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1. INTRODUCTION

Many types of positive airway pressure (PAP) devices are used to treat sleep-disordered breathing including obstructive sleep apnea, central sleep apnea, and sleep-related hypoventilation, ASV is one of them. [1]

ASV is a bilevel system that continuously changes the inspiratory PS on a breath-by breath basis in order to achieve a target ventilation or flow for a more constant breathing pattern, especially in the treatment of periodic breathing or Cheyne–Stokes respiration (CSR). Auto forms of ASV also increase EPAP in response to obstruction. [1]

By continuously monitoring the patient's breathing patterns, the ASV automatically adjusts the inspiratory pressure throughout the respiratory cycle according to individual needs and provides a backup respiratory rate when needed. This dynamic adjustment, ensures airway patency by adapting to the patient's ventilatory needs in real time, thereby reducing the incidence of apneas and respiratory instability.

ASV is specially designed for individuals with central sleep-disordered breathing (SDB). Central SDB can occur in central sleep apnoea (CSA), complex sleep apnoea (CompSA), mixed sleep apnoea, periodic breathing and various forms. Central SDB is frequently associated with cardiovascular diseases (e.g. coronary artery disease, stroke, heart failure, atrial fibrillation), the use of opioids, or PAP therapy. They can also arise spontaneously. [2]

Studies on the efficacy of ASV show that ASV is more effective in reducing apnea-hypopnea index (AHI) and improving cardiac function than control conditions, especially in patients with heart failure (HF) and sleep-related breathing disorder (SDB). [3] However, ASV does not provide similar benefits in all patient groups. For example, a study in patients with heart failure and reduced ejection fraction (LVEF ≤45%) found no effect of ASV on the primary composite outcome or mortality. [4]

In conclusion, Adaptive Servo Ventilation offers an innovative and effective approach to the treatment of specific respiratory disorders. By dynamically adapting to the individual respiratory needs of users, it improves both respiratory quality and comfort of life. However, potential risks and benefits should be carefully evaluated when planning ASV therapy, especially in individuals with cardiovascular diseases such as systolic heart failure and low ejection fraction.

2. HISTORY OF THE ASV

The development of computer-assisted control in mechanical ventilation dates back over 30 years. One of the earliest innovations was a decision-support system described by Menn and colleagues, in which patient clinical data were analyzed by a computer to generate recommended ventilator settings. However, these systems still required a human operator to implement changes.

By the early 1990s, more advanced systems began to emerge, enabling direct machine-controlled adjustments without clinician intervention. These early systems often targeted minute ventilation and adjusted either the number of machine-delivered breaths or pressure support accordingly. However, no significant improvements in clinical outcomes were demonstrated.

The introduction of the Rapid Shallow Breathing Index by Yang and Tobin led to more refined automated control strategies. Around this time, the concept of Adaptive Support Ventilation (ASV) was introduced—not only for ventilator weaning, but also for initial and ongoing management of critically ill patients. These early ASV systems estimated mechanical parameters such as dead space, compliance, and resistance-capacitance time constant, using them to automatically adjust ventilation parameters like respiratory rate and pressure support to achieve a target minute ventilation.

Over time, more sophisticated ASV systems were developed, incorporating additional inputs such as oxygen saturation (SpO_2) and functional residual capacity (FRC). Despite technical advances, these invasive ASV systems were not widely adopted, due to their complexity, difficulty handling varied respiratory pathophysiology, and a lack of robust randomized controlled trials.

In contrast, noninvasive ASV technologies for home use experienced more rapid adoption. The first autotitrating CPAP (auto-CPAP) devices emerged in the mid-1990s and received FDA approval in 1999. Building on this success, companies like ResMed and Respironics began developing noninvasive ASV devices.

Contribution of ResMed: In 1999, ResMed filed a U.S. patent (granted in 2003) for a bilevel PAP device that adjusted pressure support to maintain a set percentage of the patient's spontaneous minute ventilation. The resulting device, AutoSet CS, was successfully used in 2001 for treating Cheyne-Stokes respiration (CSR) in heart failure patients. It was later refined into more compact models (AutoSet CS2, VPAP Adapt SV).

Contribution of Respironics: Respironics filed a separate patent in 2001, using peak inspiratory flow as the control variable, in contrast to ResMed's average minute ventilation target. Their ASV systems, released as BiPAP autoSV and autoSV Advanced, used proprietary algorithms to analyze respiratory patterns and adjust pressures accordingly.

Other Developments (Weinmann): The German company Weinmann developed the SOMNOvent CR, an ASV device available outside the U.S., which adjusts EPAP, PS, and backup rate based on signals like minute ventilation, inspiratory flow flattening, and snoring. This system offers both manual and automatic backup rate modes. [5]

3. ASV ALGORITHMS

Because higher PAP pressures and high PS can induce periodic breathing and CSR, devices have been developed to try to even out the breathing over several breaths. These devices include ResMed VPAP AdaptSV (equivalent to Teijin AutoSet CS) with ASV setting, AirCurve ASV, which has been renamed AirCurve CS PaceWave with ASV and ASVAuto settings, Respironics BiPAP AutoSV Advanced and SOMNOvent CR. (Table 1). [1]

3.1 Respironics

Respironics BiPAP AutoSV Advanced is set with EPAP minimum and maximum, PSmin and PSmax, max pressure, and auto or fixed rate. Ti, rise time, and Bi-Flex can also be set for comfort. The level of PS is targeted based on instantaneous average inspiratory flow, which is the sum of the inspiratory flows during a time divided by the number of samples during a time in order to adjust for spurious values. The target peak flow is generally set at 90%–95% of the mean peak flow of the last 4 minutes. In an attempt to stabilize breathing in the setting of obstructive features (apnea [20% flow], hypopnea [20%–60% flow], and snoring), the target peak flow increases from 95% of the mean inspiratory peak flows over the last 4 minutes to the 60th percentile of the inspiratory peak flow values. The target peak flow is also increased to 60th percentile if CSR features are noted based on a CSR index, which measures similarity to a CSR pattern or a flow index that measures fluctuations in breath size. [1]

Device	ResMed ASV and ASVAuto	Respironics BiPAP AutoSV Advanced
Target	90% of average recent scaled low-pass-filtered absolute value of respiratory flow (an indication of ventilation) weighted toward last 3 min.	If no SDB, 95% of mean inspiratory peak flow over the last 4 min If SDB, 60th percentile of inspiratory peak flow values over the last 4 min.
Cycle	Cycle phase by fuzzy logic based on direction and rate of flow.	Average cycle length and midpoint based on previous breaths.
EPAP adjustments	ASV – fixed EPAP. ASVAuto– adjusts with AutoSet algorithm with apnea defined as MV <25% baseline for 10 s and hypopneas as MV<50% of baseline for 10 s.	EPAPmin and EPAPmax – pressure testing mode like AutoCPAP (increase once in every 15 s, if at least two obstructive events).
PS adjustments	PS adjustments are made every 8/50th of a second throughout inspiration inspiration based on difference of flow from expected flow to achieve a goal ventilation with smooth waveform. During apneic periods, PS gradually increases with subsequent breaths to a maximum of ten. Limited by PSmin and PSmax.	Current breath's starting PS based on prior breath's PS and how far previous breath was from target volume with gain determined from the PS needed to reach a volume during the last 30 breaths. Intrabreath adjustment of PS based on flow just prior to half point of inspiratory cycle if expected volume differs from target volume. Limited by PSmin and PSmax.
Rate	Auto rate starting at recent spontaneous rate adapting during apnea over several breaths to target rate of 15 bpm.	Fixed rate or Auto. Auto – first breath if no recent SDB = Ti +8 s; if recent SDB = Tbr +4 s; subsequent breaths = Tbr +4 s; Tbr = average time of 12 recent spontaneous breaths.
Waveform Options	Sharkfin "Easy Breathe" waveform. Ramp.	Square wave with rise and Ti and pressure relief adjustments.

Note: All pressures in cm·H_2O.
Abbreviations: SV, servoventilation; Auto, autoadjusting; EPAP, expiratory positive airway pressure; EPAPmax, maximum EPAP; EPAPmin, minimum EPAP; min, minute; MV, minute ventilation; PS, pressure support; PSmax, PS maximum; PSmin, PS minimum; SDB, sleep-disordered breathing; s, second; Tbr, breath time; Ti, inspiratory time.

Table 1: ASV Algorithms

The EPAP adjustment algorithm of AutoSV Advanced is similar to REMstar Auto algorithm, but uses a triggered breath rather than forced oscillation to differentiate obstructive from open airway events. The

automatic backup rate of AutoSV Advanced is determined based on a moving window of the last 12 spontaneous breaths. A mandatory breath is given if the breath does not occur within certain parameters, with a minimum breath rate of 8–10 bpm. A fixed backup rate can also be set.
The older BiPAP AutoSV did not automatically titrate the expiratory pressure, and the algorithm for the automatic backup rate was not proportional to the baseline breathing rate, but it would give a breath if no spontaneous breath occurred within 8 seconds of end of expected breath length or within 4 seconds, if there was recent triggered breath.35 Respironics BiPAP AutoSV Advanced has been found to be more effective than the older BiPAP AutoSV. SV, which targets recent ventilation (ASV) or recent peak flow (AutoSV) is not appropriate for managing patients with respirator insufficiency, for whom BiPAP or VAPS should be considered.

3.2 Resmed

ResMed's standard ASV uses a set fixed EPAP, samples flow 50 times per second, and alters IPAP throughout inspiration to achieve target minute ventilation. The PS range can be 0–20, but default is usually a PSmin of three and PSmax of 15. The device calculates a target minute ventilation based on the recent average weighted minute ventilation, weighted toward the last 3 minutes. ASV uses fuzzy logic to determine the part of the respiratory cycle and whether the current ventilation is below or above the desired target and then adjusts the PS throughout the cycle to achieve that target, thus avoiding abrupt pressure changes. The change in pressure is calculated by multiplying a gain of 0.3 cm H2O/L/min/s by the difference between the target minute ventilation and the actual minute ventilation. An automatic backup rate starts with the current spontaneous rate based on moving average calculated over several breaths and gradually adapts during an apnea to 15 bpm. ASVAuto also adjusts the EPAP level similar to the AutoSet algorithm in response to obstructive apneas, flow limitation, and snoring. [6]

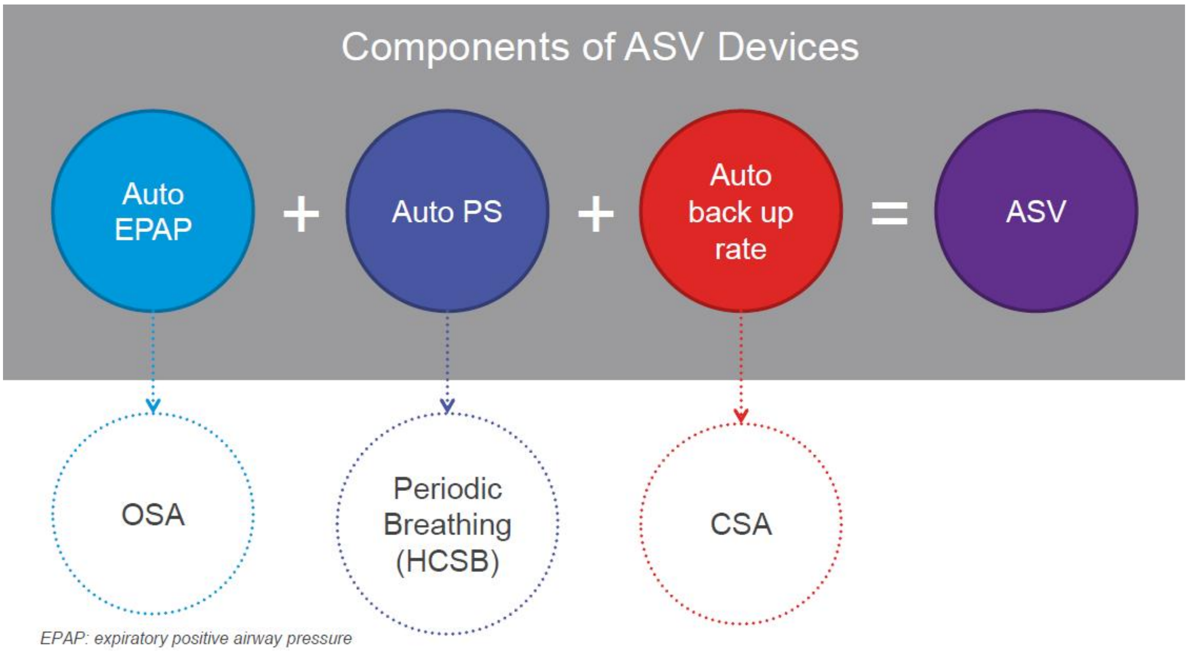


Figure 1: RESMED ASV Algorithm in Summary [7]
HSCB: Hunter Cheyne - Stokes breathing

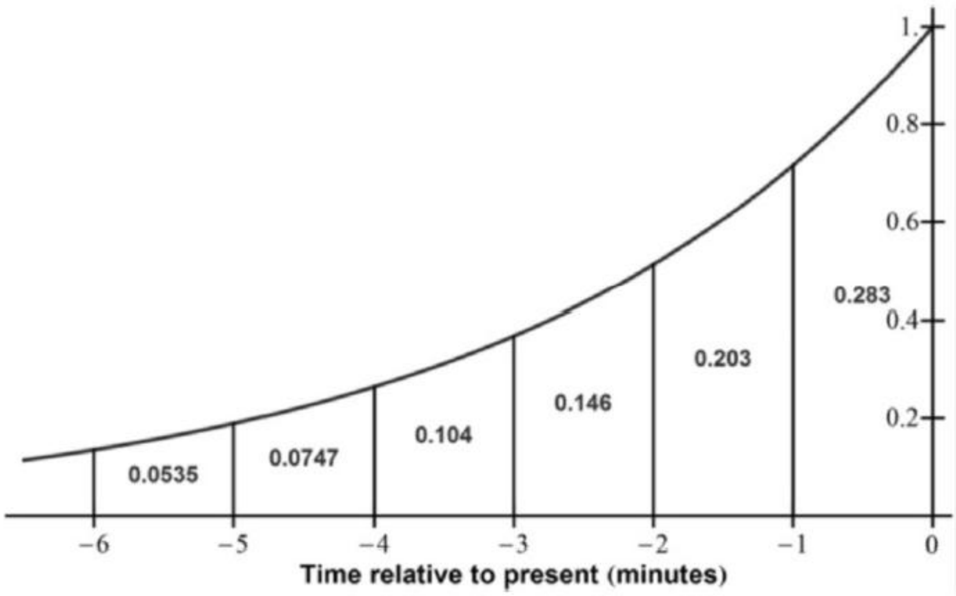


Figure 2: The graph shows the ResMed ASV method for weighted averaging of ventilation to calculate recent average minute ventilation.The graph shows the most recent 6 min, although averaging actually extends back indefi nitely, with exponentially smaller contributions to the average the longer the interval. The most recent 6 min contribute about 86% of the total. In each box on the graph (representing 1 min), the numbers under the curve represent the proportion the minute contributed
to the overall total. [8]

Aircurve10 ASV

Aircurve10 ASV creates target ventilation. Target MV is set to 90% of the patient’s recent 3 minute average. Target MV is continually adjustedto reflect changes in patient’s own MV during the night and through various sleep stages.

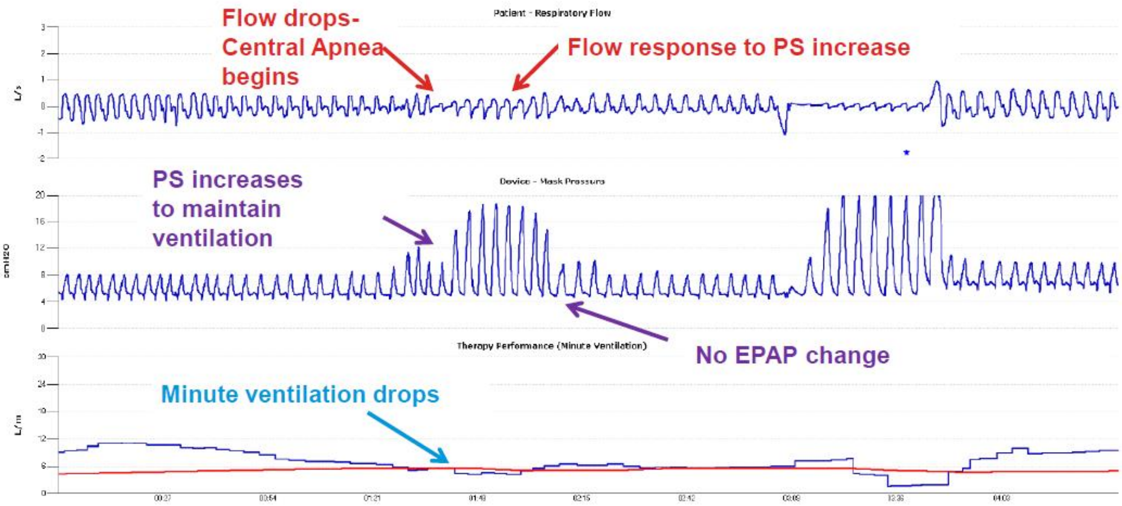


Figure 3: Central Apnea Scenario

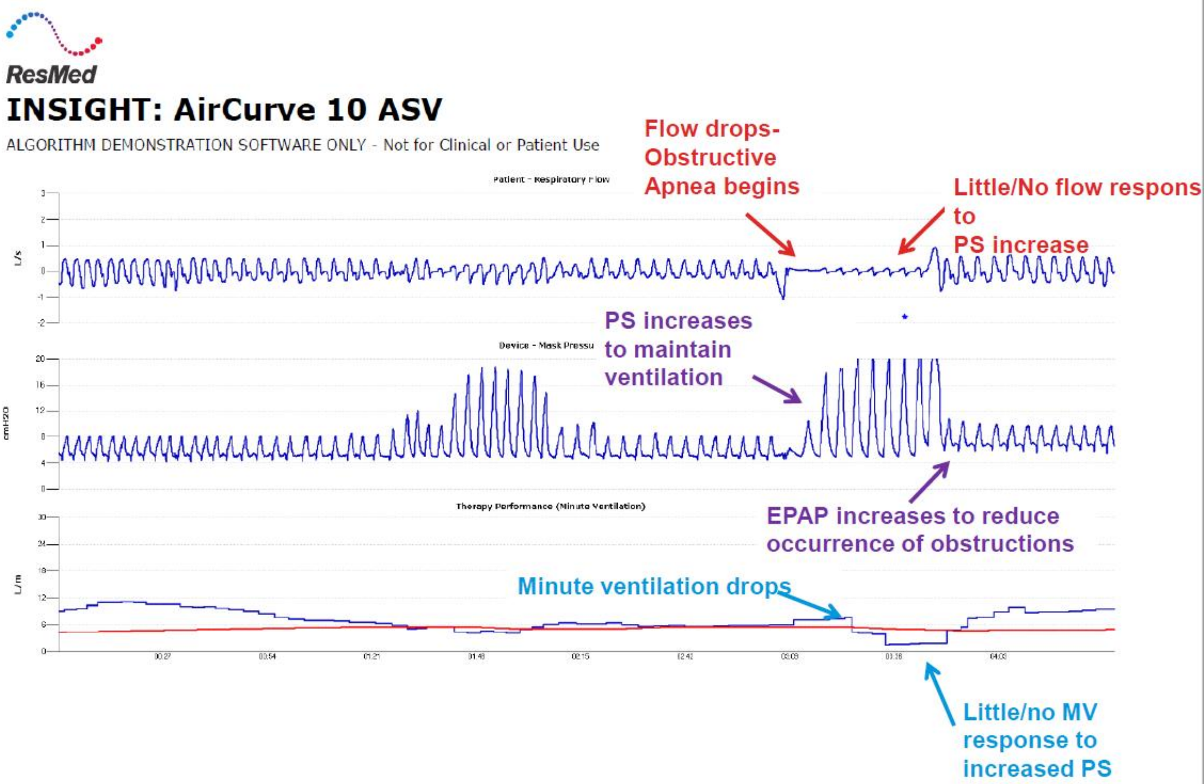


Figure 4: Obstructive Apnea Scenario

4. ASV ALGORITHM OF AIRPAP

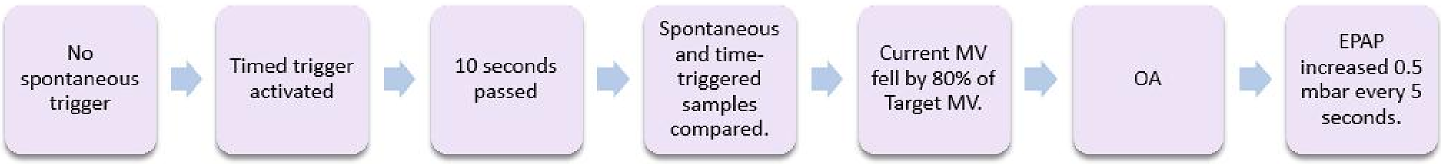
The AIRPAP ASV Algorithm dynamically monitors patient patterns to calculate a target ventilation to be applied when needed. The patterns recorded by the algorithm across the window size (100) are averaged with a “moving average”. The averaging process is renewed with each breath. In this way it continuously measures the target minute ventilation, frequency and inspiration time. When the patient's spontaneous respiratory trigger is interrupted, the device determines its response by comparing the recorded target values with the instantaneous values.

The initial default values are as follows:

MV = 6000 L/min, f = 15 bpm, Ti = 1.0 s

ASV Algorithm can react to four events, "Obstructive Apnea, Central Apnea, Hypopnea and Snoring”. These events are prioritized and reacted according to the order above. For example, when snoring and hypopnea occur at the same time, the ASV mode responds according to hypopnea, as hypopnea takes precedence.

4.1 Obstructive Apnea in ASV



Obstructive apnea and ASV response:

In the ASV algorithm, when the patient stops breathing, spontaneous triggering does not occur because the device does not detect the patient's breathing effort. In this case, the device enters the "apnea" event. A 90% decrease in the patient's airway flow for 10 seconds is "obstructive apnea". In this case, the timed triggered breathing cycle is activated. This timed trigger is the I duration and backup rate set in the algorithm. The I duration is 1 second and the backup rate is 15 bpm. After 10 seconds, the timed triggered respiratory values are compared with the previous samples (spontaneous triggers). If the instantaneous minute volume has fallen below 80% of the target minute volume as a result of the comparison, this is an "obstructive apnea". ASV's response to obstructive apnea is to increase EPAP by 0.5 mbar at five-second intervals.

Obstructive Apnea Scenario

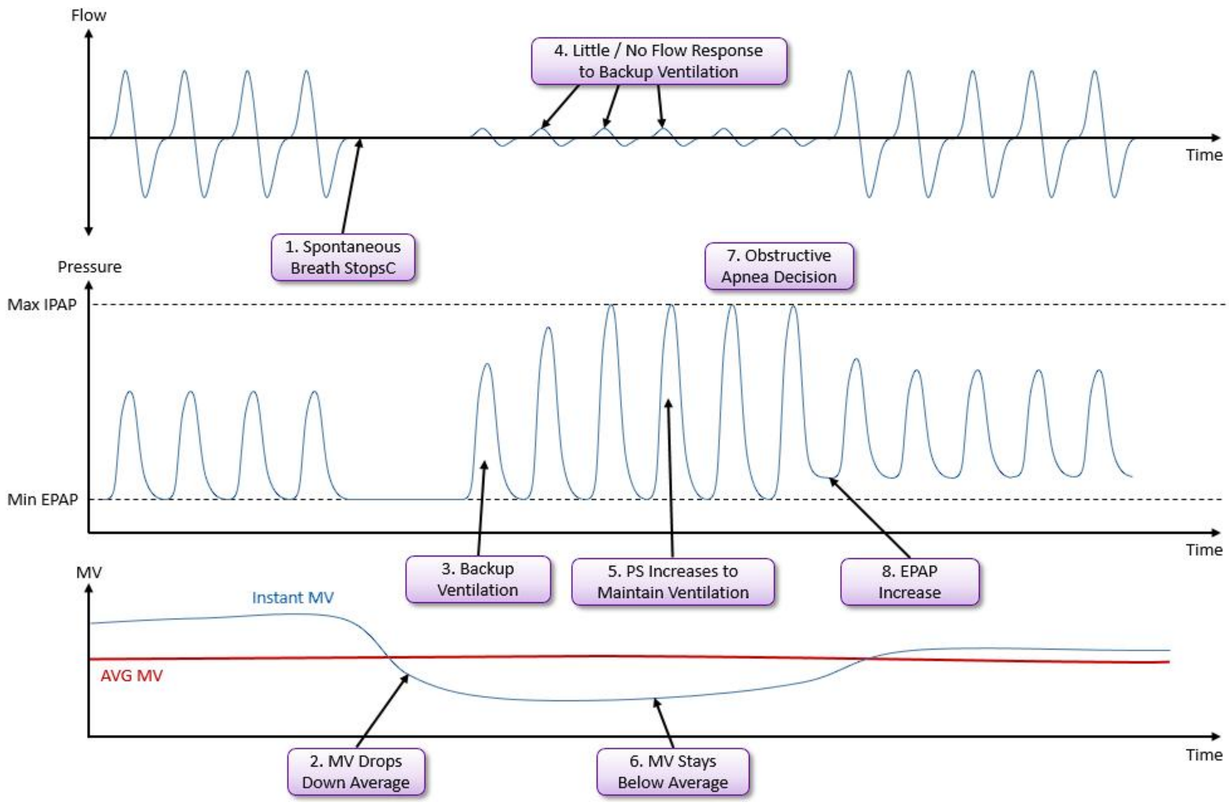
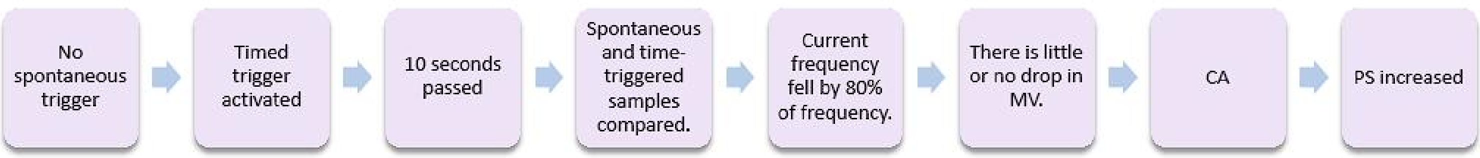


Figure 5: Airpap Obstructive Apnea Scenario

At point number 1, algorithm detects obstructive events as increases in PS do not stabilize MV. Once breathing resumes, it increases EPAP in proportion to the severity of the event. At point number 2, algorithm detects second obstructive apnea.

4.2 Central Apnea in ASV

Central apnea and ASV response:



Central sleep apnea occurs because your brain doesn't send proper signals to the muscles that control breathing.

In the ASV algorithm, when the patient stops breathing, spontaneous triggering does not occur because the device does not detect the patient's breathing effort. In this case, the device enters the "central apnea" event. When spontaneous triggering does not occur, the time-triggered breath cycle is activated. The time-triggered respiratory values are compared with the previous examples (spontaneous triggers). If, after comparison, the frequency has fallen below 80% and there is no or only a slight decrease in MV, this is a "central apnea".

ASV's response to central apnea is to automatically adjust the inspiratory pressure support (PS) to provide the necessary ventilation together with the reserve respiratory rate (set as 15 breaths per minute). PS is equal to IPAP minus EPAP. The PS change occurs within the specified maximum and minimum PS range.

Central Apnea Scenario

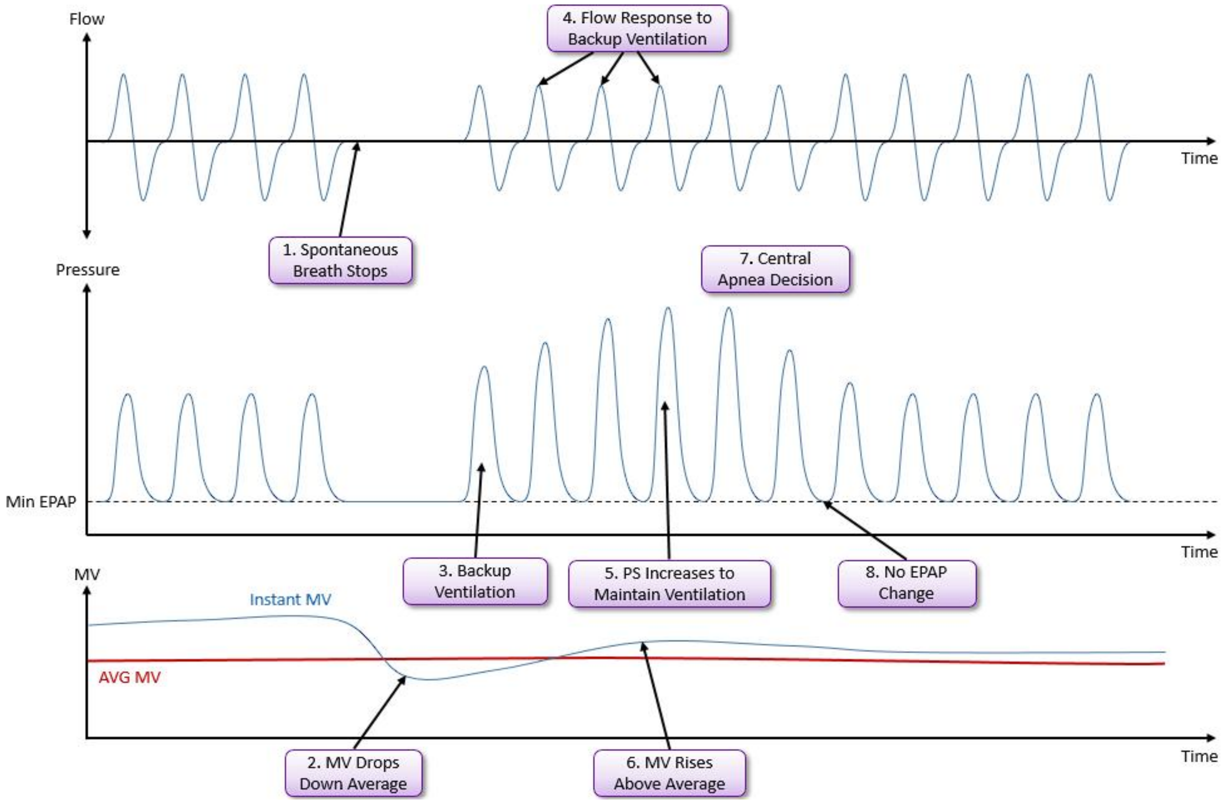


Figure 6: Airpap Central Apnea Scenario

4.3 Snoring in ASV

Snoring is vibrations caused by partial obstruction of the airway. Snoring creates irregularities in the flow curve. The ASV algorithm uses a high-pass filter for snoring detection.

The ASV algorithm uses a high-pass filter to extract high-frequency components from the device's respiratory signals. Snoring is characterized by high-frequency vibrations that occur on top of low-frequency respiratory signals. With this filter, the rapid changes characteristic of snoring can be separated from the noise. After filtering, the processed signal is analyzed for “peaks” that may represent snoring.

When the high-pass filter outputs, it starts counting peaks, detects snoring in three peaks, and responds by increasing EPAP by 0.5 mbar every five seconds.

4.4 Hypopnea in ASV

In the ASV algorithm, hypopnea is not detected at ±10% change in minute volume. A 30% decrease in minute volume is perceived as "hypopnea". In case hypopnea is detected, EPAP increases by 0.5 mbar every five seconds in response.

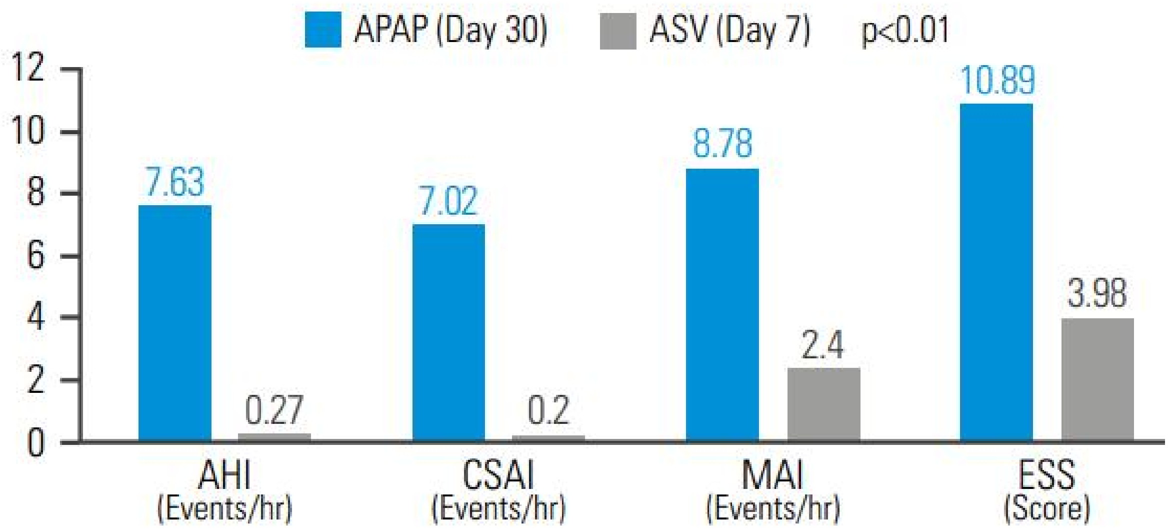
4.5 ASV Mode Parameters

Parameters	
Maximum E Pressure	5 – 20 mbar
Minimum E Pressure	3 - 20 mbar
Maximum Pressure Support	2 - 20 mbar
Minimum Pressure Support	2 - 20 mbar
Inspiration Slope	1 - 8 steps
Expiration Slope	1 - 8 steps
Sigh	On / Off
Inspiration Sensitivity	1 - 8 steps
Expiration Sensitivity	1 - 8 steps

5. CLINICAL SUPERIORITY OF ASV

A study compares the effectiveness of adaptive servoventilation (ASV) and noninvasive positive pressure ventilation (NPPV) in patients with central sleep apnea (CSA), Cheyne-Stokes respiration (CSR), predominantly mixed apneas, and complex sleep apnea syndrome (CompSAS). A total of 21 patients were randomly assigned to receive both ASV and NPPV. Findings indicate that CPAP was inadequate, with a mean residual apnea-hypopnea index (AHI) of 34.3 events per hour. NPPV reduced AHI to an average of 6.2/hr, while ASV further reduced it to 0.8/hr. ASV was notably more effective in reducing respiratory events and arousals, particularly in patients with mixed apneas and CompSAS. These results suggest that ASV is a superior treatment option when CPAP fails to adequately manage sleep-disordered breathing. [9]

Another study showed that ASV was better than two-level ST in reducing respiratory events in opioid-induced CSA. In opioid-induced CSA, ASV treatment reduced AHI by 84.7%, central apnea index (CAI) by 95.7%, apnea index (AI) by 96.4%, and respiratory arousal index (RAI) by 77.1% compared to two-level ST. Respiratory parameters returned to normal in 83.3% of patients using ASVAuto, compared to only 33.3% of patients using two-level ST. [2]



6. CONCLUSION

Adaptive Servo Ventilation (ASV) represents a dynamic approach to managing central and complex sleep-disordered breathing. Through real-time monitoring and intelligent adjustment of pressure support and expiratory pressures, ASV devices offer individualized therapy that stabilizes ventilation and mitigates both central and obstructive respiratory events. Clinical studies have consistently demonstrated ASV's superiority over conventional positive airway pressure modalities, particularly in patients with complex sleep apnea syndrome (CompSAS), opioid-induced central sleep apnea, and Cheyne-Stokes respiration.

However, while ASV improves apnea-hypopnea index (AHI), respiratory arousal index (RAI), and overall ventilation stability, it is not universally effective across all patient populations. Special attention should be paid to individuals with reduced ejection fraction due to potential adverse outcomes. Therefore, selection of ASV therapy must be guided by a comprehensive clinical assessment, balancing potential benefits with individual patient risk factors. As ASV technology continues to evolve, further research and long-term studies will be essential to fully define its optimal role in both acute and chronic respiratory management.

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