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Positive Airway Pressure Therapy With Adaptive Servoventilation

Part 1: Operational Algorithms

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The beginning of the 21st century witnessed the advent of new positive airway pressure (PAP) technologies for the treatment of central and complex (mixtures of obstructive and central) sleep apnea syndromes. Adaptive servoventilation (ASV) devices applied noninvasively via mask that act to maintain a stable level of ventilation regardless of mechanism are now widely available. These PAP devices function by continually measuring either minute ventilation or airflow to calculate a target ventilation to be applied as needed. The apparatus changes inspiratory PAP on an ongoing basis to maintain the chosen parameter near the target level, effectively controlling hypopneas of any mechanism. In addition, by applying pressure support levels anticyclic to the patient's own respiratory pattern and a backup rate, this technology is able to suppress central sleep apnea, including that of Hunter-Cheyne-Stokes breathing. Moreover, ASV units have become available that incorporate autotitration of expiratory PAP to fully automate the treatment of all varieties of sleep-disordered breathing. Although extremely effective in many patients when used properly, these are complex devices that demand from the clinician a high degree of expertise in understanding how they work and how to determine the proper settings for any given patient. In part one of this series we detail the underlying technology, whereas in part two we will describe the application of ASV in the clinical setting. CHEST 2014; 146(2):514-523

ABBREVIATIONS: AHI = apnea hypopnea index; AI = apnea index; ASV = adaptive servoventilation; CHF = congestive heart failure; CSA = central sleep apnea; EPAP = expiratory positive airway pressure; HCSB = Hunter-Cheyne-Stokes breathing; IPAP = inspiratory positive airway pressure; IPS = inspiratory pressure support; MV = minute ventilation; PAP = positive airway pressure; PB = periodic breathing; SRBD = sleep-related breathing disorder

In the last two decades we have witnessed the introduction of sophisticated positive airway pressure (PAP) devices for treatment of sleep-related breathing disorders (SRBDs).[1] CPAP devices were introduced in 1981[2] and have proven effective in the treatment of OSA, yet adherence is less than ideal. CPAP devices are also frequently not effective in a number of conditions associated with central sleep apnea (CSA) such as congestive heart failure (CHF) and opioids therapy.[3-6] A variety of pressure generators with expanded capabilities have become available. The most advanced of these

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devices, using a mode of operation known as adaptive servoventilation (ASV),[1,7-9] are the subject of this article. Also called auto servoventilation or anticyclic-modulated ventilation, ASV represents the most recent development in PAP treatment of periodic breathing (PB) due to CHF and other conditions associated with CSA not suppressed by long-term use of CPAP. In this, the first of two how-to articles regarding ASV, we discuss the operational algorithms of three ASV devices; a subsequent article will discuss practical applications.

A major motivation for the development of ASV (Fig 1) was having a means to effectively treat CSA in CHF. Patients with CHF often suffer from a pattern of breathing first described by John Hunter, although the disorder is commonly referred to as Cheyne-Stokes breathing (for details, see Javaheri[10]). This unique pattern, hereafter referred to as Hunter-Cheyne-Stokes breathing (HCSB), consists of repetitive cycles of crescendo-decrescendo changes in tidal breathing with interposed central apneas or hypopneas (Fig 2). Decrescendo breathing, central hypopneas, and apneas decrease $Pa{O_2}$ and increase $Pa{CO_2}$, which in turn stimulate chemoreceptors thereby prompting the appearance of a crescendo in breathing. The resulting hyperventilation depresses $Pa{CO_2}$ toward or below the apneic threshold, with consequent decrescendo breathing, central hypopnea, or apnea.[11] ASV devices counterbalance ventilatory instability by modulating the degree of inspiratory pressure support (IPS), providing positive IPS when tidal volume wanes and withdrawing that support when ventilation is excessive according to the prevailing airflow or minute ventilation (MV) (Fig 3). This component of ventilation that is anticyclic to the periodicity of the patient's own breathing acts to

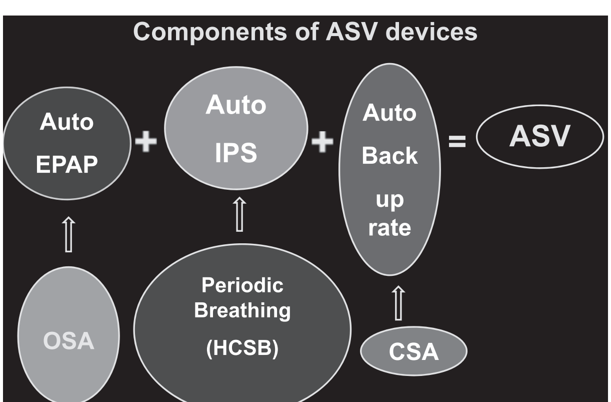

Figure 1 – *The various components of ASV. ASV = adaptive servoventilation; auto = automatic; CSA = central sleep apnea; EPAP = expiratory positive airway pressure; HCSB = Hunter Cheyne-Stokes breathing; IPS = inspiratory pressure support.*

dampen the oscillations in ventilatory drive that underlie PB. ASV devices also apply a fixed or variable end expiratory PAP (EPAP) to suppress obstructive events. These devices apply mandatory breaths in a timed backup mode to abort any frank apneas (Fig 1). These multiple strategies for suppressing a variety of SRBD events make ASV technology potentially effective in the treatment of complex SRBDs that are a combination of both central and obstructive events. Although (to date) data on autotitrating devices remain conflicting regarding improving adherence, the variable IPS could perhaps be better tolerated than conventional PAP devices and that may eventually translate into improved quality of life and survival of patients with mixed patterns of SRBD.

In theory, ASV devices should be more effective than conventional PAP devices for suppressing PB. Furthermore, SRBD may exhibit a complex pattern consisting of both CSA/HCSB and obstructive events, first recognized in early studies of patients with CHF[12-14] and confirmed subsequently.[15-22] Our practice has been to classify sleep apnea as either predominantly obstructive or predominantly central to guide therapy. However, the predominant mechanism of sleep apnea may vary throughout the night along with changes in sleep stage and position, as well as fluid shifts[23] due to the recumbent sleeping position. The severity and the phenotype of SRBD may also change long-term from adjustments in medications, changes in body weight, and acute decompensation or progression of CHF. Given this reality, ASV devices with autotitrating IPS and EPAP may offer a significant therapeutic advantage.

CPAP fails to control CSA/HCSB in almost 50% of patients with CHF[3,4] (Fig 4); furthermore, patients have difficulty adhering to CPAP even when it has effectively suppressed PB. In the Canadian Continuous Positive Airway Pressure for Patients with Central Sleep Apnea and Heart Failure (CanPAP) trial, adherence to CPAP at 1 year averaged 3.5 h/night,[4] which is inadequate even though patients with heart failure tend to exhibit short sleep time.[13,14] Meanwhile, an important post hoc analysis of the Canadian data demonstrated that those patients with CHF whose CSA was suppressed by CPAP had improved survival, whereas those in whom CPAP was ineffective did poorly.[4] We have maintained that, in the latter category of patients, CPAP should not be recommended[5] and that this group would most likely benefit from treatment with ASV.

Currently, two manufacturers market ASV devices in the United States (ResMed and Philips Respironics, Inc),