Basics Of Mechanical Ventilation:

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Basics of Mechanical Ventilation

• History [Wikipedia]

• The Greek physician Galen may have been the first to describe mechanical ventilation: "If you take a dead animal and blow air through its larynx [through a reed], you will fill its bronchi and watch its lungs attain the greatest distention."[20] Vesalius too describes ventilation by inserting a reed or cane into the trachea of animals.[21] In 1908 George Poe demonstrated his mechanical respirator by asphyxiating dogs and seemingly bringing them back to life.[22]

Lung Volumes and Capacities

Evolution of Mechanical Ventilation

Goals of Mechanical Ventilation

• Relieve symptoms
• Reduce work of breathing
• Improve or stabilize gas exchange
• Improve duration and quality of sleep
• Enhance the quality of life
• Prolong survival
• Provide cost effective care
• Improve or sustain physical and psychological function

Definitions

Non-Invasive Ventilation (NIV)
Non-invasive ventilation refers to the delivery of mechanical ventilation to the lungs using techniques that do not require an artificial airway

Invasive Ventilation (IV)
Invasive ventilation refers to a life support system designed to replace or support normal ventilatory function utilizing an artificial airway

1 Nicholas Hill, Noninvasive Positive Pressure Ventilation: Principles and Applications
2 AARC Clinical Practice Guideline: Long-Term Invasive Mechanical Ventilation in the Home Respiratory Care 2007;52(1):1056-1062
**Positive Pressure Ventilation**

- Creates a positive intra pleural pressure in presence of atmospheric extra thoracic pressure
- Mouth (atmospheric), Lungs (atmospheric) = Inspiration
- Problems - Barotrauma

**Volume-Targeted Ventilation**

- Preset volume is delivered to patient
- Inspiration ends once volume is delivered
- Volume constant, pressure variable
- Ensures proper amount of air is delivered to lungs regardless of lung condition
- May generate undesirable (high) airway pressures

**Pressure-Targeted Ventilation**

- Preset inspiratory pressure is delivered to patient
- Pressure constant, volume variable
- Clinician determines ventilating pressures
- Volumes may increase or decrease in response to changing lung conditions

**Waveforms**

- **Flow**
- **Pressure**
- **Volume**

**A Breathing Cycle**

A breathing cycle consists of:

- **Inspiratory Phase**
- **Expiratory Phase**

= One Breathing Cycle

**Mechanical Ventilation**

**Positive Pressure Ventilators**

- Volume ventilators
- Pressure ventilators
- Mixed mode ventilators
A Spontaneous Breath

A breath that has been initiated by the patient:

The ventilator has detected that the patient wants to breathe in and delivers the breath.

A Controlled Breath

A breath that has been initiated by the ventilator:

The ventilator starts the breathing cycle.

Trigger

- the mechanism that detects breathing effort of the patient and initiates the breathing cycle
  1. Digital AutoTrak (unique Philips Respironics)
  2. Patient Flow Trigger 1 – 9 L/Min

Cycle (Cycling)

- the mechanism that terminates the inspiratory phase and initiates the expiratory phase (cycles from Inspiration to Expiration).
  1. Digital AutoTrak
  2. Flow Cycle 10 - 90% of the peak flow

Peak flow

30% of peak flow

Tidal Volume (Vt)

"Is the volume of air during one breath"

Vti (= Inspiratory Tidal Volume)

Is the amount of air moved during the inspiration. When used on ventilators: the amount of air that is delivered by the ventilator to the patient during the inspiration.

Vte (= Expiratory Tidal Volume)

Is the amount of air breathed out by the patient.

\[ Vti - Vte = \text{Leak} \]
Respiratory Rate (RR)

The Respiratory Rate is the number of respirations during 1 minute. Most of the time expressed in BPM (= Breaths Per Minute)

In the monitoring screen:
The number of respiration measured during 1 minute (spontaneous and controlled)

In the setting screen of the ventilator:
(depending on the mode of ventilation)
- Minimal frequency that has to be maintained. When this value is reached the ventilator will start delivering controlled breaths (spontaneous modes).
- Mandatory frequency maintained by the ventilator (controlled modes).

Minute Ventilation (Mv or Vmin)

Is the amount of air that has moved in and out of the patient in one minute.
It is expressed in Liter/Minute (l/min)

\[ V_{\text{min}} = RR \times V_{\text{te}} \]

RR = 10 BPM
Vte = 500ml

\[ V_{\text{min}} = 10 \text{ BPM} \times 500\text{ml} = 5000 \text{ml/minute} \rightarrow 5\text{l/min} \]

Peak Inspiratory Pressure (PIP)

PIP is the highest pressure measured during the inspiratory phase.

Inspiratory Time (Ti)

Is the time expressed in seconds of the inspiratory phase.

i.e.: Ti = 1.2s

Ratio I/E or Ti/Ttot

Reflects the duration of the Inspiration compared to the whole breathing cycle

There are two ways of expressing this:
I/E or Ti/Ttot

In this example:
I/E = 1/2 (parts)
Ti/Ttot = 33%

IPAP (Inspiratory Positive Airway Pressure)

Is the pressure applied during the inspiratory phase
EPAP (Expiratory Positive Airway Pressure)

Also referred to as: PEEP (Positive End Expiration Pressure)

Is the pressure maintained during the expiratory phase

Pressure support (PS)

\[ PS = IPAP - EPAP \]

Pressure support is the amount of pressure applied above the EPAP during inspiration. This creates the "ventilation".

Rise Time

Is the time used by the machine to build up the pressure from EPAP to IPAP. It is expressed in milliseconds (ms). Usually from 100ms (fast) to 600ms (slow).

The Rise Time is a part of the TI (inspiratory time).

Spontaneous Mode (S)

Therapy mode in which all breaths are spontaneous

Spontaneous/Timed Mode (S/T)

- Therapy mode

The device triggers IPAP in response to a patient-triggered breath and cycles to EPAP during exhalation.
Timed Mode (T)
Times pressure support therapy mode with all mandatory delivered breaths.

Pressure Control Mode (PC)
Delivers assisted and mandatory breaths at a user-defined pressure.

Volume Assist Control Mode (AC)
Delivers assisted and mandatory breaths at a user-defined volume.

Volume Control (CV)
Delivers mandatory breaths with a user-defined tidal volume.

Possible Complications of Mechanical Ventilation

<table>
<thead>
<tr>
<th>Non-invasive Ventilation</th>
<th>Invasive Ventilation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aspiration</td>
<td>Barotrauma</td>
</tr>
<tr>
<td>Gastric insufflation</td>
<td>Mucosal injury</td>
</tr>
<tr>
<td>Mask issues (pressure sores, air leaks, discomfort, rash)</td>
<td>Decreased venous return</td>
</tr>
<tr>
<td>Nasal congestion/dryness</td>
<td>Hyper/hypoventilation</td>
</tr>
<tr>
<td>Eye irritation</td>
<td>Decreased urinary output</td>
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</tbody>
</table>
Long-term invasive mechanical ventilation in the home

Patients may have shown
- An inability to be completely weaned from invasive ventilatory support
- A progression of disease etiology that requires increasing ventilatory support
- Conditions may include
  - Ventilatory muscle disorders
  - Obstructive lung diseases
  - Restrictive lung diseases

Advantages of Home Noninvasive Ventilation
- Ease of use
- Reduced need for skilled caregivers
- Elimination of tracheostomy-related complications
- Improved patient comfort
- Allows speech, improved communication
- Lower overall cost of care

Indications for NIV
Symptoms of chronic hypoventilation may include
- Worsening of dyspnea or orthopnea
- Morning headaches
- Daytime hypersomnolence

Physiological criteria may include
- Worsening acid-base balance
- Sustained oxygen desaturation
- Vital capacity below 50%
- Maximal inspiratory force less than 60 cm H₂O

Goals of Noninvasive Ventilation
- Relieve symptoms
- Reduce work of breathing
- Improve or stabilize gas exchange
- Improve duration and Quality of Sleep
- Maximize Quality of Life
- Prolong survival
Which pathologies would benefit from Home NIV?

The Use of NIV in Chronic Respiratory Insufficiency

What is CRF?

- **Chronic respiratory failure (CRF)** may result from different pathologies, which make the body inept to bring oxygen and/or wash out its CO₂.
- As a result there is a decrease of the PaO₂ (hypoxemia) and/or an increase of the Pa CO₂ (hypercapnia) noticed during blood gases analysis.

Chronic Respiratory Failure Patients Management

“The management strategy is based on an individualized assessment of disease severity and response to various therapies.”

Source: Global Strategy for the Diagnosis, Management, and Prevention of Chronic Obstructive Pulmonary Disease

GOLD scientific committee - NHLBI/WHO workshop summary - AJRCCM 2001

| Therapy depends upon the patient’s pathology type and severity |

Cost of COPD

**COPD and Ventilation**

**COPD**

**COPD Patient**

**Some definitions**

**COPD**

Chronic Obstructive Pulmonary Disease is the name given to the progressive narrowing of the airways

This narrowing may result from an obstruction of the airways in patients with Chronic Bronchitis (scarring of the airways and sputum secretion) or emphysema

**Emphysema**

Emphysema is brought about by cigarette smoking which results in chemical changes that destroy lung tissue:

- Loss of lung tissue: reduction of elasticity
- Airways tend to close

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**COPD patients who may benefit from NIV**

- Severe, stable COPD & persistent symptoms despite medical therapy
- Substantial daytime CO\(_2\) retention: PaCO\(_2\) > 55 mm Hg OR
- PaCO\(_2\) of 50-54 mmHg and hospitalization related to recurrent episodes of hypercapnic respiratory insufficiency (> 2 episodes in 1 year)
- Nocturnal oxygen desaturation: SaO\(_2\) < 88% for > 5 consecutive minutes sustained while receiving oxygen therapy
- Motivated patient

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Before intubation a trial of NIV should be attempted

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**COPD Patient Oxygen Therapy**

- **LTOT (12-17hrs/day)** has been shown to
  - Increase survival
  - Decrease hospitalization rate

- **Adverse effects:**
  - Hypoventilation and CO\(_2\) retention
  - Increased PaCO\(_2\) at night may contribute to arousals
  - Sudden High PaCO\(_2\) deteriorate the gas balance and may lead to acidosis (exacerbation risks)

**COPD Patients Home NIV Therapy**

- Conflicting results of studies
- COPD population likely to benefit from NIPPV:
  - Substantial daytime CO\(_2\) retention
  - Severe airway obstruction
  - Nocturnal oxygen desaturation

- **Benefits:**
  - Reduce nocturnal hypoventilation: allows respiratory centre to reset, improves daytime hypercapnia.
  - Improve sleep quality by reduced episodes of hypoventilation and desaturations
  - Resting chronically fatigued respiratory muscles, allowing recovery of inspiratory muscle function
  - Decrease Decompensation episodes risks/severity

Benefits: improve patient quality of life

Source: Consensus conference:  Clinical indications for noninvasive positive pressure ventilation in chronic respiratory failure due to restrictive lung diseases. COPD and nocturnal hypoventilation - Chest 1999
Evidence Statements from NICE (National Institute for Clinical Excellence)

- Addition of NIV to LTOT improved daytime PaCO$_2$ during oxygen breathing
- Resting dyspnoea improved in NIV+LTOT group, and was significantly better at month 24
- After 2 years QOL was significantly improved
- Overall hospital admissions decreased by 45% in the NIV+LTOT group compared with increase of 27% in LTOT (follow back period of 12 months)

http://thorax.bmjjournals.com/content/vol59/suppl_1/

NICE Recommendation

Adequately treated patients with Chronic hypercapnic respiratory failure who have required assisted ventilation (whether invasive or non-invasive) during an exacerbation or who are hypercapnic or acidotic on LTOT should be referred to a specialist centre for consideration of long-term NIV.

Chronic Obstructive Pulmonary Disease: National clinical guideline on management of chronic obstructive pulmonary disease in adults in primary and secondary care
Thorax 2004;59(suppl 1):1-232

Rationale of chronic NIPPV in COPD

- Improved sleep
- Improved lung function
- Resting the respiratory muscles
- Less hyperinflation
- Increased respiratory drive

High Intensity NIV in Stable Hypercapnic COPD

Conclusion
“High-intensity NIV improves blood gases, lung function and hematocrit and is also associated with low exacerbation rates and a favourable long-term outcome. The current report strongly emphasises the need for randomised controlled trials evaluating the role of high-intensity NIV in stable hypercapnic COPD patients”


Restrictive Patients and NIV

Restrictive Thoracic Disorders

- Obese Hypoventilation
- Chest wall deformities
   - Kyphoscoliosis
   - Sequel of tuberculosis
- Non progressive or slowly progressive neuromuscular disorders
   - Central hypoventilation
   - Spinal cord injury, spinal muscular dystrophy
   - Myopathies
   - Sequel of Poliomyelitis
- Progressive neuromuscular disorders
  - Amyotrophic Lateral Sclerosis (ALS)
  - Duchenne muscular dystrophy
Restrictive Patients

Pathology Progression

<table>
<thead>
<tr>
<th>Stage</th>
<th>FVC (%)</th>
</tr>
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<tbody>
<tr>
<td>Mild stage</td>
<td>&gt;50</td>
</tr>
<tr>
<td>Moderate stage</td>
<td>40-50</td>
</tr>
<tr>
<td>Severe stage</td>
<td>&lt;40</td>
</tr>
</tbody>
</table>

Physical Therapy

- Noninvasive Ventilation
- Invasive ventilation

Respiratory Muscle Weakness

- Cor Pulmonale
- Oxygen desaturation during exercise

Restrictive Patients

When shall we start NIV?

- Progressive respiratory muscle weakness and difficulties with oxygenation at night
- Substantial CO2 retention: PaCO2 > 45mmHg or
- Nocturnal oxygen desaturation: SaO2 < 88% for > 5 consecutive minutes
- Maximal inspiratory pressure < 60 cmH2O and forced vital capacity < 50% predicted

Some patients may require invasive ventilation during crisis phase or long-term

Indications for NIV

Symptoms

- Worsening of dyspnea or orthopnea
- Morning headaches
- Daytime hypersomnolence

Physiological Criteria

- Vital Capacities below 50%
- Maximal Inspiratory Force less than 60 cm H2O

Study Supporting NIV Therapy in ALS

Effect of NIV assessed on QOL and survival in ALS patients

- 92 patients assessed every 2 months and randomly assigned to NIV or standard care
- 2 different QOL outcome scales were used

Results:

- NIV improved QOL and survival in all patients and in the subgroup who had better bulbar function
- The subgroup showed improvement in several measures of QOL and a median survival benefit of 205 days
- NIV improved some QOL indices in those with poor bulbar function, but conferred no survival benefit

Bourke, SC. et al., Lancet Neurology. 2006

Efficacy of NIV Therapy in Central Hypoventilation

- 54 patients with Obesity Hypoventilation Syndrome (OHS) treated with NIV to assess short and long-term effects
- Outcome measures were survival, clinical status and ABG results
- Follow-up period (50 months)

Results:

- PaO2 increased and CO2 decreased
- Improved subjective sleepiness and decrease in dyspnea in all but 4 patients
- 3 patients died during follow-up period

Conclusion

- NIV therapy is effective in the treatment of patients with OHS and provided a significant improvement in clinical status and gas exchange

Questions?