Respiratory Complications of the Muscular Dystrophies

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ABSTRACT

Pulmonary complications including chest infections, atelectasis, pulmonary hypoplasia and ventilatory failure are the leading cause of death in the muscular dystrophies and atrophies. Ventilatory insufficiency is virtually inevitable in Duchenne muscular dystrophy and type 1 spinal muscular atrophy (SMA), but more variable in limb-girdle, congenital, and facioscapulohumeral muscular dystrophy. A cardiomyopathy may complicate Duchenne, Becker, and Emery-Dreifuss muscular dystrophies. Most patients respond well to ventilatory support with reduced pulmonary morbidity and extended survival. Careful monitoring and anticipation of complications are important so that ventilatory assistance can be started in a timely fashion.

KEYWORDS: Duchenne muscular dystrophy, spinal muscular atrophy, noninvasive ventilation

Objectives: Upon completion of this article, readers should be able to: (1) describe the pathophysiology of respiratory decompensation in the muscular dystrophies; (2) identify muscular dystrophy patients at high risk of respiratory complications; and (3) understand the role of ventilatory support in the management of respiratory problems in muscular dystrophy.

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Respiratory complications are by far the commonest cause of morbidity and mortality in the muscular dystrophies. In Duchenne muscular dystrophy (DMD), respiratory problems are the cause of death in over 70% of patients, and virtually all DMD patients will develop respiratory insufficiency if they survive long enough. In other muscular dystrophies, the extent of respiratory compromise depends on the degree of inspiratory and expiratory muscle involvement, the presence of thoracic scoliosis or a rigid spine, and bulbar weakness. Congenital pulmonary hypoplasia may occur in some patients with congenital muscular dystrophy or spinal muscular atrophy (SMA). This article will cover the spectrum of muscular dystrophies and atrophies, the probability of respiratory decompensation, the evolution of the pathophysiology, and the potential for reversal of respiratory compromise.

The term *muscular dystrophy* is used classically to define a group of congenital conditions with progressive degeneration of skeletal muscle and no associated abnormality in the central or peripheral nervous system. However, this terminology is flawed. For example, some of the milder forms of facioscapulohumeral muscular dystrophy show little progression, other variants may

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not show a typically dystrophic pattern, and in some cases of congenital muscular dystrophy, there are associated central nervous system features such as white matter changes in the brain. Advances in the understanding of the molecular biology of muscular dystrophies may eventually lead to a more rational classification, but in the meantime, categorization will continue to be based on clinical phenotype, mode of inheritance, and biopsy findings.

SPECTRUM OF MUSCULAR DYSTROPHIES

The inheritance patterns and respiratory complications associated with most forms of muscular dystrophy are shown in Table 1. In the last decade, tremendous progress has been made in the identification of the genes responsible for these disorders. Indeed, the discovery of the gene responsible for DMD and identification of the gene product dystrophin have been key developments in our understanding of a whole series of neuromuscular conditions. Normally in DMD, dystrophin is absent on muscle biopsy, whereas variable amounts are present in Becker muscular dystrophy. The dystrophins are a family of proteins that form complexes linking the extracellular matrix and intracellular actin across the cell membrane. Subtle changes in the dystrophin-related complex have been implicated in the milder proximal myopathies and other non-X-linked muscular dystrophies. Abnormalities of sarcoglycan may be seen in limb-girdle muscular dystrophy (LGMD), and merosin immunohistochemistry can help elucidate the merosin positive and merosin negative congenital muscular dystrophies. As a result of these findings, we are now in a better position to accurately identify the muscular dystrophies and understand their natural histories. This research also offers the possibility of effective gene therapy in the future.

RESPIRATORY PATHOPHYSIOLOGY

In many cases, a well-recognized spiral of respiratory decline starting with a loss of lung volumes occurs, followed by progressive weakness in inspiratory and expiratory muscles, chest infections, sleep-disordered breathing, and, ultimately, daytime ventilatory failure (Fig. 1). Apneas and hypopneas are seen during rapid eye movement (REM) sleep before they appear during non-REM sleep because of the physiological changes that accompany REM sleep, including intercostal inhibition and loss of accessory muscle tone, reduction in ventilatory drive, and diminution in the arousal response (see Piper article). The rate of evolution of respiratory failure varies from disease to disease.

DUCHENNE MUSCULAR DYSTROPHY

DMD is the most common muscular dystrophy inherited in childhood with an incidence of 1 in 3500 live male births. Features of motor delay prompt the diag-

Table 1 Inheritance and Pulmonary Complications of the Congenital Muscular Dystrophies and Spinal Muscular Atrophy

	Disease	Mode of Inheritance	Gene Product (where known)	Respiratory Complications
Muscular dystrophies	Duchenne	X-LR	Dystrophin	Ventilatory failure Scoliosis Atelectasis Cardiomyopathy
	Becker	X-LR	Dystrophin	Ventilatory failure relatively uncommon Cardiomyopathy
	Limb-girdle	AR AD	Adhalin	Variable ventilatory failure
	Congenital:			Scoliosis
	Merosin +ve	AR	alpha2 laminin	Ventilatory failure
	Merosin −ve	AR		
	Facioscapulohumeral	AD		Ventilatory failure Uncommon
	Emery-Dreifuss	X-LR	Emerin	Ventilatory failure Arrhythmias
Spinal muscular atrophy (SMA)	Spinal muscular atrophy	AR, AD		Type 1–type 3 Early to late onset vent failure

AD, autosomal dominant; AR, autosomal recessive; X-LR, X-linked recessive.

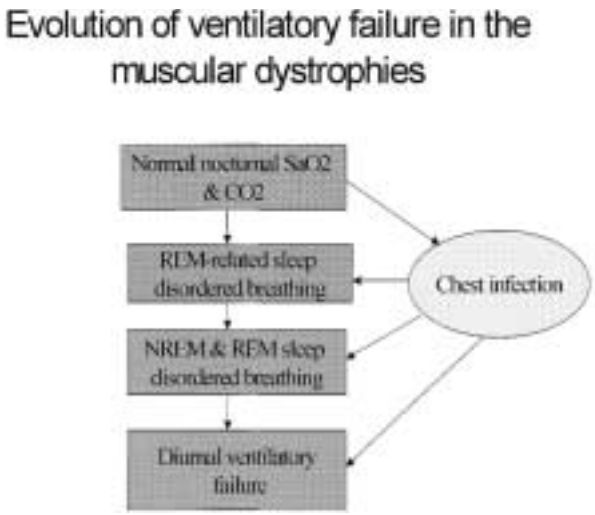

Figure 1 Development of arterial blood gas abnormalities during sleep disordered breathing in the muscular dystrophies.

nosis in approximately 20% of cases by the age of 2 years and 75% by the age of 4 years. In a series reported by Rideau et al,[1] 50% of DMD patients developed a significant thoracic scoliosis at the time of the pubertal growth spurt, and the average age for losing ambulation was 10 years. Dubowitz[2] has used loss of ambulation to distinguish the Duchenne and Becker phenotypes. Loss of ambulation before 13 years defines the Duchenne group and after 16 years typifies the Becker group. In those who begin use of a wheelchair between the ages of 13 and 16 years, the term i*ntermediate muscular dystrophy* is sometimes used. Limb muscle weakness in DMD is initially proximal, but distal involvement occurs with time.

A longitudinal study of lung function has shown that forced vital capacity (FVC) as a percent of predicted begins to fall at around the age of 10 years in DMD.[1] Baydur et al[3] found an average yearly decline in FVC of 5%. When the vital capacity falls to below 1 liter, hypercapnia is likely, although there is considerable variation between individuals. Inspiratory and expiratory muscle weakness generally occur in tandem in DMD patients, thereby simultaneously reducing ventilatory efficiency and cough effectiveness.

Sleep-disordered breathing usually arises during the early teenage years. Khan et al[4] studied 21 asymptomatic nonambulant patients with DMD aged 13 to 23 years (mean vital capacity 35% predicted). Two-thirds of the patients had hypoxemic dips to < 90% overnight, and 60% of these events were obstructive apneas and hypopneas. Most desaturations occurred during REM sleep. There was a strong correlation between the frequency and severity of hypoxemic dips and age (p < 0.005), and years of wheelchair use (p = 0.005). All boys over the age of 14 had hypoxemic events; only three of those under the age of 13 experienced such events.

Ten of the patients with nocturnal hypoxemia had serial follow-up. Over time, there was worsening hypoxemia, but a fall in the proportion of obstructive events, such that a pure hypoventilation picture predominated. Phillips et al[5] followed 19 DMD patients for 10 years after an initial sleep study and showed worsening REM-related desaturation until death or the introduction of nocturnal ventilatory support. Mean survival was unrelated to respiratory muscle strength as measured by mouth pressures, or body mass index. However, mortality was correlated with daytime pCO_2 (r = 0.72, p < 0.005), minimum nocturnal SaO_2 (r = 0.62, p < 0.007), and vital capacity (r = 0.79, p < 0.004). The best single predictor of mortality was a vital capacity of less than 1 L.

In an older group of DMD patients (mean age 18 ± 2 years, vital capacity 27% predicted)), Barbe et al[6] found that 70% had symptoms of daytime somnolence, headaches, nightmares, or difficulty sleeping. Symptoms were correlated with the number of nocturnal apneas and hypopneas. As found in the previous study, 85% of the events were central hypopneas, indicating that obstructive events progress to central hypopneas as the patient ages. In this study, the apnea/hypopnea index was correlated with daytime pCO_2 and the apnea/ hypopnea index during REM sleep was correlated with age.

Several groups have investigated factors that predict the development of sleep-disordered breathing in DMD. Hukins and Hillman[7] found that the most consistent predictors were FEV1 < 40% predicted, pCO_2 < 6.0 kPa and base excess > 4.0 mmol/L. The base excess, which is a good indicator of chronic CO_2 retention, explained 64% of the variation in total sleep time spent at SaO_2 < 90%. Numerous studies have shown that without ventilatory support, the average age of death in DMD is around 20 years. Once daytime hypercapnia starts, mean survival without therapy is roughly 9 to 10 months.[8]

COUGH EFFICACY

An effective cough has 4 components[9]:

- An intact sensory pathway to detect airway irritation and secretions
- The ability to generate a deep inspiration (which is impaired by inspiratory muscle weakness)
- Glottic closure
- Expiratory muscle contraction against a closed airway (limited by expiratory muscle involvement).

In some conditions, such as SMA, expiratory muscle weakness may be more marked than inspiratory muscle weakness. This may lead to recurrent chest infections in infancy before the development of ventilatory failure. Cough efficacy may be measured by peak

cough flow rates. Bach[10] has suggested that a peak cough flow rate in excess of 160L/min is required to clear secretions effectively. Techniques to assist cough (e.g., manually assisted coughing and/or cough insufflator-exsufflator machines) should be used in those with lower flow rates (see article by Hill).

CHEST INFECTIONS

Over 90% of pneumonias and hospitalizations are triggered by upper respiratory tract infections in individuals with neuromuscular disease.[11] Hospitalization rates are higher in patients using oxygen therapy alone rather than ventilatory support.[11] This is not surprising when one considers that oxygen therapy does not assist ventilation and may exacerbate hypercapnia. Therefore, noninvasive mask ventilation (NIV) should always be started before oxygen therapy in neuromuscular disease patients. Most often, oxygen supplementation is unnecessary once they have adapted to NIV and are using the technique properly. NIV can be used in conjunction with chest physiotherapy to increase peak cough flow, thereby enhancing secretion mobilization. In one study on the use of NIV in DMD,[12] 25% of initiations were for acute chest infection. The other initiations were for symptomatic nocturnal hypoventilation and diurnal hypercapnia. Once NIV was started, the average admission rate for chest infections was only 0.64 per year with a mean (SD) hospital stay of 4.0 (4.3) days.

Although tracheotomy intermittent positive pressure ventilation (T-IPPV) is sometimes assumed to be superior to NIV for DMD because of easier secretion clearance and more reliable ventilatory assistance, this has not been borne out in clinical practice. Some patients with severe bulbar problems may require progression from NIV to T-IPPV, but Bach et al[11] have shown that pulmonary morbidity (as measured by hospitalizations and in-hospital days) is reduced in neuromuscular disease patients by a protocol combining NIV and cough assistance compared with T-IPPV. Considering that the bulbar muscles are usually spared compared with other muscles in DMD, this supports the contention that NIV is preferred to T-IPPV for most DMD patients, as long as secretion removal is adequate.

CARDIOMYOPATHY

Cardiomyopathy complicates the clinical course of DMD in most cases. A large Italian survey[13] found evidence of subclinical cardiac involvement in 25% of DMD patients under the age of 6 years and in about 60% by age 10. Clinically apparent cardiomyopathy was present in all patients over the age of 18. Cardiac manifestations included dilated cardiomyopathies, which were the most common, hypertrophic cardiomyopathies, and conduction defects. Cheyne-Stokes respiration and pulmonary edema can complicate the course of patients with severe cardiomyopathy. Nasal continuous positive airway pressure (CPAP) may be tried in this situation, but in neuromuscular patients with profound muscle weakness and hypercapnia, NIV is preferable. Amelioration of nocturnal hypoventilation with NIV may improve cardiac function or reduce the rate of decline, but this has not been proven conclusively. Nocturnal cardiac dysrhythmias may also respond to therapy with NIV. Patients often respond well to standard therapy for cardiac failure including diuretics, angiotensin converting enzyme (ACE) inhibitors, digoxin, and spironolactone.

BECKER MUSCULAR DYSTROPHY

Respiratory problems are uncommon during childhood in Becker muscular dystrophy (BMD), but presentation with ventilatory failure in the third or fourth decade is typical. Previously, the degree of cardiomyopathy was thought to be less than with DMD because the progression of skeletal muscle weakness is slower. However, this is not the case; the electrocardiogram was abnormal in 76% of BMD patients in one series, and 37% had decreased left ventricular systolic function due to global hypokinesia.[14] In addition to the usual pharmacotherapies for congestive heart failure, cardiac transplantation has been successfully performed in BMD patients.[15]

CONGENITAL MUSCULAR DYSTROPHY

Congenital muscular dystrophy (CMD) describes infants presenting at or within the first few months of birth with dystrophic features on muscle biopsy and associated hypotonia, arthrogryposis, and contractures. Creatinine phosphokinase levels may be mildly elevated but dystrophin staining in muscle is normal.[2] Progression of muscle weakness with age is not marked but ventilation may be compromised in late childhood by a vicious cycle of worsening thoracic scoliosis and nocturnal hypoventilation. In a series of children requiring ventilatory support at Royal Brompton Hospital, the mean age $\pm$ SD at initiation of NIV in CMD patients was 11.6 $\pm$ 3.7 years.[16]

CMD cases can be divided into those with merosin (laminin M) present on biopsy and those without merosin. Merosin negative patients may have additional central nervous system features such as white matter changes on magnetic resonance imaging, and may develop ventilatory failure at an earlier age than merosin positive patients (personal observation). Because the disease progresses slowly and bulbar and cardiac involvement are rare, the prognosis of CMD patients after starting NIV is relatively good. Patients remain

vulnerable to chest infections, and precautions as described in the following text are advisable.

LIMB-GIRDLE MUSCULAR DYSTROPHY

Limb-girdle muscular dystrophy (LMG) is a problematic diagnosis because it has been used generically for patients with muscle weakness of a proximal limb-girdle distribution. Therefore, in the past, patients with conditions such as Type 3 SMA, Becker muscular dystrophy, and various other myopathies may have been misdiagnosed as having LGMD, before the development of more accurate diagnostic techniques. In fact, the condition probably does consist of a number of different syndromes with variable inheritance and gene loci (see Table 1). Accordingly, the rate of progression, severity of disease, and associated respiratory complications vary considerably between individual patients. Gigliotti and colleagues[17] reported moderate decreases in vital capacity in a group of adult patients with LGMD. Hypercapnia was present in 20%, and daytime pCO_2 was correlated most closely with the decrease in vital capacity and duration of illness, rather than respiratory muscle strength.

Cardiac complications in LGMD are rare. Within families, loss of lung volume and progression of respiratory muscle weakness tend to occur at a similar rate, typically leading to respiratory failure in the fourth or fifth decades. Because bulbar involvement is rare, the response to NIV is usually excellent, allowing patients to continue with full-time employment and extending survival sometimes for decades beyond the onset of hypercapnia. A severe, autosomal recessive variant of LGMD presents in childhood (age 3–12 years) and is rapidly progressive, resembling the severe DMD phenotype.[2] Typically, these children develop ventilatory failure before the age of 10 years.

MYOTONIC DYSTROPHY

Myotonic dystrophy is an autosomal dominant multisystemic disorder characterized by muscle wasting, myotonia, cataracts, intellectual impairment, and cardiac conduction defects. The median age of onset of symptoms is 20 to 25 years, and there is a characteristic pattern of temporal wasting and frontal balding.[18] Respiratory involvement occurs during middle age, with a progressive restriction pattern being the most common pulmonary function abnormality. However, the manifestations are quite variable, with some patients developing diaphragm paralysis and others having mainly sleep disturbances, with obstructive or central apneas, or frank central hypoventilation.[19] The latter may occur even when pulmonary function is well preserved, and may respond to progesterone therapy (N. Hill, personal observation). Ventilatory impairment responds well to NPPV,[19] although bulbar weakness may eventually develop, limiting NPPV effectiveness.

EMERY-DREIFUSS MUSCULAR DYSTROPHY

An X-linked muscular dystrophy, Emery-Dreifuss muscular dystrophy (EDMD) causes relatively mild skeletal muscle weakness, affecting particularly the scapulohumeroperoneal distribution. Marked wasting, stiffness, and contractures of the upper arms occur, along with thoracic scoliosis and an associated cardiomyopathy. Progression to respiratory failure is relatively common. Cardiac complications may manifest before respiratory problems, with the earliest changes being first-degree heart block, followed by atrial arrhythmias, and sometimes atrial paralysis.[2] Nocturnal hypoventilation may exacerbate rhythm disturbances during sleep, so that treatment with NIV may help both the respiratory and the cardiac complications.

FACIOSCAPULOHUMERAL MUSCULAR DYSTROPHY

Facioscapulohumeral muscular dystrophy (FSHMD) is an autosomal dominant disorder, with facial weakness sometimes preceding scapulohumeral involvement. Dubowitz[2] observed that variation in clinical severity within a pedigree is common, and subclinical cases can be identified by carefully assessing family members of index cases. By and large, respiratory involvement leading to ventilatory decompensation is unusual, but does occur occasionally. The prognosis for most affected individuals is quite good, as there is no associated cardiac involvement or learning disability

RIGID SPINE SYNDROME

Rigid spine syndrome causes contractures of the postspinal or postcervical extensor muscles that limit the normal flexion/extension of the spine. The resulting stiffness reduces chest wall expansion and may lead to a marked restrictive ventilatory defect. Although some individuals with the rigid spine syndrome develop scoliosis, this is not inevitable. Rigidity can be differentiated from muscle spasm in that it continues during sleep and general anaesthesia. The condition can complicate the respiratory picture in patients with CMD, EDMD, DMD, and some myopathies (e.g., central core disease, centronuclear myopathy). Because a thoracic scoliosis is not always seen, the extent of ventilatory limitation in these individuals with a rigid spine is often inapparent unless a careful physical examination and pulmonary function studies are performed. The restrictive defect is commonly severe enough to cause respiratory failure. Rigidity of the cervical spine may also impair upper air-

way function during sleep and increase the tendency to obstructive sleep apneas and hypopneas.

SPINAL MUSCULAR ATROPHY

The spinal muscular atrophies (SMAs) are a group of hereditary proximal symmetrical myopathies associated with degeneration of the anterior horn cells of the spinal cord, and in severe cases, bulbar motor nuclei. As seen in Table 2, the spectrum of clinical involvement with the various SMAs is quite wide. Respiratory complications are inevitable in children with type 1 SMA, occur to a variable extent in type 2 patients, and are rare in Type 3 SMA.

TYPE 1 SMA (WERDNIG-HOFFMAN DISEASE)

Type 1 SMA occurs in 1:10,000 to 25,000 live births. Onset is in utero or within the first few months of life. The disease causes generalized hypotonia and proximal more than distal muscle weakness, affecting the lower limbs more than the upper limbs. Head control is poor and bulbar weakness is common, but facial muscle strength tends to be preserved. The intercostal muscles are severely involved so that inspiration is dependent on the diaphragm. This causes rib recession and a characteristic chest wall and pectus deformity. Most type 1 children develop chest infections and respiratory distress in the first few months of life, and almost all die of respiratory failure by the age of 2 years unless ventilatory support is provided.

Invasive ventilation via a tracheostomy (T-IPPV) is used at some centers,[20] but concerns have been raised about quality of life for both the child and the family. This has led to major differences in the way these children are managed, based on philosophical differences between physicians and cultural differences between countries, as well as different desires between families. The use of a combination of NIV and gastrostomy feeding tubes has recently been examined in type 1 children, producing results that appear to be in conflict, at least superficially. Birnkrant et al[21] described the use of this noninvasive approach in four children diagnosed with type 1 SMA aged 1 to 5 months. Respiratory insufficiency occurred between the ages of 2 and 7 months, and despite the application of NIV using bilevel pressure support, survival after the development of respiratory insufficiency was only 1 to 3.5 months.

More encouraging results have been reported by Bach et al[22] in a retrospective analysis of 11 type 1 SMA children treated with NIV and cough inexsufflation. In this study, the average age at the time of first ventilatory decompensation was 14.6 months (range 3–28 months), and the parents of all children had refused tracheotomy. Episodes of acute respiratory failure (ARF) were managed with a protocol consisting of initial intubation followed by extubation and use of NIV if defined SaO_2 criteria were met. Using the protocol, the children required multiple admissions and intubations for infectious episodes but were successfully extubated to NIV without the need for tracheotomy on 23 out of 28 occasions. Two children survived for 37 and 66 months without intubation, although they needed 24-hour NIV from the ages of 5 and 7 months, respectively. Two children ultimately received T-IPPV, and one was lost to follow-up. The remaining six patients continued to use NIV at home for a mean of 30 months and had fewer hospitalizations or intubations than a nonprotocol comparison group.

These studies indicate that, combined with a percutaneous gastric feeding tube and aggressive management of airway secretions and esophageal reflux, NIV is feasible in type 1 SMA and that it is possible to avoid T-IPPV. However, it should be noted that the average age of developing respiratory complications in the Bach study[20] was considerably older than that in the Birnkrant study,[22] suggesting that the latter study had more severely ill children. Indeed, it is important to realize that type 1 SMA children do not have uniform

Table 2 Classification of Spinal Muscular Atrophy

	Clinical Features	Inheritance
Type 1		
Werdnig-Hoffman's disease	Hypotonic at birth. Unable to hold head up. May be accompanying brainstem abnormality and pulmonary hypoplasia. Death before the age of 4 years of 95% of cases.	Autosomal recessive
Type 1 intermediate	Able to hold head up, unable to sit. Usually diagnosed in first year, often recurrent respiratory tract infections.	Autosomal recessive and dominant
Type 2		
Kugelberg-Welander	Able to sit up, unable to walk. Proximal and intercostal muscle involvement. Diaphragm often spared. Scoliosis.	Autosomal recessive
Type 3	Symmetrical proximal weakness. Scoliosis. Respiratory insufficiency possible in young adulthood.	Autosomal recessive

levels of weakness but constitute a spectrum of severity. Therefore, management decisions should be based on careful individual assessment. Also, children in the Bach study[22] had frequent admissions for ARF. These may be burdensome for both the child and the family, and frequent admissions may pose problems in countries with limited pediatric intensive care unit resources.

None of the studies examined quality of life for the child or family. Some information on quality of life may become available from countries such as France and Japan,[23] where T-IPPV for type 1 SMA is performed more frequently than in other countries, and a cohort of older children is accumulating who can relate their experience. Although frequent hospitalizations could detract from quality of life, NIV allows children who would otherwise be institutionalized to be cared for at home by their families. Thus, even if it does not prevent rehospitalization or improve life expectancy, NIV may still have a valuable palliative role.

PREVENTION AND MANAGEMENT OF RESPIRATORY COMPLICATIONS

High-risk individuals should be identified early and followed closely. Children and adults with muscular dystrophies that are known to cause pulmonary morbidity should receive regular respiratory assessments that are determined by the severity of impairment and expected rate of loss. Yearly follow-up may be adequate for slowly progressive conditions until vital capacity is less than 50% of predicted, at which point the frequency of follow-up should be increased. Symptoms of sleep-disordered breathing should be actively sought when vital capacity is less than 30% predicted because nocturnal hypoventilation becomes progressively more likely once this degree of impairment is reached. In myotonic dystrophy, which often has a central component, symptoms of nocturnal hypoventilation should be sought even earlier. When central control mechanisms or bulbar musculature are involved, obstructive apneas and hypopneas may be present even with relatively preserved lung function.

Prophylactic measures include nutritional counseling to avoid excessive weight gain that is a risk when patients become nonambulatory. Obviously, obesity can further compromise lung function and increase the likelihood of sleep-disordered breathing. Patients should also be encouraged to get influenza and pneumococcal vaccinations unless there are contraindications, and there should be a low threshold for starting antibiotic therapy in the event of an upper respiratory tract infection.

A number of uncontrolled studies[10,24] have examined the value of cough assist machines such as the cough inexsufflator (JH Emerson Co. Inc., Cambridge, MA). This device provides a large insufflation followed by a swing to negative pressure to increase sputum clearance. Physiotherapy during NIV may provide a similar degree of assistance, but a recent randomized comparison confirms that inexsufflation produces a larger increase in cough peak flow than NIV or physiotherapy alone and is well tolerated by adults and children.[25]

The role of respiratory muscle training in the muscular dystrophies is not yet clear. Sustained improvement in inspiratory muscle strength has been demonstrated using a simple training device.[26] However, this technique may be suitable only for patients with relatively mild muscle weakness; those with diurnal hypercapnia are unlikely to benefit. Moreover, the specific type of training undertaken is probably important, and motivation may be a problem.

Spinal surgery (e.g., Harrington rod stabilization) for thoracic scoliosis is often carried out in the early teen years in DMD, CMD, and SMA patients. The overall aim is to improve sitting comfort in the wheelchair, and although there may be a small alteration in the rate of lung volume decline, scoliosis surgery is unlikely to increase lung volumes in this patient group. A progressive curve with a Cobb angle of 30 to 50 degrees may be considered an indication for surgery, but this needs to be balanced against the respiratory reserve of the individual and cardiac function. Some orthopedic surgeons use a vital capacity of 30% predicted as a minimum for acceptance for spinal surgery.[27] However, the use of NIV in the pre- and postoperative phases may allow for successful surgery on those with lower vital capacities.[28] A sensible policy is to familiarize at-risk patients with NIV preoperatively, especially if nocturnal hypoventilation is present.

NONINVASIVE VENTILATION IN THE MUSCULAR DYSTROPHIES

The ventilatory management of neuromuscular disease is discussed in detail in Bach's article. Although there is no evidence that the introduction of prophylactic ventilation (i.e., before the development of symptoms of sleep disordered breathing) is of value in DMD,[29] once diurnal hypercapnia has arisen, ventilatory support is life saving.[8] In DMD, 5-year survival using NIV is in excess of 70%.[12] Children with CMD, intermediate SMA, and congenital myopathies also tolerate NIV well.[16,30] In the less progressive muscular dystrophies, such as LGMD, FSHMD, and CMD, long-term survival is likely.

SUMMARY AND CONCLUSIONS

A number of muscular dystrophies cause pulmonary morbidity. Although most progress at more or less predictable rates, there is large variability between the different entities, and even within single disease categories

there may be considerable variability. Therefore, the best plan of management combines knowledge of the natural history with careful follow-up consisting of periodic clinical exams and pulmonary function tests. A preventive approach is best, with careful counseling and use of vaccinations and antibiotics. Potential complications should be anticipated with measures like NIV, gastric feeding tubes, and cough inexsufflation before a respiratory crisis occurs.

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