Airway Clearance Needs in Spinal Cord Injury: An Overview

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In the United States, about 10,000 people annually suffer spinal cord injuries (SCI).[1] Eight thousand of those persons survive the acute injury period.[2] In 1997, approximately 200,000 Americans were living with SCI. That number is increasing as the management of such injuries and their complications improves. Nonetheless, the life expectancies of patients with SCI remains substantially below normal.[3,4]

Spinal cord injuries are devastating and create immense burdens for victims, their families, the healthcare system, and the taxpayer.[5] Five thousand of these injuries involve the cervical spine, resulting in permanent quadriplegia. Typically, patients are young. Eighty-two per cent of SCI patients are males and most are between the ages of 16 and 30. Accordingly, lifetime healthcare costs are enormous.[6]

In SCI, first-year mortality is high, but among those who survive one year, more than 60% will survive at least 14 years.[7] Surviving patients face a constellation of intermittent complications, among which respiratory problems are the most debilitating, costly, and life-threatening. Following spinal cord injury, cardiac, renal, and gastrointestinal functions are preserved. However, in the 50% of SCI patients whose injury involves the high cervical spine, immediate, life-threatening respiratory compromise occurs. Cervical spine injury (CSI) patients frequently require permanent tracheostomies and at least intermittent mechanical ventilation. Those with injuries above the C4 vertebrae suffer permanent respiratory paralysis. Patients with lower cervical (C6 to C8) and upper thoracic (T1-T6) cord lesions lose at least 60% of their inspiratory muscle strength.[8] In general, the higher the level of injury, the greater the respiratory compromise.[9]

Respiratory complications are the major cause of morbidity and mortality in patients who have suffered cervical spinal cord injuries.[10] The incidence of such complications is determined by a variety of interrelated factors present in varying degrees from patient to patient. Depending upon the classification of SCI patients included in respiratory complication studies, the rate of incidence is reported as ranging from 36% to 86%.[11] As a consequence of paralysis of the respiratory and other muscles, severely affected SCI patients will exhibit the following physiological predispositions to respiratory complications:

- restrictive lung disease (RLD)
- ineffective or absent cough function
- atelectasis as a result of secretion retention and RLD
- chronic aspiration as a result of dysphagia and exacerbated by ineffective cough
- pulmonary complications associated with immobility

Mortality among spinal cord patients most frequently follows repeated episodes of pneumonia, bronchial mucus plugging, atelectasis, and respiratory failure.[12]

Restrictive lung disease

Restrictive lung disease may be defined as 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. The reduced compliance of the chest wall combined with weakness or paralysis of the diaphragm and other inspiratory muscles reduces maximum inspiratory pressure and limits inspiratory and vital capacities.[13]

In SCI, the major cause of respiratory impairment is the loss of supraspinal control of respiratory muscles below the level of injury. Ventilation is a complex interaction between the muscles of the chest, abdominal wall and diaphragm. In SCI, restrictive lung disease exposes patients to high risk of serious or grave pulmonary complications. Paralysis of the inspiratory and expiratory muscles precludes unassisted ventilation. Loss of intercostal and accessory muscle function decreases

ventilation of the lungs and predisposes patients to atelectasis. Loss of abdominal and expiratory intercostal muscle function results in a diminished ability to cough and clear secretions. In some cases, paralysis and paradoxical chest and abdominal movements result in erratic breathing patterns and inefficient ventilation.[14]

In SCI, effects of the restrictive component on lung volumes and capacities are determined primarily by the level of injury. For the most part, patients may be classified according to the neurologic level of injury and the associated respiratory muscle pattern.[15]

High quadriplegics, defined as those with complete injuries above the C3 level, suffer from loss of diaphragmatic motion due to paralysis of primary inspiratory and expiratory muscles. Most such patients are permanently ventilator dependent.

Mid and lower quadriplegics, patients with spinal cord injuries between the C4 and C8 levels, retain function of their diaphragm and neck muscles. However, the main muscles of expiration, the abdominals, are paralyzed as well as the intercostals that assist in inspiration and expiration. Some voluntary expiratory activity may be generated via the pectoralis major (C5).

Paraplegic patients, those whose injuries occurred at levels between T1 through L1, may have loss of abdominal muscle contraction resulting in paradoxical breathing patterns. These patients have some intercostal muscle function depending on the level of the defect (T1 through T12).

Lumbar spinal injuries (L1 and below) suffer no impairment of respiratory muscle function and consequently little respiratory compromise. Such individuals may maintain good pulmonary function by following a modified exercise program.

Impaired or ineffective cough

The cough is a complex physiologic reflex which protects the lung from inhalation of irritants and cleans the airways of excess secretions and particulate matter. An effective cough consists of three phases: 1) an inspiratory gasp, 2) a compressive phase, and 3) an expulsive phase. The cough function may be impaired or ineffective in clearing mucus in diseases and conditions in which there are 1) diminished inspiratory capacity as a result of diaphragm weakness or spinal deformity, 2) weakness of the bulbar muscle, impairing closure of the glottis and the ability to build up intrapleural pressure, and 3) weakness of the expiratory muscles (intercostal and abdominal) diminishing expulsive force and preventing mucus shearing.

Because the innervation to the muscles involved in cough consist of nerves that arise from varying levels of the spinal cord, some SCI patients have partial control over these muscles and thus can cough, though with reduced efficacy. Such patients, as well as severely injured patients who lack cough ability altogether, must be supported by appropriate assisted cough modalities. In selected patients, cough may be elicited by manual methods or by electrical stimulation of paralyzed or impaired abdominal muscles.[16]

In SCI, absent or diminished ability to cough contributes overwhelmingly to the high incidence of respiratory complications. Spinal cord injury patients, especially those with higher level cord injuries and paralysis of the trunk and abdominal muscles, lack the ability to generate an effective cough.[17] As a consequence of absent or impaired cough and decreased lung volumes, SCI patients are at great risk for morbidities including pneumonia, atelectasis, and, as a result, respiratory insufficiency and, in severe cases, respiratory failure.[18]

The importance of mucociliary clearance therapy in patients who have lost cough function cannot be overemphasized. In the absence of cough, secretions gravitate back down the airways, resulting in aspiration complications and predisposing the patient to bacterial colonization and pneumonia.

Predisposition to atelectasis

Atelectasis is a state of atrophy and airlessness in a part or the whole of a lung, due to failure of expansion or resorption of gas from the alveoli. The condition may be acute or chronic. The affected area is often characterized by a complex mixture of airlessness, infection, bronchiectasis, destruction, and fibrosis. In atelectasis, inspiratory capacity is typically diminished, rales are detected on auscultation, and arterial oxygen levels are diminished. In the immediate post-trauma period, atelectasis is seen in 36.4% of SCI patients, pneumonia is diagnosed in 31.4% of those patients, and ventilatory failure in 22.6%.[19] After initial medical stabilization, atelectasis ranks as a less frequent yet significant pulmonary complication. Atelectasis may be both a cause and an effect of restrictive lung disease.[20]

In SCI patients, impaired cough leads to inability to clear secretions. When secretions cannot be cleared and become thick and purulent, atelectasis may occur. In numerous studies, the high incidence of post-traumatic atelectasis in SCI patients is associated with impaired secretion clearance.[21]

The risk of aspiration

Aspiration lung injury is caused by a failure of the normal protective mechanisms that prevent aspiration. There are three components to the lung injury. Initially, airways may suffer mechanical obstruction from particles in the aspirate. The second component, which occurs only when aspiration of acidic gastric contents has occurred, is a chemical injury to the airways, leading initially to bronchorrhea, airway constriction, and edema. Later, the risk of bacterial colonization as a result of impaired lung defenses is markedly increased. The third component is lung injury due to the inflammatory response. This process can evolve to an adult respiratory distress syndrome pattern.[22]

The following conditions, all of which may occur in SCI patients, contribute to the risk of aspiration:

- Dysphagia
- Glottic and tracheal stenosis
- Ineffective cough
- Gastroesophageal reflux

Dysphagia and spinal cord injury

Dysphagia is characterized by difficulty in swallowing due to impaired progression of food from the pharynx to the stomach. A normal, successful swallow involves the fine coordination of at least 25 different muscle groups in order for the food-saliva bolus to move from the mouth, past the openings of the airways, and through the esophagus to the stomach.[23]

All phases of swallowing can be affected by neuromuscular pathology. Motility problems occur either because impaired sensory input delays or prevents triggering of the swallow reflex, or because residue of the bolus remains in the pharynx due to poor muscle control. Although brainstem injury patients are usually ventilator-dependent and in many cases do not take nourishment by mouth, dysphagia remains a problem because of the aspiration of oral secretions. In addition, the lack of bulbar muscle function interferes with effective coughing. Consequently, frequent suctioning is required.

Ineffective Cough

Individuals with C2 to C4 injuries generally retain sufficient neck and bulbar muscle function to generate assisted cough flows, allowing them to use non-invasive alternatives to tracheostomy. Many such patients can manage oral nutrition.[24] Esophageal dysmotility and impairment of the swallowing reflex occur in other SCI patients and are dependent on the level and severity of their injury.[25]

Potential consequences of dysphagia: Serious, progressive lung disease

The immediate consequence of dysphagia is aspiration, or the passage of food particles, and/or saliva and bacteria from the oral cavity into the airways. Episodes of aspiration create environmental conditions ideal for bacterial colonization in the respiratory tract. Abnormal quantities of bacteria concentrate, multiply, and spread within the bronchial lumen, producing factors which facilitate their persistence and spread throughout the bronchial tree.[26] A host inflammatory response ensues. If the inflammatory response fails to eliminate the infection completely, it becomes chronic. Cumulative damage to the pulmonary defense system renders the patient vulnerable to recurrent, increasingly virulent episodes of infection, inflammation, lung damage, and further compromise to pulmonary defenses.[27] This sequence of events often is referred to as the vicious circle.[28]

Glottic and tracheal stenosis

A stenosis is a stricture or narrowing of any canal or passage in the body. Glottic and tracheal stenosis may be an acquired condition resulting as a complication of intratracheal intubation. In SCI patients, clinical symptoms of such airway constriction include aspiration, dysphagia, odynophagia, dyspnea, dysphonia, and hypersecretion of airway mucus.[29] Because a significant proportion of SCI patients are intubated during the acute phase of their injuries, and many remain so permanently, they are at an increased risk of developing glottic and tracheal stenosis and, consequently, are more likely to experience aspiration.

Gastroesophageal reflux

Gastroesophageal reflux disease is the term applied to the symptoms or tissue damage caused by the reflux of gastric contents into the esophagus. In normal individuals, mild gastroesophageal reflux rarely causes symptoms more troublesome than heartburn. However, among individuals with impaired airway clearance functions, the re-entry of partially digested food, gastric acids, and vomit into the pharynx can result in aspiration of these substances. Such patients may experience recurrent bronchitis, asthma In such clearance functions, the re-entry of partially digested food, gastric acids, and vomit into the pharynx can result in aspiration of these substances. Such patients may experience recurrent bronchitis, asthma symptoms, bronchiectasis, and laryngitis.[30] Aspiration of gastric acid may also result in chemical pneumonia, or Mendelson's Syndrome. The increased secretion production associated with Mendelson's Syndrome predisposes patients to bacterial infection, dyspnea, bronchospasm, and hypoxia.[31]

Immobility

All SCI patients suffer some degree of mobility impairment, but the implications for respiratory compromise vary widely. Overwhelmingly, however, patients with traumatic SCI represent a population with extreme inactivity.

Among the health consequences of immobility, impaired secretion clearance presents the greatest risk for SCI patients. Physical exercise is an important component of normal airway clearance, increasing mucus clearance by as much as 41%.[32] Exercise augments airway clearance in at least three ways. Exercise increases air flow through the lungs to help mobilize secretions, increases activity of the parasympathetic nervous system, thereby reducing the viscosity of secretions and promoting fluid secretion, and promotes the release and circulation of certain endocrine hormones which influence the volume and viscosity of secretions.[33] Importantly, exercise plays a major role in clearing secretions not effectively cleared by coughing from the peripheral airways.

SCI patients typically manifest both absent or ineffective cough function and impaired mobility. As a consequence, they suffer from secretion retention, rendering them vulnerable to bacterial colonization and a host of associated pulmonary complications. In SCI patients, the combination of neural damage, loss of respiratory muscle function, and immobility impair the patients ability to clear secretions. Pooled secretions lead to the development of intractable mucus plugs and the respiratory sequelae which rank as the chief cause of morbidity and mortality among both acute and chronic SCI patients.

Indications for airway clearance therapy

Spinal cord injury has a considerable effect on the respiratory system and pulmonary function. The majority of critically ill SCI patients are at significant risk of developing respiratory complications related to the retention of pulmonary secretions. Paralysis or impairment of the respiratory muscles and the inability to cough or breath deeply affect profoundly the physiology of normal mucociliary clearance. Other factors, including RLD, immobility, the complications secondary to the presence of an artificial airway, and altered consciousness are risk factors as well.[34] Among SCI patients, respiratory compromise continues to pose the major threat to health and survival. For patients dependent upon permanent or intermittent use of mechanical ventilation, aspiration increases the likelihood of oropharyngeal secretions passing into the airways and places them at high risk for serial incidents of aspiration pneumonia. Among long-term SCI patients, impaired cough, retained secretions, decreased lung volumes and diminished pulmonary functions predispose them to the development of atelectasis, bronchorrhea, and pneumonia.

A review of the literature demonstrates a consensus among clinicians treating SCI patients that health and survival are associated strongly with meticulous and vigorous pulmonary hygiene.[35] Clinicians and investigators conclude that in the management of SCI, bronchial hygiene therapy (BHT), including routine secretion clearance, is associated with increased survival, a decreased incidence of pulmonary complications, and a decreased need for ventilatory support.[36,37] During the past several decades, a number of techniques have been developed to enhance secretion clearance. Among these, the oldest and most frequently prescribed is the method called chest physiotherapy (CPT) or postural drainage and percussion (PD&P).

Chest Physical Therapy (CPT)

Chest physical therapy (CPT) is recognized as an effective method to clear proximal airways and, for many clinician, it is standard against which all other modalities are compared. CPT incorporates a number of maneuvers intended to mobilize bronchial secretions and optimize ventilation-perfusion (V/Q) relationships. those maneuvers include:

- Vigorous manual percussion applied to the chest and back to produce a shock wave through the chest wall to loosen bronchial mucus.
- Positioning of the patient in various postures on a slant board to facilitate gravitational movement and expectoration of mucus.
- Utilization of cough techniques, which involve holding the breath, emitting deep, hollow coughs, taking slow breaths through the nose, coughing again, and then expectorating.

Although CPT can be used effectively in the treatment of certain patient populations, for many SCI patients, its effective application as an airway clearance modality is problematic. For obvious reasons, CPT is inappropriate for use in unstabilized SCI patients.[38,39] In such patients, postural drainage positioning and percussion are positively contraindicated.[40] As rehabilitation progresses, percussion may be performed safely in SCI patients whose injuries have been stabilized, but implementation of the postural drainage component of CPT presents serious problems.

Drainage of the left lower lobe requires a 15° to 20° Trendelenberg, semiprone, right decubitus position. Drainage of the right lower lobe requires a Trendelenberg,

semiprone left decubitus position.[41] Limitations imposed by spinal cord injury often preclude the effective use of these positions. As a consequence, the lower pulmonary lobes are prone to accumulate secretions and mucus plugs. CPT per se has been associated with an increased incidence of gastroesophageal reflux.[42]

Even among stable SCI patients without contraindications, traditional CPT is frequently impractical. Such treatment, which is labor intensive and technique dependent, requires the services of a trained caregiver, often several times a day. Because SCI patients are completely or partially paralyzed, may suffer from altered consciousness, may be ventilator-dependent, and/or attached to medical equipment including feeding tubes, catheters, and IV lines, CPT may not be a realistic airway clearance option for many patients.

High Frequency Chest Wall Oscillation (HFCWO)

For many SCI patients, The Vest™ Airway Clearance System offers an alternative therapeutic modality that provides consistent, hospital-quality airway clearance. This method mobilizes mucus utilizing an inflatable vest, which applies rapid oscillation (HFCWO). The Vest applies HFCWO to both lungs simultaneously without the need for manual percussion or postural drainage. In cases where medical and physical limitations preclude the use of other CPT techniques, the Vest offers an ideal solution for managing airway clearance needs. The Vest has been shown to meet all of the recognized objectives of airway clearance therapy; it has been demonstrated to increase mucus mobilization and improve pulmonary function. Moreover, because Vest patients can receive pulmonary care at home, a reduction of medical costs may be anticipated.

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