Positive Airway Pressure Device Technology Past and Present
What's in the "Black Box"?

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KEYWORDS

• Positive airway pressure • Obstructive sleep apnea • Central sleep apnea • Respiratory failure
• Noninvasive ventilation • Adaptive servo-ventilation • Volume assured pressure support

KEY POINTS

- Fixed continuous positive airway pressure (CPAP) flow generators are now quiet, compact, and convenient.
- Autotitrating CPAP and bilevel PAP devices detect apneas and hypopneas and may distinguish between obstructive and central events. They treat obstructive and central sleep apnea while accommodating variations in the sleep-disordered breathing phenotype.
- Adaptive servo-ventilation can suppress the periodic breathing of Hunter–Cheyne–Stokes or central sleep apnea while simultaneously treating coexisting obstructive sleep-disordered breathing.
- Volume-assured pressure support technology can provide ventilatory support in the domiciliary setting for patients with a wide variety of breathing disorders.
- The complexity of the algorithms used can make it difficult to be sure how successfully targets are achieved.

INTRODUCTION

The idea of applying positive pressure therapy in a noninvasive manner is not as recent as some might expect; in fact, the first reference to this treatment modality that is generally available appeared in *The Lancet* in 1936, reporting the use of positive pressure via facemask in the treatment of pulmonary

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edema.[1] Even more intriguing, Poulton makes reference to "artificial aerotherapeutics" having been described by Theodore Williams in Allbut and Rolleston's 1912 edition of *System of Medicine*, which I have unfortunately not been able to access. "Aerotherapeutics" is said by Poulton to include apparatus to "inflate or deflate the chest and lungs, and sometimes to carry out these processes alternately."[1] Over the ensuing years, numerous publications appeared describing the use of tight-fitting masks to achieve continuous positive airway pressure (CPAP), ventilatory support, and even ventilatory support with positive end-expiratory pressure (PEEP). Consequently, it is somewhat of a surprise that the idea of applying CPAP noninvasively to treat obstructive sleep apnea (OSA) did not emerge until the seminal report by Sullivan and colleagues[2] describing the application of CPAP via a custom nasal mask was published in 1981. Presumably, the confluence of the emerging recognition of obstructive sleep-disordered breathing (SDB), its high prevalence and effects on quality of life, along with the history of applying PAP via mask led the investigators to make the connection between these 2 threads of medical evolution. Whether this is an accurate portrayal of how the idea came to be, it is indisputable that CPAP and its various derivatives have proven to be a breakthrough in the treatment of OSA and, going forward, of other forms of SDB. Moreover, the availability of later generations of PAP apparatus made possible the routine use of noninvasive ventilation for patients with other forms of ventilatory failure, both acute and chronic as envisioned by Poulton.[1]

Following the description by Sullivan and colleagues,[2] the increasing use of CPAP for the treatment of OSA became a subject of major interest to entrepreneurs and led to the establishment of a growing cadre of manufacturers and the commercial availability of CPAP generators, masks, and accessories. This activity in turn drove the development of major improvements in PAP equipment, and the use of PAP for noninvasive ventilation added to the momentum of additional innovations. This article outlines the technology underlying the PAP equipment available commercially at the current time, focusing on the flow-generating element (generally described as the "blower"), the method for regulating the degree of positive pressure reaching the patient, the measurement of airflow received by the patient, and the use of the latter information to identify disordered breathing events, estimate minute ventilation versus mask leak, and use this information to establish a degree of closed circuit control of the patient's ventilation and breathing pattern. Much of the information herein is proprietary and not released explicitly by the manufacturers. Much of the technology is described only in patent documents, and a degree of conjecture is involved in translating the information in the patents to the technology actually used in the various types of flow generators. In addition, the history of patents in PAP technology is convoluted, involving many claims and counterclaims, canceling of certain claims at a later date, and licensing agreements between manufacturers. For that reason, the authors make no claim that the patents referenced are the only documents describing a given technology nor were licensing arrangements required when similar technology was used by a manufacturer not identified as the assignee.

BLOWERS AND CONTROL OF INTERFACE PRESSURE

It is perhaps of more than passing interest that the source of airflow used in the first report of CPAP treatment for OSA[2] used the blower from a vacuum cleaner, and this was the same source of airflow used in 1936 by Poulton[1] (in both cases, of course, using the outlet that normally served to exhaust the air that produced a vacuum). Both reports also used a means of controlling the volume of airflow, presumably by varying the voltage applied to drive the blower motors. Interestingly, Poulton used a more advanced method of providing a fixed value of positive pressure than did Sullivan and colleagues; Poulton placed what would in current terminology be identified as a PEEP valve, consisting of a spring-loaded bypass outlet fed separately from the tubing attached to the patient interface (mask). This bypass valve would open if the pressure exceeded a value that was set by the level of compression of the spring, thus maintaining a set degree of positive pressure. Sullivan and colleagues seem to have regulated pressure by varying the blower speed and the amount of resistance to airflow in series with the outlet flow to the tubing that led to the nasal mask, although shortly afterward, most systems used went back to controlling pressure with a PEEP valve.

The apparatus reported by Sullivan and colleagues clearly was not suitable for widespread deployment to treat the burgeoning number of patients being identified as suffering from OSA. According to a history of CPAP attributed to Sullivan and available on the ResMed website, the first CPAP apparatus available commercially used a "vortex blower" designed for jet or whirlpool baths. Such flow generators were heavy and noisy, attributes not particularly suited to use in a bedroom. These were alternating current