Noninvasive Ventilation

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http://www.geocities.com/jonesapjr/index.html

Learning Objective

- Explain the rationale, indications, complications and clinical applications of both positive pressure and negative pressure noninvasive ventilation techniques.

Negative Pressure Ventilation

Definitions

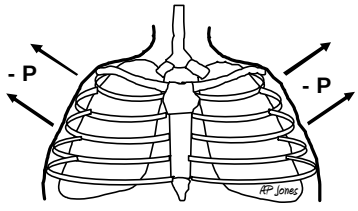
- Noninvasive ventilation - mechanical ventilation without tracheal tube.
- Noninvasive positive pressure ventilation (NPPV) - ventilation without tracheal tube and with positive airway pressure
- Negative pressure ventilation - ventilation with negative pressure applied to thorax.

Rationale for NIV

- Ventilate patients, while avoiding the complications associated with tracheal tubes:
  - ventilator associated pneumonia
  - airway trauma
  - psychological trauma, due to aphonia, restraint

Physiologic effects

- Subambient pressure surrounds thorax to inflate lungs



Physiologic effects

- Subambient pressure inflates lungs
  - intermittent, with passive deflation
  - continuous negative expiratory pressure (CNEP) - maintain FRC
- Decreased work of breathing (WOB)
- Increased distribution of ventilation
- Increased pulmonary blood flow
- Increased ventricular filling - increased cardiac output (cuirass)

Indications

- Unable to fit or tolerate mask for NPPV
- Neuromuscular disease
- Neurological trauma
- Intolerance of increased mean airway pressure; e.g., PEEP
- COPD - chronic state and acute exacerbations

Indications

- Post congenital heart surgery
  - tetralogy of Fallot correction
  - tricuspid atresia correction (Fontan)
  - phrenic nerve injury
- Neonatal respiratory distress
- Bronchopulmonary dysplasia

FYI- Click to download article on negative pressure ventilation and acute respiratory failure (interesting). http://www.erj.ersjournals.com/cgi/content/abstract/9/7/1531

Indications

- Post emphysematous lung resection
- During microlaryngeal surgery
- Cystic fibrosis
- Weaning from PPV
- Flail chest (CNEP)
- Meconium aspiration??
- Bronchopleural fistula??

Benefits

- Avoidance of tracheal tube complications
- Avoidance of facial trauma from mask
- Reduced sedation requirements
- No ventilator - induced lung injury

Benefits

- Patient can talk
- Patient can cough
- Improved enteral nutrition - patient may be able to eat

Disadvantages

- Lack of airway protection
- Large, non-portable equipment (tanks)
- Decreased patient access (tanks)
- Cumbersome to apply to some patients (tanks, wraps)
- Difficult to maintain seal
- Difficult to monitor volumes
- Patient intolerance (varies with type)

Complications

- Peripheral venous pooling (tank shock)
- Gastrointestinal bleeding
- Dynamic upper airway collapse
- Irritation at neck seal (tanks)
- Back pain

Contraindications

- Obstructive sleep apnea - upper airway collapse
- Morbid obesity
- Severe kyphoscoliosis
- Recent abdominal surgery

Negative pressure ventilators

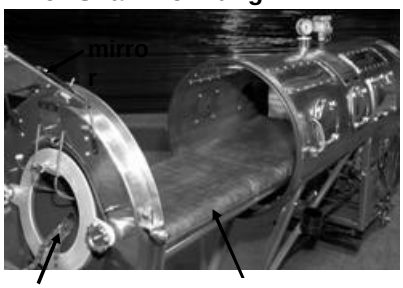
- Emerson iron lung
- Drinker-Shaw iron lung
- Coppa iron lung and cuirass
  - microprocessor-based
  - not available in the US
- Porta-Lung™ (tank, only)

Click to see Porta-Lung™
http://portalung.com/Products.htm

Click to see Coppa microprocessor iron lung and cuirass
http://www.coppabiella.it/interno.asp?pagina=elettromedicali.htm

Negative pressure ventilators

- Drinker-Shaw iron lung



patient head port

patient bed

Negative pressure ventilators

- Ventilators
  - Emerson U-Cyclit™ (not available)
  - LifeCare NEV 100™ (not available)
  - Pegaso V™
  - Hayek RTX™

Click for information on the Pegaso V™ ventilator
http://portalung.com/PEGASO_V2.htm

Click to see infant negative pressure ventilator
http://www.pubmedcentral.nih.gov/pagerender.fcgi?artid=1838133&pageindex=2

Negative pressure ventilators

- Body wraps
  - Nu-Mo suit™
  - Pulmo WrapTM
  - Poncho WrapTM

Click for presentation that shows LifeCare ventilator, Nu-Mo suit and Pneumo-Wrap (slides 13-17)
http://static.nemours.org/www-filebox/picu/respiratory-edu-series.pdf
Click to see a vintage cuirass
http://www.frca.co.uk/images/cuirass.jpg

Negative pressure ventilators

- Hayek RTX™ cuirass ventilator
  - Biphasic cuirass ventilation - inspiratory and expiratory pressure
  - Easy to apply
  - Modes:
    - High-frequency chest oscillation
    - Secretions mode - oscillation , cough
    - Continuous negative expiratory pressure

Click to see the Hayek RTX™ video
http://www.unitedhayek.com/presentations/movies/id/1

Negative pressure ventilators

- Hayek RTX™ cuirass ventilator
  - Modes:
    - High-frequency chest oscillation
    - Secretions mode - oscillations, cough
    - Continuous negative expiratory pressure
    - Control mode
    - Respiratory triggered
    - Respiratory synchronized

Click for information on Hayek RTX™ modes and settings
http://www.unitedhayek.com/clinicians#modes

Negative pressure ventilators

- Hayek RTX™ cuirass ventilator
  - Specifications
    - 6-1200 cycles per minute
    - I:E Ratio: 1:6 - 6:1
    - Maximum inspiratory pressure: -50 cm H20
    - Maximum expiratory pressure: +50 cm H20
    - Power unit weight: 9 kg
    - Four adult size cuirasses
    - Seven pediatric size cuirasses

Ventilator operation

- Settings
  - Peak inspiratory pressure - adjusts tidal volume
  - Peak expiratory pressure - active exhalation, cough assistance
  - Continuous negative expiratory pressure
    - maintains FRC
    - balances intrinsic PEEP for patient triggering

Ventilator operation

- Settings
  - Rate
  - I:E ratio
  - Trigger sensitivity
    - sensed at nares
    - sensed in cuirass (Hayek)
  - FIO2 - mask or nasal cannula

Monitoring

- Blood gases
  - baseline and PRN arterial sampling
  - pulse oximetry
  - end-tidal CO2 monitoring
- Volumes
  - spirometry with mask??
  - respiratory inductive plethysmography??

Sites for NPV

- Intensive care units
- Intermediate care units
- Long-term care facilities
- Homes

Noninvasive Positive Pressure Ventilation (NPPV)

Definitions

- Noninvasive positive pressure ventilation - PPV without tracheal tube
- Important attribute of NPPV - existence of a mask leak - that affects
  - volume delivered (volume control)
  - ventilator triggering
  - ventilator cycling

Definitions

- Modes
  - continuous positive airway pressure
  - bilevel positive airway pressure
  - pressure support
  - pressure control
  - volume control
  - proportional assist

Physiologic effects

- Decreased WOB
- Increased dynamic lung compliance
- Increased tidal volume
- Increased inspiratory capacity (CPAP and COPD patients)
- Decreased PEEPi (with PEEP)
- Improved blood gases
- Cardiac output
  - normal and COPD patients - decreased
  - some CHF patients - increased

Benefits

- Prevention of ETT complications
- Reduction in sedation requirements
- Prevention of tracheotomy
- Reduction in ICU length-of stay (LOS)

Complications

- Delayed intubation
- Patient intolerance, anxiety
- Facial ulcers
- Ear, sinus pain
- Increased WOB - patient-ventilator dyssynchrony, due to inappropriate device and/or adjustments

Complications

- Pneumothorax
- Gastric insufflation - high pressures
- Aspiration
- Mucus plugging
- Hemodynamic compromise

Contraindications

- apnea
- cardiovascular instability
- unable to fit or tolerate interface
- acute abdominal process - risk for vomiting, aspiration
- severely impaired mental status

Contraindications

- excessive and/or viscous secretions
- recent facial or gastro-oesophageal surgery
- craniofacial trauma and/or fixed nasopharyngeal abnormality

Indications

- COPD
- Acute cardiogenic pulmonary edema
- Blunt thoracic trauma
- Postoperative respiratory failure
- Weaning from invasive ventilation
- Miscellaneous conditions
- Neuromuscular disease - separate lesson
- Obstructive sleep apnea - separate lesson

Questionable Indications

- ARDS/ALI - may harm by delaying intubation
- Pneumonia - no evidence of benefit
- Asthma - no evidence of benefit

NIPPV should be tried very cautiously or not at all in patients with ALI who have shock, metabolic acidosis or profound hypoxemia. Rana S, et al. 2006.

NPPV & COPD Exacerbations

- First line treatment for exacerbations
- Strong evidence for efficacy in hypercapneic failure
- Effects
  - decreased WOB
  - reversal of ventilatory muscle fatigue
  - decreased PaCO2
  - decreased risk for intubation
  - decreased mortality

NPPV & Stable COPD

- Many COPD patients also have sleep apnea (overlap), with greater risk for hypercapneic failure
- Effects
  - Decreased air trapping (TLC)
  - Increased CO2 response
  - Stabilizes heart rhythm by reducing vagal activity

NPPV & Stable COPD

- Situations
  - home - longer survival for adherent patients (Budweiser)
  - rehabilitation - may increase exercise tolerance, except for backpack study
  - therapy ceiling for end-stage

NPPV & acute cardiogenic pulmonary edema (ACCPE)

- First line treatment - strong evidence
- Effects - CPAP and bilevel NPPV equally:
  - increased FRC
  - increased lung compliance
  - decreased WOB
  - decreased dyspnea & respiratory rate

NPPV & ACCPE

- Effects - CPAP and bilevel NPPV equally:
  - decreased intrapulmonary shunt
  - decreased heart rate
  - increased cardiac output
  - decreased intubation rate
  - may decrease mortality (meta-analysis)
- Bilevel NPPV may not be more effective than CPAP (statistical analysis)

NPPV & blunt thoracic trauma (flail)

- CPAP and bilevel NPPV studied - weak evidence
- excluded patients
  - emergent intubations
  - injuries to head, face or neck
- effects
  - decreased rate of pneumonia
  - decreased mortality
- more trials needed

NPPV & postoperative respiratory failure

- CPAP and bilevel NPPV studied - weak evidence
- Postoperative upper abdominal & thoracic surgical patients studied
- Effects:
  - decreased intubation, reintubation rate
  - decreased pneumonia, sepsis
  - decreased mortality
  - decreased length of hospitalization
- CPAP and bilevel NPPV may be equally

NPPV & weaning from invasive ventilation

- Rationales
  - shorten intubation time
    - ƒ decreased sedation
    - ƒ decrease infection
    - ƒ decrease ICU & hospital length-of-stay (LOS)
  - prevent reintubation
  - prevent tracheotomy

NPPV & weaning from invasive ventilation

- Supportive evidence is moderate, when applied to selected patients, who:
  - meet criteria to initiate spontaneous breathing trial
  - meet criteria for extubation:
    - ƒ do not have excessive secretions
    - ƒ have an effective cough
    - ƒ have acceptable mental status
    - ƒ are not a difficult intubation

NPPV & weaning from invasive ventilation

- Supportive evidence is moderate, when applied to selected patients, who:
  - have no impediments for interface
  - tolerate short term spontaneous breathing for mask adjustments, etc.

NPPV & post-extubation failure

- Evidence does not support efficacy of NPPV in treating post-extubation respiratory failure
- Evidence supports that NPPV may be effective in preventing post-extubation respiratory failure where high-risk patients are identified in advance
- NPPV not recommended as a routine intervention for post-extubation situations.

NPPV - miscellaneous indications

- During bronchoscopy to offset increased WOB and hypoxemia
- Severe bronchiolitis
- Cystic fibrosis - adults with hypercapneic exacerbations

NPPV - miscellaneous indications

- During bronchoscopy to offset increased WOB and hypoxemia
- Severe bronchiolitis
- Cystic fibrosis - adults with hypercapneic exacerbations
- Immunocompromised patients - prevents ventilator - associated pneumonia
- Pandemic respiratory infections; e.g., SARS - to prevent infection of caregivers during intubations

NPPV Interfaces & Humidification

Issues with interfaces

- Comfort
- Allowance for patient movement
- Weight
- Allergenicity
- Pressure applied to tissues ==> skin ulceration

Issues with interfaces

- Internal volume
  - dead space (V_{Drb}) - rebreathed volume
  - gas compression, decompression volume
- Leaks - mask seal >2 cm ==> negligible leaks
- Multiple sizes available

Click to hear possible mask leak

Play CPAP mask leak

Click to see Respironics leak chart

http://sleepapnea.respironics.com/PDF/LeakRate.pdf

Issues with interfaces

- Securing system (headgear)
  - comfort
  - stability
  - ease of use
  - washable for home use
  - disposable for hospital use

Click to see various brands of headgear, with prices

http://www.cpap.com/simple-find-cpap-products/cpap-masks/headgear.html

Interfaces

- Mouthpiece
- Nasal mask
- Nasal pillows
- Oronasal mask
- Full face mask
- Helmet

Mouthpiece interface

- primarily for daytime use for patients with:
  - neuromuscular disease
  - COPD
  - cystic fibrosis

Nasal interfaces

- Indications
  - primary interface for obstructive sleep apnea
  - good starting interface in mild acute respiratory failure, with limitations
  - postoperative atelectasis (see lung clearance lesson)

Nasal interfaces

- Advantages:
  - enables speech, eating, coughing
  - less risk for aspiration, gastric distension
  - less claustrophobia

Nasal interfaces

- Limitations
  - erroneous monitoring of exhaled TV
  - nasal resistance limits effectiveness
  - mouth breathing limits effectiveness and patients with ARF tend to mouth-breathe
  - lesser pressure can be administered

Nasal interfaces

- Types
  - masks
  - pillows

Respironics Curve™ nasal mask (courtesy Respironics)

Click to see various brands of nasal masks, with prices
http://www.cpap.com/simple-find-cpap-products/cpap-masks/cpap-masks/nasal.html
Click to see various brands of nasal pillows, with prices
http://www.cpap.com/simple-find-cpap-products.php?selected=106&sortBy=&shopbybrand=

Oronasal (full face) mask

- Most common for bilevel NPPV
- Advantages
  - less leakage
  - more stable pressures
  - less patient cooperation
- Limitations
  - claustrophobia
  - aspiration

Oronasal (full face) mask

Respironics ComfortGel™ mask (courtesy Respironics)

Click to see various brands of full face masks, with prices
http://www.cpap.com/simple-find-cpap-products/cpap-masks/cpap-masks/full-face.html

Total face mask

- Most effective NPPV interface for acute respiratory failure.
- Minimal leaks - accommodates greatest pressure
- Less discomfort
- Less pressure injury - larger area of contact
- Does not increase V_{Drb}
- May increase claustrophobia

Total face mask

Respironics Total Face Mask™ (courtesy Respironics)

Respironics Performax™ (courtesy Respironics)

Click to see all Respironics masks, etc.
http://masks.respironics.com/

Helmet

- advantages
  - overcomes mask-fit problems
  - more comfortable
  - no facial pressure injury
  - less need for patient cooperation
  - allows speaking, coughing

Helmet

- disadvantages
  - not currently FDA-approved
  - may decrease cerebral blood flow in infants
  - impedes patient triggering - decompression volume
  - no capability for volume monitoring
  - humidification may fog the helmet

Click to see neonatal CPAP helmet
http://farm1.static.flickr.com/80/247084940_023fdc3543_m.jpg

Click to see adult CPAP helmet
http://www.harol.it/Cataloghi%20in%20inglese/cat_harol_caschi%20inglese.pdf

Helmet

Designer CPAP helmet

Click to hear helmet voice distortion
(play darkside wma)

Ventilator circuit

- Single-limbed
  - original BiPAP circuit
  - incorporates variable flow leak port
  - requires EPAP > 4 cm H2O to minimize rebreathing

Ventilator circuit

- Double-limbed
  - ICU ventilators and recent bilevel ventilators
  - eliminates rebreathing
- The circuit and interface must be used for the specified ventilator

Humidification

- None - OK for short-term ventilation
  - humidification ability of mucosa can be overwhelmed
  - desiccated mucosa releases inflammatory mediators
  - possible mucus plugging
  - absence of humidification can impede adherence to therapy

Humidification

- Heat and moisture exchanger
  - can increase resistance
  - increase V_{Drb} ==>
    - ƒ hypercapnea
    - ƒ increased minute ventilation
    - ƒ increased WOB

Humidification

- Heat and moisture exchanger
  - increase V_{Drb}
  - can increase resistance
- Heated humidification
  - no effect on V_{Drb}
  - no effect on resistance
- Ambient temperature passive humidification increases comfort for some patients

NIPPV Ventilators

Institutional bilevel ventilators

- Desirable features
  - built-in blender
  - leak compensation
  - trigger compensation
  - backup rate
  - rise time adjustment
  - graphic display
  - alarms
  - battery power supply

Institutional bilevel ventilators

- Respironics
  - BiPAP S/T™ - no blender
  - Focus™ - no blender
  - Vision™
- Mallinckrodt Onyx™

Institutional bilevel ventilators

Respironics Vision™ Respironics Focus™

Images courtesy of Respironics

Institutional bilevel ventilators

- Respironics Vision™
  - acute care bilevel ventilation
  - blender - adjustable FIO2
  - Auto-Track™ trigger
  - rise time adjustable
  - graphic display
  - alarms
  - no battery backup

ICU ventilators

- With NIV mode - provide leak compensation
- Without NIV mode - no leak compensation
  - impedes patient triggering
  - impedes cycling to expiration in PSV mode
  - can be used; but, could lead to problems (injury, litigation)

Ventilators

- ICU ventilators with noninvasive modes (examples)
  - Maquet Servoi™
  - Drager Evita XL™
  - Newport e500™ and HT50™ (transport)
  - Viasys Vela™ and Avea™
  - Hamilton Raphael™ & C-2™
  - GE Engstrom Carestation™
  - Puritan-Bennett 840™

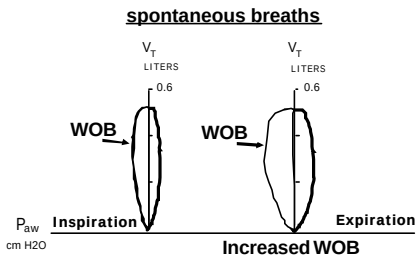
ICU ventilators

- Advantages
  - graphics
  - exhaled volume monitoring
  - expiratory cycle adjustment
  - rise time adjustment
  - invasive ventilation capability - easier to switch over
- disadvantage - expense, which may not be justifiable

ICU ventilators

- advantages
  - graphics to show:
    - triggering
    - cycling
    - intrinsic PEEP (PEEPi)
    - work of breathing (WOB)

Spontaneous WOB



ICU ventilators

- advantages
  - exhaled volume monitoring
  - expiratory cycle adjustment
  - rise time adjustment
  - invasive ventilation capability - easier to switch over
- disadvantage - expense

Modes applied to NIV

- volume control
  - identical success rate, compared to pressure control
  - stable volumes in face of changing lung mechanics
  - higher peak airway pressures that caused flatulence in two patients that sounded like a mask leak
  - common in home NIV (Europe)

Modes applied to NIV

- pressure control ventilation (PCV)
  - stable volume delivery in face of leaks
  - flow variable with patient demands
  - trial results - PCV may be more effective than PSV for COPD exacerbations

Modes applied to NIV

- pressure support
  - most common mode for NIV
  - some ventilators do not include backup rate - apnea adjustment is important

Modes applied to NIV

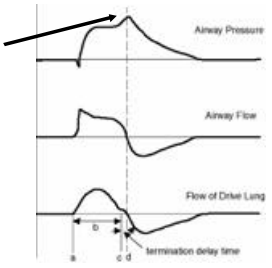
- pressure support
  - appropriate expiratory cycle adjustment is important
  - appropriate rise time adjustment is important
  - observe inspiratory time and I:E ratio - may require inspiratory time limit adjustment

Expiratory flow-cycling (PSV)

Patient expiratory effort

Late termination

Inability to trigger

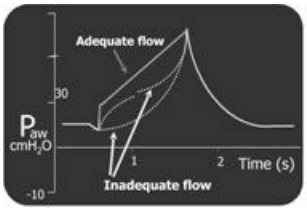


Courtesy Newport Medical

Inspiratory flow/rise- pressure wave

Linear or bowed upward rise in pressure after trigger on the pressure wave

Slow rise in pressure, concave shape of the pressure wave



Courtesy Newport Medical

Modes applied to NIV

- proportional assist ventilation (PAV)
  - delivers flow proportional to patient's inspiratory effort
  - terminates flow in response to cessation of inspiratory effort

Modes applied to NIV

- proportional assist ventilation (PAV)
  - clinical trials conclude that it is better tolerated than PSV; but, PSV was delivered with PB 7200ae?
  - Respironics Vision - PAV mode not available in U.S.
  - Puritan-Bennett 840 - company does not support use of PAV with NIV

Ventilation modes and NIV

- Pressure support with volume guarantee (VSV)??
  - no NIV with VSV trials located
  - problem with VSV - patient distress and hyperpnea causes ventilator to decrease support

Ventilation modes and NIV

- Neurally adjusted ventilatory assist (Maquet NAVA^{TM})
  - flow delivery in response to diaphragmatic electrical activity
  - eliminates leaks as a triggering and cycling factor
  - need human trials on NAVA and NIV
  - it works on rabbits (Thumper)

Ventilation settings

- PEEP 3 < > 8
- PSV, IPAP - exhaled tidal volume > 5 ml/kg IBW
- Reasonable starting pressures - PEEP = 5; PSV = 10
- FIO2 for desired SPO2

Ventilation settings

- Expiratory flow cycling adjustment:
  - patient comfort
  - ventilator graphics
  - inspiratory time, I:E ratio
  - to eliminate PEEPi

Ventilation settings

- Rise time adjustment:
  - patient comfort
  - ventilator graphics
  - leaks

NPPV Clinical Issues

Clinical indicators of successful NIV

- Favorable response in first 2 hours
- APACHE II score < 29
- pH > 7.30
- Glasgow coma score ≥ 15
- Absence of pneumonia or ARDS
- Lesser air leaks
- Patient-ventilator synchrony

FYI - Click to download article on NIV & critical care
http://www.chestjournal.org/content/132/2/711.long

Aerosol delivery

- Remove NIV interface and administer, if safe and feasible
- Aerosol medications are effective with NIV via all types of devices
- Aerosols are effectively delivered via nasal interface
- Increased dosage may be necessary, because of leaks

Aerosol delivery

- Aerosol delivery devices
  - pneumatic nebulizer
    - place proximal to patient
    - place between patient and leak valve
  - vibrating mesh (Aeroneb Pro™) - does not add flow to circuit
  - MDI & spacer - coordinate with inspiration

Click to view Aeroneb Pro™ video
http://www.aerogen.com/technology.html

Aerosol delivery

- Full face masks allow medications to enter eyes - especially problematic with ipratropium
- More research is needed to generate specific recommendations
- Regardless of device, it's a good idea to place aerosol generator between the HME and the patient

Heliox therapy

- Meta-analyses on routine use of heliox for asthma and COPD do not support routine use
- Heliox decreases PEEPi and WOB in ventilated patients with COPD exacerbations

Heliox therapy

- Problems:
  - heliox can not be used in hypoxemic patients
  - heliox causes errors in TV and FIO2 measurement and delivery
  - heliox is expensive
  - helium causes vocal distortion

Click to hear vocal distortion with helium
Play helium voice

Heliox therapy

- Viasys Avea - only FDA-approved ventilator for invasive and noninvasive ventilation with heliox

Sites for NPPV administration

- Factors
  - acuity of patient
  - expertise of personnel
  - availability of physical resources
- Monitoring capabilities
  - personal (skilled)
  - electronic

Sites for NPPV administration

- Pre-hospital - EMS
  - for some conditions, the sooner, the better for NPPV
  - avoids emergency intubations
  - especially applicable to ACCPE & COPD
- Emergency room
  - early initiation of NPPV
  - advanced resources, including RTs

Sites for NPPV administration

- Intensive care
  - intensive monitoring
  - extensive physical resources
  - personnel resources
    - ƒ respiratory therapists
    - ƒ critical care nurses
  - best site for sickest patients

Sites for NPPV administration

- Intermediate care (step-down)
  - usually telemetric monitoring
  - personnel resources varies:
    - ƒ respiratory therapists
    - ƒ patient:nurse ratio
  - stable patients

Sites for NPPV administration

- General ward
  - telemetry - maybe
  - more patients per nurses, who may be unfamiliar with NPPV
  - respiratory therapy coverage varies
  - intermittent NPPV, as for:
    - sleep apnea
    - stable COPD
    - stable neuromuscular disease

Sites for NPPV administration

- Long-term care facilities
  - chronic care
    - COPD
    - failure to wean from ventilation
  - monitoring varies by units
  - usually have skilled respiratory therapy staff

Sites for NPPV administration

- Home
  - chronic conditions
  - end-of-life care
  - requires education of patient & caregivers

NIPPV and End-of-Life Care

- Patient choices
  - do not intubate (DNI)
  - comfort measures only (CMO)
- Informed consent of patient and/or family is needed - NIV is life support
- Common conditions
  - COPD
  - cancer
  - neuromuscular diseases
  - heart failure

NIPPV and End-of-Life Care

- Goals of NIV for terminal patients
  - delay death
    - to go home
    - to settle personal issues
    - to see a person
  - provide comfort - to whom?
    - decrease dyspnea
    - comfort is not provided when a patient is resisting the treatment

NIPPV and End-of-Life Care

- Ethical controversy exists over whether NIV ought to be used at end-of-life.
- The decision should rest with the patient (author's opinion)

Summary & Review

- Negative pressure ventilation

END

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