Monitoring Neural Output

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Disclosure: Dr. Sinderby has made inventions related to neural control of mechanical ventilation that are patented. The license for these patents belongs to Maquet Critical Care. Use of this technology provides financial benefit to Dr. Sinderby through royalties. Dr Sinderby 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.
Conflict of interest

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Straight lines, periodic pattern, is seldom found in biological and physiological systems. Rather variability is weighty.
Phrenic Nerve
Golden Standard to measure "Neural respiratory drive"
The effects of end-tidal CO₂ on the discharge of individual phrenic motoneurones

By PRITAM K. GILL*

From the Department of Physiology, University of Utah College of Medicine, Salt Lake City, Utah, U.S.A.

(Received 20 June 1962)

The activity of single phrenic motoneurones was first studied by Adrian & Bronk (1928). The

Fig. 1. Response of a phrenic motoneurone at various levels of end-tidal CO₂. Upper trace, unit discharge; lower trace, tracheal CO₂ (%): the value of end-tidal CO₂ given numerically; calibration on left, % CO₂. A: inspired gas 3-9 % CO₂ in O₂; downward deflexion in CO₂ record below level in inspired gas was due to room air being drawn into sampling tube from open expiratory valve. B: inspired gas 100 % O₂. C: after ventilation was increased stepwise from level in B. D, E and F: in succession after a further stepwise increase in ventilation with 100 % O₂. Some spikes retouched.
Quantification of phrenic nerve activity (PNA).

Hakan S. Orer et al. J Appl Physiol 2006;101:521-530

Spontaneous activity of the costal diaphragm

Sinderby Unpublished observations
Trans-esophageal measurements of Diaphragm EMG (EMGdi) later
Diaphragm Electrical Activity (EA\textsubscript{di})

PETIT JM, MILIC-EMILI G, DELHEZ L.
New technic for the study of functions of the diaphragmatic muscle by means of electromyography in man.

Valid EAdi method using electrode array

Standardization document by the ATS and ERS

**Electrophysiologic Techniques for the Assessment of Respiratory Muscle Function**

Thomas K. Aldrich, Christer Sinderby, David K. McKenzie, Mark Estenne, Simon C. Gandevia, the American Thoracic Society, and the European Respiratory Society


Sinderby & Beck, Neurally Adjusted Ventilatory Assist in Principles and Practice of Mechanical Ventilation, Third Edition
Editor: Tobin MJ, McGraw-Hill Medical 2013
Measure
Neural Respiratory Drive
“EAdi Amplitude”

Temporo-spatial summation of motor unit action potentials
“firing rate and recruitment”

Fig. 7. Signal strength measurements as a function of intensity of muscle activity. Plot of RMS and full rectified average (FRA, y-axis) as a function of intensity (x-axis) in log scale.

What Affects Neural Drive

Effect of age

Characterization of Neural Breathing Pattern in Spontaneously Breathing Preterm Infants

JENNIFER BECK, MAUREEN REILLY, GIACOMO GRASELLI, HAI BO QUI, ARTHUR S. SLUTSKY, MICHAEL S. DUNN, AND CHRISTER A. SINDERBY

Keenan Research Centre in the Li Ka Shing Knowledge Institute [J.B., A.S.S., C.A.S.], St. Michael's Hospital, Toronto, Ontario M5B 1W8, Canada; Perinatal and Gynaecology Program [M.R.], Sunnybrook Health Sciences Centre, Toronto, Ontario M4N 3M5, Canada; Department of Experimental Medicine [G.G.], University of Milano Bicocca, 20090 Milano, Italy; Department of Critical Care Medicine [H.Q.], Nanjing Zhong-Da Hospital, Southeast University School of Medicine, Nanjing 210009, China; Department of Pediatrics [M.S.D.], University of Toronto, Toronto, Ontario M5G 1X8, Canada
EAdi in the Adult: Health and Disease
Unloading, HB reflex, Uncoupling, PVBC

Assessment of patient-ventilator breath contribution during neurally adjusted ventilatory assist in patients with acute respiratory failure


Ling Liu, Songqiao Liu, Jianfeng Xie, Yi Yang, Arthur S Slutsky, Jennifer Beck, Christer Sinderby, and Haibo Qiu

Graphs showing pressure-related changes with neurally adjusted ventilatory assist levels.
Sedation Monitor!
Monitoring Patient-Ventilator Interaction
Efficacy of ventilator waveforms observation in detecting patient–ventilator asynchrony

Davide Colombo, MD, PhD; Gianmaria Cammarota, MD; Moreno Alemani, MD; Luca Carenzo, MD; Federico Barra, MD; Rosanna Vaschetto, MD, PhD; Arthur S. Slutsky, MD; Francesco Della Corte, MD; Paolo Navalesi, MD

Conclusions: The ability of intensive care unit physicians to recognize patient–ventilator asynchronies was overall quite low and decreased at higher prevalence; expertise significantly increased sensitivity for breath-by-breath analysis, whereas it only produced a trend toward improvement for report analysis. (Crit Care Med 2011; 39:000–000)
Is a fixed level of assist enough?
Same patient 40 minutes apart

St-Michael’s Hospital, Campoccia et al, 2006
Keep the diaphragm going?
Or at least monitor if it is!

Diaphragm Dysfunction
(Force is reduced >48 hrs MV)

<table>
<thead>
<tr>
<th>Study</th>
<th>N</th>
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<tbody>
<tr>
<td>Normal values</td>
<td></td>
</tr>
<tr>
<td>Watson 2001</td>
<td>N=41</td>
</tr>
<tr>
<td>Cattapan 2002</td>
<td>N=19</td>
</tr>
<tr>
<td>Laghi 2003</td>
<td>N=13</td>
</tr>
<tr>
<td>Hermans 2010</td>
<td>N=10</td>
</tr>
<tr>
<td>Supinski 2013</td>
<td>N=57</td>
</tr>
</tbody>
</table>

Courtesy of Dr E Goligher
We are getting closer to count respiratory rate accurately!
Weaning readiness
Monitoring day-to-day

Spahija et al, Sacre Coeur Hospital, Montreal
SBT

RESEARCH
Open Access

Neuroventilatory efficiency and extubation readiness in critically ill patients
Ling Liu1, Huogen Liu1, Yi Yang1, Yingzi Huang1, Songqiao Liu1, Jennifer Beck2,3, Arthur S Slutsky2,4, Chirister Sinderby5,6 and Haibo Qi1

Results: Of 52 patients enrolled in the study, 35 (67.3%) were successfully extubated, and 17 (32.7%) were not. Patients for whom it failed had higher diaphragm electrical activity (ΔEAdi) and a lower efficiency to convert neuromuscular activity into inspiratory pressure and tidal volume (NVE; P < 0.001 and 0.33; P < 0.001), respectively. Neuroventilatory efficiency demonstrated the greatest predictability for weaning success.

Conclusions: This study shows that a mixed group of critically ill patients for whom weaning fails have increased neural respiratory drive and impaired ability to convert neuromuscular activity into tidal ventilation, in part because of diaphragm weakness.
Normal Edi values
“Normal” EAdi peak values
Intubated, Non-Invasive, No assist

![Graph showing EAdi peak values for different settings: INT, NIV, No Assist for Adult, PICU, NICU.](Image)
Frequency domain
EAdi Time vs Frequency Domain

EAdi power spectrum show fatigue

Changes in Respiratory Effort Sensation Over Time Are Linked to the Frequency Content of Diaphragm Electrical Activity

CHRISTER SINDBY, JADRANKA SPAHIJA, and JENNIFER BECK

Guy-Bernier Research Center, Maisonneuve-Rosemont Hospital, Department of Medicine, University of Montreal, Montreal, Quebec, Canada; Institution of Clinical Neuroscience, University of Göteborg, Göteborg, Sweden; Department of Medicine, University of Montreal; and Ste. Justine Hospital Research Center, Ste. Justine Hospital, Department of Pediatrics, University of Montreal, Montreal, Quebec, Canada

Figure 1. The relationship of changes in respiratory effort sensation (RES) to changes in diaphragm EAdi power spectrum center frequency (CFdi) over time during pressure (filled circles and crossed symbols) and volume (open circles) maneuvers in the six subjects studied. Symbols are values obtained at 0, 6, and 9 min after the start of each maneuver.

Figure 2. The relationship of changes in respiratory effort sensation (RES) to changes in diaphragm EAdi power spectrum center frequency (CFdi) over time during the pressure (filled circles) and volume (open circles) maneuvers in the six subjects studied. Symbols are values obtained at 0, 3, 6, and 9 min after the start of each maneuver.

Figure 3. The relationship of changes in respiratory effort sensation (RES) to changes in diaphragm EAdi power spectrum center frequency (CFdi) over time during the pressure (filled circles) and volume (open circles) maneuvers in the six subjects studied. Symbols are values obtained at 0, 6, and 9 min after the start of each maneuver.

Figure 4. Left panel shows group mean values with SD for respiratory effort sensation (RES) and diaphragm EAdi power spectrum center frequency (CFdi) at 0, 3, 6, and 9 min during the pressure (filled circles and solid line) and volume maneuvers (triangles and dotted line). The right panel demonstrates the relationship between changes in RES and changes in CFdi over time during both maneuvers.
If I had another hour

- Neural Respiratory Monitoring
  - Neuromuscular disorders
  - Cheyne Stoke
  - Delirium
  - Uncontrolled drive
  - Speaking, swallowing, vomiting…
Questions?

www.VentQuest.ca
Bedside measurements of "neural respiratory drive"
Respiratory pattern

ON THE REGULATION OF DEPTH AND RATE OF BREATHING

BY F. J. CLARK* AND C. VON EULER

From the Nobel Institute for Neurophysiology, Karolinska Institutet,
S-104 01 Stockholm 60, Sweden

(Received 28 June 1971)

5. In man during rebreathing, the relation between volume and inspiratory duration typically showed two different characteristics. 1, at tidal volumes up to 1-5–2 times eupnoic values, inspiratory duration did not change as tidal volume increased in response to increased $P_{CO_2}$. This range of operation has been designated range 1. 2, as tidal volume increased above this range 1 a second range designated range 2 was observed where inspiratory duration was volume dependent in the same manner as in the cat.

Fig. 10. From a human subject, the relation (a) between ventilation ($V_E$) and inspiratory volume ($V_l$), (b) between ventilation ($V_E$) and breathing rate $f$ and (c) between breathing rate ($f$) and inspiratory volume ($V_l$). The continuous lines were computed using the data from the experiments of Figs. 6 and 11a (see Table 1 for the equations).
100 ms Occlusion Pressure (P0.1)
100 ms Occlusion Pressure (P0.1) Weakness!!!

Dynamic hyperinflation Weakness


Diaphragm Dysfunction (Force is reduced >48 hrs MV)

Twitch Transdiaphragmatic Pressure (cm H2O)

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<thead>
<tr>
<th>Patient</th>
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Courtesy Dr E Goligher
Esophageal & Transdiahragmatic Pressures

• Is Neural Drive linked to Pes and Pdi?
Weakness!!!

Dynamic hyperinflation


Diaphragm Dysfunction
(Force is reduced >48 hrs MV)

Courtesy Dr E Goligher
Esophageal & Transdiaphragmatic Pressures

Proportional assist abolish Pes and Pdi but not Edi!

<table>
<thead>
<tr>
<th>NAVA unloading</th>
<th>Maximal unloading with maintained Edi</th>
</tr>
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<tbody>
<tr>
<td><strong>NAVA level</strong></td>
<td>Zero</td>
</tr>
<tr>
<td>Edi (%)</td>
<td></td>
</tr>
<tr>
<td>Volume (L)</td>
<td></td>
</tr>
<tr>
<td>Pvent (cm H2O)</td>
<td></td>
</tr>
<tr>
<td>Pes &amp; Pdi (cm H2O)</td>
<td>5s</td>
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Surface EMG

**Figure 1.** The placements of surface EMG electrodes for recording the right costal diaphragmatic and external intercostals.

*From: Sensors 2008, 8, 2174-2187*
Surface EMG

”Not for everyone”

Cross-talk
Inspiratory/Expiratory/Postural muscles

Electrode-to-muscle distance filtering
Needle EMG of the diaphragm

- Relatively standardized
- Specific to few motor units
- Not for long term monitoring of neural respiratory drive