High Velocity Nasal Insufflation (Hi-VNI™)
Emergency Medicine Application

Kansas Society for Respiratory Care
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Wichita, Kansas
Disclosure & Background

- Brent Ryherd, BSRT, RRT-NPS
  Area Clinical Manager
  St. Louis Territory

- Employee of Vapotherm, Inc.,
  Exeter, NH
Learning Objectives

• Discuss the Emergency Medicine application of High Velocity Nasal Insufflation

• Understand High Velocity Nasal Insufflation Mechanisms of Action

• Learn how to implement a High Velocity Nasal Insufflation Protocol – including identify the appropriate patients

• Review current supporting clinical data
The History of High Flow Therapy
Can’t Breathe!
Continuum of Care

• **High Flow Nasal Cannula**
  
  – Oxygen therapy that delivers high flows through a nasal cannula.

• **High Velocity Nasal Insufflation**
  
  – High Flow and High Velocity
    • Refined form of HFNC
  – Improves ventilation efficiency
  – Reduces work of breathing
  – Delivers a specific FIO2
Patient Example: Congestive Heart Failure

66 year old CHF Patient

<table>
<thead>
<tr>
<th>Time</th>
<th>HR (bpm)</th>
<th>RR(Br/min)</th>
<th>SpO₂ (%)</th>
<th>BP (mmHg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10:25</td>
<td>71</td>
<td>28</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td>10:28</td>
<td>68</td>
<td>28</td>
<td>86</td>
<td></td>
</tr>
<tr>
<td>10:46</td>
<td>68</td>
<td>28</td>
<td>86</td>
<td>157/73</td>
</tr>
<tr>
<td>10:53</td>
<td>66</td>
<td>26</td>
<td>91</td>
<td>152/72</td>
</tr>
<tr>
<td>10:58</td>
<td>66</td>
<td>26</td>
<td>89</td>
<td>142/71</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11:10</td>
<td></td>
<td></td>
<td>Hi-VNI™</td>
<td>initiated 25 LPM - 100%</td>
</tr>
<tr>
<td>11:11</td>
<td>67</td>
<td>22</td>
<td>92</td>
<td>123/75</td>
</tr>
<tr>
<td>11:17</td>
<td>63</td>
<td>22</td>
<td>96</td>
<td>130/59</td>
</tr>
<tr>
<td>11:24</td>
<td>66</td>
<td>24</td>
<td>97</td>
<td>118/64</td>
</tr>
</tbody>
</table>

15 L/min from the wall oxygen supply initiated. An ABG & clinical observation that this therapy did not alleviate dyspnea or hypoxemia. The patient was switched from the Salter cannula to Vapotherm (25 L/min and 100% oxygen).
Patient Example: COPD Exacerbation

A 60 year-old patient with history of COPD, having been intubated in the past month for a COPD exacerbation, arrived in the Emergency Department at Athens Regional Medical Center. Initial assessment noted tachypnea with nasal flaring and purse lipped breathing, as well as bilateral wheezing and wet cough.

<table>
<thead>
<tr>
<th>HR</th>
<th>RR</th>
<th>pH</th>
<th>PaCO₂</th>
<th>PaO₂</th>
<th>HCO₃</th>
<th>SaO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>124</td>
<td>36</td>
<td>7.28</td>
<td>74</td>
<td>78</td>
<td>34</td>
<td>93</td>
</tr>
</tbody>
</table>

What therapy would you typically initiate?

A. Non-rebreather
B. Bi-level
C. Mechanical Ventilation
D. High Flow Support
## Patient Response

<table>
<thead>
<tr>
<th>Time</th>
<th>HR</th>
<th>RR</th>
<th>pH</th>
<th>PaCO₂</th>
<th>PaO₂</th>
<th>HCO₃⁻</th>
<th>O₂ Hb</th>
<th>SaO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>6:08</td>
<td>124</td>
<td>36</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>97</td>
</tr>
<tr>
<td><strong>6:29</strong></td>
<td><strong>ABG Drawn and Hi-VNI™ Initiated at 25 L/min 60% FiO₂</strong></td>
<td><strong>6:30</strong></td>
<td><strong>7.28</strong></td>
<td><strong>74</strong></td>
<td>78</td>
<td>34</td>
<td>91</td>
<td>93</td>
</tr>
<tr>
<td>6:43</td>
<td>123</td>
<td>27</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>94</td>
</tr>
<tr>
<td>6:53</td>
<td>120</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>95</td>
</tr>
<tr>
<td>7:03</td>
<td>113</td>
<td>24</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>96</td>
</tr>
<tr>
<td>7:13</td>
<td>22</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>96</td>
</tr>
<tr>
<td>7:17</td>
<td></td>
<td></td>
<td>7.41</td>
<td>53</td>
<td>68</td>
<td>33</td>
<td>91</td>
<td>94</td>
</tr>
</tbody>
</table>

- RR quickly dropped
- pH Increased
- PaCO₂ Decreased
- **Acute Respir. Acidosis w chronic respir. failure**

Hi-VNI avoided an ICU admission and more invasive respiratory modalities
Mechanisms of Action
Respiratory Physiology and Ventilation

• At least 30% of inspired tidal volume is anatomical dead space

• At start of inspiration anatomical dead space is filled with expiratory CO₂

• Dead-space volume and gas composition impact breathing efficiency and ventilation
High Velocity Nasal Insufflation (Hi-VNI)

Optimally heated & humidified gas via a small-bore nasal cannula flushes dead space of expiratory gas, creating a reservoir that facilitates oxygenation & alveolar ventilation.
Ventilation Efficiency – Alveolar Ventilation

Minute Ventilation = Tidal Volume x Respiratory Rate

Alveolar Ventilation = (Tidal Volume – Dead Space) x Respiratory Rate

Alveolar ventilation improves with a reduction in dead space volume independent of tidal volume and respiratory rate

Alveolar Ventilation
Volume of gas made available to the respiratory region of the lungs per minute
Requirements for Effective Therapy

- Nares are not obstructed
- Adequate flow and velocity to flush dead space
- Patient is spontaneously breathing

Facilitates CO₂ ventilation by reduction of dead space
High Flow Fluid Dynamics
Flow and Circuit Design & Physiologic Impact
Velocity, at a constant volume of flow, varies inversely with the cross sectional area of a tube.

Velocity = Distance/Time

Volume of Flow = 5 L/min → 5 L/min → 5 L/min →

Velocity = 16.4 cm/sec
A = 5.08 cm²

Velocity = 32.8 cm/sec
A = 2.54 cm²

Adult Cannula Flow Velocity Comparison

![Graph showing the comparison of velocity (m sec\(^{-1}\)) and volumetric flow (L min\(^{-1}\)) for Small-Prong and Large-Bore cannulas. The graph illustrates the linear relationship between velocity and volumetric flow for each type of cannula.]
Prong Size Also Dictates Efficiency of Expiratory Gas Egress

The small-bore cannula allows greater opening for expiratory gas egress.
Prong Size Dictates Flow Velocity

Gas velocity impacts efficiency of expiratory gas flush from the dead space.

Small-Prong Cannula

Large-Bore Cannula

Note: CFD model assumes an open mouth.
Time to Flush is a Function of Respiratory Rate

![Graph showing the relationship between Respiratory Rate and Expiratory Phase (seconds). The graph indicates that as Respiratory Rate increases, Expiratory Phase decreases. The dotted line marks the threshold for Adult Respiratory Distress.]
Optimal Gas Conditioning
High Flow Requires Optimal Humidity & Temperature
What is Humidity?

- The given amount of water vapor in the air at a specific temperature
- As the temperature increases, so does the amount of water vapor a given volume of air can hold, also called saturated capacity

<table>
<thead>
<tr>
<th></th>
<th>22º C</th>
<th>30º C</th>
<th>37º C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saturated Capacity</td>
<td>18 mg/L</td>
<td>32 mg/L</td>
<td>44 mg/L</td>
</tr>
</tbody>
</table>
What is Absolute Humidity?

Absolute Humidity is the actual water vapor content of a given volume of air.
What is Relative Humidity?

Relative humidity is the percent of water vapor content of the saturated capacity at a given temperature.

<table>
<thead>
<tr>
<th></th>
<th>22°C</th>
<th>30°C</th>
<th>37°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saturated Capacity</td>
<td>18 mg/L</td>
<td>32 mg/L</td>
<td>44 mg/L</td>
</tr>
<tr>
<td>Absolute Humidity</td>
<td>18 mg/L</td>
<td>18 mg/L</td>
<td>18 mg/L</td>
</tr>
<tr>
<td>Relative Humidity</td>
<td>100%</td>
<td>54%</td>
<td>39%</td>
</tr>
</tbody>
</table>
Proper Gas Conditioning is Critical to Hi-VNI Tolerance & Airway Health

Physiologic state of gas in the lungs:

- **37 C**
- **Or**
- **100% Relative Humidity**
- **(44mg H₂O/L)**

Suboptimal Humidification Results in Mucociliary Dysfunction

Mucosal Function vs. Inspired Humidity

Delivery of Optimal Humidification


Mitigating Rainout

Heated Wire

Water Jacket
IS IT HUMID TODAY?

IT FEELS A BIT HUMID TO ME
Patient Selection & Protocol Implementation
Who are the right Patients?

<table>
<thead>
<tr>
<th>Symptoms</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Dyspnea</td>
<td>Acute COPD Exacerbation</td>
</tr>
<tr>
<td>Bi-level intolerant</td>
<td>Mild/Moderate Congestive Heart Failure</td>
</tr>
<tr>
<td>Hypercapnia</td>
<td>Asthma</td>
</tr>
<tr>
<td>Refractory Hypoxemia</td>
<td>Pneumonia</td>
</tr>
<tr>
<td>Increased cardiac workload</td>
<td>Bronchitis</td>
</tr>
<tr>
<td>Increased Work of Breathing</td>
<td>Bronchiolitis (RSV)</td>
</tr>
<tr>
<td></td>
<td>Influenza</td>
</tr>
</tbody>
</table>
Keep in mind...

- Patients must be:
  - Spontaneously Breathing
  - Alert & Oriented
  - Able to Protect Airway
Choose the Appropriate Interface

- Cannula should be sized not to occlude greater than 50% of the nares
- Cannula prongs should be spread enough not to pinch the nasal septum
- Allow the system to reach at least 33°C before connecting delivery tube to the cannula
Patient Application Guidelines

Start flow high and go low – Hi-VNI is a de-escalation therapy

Clinical Use Guidelines
Assess these parameters to determine therapy initiation:

- \( \text{PaO}_2 < 80 \text{ mmHg} \)
- \( \text{SaO}_2 < 90\% \)
- \( \text{PaCO}_2 > 45 \text{ mmHg} \)
- Tachycardia
- Tachypnea

<table>
<thead>
<tr>
<th>Hypercarbia (increased WOB)</th>
<th>Start</th>
<th>Titrate to Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{FLOW} )</td>
<td>40 L/min</td>
<td>Titrate to effect comfort/ventilatory effect</td>
</tr>
<tr>
<td>( \text{FiO}_2 )</td>
<td>35%</td>
<td>Desired ( \text{SpO}_2 )</td>
</tr>
<tr>
<td>( \text{TEMP.} )</td>
<td>37°C</td>
<td>Comfort/secretion mobilization</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hypoxemia</th>
<th>Start</th>
<th>Titrate to Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{FLOW} )</td>
<td>40 L/min</td>
<td>Comfort/ventilatory effect</td>
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<td>( \text{FiO}_2 )</td>
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<td>( \text{TEMP.} )</td>
<td>37°C</td>
<td>Comfort/secretion mobilization</td>
</tr>
</tbody>
</table>
IF YOU COULD CHECK IF THE CANNULA IS CONNECTED BEFORE CALLING ME...

YEAH...THAT BE GREAT
Relevant Clinical Research
# High-Flow Oxygen Adult Study


<table>
<thead>
<tr>
<th>Group</th>
<th>Flow / Pressure</th>
<th>FiO₂</th>
<th>Duration / Application</th>
<th>Outcome: Intubation Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mask</td>
<td>13 L/min 100% O₂</td>
<td>&gt; 0.80</td>
<td>Continuous or until recovery or intubation</td>
<td>47%</td>
</tr>
<tr>
<td>HFNC</td>
<td>48 L/min</td>
<td>0.82</td>
<td>Continuously for at least 2 days</td>
<td>38%</td>
</tr>
<tr>
<td>NIPPV</td>
<td>PIP/PEEP 8/5 cmH₂O</td>
<td>0.67</td>
<td>8 hr /day for at least 2 days; HFNC between applications</td>
<td>50%</td>
</tr>
</tbody>
</table>

- Patients admitted to the ICU in respiratory distress
- Patients excluded for hypercapnia
- Underwent randomization

4,777

- Patients admitted to the ICU in respiratory distress

582

- Patients excluded for hypercapnia

313

- Underwent randomization
Memorial Herman Poster Data

High Flow Therapy In The Emergency Department - A Paradigm Shift?
R Graham RRT1, B Melton RRT1, S Croft RRT1, T Green RRT1, O Easton RRT1, B Bauer RRT1, P Doshi MD2
1Memorial Hermann Healthcare System, Houston, TX 2UT-Houston Medical School, Houston, TX

Abstract
It was determined that the first trial of using our working hypothesis would be to assess both patient and provider acceptance of and a concomitant response to HFT in the ED. We developed a technical assessment form (TAF) as the instrument for data collection (Figure 1), with a technical assessment of the device (Nasal Versus Oxygen Flow, Better ENH as our primary endpoint). We prospectively collected these assessments on patients deemed appropriate for HFT by the ED physician as part of usual Care/Assurance activities. Patients presenting with COPD and/or other diagnoses with risk factors for HFT were targeted. Our health care system has 12 facilities with 10 EDs; 3 EDs participated in the study.

Methods
A total of 6 Technical Assessment Forms were completed by the three investigators, with percentage criteria, as follows (Figure 2):
- COPD: AEC (30.6%)
- CHF (14.3%)
- Other (14.0%)
- Pneumonia: (33.3%)
- General/Upper Respiratory Infections: (33.3%)
- Barotrauma: (14.0%)
- Other: (14.0%)

Results (Continued)
- 3 patients (12%) were discharged home from the ED
- 3 patients (12%) required HFT administration
- 14 patients (60%) admitted to the floor

Discussion

Conclusions

Figure 1. Technical Assessment Form

Figure 2. Initial Diagnosis

Figure 3. Technical Assessment Scoring Results

Figure 4. Knows Patient Disposition

Background
The use of HFT in treatment of respiratory distress, especially related to COPD and/or CHF in the ED, has become widely accepted. A number of centers may ultimately be contemplating the implementation of this new technology (i.e., Hyperbaric Oxygen Therapy) (HBOT) for the treatment of respiratory distress. However, despite the impressive technology, patient improvement varies and adequate framework for delivery of HFT remains somewhat less than enthusiastic. This leads to failed trials in many centers using HBOT, which may be explained in part by a treatment plateau for HBOT patients to achieve a plateau, and then a plateau to achieve a plateau. The goal of both HFT and HBOT is to support oxygenation and assist with removal of CO2. Integration of a technical assessment form that provides these clinical benefits but offers safer patient tolerance may provide better opportunity for treatment success. The early adoption of HBOT (HFT) may offer this potential.

HFT has been shown to decrease the work of breathing (WOB) and improve physiologic deadspace (VDS), and is widely used in the Intensive Care Unit (ICU). Our study indicates that HFT is superior to standard High Flow Oxygen delivery after extubation. Our group has developed a working hypothesis that early application in the Emergency Department (ED) may appear not only the need for HFT, but may also minimize extubation rates, especially in cases of mild to moderate respiratory distress. Many institutionspecific policies mandate admission with high flow O2 or nasal CPAP. Our hypothesis is that, true, if number of previous ICU admissions might be reduced, reducing ED wait times and ICU admissions.

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- Other: (14.0%)

Discussion
Our work has recognized limitations, and was not intended to formulate defensive clinical conclusions. We intended to determine whether or not application of HFT in an ICU setting would improve outcomes. Our findings suggest that HFT is associated with improved outcomes. Patients survived much longer than patients on NIV. Survival rate was significantly more with HFT and significantly less with NIV. Our findings of increased ICU admission would appear to be significant, as these patients would have to require an ICU stay if HFT was avoided.

The paradigm shift that has arisen is in thinking about an old problem in a new way. Emergency Departments across the US face difficulties in this area, cited for staff and for beds. ED wait times are a source of constant patient complaint. Committing to NIV and/or HFT can determine the hospital course, and usually involves an ICU admission. The scenario of staff and visiting staff is repeated often.

There are a number of definitions of ventilation, including the use of PEEP and PwCO2 driven HFT. The derivation and success of application of NIV in HFT may significantly impact patient disposition, as well as time spent in ICU. Planned changes to emergency, especially in the area of COPD and hospitalization, will have a profound impact on care delivery of patients considered for HFT.

At least, HFT appears to offer a readily available, well tested method of adding oxygenation to patients that may quickly offer a patient a positive outcome. It also appears that at least some cases HFT may offer symptom relief of dyspnea comparable to NIV.

Conclusions

Our group currently in the first stages of designing a RCT to address a growing non-inferiority of HFT to NIV. We hope to present these findings at the earliest opportunity.

*The authors thank Dr. Mark McIlvan for his editorial assistance.
Initial Presumed Diagnosis

- COPD: 31%
- CHF: 11%
- Asthma: 14%
- General Dyspnea: 6%
- Pulmonary Fibrosis: 3%
- Sarcoidosis: 3%
- Other: 3%
- Pneumonia: 3%

COPD

Pneumonia

Asthma

General Dyspnea

Pulmonary Fibrosis

Sarcoidosis

Other
Disposition Decision

**Known Disposition**

<table>
<thead>
<tr>
<th>Disposition</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discharged Home</td>
<td>12%</td>
</tr>
<tr>
<td>ICU Admission</td>
<td>32%</td>
</tr>
<tr>
<td>Floor Admission</td>
<td>56%</td>
</tr>
</tbody>
</table>
Multicenter Emergency Dept. Experience

- Data from 6 centers compiled in publication with 128 forms
  - Athens Regional Medical Center, Athens GA
  - Memorial Hermann – TMC, Houston TX
  - Memorial Hermann – Northeast, Humble TX
  - Memorial Hermann – The Woodlands, TX
  - Erlanger Health System, Chattanooga, TN
  - Missions Hospital, Asheville, NC

- Demonstrated clinical & economic benefits
- Expertise and clinical pathways for use (protocol developed)
Initial Presumed Diagnosis

- COPD
- General Dyspnea
- CHF
- Pneumonia
- Asthma
- Overdose
- Sarcoidosis
- Unreported
Initial Respiratory Assessment

- Increased WOB
- Combined Failure
- Hypercapnia
- Hypoxemia
Disposition Decision

<table>
<thead>
<tr>
<th>Known Disposition</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICU</td>
<td>41%</td>
</tr>
<tr>
<td>General Care Floor</td>
<td>54%</td>
</tr>
<tr>
<td>Discharged Home</td>
<td>5%</td>
</tr>
</tbody>
</table>
Summary

- HiVNI is able to flush expiratory gas from the dead space to facilitate oxygenation and alveolar ventilation
- HFNC is primarily an oxygen therapy
- Patient comfort and adherence are optimal with Hi-VNI when compared to conventional respiratory modalities
- HiVNI may be used in the Emergency Department with patients in respiratory distress and/or impending respiratory failure