Overview of Sleep-Disordered Breathing

Upper airway obstruction occurring during sleep—that is, sleep-disordered breathing (SDB)—was first demonstrated in the 1960s. SDB represents a group of physiopathologic conditions that are characterized by an abnormal respiratory pattern during sleep that can be isolated or can coexist with other respiratory, nervous, cardiovascular, or endocrine diseases. SDB is now known to be widely prevalent in the general population, and it is responsible for or contributes to numerous problems, ranging from fragmented sleep patterns to hypertension to traffic accidents.[1, 2]

SDB includes obstructive sleep apnea (OSA), which consists of breathing cessations of at least 10 seconds occurring in the presence of inspiratory efforts during sleep. Central sleep apnea consists of similar apneas, but these instead take place in the absence of inspiratory efforts.[3, 4, 5, 6, 7]

The obstructive sleep apnea syndrome (OSAS) is a potentially disabling condition characterized by excessive daytime sleepiness,[8] disruptive snoring, repeated episodes of upper airway obstruction during sleep, and nocturnal hypoxemia. It is defined by an apnea-hypopnea index (the total number of episodes of apnea and hypopnea per hour of sleep), or respiratory disturbance index, of 5 or higher in association with excessive daytime somnolence.

Risk factors for sleep apnea include obesity, increased neck circumference, craniofacial abnormalities, hypothyroidism, and acromegaly. Daytime consequences include not only excessive sleepiness but also impaired cognitive performance and disturbed moods with a reduced quality of life. Excessive daytime sleepiness is reported to be associated with a higher risk of motor vehicle accidents and work place injuries or poor work performance .

In general, everyone with SDB snores, but not everyone who snores has SDB. Snoring in the absence of SDB is termed primary or simple snoring. However, some evidence indicates that snoring is one end of a clinical continuum with an opposite extreme of severe OSA. Some health problems may be associated even with primary snoring.

Upper airway resistance syndrome (UARS) is characterized by snoring with increased resistance in the upper airway, resulting in arousals during sleep. This can disturb sleep architecture to the point of causing daytime somnolence. No distinct diagnostic criteria exist for this entity. Patients with UARS can be treated with nasal continuous positive airway pressure (n-CPAP).[9, 10]

Treatment involves elimination of contributing factors and provision of n-CPAP. n-CPAP is effective in improving sleep quality and reducing daytime sleepiness. Long-term treatment with n-CPAP reduces both mortality and the acute blood pressure elevation that occurs with SDB.[11] Over time, a trend develops toward baseline blood pressure reduction in hypertensive patients with SDB. Medical and surgical interventions may also be indicated

Epworth Sleepiness Scale

The Epworth Sleepiness Scale is a questionnaire filled out by the patient that is used to provide a standardized semiquantitative subjective assessment of daytime sleepiness.

In this questionnaire, patients are instructed to rate the chance of dozing off in a number of different situations. They are to choose the most appropriate ranking for each of these situations, working out how they would probably respond if it is something they have not actually done recently. Scoring for the Epworth Sleepiness Scale is shown in the table below.

Table 1. Epworth Sleepiness Scale Questionnaire (Open Table in a new window)

Scoring

0 - Would never doze off

1 - Slight chance of dozing off

2 - Moderate chance of dozing off

3 - High chance of dozing off

Score situation

_____ Sitting and reading

_____ Watching TV

_____ Sitting inactive in a public place (eg, theater, meeting)

_____ As a passenger in a car for an hour without break

_____ Lying down to rest in the afternoon when circumstances permit

_____ Sitting and talking to someone

_____ Sitting quietly after a lunch without alcohol

_____ In a car, while stopped for a few minutes in the traffic

_____ **Total***

*A total score of 0-5 is supernormal; 5-10 is normal; 10-15 is sleepy; 15-20 is very sleepy; and > 20 is dangerously sleepy (arrange transportation for patient)

Treatment with Nasal CPAP

When none of the above therapies are appropriate or helpful, nasal continuous positive airway pressure (n-CPAP) is the most effective method to manage obstructive sleep apnea syndrome (OSAS).[48, 49, 50, 4, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 46, 61]

n-CPAP provides a pneumatic stent for the upper airway, eliminating the airway collapse during inspiration. It is administered by a soft mask that covers the nose only. Sufficient pressure is introduced to eliminate apneas, hypopneas, and snoring. An image depicting a CPAP machine can be seen below.


CPAP machine.

Most physicians agree that patients with a respiratory disturbance index (RDI) higher than 20 require treatment. n-CPAP can also be useful for patients with a lower RDI, especially if they experience daytime sleepiness or other symptoms. If the severity of the daytime symptoms and the Epworth Sleepiness Scale score are much greater than would be expected with a particular RDI, a trial of n-CPAP can help determine whether elimination of the SDB leads to improvement of the daytime symptoms or if other factors contribute to the daytime symptoms.

Patients who are unlikely to benefit from n-CPAP include those with such severe nasal obstruction that n-CPAP cannot be used, patients with such extreme claustrophobia that they cannot tolerate a nasal mask, and patients in whom n-CPAP does not reliably eliminate apneas, hypopneas, and snoring.

Determination of positive airway pressure required

The criterion standard for determining the amount of pressure required to restore upper-airway patency is traditionally determined during polysomnography (PSG) by trained technicians. In some centers, this is performed as a split-night study, with data from the first half of the night used for diagnosis of SDB. Once this diagnosis is made, if the RDI is sufficient to suggest benefit from initiation of n-CPAP (usually an RDI of 20 or higher), the second half of the night's study is used to determine the optimal amount of pressure.

The disadvantage of the split-night approach is that the second half of a full night study often reveals more severe sleep apnea, so a diagnostic study limited to the first half of the night can underestimate disease severity.

The amount of pressure delivered is reported as cm water. An average starting point for CPAP would be 8-10 cm water. Patients report that pressures at these levels feel odd but are tolerable even when beginning treatment and become more tolerable as the patients become accustomed to treatment. Higher levels (>15 cm water) are often not well tolerated.

When a second overnight study is logistically difficult, some clinicians empirically start a patient on n-CPAP with a pressure of 8-10 cm water. A new generation of n-CPAP machines, on the basis of the patterns of inspiratory airflow, can sense the amount of pressure needed to overcome upper airway resistance. Patients are sometimes started using these machines without a prior titration study.[62, 63]

Alternatively, an autotitrating machine can be used for several nights, the record of amount of pressure required to suppress apneas and hypopneas can be downloaded and studied, and a suitable nightly pressure can be determined in this fashion. Also, the amount of pressure required to suppress snoring can be used as an audible guide to appropriate pressures.

A patient who routinely takes sedatives or ingests alcohol during the evening and does not intend to change this should probably be tested after continuing their usual nightly routine. n-CPAP titration without sedatives or alcohol is likely to lead to undertreatment of the SDB at home, when such patterns are resumed.

Effects of n-CPAP

Most patients feel better during the daytime on the first day after beginning n-CPAP. During the first week of treatment, most experience rebound sleep with prolonged episodes

of REM sleep. Sleep patterns become more normal after the first week. For these reasons, several weeks of n-CPAP use may be helpful for normalization of sleep patterns in patients with severe sleep apnea who plan to undergo surgery. Sleep patterns should be normalized prior to the planned surgery.

Regular use of n-CPAP improves both the patients' and their bed partners' quality of life.[64, 65, 66] The treatment lessens depressive symptoms, and improves daytime functioning, blood pressure and insulin sensitivity. In patients with OSA who receive antihypertensive treatment, long-term CPAP was found to be responsible for a significantly reduction of diastolic blood pressure. Asthmatic OSA patients have fewer nighttime symptoms.[67, 57, 68]

Other effects of using CPAP include increased vagal tone, increased cardiac output, increased stroke volume, decreased systemic vascular resistance, and reduced risk of cardiovascular mortality.[11]

Patients with OSA often have increased arterial stiffness and sympathovagal imbalance. CPAP therapy is reported to have beneficial effects on the vascular function in such patients: improvement of the sympathovagal balance by CPAP therapy may be significantly related to decreased stiffness of the central to middle-sized arteries, independent of the changes in the blood pressure and vascular endothelial status.[69]

Repetitive obstructive apnea produces acute impairment of left ventricular longitudinal function, suggesting the development of subendocardial ischemia. CPAP therapy not only decreases the severity of OSA but also ameliorates sleep-induced longitudinal left ventricular dysfunction.

Problems with n-CPAP

One problem with n-CPAP is that although n-CPAP provides good improvement in symptoms and physiologic parameters, compliance with treatment is not good, with regular use sometimes estimated as low as 30% (46% in one study defining use as at least 4 h/d, 5 d/wk). Noncompliance has been categorized by Zoula et al as tolerance problems, psychological problems, and lack of instruction, support, or follow-up.[70]

Tolerance problems may be due to side effects (ie, dry mouth, conjunctivitis, rhinorrhea, skin irritation, pressure sores, nasal congestion, epistaxis), mask leaks, difficulty exhaling, aerophagia, chest discomfort, and bed-partner intolerance.[64] Psychological problems include lack of motivation, claustrophobia, and anxiety. The suggestions below for dealing with some of these problems may assist the physician in improving treatment compliance.

Many patients report claustrophobia. They find that the sensation of covering the nose with a mask makes them so uncomfortable that they cannot tolerate wearing the n-CPAP. Sometimes this can be helped with a smaller or more transparent mask design. Use of nasal pillows (inserted into the nostrils) instead of a formal nasal mask may allow such patients to tolerate the n-CPAP.

Some patients have trouble tolerating the initial pressure. Especially when higher pressures (>12-13 cm water) are required for elimination of apneas and hypopneas, this level of pressure may be uncomfortable. Many n-CPAP machines have a built-in ramp or gradual increase in pressure. Using this feature, the mask can be placed and pressure begun at a

very low and easily tolerated level. Over 30 minutes, the pressure gradually builds to the full amount necessary. Often, the patient can fall asleep during this time. Full pressure is not used until the patient is actually asleep.

Patients may experience nasal obstruction. Evaluation by an otolaryngologist reveals whether this is predominantly a fixed skeletal obstruction or a soft tissue obstruction potentially modifiable without surgery. Marked septal deviation or turbinate hypertrophy usually requires surgery for resolution. Alar collapse may be adequately treated by internal or external dilators (eg, Breathe Right strip, Nozovent). Surgery is sometimes required for repair of marked alar collapse.

Mucosal edema may be due to allergic rhinosinusitis or to vasomotor or irritative rhinitis. Allergy testing and treatment and pharmacotherapy trials (eg, topical steroids or antihistamines, oral antihistamines, or decongestants) may be beneficial.

One way to determine whether sufficient potentially reversible mucosal edema exists to pursue that avenue of treatment is the topical decongestant test. The patient uses a nasal topical decongestant (eg, oxymetazoline) at bedtime for several days, with the patient and bed partner observing for any improvements in snoring or apneas. A marked improvement suggests potentially reversible mucosal edema as a main contributor to the nasal obstruction. Failure to improve suggests a fixed skeletal obstruction that requires surgical correction.

Sometimes the dryness of the air or its temperature may be irritating to the patient. Use of in-line humidification and warming of the inspired air may alleviate patient discomfort.[71, 72]

A number of patients report facial or nasal pain. Sometimes this pain can be related to a poorly fitting mask. With the many different types of masks available now, different styles and sizes can be tried to select the optimal fit for each individual anatomy. Because the mask is pulled tight against the face, an edentulous anterior maxilla may not provide the resistance necessary for a good fit. Leaving dentures in at night can help with this.

If the facial or nasal pain persists despite mask refitting, evaluation for nasal obstruction or chronic sinusitis may be helpful. The CPAP Pro delivery method anchors the tubing to a platform based on an upper retainer, obviating the need for a forehead strap.

Patients may experience dry eye or other eye discomfort. If the mask does not seal well, egress of pressurized air from the upper end of the mask toward the eye may occur, causing dry eye or even exposure keratitis. Mask refitting usually eliminates this problem.

Patients may sleep with the mouth falling open, awakening with dry mouth. Sometimes a chin strap is required to prevent the mouth from opening at night. A commercially available disposable adhesive bandage may used to pull the chin up toward the lower cheeks.[73]

Patients may experience epistaxis. This may be related to the high-flow dry air and may be helped by humidification and warming of the inspired air.

Some patients experience nasal drying. Forced dry air can be irritating to the nose, encouraging mucosal inflammation and crusting. Use of humidified air for n-CPAP usually eliminates this problem.

Other problems may also occur. Pneumopericardium has been reported with n-CPAP.[74] Pneumocephalus has occurred when n-CPAP was used in a patient with cerebrospinal fluid rhinorrhea. Eustachian tube dysfunction, serous otitis media, bulging of the eardrums, and eardrum perforation have also been reported.

Rigorous patient education and early reinforcing follow-up may improve long-term use of n-CPAP.

Other considerations

Variations of air pressure delivery can sometimes make n-CPAP use more comfortable for patients.

Autotitrating positive airway pressure (APAP) continually adjusts the pressure to barely overcome the collapsing forces. Bilevel positive airway pressure (BiPAP) provides higher pressure during inspiration (when the pneumatic splint is needed to prevent obstructive airway collapse) and lower pressure during expiration. C-Flex is another autoadjusting delivery method that increases pressure toward the end of expirations, as collapse would usually begin, and decreases pressure during early expiration.

Patients who require higher pressures to overcome obstructive apneas may tolerate these devices better than the one-level n-CPAP, which delivers the higher pressure throughout the entire respiratory cycle.

Following treatment with CPAP, some patients with obstructive sleep apnea remain sleepy despite effective CPAP, and attention should be paid to other diagnoses that can be associated to sleepiness. The so called “post-CPAP sleepiness,” as a specific disorder, may not exist.

Oxygen

Because some of the effects of sleep-disordered breathing (SDB) are due to hypoxia during sleep, the administration of oxygen would seem like a reasonable treatment. Although oxygen administration improves the lowest blood-oxygen saturation level during sleep and can improve some of the arrhythmias occurring during desaturation, repeated studies have not demonstrated sustained clinically significant improvement in SDB with oxygen administration. Some prolongation of apneas also occurs, particularly at the beginning of therapy.

Oxygen administration may be beneficial in a subset of patients. Some patients with other coexistent pulmonary disorders may also benefit from use of oxygen in conjunction with nasal continuous positive airway pressure (n-CPAP).

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Pharmacologic Treatments

Protriptyline

Protriptyline, a tricyclic antidepressant, is the medication most studied in the treatment of SDB and does yield improvement in patients with this condition. This effect, however, appears to be mainly due to suppression of rapid eye movement (REM) sleep. Because sleep-disordered breathing (SDB) is often most severe during REM sleep, less REM sleep can mean fewer apneas.

Modafinil

Modafinil is a wake-promoting medication used in association with continuous positive airway pressure (CPAP) to treat patients with obstructive sleep apnea syndrome (OSAS). It has an action similar to that of sympathomimetic agents (like amphetamine and methylphenidate), although its pharmacologic profile is not identical to that of sympathomimetic amines. The precise mechanism through which modafinil promotes wakefulness is unknown.

Headache and nervousness are the only adverse events reported. There is no benefit using Modafinil in patients with OSA who are not compliant with CPAP, so it should not be administrated in such cases.

Other drugs

Other drugs that have been investigated for treatment of sleep apnea include progestational agents, aminophylline, acetazolamide, L-tryptophan, naloxone, baclofen, bromocriptine, chlorimipramine, and prochlorperazine. None of these have shown a consistently helpful effect on sleep-disordered breathing (SDB).

How Continuous Positive Airway Pressure (CPAP) Respiratory Ventilation Systems Function

By: John Gosson

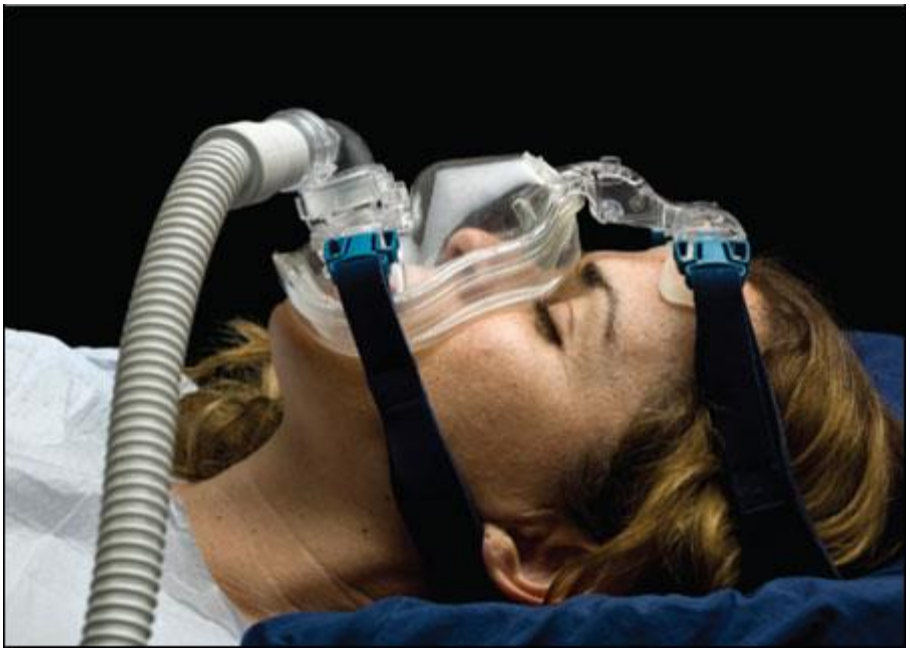
Abstract: This application note introduces how a continuous positive airway pressure (CPAP) ventilation system operates. The main subfunctions of CPAP respiratory ventilation include air-hose-environment sensing, compressor motor-drive feedback, motor-drive excitation, and a communication interface to a technician/doctor. These subfunctions are explained and a functional block diagram showing system components is also detailed.

Continuous positive airway pressure (CPAP) is a type of respiratory ventilation originally developed

for combating sleep apnea, which remains its primary use. It is also useful in providing ventilation for newborns and anyone suffering respiratory failure.

As airway muscles relax during sleep, the airway can become partially obstructed. This can lead to lower blood oxygenation and cause awakening or arousal from deep sleep. Maintaining positive air pressure by supplying a continuous source of compressed air, the face mask forms a seal to the face. It is only this air pressure that maintains the open airway, and not the actual movement of air. A sleep physician usually determines the required air pressure after completing a sleep study.

Pressure sensors supply feedback of the applied air pressure in the mask/delivery hose to the microprocessor controller. This microprocessor controller manages the motor-drive stage of a compressor to maintain the correct fan velocity necessary to generate the required air pressure.



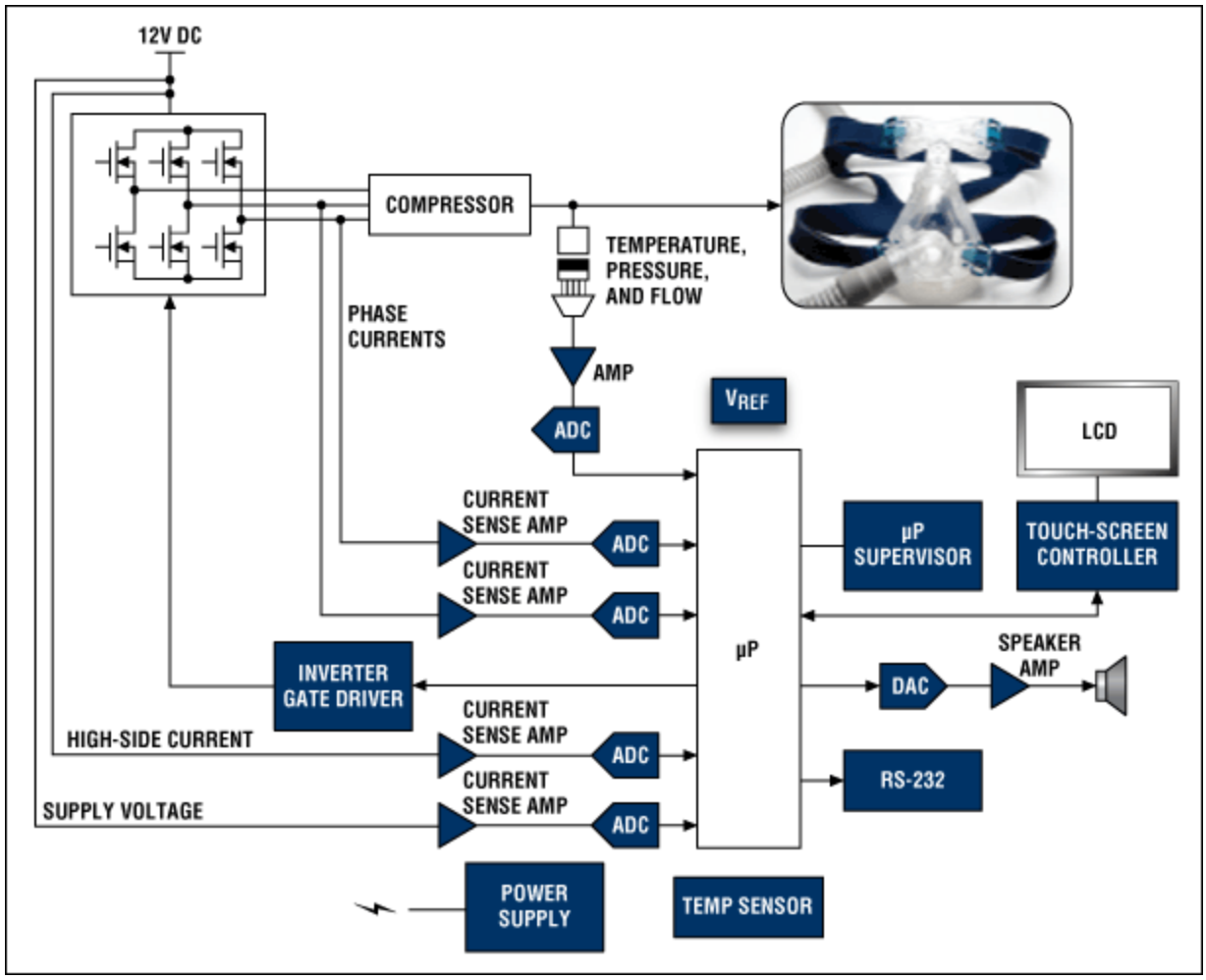
The main subfunctions that the system is required to monitor and control can be divided as follows:

1. **Air-hose-environment sensing** This covers air pressure, but may also include air temperature, humidity, and flow rate.

2. **Compressor motor-drive feedback** Similar to all motor-drive systems, some feedback must be provided to maintain torque and/or velocity control. Typically, phase currents or shunt current and rotor feedback must be provided.

3. **Motor-drive excitation** This is the generation of the waveforms necessary to both induce current in the electric motor and produce the torque that causes motion.

4. **Communication interface to technician/doctor** This requires the ability to display information as well as input commands and controls from the medical team. This can include LCD drivers and touch-screen controllers, as well as a means for audio communication alerts, such as beeps and tones.



Functional block diagram of a CPAP system. For a list of Maxim's recommended solutions for CPAP designs, please go to: www.maxim-ic.com/CPAP.

Given the time and expense required to achieve FDA approval, manufacturers must select a supplier with a customer-oriented discontinuance policy to ensure that system components will be available for many years.

Medical customers rely on Maxim products because, over the years, we have carefully avoided discontinuing parts. We realize how devastating product discontinuance can be to a customer, so we work diligently to transfer some products to newer production lines, create wafer buffers, allow last-time purchases, or develop upgrade devices. Very few Maxim parts have ever been discontinued while demand still existed. Maxim's Discontinuance Policy is one of the most flexible among our peer supplier companies