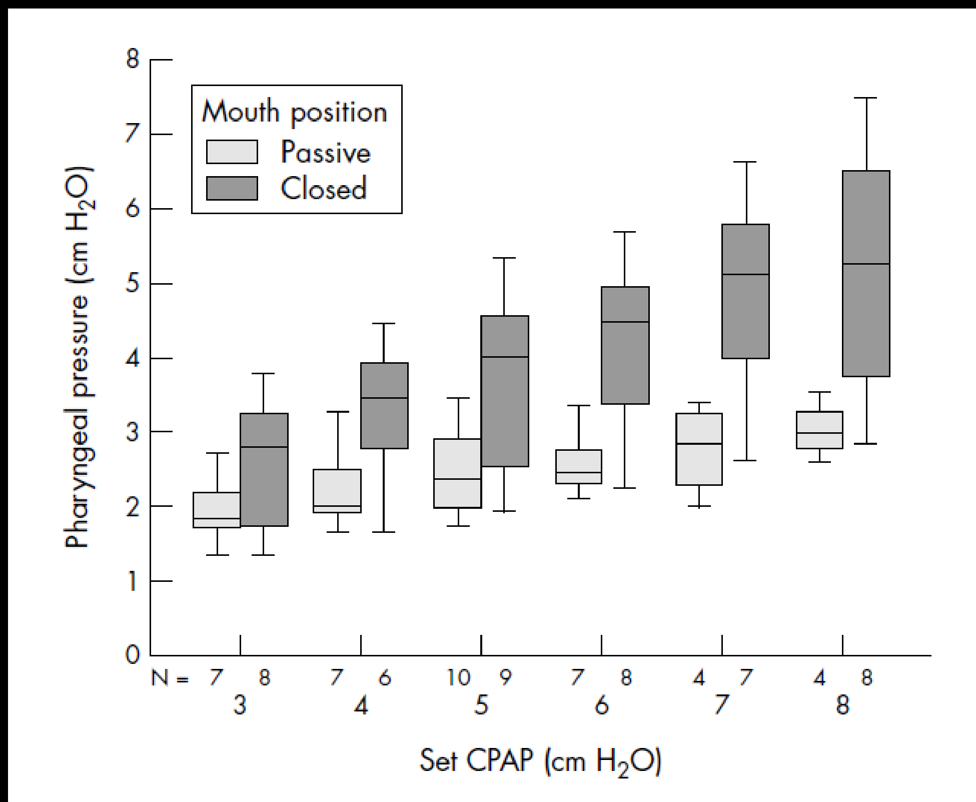
Interfaces

SHORT REPORT

Pharyngeal pressure in preterm infants receiving nasal continuous positive airway pressure

A G De Paoli, R Lau, P G Davis, C J Morley

Arch Dis Child Fetal Neonatal Ed 2005;**90**:F79–F81. doi: 10.1136/adc.2004.052274



N= 11 preterms
Binasal Hudson prongs
Bubble cpap

Intensive Care Med
DOI 10.1007/s00134-007-0882-x

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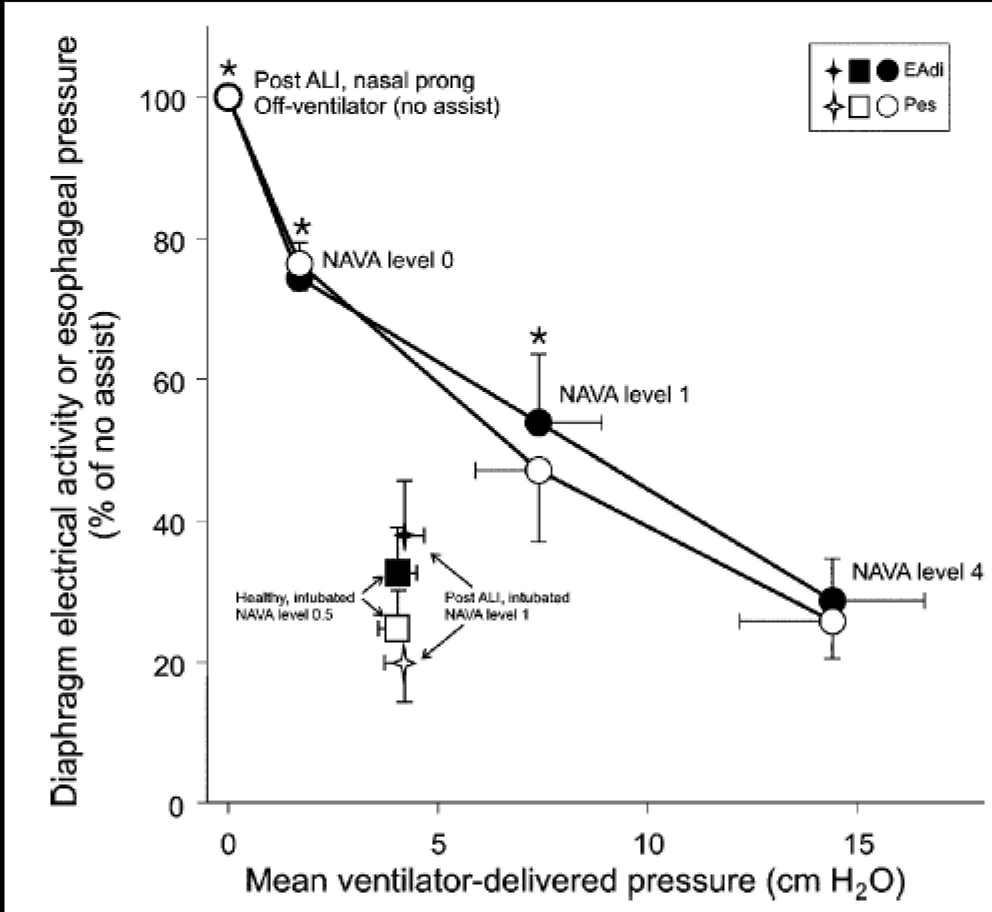

Intensive Care Med (2008) 34:1615–1623
DOI 10.1007/s00134-008-1163-z

ORIGINAL

OpenAccess

Onnen Moerer
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Roberta Costa
Michael Quintel
Arthur S. Slutsky
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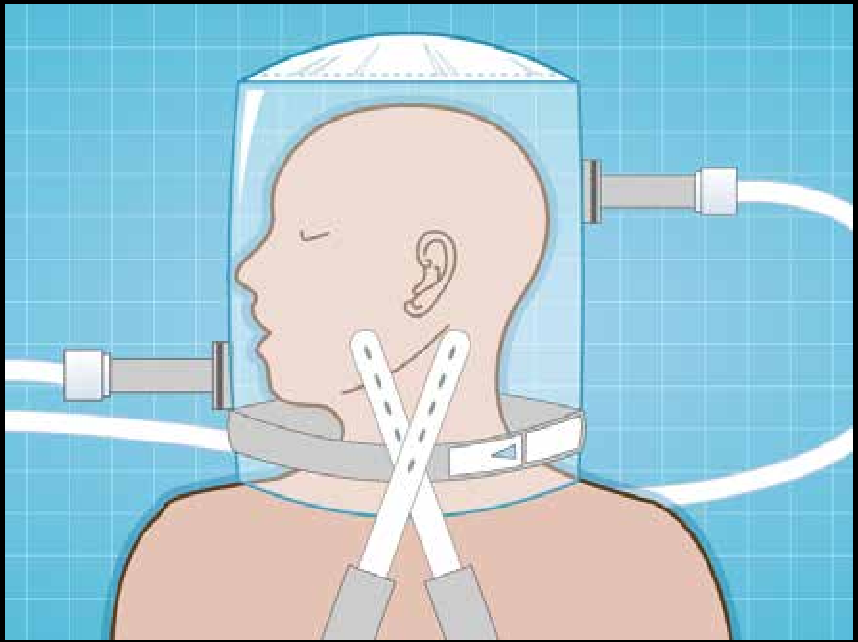
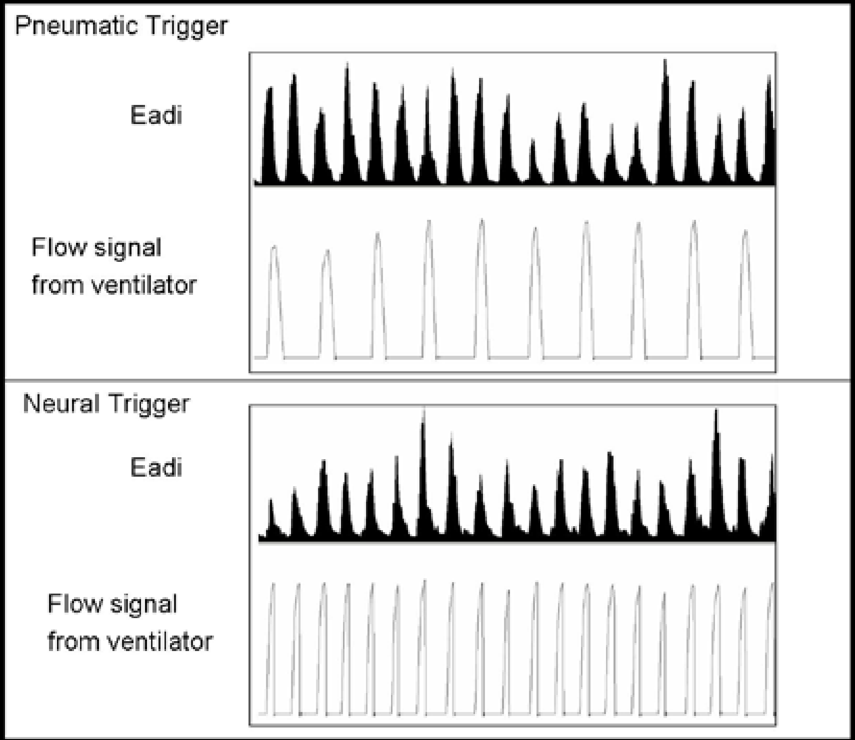
Subject–ventilator synchrony during neural versus pneumatically triggered non-invasive helmet ventilation





N= 7 Healthy
Ptrig vs Ntrig, PSV 5-20, rr 10-30
Breathing comfort with VAS

Intensive Care Med (2008) 34:1615–1623
DOI 10.1007/s00134-008-1163-z

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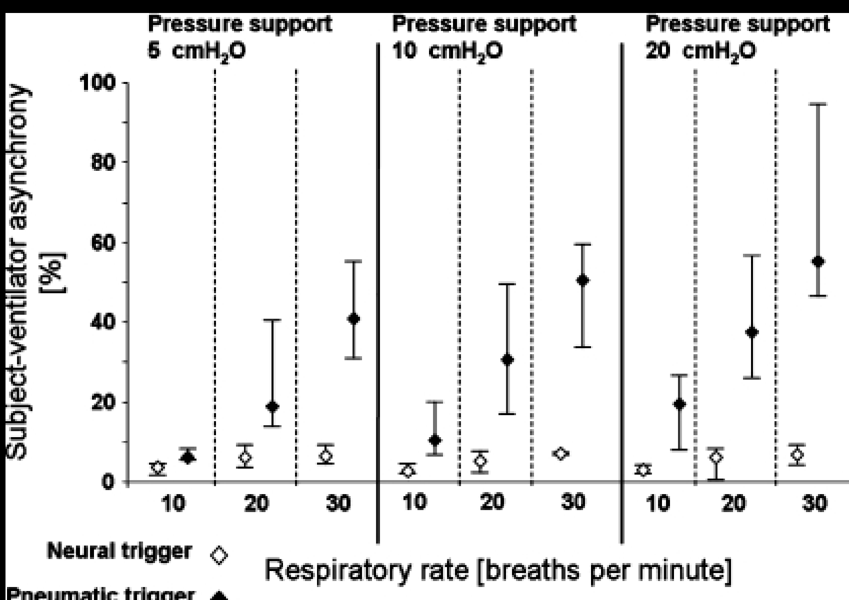

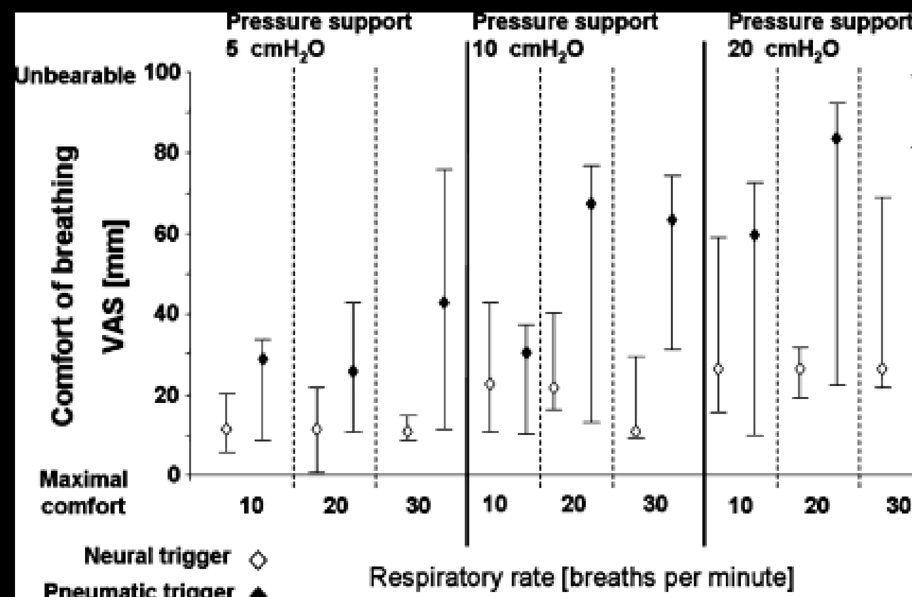

Intensive Care Med
DOI 10.1007/s00134-011-2382-2

ORIGINAL

Gianmaria Cammarota
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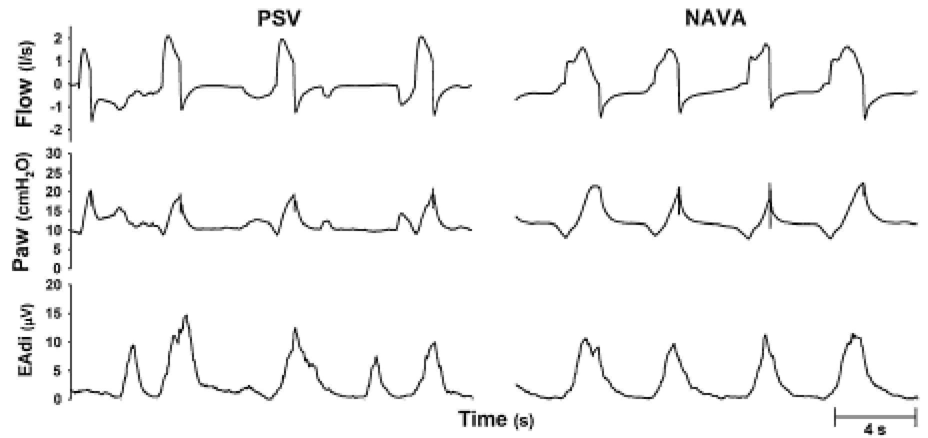
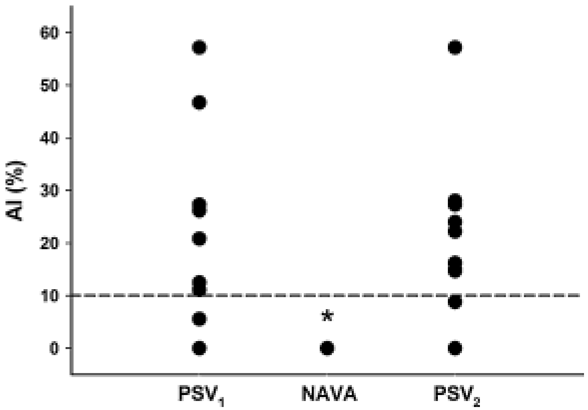
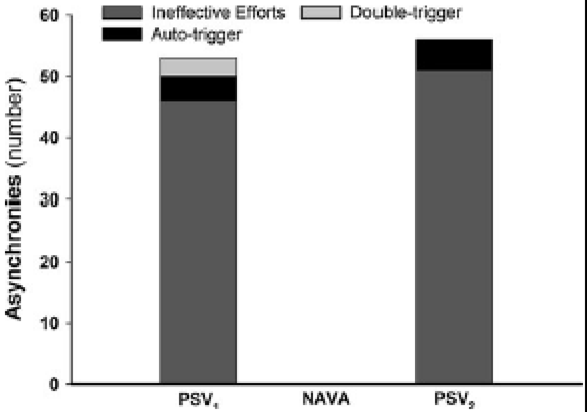
Rosanna Vaschetto
Davide Colombo
Emilia Turucz
Federico Longhini
Francesco Della Corte
Giorgio Conti
Paolo Navalesi

Noninvasive ventilation through a helmet in postextubation hypoxemic patients: physiologic comparison between neurally adjusted ventilatory assist and pressure support ventilation







N= 10 adult ICU
20 min NAVA vs PSV
Breathing comfort with VAS

Intensive Care Med
DOI 10.1007/s00134-012-2626-9

ORIGINAL

Lise Piquilloud
Didier Tassaux
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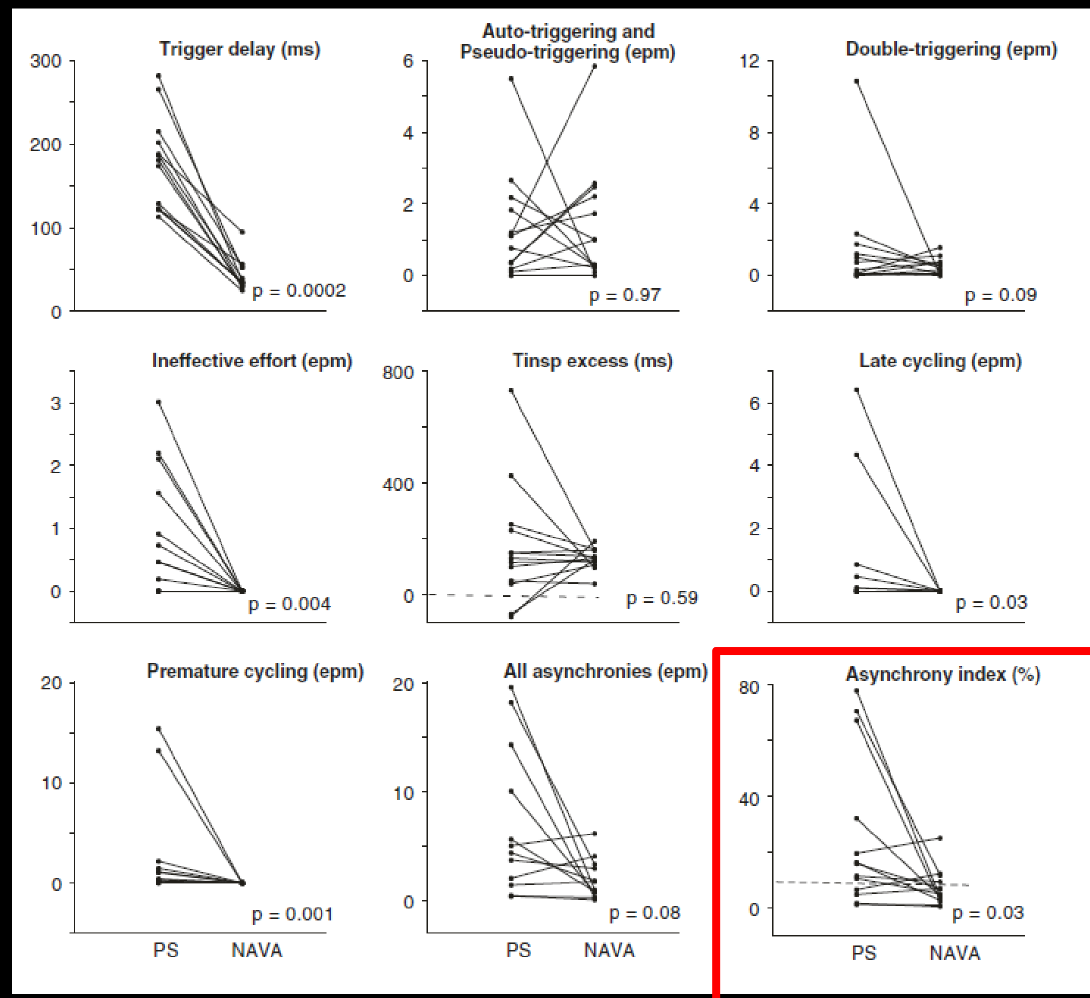
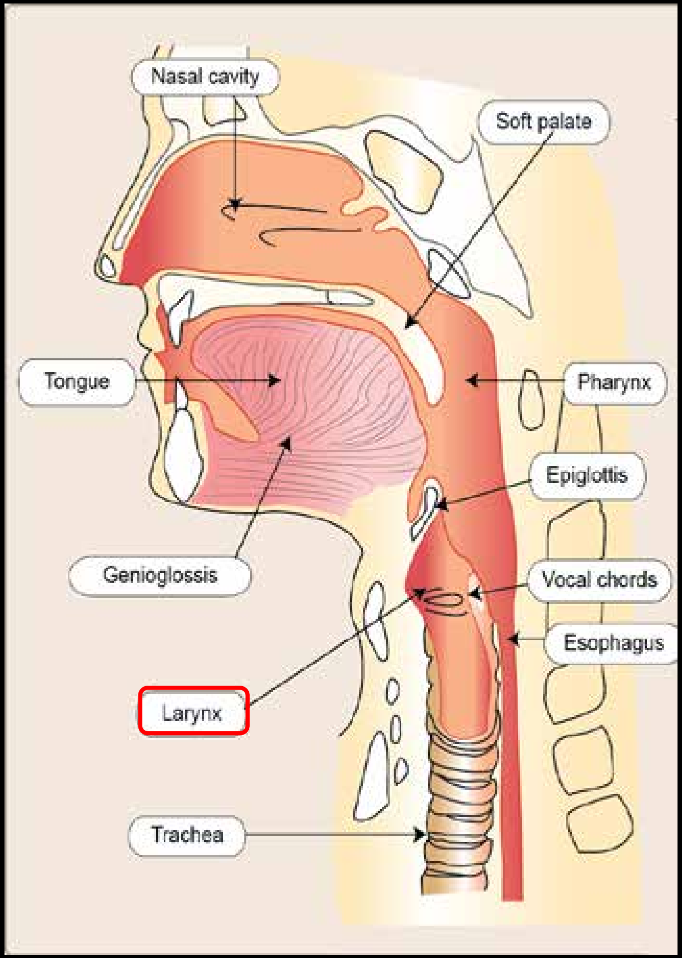
Jean Roeseler
Pierre-François Laterre
Philippe Jolliet
Jean-Pierre Revelly

Neurally adjusted ventilatory assist (NAVA) improves patient–ventilator interaction during non-invasive ventilation delivered by face mask



N= 13 Adult ICU (incl 2 COPD)
20 min NIV0NAVA, 20 MIN NIV PSV
Mask

Upper Airways

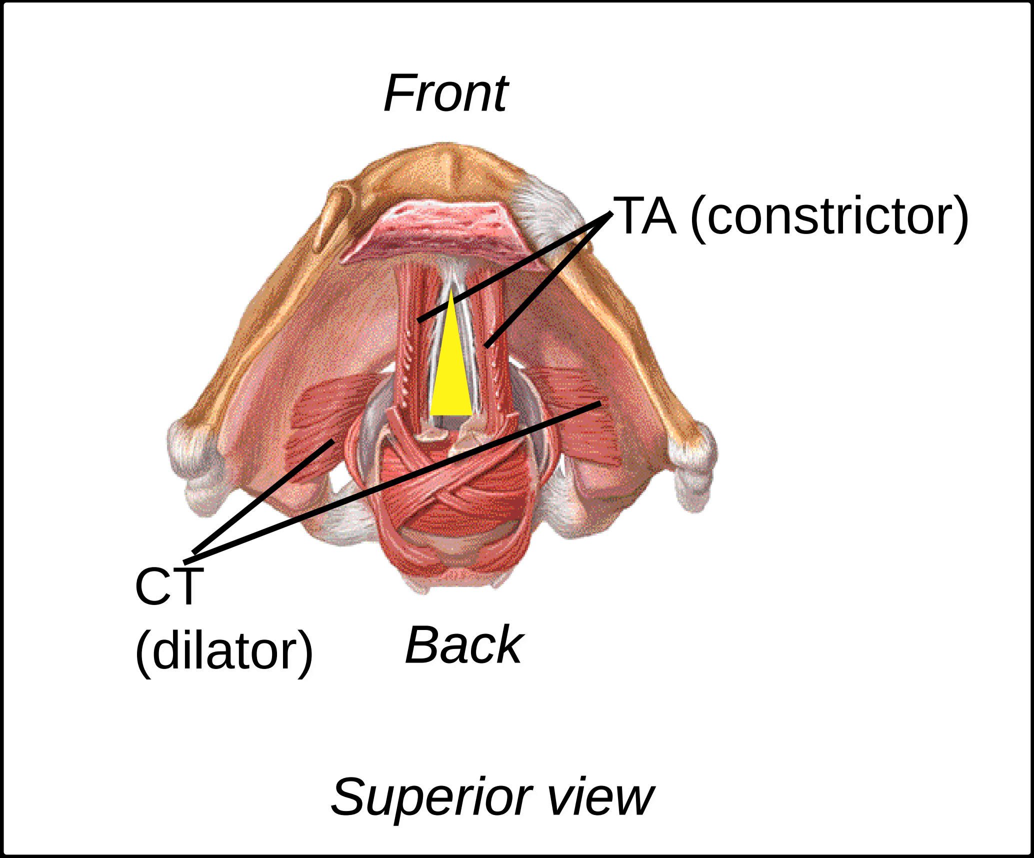


Role:

- Humidification
- Speech
- Swallowing
- Airway protection
- Airway dilation for inspiration
- Braking of expiratory flow to maintain EELV

Maquet Clinical Image Collection

Important Laryngeal Muscles

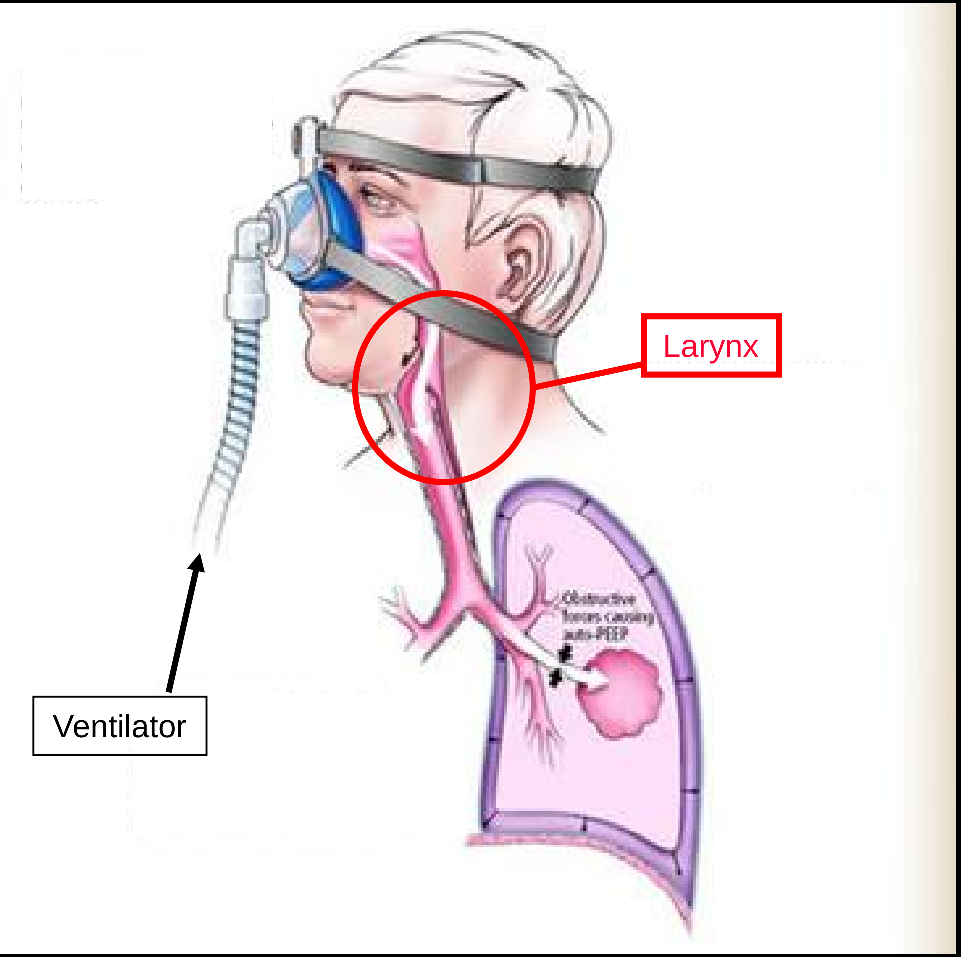


TA = Thyroarytenoid muscle

CT = Cricothyroid muscle

Larynx and NIV

- Larynx = a closing valve
- Original function = to defend the lower airways against potentially harmful intruders



Larynx and NIV

In adult humans : laryngoscopic observations

* Edi disappeared

é nIPPV levels

Laryngeal closure against ventilator insufflations

ê Lung ventilation
Gastric distension?

Jounieaux, J Appl Physiol, 1995

Larynx and NIV

In chronically instrumented newborn lambs

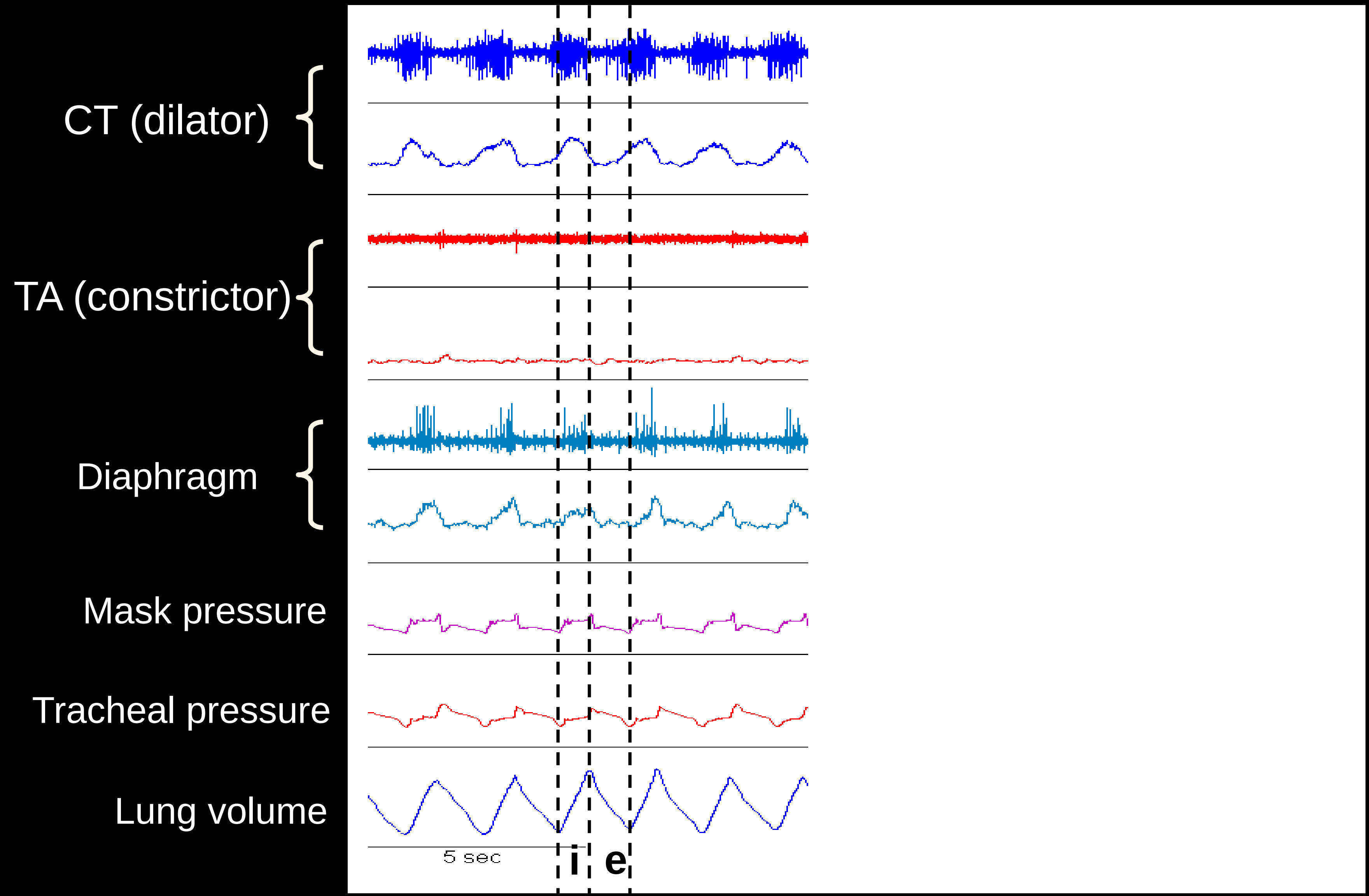
é nIPPV levels

é Laryngeal constrictor muscle EMG

Active laryngeal closure against ventilator insufflations

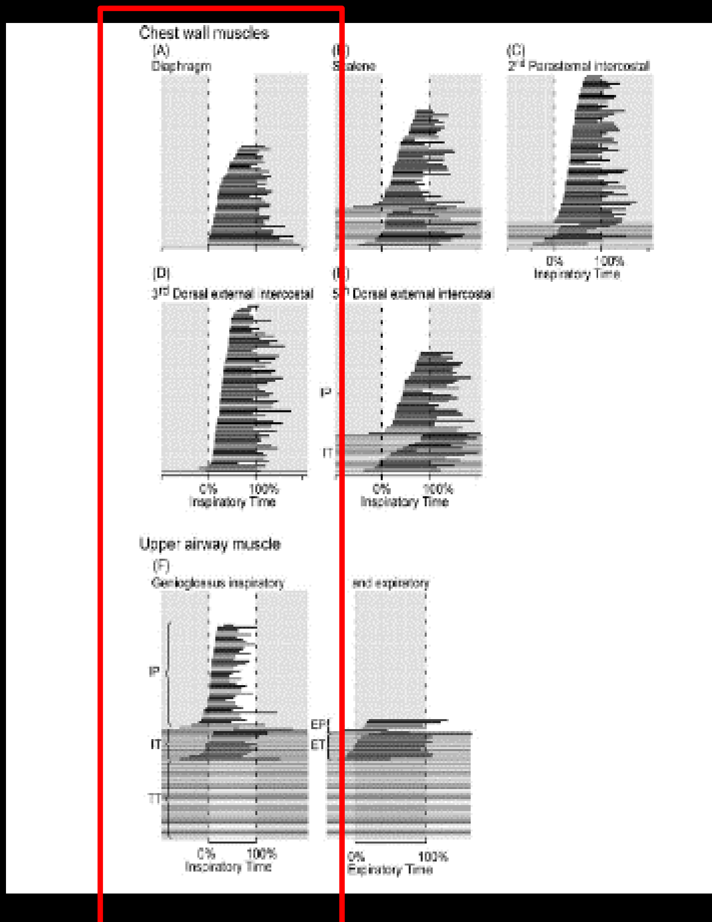
F Moreau- Bussière, J Appl Physiol 2007

CPAP 4 cm H_2O Pressure support 10/4 cm H_2O

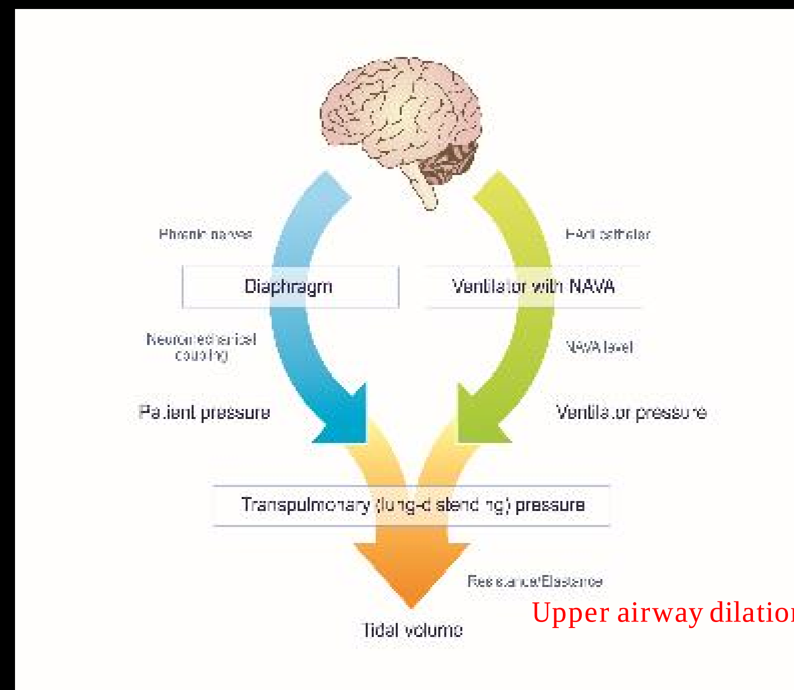


F Moreau- Bussière, J Appl Physiol 2007

Timing of Activation of Upper Airways



Butler Respir Physiol Neurobiol 2007



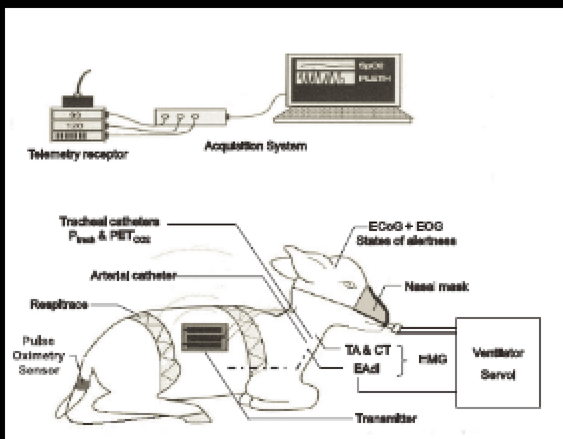
Principles and Practice of Mechanical Ventilation, M Tobin Ed.

Larynx during NIV-NAVA?

Hypothesis:

NIV-NAVA, offering a more physiological approach to assisting ventilation, would prevent activity of laryngeal constrictor muscle, contrary to nPSV

Experimental Design in Lambs



Day 2 : Surgery for chronic instrumentation

Days 3 – 4 : Post op recovery

Day 5 : increasing levels of nasal IPPV

PSV : 10/4, 15/4, 20/4 cmH_2O

vs. NAVA : 3 levels

Analysis

Glottal muscle EMG in quiet sleep

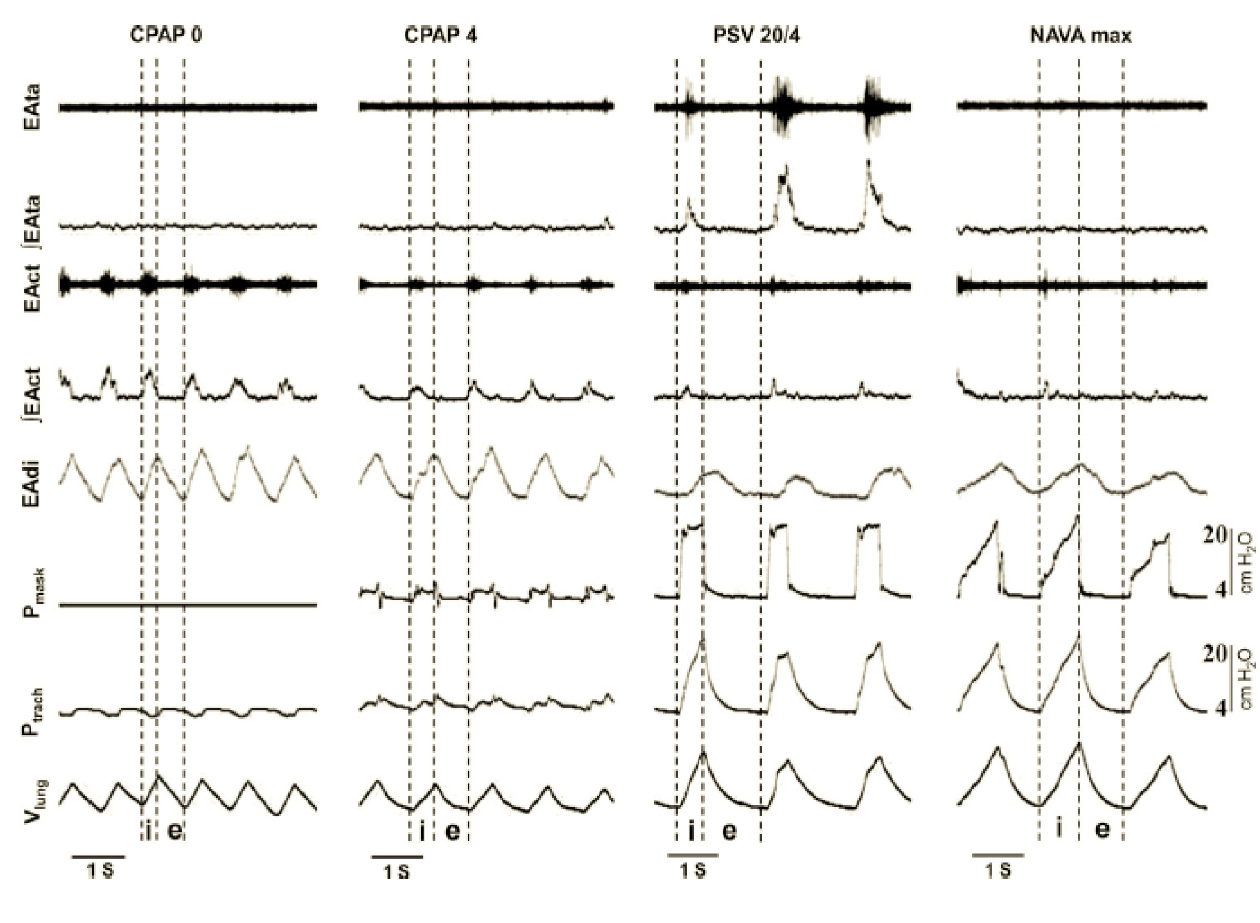
J Appl Physiol 113: 63–70, 2012.
First published April 19, 2012; doi:10.1152/japplphysiol.01496.2011.

Absence of inspiratory laryngeal constrictor muscle activity during nasal neurally adjusted ventilatory assist in newborn lambs

Mohamed Amine Hadj-Ahmed,[1] Nathalie Samson,[1] Marie Bussières,[2] Jennifer Beck,[3] and Jean-Paul Praud[1,2]

Glottal constrictor

Glottal dilator



J Appl Physiol 113: 63–70, 2012.
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Table 2. *Percentage of respiratory cycles with inspiratory phasic activity of the thyroarytenoid muscle and $PaCO_2$ during nasal pressure support ventilation or NAVA in lambs during quiet sleep*

	Nasal Pressure Support Ventilation						Nasal NAVA					
	10/4		15/4		20/4		NAVA 1		NAVA 2		NAVA max	
	%inspirEAta	$PaCO_2$	%inspirEAta	$PaCO_2$	%inspirEAta	$PaCO_2$	%inspirEAta	$PaCO_2$	%inspirEAta	$PaCO_2$	%inspirEAta	$PaCO_2$
Lamb 1	0	—	44	—	100	—	0	—	0	—	0	—
Lamb 2	51	40.5	57	40.5	100	36	0	41.5	0	46	0	41.5
Lamb 3	0	53.5	0	50	0	30.5	0	51.5	0	52.5	0	45
Lamb 4	0	38	0	43.5	0	38	0	42	0	45.5	0	40
Lamb 5	17	55	30	50.5	22	26.5	0	50.5	0	53.5	0	60
Lamb 6	0	35	33	30	62	29	0	38	0	35	0	31
Lamb 7	0	40.5	0	36.5	100	39.5	0	39.5	0	35.5	0	39.5
Lamb 8	0	45.5	0	49	0	44.5	0	49	0	46.5	0	46

%inspirEAta: percentage of ventilatory cycles with EAta.

Conclusions

- Using a controller signal that is not affected by leaks, can optimally synchronize the assist
- Both leak, and interface resistance will affect pressure delivery and may need an increase in NAVA level
- Edi useful for monitoring during NIV
- Upper airways and NIV are integrated and necessary!