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Short Communication

Adaptation to EPAP Devices is Initially More Difficult than to CPAP: What is the Reason?

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Abstract

Expiratory resistance devices have been successfully shown to be effective for treating obstructive sleep apnea and snoring in some patients. Expiratory resistance devices have a valve that allows a patient to breathe in with minimal resistance, but offer more resistance during exhalation. The high expiratory resistance causes an increase in pressure in the upper airway during expiration which is thought to be responsible for their effectiveness. It is not clear why EPAP devices are not always effective. This paper explains how EPAP devices are different from CPAP (continuous positive airway pressure), and why they are potentially not effective in some patients. There are two important issues that make the EPAP devices less effective than CPAP. With EPAP devices, pleural pressure must be maintained more negative during breathing, hence there is the sensation that breathing is more difficult with EPAP. Second, in contrast to CPAP where the pressure in the upper airway is positive during the entire breathing cycle, with EPAP, the pressure in the upper airway during inhalation is atmospheric and upper airway collapse is possible as it would be during normal breathing. The sensation of difficulty breathing is less likely to be present during sleep and with time adaptation occurs and such sensation dissipates gradually. The major challenge during adaptation to the EPAP devices is being able to fall asleep.

ABBREVIATIONS

CPAP: Continuous Positive Airway Pressure; EPAP: Expiratory Positive Airway Pressure; OSA: Obstructive Sleep Apnea; FRC: Functional Residual Capacity; Ppl: Pleural Pressure; CO2: Carbon Dioxide

INTRODUCTION

The pathophysiology of obstructive sleep apnea can be explained by collapse of upper airways secondary to the negative pressure that develops during inspiration [1,2]. During sleep, the muscles of the upper airway relax, but in most individuals the airway passage remains open enough to allow air to flow. Some individuals may have anatomically narrow upper airway, and relaxation of the muscles during sleep may cause the upper airway to collapse so air cannot easily flow into the lungs. In addition, during sleep, muscles relax and tongue and other structures tend to crowd the back of the mouth causing greater potential for upper airway obstruction. Partial obstruction of the upper airway causes snoring noise and complete obstruction causes total cessation of airflow called obstructive sleep apnea (OSA). At end expiration, upper airway is narrowest [3,4] and most susceptible to collapse because lung volume is smallest, the pressure in the pharyngeal region is low, and dilator neural activity to the upper airways is least [2]. The preferred treatment for obstructive sleep apnea is continuous positive airway pressure (CPAP) therapy. The primary mechanism for improving upper airway patency with CPAP is the mechanical splinting effect by the positive pressure, which stabilizes the upper airway, preventing collapse during inspiration [1,2]. Sanders and Kern [5] suggested that the pressure during expiration is important for preventing upper airway obstruction and for maintaining normal breathing. Some investigators suggested that the increase in lung volume at end expiration (FRC) can also play an important role in stabilizing the upper airway [2,6], but the importance of lung volume is not universally accepted. Neural activity is also thought to play a role but will not be discussed here. Although the evidence for CPAP benefits in OSA patients is compelling, acceptance and adherence remain a challenge for patients and healthcare providers [7]. Therefore there is always a desire to seek a more convenient therapy.

Historical summary of the EPAP devices

Expiratory resistance devices have been successfully shown to be a viable option for people with sleep disordered breathing including obstructive sleep apnea and snoring [8,9]. Expiratory resistance devices have a valve that allows a patient to breathe in with minimal resistance, but offer more resistance during exhalation. The high expiratory resistance causes an increase in pressure in the upper airway during expiration (EPAP) while the pressure during inspiration remains unchanged near atmospheric. In addition, lung volume at end expiration is thought to be larger and may contribute to the function of EPAP devices. The increases in lung volume are reportedly equal with EPAP and CPAP at the same pressure therapy [10], but some reported smaller change in volume with EPAP [3,6]. In either case, the importance of lung volume in preventing upper airway collapse is, like with CPAP, not very clear. The effectiveness and safety of expiratory resistance technology were validated through several clinical trials [11-14] with substantial reductions in apnea-hypopnea index, oxygen desaturation, and daytime sleepiness, but curiously not in all patients. The EPAP devices simulate experiments that were published in 1983 [15] which concluded that increased pressure during expiration is in itself sufficient to prevent or alleviate obstructive sleep apnea (OSA). Although expiratory resistance devices have been deemed safe for prolonged use [12], some patients do not benefit substantially for unclear reasons [8,9]. The lack of consistent effectiveness in some patients was not explained [16]. The effectiveness of EPAP devices is, like CPAP, related to the pressure and perhaps volume changes, but a better understanding of the exact difference between CPAP and EPAP may make the EPAP devices better accepted and will help to better select patients who are likely to benefit from EPAP devices.

Several studies provided compelling evidence for the effectiveness of EPAP devices, regardless of the mechanisms, and the methods that were used to generate a positive pressure during expiration. Some investigators used a column of water to increase the EPAP [15], some used a CPAP machine [17], some used an expiratory resistance device [11,12,14], and some used nasal pillow type mask with adjustable expiratory resistance [18]. Provent and Theravent are EPAP devices that have been available for several years. Optipillows EPAP mask is a new over-the-counter EPAP device that was cleared for treatment of snoring [18]. Bongo Rx is another new EPAP device, designed as a nasal pillow mask. There is a general agreement that EPAP devices are useful for sleep disordered breathing but a better understanding of how they work is necessary [8,9,19], so we can better understand why some patients do not benefit significantly or have difficulty adapting to them [6,11,13]. In addition, it is helpful to explain why EPAP is not always as effective as CPAP. The obvious difference between EPAP and CPAP is that with CPAP the pressure in the upper airway remains positive during the entire breathing cycle. In contrast, during EPAP, the pressure in the upper airway becomes positive only during expiration [16]. The difference in lung volume between EPAP and CPAP is less obvious. In this discussion we will rely on the findings of a well conducted study [10] that showed that lung volume at end expiration with CPAP and EPAP is similar for the same treatment pressure. Others reported similar results in humans undergoing surgery [20]. We will compare the expected pressure and volume changes in a model of the respiratory system during CPAP or EPAP therapy. The goal is to show the differences between EPAP and CPAP therapy in terms of changes in pressure and lung volume, to explain why the EPAP is not effective in all patients, and why EPAP is less effective than CPAP.

MATERIALS AND METHODS

Figure 1 illustrates schematically ideal tracings of pressure and volume swings within the respiratory system during one breathing cycle, including changes in alveolar pressure (dotted line), intra-pleural pressure (dashed line), and changes in lung volume (solid line) during CPAP or EPAP. For reference, the pressure and volume changes during a normal breathing cycle are illustrated in the left panel. In this example representing the average adult, lung volume at end of normal expiration (FRC) without CPAP or EPAP is assumed to be 2 liters. The numbers near the volume tracings represent the trans-pulmonary pressures (alveolar – pleural) at the beginning and end of each breath. Because lung volume at end expiration is thought to be equal with EPAP and CPAP, consequently one would have to accept that the trans-pulmonary pressure would also be equal at end expiration with EPAP and CPAP. During a normal breath, at end expiration, Pleural pressure (Ppl) is approximately -5 cmH20 and deceases progressively during inspiration to -10 cmH2O (Left panel), while alveolar pressure starts at zero, becoming slightly negative but returns to zero at end inspiration. This causes the trans-pulmonary pressure to increase from 5 to 10 cmH2O and would be associated with an increase in lung volume by 300 ml (Tidal Volume). During expiration, respiratory muscles relax and air is expelled due to passive recoil pressure of the lungs with pressures and volume returning to initial values at FRC. During CPAP of 10 cmH2O (middle panel), at end expiration, alveolar pressure would be 10 cmH2O and lung volume would be increased to 2.3 liters while Ppl would be approximately zero. During inspiration, pleural pressure falls progressively from zero to – 5 cmH2O while alveolar pressure remains at 10 cmH2O at end of the inspiration. This would cause the transpulmonary pressure to increase from 10 to 15 cmH2O, and would be associated with an increase in lung volume from 2.3 to 2.6 liters.

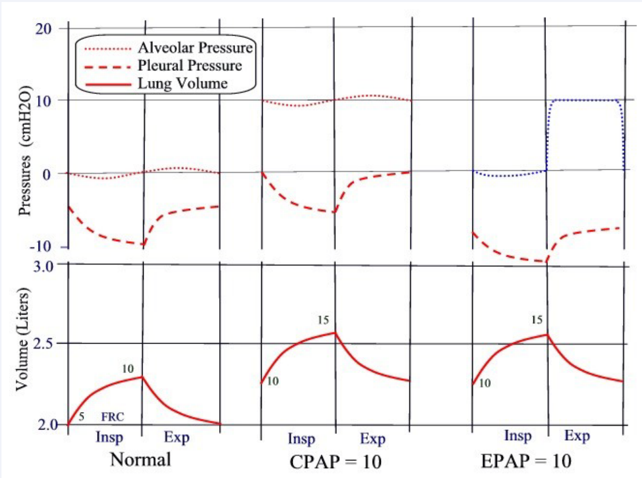

Figure 1 Schematic illustration of changes in alveolar pressure, Pleural pressure and lung volume during application of CPAP of 10 cm H2O (middle panel) or EPAP of 10 cmH2O (right panel). For reference, the changes during normal breathing are also illustrated (left panel). FRC during normal spontaneous breathing without CPAP or EPAP is assumed to be 2000 ml. Numbers near the volume tracing represent trans-pulmonary pressure (Alveolar-pleural) at beginning and end of each breath.

During exhalation the pressures and volume return to their initial values. Therefore, with CPAP, the alveolar pressure (as well as the pressure in the upper airway), remains positive during the entire breathing cycle (middle panel), maintaining upper airway patency, and preventing snoring and OSA. The right panel in Figure 1 illustrates the changes in pressure and volume during the use of EPAP of 10 cmH2O. Based on the results of Layon et al. [10], at end expiration, lung volume would be 2.3 L, and trans-pulmonary would be 10 cmH2O (as with CPAP of 10). Because alveolar pressure would be zero at end expiration, pleural pressure would have to be -10 cmH2O. The negative pleural pressure at end expiration would be due to the passive elastic recoil forces of the lungs. During inspiration, pleural pressure decreases progressively from -10 cmH2O to -15 cmH2O, while alveolar pressure remains at zero at the end of inspiration (right panel). Therefore transpulmonary pressure would increase from 10 to 15 cmH2O and lung volume would increase from 2.3 to 2.6 L as it did during CPAP. During expiration, respiratory muscle relax and pleural pressure would return to -10 cmH2O, and alveolar pressure rises to 10 cmH2O for most of the expiratory time, but return to zero at the end of expiration. During inspiration with EPAP, the pressure in the upper airway would remain close to zero (right panel) and potential for upper airway collapse is as likely as it was during a normal breath. The changes that we described may become easier to understand after we describe the events in another way as in Figure 2.

Figure 2 illustrates in a diagram of the lungs (dotted line) and chest wall/diaphragm (solid line), the predicted pressures and lung volume at end expiration (top row) and end inspiration (bottom row) during a spontaneous breath during normal conditions and with CPAP of 10 cmH2O and EPAP of 10 cmH2O. The pleural and alveolar pressures are shown. The pressure in

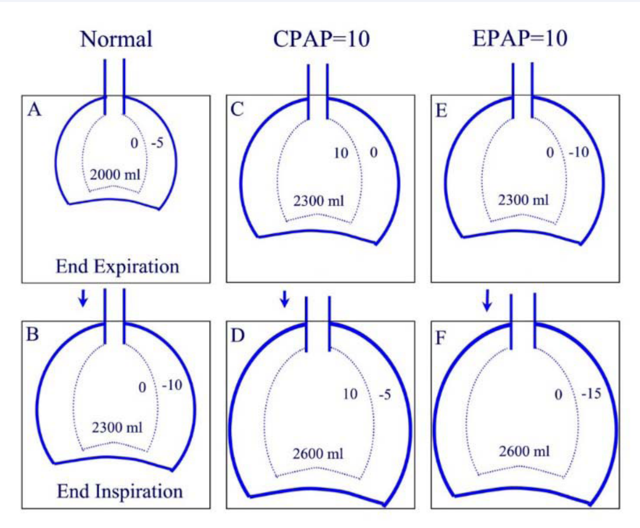

Figure 2 Diagrammatic illustration of changes in lung volume and associated changes in alveolar and pleural pressures during CPAP or EPAP of 10 cm H2O. The top row represents the volumes at end expiration, and the bottom row represents the volumes at end inspiration. The pressure in the upper airway in these states is equal alveolar pressure. A square of the same size is drawn around each condition.

the upper airway would be equal to alveolar pressure at end expiration and end inspiration. Lung volume at end expiration during a normal breath (FRC) is assumed to be 2000 ml. During a normal breath, at end expiration (A), alveolar pressure is zero, pleural pressure is -5 cmH2O (Trans-pulmonary pressure = 5 cmH2O) and lung volume is 2000 ml. At end inspiration (B), alveolar pressure would remain zero, pleural pressure would decrease from -5 to -10 cmH2O, and lung volume would increase to 2300 ml. During inspiration, the pressure in the upper airway becomes slightly negative, leading to potential collapse of the upper airway in a patient with OSA. A square of equal size was drawn for reference to bring out differences in lung volume under the different conditions. Figure 2, middle two panels, illustrate the changes with CPAP of 10 cmH2O. At end expiration (C), alveolar pressure (as well as upper airway pressure) would be 10 cmH2O, while Ppl may become less negative (perhaps close to zero). During inspiration, lung volume increases to 2600 ml, Ppl decreases from zero to -5 cmH2O, and alveolar pressure remains at 10 cmH2O, thus preventing potential upper airway collapse (D). With CPAP, the inspiratory muscles effort may be reduced compared to normal because less negative pleural pressure is being generated. During EPAP of 10 cmH2O, the changes in volume and pressure are illustrated in the right two panels (E,F). At end expiration, lung volume is 2300 ml (as it was with CPAP) and alveolar pressure would be zero, while pleural pressure would be -10 cmH2O (E). At end inspiration, alveolar pressure would remain zero and pleural pressure would decrease from -10 to -15 cmH2O (F), with lung volume increasing to 2600 ml (as with CPAP). The volume changes and transpulmonary pressure changes are equivalent in CPAP and EPAP. However, compared to CPAP during inspiration, during EPAP, pleural pressure was maintained more negative. This may require more effort by the inspiratory muscles.

Because the upper airway pressure remains near zero with EPAP, the small sub-atmospheric pressure in the upper airway that develops during inspiration could potentially cause upper airway collapse as it did during a normal breath. However, because of the EPAP, the walls of the upper airway may remain stable and less susceptible to collapse. In addition, lung volume at end expiration would be expanded. The combination of expanded lung volume and somewhat stabilized upper airway with EPAP would help prevent potential upper airway collapse during the subsequent inhalation. The patency of the upper airway with EPAP may be less secure than with CPAP because of the pressure in the upper airway remains near zero. At higher levels of EPAP (not shown), inspiration becomes more difficult, because more effort would be required by the inspiratory muscles to maintain a more negative pressure. In addition, the lungs may become over-expanded leading to a decrease in the tidal volume, resulting in hypoventilation with CO2 retention [3]. Therefore, it is safer to use low levels of EPAP, and limit the use of EPAP devices to patients requiring low therapeutic pressure, such as snoring and low levels of obstructive sleep apnea. Evidence shows that EPAP devices are less effective in patients with severe OSA and perhaps may cause CO2 retention [6,11,21].

RESULTS AND DISCUSSION

Obstructive sleep apnea (OSA) is attributed to frequent and recurring upper airway collapse during sleep. At end expiration, lung volume is small, pressure in the upper airway is zero, and dilator neural influences are minimal, all of which are conditions that render the upper airway susceptible to collapse. Consequently during inspiration a small decrease in pharyngeal pressure below atmospheric may cause upper airway collapse. In most people upper airway collapse is prevented because of structural stability of the upper airway. However, in some individuals, upper airway wall stability becomes less effective leading to obstruction of air flow, causing snoring and OSA. CPAP machines prevent snoring and OSA by maintaining a positive pressure in the upper airway throughout the breathing cycle, which stabilizes the upper airway and prevents collapse of the upper airway. EPAP devices also increase the pressure in the upper airway but only during expiration, and have been shown to alleviate OSA [11,12,15,22], albeit not in all patients. EPAP devices have been shown to alleviate snoring [12,22-24]. In addition to the increase in pressure in the upper airway, CPAP and EPAP are also associated with an increase in lung volume at end expiration which may also contribute to upper airway stability. EPAP devices may also give the sensation that breathing is more difficult, making them more difficult to get used to them. Initially the user experiences more difficulty breathing and would be inclined not to use EPAP. Nevertheless, once the user gets used to the EPAP device, the individual apparently adapt and is able to use it safely and effectively for a long time [12].

Expiratory resistance devices are FDA cleared devices some of which are for treating snoring and some for obstructive sleep apnea. EPAP devices are convenient devices because they are portable and generate positive pressure without the need for a power source. With EPAP devices, there is compelling evidence that regardless of the mechanisms, they are effective and can prevent upper airway obstruction and improve OSA, oxygenation and daytime sleepiness [11-14]. The most extensive research on EPAP devices was done using Provent and showed the EPAP devices to be more effective in mild to moderate OSA patients [11,12,22], whereas in severe OSA patients, EPAP devices are much less effective [14,22,17,21]. In contrast CPAP is always effective with all severities of OSA. This report emphasizes the differences between EPAP and CPAP and explains the reasons why EPAP devices are not always effective and why there is difficulty adapting to them. There are three factors that may explain the difference in effectiveness of EPAP compared to CPAP.

Work of breathing

EPAP devices are desirable because of their convenience but often some users are disappointed with the EPAP devices when they use them. We explained the differences between CPAP and EPAP therapy based on the physiological parameters of the respiratory system. We have shown that the volume and pressure changes in the two modes of therapy may be different and explained why it may be easier to adapt to CPAP than to EPAP. We have explained that because the pleural pressure need to be maintained more negative during inspiration with EPAP, the inspiratory muscles need to make more effort during use of EPAP than during CPAP. This extra effort gives the user the sensation that it is more difficult to breathe. Convenient as they may be, EPAP devices give the sensation that the muscles need to work harder during breathing. Indeed, work of breathing have been shown to be greater with EPAP than with CPAP [25}, and work of breathing have also been shown to be less during CPAP therapy than without CPAP [26]. This explains the sensation of breathing being more difficult with EPAP. This may also explain why many people initially are unable to use the EPAP device, despite the fact that they are reminded that it may take time to adapt to them. Adaptation to the EPAP devices may be difficult for some and often people give up before they become adapted to them. With some persistence, many patients are able to adapt to using EPAP devices, for a long period of time. The sensation of difficulty will dissipate gradually as the user becomes more adapted to the EPAP device. Furthermore it is likely that patients may be less aware of the sensation of more difficulty breathing during sleep. Therefore the challenge during adaptation is to be able to fall asleep while using the EPAP mask. If necessary, patients are encouraged to utilize mouth breathing while they are trying to fall asleep.

Airway pressure

Another reason that makes EPAP devices not very effective in some patient is the fact that during inspiration, the pressure in the upper airway is positive only during expiration but remains close to zero during inspiration. With CPAP, the pressure remains positive throughout the entire breathing cycle securing patency of the upper airway. Consequently, upper airway stability with EPAP may not be as secure as with CPAP. At end of expiration, pressure in the upper airway returns to zero, and inhalation will be associated with a slight negative pressure as would be the case during normal breathing. Therefore in some individuals, patency and stability of the upper airway is not as secure as with CPAP, and the potential for upper airway collapse may be present during use of EPAP. Because the upper airway is exposed to positive pressure during part of the expiratory time, upper airway may remain somewhat more stabilized and potential collapse may be alleviated. This may explain why EPAP is sometimes not very effective in some patients. In most patients, EPAP may be effective, but it may not be as effective as with CPAP where the pressure remains positive during the entire breathing cycle ensuring patency and stability of the upper airway.

Lung volume

Although this is controversial, the increase in lung volume at end expiration may also contribute to stability of the upper airway but the exact mechanism is not clear. With CPAP, the increase in lung volume at end expiration is indisputable, however, the role of lung volume on stability of the upper airway is less clear. In this discussion, we assumed that lung volume increase at end expiration is equivalent with EPAP and CPAP. Because of the increase in lung volume, more “tug” or tension develops in the tissues, enhancing upper airway wall stability [2]. Not only the effect of lung volume is somewhat unclear, but also the increase in volume may not always be consistently present, leading to less effect in some individuals. Nevertheless, a smaller volume would mean less wall traction to prevent upper airway collapse.

EPAP devices have been successfully used for treatment of OSA and snoring, and have been hailed as a welcome addition to OSA therapy [8,9,19] but there is always a cautionary reminder that a better understanding of their use is necessary. This study provides a possible explanation why EPAP devices are not always effective in all patients based on the greater negative pressure that must be maintained by the inspiratory muscles. Furthermore we clarified the difference between EPAP and CPAP in terms of the duration of the positive pressure in the upper airway. This information provides the care provider a better understanding how to utilize the EPAP device. It is recommended to avoid using the EPAP devices for patients with severe OSA where high pressure may be necessary. EPAP devices are best for primary snorers, or for OSA patients with mild to moderate severity of OSA. Long time CPAP users also may find it difficult to switch to using an EPAP device [21], perhaps because the respiratory muscles may have become weaker and more dependent on having the pressure support during inspiration. In either case, given adequate time, the patient will adapt to the increased expiratory resistance in EPAP devices, to the new lung volume and more negative pleural pressure. A newly diagnosed OSA patient is more likely to get used to the expiratory resistance device much easier than a long time CPAP user.

CONCLUSION

Although EPAP devices have been shown to be effective in some patients with OSA, they are not always effective, and usually are less effective than CPAP but the reason is not clear. In this paper we explained the reasons. With CPAP, alveolar pressure remains elevated throughout the breathing cycle securing the patency of the upper airway. The positive pressure acts like a stent to stabilize the upper airway and prevent snoring and obstructive sleep apnea. EPAP devices are convenient because they generate a positive pressure during the expiratory phase of the breathing cycle without using a machine. Nevertheless, there is a perception that EPAP devices are more difficult to adapt to them than to CPAP therapy. The reason is that the respiratory muscles may have to maintain and generate more negative pleural pressure during inspiration and therefore the inspiratory muscles may need to work a little harder during inhalation. Despite the initial sensation of more difficulty with EPAP devices, respiratory muscles can adapt with time. Patients are likely to be less aware of the difficulty with breathing after they fall sleep. Therefore, learning to fall asleep with an EPAP device is an important step during adaptation. To avoid the potential difficulties described above, use of EPAP devices should be limited primarily to patients with sleep disordered breathing who require low pressure such as patients with snoring or mild OSA because adaptation to the EPAP device would be easier making the EPAP device more effective.

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Conflict of Interest

No financial support from outside sources. Dr. Hakim is the inventor of one of the discussed EPAP devices, Optipillows EPAP Mask, which was discussed equally as other EPAP devices.

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