Noninvasive Ventilatory Support during
Sleep Improves Respiratory Failure
in Kyphoscoliosis*

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We investigated the effect on daytime respiratory function and
quality of sleep, of providing adequate ventilation either by intermittent positive pressure ventilation (IPPV)
or by continuous positive airways pressure (CPAP) both administered through a nose mask in a group of seven patients with severe thoracic kyphoscoliosis. All night control
sleep studies were performed with and without ventilatory assistance. Patients underwent standard polysomnography including all night measurements of transcutaneous CO₂ (tcCO₂) and arterial oxyhemoglobin saturation (SaO₂). Awake arterial blood gas tensions (ABGs),
respiratory muscle strength (Pmus), and lung function tests were measured in the sitting position. Follow-up studies after three months of treatment showed normal sleep patterns, improvement in daytime ABGs, lung volumes, and respiratory muscle strength. We concluded that maintenance of nocturnal ventilation by either nasal CPAP or nasal IPPV in patients with nocturnal respiratory failure does significantly improve clinical measurements of respiratory function and quality of sleep. (Chest 1998; 94:811-15)

Patients with severe kyphoscoliosis eventually develop respiratory failure, and this is a common mode of death in such individuals. Bergovský has estimated that as many as 200,000 scoliotic individuals are at risk of developing respiratory insufficiency during their lifespan. It has been suggested that the onset of respiratory failure is first heralded by the occurrence of severe nocturnal hypoxemia. These patients frequently have obstructive apnea, as well as hypoventilation. Short-term ventilation has been associated with a marked improvement in clinical signs of respiratory failure in kyphoscoliosis. The clinical improvement was paralleled by an improvement of respiratory muscle strength. In these studies, fatigue of respiratory muscles was considered to be a key factor in the deterioration in patients with kyphoscoliosis; the rest achieved on assisted ventilation has been suggested as the cause of improvement. Long-term invasive, respiratory support has been shown to improve longevity and quality of survival, particularly in patients in whom the underlying cause is stable.

Kyphoscoliosis poses particular problems in management with assisted ventilation. Intubation or tracheostomy can be difficult because of the curvature of the cervical spine and the resultant twisting of the extrathoracic trachea. Negative pressure ventilators are difficult to fit to the distorted chest wall and can induce upper airway obstruction. Our aim was to test new noninvasive methods of nocturnal ventilatory support which we have developed in a group of patients with severe kyphoscoliosis and daytime awake respiratory failure. These patients can be effectively managed by either nasal CPAP or by nasal IPPV, depending on the proportion of upper airway dysfunction to respiratory pump dysfunction. The recovery found with this new technique which permits the patient complete independence during home treatment was similar to that found with more invasive techniques.

Methods

Seven patients with severe kyphoscoliosis were studied before and after intervention. Patient 5 had a kyphoscoliosis secondary to poliomyelitis and patients 1 and 4 had surgical correction at some time in the past. Anthropomorphic data are given in Table 1. All patients had pretreatment, all-night control studies and were monitored continuously, from lights out at approximately 2300 until awakening in the morning at 0600. Sleep was monitored with two channels of electroencephalogram (EEG), (C4/A1 C3/A2), two channels of electro-oculogram (EOG), and one channel of submental electromyogram (EMG). Sleep stage was classified by the standard criteria of Rechtschaffen and Kales. Airflow through the nose was detected by a pressure transducer linked to a pair of nasal prongs. Arterial oxyhemoglobin saturation (SaO₂), was measured with an ear oximeter. Transcutaneous carbon dioxide tension (tcCO₂) was measured continuously with a capnometer. Rib-cage and abdominal wall motion were recorded with a respiratory inductive plethysmograph. Electrocardiogram was also monitored. All variables were recorded continuously on a 16-channel EEG polygraph. Arterial blood gas tensions and standard respiratory function tests were measured in the sitting position.

Vital capacity (VC) was measured by a spirometer, and corrected for temperature and pressure. Respiratory muscle strength was assessed by multiple measurements of the maximal inspiratory and expiratory mouth pressure (Pmus), generated against an occluded

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University, Sydney, NSW, Australia 2006
Table 1—Characteristics of Group of Kyphoscoliotic Patients

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<th>Patient No.</th>
<th>Age, Yrs</th>
<th>Sex</th>
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</table>

Mean SD 43 ± 18 166 ± 16 54 ± 16

Airway according to Byrd and Hyatt.13

All patients were first tested with nasal CPAP and if this was ineffective in preventing nocturnal hypventilation, then nasal IPPV was commenced. Nasal CPAP was used for long-term treatment in two patients (patients 6 and 7), and five patients were treated with nasal IPPV. All patients were reassessed with a sleep study and all respiratory function indices repeated after three months of treatment.

Nasal CPAP was provided through the mask and blower system described by Sullivan et al.11 This system consists of a blower motor which provides room air at a high flow rate via corrugated tubing, to a close-fitting custom-built nose mask. A small expiratory resistance provides a critical CPAP level for each patient. Nasal ventilation was achieved with volume cycled, portable home ventilators. Room air, without humidification, was driven through clear corrugated tubing to the patient via a nose mask. The nose mask used in this study was custom-made and had a pliable lightweight shell with a self-sealing return for contact with the face.

Results

All patients had daytime decompensated respiratory failure with CO2 retention as well as excessive daytime sleepiness. They had markedly reduced lung volumes, and respiratory muscle strength was well below predicted for their age and height (Table 2).

The control sleep studies showed that all patients had severe hypoxemia and hypercapnia (Table 2) prior to intervention. This was typically worse in REM sleep (Fig 1 Panel A), although in some patients, this occurred in all sleep states. Snoring, complete upper airway obstruction, and hypopneas occurred. Associated with these changes was severe sleep fragmenta- tion, particularly of REM sleep.

Nasal CPAP

In patients 6 and 7, in whom repetitive upper airway obstruction was a key part of their hypoxemia, CPAP was sufficient to allow maintenance of SaO2 and to stabilize CO2 and reduce daytime symptoms. For the other five patients, CPAP was ineffective and CO2 rose or remained at a very high level over a number of days.

Nasal IPPV

For these five patients, nasal IPPV effectively maintained SaO2 and reduced TcCO2 (Fig 1, panel B); however, four of these patients required between 5 and 10 cmH2O positive end-expiratory pressure (PEEP) to allow effective ventilation.

After intervention, stable awake daytime PaCO2 decreased from a mean value of 62 ± 6 to 49 ± 5 mm Hg (p = 0.01) following regular nocturnal treatment for three months. Similarly, the PaO2 increased from a mean value of 51 ± 13 to 64 ± 4 mm Hg (p = 0.05) (Table 3).

All patients increased their respiratory muscle strength from a mean pretreatment value of -42 ± 25 cmH2O to a mean of -77 ± 23 cmH2O (p < 0.05) after treatment, although only minor changes in lung volumes occurred (Table 2).

Sleep staging during both IPPV and successful CPAP

Table 2—Pretreatment and Three Months After Commencement of Nocturnal Treatment Values

<table>
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<tr>
<th>Patient No.</th>
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<th>NREM SaO2tcCO2</th>
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Mean SD 0.97 ± 0.5 142 ± 25 42 ± 12 85 ± 10 79 ± 7 78 ± 12 1.1 ± 0.5 77 ± 23 93 ± 3 59 ± 12 94 ± 3 59 ± 9
showed a marked increase in the length and quality of REM sleep, and the patients reported that they awoke feeling refreshed, and had begun dreaming again. There was a marked clinical improvement with reduced daytime sleepiness and a reduced breathlessness on exertion. One patient, who had been previously oxygen-dependent, was able to achieve a functional capacity sufficient to allow a return to work.

**Long-term Domiciliary Use:** Following the initial period in hospital and recovery in clinical state, blood gas and respiratory muscle function, all patients continued their own treatment at home. In each case, nasal ventilation has been used each night for periods of 11 to 22 months. Although they did not require home nursing assistance, our unit provided a close follow-up service, including home visits, if required. In the first two months, most patients required practical help on one or two occasions, but after that were remarkably independent. The recovery seen in blood gases and respiratory muscle function was sustained at repeated testing every few months. At repeat sleep studies, the patients had difficulty sleeping without their ventilator, and continued to show marked desaturation during REM sleep. All reported a return of symptoms after sleeping without their ventilator for more than a few nights.

**DISCUSSION**

Our results demonstrate that chronic respiratory failure in kyphoscoliosis is reversed by adequate ventilation during sleep. Furthermore, nasal positive pressure ventilation, used only in sleep periods, is a safe and practical long-term solution to sleep-induced respiratory failure in kyphoscoliosis. In addition, this method has many advantages over more invasive methods of assisted ventilation.

Subjects with severe chest wall deformity secondary to kyphoscoliosis often develop hypercapnic respiratory failure after a minor trigger such as a respiratory tract infection. A common clinical history is of long-standing deformity with relatively few symptoms, apart from increasing fatigue and shortness of breath on exertion. Then, for ill-defined reasons, a series of episodes of acute respiratory failure precipitate a rapidly deteriorating clinical course with a poor prognosis. Recent reports indicate that people with severe kyphoscoliosis have a variety of sleep-related breathing disorders, suggesting that such changes may be

<table>
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<th>Patient No.</th>
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*Mean SD 51 ± 13 62 ± 6 7.29 ± 0.04 64 ± 4 49 ± 5 7.36 ± 0.04

*Base excess
important in the development of respiratory failure. Further, these patients have had marked improvement in clinical state, improved blood gases, and increases in respiratory muscle strength after short-term invasive ventilation particularly when this was provided overnight.5,14

Our results confirm and extend this work, first by showing that sleep induces marked deterioration in oxyhemoglobin saturation and elevation of TcCO2, and second, that noninvasive ventilatory support used only in sleep periods produces a reversal of respiratory decompensation, with a marked improvement in clinical status.

The acute hypoxemia was largely REM-related; however, in the more severely decompensated patients, severe desaturation occurred in both the major sleep states. Our results show that the primary mechanism is hypoventilation probably caused by gross mechanical derangement of the diaphragm. Upper airway obstruction contributed to the REM hypoxemia in some cases, and this persisted even when REM rebound occurred and there was an improved drive for ventilation. While this primary mechanism is responsible for the acute hypoxemia, particularly in REM sleep, the diverse clinical signs of respiratory failure are more likely to be the result of adaptation to the chronic nocturnal hypoventilation. This interpretation is strongly supported by the work of Berthon-Jones and Sullivan16 which shows that in patients with obstructive sleep apnea who develop CO2 retention, the chronic disturbance of blood gases in sleep causes resetting of the central chemoreceptors and that treatment with CPAP alone in these patients leads to a lowering of their daytime awake CO2. This work strongly supports the concept that sleep-disordered breathing during sleep is one of the key causes of CO2 retention in respiratory disease, and is thus, potentially reversible with treatment of the nocturnal breathing disturbance.

An alternative explanation is that the chest wall deformity alone was sufficiently severe to cause hypoxemia, and that this hypoxemia in turn induced the periodicity of tidal volume and influenced upper airway resistance and apnea.17 In addition, the somnolence may have been due to hypercapnia alone and not sleep fragmentation.18 If these two arguments are correct, then ventilating patients at any time during the day or night, to either rest their muscles or to improve their arterial blood gases, should be sufficient to see the clinical improvement and contradict the theory that it is nocturnal or sleep-related events that are critical in the deterioration of these people. Our clinical experience is, however, that after months of treatment when the arterial blood gases are considerably better and the muscles have been rested nightly with nasal ventilation, these people still desaturate severely during REM sleep implying that the underlying problem still exists, which we suggest is the diaphragm dysfunction.

There is no doubt that many factors contribute to the clinical picture of chronic respiratory failure and to the improvement seen with treatment. We suggest that the key mechanism for improvement in these patients is an overall increase in respiratory drive. However, additional mechanisms may be involved. Sleep was severely fragmented, and following treatment, sleep patterns were normalized. Sleep fragmentation is associated not only with excessive daytime sleepiness but also reduced ventilatory drive. White and co-workers19 have shown that even one night of sleep deprivation can lead to a reduction in ventilatory response to carbon dioxide. On the other hand, recent work has shown that severe sleep fragmentation is not necessarily linked to reduced respiratory muscle strength. Patients with severe sleep fragmentation due to obstructive sleep apnea do not show any evidence of weak respiratory muscles, and after nasal CPAP, do not show improvement (Chan S, unpublished data). Therefore, this is unlikely to be a dominant mechanism. The improvement in respiratory muscle strength could be explained by a number of factors. First, the respiratory muscles are at a severe biomechanical disadvantage in kyphoscoliosis and would be susceptible to fatigue and damage with upper airway loading in REM sleep. The rest accompanying controlled ventilation and reduction of upper airway loading with CPAP may have allowed a certain amount of recovery and repair. Second, after treatment, the improvement in oxygen and carbon dioxide levels would provide an improved environment for efficient function of the respiratory muscles. A third possible mechanism is that the severe repetitive hypoxemia and hypercapnia prior to treatment may have depressed motor-unit function, contributing to a central fatigue mechanism. Although we began to test whether oxygen alone would improve the condition of these patients, this was quickly abandoned as most developed unstable progressive rises of CO2.

We have tested a new mode of treatment previously described by our group,10,14 on patients with severely restricted chest walls. This noninvasive ventilatory support is particularly suited to the kyphoscoliotic patient, because these people are difficult to ventilate with other methods. Even tracheostomy can be difficult, because of the loss of extrathoracic trachea, which is typically twisted and narrowed, and the fitting of sheet or cuirass ventilators is made exceptionally difficult by the chest wall deformity. By contrast, this new ventilator system was able to accommodate the high pressures required for ventilation of people with low chest wall compliance and who required additional PEEP.
It is now clear that some patients with kyphoscoliosis who develop chronic respiratory failure do so because of severe sleep-related breathing disorders. The symptoms which characterize such disturbed breathing during sleep are relatively simple to identify clinically and should be sought by the physician. Previously, this clinical state has been regarded as the endstage of kyphoscoliosis, and our own experience has been that some physicians have previously believed these patients to be untreatable and have therefore, allowed them to die. Treatment is now easily implemented, and when adequate nocturnal ventilation is maintained, there is marked and sustained clinical improvement. There is no doubt that this new development will greatly improve the quality of life and longevity of these individuals.

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REFERENCES