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SERIES "NONINVASIVE VENTILATION IN ACUTE AND CHRONIC RESPIRATORY FAILURE"
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Noninvasive ventilation for chest wall and neuromuscular disorders

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Noninvasive ventilation for chest wall and neuromuscular disorders. J.M. Shneerson, A.K. Simonds. ©ERS Journals Ltd 2002.

ABSTRACT: Neuromuscular and chest wall disorders are individually uncommon but together form an important group of conditions that can lead to chronic ventilatory failure. This is best recognised in scoliosis, kyphosis, following a thoracoplasty, in muscular dystrophies, such as Duchenne muscular dystrophy (DMD), and myotonic dystrophy, after poliomyelitis and with motor neurone disease (amyotrophic lateral sclerosis).

If bulbar function is impaired, tracheostomy ventilation may be required, but in other situations, noninvasive ventilation is preferable. Positive pressure techniques using nasal and face masks are usually the first choice, but negative pressure ventilation is an alternative.

There are no randomised-controlled trials regarding the indications for initiating noninvasive ventilation, but this is usually provided if there are symptoms due to nocturnal hypoventilation or right heart failure in the presence of a raised carbon dioxide tension in arterial blood (P_{a,CO_2}) either at night or, more usually, in the daytime as well. There is no evidence that "prophylactic" ventilatory support is of benefit if this is provided before ventilatory failure has appeared. Careful selection of patients is required, especially in the presence of progressive neuromuscular disorders such as DMD and motor neurone disease.

There are no randomised-controlled trials concerning the outcome of noninvasive ventilation in these conditions, but studies have shown an improved quality of life, physical activity and haemodynamics, normalisation of blood gases and slight improvement in other physiological measures, such as the vital capacity and maximal mouth pressures. Survival in chest wall disorders is ~90% at 1 yr and 80% at 5 yrs, and similar figures have been obtained in nonprogressive neuromuscular conditions. If, however, the underlying disorder is deteriorating, particularly if it involves the bulbar muscles, it may limit survival despite the provision of adequate noninvasive ventilatory support.

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Hypercapnic ventilatory failure may occur in most disorders of the thoracic skeleton. These have common physiological features, particularly a restrictive ventilatory defect and decreased compliance of the chest wall [1]. Hypercapnia first appears in sleep and during activities such as exercise. In general, sternal diseases rarely cause respiratory failure except when there is a traumatic fracture associated with fractures of several ribs leading to a flail segment. The most common rib abnormality leading to respiratory failure is a thoracoplasty. Scoliosis and, less frequently, a kyphosis with severe deformity may cause severe ventilatory failure, but other spinal disorders, such as ankylosing spondylitis, rarely cause this complication.

The respiratory drive is intrinsically normal in these conditions but the mechanical abnormalities prevent it from being translated into a normal degree of lung inflation and deflation. Ventilation/perfusion matching is usually well preserved but hypercapnia develops when the force that can be generated by the respiratory muscles is outweighed by the extra load placed on them by the reduced compliance of the respiratory system. The increased work of breathing and reduced respiratory muscle activity during rapid eye movement (REM) sleep leads to hypercapnia being seen at this time before it develops during the deeper stages of nonrapid eye movement (NREM) sleep and, later, wakefulness [2, 3].

Considerable experience has been gained over the

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last 15–20 yrs in noninvasive ventilation for chest wall disorders, but despite this there are no randomised-controlled studies on its effectiveness or indications. The evidence that is available, however, suggests that there is little difference in the ventilatory requirements between the various conditions.

Chest wall disorders

Types of ventilatory support

Some respiratory muscle activity persists even during REM and stages 3 and 4 NREM sleep, so that partial rather than total respiratory support is usually required. This can be delivered in two ways as described below.

Noninvasive positive pressure ventilation. A nasal mask is usually preferable to a full face mask or a mouthpiece. Patients with chest wall disorders are no more prone to complications, *e.g.* nasal ulcers, mask displacement, air leaks or upper airway obstruction, from this type of treatment than those with other disorders [4]. Either pressure- or volume-preset ventilation is likely to be effective [5–7]. A peak inspiratory pressure of 20–25 cmH_2O is often required with pressure-preset ventilation and an inspiratory time of 0.8–1 s with an expiratory time of ~2 s. A sensitive triggering system with a short response time is required in view of the rapid respiratory frequency that is adopted by these subjects. Positive end expiratory pressure is not essential, apart from in some bilevel pressure-support systems in which it is mandatory to flush the dead space, but may be useful at a level of 2–4 cmH_2O [8]. Supplemental oxygen is rarely required unless the oxygen tension in arterial blood (P_{a,O_2}) cannot be normalised.

Negative pressure ventilation. A cuirass or jacket (poncho) type of negative pressure ventilator is almost invariably preferred to a tank ventilator, but these have the disadvantage that the subjects have to lie on their back throughout the night and have a restricted range of movements. This is particularly problematic with a kyphosis, where the sharp angulation of the spine can become uncomfortable. There may also be difficulty in moulding a cuirass to those with a severe thoracic scoliosis. Negative pressure ventilation is a form of pressure-preset ventilation, but is only widely available in the controlled mode because triggering is only present with a limited range of modern tank ventilators. This can cause incoordination between the ventilator and the patient and upper airway obstruction may develop due to the negative pressure applied to the airway [9]. The inspiratory and expiratory times are similar to those required for positive pressure ventilation.

Patient selection

Noninvasive ventilation has been proposed in the following situations.

Asymptomatic high-risk patients. Patients with a vital capacity of <1–1.5 L, scoliosis developing before the age of 8 yrs and a high thoracic curve are at risk of developing respiratory failure, usually in the fourth or fifth decade [10]. Such patients should be identified early and warned of the symptoms (table 1) that suggest nocturnal hypoventilation [3]. They should be followed-up long term since the onset of ventilatory failure is often insidious. Ventilatory failure may present as an emergency either during an acute illness, such as a chest infection, or following symptoms suggestive of nocturnal hypoventilation over the preceding weeks.

Normal diurnal blood gas tensions. Treating those at risk of developing hypercapnic respiratory failure could theoretically prevent the complications related to this and delay the onset of respiratory failure. The only evidence about this comes from those with Duchenne muscular dystrophy (DMD) in whom it was found that "prophylactic" ventilatory support was associated with a worse rather than improved survival [11]. The cause of this is unclear but it may have been due to over confidence during respiratory infections in the ventilator subjects, which led them and their carers to seek help too late. There is no evidence of any benefit of noninvasive ventilatory support if the carbon dioxide tension in arterial blood (P_{a,CO_2}) while breathing air remains normal. A normal P_{a,CO_2} while awake, associated with a high P_{a,CO_2} during sleep, could be an indication for nocturnal ventilatory support, but again there is no evidence of this. In practice the decision whether or not to start noninvasive support in these situations usually depends on the severity of the physiological abnormalities that are detected during sleep, in particular the degree of hypoxia and hypercapnia, and the presence or absence of complications such as polycythaemia or a high pulmonary artery pressure. In those with a scoliosis associated with poliomyelitis, early ventilation, if there is evidence of nocturnal hypoventilation without abnormal arterial blood gas tensions while awake, may be of benefit, as prompt relief of excessive muscle activity may prevent, delay or reduce the rate of progress of the postpoliomyelitis syndrome [12].

Abnormal diurnal blood gas tensions. If hypercapnia is present during the day as well as at night, but without symptoms or any complications such as polycythaemia or pulmonary hypertension, the indication for treatment is stronger than with nocturnal hypercapnia alone, but there is little evidence from large or controlled studies to support noninvasive positive-pressure ventilation (NPPV) in this situation.

Table 1. – Symptoms of nocturnal hypoventilation

Sudden awakenings from sleep
Irregular respiratory pattern while asleep
Early morning bifrontal headaches
Excessive daytime sleepiness

Abnormal diurnal blood gas tensions and symptoms. Symptoms such as increasing shortness of breath on exertion, physical tiredness, sleepiness and ankle swelling may all reflect hypercapnic respiratory failure and right heart failure and can be relieved by ventilatory support. Symptoms are unusual in the absence of daytime hypercapnia and a combination of symptoms is the primary indication for starting NPPV. It has been suggested that ventilatory support should be initiated when there are symptoms with either P_{a,CO_2} >6 kPa (45 mmHg) or >5 min spent asleep with an arterial oxygen saturation (S_{a,O_2}) <88%, although these recommendations are not based upon any published data [13].

Contraindications

The contraindications to treatment with nasal ventilation in chest wall disorders are similar to those with other conditions. They include inability to apply the headgear or cuirass or jacket and lack of motivation. Psychological factors, such as claustrophobia, may be important. Extensive or severe nonrespiratory disease, such as disseminated cancer, may limit the value of noninvasive support.

Outcome

Quality of life. Breathlessness on exertion, quality of sleep, daytime sleepiness and fatigue, and early-morning headaches can all be improved [14–16]. Activities of daily living, such as shopping, cooking and cleaning, may be carried out with less difficulty than before. There are few studies on the effects of treatment of respiratory problems on education [17] but continued schooling is feasible despite the need for ventilatory support. Adults may be able to return to work [18] and long-term ventilatory support has been shown to reduce the number of days spent in hospital [4, 19–21] and improve psychosocial and mental function [19, 22].

Physiological measures. Sleep architecture [23], oxygen saturation and transcutaneous P_{a,CO_2} during sleep, as well as the arterial blood gases during the day, improve [20, 21, 24, 25–27], often within the first few days of treatment.

Small improvements in vital capacity, functional residual capacity, maximum inspiratory and expiratory mouth pressures, inspiratory muscle endurance and respiratory drive have also been demonstrated [19]. In a 3-month prospective controlled trial, SCHONHOFER *et al.* [28] showed a significant improvement in endurance time in three different tests in the NPPV group compared with controls. Endurance time increased by 278±269% during an inspiratory threshold loading test, by 176±159% during a cycle ergometer test, and by 32±22% during a shuttle walking test. Pulmonary haemodynamics have also been shown to improve significantly after 1 yr of NPPV in patients with chest wall deformity [29].

Survival. There have been no controlled studies with survival as an end point in chronic respiratory failure due to chest wall disorders, but uncontrolled studies have shown that in stable disorders such as scoliosis, the 1-yr survival is ~90% and 5-yr survival ~80% [24, 30]. The results appear to be similar whether the treatment is provided with a positive or negative pressure system, but there is less data regarding the latter [26]. Patients with a thoracoplasty have a similar outlook despite extensive pulmonary disease due to a previous tuberculous infection [31]. If scoliosis is due to a neuromuscular disorder the prognosis depends as much on the progress of this condition as on the scoliosis itself, but for those who have had poliomyelitis, for instance, the survival figures are as good as in scoliosis without any neuromuscular weakness [14, 24].

Pregnancy. Pregnancy may precipitate hypercapnic respiratory failure in the presence of a chest wall disorder. Risk factors appear to be a vital capacity of <1 L, thoracic scoliosis >100 degrees, abnormal blood gases, especially an elevated P_{a,CO_2}, and the presence of bilateral diaphragm weakness or extensive intercostal muscle weakness in addition to the chest wall disorder. Patients with these features should be monitored closely during pregnancy with arterial blood gas analysis, maximum inspiratory and expiratory pressures, vital capacity and sleep studies.

While ventilatory failure developing early in pregnancy may be best treated by termination of pregnancy, later in pregnancy, noninvasive respiratory support is an important technique [32–34]. Negative-pressure systems are difficult to use because of the continual change in the abdominal dimensions and NPPV is preferable. The need for respiratory support alters abruptly during labour at which time the pain from uterine contractions is a respiratory stimulant, but conversely, analgesics and other respiratory sedatives can precipitate hypercapnic respiratory failure.

Neuromuscular disorders

Neuromuscular disorders can be divided into slowly and rapidly progressive (table 2). There is no accepted definition of these subgroups but understanding the speed of progression of the disease is important in deciding the appropriateness of NPPV. Symptoms are similar to those described above (table 1). Central hypoventilation syndromes are rare, and either congenital or acquired in origin. In congenital central hypoventilation syndrome (CCHS), ventilatory failure is seen soon after birth due to absent or negligible ventilatory responses to hypercapnia and hypoxaemia. The clinical course may be complicated by pulmonary hypoplasia, feeding difficulties, and autonomic dysfunction [35]. Acquired central hypoventilation syndromes occur as result of brainstem lesions due to cerebrovascular accident, encephalitis or tumours *etc.*, or there may be no obvious cause.

The use of NPPV in progressive neurological disease (as opposed to nonprogressive conditions such as previous poliomyelitis) has previously been

Table 2. – Course of neuromuscular and neurological disease

Rapidly progressive	Variable progression	Slowly progressive or nonprogressive
Motor neurone disease/ALS	Limb girdle MD	Previous poliomyelitis
DMD (in teenage years)	Myopathies	Facio scapulo humeral MD
	Nemaline	Type III SMA
	Metabolic	Central hypoventilation
	Merosin negative congenital muscular dystrophy	Spinal cord injury

ALS: amyotrophic lateral sclerosis; DMD: Duchenne muscular dystrophy; SMA: spinal muscular abrophy; MD: muscular dystrophy.

regarded as controversial because of fears that the use of ventilatory support in a terminal stage might simply protract death rather than extend good quality life. In addition, there are fears that use of noninvasive ventilation will inevitably progress to invasive tracheostomy ventilation thereby leading to entrapment on a ventilator. There are a growing number of studies addressing these concerns, and recent information suggests that NPPV may improve symptom control and quality of life in some patients. However, the selection of patients is likely to remain of critical importance. At present, there are no randomised controlled studies of NPPV in respiratory failure due to progressive neuromuscular diseases, and quality of life information is limited. Recommendations are therefore based on case series data, but it should be noted that in some instances randomised controlled trials may be unethical since the inevitable result of with-holding ventilatory support is death.

Choice of ventilatory equipment

NPPV is superior to negative-pressure ventilation, with the latter reserved for patients who cannot tolerate positive-pressure techniques. Bilevel pressure-support devices may aid upper airway stabilisation and reduce atelectasis in neuromuscular patients, thereby improving overnight arterial blood gas control, but this has not been confirmed in detailed studies. Some authors advocate use of cough in-exsufflators when cough expiratory peak flow falls to <160 L·min^{-1} [36]. There are no controlled studies of this cough-assist equipment, but case series suggest that a combination of expiratory muscle-assist equipment and NPPV are more effective at reducing hospital admissions than tracheostomy ventilation [37].

Management of acute ventilatory failure

Patients with neuromuscular disease often develop ventilatory insufficiency or failure for the first time during an acute chest infection. Cough-assist devices alone may be of value to facilitate sputum clearance in those without overt ventilatory failure, particularly in patients with marked expiratory-muscle weakness, but this work needs to be confirmed. Otherwise, acute NPPV may be used to reduce the need for intubation and/or facilitate weaning [38]. The addition of a minitracheostomy ("minitrach") to NPPV may be helpful in the acute phase of a chest infection to allow efficient removal of bronchial secretions [39].

Progression in ventilatory need

Ventilatory dependency is likely to increase over time with progressive neuromuscular disease and ventilator settings may also need to be changed. Ventilatory adjuncts, such as mouth ventilation with a mouthpiece attached to a support on a wheelchair, can be helpful [40]. Some patients with progressive bulbar problems and/or increasing ventilator dependency may wish to progress to invasive ventilation. Options should be carefully discussed with the patient and family, and advanced directives formulated where possible.

Tracheostomy ventilation

Tracheostomy-intermittent positive-pressure ventilation (T-IPPV) is more frequently used in some countries (*e.g.* France) than others (*e.g.* Italy and the UK). It should be considered in patients with a high level of ventilatory dependency (near 24 h), but is most relevant in individuals with severe swallowing problems, resulting in aspiration. Discharge of T-IPPV patients from hospital is more complex than NPPV recipients, but can be achieved efficiently in well-experienced units [41].

Oxygen therapy

As the main cause of respiratory insufficiency in neuromuscular disorders is alveolar ventilation, the use of oxygen therapy alone in acute or chronic ventilatory failure is usually inappropriate. The addition of oxygen therapy to ventilatory support is sometimes required during episodes of acute pneumonia, but it is unlikely to be required long term. Close monitoring of P_{a,CO_2} is indicated if oxygen therapy is used.

Slowly progressive neuromuscular disease

As indicated in table 2, some neuromuscular conditions may be nonprogressive (*e.g.* poliomyelitis) or slowly progressive (*e.g.* some myopathies and muscular

dystrophy variants). However, physiological changes, such as weight gain, chest infection, additional chronic cardiorespiratory pathology or sleep-disordered breathing, may cause ventilatory decompensation, in the absence of progression of the underlying disease.

Patient selection

As with chest wall disease patients, current consensus conference recommendations [13] indicate that NPPV should be used in symptomatic patients with one of the following: 1) diurnal P_{a,CO_2} >6.0 Pa; and 2) nocturnal S_{a,O_2} <88% for 5 consecutive min. There is no evidence that the prophylactic use of ventilatory support offers any advantages.

Outcome

Significant improvements in nocturnal and diurnal arterial blood gas tensions, mortality and quality of life are reported in patients with old poliomyelitis and other slowly progressive conditions [24, 30]. The 5-yr survival rates on nocturnal NPPV are near 100% in patients with previous poliomyelitis. Mortality in central hypoventilation syndromes depends on the underlying aetiology of the condition.

Pregnancy

As with patients with restrictive ventilatory defects due to chest wall disease, successful pregnancy has been reported in individuals with neurological and neuromuscular diseases [42–44], although the outcome is unlikely to be favourable in patients with a vital capacity much below 1 L and severe respiratory muscle weakness [45, 46].

Progressive neuromuscular disease

Duchenne muscular dystrophy. The mean survival following the development of diurnal hypercapnia in DMD is 9.7 months if ventilatory support is not provided [47]. A Consensus recommendation [13] is that NPPV should be initiated in symptomatic DMD patients with a daytime P_{a,CO_2} >6.0 kPa. There is no evidence that NPPV is effective when started as prophylactic therapy before the development of diurnal hypercapnia [11]. NPPV is relatively contraindicated in DMD patients with severe bulbar weakness, but a proportion of these may be satisfactorily managed by NPPV, which should be tried initially. Complications are minor and include nasal bridge sores and gastric distension. Overnight titration of ventilator settings will allow avoidance of such complications as over ventilation.

Patient selection for noninvasive positive-pressure ventilation. It is suggested that DMD patients receive respiratory outpatient follow-up once vital capacity or forced expiratory volume in one second (FEV1) is <40–50% predicted. Patients should be questioned about symptoms of nocturnal hypoventilation. Overnight monitoring of respiration should be considered once vital capacity is <30% pred. A base excess of >4 $mmol \cdot L^{-1}$ is predictive of significant nocturnal desaturation [48]. Some patients develop obstructive sleep apnoea/hypopnoea syndrome before the appearance of overt nocturnal hypoventilation [49]. In this subgroup, continuous positive airway pressure (CPAP) may be effective, but subsequent transfer to NPPV is usually required, and the need for this should be ascertained by follow-up sleep studies, *e.g.* every 6 months. Maximal inspiratory pressures of <30% pred are associated with nocturnal and diurnal hypercapnia. Cardiac assessment, including electrocardiogram and echocardiogram, should be carried out regularly to determine the development of cardiomyopathy. Once NPPV is initiated, ventilatory settings can be titrated to overnight S_{a,O_2} and carbon dioxide measurements, to avoid overventilation, which is relatively easy in patients with neuromuscular disease as the impedance to inflation is low. DMD patients receiving NPPV should be reviewed regularly, *e.g.* every 6 months.

Outcome. Quality of life. Social and mental health aspects of health-related quality of life in DMD patients are not significantly different to findings in age-matched controls and other nonprogressive groups using NPPV [38], although studies of quality of life before and after initiation of NPPV have not been reported. Healthcare workers tend to underestimate the quality of life of DMD patients [50]. Most patients receiving ventilatory support judge their quality of life as satisfactory [50]. It should also be noted that some physicians may fail to explore the possibility of assisted ventilation fully with patients because of quality of life concerns [51].

Physiological indices. The effects of NPPV on the evolution of cardiomyopathy, lung function, respiratory muscle strength and functional impairment have not been clearly determined.

Survival and morbidity. LEGER *et al.* [30] showed a 3-yr probability of continuing NPPV in DMD of 36%. In this series of 16 patients, five progressed to tracheostomy ventilation. By contrast, a 1-yr survival of 85% and 5-yr survival of 73% have been shown in another series [38] using NPPV as the sole means of ventilatory support, indicating that transfer to invasive ventilation should not be seen as inevitable. BACH *et al.* [37] have shown a reduction in hospitalisation for pulmonary complications in a DMD group treated with a noninvasive approach (NPPV plus cough in-exsufflation) as opposed to those using tracheostomy ventilation.

Amyotrophic lateral sclerosis. Amyotrophic lateral sclerosis (ALS) differs from DMD in being an acquired disorder, which tends to be more rapidly progressive. This makes psychological and physical adaptation more difficult. Patients with ALS tend

not to present with respiratory symptoms until vital capacity is <50% pred. Patients may report somnolence due to severe sleep fragmentation and patients with absent or markedly reduced diaphragm function have been shown to have reduced time in REM sleep and a worse survival than patients with preserved diaphragm function [52]. It should be noted that while a proportion of patients with stable restrictive disorders may remain reasonably steady state with mild hypercapnia for some time, in ALS patients, even a small elevation in diurnal P_{a,CO_2} indicates a high risk of imminent severe ventilatory decompensation. There are no prospective randomised controlled trials of NPPV in ALS, although in two studies [53, 54], patients who chose NPPV were compared with those who declined [53, 54] or used it for <4 h·night^{-1} [54].

Patient selection for noninvasive positive airway pressure. NPPV is indicated in patients with diurnal P_{a,CO_2} >6 kPa [13] and may be of value in patients with normocapnia but severe dyspnoea or othopnoea [55] due to respiratory muscle weakness. In this group, vital capacity is likely to be <50% and maximum inspiratory pressure <60 cmH_2O. NPPV is unlikely to benefit patients without symptoms or those with profound bulbar weakness. Some patients protect their blood gas tensions by poor quality sleep and patients who sleep poorly with evidence of respiratory muscle weakness can be considered for NPPV.

Outcome. Quality of life. There are few detailed studies of the impact of NPPV on the quality of life in ALS, and PINTO *et al.* [53] showed that NPPV did not produce a significant improvement. However, more recent work suggests that meaningful gains in quality of life can be achieved despite a continued decline in physical function [56, 57]. It is important that any future work examining this area reviews quality of life over the course of the illness not just at the time ventilatory support is initiated.

Survival. Prolonged survival in ALS patients receiving T-IPPV has been demonstrated by OPPENHEIMER [58] and others. In a series of 101 patients, 1-yr survival was 87%, 3-yr survival 58%, and 5-yr survival 33%. As ~30% of patients present with marked bulbar involvement, T-IPPV may be the only form of ventilatory support feasible. Using nocturnal bilevel pressure support NPPV, PINTO *et al.* [53] showed a very significant survival advantage in ALS patients with abnormal blood gas tensions compared to a group who did not receive NPPV. Elderly patients did just as well as younger patients in this study. In another series [59] where selected symptomatic ALS patients were allocated NPPV, median survival of ALS patients was ~10 months. In a retrospective study of 122 patients with ALS offered NPPV when the forced vital capacity fell to <50% pred, patients were divided into three groups. Group 1: accepted NPPV and used it >4 h·day^{-1} (n=38). Group 2: did not tolerate NPPV well and used it <4 h·day^{-1} (n=32). Group 3: refused to try NPPV (n=52). There was a statistically significant improvement in survival from initiation of NPPV in group 1 (14.2 months) compared to group 2 (7.0 months, p=0.002) or 3 (4.6 months, p<0.001), respectively. Furthermore, when the slope of vital capacity decline was examined, the group that used NPPV for >4 h·day^{-1} had a slower decline in vital capacity (-3.5% change per month) compared to group 2 (-5.9% change per month, p=0.02) and group 3 (-8.3% change per month, p<0.001). These data suggest that NPPV should be considered when the forced vital capacity falls <50% pred.

Complications. Failure rates with NPPV in ALS are probably higher than in other neuromuscular diseases. In a study examining factors determining the success of NPPV in ALS, ABOUSSOUAN *et al.* [60] found that 46% of hypercapnic and/or orthopnoeic patients were able to tolerate NPPV (defined as ability to use during sleep for >4 consecutive hours). Moderate or severe bulbar symptoms were commoner in those with tolerance problems (67% *versus* 33%; p=0.04) but did not preclude use. This indicates that a trial on NPPV is reasonable even in patients with moderately severe bulbar symptoms. Clearly, if problems with the ventilator outweigh beneficial effects, then NPPV can be rapidly discontinued. Patients who tolerate NPPV tend to live longer than those who cannot tolerate it [60]. Progression of NPPV to T-IPPV has not been systematically evaluated in ALS patients. The use of cough in-exsufflators in ALS has been advocated. This approach awaits further evaluation, but early results are encouraging.

Advance directives. Most patients with ALS and DMD wish to be actively involved with decision-making about their care. Sensitive discussion about the escalation of ventilation support, limits to therapy, and resuscitation status with the patient and family is to be encouraged [61, 62].

Conclusion

Noninvasive ventilation is well established in these conditions and it is unlikely that randomised controlled studies with survival as an end point would ever gain ethical approval in most of these disorders. There are so few adequate studies on noninvasive ventilation in chest wall disorders and neuromuscular disease that research is required in many aspects. It is particularly needed to examine breath-by-breath interactions between the patient and the ventilator, the mechanisms by which noninvasive ventilation influences cardiorespiratory function, the optimal time at which assisted ventilation should be started and the requirements for ongoing assessment. Studies of the effect on the natural history of more rapidly progressive neuromuscular diseases, upon the quality of life of both the patient and their carers at various stages in the disease, the most appropriate time to introduce noninvasive positive pressure ventilation, and

how to predict individuals most likely to respond are needed. Quality of life assessment tools specific to these disorders need to be developed.

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