Mechanical aids for secretion clearance

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One in 3500 of the population may be expected to have a disabling inherited neuromuscular disease (NMD) presenting in childhood or in later life. Respiratory tract infections are a major cause of morbidity and mortality in this patient group. An effective cough is essential for secretion clearance and protection against respiratory infections. This review concentrates on mechanical aids and cough augmentation techniques to assist secretion clearance in NMD patients. Cough augmentation techniques have been shown to be safe and effective for increasing peak cough flow (PCF) in stable NMD patients and it is recommended they should be taught to all with an unassisted PCF <270 L·min^{-1}. Patients with an unassisted PCF between 270–245 L·min^{-1} will benefit from manual assisted coughing (MAC). When unassisted PCF is between 245–155 L·min^{-1} a combination of maximum insufflation capacity (MIC) and MAC should be used. In patients with unassisted PCF <160 L·min^{-1}, mechanical insufflation/exsufflation will be required. Whilst mechanical methods of secretion mobilisation techniques have been shown to be safe, there are no randomised long-term studies to evaluate the most effective method in patients with NMD.

The ability to clear broncho-pulmonary secretions is essential to prevent sputum retention and associated complications, including lower respiratory tract infection. An effective cough is a vital mechanism to protect against respiratory tract infections, which are the commonest cause of hospital admission in patients with respiratory muscle weakness due to neuromuscular disease (NMD) and spinal cord injury (SCI).[1] An effective cough requires an individual to be able to inspire up to 85–90% of total lung capacity, have intact bulbar function so that there is then rapid closure of the glottis for approximately 0.2 seconds, and subsequent contraction of abdominal and intercostal (expiratory) muscles to generate intrapleural pressures of >190 cmH_2O.[2] Upon glottic opening, there is an explosive decompression that generates transient peak cough flows (PCF) in adults of 360–1200 L·min^{-1}.[2] If one or more of the above components are impaired the cough will be less effective[3] and the individual may be unable to produce transient flow spikes that are essential for an effective cough.[4]

Secretions need to be in the larger airways for a cough to be effective. Secretion mobilisation techniques assist in mobilising secretions from the peripheral airways into the larger airways. This review will focus on non-invasive cough augmentation and secretion mobilisation techniques.

PEAK COUGH FLOW (PCF)

A normal PCF in adult patients is >360 L·min^{-1}.[5,6] In adult patients who have difficulty clearing secretions due to respiratory muscle weakness a minimum assisted PCF of 160 L·min^{-1} is required to clear airway debris.[1,7,8] A PCF of # 270 L·min^{-1} has been identified as a threshold for patients to be taught assisted cough techniques[1] as these patients are likely to deteriorate to the critical threshold of 160 L·min^{-1}. Poponick and co-workers[9] demonstrated that acute viral illness was associated with a reduction in vital capacity (VC) due to a reduction in inspiratory and expiratory respiratory muscle strength (by 10–15% of baseline values), which in turn causes a decline in PCF to the critical level of 160 L·min^{-1}.

PCF is a simple manoeuvre to perform; it involves the patient being encouraged to take a deep breath in and then cough into a peak flow meter via a full face mask or mouthpiece. Sancho *et al.*[10] reported that stable amyotrophic lateral sclerosis (ALS) patients with a PCF of >245 L·min^{-1} were able to clear secretions effectively with a manual assisted cough (MAC) and those with a PCF of <155 L·min^{-1} required mechanical insufflation/exsufflation (MI-E). It is important to bear in mind that in children, PCF will not reach adult values until age 12–13 in both sexes.[11] In paediatric patients MI-E was provided as part of a protocol in patients with a PEmax less than 60 cmH_2O.[12] However, these patients had a measured PEmax of 20 cmH_2O or less.

It is important to note bulbar insufficiency. When bulbar function is severely impaired and maximal insufflation capacity (MIC) is equal to vital capacity (VC), the chances of improving cough strength are poor.[13] Non-invasive methods of cough augmentation are likely to be minimally effective and it may be appropriate to consider other methods to manage the airway, for example tracheostomy if appropriate.

COUGH AUGMENTATION TECHNIQUES

Like non-invasive ventilation (NIV), non-invasive aids for secretion clearance were developed as a result of the polio epidemic in the 1940s and 1950s. In 1953 various portable devices were manufactured to deliver MI-E (e.g. OEM Cofflater portable cough machine, St Louis, MO, USA). The most commonly used MI-E is the CoughAssist™ (JH Emerson Co, Cambridge, MA, USA). Other devices recently marketed include the Pegaso, (Dimla Italia, Bologna, Italy) and Nippy clearway (B&D Electromedical, Warwickshire, UK) (see Figure 1). All these devices clear secretions by (gradually) applying a positive pressure to the airway (insufflation), then rapidly shifting to negative pressure. The rapid shift in pressure produces a high expiratory flow of 6–11 L·s^{-1}, simulating a natural cough.[14]

Beck and Barach[15] published a case report about MI-E, and its success with the immediate elimination of large amounts of purulent secretions, along with substantial clearance of atelectasis after 12 hours' treatment in a patient with poliomyelitis. These authors have also demonstrated clinical and radiographic improvement in 92 of 103 acutely ill patients with respiratory tract infections with the use of MI-E.[16] Potential side effects of MI-E were initially studied in 1956 by Beck and Scarrone.[17] They studied the cardiovascular effects of MI-E on patients and demonstrated an increase in mean heart rate of 17 beats per minute, along with an increase in systolic blood pressure of 8 mmHg and cardiac output of 2.1 L·min^{-1}; these changes have little clinical relevance in cardiovascular stable patients. MI-E has also been shown to produce electrocardiography changes that reflect the rotation of the heart that occurs during normal coughing.[17] Suri *et al.*[18] reported on pneumothorax, a small but potential side effect of MI-E as per the use of other positive pressure devices. These devices can be used in manual or automatic mode, and with an oronasal mask or via tracheostomy tube. Initially the device is set up to give pressures that are tolerated by the patient and then increased as tolerated to produce an effec-

tive cough. Garstang *et al.*[19] found 89% of patients with SCI preferred MI-E to suctioning; 89% also found MI-E faster, 78% found MI-E more convenient, and 72% found MI-E more effective than suctioning. Chatwin and Simonds[20] also found that the addition of MI-E to conventional airway clearance shortened treatment times in NIV dependent patients. Bach and co-workers have advocated high pressure spans (+40 cmH_2O to -60 cmH_2O),[8,21–25] while others report a good outcome with lower pressures (+30 cmH_2O to -30 cmH_2O[12] and +20 cmH_2O to -30 cmH_2O[5,26]).

The effect of the Emerson CoughAssist device on airway pressure rather than PCF was evaluated in a physiological study involving a paediatric population.[27] The authors measured airflow and pressure via a face mask during six cycles of a 2 second insufflation followed by a 3 second exsufflation, and concluded that the pressure measured at the mask was significantly lower than the pressure indicated on the CoughAssist device. This importantly highlights the inaccuracy between the pressure settings on the device and those measured at the mouth and therapists should be less anxious about the device's high pressure setting.

Mechanical insufflator/exsufflators are expensive devices and other cough augmentation techniques (singularly or in combination) may suffice instead. MAC may be used when expiratory muscle weakness prevents effective cough. The aim of the MAC is to increase expiratory airflow by either compression of the chest wall or abdomen (see Figure 2). Synchronous compression of the abdomen when the patient coughs causes a sudden increase in abdominal pressure; this causes the abdominal contents to push the diaphragm upwards, increasing expiratory airflow.[21,28] MAC is a simple effective technique that can be used anywhere and some patients are able to use their arms to perform their own MAC. MAC has been shown to significantly improve PCF in various groups of neuromuscular patients.[21,29,30] In stable state NMD patients with a PCF of >245 $L \cdot min^{-1}$ a MAC is likely to be adequate to clear secretions when they are unwell.[10]

If inspiratory muscle weakness is a problem then the patient will benefit from various techniques. The aim is to produce a MIC; this is the maximum volume of air stacked within the patient's lungs beyond spontaneous VC. MIC techniques include: breath stacking, intermittent positive pressure breathing (IPPB) and glossopharyngeal breathing (GPB). MIC can be augmented by a non-invasive ventilator set in volume mode or a resuscitation bag and mask with or without a one-way valve depending on the patient's ability to hold their breath. After the first assisted breath, the individual is instructed not to expire and to take a second assisted breath. This may be repeated for a further one to three breaths, to augment a greater inspiratory VC beyond that of the patient's spontaneous VC. MIC has been shown to be an effective method of increasing VC and PCF.[13,31–33] In patients with severe bulbar weakness, a passive deep breath in with a resuscitation bag can improve VC and may assist in coughing.[13]

IPPB is a technique used to augment lung expansion; it can be used to deliver aerosol medication but not long-term ventilation. IPPB delivers flow-triggered, time-limited inspiratory positive pressure.[34] In children with NMD, IPPB has been shown to increase VC and PCF[34] indicating that this can support the inspiratory component and augment cough.

GPB consists of a series of (6–10) pumping strokes produced by the action of the lips, tongue, soft pallet, pharynx and larynx. Air is held in the chest by the larynx, which acts as a valve as the mouth is opened for the next breath and expiration occurs by normal elastic recoil of the lungs and rib cage.[35,36] This resembles the breathing of a frog and is also known as 'frog breathing'. GPB has been shown to improve and maintain VC in patients with Duchenne muscular dystrophy (DMD), spinal muscular atrophy and SCI patients,[31,37–39] and has been used as a technique to increase PCF and thus cough strength.[31,39]

Figure 1. The most commonly used MI-E available in Europe: A. CoughAssist (JH Emerson Co, Cambridge, MA, USA); B. Pegaso Cough (Dimla Italia, Bologna, Italy); and C. Nippy Clearway (B&D Electromedical, Warwickshire, UK).

Most studies have compared an unassisted cough to MIC, MAC and MI-E.[5,8,29,31,34,40] Where MIC+MAC was compared to MAC and MIC alone there was a significant improvement in PCF of around 140 $L \cdot min^{-1}$.[30,33,41] Figure 3 shows a suggested algorithm for choice of cough augmentation technique, according to the individual's PCF.

SECRETION MOBILISING TECHNIQUES

Before encouraging patients to cough, it is essential to ensure any secretions are high enough to clear. Secretion mobilising techniques such as positive expiratory pressure (PEP), active cycle of breathing techniques (ACBT), and Flutter® (Clement Clarke International, Essex, UK) are of little use in patients with NMD as they are unlikely to have the mus-

Figure 2. Illustration of a Heimlich type manual assisted cough. The upper arm stabilises the chest and the lower arm performs a sharp inwards and upward movement pushing the abdomen upwards and thus increases expiratory airflow.

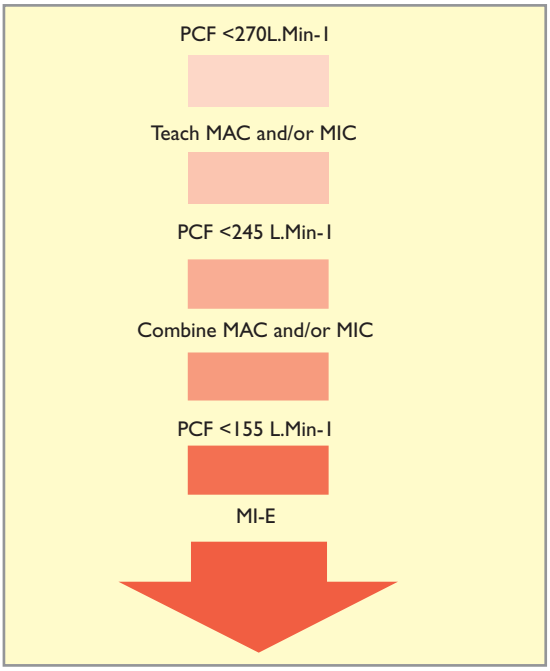

Figure 3. Suggested algorithm for choosing appropriate cough augmentation technique based on peak cough flow (PCF) (L·min-1). MAC = manually assisted cough augmentation. MIC = mechanical insufflation capacity; this includes techniques such as glossopharyngeal breathing, breath stacking with a resuscitation bag or volume cycled ventilator, or intermittent positive pressure breathing assisted insufflation. MI-E = mechanical insufflation/ exsufflation.

cle strength to perform the techniques effectively and there is therefore no evidence base in this area.

The ACBT can be modified in patients with NMD.[42] Thoracic expansion exercise (TEEs) can be augmented by increasing the pressure or volume on NIV and to provide a MIC before cough is initiated. Manual percussion and shaking can be combined with the TEEs in an attempt to shear off secretions. Airway clearance sessions consisting of modified ACBT with NIV have been shown to be effective in preventing oxygen desaturation compared to ACBT alone in adults and children with cystic fibrosis.[43,44] It has also been shown to clear secretions in patients with NMD whilst maintaining oxygen saturation.[20]

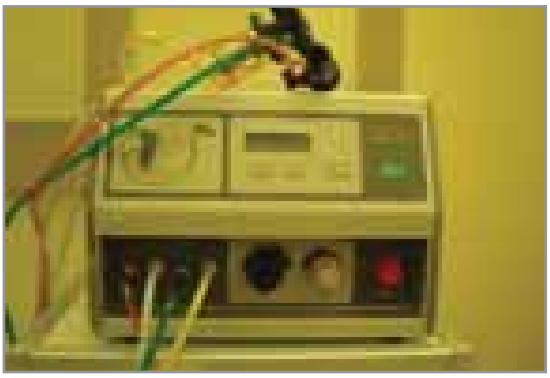

Figure 4. Intrapulmonary percussive ventilator, the IMPII (Breas Medical, Mölnlycke, Sweden).

Intrapulmonary percussive ventilation (IPV) is a modified method of IPPB. It superimposes high frequency mini bursts of air (50 to 550 cycles per minute) on the individual's intrinsic breathing pattern. This creates an internal vibration (percussion) within the lungs. Internal or external vibration of the chest is hypothesised to promote clearance of sputum from the peripheral bronchial tree.[45] IPV devices include: Impulsator®-F00012, IPV1C®-F00001-C, IPV2C®-F00002-C (Percussionaire® Corporation, ID, USA); and IMP II (Breas Medical, Sweden) (Figure 4).

Previous studies have investigated sputum mobilisation in CF patients by comparing the use of IPV to other modes of airway clearance e.g. postural drainage and percussion, high frequency chest wall oscillation (HFCWO) and the Flutter® device.[46–48] These studies have shown IPV to be as effective as the other methods of airway clearance in sputum mobilisation, when the amount of sputum produced was assessed by dry weight. IPV has also been evaluated in tracheotomised patients with DMD, compared to conventional physiotherapy consisting of the forced expiratory technique and MAC.[49] The patient group was divided into DMD patients who were hypersecretive, and those who were normosecretive; it was concluded that IPV enhanced peripheral bronchial secretion clearance in hypersecreative DMD patients compared to conventional physiotherapy. IPV has been shown to decrease the work of breathing in stable state patients with chronic obstructive pulmonary disease (COPD),[50] and that the energy expenditure of the diaphragm decreased at lower frequencies (250 c·min^{-1} *vs.* 350 c·min^{-1}) and higher pressures. It concluded that the device not only assists in secretion mobilisation but also provides some ventilatory support.

Other methods of HFCWO may have a role in secretion clearance. Some of these devices include the RTX (Medivent International, London, UK), SmartVest® (Electromed Inc, MN, USA), and The Vest® (Hill-Rom, MN, USA). At present there have been no randomised controlled trials evaluating HFCWO as a method of airway clearance in NMD patients. Calverley *et al.*[51] studied the effect of HFCWO on spontaneously breathing normal subjects. They found that at a frequency of 3 Hz and 5 Hz there was a decrease in the spontaneous minute ventilation with maintenance of normal oxygen saturation and carbon dioxide levels. Calverley *et al.*[51] hypothesised that HFCWO could potentially assist ventilation in spontaneously ventilating patients. Lange *et al.*[52] have compared lung function parameters in ALS patients who were randomised to 12 weeks of HFCWO or no treatment.[52] Results of a subset in the HFCWO group showed maintenance of FVC and decreased fatigue and dyspnoea compared to the untreated group. Further studies are warranted in this area to compare HFCWO to other secretion mobilisation techniques and to identify whether these devices can be used alone or in combination with NIV.

CONCLUSION

In summary, a variety of techniques are available for cough augmentation and these can be used alone or in combination to further improve PCF. To date there have been no long-term randomised controlled trials investigating which is the best method of cough augmentation. Current evidence does support the use of MI-E devices in adult NMD patients when unassisted PCF is less than 160 L·min^{-1}. Secretion mobilising techniques have been shown to be safe in patients with NMD but there are also little data on which secretion mobilisation aids are most effective.

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