A Pulmonologist's Approach to Chronic Hypoventilation and Home Assisted Ventilation

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Educational Objectives:

1. Develop a systematic approach to the evaluation of patients with neuromuscular disease and chronic hypoventilation
2. Gain familiarity with interventions in respiratory care that have significantly improved outlook, including survival and quality of life in patients with chronic respiratory failure

Case:
Michael is a 21-year-old male with Duchenne Muscular Dystrophy (DMD) who presents to your clinic to transition care from the Children's Hospital. He brings no medical records with him. He has no complaints stating he was just told he would need to follow up with a pulmonologist. He denies any dyspnea, chest pain or cough. He is on enalapril, omeprazole, montelukast, flovent, glycopyrrolate and Vitamin D. On examination, he is seated comfortably in a motorized wheelchair, BP 116/68, HR 90, RR 22, SpO_2 98% RA. He has limited head flexion, JVP flat with regular heart sounds. There is a midline scar on his back with asymmetrical breath sounds but no added sounds. He has limited movement of his fingers only. There is no peripheral edema.

<u>Question 1:</u> Michael stares at you. You are silently thinking to yourself you are not a neurologist. He has no complaints – why is he here? Why am I here? On a slightly more serious note, what are the potential pulmonary complications of neuromuscular disorders and what, if any, testing should you do?

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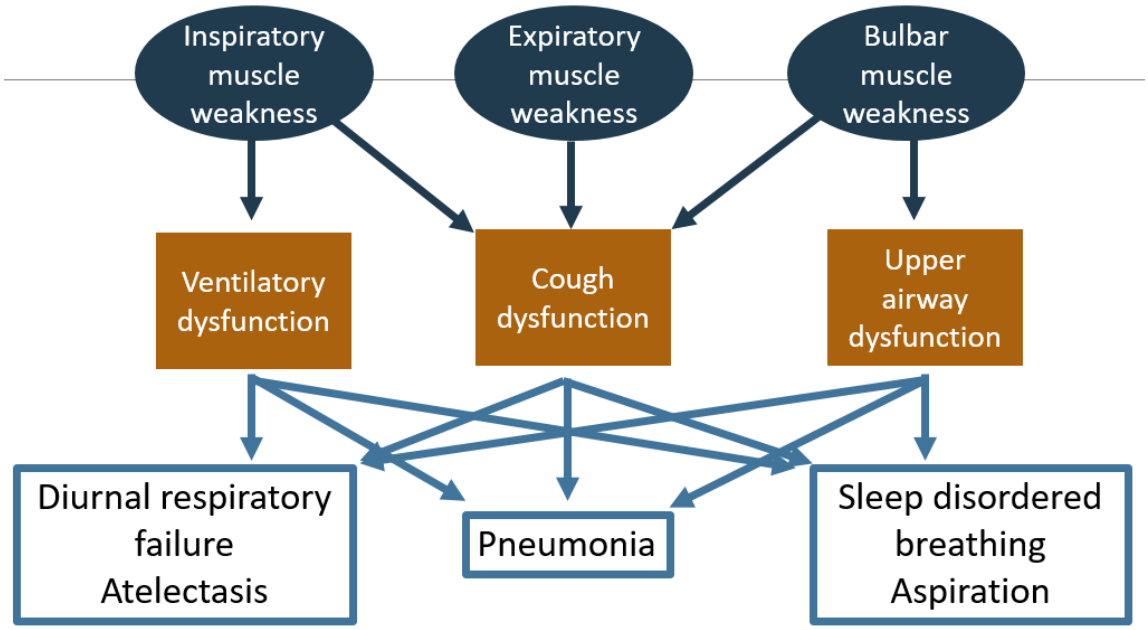
Pulmonary complications are the leading cause of death in progressive neuromuscular disease (NMD). A systematic approach can approach the functions of the respiratory system using an anatomical organization:



Adapted from Benditt JO, Biotano LJ. Pulmonary Issues in Patients with Chronic Neuromuscular Disease. Am J Respir Crit Care Med. 2013; 187(10): 1046-1055, Figure 1[1]

Thus, the focus of evaluating NMD from a pulmonary perspective focuses on the following concepts:

1) **Ventilation**
2) **Cough function/airways clearance**
3) **Upper airway: bulbar and swallowing function**
4) **Sleep quality**

<u>Question 2:</u> You first decide to focus on ventilatory dysfunction and wonder if he has evidence of hypoventilation that would require additional supportive therapies. How do you approach your evaluation? What diagnostic tests would you order?

- Clinical evaluation: Dyspnea, tachypnea, accessory muscle use, paradoxical chest-abdominal breathing, SpO_2, transcutaneous CO2

- Diagnostic testing:
  - **Pulmonary function testing to evaluate the "respiratory pump"–**
    - Vital capacity (VC) is not a sensitive marker and usually does not fall below normal limits until there has been a major decline in muscle strength. The VC provides prognostic information.
      - Non-invasive ventilation (NIV) recommended in DMD if FVC falls below 50% of predicted normal. [2]

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- Upright to Supine VC % change more sensitive than upright FVC in detecting diaphragm weakness
    - Decline of ≥25% = indicator of significant diaphragmatic weakness. [3,4] Up to 10% decline is normal.
    - Supine result may be recorded in PFT results under "post bronchodilator" section depending on your PFT lab
- Slow Vital Capacity (SVC) may be easier for patients with advancing disease and bulbar symptoms (such as in amyotrophic lateral sclerosis). [5]

- **Respiratory muscle strength –**
    - Maximum inspiratory pressure, MIP or Pimax, and maximum expiratory pressure (MEP, Pemax) –sensitive but not specific. Useful for excluding weakness if normal but difficult to interpret if abnormal. Can be used to qualify for bilevel noninvasive ventilation if abnormal as well.
        - MIP: Think diaphragm and external intercostal muscles.
            - Normal: more negative than -60 cm H20
        - MEP: Think abdominal and internal intercostal muscles.
            - Normal: More positive than +60 cm H20

    - The sniff nasal inspiratory pressure (SNIP/SNIF) – Maximal sniffing with a pressure transducer occluding one nostril. Helpful when bulbar weakness is present.
        - Normal: SNIP more negative than -50 cm H2O for women and -60 cm H2O for men

- **Ventilation**
    - CO2 measurements – Late finding!
        - Normal pCO2: 35 to 45 mm Hg.
    - Methods for measurement:
        - **ABG** – snap shot in time
        - **Transcutaneous CO2 –***Sentec*™
            - CO2 measurement display with 1-2 minute delay between real time CO2
            - Accuracy: within 1-2 mm Hg
        - Other considerations - serum bicarbonate, end-tidal CO2 (if tracheostomy), serum chloride

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Case Continued:
Michael returns to your clinic for follow up after having completed the requested diagnostic testing:

PFT: FEV1 1.23 (30% predicted), FVC 1.40 (29%), FEV1/FVC 88
Supine FVC: 0.9 L (30% change)

MIP -38 cm H2O (37%), MEP 26 cm H2O (30%)

Transcutaneous CO2 (in office): 62
Serum HCO3: 33

Question 3: Based on the results above, should you start Michael on non-invasive ventilation? What is the evidence to support this decision?

Indications for starting a person on Non-Invasive Ventilation in NMD:

Coverage requires criteria A-C

A. Medical record documentation of a neuromuscular disease or severe thoracic cage abnormality

B. At least one of the following:
   i) A $PaCO_2$ on an ABG drawn while awake and breathing the patient's prescribed $FiO_2 \geq$ 45 mmHg, or
   ii) Sleep oximetry done while breathing the patient's usual prescribed FiO_2 demonstrating SpO2 $\leq$ 88% for $\geq$ 5 minutes of nocturnal recording time (minimum recording time of 2 hours), or
   iii) For neuromuscular disease only, either a maximal inspiratory pressure (MIP) < -60 cm H_2O or a forced vital capacity (FVC) < 50% predicted

C. COPD does not contribute significantly to the patient's pulmonary limitation

Evidence of Utility in Ventilatory Dysfunction:

1) NIV has been shown in DMD and ALS to *improve survival*.[7,8] NIV may also improve quality of life, improve symptoms, improve sleep disordered breathing, improve gas exchange and slow rate of decline in pulmonary function.
2) Guidelines for DMD and ALS now exist which recommend NIV.[2,9] The optimal timing of NIV initiation remains unclear and is in part dictated by reimbursement criteria. As a *general* rule, the most effective thresholds for introducing NIV are:
   - FVC< 50% predicted
   - Awake pCO2 >45 mm Hg
   - MIP < -60 cm H20

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<u>Question 4:</u> Now that you determined that you want to start Michael on NIV, what are the different options for equipment? What ventilator settings do you choose?

<u>Ventilators</u>

"Heavyweights"

	Astral (ResMed)	**Trilogy** (Philips Respironics)	**LTV** (Carefusion)	**VOCSN** (Ventec)
Weight (lbs)	7	11	14	18 lbs
Internal Battery (hours)	8	3	1	9 (internal + external battery)
External battery (hours)	8 (x2)	3	6	
Programs	4	2	1	3
PEEP	✓	✓	Not necessarily	✓
VAPS mode	✓ (iVAPS)	✓ (AVAPS)	✗	✓ (technically a volume-targed PS mode similar to VAPS but its own proprietary algorithm)
Variable EPAP	✓	✓	✗	✗
Remote data monitoring*	✓	✓	✗	✓

**Remote monitoring requires a modem which sometimes requires an extra prescription and is an extra cost to patients, so isn't always possible and manual downloads can be required for patients with existing / older models of these vents*

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"Lightweights"

	Aircure (Resmed)	**Dreamstation** (Philips Respironics)	**Life2000** (Hillrom)
Weight (lbs)	3	3	1
Internal Battery (hours)	✗	✗	4
Portability	✗	✗	✓
Oxygen capability	✓	✓	✓
Data downloads	✓	✓	✓
VAPS mode*	✓ (iVAPS)	✓ (AVAPS)	✗

**Both Respironics and Resmed also make devices that only support Bilevel S or Bilevel S/T*

Modes of ventilation

Target	Modes	Notes
Pressure	**Spontaneous/Timed (S/T)** **Pressure Control (PC)** Spontaneous (S) and Timed (T) Pressure Support (PS) PC-Synch Intermittent Mandatory Vent (PC-SIMV)	Bilevel S and Bilevel T are rarely used PS and S/T have variable inspiratory time (Ti) PC has mandatory Ti
Volume	Assist Control (AC) Volume Assured Pressure Support (VAPS) Mouthpiece ventilation (MPV) VC-SIMV	VAPS targets a volume by adjusting IPAP Trilogy: Tidal volume (AVAPS) Astral: Alveolar ventilation (iVAPS)

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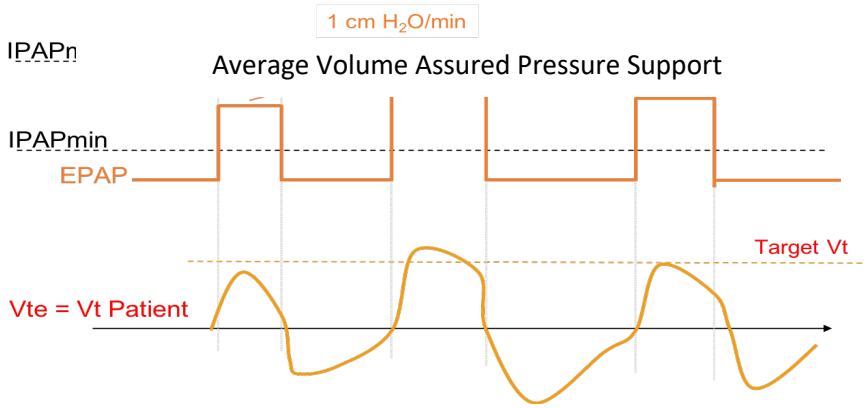
AVAPS Algorithm

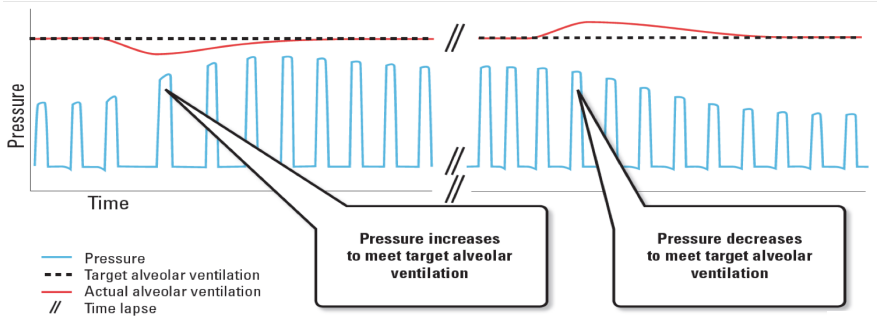


AVAPS targets a tidal volume

Changes IPAP slowly over several breaths

We typically target 6-8 cc/kg

iVAPS Algorithm



Intelligent Volume Assured Pressure Support

iVAPS targets an alveolar ventilation

Set patient height

Target alveolar ventilation: typically 6-8 cc/kg

Changes IPAP breath to breath

How should I set the EPAP?

- EPAP 4-5 is usually sufficient; the majority of NMD patients do not have upper airway obstruction.

If you do need to adjust EPAP:

- Trilogy has "AVAPS-AE" (AE = Auto-EPAP) mode
- Astral has iVAPS with AutoEPAP mode

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Case continued:
You see Michael back in the office after starting on home assisted ventilation. He continues to cough but feels that it is harder to expectorate sputum. He also notes some mild dysphagia and history of two episodes of pneumonia in the last year.

Question 5: What are other aspects of your patient's neuromuscular disease that may impact his respiratory function? Let's focus on cough and airway clearance, bulbar symptoms, and sleep disordered breathing. What diagnostic testing might you order to assess for dysfunction?

***1.* Cough**

- Clinical evaluation: history of pneumonias, weak cough
- Diagnostic testing:
  - Peak cough flow (PCF) scale: [6]
    - Might be measured / calculated in PFT lab via spirometry
      - Calculated via spirometry FEF max (in L/s), multiply by 60 to obtain PCF
    - Normal: >300 L/min
    - Moderate: <270 L/min
    - Severe: <160 L/min
  - PCF can be done with a hand-held peak flow meter in clinic (patient coughs into peak flow meter, may need mask if unable to make good seal)
- Consider thoracic imaging (CXR, CT scan) if patient has significant history of pneumonias
- Cough assistance is recommended if:
  - clinical history suggests difficulties with airway clearance
  - weak cough on exam
  - PCF falls <270 L/min
  - MEP < +60 cm H_2O

You obtain testing including a peak cough flow and barium swallow. Results are shown below.

Swallow evaluation: Conclusion: 1. Visible laryngeal penetration. This is intermittent and is completely extruded from the laryngeal vestibule.

Post Test Comments: Peak Force cough performed x 3 repeatable maneuvers. PFC= 126 lmp.....AT

	Pre-Bronch				Post-Bronch		
	Actual	Pred	%Pred	LLN	Actual	%Pred	%Chng
---- SPIROMETRY ----							
FVC (L)		4.79		4.00	*0.45	*9	
FEV1 (L)		3.93		3.28	*0.43	*10	
FEV1/FVC (%)		81		68	*96	*117	
FEV1/SVC (%)		82		68			
FEV3/FVC (%)		97		81	100	103	
FEF Max (L/sec)		9.38		7.83	*2.10	*22	
FEF 25-75% (L/sec)		4.02		3.36	*0.36	*8	
FEF 50% (L/sec)		4.76		3.97	*1.54	*32	
FIF 50% (L/sec)		5.45		4.55	*0.58	*10	
FIVC (L)					0.34		

PF Interpretation:

This is test of peak cough flow. Please see separate report for pulmonary function tests performed the same day.

The peak cough flow (captured under FEFmax) is 2.10 L/s, or 126 L/min. A peak cough flow <160 L/min is considered an ineffective cough.

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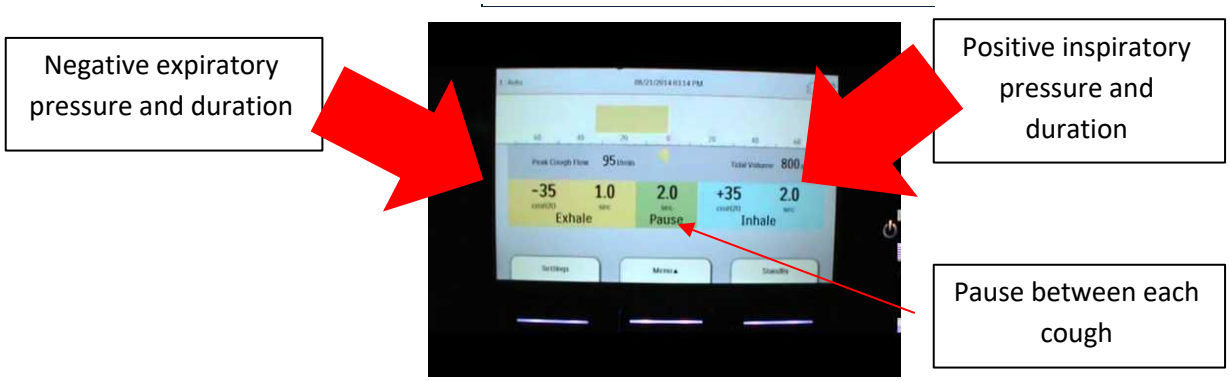
2. **Central airway clearance:** This is the mainstay of airway clearance for NMD, rather than peripheral airway clearance techniques (eg, vest) used for patients with suppurative lung disease like bronchiectasis. Consider vest for patients with cognitive impairment who are unable to tolerate MIE or manual cough augmentation.
   - Mechanical insufflator-exsufflator (MIE) aka "cough assist device"
     - Settings range: -20 to -40 and + 20 to +40
     - Timing: manual or auto; cough-trak
     - Daily use: "5 sets of 5" = 5 rounds of 5 simulated coughs each, repeated twice daily
     - Increase frequency of use during chest congestion
- **Manual Cough Augmentation –**
  - Concept of 'maximum insufflation capacity'. Shown to improve lung compliance and increase PCF. Techniques: glossopharyngeal (frog) breathing, manual insufflation with a resuscitator ambu-bag
  - Forced exhalation can be augmented by timed chest wall or upper abdominal thrusts as the patient volitionally coughs, quad cough

Phillips Respironics T70 – cough assist device



3. ***Swallowing and bulbar dysfunction –***

Clinical evaluation: dysphagia, choking on food, nasal tonality of the voice, dysarthria, oral accumulation of saliva, weight loss and weak cough

- Diagnostic testing:
  - Barium swallow, video esophagram, fiberoptic endoscopic evaluation of swallowing (FEES)

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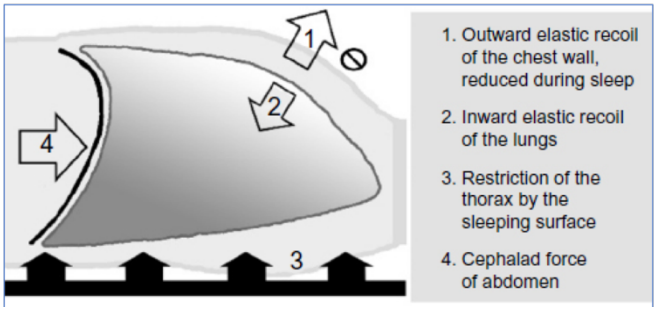
- Don't forget nutrition and the timing of the PEG.
- "Sweet spot" for PEG placement is likely before an FVC of 30-50%.
  - Risks increased when FVC<30%

Consider rapidity of progression of disease

Supine position reduces functional residual capacity of lung:



***4.* Sleep disordered breathing** –
The first signs of respiratory insufficiency occur during sleep when skeletal muscle tone is generally decreased, supine positioning hinders diaphragm function

- Clinical evaluation: Frequent nocturnal awakenings, inability to lay flat at night, daytime hypersomnolence, morning headaches, "brain fog"

- Diagnostic testing:
  - pCO2 [end-tidal (if tracheostomy); transcutaneous, arterial blood gas]
  - In-laboratory polysomnography with CO_2 monitoring
  - Overnight oximetry: cannot discriminate between hypoxemia secondary to obstructive apneas and hypoventilation

Case continued:
Michael returns to your clinic for follow-up six months later. He reports that since you put him on nocturnal NIV he has significantly improved energy during the day. He no longer wakes up with headaches. He has been using his cough assist twice daily with the assistance of his parents. He feels like it works well to help stretch his lungs, and he has not noticed any significant mucus.

<u>Question 6:</u> Michael is now pleasantly smiling. He and his family ask, "What's next?" What are your long-term monitoring parameters for patients with NMD?

i) Monitoring for respiratory complications of NMD

Baseline:

History:
- Issues with ventilator
- Sleep quality, morning headaches, daytime fatigue
- Coughing/airway clearance
- Swallowing dysfunction

Data:

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- Transcutaneous CO2
- Machine data download
  - Phillips Respironics: Care Orchestrator - online portal
  - ResMed: Airview – online portal
  - May need to download an SD card for some machines / models if modem not available
  - Mask leak
  - Tidal volume
  - Respiratory rate
  - Average IPAP versus Max/Min IPAP
- Polysomnography

Every 3-6 months:

History:
- As above

Data:
- Transcutaneous CO2
- Data download
- PFTs
  - Spirometry (upright and supine)**
  - MIP/MEP
  - Peak Cough Flow

Advanced considerations:
Some patients with NMD will require more than nocturnal ventilation.
Consider daytime ventilation when despite nocturnal ventilation: [10]
- SpO2 < 95%
- pCO2 > 45 mm Hg
- Dyspnea when awake
  (extrapolated from DMD guidelines)

Options for daytime ventilation include:
- Use nighttime mode continuously with same mask interface
- Add second mode (only with "heavyweight"' ventilators above) for daytime use, with a mouthpiece interface (thick plastic straw often referred to as a "sip" or "sip and puff" interface) → usually this is volume AC, 10-12 mL/kg, PEEP 0 and rate 0. Can be mounted to power wheelchair and allows patients to take a breath when needed
- Tracheostomy for invasive ventilation

Additional Information:

HELP! Who can I call with ventilator issues?

Clinical support lines for the devices (24 hours):

Phillips Respironics: 1-800-345-6443, option 4, then option 5

ResMed: 1-855-245-4640

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