

Airway Clearance Dysfunction Associated with Cerebral Palsy: An Overview

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Cerebral palsy (CP) is a functional neurological disorder affecting more than half a million Americans.¹ Currently, it is the commonest cause of physical disability in children; approximately one-third of children with CP are identified as severely impaired.²

Cerebral palsy is not a disease. Rather, the term denotes a variety of clinical syndromes associated with nonprogressive abnormalities of brain development characterized by abnormal motor function and postural manifestations. Although CP cannot be cured, neuromotor impairment does not worsen during the patient's lifetime. In mildly to moderately afflicted individuals, life expectancy is not much lower than that of healthy cohorts.³ However, half of those severely affected with CP die before they reach the age of 20; many die in early adulthood.⁴ Such deaths are usually a result of secondary medical complications associated with primary neurological dysfunction. Respiratory infection and diminished pulmonary function rank as the chief causes of morbidity and mortality.^{5,6}

Etiology

Cerebral palsy is a condition that can arise at any time during brain development. Although its etiology is multifactorial, CP is usually linked to one of several prenatal, perinatal, neonatal or early childhood brain injuries or infections. Frequently, such injuries are sequelae of treatment for pulmonary complications associated with prematurity.^{7,8} The disorder occurs in proportion to the increasing rates of survival among low birthweight infants; incidence varies inversely with gestational age and/or birthweight, affecting approximately one significantly premature infant per hundred and one newborn infant per thousand.^{9,10,11} While the etiology of CP is not fully understood, recognized causes include prenatal infection with rubella (German measles), cytomegalovirus, toxoplasmosis and meningitis; Rh blood group incompatibility between mother and child; fetal stroke; severe asphyxia during delivery, as well as a range of complications associated with prolonged mechanical ventilation. CP may also be acquired postnatally as a result of stroke, head trauma, or brain infection.¹²

Clinical manifestations

Disabilities associated with CP range from mild to profound, and may include involuntary movements, poor coordination, problems maintaining balance, and difficulty executing voluntary movement.

CP is classified on the basis of motor symptoms¹³:

CATEGORY	CHARACTERISTICS	% OF CP POPULATION
spastic	muscle tightness; hemiparetic tremors	70-80
ataxic	intention tremors; poor balance/ coordination	5-10
athetoid	involuntary writhing movements; dysarthria	10-20
mixed	combination of above manifestations	N/A

Although CP is characterized by motor dysfunction, concomitant disorders of cerebral function are also common, including abnormalities of cognition, vision, hearing, speech, learning ability, attention, and behavior.¹⁴ Many individuals with CP also experience seizures.¹⁵

Pulmonary complications in CP

Individuals with CP suffer from a high incidence of recurrent pneumonia, atelectasis, bronchiectasis, and restrictive lung disease. Illness and premature death occurs most frequently as result of compromised pulmonary function and associated respiratory infections. While the condition itself does not directly cause pulmonary complications, the *consequences* of

neuromuscular dysfunction do.¹⁶ Most significantly, aspiration and ineffective cough may disrupt normal airway clearance, impair respiratory function, and precipitate lung damage, resulting in *increased* secretion production and *impaired* secretion clearance. Poor secretion clearance affects all components of normal mucus function. Consequent impairment of the pulmonary defense system increases susceptibility to serious, progressive, and ultimately life-threatening lung disease.

Normal Airway Clearance

Normal respiratory function requires open airways to permit efficient gas exchange and an effective mechanism to keep airways free of harmful pathogens. Respiratory mucus plays an essential role in the maintenance of good respiratory health. The chemical and physical properties of normal mucus function to prevent or fight infection and to provide appropriate humidification in the respiratory tract. Normal clearance of airway secretions requires:

- Effective cough reflex
- Functioning mucociliary apparatus
- Unobstructed airways

Airway clearance compromise in cerebral palsy

The high incidence of respiratory-related illness and death in CP is influenced by several interrelated pathophysiological factors associated with neuromuscular dysfunction. Although the significance of each of the following conditions varies markedly from individual to individual, people with CP are predisposed to the following life-threatening vulnerabilities:

- Chronic aspiration as a result of dysphagia, gastroesophageal reflux, and seizures
- Ineffective cough as a result of dyscoordination of bulbar muscles and weakness of the muscles of the abdomen and diaphragm
- Restrictive lung disease as a result of respiratory muscle weakness and spinal deformity
- Immobility as a result of muscle dyscoordination and weakness, frequently complicated by cognitive impairment

Aspiration

Aspiration, which involves the inhalation of secretions, vomitus, or foreign bodies into the lungs on inspiration, is the major proximate cause of lung injury in CP.¹⁷ Because saliva and gastric contents contain bacteria, aspiration introduces microorganisms into normally sterile airways. Although most individuals aspirate occasionally, pneumonia is uncommon due to the highly efficient host bronchopulmonary clearance mechanisms.¹⁸ The

efficiency of cough reflex, ciliary performance, integrity of interstitial lymphatics, local immunoglobulin production, and the scavenging ability of macrophages are crucial to the proper function of the body's bronchopulmonary clearance mechanism.¹⁹ However, aspiration poses risk of severe, often fatal pneumonia in individuals with CP.

Consequences of aspiration:^{20,21}

- Aspiration of particulate matter or large volumes of fluid may produce airway obstruction
- Chemical pneumonitis may develop after inhalation of gastric acid and other harsh compounds
- Pleuropulmonary infections ranging from simple aspiration pneumonia to necrotizing pneumonia and lung abscesses may arise from aspiration of contaminated oropharyngeal or gastric material.

Three conditions that occur commonly in CP greatly increase the risk for aspiration:

Dysphagia:

Dysphagia, or difficulty in swallowing, is a consequence of dyscoordination or weakness of the muscles associated with swallowing. A significant proportion, by some estimates up to 60%, of individuals with CP experience this complication.^{22,23} CP patients with dysphagia may exhibit drooping of the palate, a depressed gag reflex, pooling of saliva in the pharynx, a weak cough, and poor control of the tongue. Dyscoordination of swallowing results in choking and coughing while eating, frequently followed by aspiration.²⁴ Aspiration of oral contents introduces bacteria into normally sterile airways, resulting in pulmonary infection and lung damage. In addition to dysphagia associated with deglutation, salivary dysphagia secondary to drooling and labial incompetence may present a significant challenge in the management of CP.

Gastroesophageal reflux:

Gastroesophageal reflux (GER) occurs when a defective lower esophageal sphincter allows stomach contents to surge into the esophagus. Refluxed gastric contents, which contain both bacteria and caustic substances, are recognized as a significant cofactor in aspiration-related pulmonary deterioration.²⁵ The prevalence of GER in severe CP is extremely high; in a recent study, more than 90% of participants demonstrated some degree of GER.²⁶ Although precise explanations for the high incidence of GER in this population are lacking, factors may include abdominal

compression resulting from postural abnormalities and/or spasticity of the abdominal muscles.²⁷ Other causes include insufficiency of the lower abdominal sphincter with regard to mean basal tone, compromised by medications such as anticholinergics and sedatives, and incompetence of the antireflux barrier.²⁸

Seizures:

Seizures are recurrent disorders of cerebral function characterized by sudden, brief attacks of loss of consciousness and motor control. An estimated 30-40% of children with CP experience seizures early in life; that figure is greater among the severely mentally retarded, whose risk for aspiration and ensuing respiratory complications is high.²⁹

In addition to risks to pulmonary health posed by aspiration, disordered airway clearance in CP may also arise as a consequence of ineffective cough, restrictive lung disease, and immobility.

Ineffective cough

Coughing is an important component of respiratory health. Forceful expulsion of air from the lungs during a cough loosens, mobilizes, and clears mucus secretions. In CP, muscle weakness, spinal deformity, and consequent RLD result in a weak cough and ineffective airway clearance.

An effective cough generates a force sufficient to clear secretions and provide adequate airway defense. Such a cough requires inspiration or insufflation to 85%-90% of total lung capacity, followed by closure of the glottis for approximately 0.2 seconds. Simultaneous with glottis closure, the expiratory muscles, stretched by the volume of the inspiration, recoil, thus allowing intrapleural pressure to build up in the lungs. As a result of such pressure, when the glottis opens, mucus is sheared from the walls of the airway by expired gas at high linear volumes.³⁰ When cough function is impaired, the following may occur: 1) diminished inspiratory capacity as a result of diaphragm weakness or spinal deformity 2) poor coordination of the bulbar muscle, impairing closure of the glottis and the ability to build up intrapleural pressure and 3) poor coordination of the expiratory muscles, diminishing expulsive force and mucus shearing.

Restrictive lung disease (RLD)

Restrictive lung disease (RLD) is a breathing disorder resulting from impairment of the elastic properties of the lungs and chest wall and characterized by static or reduced lung volumes and capacities. In CP, the spine and thorax are typically deformed.³¹ Additionally, many individuals with neuromotor impairment exhibit poorly coordinated breathing

that relies on abdominal muscles instead of chest muscles.^{32,33} Eventually, chest movement is restricted and chest muscles are weakened. As a result, the ability to take a big breath, to generate expiratory force, and to cough effectively is impaired.

Immobility

In CP, neuromotor dysfunction may limit or prevent physical exercise, impairing ability to maintain aerobic capacity, bellows function, and lung volume.^{34,35} Physical exercise is an important component of normal airway clearance, increasing mucus elimination by as much as 40% compared to quiet breathing at rest.³⁶ For those peripheral airways not cleared effectively by coughing, exercise is the most important component of the clearance mechanism.³⁷ Obstruction of the airway by mucus plugs is the chief cause of atelectasis in children with neuromuscular disabilities.³⁸

Consequences of poor secretion clearance

The prevalence of chronic aspiration, restrictive lung disease, immobility, ineffective cough, and consequent atelectasis diminishes ability to clear secretions from the tracheobronchial tree. Poor secretion clearance affects normal mucus function, disrupting the physical, biological, and chemical components of the pulmonary defense system. Excessive or retained secretions undergo qualitative changes that make it thick, sticky, infectious, and eventually injurious to healthy lung tissue. When mucus accumulates in the airways, harmful consequences ensue, including:³⁹

- Retention of particulate matter, including pathogens
- Activation of inflammation
- Further cough impairment, resulting from mucus accumulation in the airways
- Airway obstruction, inhibiting O₂/CO₂ exchange

Inflammation

Inflammation plays an important role in overcoming infection and restoring lung health. When pulmonary defenses are impaired, however, microorganisms are poorly cleared, and the inflammatory mediators accumulate in increasingly high concentrations as illness escalates, jeopardizing the integrity of the lung parenchyma. Left unchecked, inflammatory disruptions in intercellular function progress until they result the overproduction and subsequent retention of airway mucus, thus initiating the classic vicious cycle of pulmonary decline.⁴⁰

Whether initiated by chronic aspiration and gastroesophageal reflux or by pulmonary infection, excessive inflammatory response is a major cause of respiratory decline in CP. Inflammation is characterized by the presence of inflammatory cells and various inflammatory mediators, including proteases, chemo attractants, cytokines, leukotrienes,

and others. The magnitude and persistence of inflammation contributes to the development of parenchymal lung destruction and pulmonary fibrosis.

Airway mucus: Response to inflammation

Airway mucus is a complex secretion that, together with the mucociliary transport system, serves primarily as a renewable and transportable barrier against inhaled or toxic agents. Disturbances of this defense mechanism, such as those caused by chronic inflammation, lead to mucus hypersecretion and its accumulation in the airways.⁴²

Retained secretions play at least two key roles in pulmonary pathology in CP:

- Retained secretions *physically* obstruct airways, leading to:
 - Infectious exacerbations and bacterial colonization, resulting from stagnation of secretions
 - Immobilization of cilia
 - Pulmonary overinflation
 - Ventilation /perfusion mismatch
 - Atelectasis
 - Airway obstruction
- Retained secretions *chemically* damage airways. Uncleared secretions contain high concentrations of cytotoxic inflammatory mediators, such as cytokines and leukotrienes, which can cause:
 - More mucus production
 - Intensified inflammatory response
 - Edema
 - Bronchospasm
 - Destruction of cilia
 - Progressive parenchymal damage
 - Irreversible fibrosis

Rationale for Airway Clearance Therapy in CP

In CP, pulmonary problems represent the major threat to both health and quality of life. Although a variety of factors impair normal airway clearance, the *primary focus* of respiratory management for individuals with CP must be to prevent mucus stasis that will lead to atelectasis and infection.⁴³ Aggressive attention to airway clearance is central to breaking the lethal cycle of recurrent infection and progressive pulmonary deterioration.⁴⁴

Optimizing outcomes

Airway clearance therapy is an essential component in the management of respiratory complications associated with severe CP.⁴⁵ To achieve optimal outcomes, however, it is critical to identify *at an individual level* which form of treatment is most effective.

Among physically able CP patients, exercise programs that encourage deep breathing, increase airway airflow rates, and stimulate cough may enhance secretion clearance.⁴⁶ For those who are severely spastic or non-ambulatory, however, airway clearance must be accomplished with therapeutic interventions.⁴⁷

An array of airway clearance modalities are used to treat individuals with CP, including chest physiotherapy (CPT), the Flutter[®] device, intermittent positive pressure breathing (IPPB), the in-exsufflator, and The Vest[™] airway clearance system.^{48,49,50} For treatment to be effective, choice of modality must accommodate individual patient requirements and capabilities. CPT, for example, is contraindicated when gastroesophageal reflux or inability to tolerate transient hypoxemia are factors.⁵¹ Likewise, its value is compromised by problems associated with spasticity, skeletal deformity, inability to perform breathing techniques, etc.⁵² Effective use of the Flutter[®] requires the ability to form a seal at the mouth and some strength, endurance, and cooperation in controlling exhalation. IPPB is useful for individuals unable to take a deep breath sufficient to initiate a cough, but does require ability to synchronize inspiration with the machine. The in-exsufflator may work well for individuals with weak respiratory muscles, but successful users must be motivated and able to perform required breathing techniques. The Vest[™] system, which loosens and mobilizes secretions by administering high-frequency chest wall oscillations (HFCWO), has been used effectively in clearing secretions and resolving atelectasis in CP and developmentally delayed individuals with and without tracheostomies.⁵³ Because it is a technique-independent method, The Vest[™] system is a practical choice for patients who are physically or cognitively unable to participate proficiently in airway clearance procedures.

Respiratory complications associated with CP are *avoidable* or *treatable*. Neglect of preventive pulmonary healthcare in individuals with CP results in increased morbidity and premature mortality, increased medical and axillary care costs, and, for both patients and their caregivers, diminished quality of life. For CP patients with secretion clearance problems, health and well-being depend upon careful assessment of pulmonary risk factors followed by an individualized respiratory health management program. For those with airway clearance dysfunction, treatment must include aggressive bronchial hygiene including daily airway clearance therapy.

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