

# Positive airway pressure

**Positive airway pressure (PAP)** is a method of respiratory ventilation used primarily in the treatment of sleep apnea, for which it was first developed. CPAP means Continuous PAP.

PAP ventilation is also commonly used for critically ill patients in hospital with respiratory failure, and in newborn infants (neonates). In these patients, PAP ventilation can prevent the need for endotracheal intubation, or allow earlier extubation. Sometimes patients with neuromuscular diseases use this variety of ventilation as well.

## History

Professor Colin Sullivan first developed the Continuous Positive Airway Pressure (CPAP) system at Royal Prince Alfred Hospital in Sydney, Australia, in 1981.

## How it works

### Continuous pressure devices

#### Fixed-pressure CPAP

A continuous positive airway pressure (CPAP) machine was initially used mainly by patients for the treatment of sleep apnea at home, but now is in widespread use across intensive care units as a form of ventilation. Obstructive sleep apnea occurs when the upper airway becomes narrow as the muscles relax naturally during sleep. This reduces oxygen in the blood and causes arousal from sleep. The CPAP machine stops this phenomenon by delivering a stream of compressed air via a hose to a nasal pillow, nose mask or full-face mask, splinting the airway (keeping it open under air pressure) so that unobstructed breathing becomes possible, reducing and/or preventing apneas and hypopneas. It is important to understand, however, that it is the air pressure, and not the movement of the air, that prevents the apneas. When the machine is turned on, but prior to the mask being placed on the head, a flow of air comes through the mask. After the mask is placed on the head, it is sealed to the face and the air stops flowing. At this point, it is only the air pressure that accomplishes the desired result. This has the additional benefit of reducing or eliminating the extremely loud snoring that sometimes accompanies sleep apnea.

The CPAP machine blows air at a prescribed pressure (also called the titrated pressure). The necessary pressure is usually determined by a sleep physician after review of a study supervised by a sleep technician



A typical CPAP machine houses the air pump in a case lined with sound-absorbing material for quieter operation. A hose carries the pressurized air to a face mask or nasal pillow.

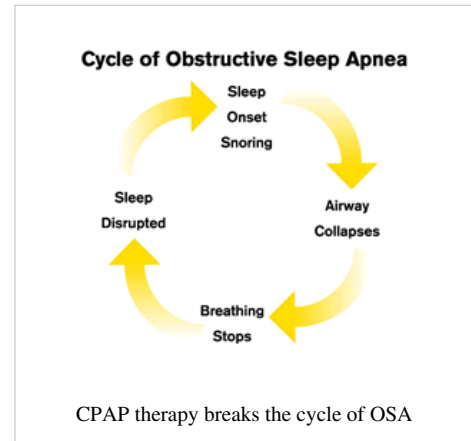


The Sullivan V Plus, a typical mid-1990s CPAP (the mask is more modern).



A typical full face CPAP mask.

during an overnight study (polysomnography) in a sleep laboratory. The titrated pressure is the pressure of air at which most (if not all) apneas and hypopneas have been prevented, and it is usually measured in centimetres of water (cm H<sub>2</sub>O). The pressure required by most patients with sleep apnea ranges between 6 and 14 cm H<sub>2</sub>O. A typical CPAP machine can deliver pressures between 4 and 20 cm H<sub>2</sub>O. More specialised units can deliver pressures up to 25 or 30 cm H<sub>2</sub>O.



CPAP treatment can be highly effective in treatment of obstructive sleep apnea. For some patients, the improvement in the quality of sleep and quality of life due to CPAP treatment will be noticed after a single night's use. Often, the patient's sleep partner also benefits from markedly improved sleep quality, due to the amelioration of the patient's loud snoring.

Given that sleep apnea is a chronic health issue and doesn't go away, ongoing care is needed to maintain CPAP therapy. Based on the study of cognitive behavioral therapy (referenced above), ongoing chronic care management is the best way to help patients continue therapy by educating them on the health risks of sleep apnea and providing motivation and support.

**APAP or AutoPAP or AutoCPAP** (Automatic Positive Airway Pressure)

automatically *titrates*, or tunes, the amount of pressure delivered to the patient to the minimum required to maintain an unobstructed airway on a breath-by-breath basis by measuring the resistance in the patient's breathing, thereby giving the patient the precise pressure required at a given moment and avoiding the compromise of fixed pressure.

### Bi-level pressure devices

- **VPAP or BiPAP** (Variable/Bilevel Positive Airway Pressure) provides two levels of pressure: Inspiratory Positive Airway Pressure (IPAP) and a lower Expiratory Positive Airway Pressure (EPAP) for easier exhalation. (Some people use the term **BPAP** to parallel the terms **APAP** and **CPAP**.)
  - Modes
    - **S** (Spontaneous) – In spontaneous mode the device triggers IPAP when flow sensors detect spontaneous inspiratory effort and then cycles back to EPAP.
    - **T** (Timed) – In timed mode the IPAP/EPAP cycling is purely machine-triggered, at a set rate, typically expressed in breaths per minute (BPM).
    - **S/T** (Spontaneous/Timed) – Like spontaneous mode, the device triggers to IPAP on patient inspiratory effort. But in spontaneous/timed mode a "backup" rate is also set to ensure that patients still receive a minimum number of breaths per minute if they fail to breathe spontaneously.

## Components

- **Flow generator** (PAP machine) provides the airflow
- **Hose** connects the flow generator (sometimes via an in-line humidifier) to the interface
- **Interface** (nasal or full face mask, nasal pillows, or less commonly a lip-seal mouthpiece) provides the connection to the user's airway

## Optional features

- **Humidifier** adds moisture to low humidity air
  - **Heated:** Heated water chamber that can increase patient comfort by eliminating the dryness of the compressed air. The temperature can usually be adjusted or turned off to act as a passive humidifier if desired. In general, a heated humidifier is either integrated into the unit or has a separate power source (i.e. plug).
  - **Passive:** Air is blown through an unheated water chamber and is dependent on ambient air temperature. It is not as effective as the heated humidifier described above, but still can increase patient comfort by eliminating the dryness of the compressed air. In general, a passive humidifier is a separate unit and does not have a power source.
- **Mask liners:** Cloth-based mask liners may be used to prevent excess air leakage and to reduce skin irritation and dermatitis.
- **Ramp** may be used to temporarily lower the pressure if the user does not immediately sleep. The pressure gradually rises to the prescribed level over a period of time that can be adjusted by the patient and/or the DME provider.
- **Exhalation pressure relief:** Gives a short drop in pressure during exhalation to reduce the effort required. This feature is known by the trade name C-Flex or A-Flex in some CPAPs made by Respironics and EPR in ResMed machines.
- **Flexible chin straps** may be used to help the patient not breathe through the mouth (full-face masks avoid this problem), thereby keeping a closed pressure system. The straps are elastic enough that the patient can easily open his mouth if he feels that he needs to. Modern straps use a quick-clip instant fit. Velcro-type adjustments allow quick sizing, before or after the machine is turned on.
- **Data logging** records basic compliance info or detailed event logging, allowing the sleep physician (or patient) to download and analyze data recorded by the machine to verify treatment effectiveness.
- **Automatic altitude adjustment** versus manual altitude adjustment.
- **DC power source** versus AC power source.

Such features generally increase the likelihood of PAP tolerance and compliance.<sup>[1]</sup>

## Care and maintenance

As with all durable medical equipment, proper maintenance is essential for proper functioning, long unit life and patient comfort. The care and maintenance required for PAP machines varies with the type and conditions of use, and are typically spelled out in a detailed instruction manual specific to the make and model.

Most manufacturers recommend that the end user perform daily and weekly maintenance. Units must be checked regularly for wear and tear and kept clean. Poorly connected, worn or frayed electrical connections may present a shock or fire hazard; worn hoses and masks may reduce the effectiveness of the unit. Most units employ some type of filtration, and the filters must be cleaned or replaced on a regular schedule. Sometimes HEPA filters may be purchased or modified for asthma or other allergy clients. Hoses and masks accumulate exfoliated skin, particulate matter, and can even develop mold. Humidification units must be kept free of mold and algae. Because units use substantial electrical power, housings must be cleaned without immersion.

In cold climates, humidified air may require insulated and/or heated air hoses. These may be bought ready-made, or modified from commonly available materials (aluminium foil and bubble-wrap insulation. Noisy machines may be distanced from the sleeper by extension hoses between the machine and the sleeping person).

Modifications are usually needed by the end-user. Straps are easily twisted wrongly (add hot-melt glue or silicon rubber on the "wrong" side). Fittings and buttons are invisible or without adequate sensation in the darkness of the night, so use bright tape or other fittings (self-adhesive children's earrings, masking tape, etc.) to help prevent mistakes.

## **Portability**

Since continuous compliance is an important factor in the success of treatment, it is of importance that patients who travel have access to portable equipment. Progressively, PAP units are becoming lighter and more compact, and often come with carrying cases. Dual-voltage power supplies permit many units to be used internationally.

Long distance travel or camping presents special considerations. Most airport security inspectors have seen the portable machines, so screening rarely presents a special problem. Increasingly, machines are capable of being powered by the 400 Hz power supply used on most commercial aircraft and include manual or automatic altitude adjustment. Some machines allow power-inverter and/or car-battery powering, but polarity of the connecting cables needs consideration.

Some patients on PAP therapy also use supplementary oxygen. When provided in the form of bottled gas, this can present an increased risk of fire and is subject to restrictions. (Commercial airlines generally forbid passengers to bring their own oxygen.) As of November, 2006, most airlines permit the use of oxygen concentrators.

## Availability

In many countries, PAP machines are only available by prescription. A sleep study at an accredited sleep lab is usually necessary before treatment can start. This is because the pressure settings on the PAP machine must be tailored to a patient's treatment needs. A sleep medicine doctor, who may be also trained in respiratory medicine, psychiatry, neurology, pediatrics, family practice or otolaryngology (ear, nose and throat), will interpret the results from the initial sleep study and recommend a pressure test. This may be done in one night (a split study with the diagnostic testing done in the first part of the night, and CPAP testing done in the later part of the night) or with a follow up second sleep study during which the CPAP titration may be done over the entire evening. With CPAP titration (split night or entire night), the patient wears the CPAP mask and pressure is adjusted up and down from the prescribed setting to find the optimal setting.

- In the United States, PAP machines are often available at large discounts online, but a patient purchasing a PAP personally must handle the responsibility of securing reimbursement from his or her insurance or Medicare. Many of the internet providers that deal with insurance such as Medicare will provide upgraded equipment to a patient even if he or she only qualifies for a basic PAP. In some locations a government program, separate from Medicare, can be used to claim a reimbursement for all or part of the cost of the PAP device.
- In the United Kingdom, PAP machines are available on National Health Service prescription after a diagnosis of sleep apnea or privately from the internet provided a prescription is supplied.
- In Australia, PAP machines can be bought from the Internet or physical stores. There is no requirement for a doctor's prescription, however many suppliers will require a referral. Low-income earners who hold a Commonwealth Health Care Card should enquire with their state's health department about programs that provide free or low-cost PAP machines. Those who have private health insurance may be eligible for a partial rebate on the cost of a CPAP machine and the mask. Superannuation may be released for the purchase of essential medical equipment such as PAP machines, on the provision of letters from two doctors, one of whom must be a specialist, and an application to the Australian Prudential Regulation Authority <sup>[2]</sup> (APRA).
- In Canada, CPAP units are widely available in all provinces. Funding for the therapy varies from province to province. In the province of Ontario, the Ministry of Health's Assistive Devices Program will fund a portion of the cost of a CPAP unit based on a sleep study in an approved sleep lab showing Obstructive Sleep Apnea Syndrome and the signature of an approved physician on the application form. This funding is available to all residents of Ontario with a valid health card once every 5 years.<sup>[3]</sup>



CPAP flow generator in the back to the left, connected to a 1500 gram preterm newborn by a hose and kept in place on the patient with an improvised interface: a diaper.

## Disadvantages and side effects

Most factors associated with these machines and parts are well known to manufacturers, suppliers, and end-user groups. The Internet has the contacts needed: user and manufacturer web sites, local, national and international user groups, with occasional local face-to-face meetings or other forms of user-to-user interaction.

Prospective PAP candidates are often reluctant to use this therapy, since the nose mask and hose to the machine look uncomfortable and clumsy, and the airflow required for some patients can be vigorous. Some patients will develop nasal congestion while others may experience rhinitis or a runny nose.<sup>[4]</sup> Some patients adjust to the treatment within a few weeks, others struggle for longer periods, and some discontinue treatment entirely. However, studies show that cognitive behavioral therapy at the beginning of therapy dramatically increases compliance—up to 148%.<sup>[5]</sup> While PAP side effects are a nuisance, serious side effects are very uncommon. Furthermore, research has shown that PAP side effects are rarely the reason patients stop using PAP.<sup>[6]</sup>

PAP manufacturers frequently offer different models at different price ranges, and PAP masks have many different sizes and shapes, so that some users need to try several masks before finding a good fit. These different machines may not be comfortable for all users, so proper selection of PAP models may be very important in furthering adherence to therapy. Every few years, advancing technologies may mean the upgrading of a PAP machine and parts.

Beards, mustaches or facial irregularities may prevent an air-tight seal. Where the mask contacts the skin must be free from dirt and excess chemicals (such as skin oils). Shaving before mask-fitting may be necessary.

## In a hospital setting

PAP ventilation is often used for patients who have acute type 1 or 2 respiratory failure. Usually PAP ventilation will be reserved for the subset of patients for whom oxygen delivered via a face mask is deemed to be insufficient or deleterious to health (see CO<sub>2</sub> retention). Usually, patients on PAP ventilation will be closely monitored in an intensive care, high dependency, coronary care unit or specialist respiratory unit.

The most common conditions for which PAP ventilation is used in hospital are congestive cardiac failure and acute exacerbation of obstructive airway disease, most notably exacerbations of COPD and asthma. It is not used in cases where the airway may be compromised, or consciousness is impaired. CPAP is also used to assist premature babies with breathing in the NICU setting.

The mask required to deliver CPAP must have an effective seal, and be held on very securely. Some full-face masks "float" on the face like a hover-craft, with thin, soft, flexible "curtains" ensuring less skin abrasion, and the possibility of coughing and yawning. Most people find wearing the mask uncomfortable. Breathing out against the positive pressure resistance (the expiratory positive airway pressure component, or EPAP) is also unpleasant. These factors lead to inability to continue treatment due to patient intolerance in about 20% of cases where it is initiated. Those who suffer an anxiety disorder or claustrophobia<sup>[7]</sup> are more likely to be unable to tolerate PAP treatment. Sometimes medication will be given to assist with the anxiety caused by PAP ventilation.

Unlike PAP used at home to splint the tongue and pharynx, PAP is used in hospital to improve the ability of the lungs to exchange oxygen and carbon dioxide, and to decrease the work of breathing (the energy expended moving air into and out of the alveoli). This is because:

- During inspiration, the inspiratory positive airway pressure, or IPAP, forces air into the lungs—thus less work is required from the respiratory muscles.
- The bronchioles and alveoli are prevented from collapsing at the end of expiration. If these small airways and alveoli are allowed to collapse, significant pressures are required to re-expand them. This is because of the Young–Laplace equation (which explains why the hardest part of blowing up a balloon is the first breath).
- Entire regions of the lung that would otherwise be collapsed are forced and held open. This process is called recruitment. Usually these collapsed regions of lung will have some blood flow (although reduced). Because these

areas of lung are not being ventilated, the blood passing through these areas is not able to efficiently exchange oxygen and carbon dioxide. This is called ventilation/perfusion (or V/Q) mismatch. The recruitment reduces ventilation perfusion mismatch.

- The amount of air remaining in the lungs at the end of a breath is greater (this is called the functional residual capacity). The chest and lungs are therefore more expanded. From this more expanded resting position, less work is required to inspire. This is due to the non-linear compliance-volume curve of the lung.

## External links

- International Ventilator Users Network <sup>[8]</sup>
- American Sleep Apnea Association <sup>[9]</sup>
- Sleep Review Journal <sup>[10]</sup>
- National Sleep Foundation <sup>[11]</sup>
- <http://www.fphcare.com/product-overview/cpaps/bubble-cpap/delivery-system.html> - CPAP products

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- [10] [http://www.sleepreviewmag.com/press\\_release.asp?id=10222808](http://www.sleepreviewmag.com/press_release.asp?id=10222808)
- [11] [http://www.sleepfoundation.org/site/c.huIXKjM0IXF/b.4814895/k.3A24/Continuous\\_Positive\\_Airway\\_Pressure\\_and\\_Sleep.htm](http://www.sleepfoundation.org/site/c.huIXKjM0IXF/b.4814895/k.3A24/Continuous_Positive_Airway_Pressure_and_Sleep.htm)

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