Exploring clinicians' beliefs and practices regarding Non-Invasive Ventilation devices: An international survey study

Kevin Benavente, [1] Eric W. Robbins, [2] Bradley Fujiuchi, [3] Kamran Manzoor, [4] Ehab G. Daoud [5]

DOI: https://doi.org/10.53097/JMV10078

Cite: Benavente K, Robbins ER, Fujiuchi B, Manzoor K, Daoud EG. Exploring clinicians' beliefs and practices regarding Non-Invasive Ventilation devices: An international survey study. J Mech Vent 2023; 4(2):84-91.

Abstract

Introduction

Non-invasive ventilation (NIV) has a significant role in supporting patients with respiratory failure with the goal of avoiding mechanical ventilation. Traditionally, NIV has been applied using dedicated NIV-specific devices but over the last decade, newer generation critical care ventilators have updated their capabilities to include NIV options with improved synchrony and leak compensation. No recent trials have compared the efficacy of new generation critical care ventilators to NIV ventilators. The purpose of this study was to evaluate clinicians attitudes and perceptions toward the use of NIV between the dedicated NIV and critical care ventilators.

Methods

An online survey of clinicians with seven questions regarding their thoughts and experience in using NIV in acute care settings was posted online and promoted through emails and social media. The survey was anonymous and an exemption of consent was obtained from the Institutional Review Board. Analysis of variants (ANOVA) was done for the total responses in each question, followed by multivariate analysis of variants (MANOVA) for responses per occupation.

Results

514 responses from 54 countries were recorded. 151 from North America, 109 from South America, 125 from Europe, 97 from Asia, 21 from Africa, and 11 from Australia. 218 responders were physicians, 218 were respiratory therapists, 28 were nurses, and 50 were reported as other professionals (engineers, biomedical technicians). 346 (67.3%) reported using both types of ventilators for NIV, 91 (17.7%) use only NIV -specific devices, and 77 (15%) only use critical care ventilators (P 0.097), responses per occupation (P < 0.001). 290 (56.4%) have automatic synchronization software on either of their ventilators, 113 (22%) do not, while 111 (21.6%) are unsure if they do (P 0.22), with significant variation by occupation (P 0.008). Regarding synchrony, 233 (45.3%) said NIV ventilators are better, and 165 (32.1%) said critical care ventilators are better, while 116 (22.5%) said both are similar (P 0.59) with significant variation by occupation (P 0.04). Regarding leak compensation, 241 (46.9%) said NIV ventilators are better, and 146 (284%) said critical care ventilators are better, while 127 (24.7%) said both are similar (P 0.6) without significant variation by occupation (P 0.07). Regarding the general opinion of superiority, 273 (53.1%) said NIV ventilators are better, 131 (25.5%) said critical care ventilators are better, and 110 (21.4%) said both are similar (P 0.42) without significant variation by occupation (P 0.098).

Conclusion

Despite the lack of evidence, there is wide variability in opinion with no clear consensus regarding the clinicians' attitude towards which ventilators are superior to use during NIV, especially according to surveyed occupation.

Keywords: NIV, synchrony, leak compensation

Authors
1. DO, JABSOM, University of Hawaii, HI, USA
2. MD, Alpert Medical School, Brown University, RI, USA
3. MD, JABSOM, University of Hawaii, HI, USA
4. MD, Tufts University School of Medicine, MA, USA
5. MD, Associate professor, JABSOM, University of Hawaii, USA

Corresponding author: kevinb33@hawaii.edu
Conflict of interest/Disclosures: None
Funding: None

Journal of Mechanical Ventilation 2023 Volume 4, Issue 2

Introduction

The use of Non-Invasive Ventilation (NIV) in the acute care setting has expanded over several decades and has been the standard of care for many conditions with acute respiratory failure such as COPD exacerbations and acute cardiogenic pulmonary edema. [1] The indications have further expanded to include postoperative hypoxia, post extubation respiratory failure and reducing post extubation failure in high-risk patients. [2,3] NIV has some attractive features compared to invasive ventilation with artificial airways such as the reduced need for sedation, reduction in ventilator associated pneumonia, and reduced need for invasive ventilation. [3]

Traditionally, NIV has been applied with the use of dedicated NIV ventilators as they were documented in studies to perform better than critical care ventilators especially regarding leak compensation and patient-ventilator synchronies. [4] However, many new generation critical care ventilators are now equipped with NIV software capabilities that challenge this notion of inferiority to dedicated non NIV specific devices. [4] The development of sophisticated software in NIV and high flow oxygen therapy (HFOT) modes make the use of critical care ventilators a more attractive option as an all-in-one machine, on the other hand, critical care ventilators are larger, more sophisticated, and more expensive and might be difficult to use outside of the intensive care settings.

Most studies that compare different ventilators used for NIV are bench lung models simulator studies that utilize different model criteria, and the lack of standard references or consistent terminology may have influenced the understanding and assessment of NIV devices. [5] Given the conflicting literature results, we aimed to assess clinicians attitudes and perceptions toward the use of NIV and how they differ between dedicated NIV and critical care ventilators.

Methods

An international online survey to clinicians with seven questions (Table 1) regarding their thoughts and experience in using NIV in their acute care settings was posted on the Society of Mechanical Ventilation website and promoted via emails and social media. The study dates were from November 2022 to March 2023. The survey was anonymous, and an exemption of consent was obtained from the Institutional Review Board. Analysis of variants (ANOVA) was performed for the total responses in each question, followed by Multivariate analysis of variants (MANOVA) for responses per occupation. Statistics was performed using R software (version 4.3.0, R Core Team 2022, Vienna, Austria) to analyze the differences in results, using the null hypothesis that there is no significant difference between the groups in terms of their average answers to the different questions, P value of < 0.05 was considered significant.

Results

A total of 514 respondents participated in the survey. Respondents were comprised of 218 physicians, 218 respiratory therapists, 28 nurses, and 50 other clinical roles involving respiratory management (engineering and technicians). The responders were from 28 countries (Table 2).

The majority of respondents (67.3%) reported using both critical care ventilators and dedicated non-invasive ventilators for patients requiring non-invasive positive pressure support. This was maintained across all professional designations, with greater than 67% of nurses, respiratory therapists, physicians, and other practitioners using both types of ventilators in their practice. In general, those differences were not statistically significant (P 0.09). However, with multivariate analysis per occupation, the results were statistically significant ($P < 0.001$) (Table 3).

A majority (45.3%) of participants reported the dedicated non-invasive ventilator systems provided the best synchrony with patient respirations, with 50% of nurses and 58.3% of respiratory therapists attesting to its superiority. A plurality of both physicians (40.8%) and the other respiratory specialist participants (40%) favored critical care ventilators for synchrony. Those were not statistically significant (P 0.59) but were significant with multivariate analysis per occupation (P 0.04).

Non-significant results in general (P 0.6) and in multivariate analysis (P 0.07) were obtained in evaluating for leak compensation, with 57.1% of nurses and 63.8% of respiratory therapists reporting better results with dedicated non-invasive ventilators. Physicians were relatively evenly split, with approximately one-third of participants split among all categories. Non-denomination participants were largely in favor of critical care machines (52%).

Overall, 53.1% of participants expressed that dedicated non-invasive ventilators to be superior in providing non-invasive positive pressure support, with a majority of participants expressing similar preferences among nurses (67.9%), respiratory therapists (70.6%), and other respiratory practitioners (40%). However, among physicians, a majority (42.2%) favored critical care ventilators over the dedicated devices in providing non-invasive support. The general results were not statistically significant (P 0.42) even with multivariate analysis per occupation (P 0.098).

56.4% of the participants indicated that they have automatic synchronization software on the ventilators they use, 22% that they don't have such software, and 21.6% were not sure if they do or not. The results were not statistically significant in all responders (P 0.22) but significant in multivariate analysis per occupation (P 0.008).

Table 1. Surveyed questions and answers options

Questions	Answer options
I am	Physician Respiratory Therapist Nurse Other
Country of practice	Enter country
For Non Invasive Ventilation, I use:	Dedicated noninvasive ventilator Critical care ventilator Both
In your opinion, which ventilators are better in synchrony?	Dedicated noninvasive ventilator Critical care ventilator Both
In your opinion, which ventilators are better in leak compensation?	Dedicated noninvasive ventilator Critical care ventilator Both
In your opinion, which ventilators are superior for NIV in general?	Dedicated noninvasive ventilator Critical care ventilator Both
Does the ventilators you use have automatic synchronization software?	Yes No Not sure

Table 2. Demographics of participants

N. America	S. America	Europe	Africa	Asia	Australia
151	109	125	21	97	11
Physician	Respiratory Therapy	Nurse	Other		
218	218	28	50		

Table 3. Summary of the results. NIV: Dedicated Non-Invasive Ventilator, CCV: Critical Care Ventilator. P: Physician, R: Respiratory Therapist, N: Nurse, O: Other

Question	Occupation	NIV	CCV	Both	P value
Non-Invasive Ventilation, I use		91 (17.7%)	77 (15%)	346 (67.3%)	0.09
	P	34	35	149	
	R	41	30	147	< 0.001
	N	8	1	19	
	O	8	11	31	
In your opinion, which ventilators are better in synchrony?		233 (45.3%)	165 (32.1%)	116 (22.6%)	0.59
	P	77	89	52	
	R	127	48	43	0.04
	N	14	8	6	
	O	15	20	15	
In your opinion, which ventilators are better in leak compensation?		241 (46.9%)	146 (28.4%)	127 (24.7%)	0.6
	P	74	70	74	0.07
	R	139	43	36	
	N	16	7	5	
	O	12	23	12	
In your opinion, which ventilators are superior for NIV in general?		273 (53.1%)	131 (25.5%)	110 (21.4%)	0.42
	P	80	92	46	0.098
	R	154	22	42	
	N	19	5	4	
	O	20	12	18	
		No	Yes	Not sure	
Does the ventilators you use have automatic synchronization software?		113 (22%)	(56.4%)	(21.6%)	0.22
	P				
	R	37	119	62	0.008
	N	54	123	41	
	O	4	22	2	
		18	26	6	

Discussion

Our results show that the majority of clinicians use both dedicated and critical care ventilators compared to exclusively using either one alone. Historically, the use of NIV has been limited to dedicated non invasive ventilators and many studies have documented that dedicated non invasive ventilators operate better than critical care ventilators for NIV. [6,7] Newer generation critical care ventilators have added new software with different algorithms that challenge this hierarchy. [8] With recent recalls of some of the dedicated non invasive ventilators, it seems that the use of critical care ventilators for NIV is on the rise. [9] Additionally, having HFOT, NIV, as well as invasive modes available make critical care ventilators an attractive option as all features are in one device.

Our results showed a non-significant difference in opinions regarding patient-ventilator synchrony between NIV and critical care ventilators, however in the multivariate analysis, there was a significant difference largely favoring NIV influenced by RT favoring NIV. The majority of clinicians now have some kind of automatic synchronization software on the ventilators they use.

Patient-ventilator asynchronous events (AEs) have long been an area of concern in ventilated patients, leading researchers, and manufacturers to investigate methods of detecting and reacting to AEs utilizing algorithmic software. Early efforts included algorithms designed to detect ineffective respiratory efforts in ICU ventilators. [10] However, ICU ventilators were previously designed without consideration of significant circuit leaks, given that patients were

typically ventilated via endotracheal tubes. As these devices added additional ventilator modes, including non-invasive ventilation (NIV), leaks became a more commonly encountered issue, as NIV masks have far more frequent leaks than do endotracheal tubes.

Leaks were shown to be a major source of AEs in ICU ventilators in a multi-center study in France. [11] Shortly thereafter, efforts for algorithmic detection of AEs during ICU ventilator NIV were started. [12,13] In contrast, dedicated NIV machines, such as those used at home by patients with chronic respiratory failure, have long had to deal with leaks. However, in hospitalized patients with acute or acute-on-chronic respiratory failure, the comparative efficacy of dedicated NIV machines versus ICU ventilators' NIV modes was previously unknown.

Carteaux and colleagues [14] recognized that dedicated NIV machines did better managing asynchronous events (AEs) especially when related to leaks than did ICU ventilators in NIV mode. Leaks can be mistaken for inspiratory efforts, thus causing an auto-trigger (AT) event. This finding was true even with ventilators utilizing algorithms to detect and correct AEs. The same authors also found significant variation among tested ventilators at the time, such that each machine needed to be individually assessed, rather than being able to draw conclusions about ICU ventilators as a whole. Later studies showed ICU ventilator NIV algorithms equaling or surpassing dedicated NIV machines, with some systems incorporating diaphragm electrical activity. [15]

As NIV software evolved, there was particular interest in utilizing ventilator waveforms alone for detecting all varieties of AEs during NIV. To establish a "gold standard" to compare software algorithms against. Longhini and colleagues [16] tested the sensitivity, specificity, PPV, and NPV of ICU clinicians at recognizing AEs during NIV. Prior software algorithms had been successful at detecting NIV ineffective efforts, [7,9,17] but Lettelier and colleagues [18] were the first to algorithmically autodetect and categorize a variety of NIV AEs (including auto-triggering, double-triggering, and ineffective efforts). Notably, their model made specific corrections for leak detection so that when leaks were too large ventilatory cycles were discarded, rather than being mistakenly categorized as auto-triggers.

To date, the overwhelming majority of software algorithms utilize explicitly programmed mathematical models to detect and categorize AEs. With the rise of machine learning (ML) methodologies, especially supervised ML where pre-categorized training datasets are fed into ML models, new forms of AE detection are being assessed. Similar to older modeling efforts using explicitly defined algorithms, ineffective efforts were some of the first AEs modeled using ML.[19] However, invasive mechanical ventilation was a more common target of ML research, and several studies have attempted to broaden the detection and classification of AE varieties. [20,21,22,23,24] To date, no ML models have been published that directly assess NIV modes of ventilation, either with dedicated NIV machines or ICU ventilators.

One significant limiting factor in assessing the clinical utility of automatic synchrony software's and software-driven AE detection is the lack of head-to-head comparisons of software varieties. Typically, studied synchrony software is compared to a gold standard measure-expert clinician detection and classification of AEs. AEs. No direct comparisons have yet been published that of either compare different between-group differences in explicitly designed algorithms, or different competing ML models, or that assess the performance difference between designed algorithms versus and ML models have yet been published. In summary, while software utilizing either algorithm- or ML-based detection of AEs shows significant promise to improve patient-ventilator synchrony in both NIV and other ventilator modes, there is marked heterogeneity in software between ventilator machine types, manufacturers, and the underlying methodology used to detect and intervene on AEs.

Circuit leaks in both invasive and non-invasive mechanical ventilators continue to constitute a major challenge as it limits the ability of mechanical ventilators to deliver a synchronized breath. Air leak in non-invasive ventilation is a major concern as it not only impacts arterial oxygenation but also causes mouth and throat dryness, eye irritation but also impact on sleep quality. Alternative mechanisms to address this by tightening the mask would lead to skin and nasal lesions in a significant percentage of the patients. [25] Most mechanical ventilators have leak compensation software that allows them to adjust and respond to increase or decrease in leaks accordingly. Such software monitors the percent leak and responds to leaks by correct quantification within a few breaths, but it also attempts to reduce auto trigger. [26,27]

Opinions on leak compensation between ventilator types also did not differ significantly. As noted by Scott, [4]these findings may be explained by the wide

range of leak detection and adjustment algorithms used by modern ventilators resulting in varying performance between critical care ventilators. Direct comparisons between individual systems are needed to establish how critical care ventilators compare to NIV dedicated ones in the presence of a leak. Similarly, as new ventilator systems continue to be implemented and updated, it is difficult for clinicians to evaluate the effectiveness of systems in the absence of existing studies.

While our results showed no significant difference between those favoring dedicated NIV versus critical care ventilators in both the general and multivariate analyses, dedicated NIV ventilators had a greater number of votes for being the superior respiratory strategy, even when combining votes from those who favored critical care ventilators with those who had no preference (273 vs 241). In fact, the dedicated NIV group had more than double the votes of either the other two groups. When taking this result in context with trends in our data showing a nonsignificant signal favoring NIV for patient synchrony and leak compensation, it is possible these components contributed to respondent favoring NIV as their preferred mode. This is supported by early research from Miyoshi and colleagues [28] comparing ICU ventilators to bilevel NIV dedicated devices, in which the critical care ventilators experienced more frequent and severe episodes of auto triggering when compared to the bilevel devices. This was further confirmed by Ferreira and colleagues [29] in which a bilevel, dedicated NIV required no user adjustments in response to increasingly worsening leak, compared to 8 other ICU ventilators that did require user adjustments despite having an NIV setting, and 1 ICU ventilator that did not. Thus, it can be hypothesized that despite the apparent trends favoring dedicated NIV, the heterogeneity in the proprietary software and computer algorithms used to optimize synchrony and leak compensation perhaps contributed to the underpowering of our result. Vignaux [10] demonstrated that even among critical care ventilators with specified NIV settings, wide variation existed between ventilators in their ability to compensate for leaks.

In addition to leak compensation and synchrony, a survey by Crimi and colleagues [30] reported the presence of a dual circuit, inspiratory oxygen fraction control, transportability, monitoring capabilities, drug delivery and alarm control as additional factors influencing ventilator choice, in order of decreasing power. In contrast, they also demonstrated that geographic location of the respondents, clinical scenario (i.e. cardiogenic edema vs hypercapnic failure), familiarity with the devices, availability of the machines, and difficulty in setting the ventilator were factors not significantly associated with influencing ventilator preference, however the external validity of these results to hospitals outside of Europe has yet to be proven. The training and experience of those who utilize NIV also likely has a prominent role in influencing the preferred mode of ventilation, and perhaps accounts for the significant difference in opinion demonstrated in the multivariate analysis of superior patient synchrony. The same study [27] highlight that pulmonologists and those who practice more frequently outside of the ICU have more familiarity with dedicated NIV machines and thus may be more inclined to favor these machines, when compared to intensivists who may be more familiar with the opposite.

One belief is that dual circuits provided by critical care ventilators minimize the risk of CO_2 rebreathing, making them preferable for cases of hypercapnic respiratory failure. Non-rebreather valves lower this risk in single-limbed circuits, at the cost however of adding expiratory resistance to the circuit. [31] Given the lack of consensus on the overall best ventilator type to use for NIV, it's likely that the decision is influenced by multiple factors, with cost and availability of modes and settings also influencing personal preferences. [4,5]

Our study has limitations. Although surveys can be a valuable tool for medical research, the results should be viewed with caution. The purpose of this study was to gain insight into device preferences and perceptions in the delivery NIV. Practice variation, participant bias, variable availability of different devices, level of training, and technical education should all be considered.

Conclusion

Although multiple devices can provide NIV, clinicians have adapted to evolution in technology. Despite the lack of evidence, there is wide variability in opinion with no clear consensus regarding the clinicians' attitude towards which ventilators are superior to use during NIV, especially according to surveyed occupation. Well conducted comparative studies are needed to answer the question of which ventilators are superior in NIV.

References

1. Girault C, Briel A, Hellot MF, et al. Noninvasive mechanical ventilation in clinical practice: a 2-year experience in a medical intensive care unit. Crit Care Med 2003; 31(2):552-559.

2. Rose L, Gerdtz MF. Review of non-invasive ventilation in the emergency department: clinical considerations and management priorities. J Clin Nurs 2009; 18(23):3216-3224.

3. Chawla R, Dixit SB, Zirpe KG, et al. ISCCM Guidelines for the use of non-invasive ventilation in acute respiratory failure in adult ICUs. Indian J Crit Care Me 2020; 24(Suppl 1):S61-S81.

4. Scott JB. Ventilators for noninvasive ventilation in adult acute care. Respir Care 2019; 64(6):712-722.

5. Olivieri C, Costa R, Conti G, et al. Bench studies evaluating devices for non-invasive ventilation: critical analysis and future perspectives. Intensive Care Med 2012; 38(1):160-167.

6. Scala R, Naldi M. Ventilators for noninvasive ventilation to treat acute respiratory failure. Respir Care 2008; 53(8):1054-1080.

7. Vignaux L, Tassaux D, Jolliet P. Performance of noninvasive ventilation modes on ICU ventilators during pressure support: a bench model study. Intensive Care Med 2007; 33(8):1444-1451.

8. Chatburn RL. Which ventilators and modes can be used to deliver noninvasive ventilation? Respir Care 2009; 54(1):85-101.

9. Owens RL, Wilson KC, Gurubhagavatula I, et al. Philips Respironics recall of positive airway pressure and noninvasive ventilation devices: a brief statement to inform response efforts and identify key steps forward. Am J Respir Crit Care Med 2021; 204(8):887-890.

10. Chen CW, Lin WC, Hsu CH, et al. Detecting ineffective triggering in the expiratory phase in mechanically ventilated patients based on airway flow and pressure deflection: feasibility of using a computer algorithm. Crit Care Med 2008; 36(2):455-461.

11. Vignaux L, Vargas F, Roeseler J, et al. Patient–ventilator asynchrony during non-invasive ventilation for acute respiratory failure: a multicenter study. Intensive Care Med 2009; 35:840–846.

12. Cuvelier A, Achour L, Rabarimanantsoa H, et al. A noninvasive method to identify ineffective triggering in patients with noninvasive pressure support ventilation. Respiration 2010; 80(3):198-206.

13. Vignaux L, Tassaux D, Carteaux G. et al. Performance of noninvasive ventilation algorithms on ICU ventilators during pressure support: a clinical study. Intensive Care Med 2010; 36:2053–2059.

14. Carteaux G, Lyazidi A, Cordoba-Izquierdo A, et al. Patient-ventilator asynchrony during noninvasive ventilation: a bench and clinical study. Chest 2012; 142(2):367-376.

15. Doorduin J, Sinderby CA, Beck J. et al. Automated patient-ventilator interaction analysis during neurally adjusted non-invasive ventilation and pressure support ventilation in chronic obstructive pulmonary disease. Crit Care 2014; 18(5):550.

16. Longhini F, Colombo D, Pisani L, et al. Efficacy of ventilator waveform observation for detection of patient-ventilator asynchrony during NIV: a multicentre study. ERJ Open Res 2017; 3(4):00075-2017.

17. Mulqueeny Q, Ceriana P, Carlucci A. et al. Automatic detection of ineffective triggering and double triggering during mechanical ventilation. Intensive Care Med 2007; 33(11):2014–2018.

18. Letellier C, Lujan M, Arnal JM, et al. Patient-ventilator synchronization during non-invasive ventilation: A pilot study of an automated analysis system. Front Med Technol 2021; 3:690442.

19. Chouvarda IG, Babalis D, Papaioannou V et al. Multiparametric modeling of the ineffective efforts in assisted ventilation within an ICU. Med Biol Eng Comput 2016; 54(2-3):441–451.

20. Gholami B, Phan TS, Haddad WM, et al. Replicating human expertise of mechanical ventilation waveform analysis in detecting patient-ventilator cycling asynchrony using machine learning. Comput Biol Med 2018; 97:137-144.

21. Bakkes THGF, Montree RJH, Mischi M, et al. A machine learning method for automatic detection and classification of patient-ventilator asynchrony. Annu Int Conf IEEE Eng Med Biol Soc 2020; 2020:150-153.

22. Zhang L, Mao K, Duan K, et al. Detection of

patient-ventilator asynchrony from mechanical ventilation waveforms using a two-layer long short-

term memory neural network. Comput Biol Med 2020; 120:103721.

23. Pan Q, Zhang L, Jia M, et al. An interpretable 1D convolutional neural network for detecting patient-ventilator asynchrony in mechanical ventilation. Comput Methods Programs Biomed 2021; 204:106057.

24. Bakkes T, van Diepen A, De Bie A, et al. Automated detection and classification of patient-ventilator asynchrony by means of machine learning and simulated data. Comput Methods Programs Biomed 2023; 230:107333.

25. De Luca A, Sall FS, Khoury A. Leak Compensation Algorithms: The Key Remedy to Noninvasive Ventilation Failure? Respir Care 2017; 62(1):135-136.

26. Oto J, Chenelle CT, Marchese AD, et al. A comparison of leak compensation in acute care ventilators during noninvasive and invasive ventilation: a lung model study. Respir Care 2013; 58(12):2027-2037.

27. Zhu K, Rabec C, Gonzalez-Bermejo J, et al. Combined effects of leaks, respiratory system properties and upper airway patency on the performance of home ventilators: a bench study. BMC Pulm Med 2017; 17(1):145.

28. Miyoshi E, Fujino Y, Uchiyama A, et al. Effects of gas leak on triggering function, humidification, and inspiratory oxygen fraction during noninvasive positive airway pressure ventilation. Chest 2005: 128:3691–3698

29. Ferreira JC, Chipman DW, Hill NS, et al. Bilevel vs ICU ventilators providing noninvasive ventilation: effect of system leaks: a COPD lung model comparison. Chest 2009;136(2):448-456.

30. Crimi C, Noto A, Princi P, et al. A European survey of noninvasive ventilation practices. Eur Respir J 2010; 36(2):362-369.

31. Lofaso F, Brochard L, Touchard D, et al. Evaluation of carbon dioxide rebreathing during pressure support ventilation with airway management system (BiPAP) devices. Chest 1995; 108(3):772-778.