

Respiratory Care of Patients with Neuromuscular Diseases

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Key Points

- Respiratory failure is the most common cause of mortality in patients with neuromuscular diseases (NMD).
- Ongoing, regular assessment of respiratory health is crucial for children with NMD.
- Airway clearance is essential to maintain their respiratory health.
- Assisted ventilation is required when hypoventilation develops.

Definition

- Neuromuscular disorders (NMDs) are a heterogeneous group of inherited or acquired diseases with different natural histories.
- Some patients with NMD will present acutely or subacutely with respiratory muscle weakness and failure.
- Other patients with more indolent NMDs develop slowly progressive respiratory failure.
- The most prominent and life-threatening complication of NMD is respiratory failure.

Pathophysiology of Respiratory Impairment in NMD

Respiratory Pump Dysfunction

- Respiratory failure is the most common cause of mortality in patients with NMD.
- Respiratory weakness is defined as the inability of the respiratory muscles to generate sufficient levels of pressure and flow to overcome the respiratory load.

- Alveolar hypoventilation will develop first during sleep and then will progress to involve wakefulness.
- Respiratory failure is contributed by several factors:
 - Low lung compliance
 - Low chest wall compliance
 - Reduced chest wall and/or lung compliance increases the load against which the respiratory pump has to work.
 - During infancy and early childhood high chest wall compliance results in energy being spent deforming the chest wall during breathing, leading to reduced tidal volume, increased work of breathing and atelectasis.
 - Increase upper airway collapsibility
 - Weak inspiratory and expiratory respiratory muscles lead to weak respiratory pump.
 - Inspiratory muscle weakness
 - Low tidal volumes, derecruitment of alveoli and subsequent atelectasis
 - Expiratory muscle weakness
 - Decrease cough efficacy, reduced clearance of airway secretions, mucus plugging
 - Bulbar (facial, oropharyngeal, laryngeal) muscle weakness leads to impaired swallowing and speech and increased risk of aspiration.
 - Respiratory muscles are more prone to fatigue in children with NMD.

Ineffective Cough

- Cough is crucial for clearance of airway secretions.
- Coughing consists of an inspiratory phase, contraction phase (glottis closure) and expiratory phase.
- In general, patients with NMD could have any cough component affected by muscle weakness, bulbar dysfunction, scoliosis, decreased chest wall compliance, or the presence of a tracheostomy, which leads to an ineffective cough.
- Improper airway clearance, especially with respiratory infections, will lead to mucus plugging causing
 - Atelectasis
 - Ventilation perfusion mismatch and hypoxemia
 - Pneumonia
 - Respiratory failure

Swallowing Dysfunction and Aspiration Lung Disease

- Aspiration is common due to dysfunction of larynx and pharynx and ineffective cough.
- Aspirated solids or liquids can come from above or below the airway opening:
 - From above during swallowing
 - The aspirated material can be solid and liquid food in orally fed children, saliva, and oral flora.
 - Drooling is an indicator of severe swallowing impairment.
 - From below during episodes of gastroesophageal reflux
- Chronic aspiration leads to
 - Lung inflammation
 - Worsening of restrictive lung disease
 - Recurrent aspiration can lead to bronchiectasis and pulmonary fibrosis
- Aspiration can be silent (absence of cough or other external signs) leading to recurrent pneumonia.

Atelectasis

- Patients with NMD are prone to develop atelectasis which can be inapparent (microatelectasis) due to:
 - Retention of airway secretions and ineffective cough
 - Aspiration episodes
 - Inspiratory muscle weakness leading to the loss of the ability to take periodic deep breaths (sighs)
 - Compression of the bronchi as they traverse bony structures leading to partial or complete obstruction.
 - Increased chest wall compliance early in life (before age of 4)
 - Atelectasis decreases lung distensibility, which causes the patient to breathe at lower lung volumes. Low functional residual capacity leads to progressive atelectasis, increasing the ventilation-perfusion mismatch and hypoxemic respiratory failure.

Respiratory Tract Infections (RTI)

- RTI in children with NMD reduces muscle strength, increases elastic and resistive load on the respiratory system and can precipitate acute respiratory failure.
- Acute viral RTI is well known to be associated with high morbidity and mortality.
- Upper RTI can lead to increased lower airway secretions, atelectasis, and secondary bacterial pneumonia.

Scoliosis

- Is a common feature in many NMD conditions as a result of muscle weakness
- Contributes to pulmonary complications associated with NMD such as
 - Decreased lung and chest wall compliance
 - Distortion of the thoracic cage and diaphragm leading to decrease in vital capacity
 - Affects cough effectiveness

Assessment

Clinical Assessment

Clinical assessment of respiratory health should be part of every medical consultation for children with NMD

- Pattern and progression of weakness
- Degree of ambulation
- Degree of muscle fatigability
- Change in strength of voice or a cough
- Drooling
- Choking with food
- Difficulties in clearing secretions
- Difficulties in chewing
- Presence of scoliosis, kyphosis
- Growth and nutritional status
- Frequency and severity of respiratory infections
- Symptoms of nocturnal hypoventilation
 - Disturbed sleep
 - Morning headache

- Daytime sleepiness
- Tachypnea at rest
- Fatigue
- Poor concentration
- Diminished school performance
- Symptoms relating to obstructive sleep apnea
 - Snoring
 - Breathing effort
 - Arousal

Spirometry

- Periodic monitoring of pulmonary function in NMDs is mandatory in children when they are able to perform the test after the age of 5 years.
- In patients with Duchenne Muscular Dystrophy, it has been recommended to do a yearly pulmonary function test in ambulatory patients and every six months in nonambulatory patients.
- Characteristic restrictive pattern present in pulmonary function test (PFT)
 - Reduced total lung capacity (TLC), vital capacity, functional residual capacity, and expiratory reserve volume in lung volume measurements; residual volume/TLC ratio could be elevated but not due to obstructive disease.
 - Reduced forced expiratory volume in one second (FEV1) and forced vital capacity (FVC)
 - Normal to elevated ratio of FEV1/FVC
 - Slow vital capacity (SVC) and maximum inspiratory capacity can also be used in young children who have technical difficulty in performing lung volumes.
 - Deterioration in lung function is a predictor and risk of significant morbidity and mortality in patients not receiving assisted ventilation or methods of assisted airway clearance

Cough Peak Flow (CPF)

- It is a measure of the maximum expiratory airflow achieved during a cough.
- It is a measure of expiratory muscle strength.
- Assesses cough effectiveness in children with NMD.
- CPF >160 L/min is necessary for effective secretion clearance and CPF >270 L/min is sufficient to clear secretions effectively during respiratory infection in children over 12 years of age and adults; equivalent threshold values for children less than 12 years of age are not available.
- Standard values of CPF for normal children 4-18 years of age are available.

Assessment of Respiratory Muscle Strength

- Maximal inspiratory pressure (MIP) and maximal expiratory pressure (MEP) are sensitive measurements of inspiratory and expiratory muscles strength, respectively.
- Sniff nasal inspiratory pressure (SNIP) is another measure of inspiratory muscle strength, specifically the diaphragm, and is easier to perform than MIP.
- MIP, MEP, and SNIP correlate with vital capacity and predict respiratory complications associated with NMD.
- Reference values are available for all measurements.

Blood Gases

- Daytime hypercapnia indicates hypoventilation during wakefulness and identifies patients with nocturnal hypercapnia.
- Daytime normocapnia does not exclude nighttime hypercapnia.
- Patients with respiratory failure will show hypoxemia and compensated respiratory acidosis with a raised PCO_2 and bicarbonate with normal or mildly reduced pH.
- Elevated serum bicarbonate suggests nocturnal hypoventilation.
- Increased end-tidal PCO_2 levels indicate the presence of hypoventilation either nocturnal (with a spillover effect to the morning) or day and nighttime hypoventilation.

Imaging

- Initial chest radiograph to have a baseline reference and to evaluate chest wall deformity.
- It can also be useful to evaluate for aspiration, atelectasis, pneumonia, cardiomegaly, and position of hemidiaphragms.
- Specific spine radiographs are needed to determine the degree of scoliosis.

Pulse Oximetry

- Oxyhemoglobin saturation (SpO_2) can be followed on a day-to-day basis.
- Normal SpO_2 while breathing room air generally indicates adequate gas exchange and minimal ventilation-perfusion (V/Q) mismatch.
- Hypoxemia could be caused by V/Q mismatch which can be associated with an elevated A-a gradient or caused by hypoventilation associated with a normal A-a gradient.
- If new-onset hypoxemia develops during the day in a clinically well patient, it is most likely related to alveolar hypoventilation; if it develops in an acutely ill patient with a viral disease, it is indicative of V/Q mismatch due to poor airway clearance.

Sleep Studies

- Assessment of sleep-disordered breathing should be conducted at least annually for all children with NMD with the following indications
 - Inspiratory vital capacity of <60% predicted
 - Loss of ambulation because of progressive muscle weakness or those patients who never attain the ability to walk
 - Infants with weakness
 - Symptoms of obstructive sleep apnea or hypoventilation
 - Diaphragmatic weakness
 - Rigid spine syndrome
 - Uncertain progression rate of the disease in young children or older children who show clinical deterioration or repeated infections
- Overnight polysomnography is the gold standard to diagnose sleep-disordered breathing and nocturnal hypoventilation.
- In places where sleep studies are unavailable overnight pulse oximetry can be performed. Overnight oximetry that shows $\text{SpO}_2 > 94\%$ is probably sufficient to exclude significant nocturnal hypoventilation in asymptomatic children with NMD but it doesn't exclude other sleep-disordered breathing not associated with hypoxemia.
- All children with abnormal overnight oximetry should undergo a sleep study.

Studies to Identify Aspiration Lung Disease

- No gold standard test exists to identify aspiration of food, liquid or oral secretions (saliva).
- If swallowing difficulties present, assessment of feeding should be done by a swallowing specialist (e.g., speech therapist) including video fluoroscopic swallow study (VFSS) or fiberoptic endoscopic evaluation of swallowing (FEES) if there is concern about the safety of swallowing.
- Salivagram is a tool that specifically diagnoses salivary aspiration.

Management

Airway Clearance

A combination of mucociliary clearance (secretion mobilization) and cough clearance (secretion extraction); patients with NMD have normal mucociliary clearance but an ineffective cough.

- Improving mucociliary clearance
 - Standard chest physiotherapy: Percussion and postural drainage (percussion and vibrations)
 - Intrapulmonary percussive ventilation (IPV) delivers high frequency mini-bursts of air (100-300+ cycles per minute) thus creating internal vibrations within the lungs; IPV helps in reducing rate of hospitalization and resolution of atelectasis.
 - High-frequency chest wall oscillation (HFCWO) device
 - Inflatable jacket attached to a machine to deliver high-frequency pulses of pressure to the chest wall provides intermittent compression of the chest wall using frequencies of 5-20 Hz.
 - HFCWO devices are widely used especially in the inpatient setting for children who have difficulty mobilizing secretions despite the use of other mucociliary clearance techniques. There is a lack of supportive literature to the use of HFCWO devices in uncomplicated NMD in the absence of documented bronchiectasis.
- Improving cough clearance
 - Secretion clearance needs an effective cough.
 - Assisting cough clearance can be achieved in two ways: manual cough assistance and mechanical cough assistance.
 - Manually assisted cough (MAC): Insufflating the patient to a maximal capacity using AMBU bag, glossopharyngeal breathing (breath stacking) or ventilator breath and then using an abdominal thrust or a thoracic squeeze to augment the patient cough.
 - Mechanical insufflation-exsufflation devices (MI-E), also called “cough assist” devices:
 - Provide positive pressure to the airway then rapidly shift to the negative pressure producing high expiratory flow resembling the mechanism of cough.
 - In conjunction with MAC during illness.
- Children with chronic aspiration who develop bronchiectasis will probably benefit from a combination of augmented mucociliary clearance from HFCWO therapy followed by MI-E.

Humidification

Should be considered in children who use non-invasive ventilation and who have tenacious airway

secretions.

Assisted ventilation

- Used in children with NMD to
 - Treat the symptoms of nocturnal hypoventilation
 - Treat the symptoms of daytime hypoventilation
 - Prevent and/or reverse alveolar derecruitment and help maintain lung volume (vital capacity)
 - Reduce the frequency of hospital admission for chest infections
 - Prevent chest wall deformity in young children with the expectation of improved long term outcome
 - Prolong life
 - Assisted ventilation is provided with the assistance of a pulmonary specialist or other specialist in long-term mechanical ventilation.

Non-invasive ventilation (NIV)

- Ventilation delivered via nasal mask, nasal pillows, facemask, or mouthpiece
- Children with NMD resulting in symptomatic nocturnal hypoventilation or daytime hypercapnia should be supported with NIV.
- Low pulmonary function values (assessed by spirometry) may provide other indications for initiation of NIV, even in absence of nocturnal symptoms or hypercapnia.
 - A pulmonary specialist can help determine the appropriate time to initiate NIV.
- NIV can be used as to bridge postanesthesia recovery to prevent complications, including atelectasis and reintubation in individuals with NMD.
- NIV is also used to tide over acute decompensation in viral respiratory illness.
- NIV has been proven to improve nocturnal hypoventilation.
- When established on NIV, children should be assessed regularly with sleep studies to ensure the effectiveness of NIV in preventing hypoventilation.

Invasive ventilation

- Mechanical ventilation via tracheostomy should be considered in the following conditions
 - Severe bulbar dysfunction
 - Significant intellectual disability
 - When there is failure to correct hypoxemia or hypercapnia with NIV
 - When high pressures are required to overcome reduced chest wall or lung compliance
 - Severe mid-face hypoplasia not correctable by adjusting the NIV interface
 - Family and child preference or poor tolerance of NIV

Oxygen

Oxygen alone should not be used to correct hypoxemia caused by hypoventilation in patients with NMD. If it is used in cases of V/Q mismatch, it should be used with caution and only in the setting of monitoring CO₂ levels as it can suppress respiratory drive and precipitate acute respiratory failure.

Scoliosis

- The primary consideration when planning surgery for children with scoliosis associated with NMD should be comfort and quality of life as surgery does not lead to improvement in vital capacity and whether it changes the decline in respiratory function is uncertain.

- There are no absolute contraindications for scoliosis repair. The decision to have surgery is based on the likelihood of preventing progression, improving the quality of seating, and avoidance of pain.
- It is critical that the patient's nutritional and respiratory status be optimized before surgery; post-operative management should involve NIV, airway clearance therapy and MI-E to reduce the incidence of atelectasis and pneumonia.
- Preoperative and postoperative use of non-invasive ventilation is strongly recommended for patients with a baseline forced vital capacity of below 50% predicted and necessary when FVC is below 30% predicted.

Problems and Interventions that Impact Respiratory Health

Excessive Oral Secretions

Drooling happens due to poor tongue control, swallowing dysfunction and dental malocclusion. Several measures can be used to alleviate the problem although with no evidence:

- Oral anticholinergic medications as glycopyrrolate, and hyoscine patches
- Ductal ligation of salivary glands in cases uncontrolled by medications

Gastro-esophageal Reflux

Gastro-esophageal reflux is common in children with NMD and may contribute to aspiration lung disease. Medications can be used to relieve the symptoms. Anti-reflux surgery is considered for reflux failed to respond to medical treatment. Fundoplication and gastrostomy insertion are undertaken by many centers for type 1 and severe type 2 SMA patients after diagnosis.

Nutritional Concerns

- Nutritional concerns may span from obesity to malnutrition over the course of life.
 - Obesity adds to the resistive load of already compromised muscles.
- Malnutrition becomes more prevalent with advancing age and is associated with ambulatory status and lower forced vital capacity.
- Malnutrition arises from feeding difficulties, dysphagia and gastroesophageal reflux.
- Gastrostomy is useful to maintain nutritional support in patients with NMD.
- Management of aspiration also involves determining the safest and most efficient route for caloric intake.
- Constipation is also one of the major problems leading to uncomfortable breathing, especially in nonambulatory patients.
- Stool softeners, laxatives, and stimulants are necessary if the patient has acute constipation or fecal impaction, and use of enemas might be needed occasionally.

Pain Management

- Effective pain management requires accurate determination of the cause.
- Back pain, particularly in the context of glucocorticoid treatment in patients with DMD is important and an indication for a careful search for vertebral fractures or other skeletal fractures.
 - The bone health of these children should not be overlooked as they are prone to significant osteopenia due to immobility and low exposure to sunlight.
- Interventions to address pain include physical therapy, postural correction, appropriate and orthoses, wheelchair and bed enhancements, and individualized pharmacological approaches.

Intervention during Viral Respiratory Illness

- During viral illness, look for common causes of oxygen desaturation, such as mucus plugging or atelectasis.
- Mechanical airway secretion mobilization and clearance with assisted coughing should be the first line of intervention.
- The mechanical insufflation-exsufflation devices (MI-E) or cough assist machine should be used as often as needed and pulse oximetry should be used to guide intervention.
- If there is no improvement and oxygen saturation is less than 94%, an airway-clearance treatment like IPV or HFCWO should be initiated along with cough assist device.
- Patient should be placed on their respiratory support device through Non Invasive interface.
- The use of NIV with aggressive airway clearance may decrease the need for endotracheal intubation.
- If airway clearance and respiratory support are optimized and hypoxemia continues, supplemental oxygen should be used.
- Oxygen alone should not be used to correct hypoxemia caused by hypoventilation in patients with NMD as described above.

Prevention of Infection

- All patients with NMD should receive the pneumococcal vaccine including 23-valent pneumococcal polysaccharide vaccine (PPSV 23) for children above 2 years, and annual influenza vaccine for children above 6 months.
- RSV immunoprophylaxis per American Academy of Pediatrics Guidelines and the ANGELS guideline, [Respiratory Syncytial Virus](#).

Multidisciplinary Team Approach to the Care of Children with NMD

- Children with neuromuscular diseases benefit from a coordinated multidisciplinary team approach including
 - Pulmonologist
 - Neuro-muscular specialist
 - Orthopedic specialist
 - Physical and occupational therapy
 - Respiratory therapist
 - Registered dietician
 - Palliative care
 - Home nursing
 - Genetic counselor

This guideline was developed to improve health care access in Arkansas and to aid health care providers in making decisions about appropriate patient care. The needs of the individual patient, resources available, and limitations unique to the institution or type of practice may warrant variations.

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