Respiratory – The failing Lung

The future of NIV

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The Future of NIV

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“CPAP is no longer a new therapy, nor, alas is the strapped positive-pressure breathing mask a new device. It is rather, as antiquated as it is inhumane and unsafe….. A patient who is sick enough to need CPAP is sick enough to need an endotracheal tube.”

Former editor-in-chief of Respiratory Care, 1977
Timeline for History of Non-Invasive Ventilation

The Future of Non-Invasive Ventilation

• Clinical uses
  – New guidelines (BTS/ICS guidelines for acute hypercapnic respiratory failure in adults – March 2016)
  – Expanding indications for chronic hypercapnic respiratory failure
  – Additional use acutely for non-acidotic CHRF with NMD, CWD
  – Organisational aspects of delivery of NIV acutely
  – Understanding limitations of NIV use

• Technical advancements
  – NIV machines designed for acute and chronic applications
  – Newer modes of ventilation

• Advancements in mask interfaces
  – Helmet vs facemasks
  – Nasal High Flow systems

• Extracorporeal circuits..............ECCO₂R
Physiological effect of CPAP and NIV in ALI-ARDS

- 10 patients with indications for acute for NIV
- Short-term cross-over effects of:
  - CPAP 10 cmH₂O
  - 2 combinations of NIV: PSV 10–PEEP 10; PSV 15-PEEP 5

Respiratory rate

<table>
<thead>
<tr>
<th></th>
<th>Initial</th>
<th>CPAP-10</th>
<th>PSV 10-10</th>
<th>PSV 15-5</th>
<th>Final</th>
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<tbody>
<tr>
<td>Rate</td>
<td>26</td>
<td>28</td>
<td>30</td>
<td>32</td>
<td>34</td>
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PaO₂/FiO₂

<table>
<thead>
<tr>
<th></th>
<th>Initial</th>
<th>CPAP-10</th>
<th>PSV 10-10</th>
<th>PSV 15-5</th>
<th>Final</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td>120</td>
<td>150</td>
<td>180</td>
<td>210</td>
<td>240</td>
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</tbody>
</table>

*L ’Her E. Am J Respir Crit Care Med 2005;172:1112-8*
CPAP and NIV in ALI-ARDS: Work of breathing, neuromuscular drive and dyspnoea

- PSV + PEEP is reduces inspiratory muscle effort
- CPAP improves oxygenation but does not unload respiratory muscles
- PSV levels of 10 and 15 cmH$_2$O provide similar unloading but differ in their effects on dyspnoea

L’Her E et al. Am J Respir Crit Care Med 2005;172:1112-8
Introduction

- Patients with AHRF are not receiving optimal therapy:
  - BTS NIV audit reports 2011-13
  - Acidosis, non-invasive ventilation and mortality in hospitalised COPD exacerbations. Thorax 2011

- “provision of NIV is often poorly performed, patients not treated until acidosis severe and some patients inappropriately denied admission to the ICU”  Better Lung Health for All
BTS/ICS Guidelines for the ventilatory management of acute hypercapnic respiratory failure in adults

- Start NIV early when pH<7.35, PaCO2 >6.5kPa, RR >23
- Consider NIV in absence of acidosis in hypercapnic NMD or CWD
- Do not delay NIV or continue if deteriorating as both increase mortality
- NIV should not delay escalation to IMV if indicated
- Clinicians underestimate survival potential in AHRF treated by IMV
- A care environment with level 2 equivalence improves outcome of NIV
- Ward based care risks greater delay to senior review and escalation to IMV
Risk stratification of NPPV failure was assessed in 1,033 consecutive patients admitted to experienced hospital units, including two intensive care units, six respiratory intermediate care units, and five general wards. NPPV was successful in 797 patients.

<table>
<thead>
<tr>
<th>GCS 15</th>
<th>pH admission &lt;7.25</th>
<th>pH admission 7.25–7.29</th>
<th>pH admission &gt;7.30</th>
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<tbody>
<tr>
<td>RR</td>
<td>APACHE ≥29</td>
<td>APACHE &lt;29</td>
<td>APACHE ≥29</td>
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<tr>
<td>&lt;30</td>
<td>29</td>
<td>11</td>
<td>18</td>
</tr>
<tr>
<td>30–34</td>
<td>42</td>
<td>18</td>
<td>29</td>
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<tr>
<td>≥35</td>
<td>52</td>
<td>24</td>
<td>37</td>
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<td>GCS 12–14</td>
<td>pH admission &lt;7.25</td>
<td>pH admission 7.25–7.29</td>
<td>pH admission &gt;7.30</td>
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<td>&lt;30</td>
<td>48</td>
<td>22</td>
<td>33</td>
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<tr>
<td>30–34</td>
<td>63</td>
<td>34</td>
<td>48</td>
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<tr>
<td>≥35</td>
<td>71</td>
<td>42</td>
<td>57</td>
</tr>
<tr>
<td>GCS ≤11</td>
<td>pH admission &lt;7.25</td>
<td>pH admission 7.25–7.29</td>
<td>pH admission &gt;7.30</td>
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<tr>
<td>&lt;30</td>
<td>64</td>
<td>35</td>
<td>49</td>
</tr>
<tr>
<td>30–34</td>
<td>76</td>
<td>49</td>
<td>64</td>
</tr>
<tr>
<td>≥35</td>
<td>82</td>
<td>59</td>
<td>72</td>
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</tbody>
</table>

FIGURE 2. Failure risk chart of noninvasive positive pressure ventilation at admission (the values in the table correspond to the percentage of patients who fail in each category). ■ 0–24%; □ 25–49%; △ 50–74%; ▲ 75–100%. RR: respiratory rate; APACHE: acute physiology and chronic health evaluation II score; GCS: Glasgow Coma Scale.
### FIGURE 3. Failure risk chart of noninvasive positive pressure ventilation after 2 h (the values in the table correspond to the percentage of patients who fail in each category). Light green, 0–24%; yellow, 25–49%; orange, 50–74%; red, 75–100%. RR: respiratory rate; APACHE: acute physiology and chronic health evaluation II score; GCS: Glasgow Coma Scale.
Acute NIV – late failures

- n=137 Acute exacerbations of COPD
- 23% deteriorated after 48 hours
- Mortality IMV 53%, continuing NIV 92%
- (NIV group pH 7.1 IMV 7.29)
- Late failure predicted by low ADL scores, pH and co-morbidity at admission

Chandra et al. Am J Respir Crit Care Med 2012;185(2):152-159
NMD & Ventilatory Failure

- Alveolar hypoventilation
  - Hypoxia
  - Hypercapnia

- Hypoxia

- Hypercapnia
  - Pulmonary Hypertension
  - Right heart failure

- Death

Non-invasive ventilation
Limitations of NIV use
In Hypoxaemic Respiratory Failure

Low Tidal Volume Ventilation (6ml/kg or less)

Low – Moderate PEEP

Higher PEEP

EcMO
ECCO₂-R
HFO
iNO
Neuromuscular Blockade
Prone Positioning

Increasing Severity of Lung Injury

Mild ARDS
Moderate ARDS
Severe ARDS

Increasing Intensity of Intervention

PaO₂/FiO₂
Hypoxaemic Respiratory Failure: predictors of failure of NIV

Role of Non-invasive Ventilation in Acute Respiratory Distress Syndrome: Proportion Meta-analysis

Agarwal R et al Respir Care 2010;55(12):1653–1660

Intubation rate (50%)  Mortality rate (45%)
The Machines
NIV Equipment Developments

• Size / portability for home setting
• User friendly touch screen technology
• Pressure range – IPAP 50 and above
• Modes
  – PSV/PCV (assist control)/ VCV +......
  – Volume assured pressure support (AVAP, AVAPS -AE, iVAPS)
• Patient – Ventilator Synchrony
  – Automatic leak compensation, inspiratory triggering and expiratory cycling
• Battery technology (Internal/External)
• Turbine technology for acute setting – high flow rates
  – Oxygen blenders
PtcCO2 during the night at baseline, and during therapy with CPAP, BPV-S/T, and BPV-S/T-AVAPS

Storre, J. H. et al. Chest 2006;130:815-821
Table 2: Evolution of blood gases, vital signs, and ventilatory parameters (mean ± SD)

<table>
<thead>
<tr>
<th>Variables</th>
<th>Groups</th>
<th>Initial</th>
<th>1 hour</th>
<th>3 hours</th>
<th>12 hours</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BIPAP S/T</td>
<td>83 ± 14</td>
<td>9.7 ± 2</td>
<td>12 ± 1.5</td>
<td>13 ± 1</td>
<td>.00001</td>
</tr>
<tr>
<td></td>
<td>BIPAP S/T + AVAPS</td>
<td>83 ± 16</td>
<td>11 ± 1</td>
<td>141 ± 0.8</td>
<td>15 ± 0</td>
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<tr>
<td>pH</td>
<td>BIPAP S/T</td>
<td>7.28 ± 0.02</td>
<td>7.30 ± 0.05</td>
<td>7.31 ± 0.11</td>
<td>7.32 ± 0.12</td>
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<td>BIPAP S/T + AVAPS</td>
<td>7.29 ± 0.03</td>
<td>7.34 ± 0.04</td>
<td>7.37 ± 0.11</td>
<td>7.37 ± 0.08</td>
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<td>pCO₂</td>
<td>BIPAP S/T</td>
<td>648 ± 9.1</td>
<td>583 ± 8.7</td>
<td>532 ± 9</td>
<td>501 ± 6.5</td>
<td>.03*</td>
</tr>
<tr>
<td></td>
<td>BIPAP S/T + AVAPS</td>
<td>63 ± 16.3</td>
<td>50.7 ± 11.2</td>
<td>454 ± 7.9</td>
<td>436 ± 6.5</td>
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<tr>
<td>PO₂</td>
<td>BIPAP S/T</td>
<td>66.6 ± 12.7</td>
<td>83.1 ± 17.8</td>
<td>75.3 ± 26.7</td>
<td>79.7 ± 16.2</td>
<td>.31</td>
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<tr>
<td></td>
<td>BIPAP S/T + AVAPS</td>
<td>71.5 ± 16.8</td>
<td>78 ± 19.1</td>
<td>87.5 ± 11.5</td>
<td>87.4 ± 18</td>
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<td>HCO₃</td>
<td>BIPAP S/T</td>
<td>269 ± 5.7</td>
<td>244 ± 6.3</td>
<td>258 ± 4.6</td>
<td>271 ± 4.3</td>
<td>.19</td>
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<td></td>
<td>BIPAP S/T + AVAPS</td>
<td>244 ± 5</td>
<td>225 ± 3.5</td>
<td>237 ± 5.2</td>
<td>246 ± 4.3</td>
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<tr>
<td>Base excess</td>
<td>BIPAP S/T</td>
<td>33 ± 6.9</td>
<td>0.1 ± 7</td>
<td>10.3 ± 31.7</td>
<td>3.6 ± 4.7</td>
<td>.06</td>
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<tr>
<td></td>
<td>BIPAP S/T + AVAPS</td>
<td>-1.8 ± 5</td>
<td>2.8 ± 18</td>
<td>5.7 ± 19.8</td>
<td>2.9 ± 9</td>
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<td>Systolic blood pressure</td>
<td>BIPAP S/T</td>
<td>125.1 ± 10</td>
<td>124.2 ± 12.6</td>
<td>1304 ± 14.3</td>
<td>1306 ± 13.8</td>
<td>.29</td>
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<td></td>
<td>BIPAP S/T + AVAPS</td>
<td>125.9 ± 173</td>
<td>131.1 ± 21.1</td>
<td>1299 ± 18.4</td>
<td>1235 ± 16.9</td>
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<td>Diastolic blood pressure</td>
<td>BIPAP S/T</td>
<td>739 ± 9.8</td>
<td>722 ± 8.4</td>
<td>718 ± 9.4</td>
<td>73.7 ± 10.7</td>
<td>.07</td>
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<td></td>
<td>BIPAP S/T + AVAPS</td>
<td>653 ± 11.6</td>
<td>698 ± 11.6</td>
<td>701 ± 11.1</td>
<td>659 ± 8.5</td>
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<td>Heart rate</td>
<td>BIPAP S/T</td>
<td>867 ± 9.1</td>
<td>821 ± 7.8</td>
<td>804 ± 5.8</td>
<td>791 ± 5.5</td>
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<td></td>
<td>BIPAP S/T + AVAPS</td>
<td>82 ± 10.9</td>
<td>825 ± 9.9</td>
<td>728 ± 14.1</td>
<td>72 ± 11.2</td>
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<td>Respiratory rate</td>
<td>BIPAP S/T</td>
<td>279 ± 5.6</td>
<td>232 ± 3.9</td>
<td>21 ± 2.6</td>
<td>20 ± 1.61</td>
<td>.01*</td>
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<tr>
<td></td>
<td>BIPAP S/T + AVAPS</td>
<td>29 ± 6.9</td>
<td>174 ± 3.2</td>
<td>185 ± 3.6</td>
<td>199 ± 5.1</td>
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<td>Maximum delivered IPAP received</td>
<td>BIPAP S/T</td>
<td>123 ± 0.9</td>
<td>126 ± 0.9</td>
<td>143 ± 0.8</td>
<td>147 ± 1</td>
<td>.005*</td>
</tr>
<tr>
<td></td>
<td>BIPAP S/T + AVAPS</td>
<td>198 ± 2.2</td>
<td>183 ± 2.3</td>
<td>18 ± 2.6</td>
<td>17.2 ± 3</td>
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<td>EPAP</td>
<td>BIPAP S/T</td>
<td>59 ± 0.3</td>
<td>6 ± 0</td>
<td>6 ± 0</td>
<td>6 ± 0</td>
<td>.32</td>
</tr>
<tr>
<td></td>
<td>BIPAP S/T + AVAPS</td>
<td>6 ± 0</td>
<td>6 ± 0</td>
<td>5.9 ± 0.3</td>
<td>5.9 ± 0.3</td>
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<tr>
<td>Minute volume</td>
<td>BIPAP S/T</td>
<td>8.7 ± 3.1</td>
<td>9.2 ± 2.2</td>
<td>10.8 ± 1.4</td>
<td>106 ± 1.4</td>
<td>.17</td>
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<tr>
<td></td>
<td>BIPAP S/T + AVAPS</td>
<td>8.5 ± 2.2</td>
<td>10.5 ± 2.5</td>
<td>11.5 ± 3.1</td>
<td>116 ± 1.8</td>
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<td>Exhaled tidal volume</td>
<td>BIPAP S/T</td>
<td>304 ± 60.6</td>
<td>4005 ± 73.9</td>
<td>519 ± 61.4</td>
<td>531 ± 63.6</td>
<td>.01*</td>
</tr>
<tr>
<td></td>
<td>BIPAP S/T + AVAPS</td>
<td>298.6 ± 54.3</td>
<td>6063 ± 75.4</td>
<td>6263 ± 77.6</td>
<td>6176 ± 77.4</td>
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<td>Leak</td>
<td>BIPAP S/T</td>
<td>93 ± 3.8</td>
<td>21 ± 2</td>
<td>11 ± 3</td>
<td>11 ± 3.4</td>
<td>.20</td>
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<tr>
<td></td>
<td>BIPAP S/T + AVAPS</td>
<td>14 ± 11.2</td>
<td>183 ± 3.7</td>
<td>175 ± 16</td>
<td>175 ± 16</td>
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</table>

*Statistically significant (P value <.05).
**The ANOVA with repeated measures to compare the ability of different variables the both groups at 1, 3, 12 hours.
Non invasive ventilation: NAVA

The electrical discharge of the diaphragm is captured by an Edi Catheter fitted with an electrode array. The Edi Catheter is positioned in the esophagus.

NAVA/Neurally adjusted ventilator assist is a mode of synchronisation which uses diaphragmatic electromyography to synchronise not only the time of breath according to patients initiation of inspiration, but also it gives breath proportionate to electrical activity of diaphragm.
Neurally Adjusted Ventilatory Assist vs Pressure Support Ventilation for Acute NIV during Acute Respiratory Failure


Figure 2.
Total number of asynchronies during PSV and NAVA. Data are presented as median (horizontal line within the box), interquartile range (upper and lower edges of the boxes), maximum and minimum (upper and lower bars), and means (● within the boxes). See Figure 1 legend for expansion of abbreviations.

n= 13 Post extubation and pneumonia, P/F ratio >200
Interfaces

- Disposable - acute setting
- Re-usable - home long term setting
- Vented vs Non-vented
- Material
  - Bespoke - face matched
- Nasal / Full Face masks
- Total Face masks
- Helmet

Features and benefits:

- Patient access port
  With bi-directional anti-asphyxiation valve
- New large dimension accesses on the collar
  Ideal for single and multiple lumen probes or catheters
- Transparent
  For ease of patient monitoring
- Easy removal
  For rapid patient access
- Inflatable neck cushion
  For added patient comfort
Noninvasive ventilation with helmet versus control strategy in patients with acute respiratory failure: a systematic review and meta-analysis of controlled studies

Liu Q et al. Crit Care 2016;20:265
High Flow Nasal Cannula Oxygen Therapy

- Air-Oxygen blender generating FiO2 1.0 at a flow rate of 60l/min
- Active heated humidifier with single limb heated inspiratory circuit to avoid heat loss
- Nasal prongs fitting into nares
- High flow maintains nasopharyngeal dead space washout, reduces CO2 rebreathing
- Low level PEEP effect (dependent on mouth opening)
- Failure of HFNC – risk of delayed intubation and worse outcomes (Kang et al 2015)
- Pre-oxygenation and apnoeic oxygenation
  - HFNS as a pre-oxygenation device did not reduce lowest level of desaturation. Vour’ch at al 2015 (PREOXYFLOW Trial)
  - Difficult airways undergoing anaesthesia – mean apnoea times of 14 minutes without desaturation (SaO2 >90%). Patael et al 2015 THRIVE Study.
High Flow Oxygen through Nasal Cannula in Acute Hypoxaemic Respiratory Failure (FORALI Study Group)

**Figure 2. Kaplan–Meier Plots of the Cumulative Incidence of Intubation from Randomization to Day 28.**

Results in the overall population and in patients with a PaO$_2$-FiO$_2$ of 200 mm Hg or less are shown. PaO$_2$-FiO$_2$ denotes the ratio of the partial pressure of arterial oxygen to the fraction of inspired oxygen.
A Novel Extracorporeal CO\textsubscript{2} Removal System

Extracorporeal CO\textsubscript{2} Removal in COPD: Results of a Pilot Study of Hypercapnic Respiratory Failure in Patients With COPD

The feasibility and safety of extracorporeal carbon dioxide removal to avoid intubation in patients with COPD unresponsive to non-invasive ventilation for acute hypercapnic respiratory failure (ECLAIR study): multicentre case–control study

Table 2  Clinical course and outcomes

<table>
<thead>
<tr>
<th>Clinical course</th>
<th>ECCO₂R group (n = 25)</th>
<th>Control group (n = 25)</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Days on ECCO₂R</td>
<td>8.5 (1.0–27.0)</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Days on IMV</td>
<td>8.3 (0–60.0)</td>
<td>13.7 (1.0–52.0)</td>
<td>0.02*</td>
</tr>
<tr>
<td>Tracheotony</td>
<td>9.0 (36.0)</td>
<td>15.0 (60.0)</td>
<td>0.09*</td>
</tr>
<tr>
<td>Days on NIV during ECCO₂R</td>
<td>4.6 (0–22.0)</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Mode of NIV used during ECCO₂R</td>
<td>A-NIV 12.0 %</td>
<td>C-NIV 8.0 %</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>Mix-NIV 44.0 %</td>
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<td></td>
</tr>
<tr>
<td>Length of stay</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Days in ICU</td>
<td>28.9 (8.0–100.0)</td>
<td>24.0 (2.0–66.0)</td>
<td>0.09*</td>
</tr>
<tr>
<td>Days in hospital</td>
<td>36.9 (9.0–100.0)</td>
<td>37.0 (12.0–248.0)</td>
<td>0.49*</td>
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<tr>
<td>Mortality n (%)</td>
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<td></td>
</tr>
<tr>
<td>28-day mortality</td>
<td>4.0 (16.0)</td>
<td>3.0 (12.0)</td>
<td>0.68</td>
</tr>
<tr>
<td>Hospital mortality</td>
<td>6.0 (24.0)</td>
<td>3.0 (12.0)</td>
<td>0.28</td>
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<td>90-day mortality</td>
<td>7.0 (28.0)</td>
<td>7.0 (28.0)</td>
<td>1.0</td>
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</tbody>
</table>

Values presented as mean (range) or number (%)

ECCO₂R extracorporeal carbon dioxide removal, ICU intensive care unit, IMV invasive mechanical ventilation, N/A not applicable, NIV noninvasive ventilation, A-NIV pressure-assisted NIV, C-NIV pressure-controlled NIV, Mix-NIV pressure-controlled and pressure-assisted NIV

* Adjusted p value
Future of NIV