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Workshop report

228th ENMC International Workshop: Airway clearance techniques in neuromuscular disorders Naarden, The Netherlands, 3–5 March, 2017

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The European Neuromuscular Centre (ENMC) convened the 228th ENMC Workshop on airway clearance techniques (ACT) in neuromuscular disorders (NMD) in Naarden, The Netherlands from the 5th to 7th March 2017. The meeting program is available as Online Supplement 1. While the need for ACT in NMD is well recognised clinically and recommended for some NMDs in guidelines [1–7], the paucity of comprehensive and comparable research has resulted in few recommendations that can be used by all people with NMDs, their families, carers and clinicians. The meeting therefore drew together clinicians, researchers and consumer representation from 12 countries to develop a consensus approach for the management of airway clearance techniques in people with NMDs across the lifespan.

Normal secretion movement occurs via a cephalad airflow bias [8] which occurs naturally in small airways during normal ventilatory breathing patterns. Flexible airways diameters widen on inspiration and narrow on expiration. Airway narrowing on exhalation increases linear velocity and shearing forces in the airway, resulting in a cephalad airflow bias during tidal breathing, deeper voluntary breaths and sighs. This bias is also a factor in larger airways, and may be amplified during a cough [8]. Typically, people with NMDs have no abnormalities of the mucociliary escalator. However, people with NMDs have weak respiratory muscles, predisposing them to shallow breathing and an ineffective cough with subsequent retention of secretions and further respiratory sequelae.

Secretion clearance may be enhanced by achieving a higher expiratory than inspiratory airflow bias. A greater expiratory flow favours secretion clearance, whilst a greater inspiratory flow bias favours secretion retention. In order to enhance secretion movement physiotherapists aim to create a peak expiratory flow rate to peak inspiratory flow rate that is > 1.1 [9].

When people with NMD become unwell, they typically modify how they manage their respiratory secretions. ***Johann Chaulet***, a patient representative, reflected and led the conversation regarding this issue by proving insights into his own airway secretion management during periods of respiratory illness or exacerbations. Eating can be harder and upper airway secretions often become bothersome and require more active management when unwell. The group provided clinical examples of the additional challenges posed by bulbar dysfunction when secretion load of the entire airway increases. The group unanimously agreed that training carers and patients in preparation for respiratory tract infections and the likely increased ventilatory support (using ventilator more or with altered settings, additional airway clearance techniques sessions balanced against fatigue, etc.) was desirable.

In optimally ventilated patient cohorts with NMD, airway clearance protocols that target a desaturation of less than 95% have been shown to result in secretion clearance and re-normalisation of oxygen saturation (SpO_2) [10–13]. Group discussion revealed that home use of SpO_2 monitoring in NMD was not routine and as such it is recommended where feasible. Further research is required to better understand indications, longitudinal outcomes and impact.

Two studies investigated the effects of a common cold in healthy [14] and in patients with NMD [15]. The NMD study reported a mean 20% and 40% decrease in inspiratory and expiratory muscle strength during colds, respectively [14,15]. During an intercurrent illness or infection, patients with NMD will typically experience a worsening of respiratory muscle

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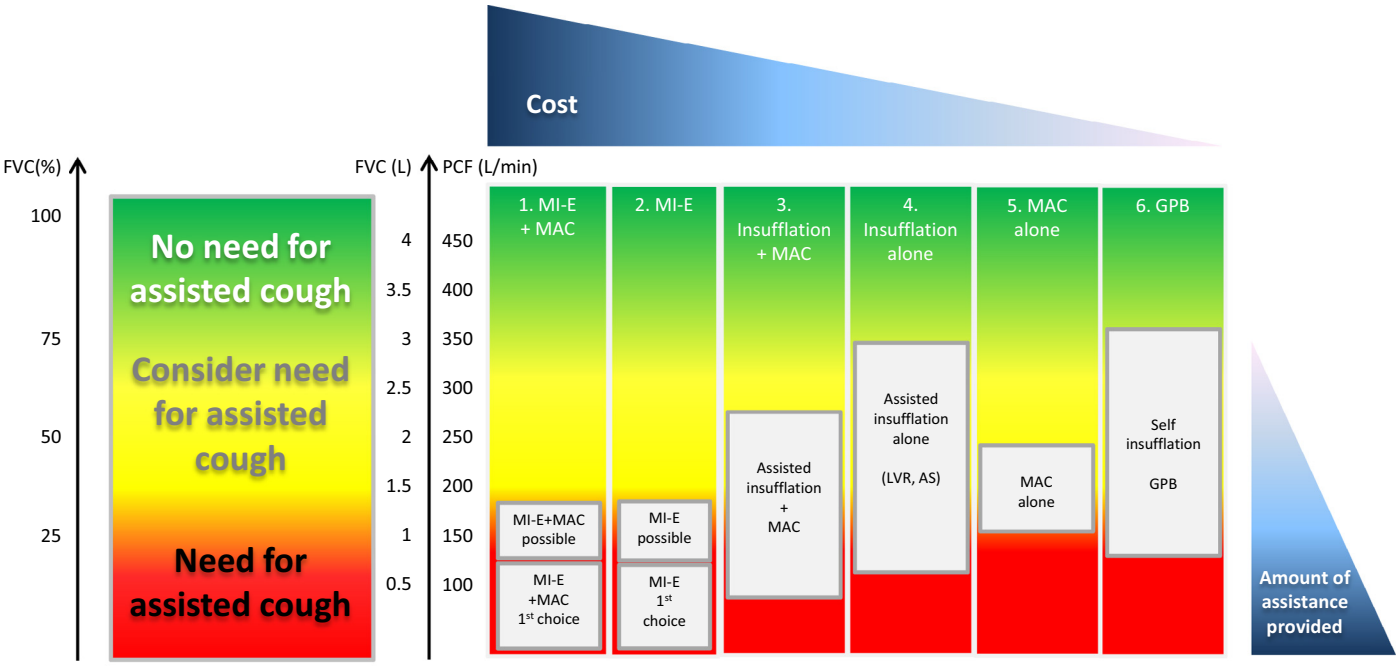

Fig. 1. Figure 1 seeks to integrate the published literature regarding critical values percent predicted FVC (%FVC, in all individuals), vital capacity (FVC, in adolescents and adults only) and peak cough flow (PCF, in adolescents and adults only), relative cost and the amount of assistance required for the initiation of proximal airway clearance techniques (cough augmentation) (excluding training costs and time). The values on the axes are intended to be used as a guide to practice in neuromuscular disease (NMD) as a group, but not as critical or threshold values in any individual patient with NMD and intact bulbar function. FVC% is the input axis to guide the reader. The ENMC participants considered individualisation of care critical for effective practice in NMD. The clinician can decide on what technique mechanical in-exsufflation (MI-E), manually assisted cough (MAC), air stacking (AS) lung volume recruitment (LVR) or glossopharyngeal breathing (GPB) to use depending on the following objective measurements: FVC% (in all individuals), and PCF and FVC in individuals 12 years and older. Therapy for the person with NMD must be individualised according to local availability, efficacy, comfort, tolerance and preference. Note that reported PCF values may be measured when patients are either well or unwell.

weakness, breathlessness and an increase in ventilatory dependency [16]. Young children often lose the ability to cry or they may develop new swallowing difficulties and an increased aspiration risk. Similarly, voice projection and swallowing efficacy may be impaired in adults. These effects may be reversible with resolution of the intercurrent problem, but often acutely render a previously effective cough, ineffective.

1. Airway clearance techniques in NMD

Lannefors identified that for effective secretion clearance, physiotherapists first need to (1) open up and get air behind secretions, (2) mobilize and collect secretions from the peripheral airways, (3) transport secretions towards the central airways and (4) evacuate secretions [17]. The first three components involve peripheral airway clearance techniques and the last proximal airway clearance techniques. Proximal airway clearance techniques (ACT) (also commonly known as cough augmentation techniques) are techniques that aim to improve cough efficacy by augmenting inspiration, expiration or both, whereas peripheral ACTs aim to improve ventilation and mucus transport from the peripheral to the central airways.

1.1. Proximal airway clearance techniques (cough augmentation techniques)

In patients with NMD, respiratory decompensation typically arises from an inability to effectively clear airway secretions, particularly during seemingly mild upper or lower respiratory tract infections [18]. An inability to cough effectively and clear secretions during these episodes places patients at risk of ventilatory failure. Normal pre-cough inspiration reaches 85–90% of total lung capacity and therefore assistance with inspiration can directly improve cough efficacy. Inspiratory assistance may be provided by devices and techniques that increase inspiratory volume and thus enhance expiratory flow bias during a spontaneous cough and thereby mobilise secretions [19]. These inspiratory assistance manoeuvres and techniques are often referred to as Lung Volume Recruitment (LVR). Fig. 1 seeks to integrate the published literature regarding critical values percent predicted FVC (%FVC), FVC, peak cough flow (PCF), relative cost and the amount of assistance required for the initiation of proximal airway clearance techniques.

1.1.1. Assisted inspiration in patients without bulbar dysfunction

1.1.1.1. Glossopharyngeal breathing. Both inspiratory and, indirectly, expiratory muscle function can be assisted by glossopharyngeal breathing (GPB). The technique involves the use of the glottis to add to an inspiratory effort by projecting (gulping) boluses of air into the lungs. The glottis closes with each "gulp". One breath usually consists of 6 to 9 gulps of 40 to 200 mL each either through the nose or mouth [20]. During the

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training period the efficiency of GPB can be monitored by spirometer measuring the inspiratory volume of air per gulp, and by recording gulps per breath and breaths per minute.

People with NMD can use GPB to assist them with a range of activities including improving cough efficacy and voice projection, and with both maintenance of external ventilator-free time electively and as a short-term emergency strategy if required. Importantly, not all people can learn to perform GPB effectively, with case series reports of between 27 and 80 percent of patients able to master the technique [21]. The meeting participants' clinical experience was consistent with this range of success and the group extensively discussed the challenges of teaching and of patient mastery of GPB.

Patients and therapists need to be aware that it may take a long time to master GPB, but success in teaching children from the age of six was reported [22]. Videos and mirrors can assist with skill acquisition, as can assistance from other experts such as speech and language therapists and peers with NMD who are already expert.

https://www.youtube.com/results?search_query=glossopharyngeal+breathing

Meeting participants reported observed increases in maximum inspiratory capacity (MIC) of up to five times the measured vital capacity (VC). The group agreed that patients able to master the technique reported that it "makes me feel safer" and that it is effective from their point of view. In patients who learn the method themselves the technique can be optimised with advice from the therapist.

There is little evidence to suggest what pattern of GPB might be better; fewer larger "gulps" of air or more, smaller ones. The group noted that patients use both strategies and thus their preference is clearly important, especially as there are little empirical data to guide practice however, fewer efforts may theoretically be less tiring in a particular patient who is struggling. While there are no data clearly describing which patient groups master GPB more readily, children especially have been known to develop the approach spontaneously. Glossopharyngeal breathing is an effective strategy in those able to master the technique, but there are both those who cannot do GPB and even in people who can manage GPB, there are times when additional, external inspiratory support is indicated.

1.1.1.2. External assisted inspiratory support. In patients with advanced NMDs, deep lung insufflation has become primary management of insufficient cough. Beyond GPB, weak inspiratory muscles can be assisted by providing deep lung insufflations with positive pressure delivered through a "bagging (Resuscitation/Ambu bag or other LVR) circuit" (a resuscitation bag with a one way valve preventing expiration in the circuit) or a ventilator. The externally applied volume is typically pressure limited and the expiratory control remains with the participant and her/his glottis [23]. Breath-stacking is an LVR manoeuvre which utilises stacking of breaths by applying inspiratory pressure, transmitted to the airways through an airtight facemask or mouthpiece. This results in lung inflation, which is followed by a spontaneous or assisted forced expiratory manoeuvre [24,25]. The MIC delivered in this fashion can exceed predicted inspiratory capacity (IC) in people with intact glottic function, but it only approaches predicted IC in patients with moderate to severe glottic dysfunction. With complete loss of glottic closure, the MIC can no longer exceed VC and the technique becomes ineffective. At this point a single augmented breath to lung insufflation capacity (LIC) may be taught [26]. A description of the Breath Stacking technique can be found at http://www.irrd.ca/education/policy/LVR-policy.pdf

The group agreed that the overall aims of LVR were to increase alveolar recruitment, to maintain chest wall expansion and the range of motion and to augment cough efficacy. Different aspects were important to different patients at different times in their disease progression and the relative importance within patients also changes over time.

As with GPB, not all people with intact glottic function can effectively breath-stack. Toussaint et al [27] showed in a naïve population that 10% could not stack and others [23,28,29] have reported that up to 28% of patients are unable to obtain MIC with breath stacking. In those able to use breath stacking the lung volume improvements are inversely proportional to the starting PCF and VC [23,30].

In terms of safety, there are case reports of complications with externally applied lung insufflations [31,32] and a number of the conference participants reported personal clinical experience of isolated cases where the use of external assisted inspiratory support may have been associated with gastric distension or discomfort and pneumothorax. As the group noted, super maximal lung volumes have been clearly associated with barotrauma and volutrauma in the intensive care literature but the relationships in the spontaneously breathing, non-intubated patient are not well established.

The consensus committee discussed a number of issues and approaches to managing the potential risks associated with externally assisted inspiration. A number of participants include a pressure-relief value in the circuit that vents to atmosphere at defined pressure limit, for example at 40 mmHg. This was more commonly used during training and treatment dose titration but infrequently incorporated into routine, home-based care. The group discussed paediatric issues and while consensus of practice was not evident, consideration was given to provision of LVR that targeted the predicted VC (i.e. a 1L bag rather than a 1.5L bag), LVR that aimed to deliver sub-maximal volumes and consideration of developmental stages and needs. The clinical practice during training described by the meeting participants typically consisted of insufflation until resistance was felt by the therapist from the bag and questioning of the patient about comfort and tolerability. As such, it was agreed by the group that the recommended volume supplied by LVR, regardless of technique, should be the "maximum tolerable volume".

Lung insufflation can also be delivered using a volume cycled ventilator and pressure limited, flow-driven devices such as Intermittent Positive Pressure Breathing (IPPB). The clinical experience of the group was that the majority of patients who need breath stacking can be successfully taught the technique.

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As with all manual techniques, there are patient factors that may limit adherence and utility, particularly in terms of long-term, home use. Patient specific considerations include cognition and both formal and informal carer availability. Adaptations commonly in use include modifying how the bag is squeezed; leaning against a table or bag compressions using knees and the use of both formal and informal carers. Both multiple, stacked breaths and single large breaths are used clinically. Single breaths may have more utility in children (smaller lungs) and during respiratory infections or exacerbations. When unwell, the urgency to cough may not allow for multiple, stacked breaths and hence one large insufflation may be better but as always, much of the decision-making is driven by patient preference. The group also noted that manufacturer integration of adherence monitoring into LVR would assist greatly with both clinical practice and research.

1.1.1.3. Assisted expiration and assistance through both inspiration and expiration in patients without bulbar dysfunction. Expiratory Aids are a group of techniques that aim to further enhance cough effectiveness and secretion clearance through manually applied assistance during the expiratory phase of respiration or, more typically, cough. Expiratory aids can be applied alone or more usually after an assisted inspiration. The most common expiratory assistance techniques that are both reported in the literature and used in clinical practice are the manually assisted cough (MAC) and the exsufflation component of mechanical insufflation-exsufflation (MI-E) devices. The MAC can include a thoracic compression technique, abdominal thrust or combination of the two.

The meeting participants believed it is important to emphasise that combinations of inspiratory assistance and expiratory assistance are more effective in augmenting cough than expiratory aids alone. Various methods of insufflation have been studied; namely single breath insufflations (NIV [33,34], IPPB [35,36], insufflation component of an MI-E device [37]) and stacked insufflations (GPB [38], breath-stacking via a volume-cycled ventilator [28,33,39–41] and breath-stacking via an Ambu or lung volume recruitment bag [38,39,42]). Regardless of insufflation method, Peak cough flow achieved with combined techniques has been shown to be consistently greater than that with expiratory techniques alone. These data would suggest that coughing from an increased inspiratory capacity is critical for improved cough effectiveness.

1.1.1.4. Mechanical insufflation-exsufflation. A specific technology that is widely used to assist with secretion clearance and cough is Mechanical insufflation-exsufflation (MI-E). MI-E delivers positive inspiratory airway pressure followed by a rapid switch to negative pressure. While the use of these devices is common, their use by patients is highly variable. The meeting participants reported the full range of patient use from regular daily prophylaxis to "putting it in the cupboard" after prescription; experiences consistent with published qualitative data [43]. The meeting participants discussed this heterogeneity of use and while consensus as to the reasons for it was unable to be obtained, both limited evidence and respect for patient preferences were frequent themes.

A previous systematic review of controlled trial use of MI-E [44] failed to demonstrate conclusive benefit, whereas a recent review incorporated case series, cohorts and other less rigorous pre-post trial designs [45]. All 12 included studies in the more recent review provided no data regarding survival, two studies (21 patients) found no change in hospital length of stay, two studies found a decrease in respiratory exacerbation rates and across a number of studies, improvements in quality of life were observed (>100 patients) however, the heterogeneity of the measures employed made summary difficult [45]. No study objectively measured sputum quantity or encumbrance and an improvement in PCF was a consistently reported benefit. Despite these limitations, most relevant, international guidelines recommend the use of MI-E. The ENMC meeting participants were supportive of further research into MI-E but no clear strategy emerged.

People living with NMD, their families and their carers clearly manage the need for cough assistance on a daily basis. These needs are not fixed and change with ageing, during respiratory exacerbations and with disease progression. These changing needs and capacity likely influence the range of ways that people use MI-E "in the real world" [43]. Considering there is no clear scientific evidence supporting effective dose, this individualised, patient-centric approach was supported by the meeting.

The ENMC meeting participants are clinical content experts and their clinical experience of the use of MI-E are included below to highlight practice and/or special considerations.

- Face masks, rather than mouthpieces should be used
- Attention to a good seal from the sides, not just "more pressure onto the face".
- Optimization of both inspiratory and expiratory pressure and flow, particularly if the application of MI-E was associated with new or worsening of bulbar control (laryngeal adduction) and cough efficacy.
- If the individual flow and pressure profile induce a swallow after retrograde movement of the tongue, then consider a single cough and pause rather than a series.
- In patients with intact bulbar function, the ability to perform MI-E effectively through a tracheostomy was considered a good prognostic indicator for successful decannulation.
- Start MI-E low and rapidly titrate up with tolerance and evaluate the efficacy of the resultant cough by measuring peak cough flow and by listening to the quality of the resultant cough.

1.1.1.5. Proximal ACT in children. Practice appears to vary more widely in paediatrics, with much based on first principles and local experience. Relatively higher inspiratory flow rates appear more common in infants and children with time and pressure settings generally higher in older children. To minimise the risk of peripheral airway closure in younger children, the switch from insufflation to exsufflation is typically continuous and asymmetrical MI-E pressures (expiratory higher than inspiratory) are often employed.

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It was considered important to note that even low target inspiratory pressures may be effective, as long as they are coupled with higher inspiratory flows. Beginning with pressures of 20 to –20 cmH_2O or +20 to –40 cmH_2O was suggested by the group with increases as tolerated to gain an effective cough. Higher pressures are employed with infants in some centres however, as with much of the infant and paediatric literature, the practice is poorly supported by evidence.

1.1.1.6. The patient with NMD and bulbar dysfunction. Compromised upper airway function impacts on breathing, swallowing, coughing and speech. Severe bulbar dysfunction and glottic dysfunction most commonly occurs in patients with ALS/MND, SMA type 1, and the pseudobulbar palsy of central nervous system etiology [46]. It is also more likely to develop as NMD disease progresses and as such requires modification of ACT. The meeting discussed the application of peripheral and proximal ACT in bulbar dysfunction across the entire meeting, usually in the context of clinical situations that would complicate application of ACT.

Of note, "bulbar dysfunction" is a relatively non-specific term as in any one person with NMD there may be excessive saliva production, combinations of upper and lower motor nerve impairment (with associated spastic and flaccid muscles), integrative neuromuscular control issues and mechanical upper airway dysfunction. Similarly, there is substantial heterogeneity across individuals with NMD. This variability complicates clinical research and reinforces the need for an individualised approach to management.

Publications in ALS/MND who use MI-E [47,48] provide clear evidence for the need for individual titration of MI-E in patients with bulbar dysfunction. Both the inspiratory and the active expiratory phase of MI-E can lead to dynamic upper airway narrowing and/or closure resulting in a reduction, rather than the desired improvement in cough flow efficacy.

The meeting participants shared their individual approaches for increasing PCF in those with bulbar dysfunction and a number of common themes and approaches emerged from the discussion. It was suggested that, especially in patients with ALS/MND, manually assisted techniques are more effective than MI-E, but this changes and a manually assisted cough becomes relatively less effective and MI-E becomes relatively more effective with disease progression. As observed with NIV in MND/ALS [49], patients with both bulbar dysfunction and MND/ALS appear to benefit the most from MI-E but effective use of the technology is challenging in this subgroup.

1.2. Peripheral airway clearance techniques

A number of peripheral ACTs are described below. Unfortunately, and in common with much of the literature concerning ACT in NMD, the evidence base is not comprehensive and in most cases, clinical practice is extrapolated from cases series or small studies in discrete populations. This paper should thus be considered as a statement of best clinical practice based on available evidence and consensus opinion developed by content experts. Further, this review should not be considered exhaustive, rather a report on the techniques considered by the ENMC meeting participants.

1.2.1. Standard chest physiotherapy

Standard chest physiotherapy consists of postural drainage and manual techniques (percussion and vibrations). Chest percussion (chest clapping) is carried out using a hand, fingers or facemask and is generally well tolerated and widely used in babies, small children and in patients unable to cooperate with therapy. However there are no data available on effective chest percussion in weak patients with NMD.

1.2.2. Active cycle of breathing technique

The active cycle of breathing technique (ACBT) consists of breathing control, three or four thoracic expansion exercises and one or two forced expiration techniques [50,51]. The ACBT, in particular, but essentially all active and assisted ACT, can be modified for the patient with NMD. If a patient is breathless they can be supported with NIV or intermittent positive pressure breathing (IPPB) [52]. This has been demonstrated to be a safe treatment option in adults [53] and children with cystic fibrosis [54] and also in individuals with NMD [55].

1.2.3. Chest wall strapping

Chest wall restriction through the application of chest wall strapping (CWS) with elastic material has been demonstrated to be beneficial for lung secretion clearance. The principles and physiological effects of CWS are similar to other breathing techniques such as Autogenic Drainage [56]. The view of the meeting was that in NMD, CWS should be combined with NIV to maintain tidal volume.

1.2.4. Intrapulmonary percussive ventilation

Intrapulmonary percussive ventilation (IPV) refers to therapy delivered by machines that deliver short bursts of air into the airways to aid airway clearance. Bench studies have demonstrated expiratory to inspiratory flow ratios exceeding three, and as such IPV has a potential role as an ACT in NMD [57–60]. Patients with neuromuscular weakness have reported that compared to chest physical therapy, IPV is associated with improved airway clearance, less fatigue and absence of discomfort, however the data are limited [57,61]. There are also case reports of using IPV as an effective "rescue-therapy" after other forms of ACT have proven ineffective [62].

1.2.5. Positioning

Altering the body position has the ability to redistribute regional lung ventilation, providing perspectives for the treatment of unilateral/isolated lung infiltrations. In adults (>18y) the lateral position is associated with preferential dependent lung ventilation in patients with preserved diaphragmatic function [63,64]. In children (<18y) it was believed that the lateral position redistributes ventilation to the uppermost lung region, the opposite of adults, but more recent data suggests the effect is far more heterogeneous in paediatrics [65].

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1.2.6. High frequency chest wall oscillation

A number of devices are available that envelop the chest like a vest and apply high frequency chest wall compression (HFCWC) or oscillation (HFCWO) aiming to produce a transient / oscillatory increase in airflow in the airways such that secretions are mobilised proximally. There have been no studies that report patient adherence or the efficacy of these devices for secretion clearance in patients with NMD. As with all ACT, individual patient use of specific therapies is highly dependent on local resources and practice.

1.2.7. Positive expiratory pressure (PEP) and oscillatory PEP

Positive Expiratory Pressure is a small device that a patient exhales into. The PEP device maintains pressure during expiration and delays airway closure. Patients with NMD typically do not have the respiratory muscle strength to perform PEP therapy and there is no evidence for PEP efficacy in NMD.

1.2.8. Discussion on peripheral airway techniques

The group discussed that the devices are typically expensive and variably available throughout the world, but that if a recent paper suggesting a health economic benefit could be confirmed in other sites and jurisdictions [66], this may improve access. The meeting noted that the British Thoracic Society guidelines suggest oscillatory and percussive techniques should be considered in children who have persistent atelectasis not cleared with other techniques [1] and that HFCWC, HFCWO and IPV are advocated to mobilise secretions rather than to increase PCF [2]. The detailed results of the Murvey© online surveys are available as Online Supplements 2 (proximal ACT) and 3 (Peripheral ACT). As summarized above, there are a wide array of peripheral ACT, all with varying degrees of evidence and clinical practice to support them. What is clear however, is that the overall aim is similar throughout; to increase expiratory flow above inspiratory and to move peripheral secretions proximally.

1.2.8.1. ACT cost and effectiveness. In general, all peripheral ACT were perceived as inexpensive and available, with the exceptions of HFCWO and IPV (Fig. 2). Few peripheral ACT were considered by the 228th ENMC meeting expert group as effective in the management of people with NMD, and there was considerable variation amongst participants' scoring. IPV, positioning and CWS were considered the most effective peripheral ACTs, also feasible to implement and teach in infants and children. Breathing exercises, HFCWO, manual techniques and oscillatory PEP were considered to be moderately or minimally effective ACTs. HFCWO and IPV were rated as expensive and not readily available peripheral ACT, while all other techniques were considered to be inexpensive and easily available.

1.2.8.2. Physical cooperation, skills and teaching needs of the ACT. HFCWO, IPV, manual techniques and positioning were considered to require little cooperation, whilst breathing exercises and oscillatory PEP were thought to require substantial cooperation. CWS requires a moderate amount of cooperation. It was felt that the majority of peripheral ACT required skills from the therapist, with the exception of positioning, and somewhat for HFCWO. All peripheral ACT, except for breathing exercises, were considered relatively easy to teach. HFCWO, IPV, manual techniques and position were considered to require little cooperation. CWS is thought to require moderate patient cooperation and could be utilized if assisted with NIV support. Breathing exercises and oscillatory PEP were believed to require substantial cooperation and were therefore not recommended. The expert group suggested that breathing exercises could be combined with NIV.

1.2.8.3. Implementation of ACT in infants and children. Only IPV, manual techniques and positioning were felt to be easily and feasibly implemented in infants, whilst CWS was considered to be possible in this population. All peripheral ACT were considered possible to implement in children, IPV and positioning relatively easily but breathing exercises and oscillatory PEP were not considered easy to implement in this population group.

1.2.9. Conclusion on peripheral airway techniques

In summary, the consensus view was that "absence of evidence of benefit is not evidence of absence of benefit" and that particularly in children and in those less able to cooperate, manual and externally applied techniques have clinical utility, particularly if supported by NIV as required during secretion management sessions. The majority of peripheral ACT was felt to require specific therapeutic skills, with the clear exception of positioning, and the possible exception of HFCWO. The meeting participants also reinforced the need for attention to medical care of these patients with treatment of infection, bronchospasm, excessive salivation and other potential contributors to excess secretion load.

1.2.10. Pathway for assessment and decision-making for ACT in people with NMD

The meeting considered the need for a clear algorithmic approach to the assessment and subsequent approach to prioritisation of ventilatory/medical support and ACT management in people with NMD presenting to healthcare providers. The consensus, simplified, approach reached by the participants is presented in Fig. 3.

2. Future directions and research

One of the drivers for the 228th ENMC International Workshop on Airway Clearance Techniques in neuromuscular disorders was the acknowledgement that the practice of ACT in NMD is ahead of the science, and that as such, expert, consensus opinion was critical. It is apparent that controlled, clinical research into the efficacy, criteria for initiation and progression of ACT in NMD is required.

The peak cough flow (PCF) is considered a key marker of the effect of any ACT in NMD yet there is no internationally recognised standard for its measurement such as those from the American Thoracic Society and the European Respiratory Society for spirometry or muscle testing [67,68]. The meeting

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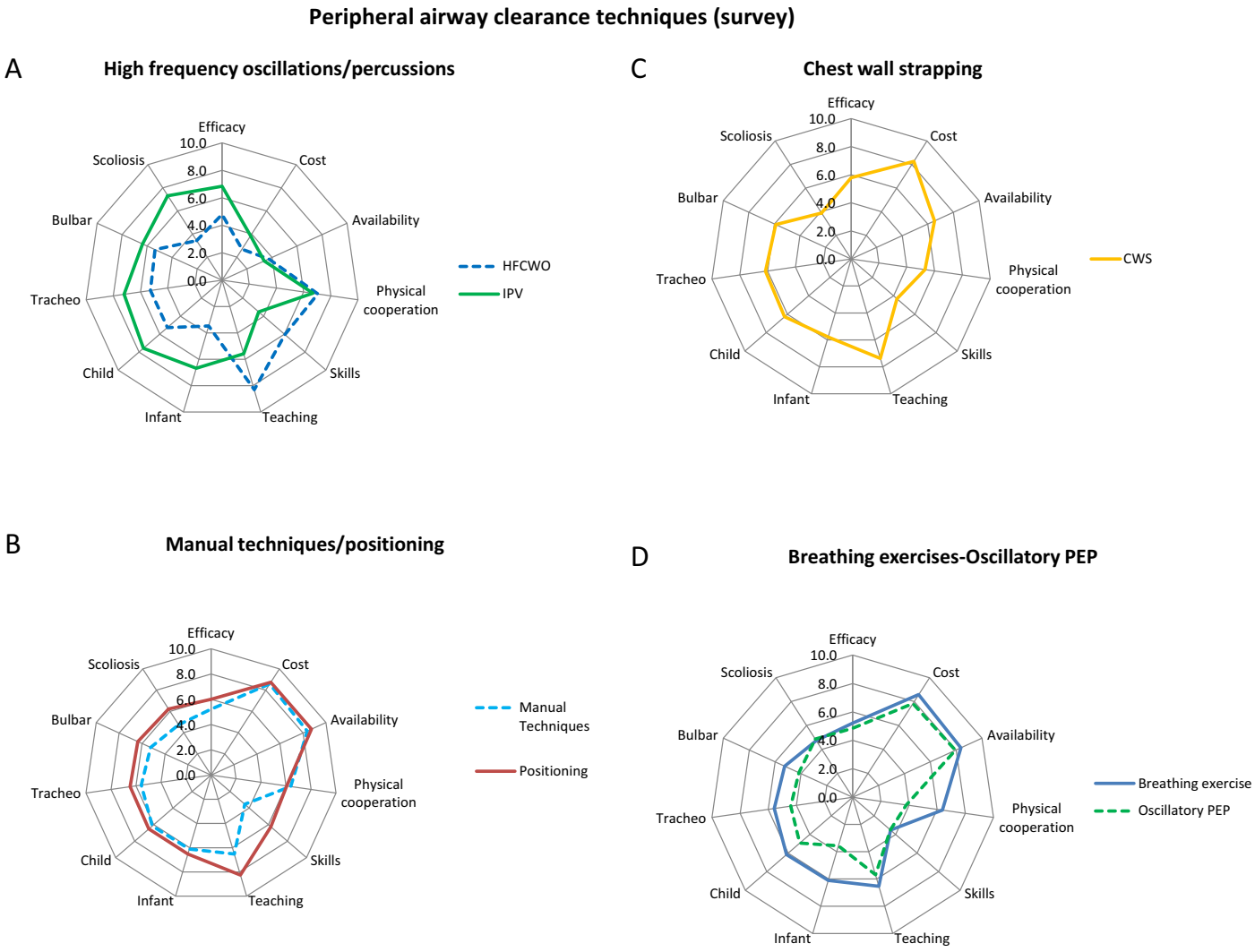

Fig. 2. The ENMC meeting participants' average rating of peripheral airway clearance techniques. Each of the 11 domains of utility was rated on a 10-point Likert scale, with higher scores indicating participant preference on all scales (for example, a higher "cost" score suggests the technique is less expensive). An online survey (Murvey© online surveys, https://www.murvey.com) was used to summarize the views of the meeting regarding peripheralACT. The participants scored each ACT on a 10 point Likert scale (0: not in favor; 10: in favor of the technique) across 11 domains. HFCWO: High frequency chest wall oscillation; IPV: Intrapulmonary percussive ventilation; CWS: Chest wall strapping; PEP: Positive expiratory pressure.
Peripheral airway clearance techniques (survey).

discussed the development of a PCF test process that would include device specification, instructions, normal ranges, etc. as a future research priority for the field.

The need for paediatric populations to be included in research was highlighted by the meeting participants as a specific evidence gap, as was consideration of a patient registry of proximal and peripheral ACT use in the community. Such a registry could include both clinician provided prescription information alongside patient-completed or device-downloaded usage data.

Much of the discussion centred on translational research questions. An exploration of the role of medical simulation for carer training and associated studies of outcomes and competency assessment for carers was suggested. A guidebook so that the "patient can feel safe at home" and different materials aimed at information dissemination so that patients can go to their clinical care providers and advocate for their own best treatment. These ranges of resources were believed to be essential for the best use of ACT in NMD to be fostered internationally.

3. List of participants

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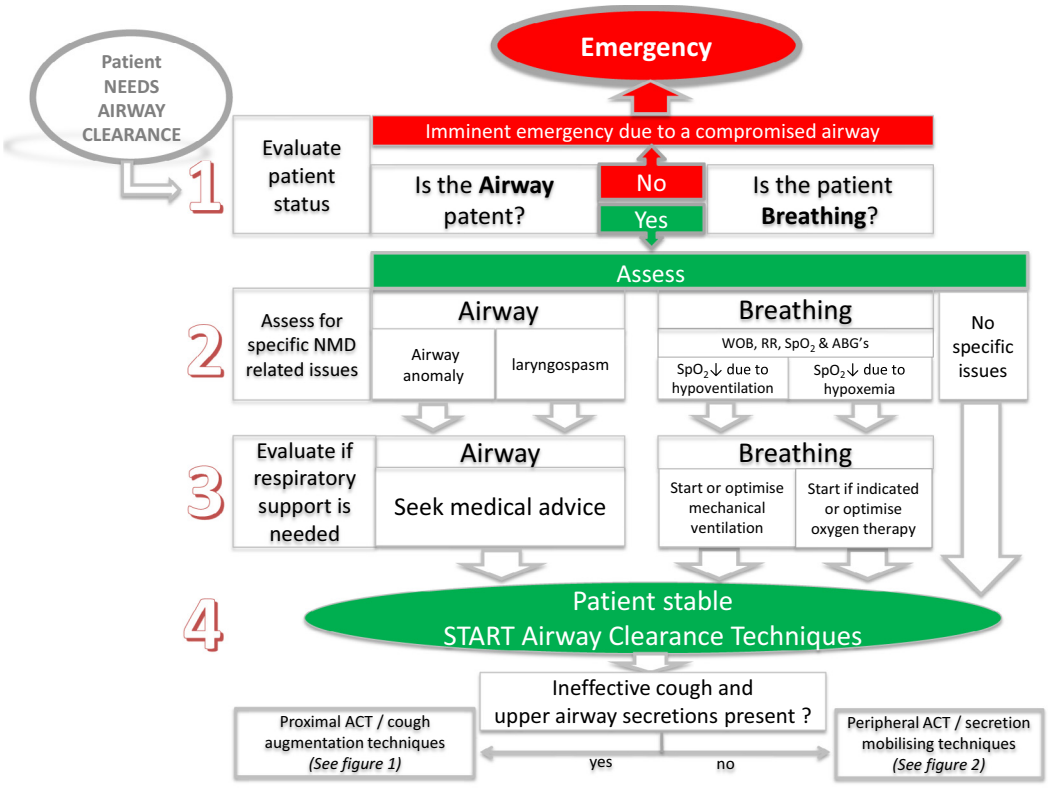

Fig. 3. Figure 3 shows a suggested approach to management for a patient with neuromuscular disease (NMD) that requires airway clearance techniques. Firstly, the clinician should evaluate the patient's status and decide whether it's an emergency situation or whether it is safe to go on and assess the patient. Airway anomalies may consist of tracheomalacia, stenosis, vocal cord dysfunction, etc. Laryngospasm may be more evident in patients with bulbar insufficiency due to amyotrophic lateral sclerosis or patients with multiple sclerosis. With regard to the assessment of breathing suggested measurements include where able: work of breathing (WOB), respiratory rate (RR), oxygen saturation (SpO_2), arterial blood gases (ABGs). These will assist in deciding whether respiratory support is required. Please note any individual with NMD who are given oxygen therapy should be closely monitored as they have the potential to retain carbon dioxide and become hypercapnic requiring ventilator support or optimisation of their settings. Once the patient is optimally managed then a decision about which airway clearance techniques (ACT) need to be performed can be made (see Fig. 1 and 2).

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Appendix: Supplementary material

Supplementary data to this article can be found online at doi:10.1016/j.nmd.2017.10.008.

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