Invited review

Noninvasive respiratory management of high level spinal cord injury

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This article describes noninvasive acute and long-term management of the respiratory muscle paralysis of high spinal cord injury (SCI). This includes full-setting, continuous ventilatory support by noninvasive intermittent positive pressure ventilation (NIV) to support inspiratory muscles and mechanically assisted coughing (MAC) to support inspiratory and expiratory muscles. The NIV and MAC can also be used to extubate or decannulate 'unweanable' patients with SCI, to prevent intercurrent respiratory tract infections from developing into pneumonia and acute respiratory failure (ARF), and to eliminate tracheostomy and resort to costly electrophrenic/diaphragm pacing (EPP/DP) for most ventilator users, while permitting glossopharyngeal breathing (GPB) for security in the event of ventilator failure.

Keywords: Spinal cord injuries, Tetraplegia, Glossopharyngeal breathing, Assisted cough, Mechanical insufflation–exsufflation, Respiratory therapy, Noninvasive mechanical ventilation, Electrophrenic pacing, Diaphragm pacing

Introduction to pathophysiology

Respiratory impairment results from either primarily lung/airways diseases, in which case pulmonary function testing (PFT) can be diagnostic and supplemental oxygen beneficial, or from primarily ventilatory impairment, most often from respiratory muscle dysfunction. The former is characterized by hypoxia in the presence of eucapnia or hypocapnia until an exacerbation results in acute respiratory failure (ARF). The latter is characterized by hypoventilation-induced hypercapnia and hypoxia with intercurrent episodes of ARF due to an ineffective cough. Unfortunately, physicians rarely distinguish between the two paradigms, but evaluate and manage both like lung/airways diseases. This often results in needless morbidity, avoidable airway cannulation, and unnecessary electrophrenic/diaphragm pacing (EPP/DP) for a waste of resources and compromised quality of life.

There are three respiratory muscle groups: the inspiratory muscles, expiratory (predominantly abdominal and upper chest wall) muscles for coughing, and the bulbar-innervated ('bulbar') muscles. The inspiratory and expiratory muscles can be completely supported

noninvasively such that even patients with no ventilator or EPP/DP-free breathing ability (VFBA) and 0 ml of vital capacity (VC) have used noninvasive intermittent positive pressure ventilation (NIV) for decades, as long as 58 years for one of our patients, without resort to tracheostomy. However, there are no effective noninvasive measures to counter bulbar dysfunction aspiration. Thus, the only indication for tracheotomy in an alert but 'unweanable' (unable to pass any pre- and post-extubation/decannulation spontaneous breathing trials) patient with spinal cord injury (SCI) is when saliva aspiration occurs to the degree that the oxyhemoglobin saturation (SpO₂) decreases and remains below 95% irrespective of optimal use of NIV and mechanically assisted coughing (MAC).¹ Fortunately, cooperative SCI patients, individuals without concomitant severe traumatic brain injury, rarely have bulbar dysfunction that causes loss of speech, deglutition, and adequate airway protection and are usually ideal candidates for noninvasive management.

Respiratory muscle aids

Inspiratory and expiratory muscle aids, i.e. NIV and MAC, are techniques that involve the manual or mechanical application of forces to the body or intermittent pressure changes to the airways to assist respiratory

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muscle function. Of the devices that act on the body, only the intermittent abdominal pressure ventilator (IAPV) will be discussed because negative pressure body ventilators are rarely, if ever, as effective as NIV. Negative pressure applied to the airway during expiration, however, assists coughing, just as positive pressure applied during inhalation (NIV) assists breathing. Continuous positive airway pressure (CPAP), although useful for patients with obstructive sleep apnea syndrome, is not helpful for managing hypoventilation. Likewise, airway and chest wall oscillation devices and vibration techniques will not be discussed since they do not directly act on the first six divisions of the airways to increase cough peak flows (CPF) to expulse airway secretions. Such techniques are designed to enhance the mucociliary function of the more peripheral airways for patients with airways diseases but not cough impairment.

Noninvasive intermittent positive pressure ventilation

Full, continuous ventilatory support using NIV is an alternative to tracheotomy and EPP/DP. It is delivered via lip seals, nasal, and oral–nasal interfaces for nocturnal ventilatory support. Lip seal and nasal NIV are open systems that require lower brain reflexes to prevent excessive insufflation leakage, especially during sleep;^{2,3} thus, supplemental oxygen and sedatives can render NIV ineffective. NIV can be introduced in the clinic or home setting.

There are numerous commercially available interfaces including ‘CPAP masks’ and nasal prong designs. Excessive insufflation leakage during sleep can be decreased by using a chin strap (Fig. 1) and avoided by switching to closed nasal prong–mouth covering systems (Liberty interface, ResMed, San Diego, CA, USA; Hybrid interface, Teleflex Medicine, Research Triangle Park, NC, USA). Such interfaces deliver air via mouth and nose and require minimal strap pressure. They also optimize skin comfort. Excessive leakage is also prevented by sustaining ventilatory drive by maintaining normal daytime CO₂ and avoiding supplemental O₂ and sedation. All interfaces designed for passive CPAP and bi-level positive airway pressure circuits with holes to vent CO₂ need to have the holes covered when used on active ventilator circuits with exhalation valves.

NIV via 15-mm angled mouth piece is the most important method of daytime ventilatory support. The mouthpiece can be kept between the teeth all day,⁴ but most have it fixed near the mouth by a flexible metal support arm attached to the wheelchair, or adjacent to

Figure 1 Soldier with SCI transferred from the Greek military to New Jersey for electrophrenic pacemaker (EPP) despite having 750 ml of VC and daytime periods of ventilator-free breathing. After the pacemaker was placed he was transferred to us and decannulated. He then permanently discontinued EPP and used mouth piece NIV during the day and nasal NIV at night with a chin strap (seen here) to reduce insufflation leak.

sip and puff, chin, or tongue controls on the motorized wheelchair (Fig. 2). The ventilator is set to deliver 800- to 1500-ml volumes to permit the patient to vary the volume taken from each ventilator cycle to augment speech volume, cough, and to air stack to expand the lungs. Some neck movement and lip function are needed to grab the mouth piece. The soft palate must move posterior–cranially to seal off the nasopharynx. In addition, the patient must open the vocal cords to maintain airway patency. These normally reflex movements may take time to learn for patients who have been using tracheostomy ventilation.^{5,6}

Rare patients who cannot grab a mouth piece for daytime NIV can use nasal NIV as a desirable alternative to tracheostomy.² Nasal NIV users learn to close their mouths or seal off the oropharynx with their soft palates and tongues to prevent oral insufflation leakage.

Figure 2 Chin control motorized wheelchair with 15-mm angled mouth piece adjacent to the mouth for easy access for patient dependent on continuous noninvasive ventilation (NIV) for 38 years, apparently the longest duration of NIV dependence for any patient with SCI.

Other than for an uncontrollable seizure disorder and inability to cooperate, there are no contraindications to the long-term use of NIV. Abdominal distention tends to occur sporadically in NIV users with the air passing as flatus once the patient is mobilized in the morning. However, aerophagia and abdominal distension before beginning NIV can be exacerbated by it and result in failure to use it effectively. Distension can decrease VFBA and necessitate passing a rectal tube or more frequently, a gastrostomy tube to 'burp' out the air.

The IAPV or 'Exsufflation Belt™' (Respironics International Inc., Murrysville, PA, USA) continues to be a useful daytime support. It involves the intermittent inflation of an elastic air sac that is contained in a corset or belt worn beneath the patient's outer clothing (Fig. 3). The sac is cyclically inflated by a positive pressure ventilator. Bladder inflation moves the diaphragm upward for a forced exsufflation. During bladder deflation, gravity causes the abdominal contents and diaphragm to re-descend and inspiration occurs passively. A trunk angle of 30° or more from the horizontal is necessary for this. If the patient has any inspiratory capacity or is capable of glossopharyngeal breathing (GPB), volumes of air can be autonomously added to each IAPV cycle. The IAPV augments tidal volumes by 300 to as high as 1200 ml; patients with less than 1 hour of VFBA often prefer to use the IAPV to NIV during daytime hours.⁷

Mechanically assisted coughing

Although often described as a complication or limiting factor for NIV and justification for tracheotomy, secretion encumbrance most often results from retention

Figure 3 Patient who was continuously dependent on tracheostomy ventilation for 2 years, decannulated, then managed for 15 years by daytime intermittent abdominal pressure ventilation (IAPV) and nocturnal lip seal ventilation, seen here with the hose of the portable ventilator entering his IAPV under his clothing. This patient died when he could not access mouth piece ventilation during an epileptic seizure.

of secretions that can usually be resolved by MAC. MAC is the combination of the use of mechanical insufflation–exsufflation (CoughAssist™ Philips-Respironics International Inc., Murrayville, PA, USA) with an exsufflation-timed abdominal thrust. Insufflations at pressures of 40–60 cmH₂O followed immediately by exsufflations to –40 to –60 cmH₂O are most effective and preferred.⁸ MAC can be provided via an oral–nasal mask, a simple mouthpiece, or via a translaryngeal or tracheostomy tube, preferably with an inflated cuff. Whether via the upper airway or airway tube, routine deep suctioning misses the left main stem bronchus about 90% of the time,⁹ but MAC flows can be effective in both left and right airways without discomfort or airway trauma and is invariably preferred.¹⁰

The CoughAssist™ can be cycled manually or automatically. Manual cycling to synchronize with the patient's breathing is necessary for patients who cannot cooperate with automatic cycling but it requires three hands, one to deliver an abdominal thrust, one to hold the mask on the patient, and one to cycle the machine. The goal is rapid clinically full chest expansion followed by rapid full lung emptying. One treatment consists of about five cycles of MAC followed by a short period of normal breathing or ventilator use to avoid hyperventilation. Exsufflation-timed abdominal thrusts are always used unless specifically contraindicated. Treatment continues until no further secretions are expelled and secretion-related oxyhemoglobin desaturations are reversed. Treatments can be required as

frequently as every 30 minutes almost around the clock during chest infections and for 1–2 days following extubation or decannulation.

Of the three muscle groups required for effective coughing, MAC can only take the place of the inspiratory and expiratory muscles. Thus, it cannot be used to avert tracheotomy when bulbar dysfunction results in continuous saliva aspiration and oxyhemoglobin desaturation, a situation rare in SCI. On the other hand, patients with completely intact bulbar function, such as for many patients with high level SCI, can usually air stack to volumes of 3 l or more, and, unless very old, scoliotic, or obese, a properly delivered abdominal thrust can result in assisted CPF of 6–9 l/s. These flow rates should be more than adequate to clear the airways and prevent pneumonia and ARF without MAC. Thus, the patients who benefit most from MAC tend to be older and with assisted CPF < 300 l/m.

Evaluation and management in the acute care setting

Most apneic individuals die at injury. Clinically, therefore, when ventilatory failure develops, it usually does so during the first week of hospitalization. However, invasive management can sometimes be avoided by using the principle that it is impossible to develop severe CO₂ retention or ARF when SpO₂ ≥ 95% in ambient air. SpO₂ < 95% indicates hypercapnia, airway congestion, and if the latter is not expeditiously cleared, intrinsic lung disease including atelectasis or infiltrate. Unfortunately, supplemental O₂ is typically administered without regard to the patient's PaCO₂ or SpO₂. It renders oximetry essentially useless as a gauge of alveolar ventilation and airway secretion status. In addition, sedatives, narcotics, and O₂ therapy dull respiratory drive leading to shallow breathing and exacerbated hypercapnia. Once secretions and hypoventilation cause distress, instead of using full-setting NIV and MAC, the patient is conventionally intubated. Intubated patients, even for a day or two, are usually told that tracheotomy is needed, especially when surgery and general anesthesia are planned or spontaneous breathing trials failed. This occurs even though some studies indicate that airway complications are more frequent for intubated patients undergoing tracheotomy than when simply maintaining intubation for up to 30 days.⁹ Even when not quickly undergoing tracheotomy, patients who fail ventilator weaning parameters and spontaneous breathing trials are usually wrongly informed that tracheotomy is necessary for extubation.

Rather than undergo PFT which, besides not being easily performed in critical care, is not appropriate for the SCI patient. Oximetry, end-tidal (EtCO₂) or transcutaneous carbon dioxide (TcCO₂) monitoring, spirometry, and CPF analyses are indicated for this population. The VC is most important for determining whether the respiratory condition is improving or worsening and likely to result in ventilatory failure. It should be measured every 8 hours until it is clearly not decreasing. If decreasing, a portable ventilator should be available to the patient for NIV at full support settings to relieve dyspnea and avert intubation for ventilatory failure.

No supplemental O₂ should be provided unless the SpO₂ cannot be normalized by NIV and MAC. It should be immediately determined if any desaturation is due to hypercapnia thereby indicating NIV, whether due to airway secretions and providing MAC until secretions are cleared and the SpO₂ returns to normal, or due to acute lung/airways disease for which the SpO₂ baseline cannot be re-normalized. Only in the latter case, confirmed by chest radiography, should intubation be considered. Patients are often intubated because of acute distress caused by airway mucus plugging that could have been cleared by MAC.

Uncomplicated patients managed by full setting NIV do not develop airway congestion or require MAC (Fig. 4).¹¹ Surgical interventions and general anesthesia necessitate intubation but not tracheostomy since these patients can be extubated back to NIV and MAC. Unfortunately, most acute SCI patients' conditions are complicated by traumatic brain injury, chest trauma, complicating orthopedic and medical conditions, anxiety, and/or narcotic therapy for pain management that dulls respiratory drive and renders NIV ineffective so that intubation is needed. Intubation should be maintained for up to a month if an unweanable patient is cognitively intact with functioning bulbar musculature and, thereby, has the potential to be extubated to NIV and MAC. We have successfully extubated 'unweanable' patients intubated for 77 days without clinically significant upper airway complications of the intubation.

More than 215 'unweanable' patients with neuromuscular weakness including 19 with SCI were extubated without resort to tracheotomy.¹² The patients had typically failed extubation at other facilities because of insufficient post-extubation ventilatory support and failure to use MAC. Upon arrival, baseline ambient air SpO₂ was below 95% because of hypercapnia/airway secretions. Ventilator settings were immediately adjusted to normalize EtCO₂ and aggressive MAC instituted up to every 30 minutes when awake. This almost

Figure 4 A 15-year-old patient with C3 complete motor SCI as a result of a diving accident, whose VC fell to 750 ml and PaCO₂ rose to 50 mmHg 24 hours after hospital admission. Initially he used a chest shell ventilator and within 24 hours his VC decreased further to 480 ml and he had no ventilator-free breathing ability. To accommodate Halo traction, he was switched to noninvasive ventilation (NIV). After trying nasal, oral, and lip seal NIV he chose to use mouth piece NIV (seen here) when awake and lip seal NIV for sleep. After 11 days of continuous NIV dependence, he weaned entirely over the next few days. Since he was not intubated, he never developed any airway secretion difficulties.

invariably returned SpO₂ baseline to normal within 24 hours. When other extubation criteria were also satisfied (Table 1), the patients with SCI were always successfully extubated.

Following removal of any naso- or orogastric tube, patients were extubated directly to NIV on assist/control 800–1500 ml, rate 10–14/minutes in ambient air. Volume cycling was used to encourage air stacking to maintain pulmonary compliance and facilitate coughing as well as to maintain normal lung ventilation. None of the patients with SCI had lost the ability to swallow food safely but for other patients who do, open gastrostomy can be done without intubation.¹³ All patients with pre-extubation VCs of 250 ml or more regained VFBA by up to 3 weeks post-extubation, however, some continued to require NIV during sleep. Patients whose VCs remained less than 250 ml tended to require continuous NIV indefinitely.

Post-extubation NIV is provided nocturnally via lip seal (Fig. 5), nasal, or oro-nasal interface. Daytime support is provided by 15-mm angled mouth piece (Fig. 2). Patients wean themselves, when possible, by taking fewer and fewer intermittent positive pressure ventilations as tolerated. For episodes of SpO₂ <95%, ventilator positive inspiratory pressure, interface or tubing air leakage, CO₂ retention, ventilator settings, and airway secretions are considered. The care providers and especially the family provide MAC via oro-nasal interfaces up to every 30 minutes until SpO₂ no longer dips below 95% and the patient remains clear of secretions. Extubation success is and was defined as not requiring re-intubation during the hospitalization. In our experience, the success rate using the protocol for first attempts at extubation in individuals with high cervical SCI and unable to pass spontaneous weaning trials either before or after extubation was 100% (19/19).

Table 1 Invasive and noninvasive respiratory management indications for spinal cord injured patients

Level of lesion	VC (ml)	Function, bulbar/neck		Ventilation, daytime nocturnal	
Above C1	0	—	—	TIV	TIV
C1–C2	<200	+	—	EPP/DP	EPP/DP/NIV
C3 or lower	>200	+	+	NIV/IAPV	NIV

Adequate neck function involves sufficient lip and neck control to rotate, flex, and extend the neck to grab and use a mouthpiece for NIV; adequate bulbar adequate bulbar function (+) prevents saliva aspiration to the degree that SpO₂ remains below 95%.

Figure 5 A 72-year-old woman with VC of 180 ml and no ventilator-free breathing ability, extubated to daytime mouth piece and nocturnal lip seal ventilation (Lipseal™, Phillips-Respironics International Inc., Murrysville, PA, USA).

All cases had post-extubation-assisted CPF ≥ 2.7 l/s despite unmeasurable VCs in some cases.¹²

Long-term management of slowly progressive respiratory dysfunction

For the patient without intrinsic pulmonary disease and with sensation, arterial blood gas sampling can be unnecessary, uncomfortable, and 25% of patients may hyperventilate from the anxiety or pain of the procedure.¹⁴ As in critical care, oximetry, EtCO₂, spirometry, CPF, and not PFT are required for long-term monitoring. Unassisted and assisted CPF are measured using an inexpensive peak flow meter (Access Peak Flow Meter, Healthscan Products Inc., Cedar Grove, NJ, USA). Post-extubation CPF > 160 l/m essentially guarantees successful extubation,¹² just as attaining 5 l/s indicates minimal risk of pneumonia during intercurrent respiratory tract infections.¹⁵

The manually assisted CPF is the flow obtained by applying an abdominal thrust that coincides with glottis opening after any patient with less than 1500 ml of VC air stacks to a maximally deep volume. The resulting flow is the assisted CPF. With the higher lung volumes by air stacking, assisted CPF of 4.3 ± 1.7 l/s were obtained in a general neuromuscular weakness population by comparison with 2.5 ± 2.0 l/s unassisted.¹⁶ In 28 evaluations of patients with SCI with assisted CPF < 300 l/m and mean age 47 ± 13 years, with mean VC in the sitting position 1031 ± 354 ml using accessory muscles and mean VC supine 512 ± 207 ml, the mean maximum insufflation capacity (MIC) was 1795 ± 948 ml, and although unassisted CPFs were 1.4 ± 0.6 l/s mean, assisted CPF were 3.5 ± 1.7 l/s. Although this can be the difference between coughing effectively to prevent pneumonia

and ARF or not, the low assisted CPF of these patients warranted access to MAC during intercurrent respiratory infections.

Indeed, all patients whose assisted and unassisted CPF cannot exceed 5 l/m should have oximeters at home for continuous monitoring and access to a CoughAssist™ for MAC to maintain SpO₂ $\geq 95\%$ during intercurrent infections.^{15,17} Any SpO₂ dip below 95% is due either to underventilation or bronchial mucous plugging which, if not promptly addressed, may result in atelectasis, pneumonia, and ARF.

For adults with infrequent chest colds, rapid access to MAC may be all that is necessary.^{15,17} Patients who have assisted CPF > 5 l/s when well may have ineffective flows when weakened by illness and still benefit from MAC. Such patients who have adequate access to manually assisted coughing at home rarely require MAC to avoid pneumonia. It can be argued that all patients with complete SCI should have oximeters at home since they can now be obtained for under \$25 and the first sign of desaturation warrants immediate attention.

The VC peaks at age 20 years for all people and then decreases 1% per year for men and 1.2% per year for women. Patients with SCI have diminished VCs because of at least some inspiratory and expiratory (abdominal) muscle weakness. With age they often develop symptomatic hypoventilation and possibly obstructive sleep apneas.^{18,19} This is especially true when obesity or scoliosis complicates the clinical picture. Hypercapnic patients not using NIV, and especially those receiving supplemental oxygen, can eventually develop carbon dioxide narcosis and ventilatory arrest. All symptomatic patients with diminished VC should be offered a trial of NIV to ease symptoms. When symptoms are questionable, home nocturnal EtCO₂ and SpO₂ monitoring that demonstrates CO₂ > 50 cmH₂O and multiple hourly desaturations below 95% indicates need for a trial of nocturnal NIV to clear symptoms and normalize blood gases. Simple daytime EtCO₂ measurement along with EtCO₂ or TcCO₂ and SpO₂ sleep monitoring are more appropriate than polysomnograms because the latter are not programmed to distinguish obstructive apneas from inspiratory muscle dysfunction and both are successfully treated by NIV (without expiratory positive airway pressure). When sleep-only NIV is no longer adequate and symptomatic daytime hypoventilation results in SpO₂ $< 95\%$, patients are instructed to normalize daytime ventilation. A finger oximeter can be worn and SpO₂ alarm set to 94%. The patient sees that by taking slightly deeper breaths, SpO₂ will exceed 95% within seconds and hypercapnia diminishes. The goal

is to maintain normal SpO_2 all day. This can be achieved by unassisted breathing for a period of time, and once tired, by mouthpiece or nasal NIV. With time, the patient requires increasing periods of NIV to maintain adequate ventilation. In this manner, an oximeter may also help to reset central ventilatory drive and NIV dependence can become continuous without hospitalization, ARF, or resort to tracheostomy. With aging and continued loss of VC some patients with SCI develop the need for around-the-clock NIV.¹⁸

Lung and chest wall mobilization

Pulmonary compliance diminishes along with VC and other lung volumes. Like limb articulations, regular mobilization is required to prevent chest-wall contractions and lung restriction. This can only be achieved by active (air stacking) or passive deep insufflations.

Air stacking is deep lung expansion by receiving consecutively delivered volumes of air via manual resuscitator or volume cycling ventilator and holding them with the glottis. If the lips are weak then stacking is done via nasal prongs or oro-nasal interface but this is rarely the case in SCI. The maximum volume held is the MIC and it, minus the VC, is an objective, quantitative indicator of glottis function and, therefore, bulbar function. Despite air stacking three times daily, often to pressures exceeding 70 cmH_2O , and along with NIV support for more than 50 years in many cases, only one case of pneumothorax occurred in more than 1500 NIV users. Patients who cannot close the glottis and, therefore, cannot air stack, must be passively insufflated at pressures of 40–70 cmH_2O by manual resuscitator with the exhalation valve blocked or by using the CoughAssist™. The maximum passive insufflation volume can be termed the ‘Lung Insufflation Capacity’ or LIC.²⁰

The primary objectives of lung expansion therapy are to increase the VC and to maximize CPF, to maintain or improve pulmonary compliance, to diminish atelectasis, and to master NIV. The 282 patients with

neuromuscular weakness had mean values of VC, MIC, and LIC of 1131 ± 744 , 1712 ± 926 , and 2069 ± 867 ml, respectively.²⁰ Patients with good bulbar function and air stacking ability often have MICs approaching their LICs and thus, usually do not require passive insufflation.

Patients with VCs less than 70% of predicted normal are instructed to air stack 10–15 times, at least two or three times daily usually using a manual resuscitator to pressures exceeding 60 cmH_2O or NIV provided by volume cycling on assist/control mode.

Glossopharyngeal breathing

GPB can provide individuals with no VC or VFBA with normal alveolar ventilation off the ventilator or when the ventilator fails day or night and GPB is a means for independent ‘air stacking’. With good bulbar function two-thirds of patients with SCI with no VFBA can use GPB for it.^{5,6}

The technique involves the use of the glottis to add to an inspiratory effort by pistoning (gulping) boluses of air into the lungs. The glottis closes with each ‘gulp’. One breath usually consists of six to nine gulps of 40–200 ml each (Fig. 6). During the training period, the efficiency of GPB can be monitored by spirometrically measuring the milliliters of air per gulp, gulps per breath, and breaths per minute. A training manual,²¹ and numerous videos are available,²² the best of which for patients with SCI was produced in 1999.²³ Since GPB is rarely useful in the presence of an indwelling tracheostomy tube, the safety and versatility afforded by it are additional important reasons to eliminate tracheostomy in favor of noninvasive management (Table 1).^{5,6}

Decannulation of unweanable patients

Conventionally, patients with high level SCI must wean from all ventilator use before decannulation is considered. However, patients may be sent home with

Figure 6 As for the majority of patients who can master GPB for ventilator-free breathing once they are decannulated, this patient, with no measurable VC, has 60–90 ml per gulp, 6–8 gulps per breath, 12 breaths per minute for 48 ml/gulp or 4760 ml/min of alveolar ventilation and normal PaCO_2 throughout daytime hours by GPB and a maximum glossopharyngeal single-breath capacity of 3500 ml.

Table 2 Extubation criteria for unweanable patients with SCI

- Fully alert and cooperative, receiving no sedative medications
- Afebrile and normal white blood cell count
- $\text{PaCO}_2 \leq 40$ mmHg at peak inspiratory pressures <30 cmH₂O on full ventilatory support and normal breathing rate, as needed
- $\text{SpO}_2 \geq 95\%$ for 12 hours or more in ambient air
- All oxyhemoglobin desaturations $<95\%$ reversed by MAC and suctioning via translaryngeal tube
- Chest radiograph abnormalities cleared or clearing
- Air leakage via upper airway sufficient for vocalization upon cuff deflation

tracheostomy tubes despite having intact bulbar-innervated muscles and being free of ventilator use. This is done because few clinicians consider objective criteria for either tracheotomy or decannulation. The ability to generate ≥ 2.7 l/m of assisted CPF, as an important determinant for adequate bulbar function and airway patency for successful decannulation,²⁴ indicates sufficient upper-airway patency and control to permit decannulation and effective use of MAC to clear airway secretions irrespective of VFBA. Assisted minus unassisted CPF, like MIC minus VC, is an objective quantitative parameter of glottis function and bulbar-innervated muscle integrity.²⁵

In 1990 and 1991 we and others reported the routine decannulation of over 50 high level SCI patients to NIV.^{5,6} The principles of decannulating unweanable patients are essentially the same as those for extubation.¹² As for intubated patients, all with tracheostomy tubes who had no VFBA with VCs of 250 ml or greater invariably developed VFBA in the days following decannulation. Tube removal also facilitated speech and swallowing. All decannulated patients preferred NIV to tracheostomy ventilation for convenience, speech, swallowing, cosmesis, comfort, safety, and preferred it overall.²⁶ An April 2010 consensus of clinicians from 22 centers in 18 countries reported 1623 NIV users of which 760 required continuous NIV to prolong survival by over 3000 patient-years without tracheostomies.²⁷ Four of the centers reported having routinely decannulated more than 200 unweanable patients with functioning bulbar musculature.

Phrenic and diaphragm pacing

Unlike NIV and MAC, EPP and DP represent high technology and cost and can greatly remunerate those who place the devices and the institutions that facilitate their placement and use but are unhelpful or unnecessary for many patients getting them. Table 1 demonstrates their place in SCI management. No EPP or DP publications^{28–31} have described the decannulation of paced patients even though many SCI patients without them have been decannulated to NIV despite having no VFBA. No EPP or DP publications have described improved autonomous respiratory function in SCI

subsequent to pacer placement either. Thus, patients who do not satisfy Table 2 criteria, that is, who have some diaphragm use and VFBA, might best be managed by decannulation and transition to NIV rather than be subjected to the cost and potential complications of pacing.³²

Conclusion

A new evaluation and management paradigm designed to assess and treat respiratory muscle function rather than lung/airways disease can permit successful extubation of unweanable SCI patients without tracheotomy and permit patients with ineffective cough to avoid pneumonia and ARF during respiratory tract infections. Tracheostomy decannulation is even feasible for patients with little or no VFBA, permitting most of them to learn GPB sufficiently for VFBA and relief from fear of accidental disconnection or ventilator failure. Thus, a paradigm shift is required for optimal and humane community management of patients with SCI who require ventilatory assistance.

In 2007, however, David Wootton published *Bad Medicine*,³³ which gave hundreds of examples of bad ideas triumphing over good ones and failures of physicians to make paradigm shifts that have resulted in hundreds of thousands of deaths. New paradigms are only considered when there is benefit, that is, financial incentive. There is clearly none for noninvasive measures since invasive interventions like tracheotomy and EPP/DP create revenue for physicians, nurses, and institutions. Tracheostomy ventilation most often results in lifetime institutionalization at \$330 000 cost to taxpayers per year, whereas discharge home using NIV with minimal nursing care is cheaper but benefits no one but the patient.

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