

The present study also shows that nutritional status relates more to duration of diarrhoea than to the number of attacks but goes further by emphasising that it is the wasted child who is particularly at risk of more frequent and more protracted episodes of diarrhoea.

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### REVERSAL OF OBSTRUCTIVE SLEEP APNOEA BY CONTINUOUS POSITIVE AIRWAY PRESSURE APPLIED THROUGH THE NARES

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**Summary** Five patients with severe obstructive sleep apnoea were treated with continuous positive airway pressure (CPAP) applied via a comfortable nose mask through the nares. Low levels of pressure (range 4.5-10 cm H<sub>2</sub>O) completely prevented upper airway occlusion during sleep in each patient and allowed an entire night of uninterrupted sleep. Continuous positive airway pressure applied in this manner provides a pneumatic splint for the nasopharyngeal airway and is a safe, simple treatment for the obstructive sleep apnoea syndrome.

#### Introduction

THE syndrome of obstructive sleep apnoea is a common disorder, particularly in middle-aged overweight males.<sup>1-3</sup> The underlying problem is sleep-induced occlusion of the oropharyngeal airway, which results in multiple apnoeic episodes during sleep. There is severe fragmentation of sleep and, as the disease progresses over months or years, greater

degrees of asphyxia occur; the duration of apnoea frequently exceeds two minutes and the arterial haemoglobin oxygen saturation falls below 50%. Remarkably, the patient may be unaware of his nightly struggle for breath. Rather, his major symptoms are those of excessive daytime sleepiness and snoring. The nocturnal asphyxia eventually causes a variety of clinical presentations including cardiac arrhythmias, pulmonary hypertension and right heart failure, systemic hypertension, severe morning headache, intellectual and personality changes, and polycythaemia. The true cause of these findings may not be suspected. The disease is a recognised cause of sudden "unexpected" death.<sup>2,3</sup>

In the obese subject, weight loss may reduce the number of obstructive episodes. Other measures such as neck collars<sup>4</sup> and respiratory stimulants (progesterone<sup>5,6</sup> or protryptiline<sup>7</sup>) are less satisfactory. The only effective treatment now available is a tracheostomy which is left open at night.<sup>8,9</sup> This immediately results in disappearance of the excessive daytime sleepiness; and the life-threatening complications of hypoxaemia, such as arrhythmias and cor pulmonale, improve dramatically within days. In patients who do not have any of the immediately life-threatening complications, a decision to do a tracheostomy is invariably difficult, despite the knowledge that the disease is progressive. We describe here a method which has prevented upper airway occlusion for an entire night of sleep in each of five patients with severe obstructive sleep apnoea.

#### Methods

##### Theoretical Background

Existing evidence supports the hypothesis that the sleep-related upper airway occlusion is passive. Remmers et al.<sup>10</sup> have suggested that the subatmospheric pressure in the airway during inspiration sucks the tongue and soft palate against the posterior oropharyngeal wall. Guilleminault et al.<sup>11</sup> have found evidence that there is a failure of the dilator action of pharyngeal muscles during obstructive apnoea. The pre-existing conditions which would allow suction-collapse of the oropharyngeal airway are a combination of increased upper airway resistance (e.g., congenitally small airway, nasal polyps, tonsillar or adenoid enlargement) and a normal or excessive<sup>11</sup> sleep-induced reduction of muscle tone in the palate, tongue, and pharynx (fig. 1). To provide adequate airflow the subject with a pre-existing high upper airway resistance must generate more subatmospheric airway pressure than a normal subject, and therefore more suction pressure in the oropharyngeal airway during inspiration. The forces favouring airway collapse are the suction pressure generated within the airway during inspiration, and gravity (particularly the weight of the tongue and jaw). The forces resisting collapse are the tissue elastic components and muscle tone. Loss of muscle tone in sleep causes a further narrowing of the oropharyngeal airway and increased resistance; thus greater suction pressures are required to sustain airflow. At some critical point the tongue and soft palate are sucked onto the posterior oropharyngeal wall, causing complete occlusion (fig. 1). The aim of the present study was to test the hypothesis that continuous positive airway pressure applied through the nares would act as a pneumatic splint and prevent upper airway occlusion by pushing the soft palate and tongue forward and away from the posterior oropharyngeal wall.

Fig. 2 is a schematic diagram of the method. Two soft plastic tubes were shaped to fit snugly in each naris. The other ends of these tubes were inserted into a lightweight wide-bore tube. This arrangement was strapped to the patient's face. A medical grade silicone rubber ('Silastic No. 382', Dow Corning, Midland, Michigan, U.S.A.) was then run over the nose and nares to provide a comfortable seal. Continuous positive pressure was produced by connecting one end of the wide-bore tube to a vacuum-cleaner blower motor with variable speed control. The other end of the wide-bore tube was led

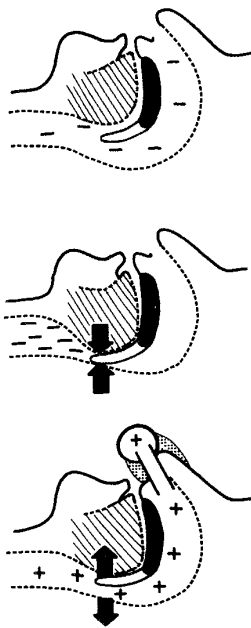


Fig. 1—Mechanism of upper airway occlusion and its prevention by CPAP.

When the patient is awake (upper panel) muscle tone prevents collapse of the airway during inspiration; during sleep the tongue and soft palate are sucked against the posterior oropharyngeal wall (middle panel). CPAP with low pressure provides a pneumatic splint and keeps the airway open (lower panel).

away from the patient and was narrowed with mechanical resistance. The resistance of the circuit was chosen so that a high bias flow (20–40 l/min) was sustained for the range of pressures required at the nose. Pressure was measured continuously via a catheter inserted into one nasal tube (Statham 'PM 131 TC') and airway CO<sub>2</sub> was sampled continuously via a catheter in the other nasal tube and measured with a CO<sub>2</sub> meter (Godart 'Capnograph'). The blower motor was installed in a box lined with acoustic material, which reduced the noise level to that of a fan.

All-night Sleep Studies

Three all-night sleep studies were done in each patient. In the first study the diagnosis of severe obstructive sleep apnoea was established. Sleeping posture (supine, prone, lateral, and sitting) had no effect on the occlusive episodes. The second study, done 6 weeks to 7 months later, was a night of control observations immediately before a third all-night study during which CPAP was applied. The second two studies were done with the patient sleeping in the supine position. Sleep state was assessed with two electroencephalographic (EEG) records (C<sub>3</sub>/A<sub>2</sub>, C<sub>4</sub>/A<sub>1</sub> positions), a postural (submental or nuchal) electromyographic record, and two ocular movement records. Electrocardiogram and heart rate were recorded continuously. Arterial haemoglobin oxygen saturation was measured with a Hewlett Packard ear oximeter and chest wall and abdominal movements were recorded with a circumferential inductance device ('Respirace', Ambulatory Monitoring Inc., Ardsley, N.Y., U.S.A.). In the control study, airflow at the nose and

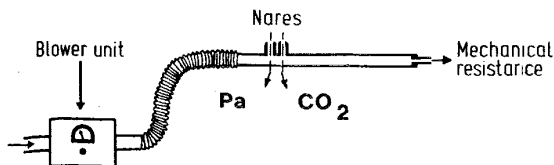


Fig. 2—Diagram of apparatus used to provide continuous positive airway pressure through the nares.

Pa=airway pressure; CO<sub>2</sub>=FCO<sub>2</sub>.

mouth was monitored by a pressure transducer inserted into a loose-fitting, lightweight plastic face mask which covered both nose and mouth. Face masks were not used in the original diagnostic studies. All variables were recorded with a Grass model 78 16-channel EEG polygraph system. Sleep was staged according to standard criteria.<sup>12</sup>

Clinical Summaries

All five patients had a long history of noisy snoring and in the past 1–5 years had complained of excessive daytime sleepiness. The sleepiness had seriously interfered with the patient's life. For example, patient 1 had been forced to stop work in the building industry because he would fall asleep while working on scaffolding and while driving. Patient 3, a company executive, often fell asleep during important office meetings; and patient 4 had lost his job as a clerk because he fell asleep at his desk every afternoon. Patient 5, a boy of 13, had been considered mentally retarded. However, a large component of this retardation was secondary to his inability to stay awake at school. All five patients were normal on physical examination. Four, however, seemed to have a narrow oropharynx. Radiography of the upper airway did not identify any underlying abnormality. Respiratory function and arterial blood gases were normal. Three of the five patients refused tracheostomy.

Results

The control study confirmed the presence of severe obstructive sleep apnoea in all five patients—cyclic episodes of apnoea, interrupted by four or five loud snoring breaths, for the entire night of sleep. The mean apnoea index<sup>3</sup> in non-rapid-eye-movement (NREM) sleep was 62 apnoea episodes per sleep hour (range 33–97), the mean apnoea duration was 35 s (n=434, range 16–70 s), and the mean of the lowest levels of haemoglobin oxygen saturation during apnoea was 84% (range 71–95%).

As described previously,<sup>13</sup> the duration of apnoea was longer in REM sleep (mean 45 s, n=265, range 22–122 s) and the levels of haemoglobin oxygen saturation were lower (mean 73%, range 48–92%). The mean apnoea index in REM sleep was 64 apnoea episodes per sleep hour (range 48–85). Comparison with the original diagnostic studies showed no lessening in the severity of disease. Specifically, there were no statistical differences in the apnoea indices, duration of apnoea, and levels of oxygen saturation.

Continuous positive airway pressure completely prevented the upper airway occlusion in each of the five patients. The upper airway occlusion could be turned off and on simply by increasing or reducing the level of positive airway pressure. A typical record is shown in fig. 3. The first part of the tracing shows the characteristic cyclic occlusive apnoea with progressive asphyxia followed by a transient arousal with a few gasping breaths. The application of 4.5 cm H<sub>2</sub>O of continuous positive airway pressure through the nares completely abolished the occlusion (arrow A). Within two minutes of unobstructed breathing this patient went into

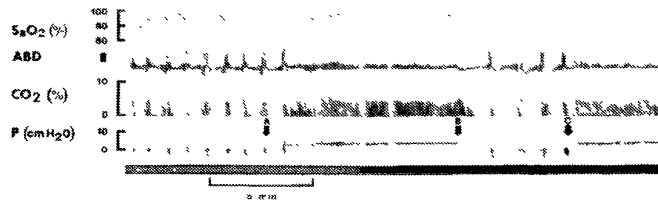


Fig. 3—Part of pen record from patient 2.

SaO<sub>2</sub>(%)=arterial haemoglobin oxygen saturation; ABD=abdominal movement, upward deflection indicating diaphragm descent; CO<sub>2</sub>(%)=airway carbon dioxide sampled from one nostril; P=pressure recorded from the second nostril. The hatched bar is NREM sleep; the closed bar is REM sleep. For explanation of arrows, see text.

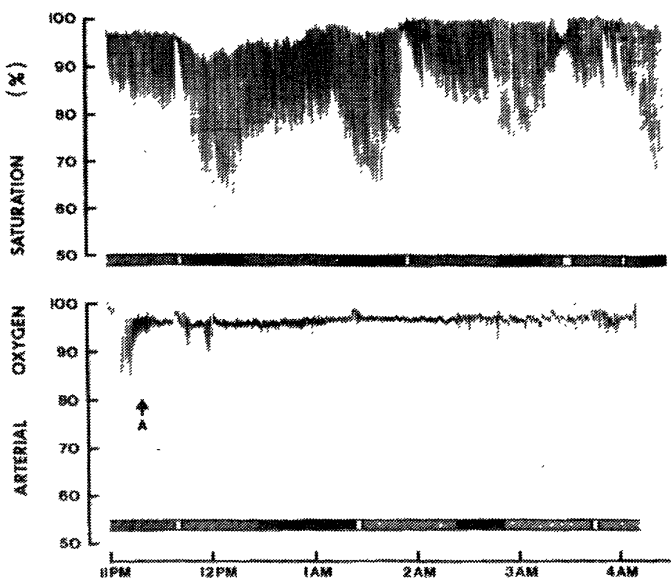


Fig. 4—All-night slow recordings of arterial haemoglobin oxygen saturation from patient 4.

Control night (upper panel); test night (lower panel); hatched bar, NREM sleep; closed bar, REM sleep; open bar, awake. CPAP of 7·0 cm H<sub>2</sub>O was applied at arrow A and sustained for the rest of the night. See text for details.

REM sleep. Note the episodes of central apnoea typical of this sleep-state. Reduction of the nasal pressure (arrow B) caused the immediate return of occlusion. The longer apnoeic periods and greater falls in haemoglobin oxygen saturation are typical of REM sleep. Increasing the nasal pressure (arrow C) again completely abolished the occlusive episodes.

The all-night slow recordings of arterial haemoglobin oxygen saturation from the control night (upper panel) and test night (lower panel) of patient 4 are shown in fig. 4. The repetitive decreases of saturation shown here for the control night were typical of the control night in each of the five patients. In the early part of the test night (lower panel, fig. 4) the patient showed the typical occlusive episodes. Continuous positive airway pressure of 7 cm H<sub>2</sub>O was applied at arrow A and sustained for the rest of the night. This level of pressure completely abolished the occlusive episodes.

The small decreases of arterial haemoglobin oxygen saturation which occurred during the rest of the night resulted from short episodes of central apnoea in stage I NREM sleep and in REM sleep; these are normal findings for those sleep stages.

Once identified, the level of continuous positive airway pressure required to prevent upper airway occlusion required no further adjustment for the entire night. These pressures were 10·0, 4·5, 6·0, 7·0, and 4·5 cm H<sub>2</sub>O in patients 1–5, respectively. No patient had difficulty sleeping with the nose-mask in operation. The short sleep-onset latency which is typical of this disorder was found on both control and test nights, and there was a pronounced increase in the time spent in stage III and IV NREM sleep and REM sleep on the test night (table). Two of the patients had very long episodes of REM sleep (90 min patient 1, 70 min patient 5) within seconds after the upper airway had been made patent with continuous positive pressure, and there was a reduction in the latency to REM sleep in all patients.

The immediate clinical response to one night of unobstructed sleep was remarkable. Each patient awoke spontaneously, was alert, and remained awake unprompted for the rest of the day. None of the patients had excessive daytime sleepiness for that day. One of the patients (patient 1) had been unable to stay awake for longer than a few minutes each day and for the three days before the test he was observed to be asleep with an occluded upper airway during most of the daylight hours. After the test night he remained awake for the entire day and was able to watch television for several hours—something he had been unable to do for years.

To evaluate whether the patients could continue to sleep with the nose-mask and continuous positive airway pressure after losing the pathological sleepiness which characterises this disease, further studies were undertaken. On separate occasions, two of the patients were treated with continuous positive airway pressure on three consecutive nights, after a control all-night study in which the nose-mask was in place but with positive pressure below the critical level for reversal of occlusion. In these patients the pattern of obstruction on the control night was identical with that seen previously. On the three treatment nights there were no episodes of obstructive apnoea during sleep while continuous positive airway pressure was maintained. Despite the absence of clinical and self-reported pathological sleepiness by the

SLEEP PROFILE ON CONTROL AND TEST NIGHTS

| Patient   | Age (yr) | Weight % predicted | Time of study                  | Sleep latency (min) |                         | Total sleep time (min)  | % NREM sleep |               | % REM sleep  |
|-----------|----------|--------------------|--------------------------------|---------------------|-------------------------|-------------------------|--------------|---------------|--------------|
|           |          |                    |                                | NREM sleep          | REM sleep               |                         | Stage I, II  | Stage III, IV |              |
| 1         | 40       | 109                | C 23·29–06·02<br>T 22·20–05·57 | 0<br>0              | 127<br>0                | 381<br>417              | 65<br>38     | 0<br>21       | 35<br>41     |
| 2         | 52       | 92                 | C 22·14–05·43<br>T 23·58–05·35 | 4<br>0              | 147<br>51               | 385<br>288              | 81<br>54     | 0<br>14       | 19<br>32     |
| 3         | 55       | 108                | C 22·38–05·25<br>T 22·52–05·28 | 3<br>5              | 80<br>51                | 376<br>372              | 77<br>51     | 3<br>20       | 20<br>29     |
| 4         | 48       | 186                | C 22·42–05·56<br>T 23·30–04·40 | 0<br>2              | 96<br>90                | 418<br>310              | 72<br>26     | 2<br>45       | 26<br>29     |
| 5         | 13       | 80                 | C 23·23–05·39<br>T 22·39–05·28 | 2<br>0              | 256<br>0                | 362<br>364              | 72<br>40     | 18<br>26      | 10<br>34     |
| Mean ± SE |          |                    |                                | 1·8±0·8<br>1·4±1·0  | 141·2±30·9<br>38·4±17·2 | 384·4±9·2<br>350·2±23·0 | 73±3<br>42±5 | 5±3<br>25±5   | 22±4<br>33±2 |

C = Control night; T = test night.

second day after treatment, both patients were still able to sleep with the nose-mask and continuous positive pressure on the third night of treatment, and awoke spontaneously after total sleep durations of 446 and 330 min.

### Discussion

Our simple method of reversing sleep-induced upper airway occlusion was remarkably effective in these five patients with severe disease. The fact that the occlusion could be turned off and on in each patient by increasing and decreasing the level of continuous airway pressure is proof that the therapy works. It cannot be argued that the method worked by keeping the patient awake or even at a light stage of sleep. On the contrary, each patient had a night of uninterrupted sleep—probably the first for months or even years—and there was a shift from the lighter stages of NREM sleep to stages III and IV NREM sleep. The abnormally short REM sleep latency and long REM sleep episodes found in some of the patients is typical of the rebound effect after sleep fragmentation or deprivation. The fact that each patient remained without any obstruction during these REM episodes is further evidence of the efficacy of the method, for it is in REM sleep that muscle tone is lowest and patients with obstructive sleep apnoea tend to be worst. Some patients have occlusive episodes only during REM sleep.

Tracheostomy is the most direct form of treatment and rapidly reverses the symptoms and life-threatening complications of obstructive sleep apnoea.<sup>8,9</sup> However, most patients are reluctant to have such therapy and many refuse. The decision to do a tracheostomy is usually difficult. Unless there are life-threatening complications such as arrhythmias or pulmonary hypertension and right heart failure, there are no absolute criteria for its use, despite the knowledge that the relentless, repetitive nocturnal asphyxia is probably causing tissue damage. Non-invasive forms of therapy are attractive to patient and clinician but to date none has been very successful. We believe our method will provide a useful adjunct to the treatment of this disorder.

A crucial question is whether patients will be able to tolerate the nose-mask after they recover from their pathological sleepiness. The fact that the two patients who were treated over three consecutive nights were still able to sleep without discomfort on the third night, despite loss of the pathological sleepiness, is encouraging evidence that this form of treatment can play an important part in the management of these patients. However, whether long-term treatment will be practical or whether treatment with continuous positive airway pressure over a short period will in itself reduce the frequency and severity of the obstructive episodes remains unanswered.

Irrespective of its potential for long-term treatment, the method is well suited to the in-hospital management of those patients with the difficult combination of lung disease and sleep-induced upper airways obstruction, and of those in whom obesity makes tracheostomy difficult or dangerous. Such patients frequently present with cor pulmonale as a direct consequence of severe nocturnal hypoxaemia. The use of nasal continuous positive airway pressure could play a major role in the initial management by rapidly reversing the hypoxaemia and pulmonary hypertension and providing time for other measures such as weight reduction to become effective.

Theoretical disadvantages of continuous positive airway pressure have been widely discussed.<sup>14,16</sup> Initially, inspiration is facilitated and expiration is impeded; the end-

expiratory lung volume shifts to a higher level and a new balance between inspiratory muscle effort and lung elastic recoil is established. In animals a reflex activation of expiratory muscle occurs. The major concern with continuous positive airway pressure is that it reduces cardiac output and renal function. However, this is only a problem with pressures in excess of 10 cm H<sub>2</sub>O. Less serious potential effects relate to pressure on the upper airway. Airway pressures of 5–10 cm H<sub>2</sub>O would be expected to reduce mucosal blood flow. This could be an advantage, through reduction of mucosal oedema and swelling. Increased pressure in the sinuses might decrease drainage and cause problems in patients with pre-existing abnormalities. Drying of the airway mucosa, another possible complication, could be overcome by inclusion of a humidifier in the circuit. None of our patients had a sore or dry nose after the procedure.

Mechanical failure of the positive airway pressure device is another potential hazard. Occlusion of the exhaust line could theoretically cause hyperinflation of the lungs and perhaps even lung rupture. This can not happen if a low pressure pump, e.g., a fan, is used (maximum pressure say, 15 cm H<sub>2</sub>O). Furthermore, because the pressure is applied only through the nares, the mouth should act as a blow-off valve. A more likely mechanical failure is that of a loss of pressure. If this did occur, it would simply return the patient to his usual state of upper airway obstruction. However, since the mouth is unoccluded by the apparatus he will be able to breathe room air at the moment of arousal and return of muscle tone. This is, in effect, a fail-safe system which would not be available if the method required a face-mask covering both the mouth and the nose. The inherent simplicity and safety suggest that home use will be possible.

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