Leak Compensation Algorithms: The Key Remedy to Noninvasive Ventilation Failure?

Noninvasive ventilation (NIV) was first used in the early 1980s for the management of chronic respiratory failure and nocturnal hypoventilation. The rapid development of new ventilatory technologies able to synchronize with the patient's demand has made NIV accessible for a large number of indications, such as chronic obstructive diseases, neuromuscular disorders and restrictive pulmonary diseases.[1-3] In this population, the use of NIV has proved to reduce the length of hospital stay, morbidity, and mortality compared with invasive ventilation.[4-6] Noninvasive ventilation is also associated with a significant reduction in the incidence of nosocomial infections, which is 3–5 times lower than that with invasive ventilation.[6-8] Ventilator-associated pneumonia is now described as tube-associated pneumonia, especially in immunosuppressed patients and those with comorbidities.[9] Because NIV can be provided without the need for deep sedation, it is becoming a major therapeutic tool even outside the ICU. However, it should be applied by a trained and experienced team, because it is not totally exempt from serious adverse effects and complications.

One of the main factors leading to NIV failure is leak. This decreases arterial oxygenation by reducing tidal volumes and patient synchrony, and also causes mouth and throat dryness, conjunctivitis, and sleep disturbances.[10] In an attempt to reduce air leak by tightening the straps of the mask, most caregivers are increasing patient discomfort by inducing nasal skin lesions, which potentially occurs in 50% of patients.[11,12] Minimizing leak is a major clinical concern that can only be achieved by adjusting the patient interface and pressurization levels. Specific algorithms for leak compensation have thus been incorporated into last-generation ventilators to reduce these adverse effects.

Two types of technologies for leak compensation are available: pressure control compensation and volume control compensation. It is important to understand that we are not talking about ventilatory modes stricto sensu, but about algorithms used in the ventilator to compensate air leak. While using volume control compensation, leak volume is estimated from the difference between inspiratory and expiratory volumes. Given the fact that leak is also occurring during exhalation, the ventilator cannot accurately assess the proportion of leak occurring during the inspiratory phase. Thus, tidal volume is often underestimated, leading to inaccurate compensations of the pressure support.[13] The operating mode of pressure control compensation is more basic, because it simply measures the inspiratory pressure and increases the inspiratory flow in the case of significant leak to reach the pressure set by the operator.[1] Storre et al[10] showed that pressure control compensation has higher compensation capabilities than volume control compensation. Nevertheless, the marked increase in inspiratory flow during compensation might have non-negligible side effects, such as impairing face mask seal and inducing more leak and patient discomfort, or causing gastric insufflation. During NIV, aerophagia can occur in 30–40% of patients, depending on respiratory system characteristics, lower esophageal sphincter pressure, head position, and inspiratory flow.[14,15] Gastric distention compresses the lungs and induces high intrathoracic pressures that therefore require high inspiratory pressure to ventilate the lung. This generates more air leak, and the ventilator compensates by increasing inspiratory flow and thereby creating a vicious circle.[15,16]

See the Original Study on Pages 10 and 22

Another adverse effect of air leak is patient asynchrony. A relevant indicator of a ventilator's efficiency is the inspiratory delay, which is the time needed for the ventilator to reach positive pressure in the patient's airway from the start of inspiratory effort.[17] A long inspiratory delay significantly increases the patient's work of breathing, because it reduces the amount of assistance delivered to the patient in the early stages of the breathing effort.[18-20] Therefore, the ventilator must have efficient triggering and pressurization capacity to promptly meet the patient's demand and reduce the work of breathing and discomfort. The sensitivity of the inspiratory trigger is a key element that depends both on the sensing technology and the sealing level of the inspiratory circuit. Significant leak can induce a pressure drop or generate flows that are perceived as patient inspiratory efforts by the ventilator. This inevitably

The authors have disclosed no conflicts of interest.

Correspondence: Alban De Luca MSc MEng. E-mail: alban.deluca@gmail.com.

DOI: 10.4187/respcare.05289

results in auto-triggering that is a highly undesirable phenomenon that can only be resolved by reducing triggering sensitivity, which in turn creates late cycling or failed triggering, occurring in 12–23% of patients.[21]

In the past 2 decades, NIV has become a new standard of care for adults and children. Improving patient tolerance to NIV by optimizing mask sealing and ventilator synchrony is a new challenge that requires close monitoring of the patient's vital signs and a strong knowledge of the triggering technologies. In a qualitative review of randomized trials published recently, Carron et al[16] concluded that NIV efficiency was mainly determined by the choice of an adequate device, even when performed by experienced teams.

In this issue, Itagaki et al[23] evaluate the leak compensation algorithms of various ICU ventilators and their effects on patient-ventilator synchrony. The authors make extensive investigations and find interesting results that are essential to help clinicians decide which ventilators best meet their expectations and allow them to minimize the risk of NIV failure. This paper also represents a major effort to evaluate and discuss the technical origins of asynchrony, including missed triggering, auto-triggering double-triggering, and cycling problems. Finally, Itagaki et al[23] explain in an easy understandable way the clinical consequences of asynchrony and find some interesting correlations with patient physiological characteristics.

Alban De Luca MSc MEng

Fatimata S Sall PhD

Abdo Khoury MD MSc

Department of Emergency Medicine and Critical Care
Clinical Investigation Center
University Hospital of Besançon
Besançon, France

REFERENCES

1. Mehta S, Hill NS. Noninvasive ventilation. Am J Respir Crit Care Med 2001;163(2):540-577.
2. Hess DR. The evidence for noninvasive positive-pressure ventilation in the care of patients in acute respiratory failure: a systematic review of the literature. Respir Care 2004;49:810-829.
3. Hess DR. Noninvasive ventilation in neuromuscular disease: equipment and application. Respir Care 2006;51(8):896-911; discussion 911-912.
4. Conti G, Antonelli M, Navalesi P, Rocco M, Bufi M, Spadetta G, Meduri GU. Noninvasive vs conventional mechanical ventilation in patients with chronic obstructive pulmonary disease after failure of medical treatment in the ward: a randomized trial. Intensive Care Med 2002;28(12):1701-1707.
5. Lightowler JV, Wedzicha JA, Elliott MW, Ram FS. Non-invasive positive pressure ventilation to treat respiratory failure resulting from exacerbations of chronic obstructive pulmonary disease: Cochrane systematic review and meta-analysis. BMJ 2003;326(7382):185.
6. Brochard L, Mancebo J, Wysocki M, Lofaso F, Conti G, Rauss A, et al. Noninvasive ventilation for acute exacerbations of chronic obstructive pulmonary disease. N Engl J Med 1995;333(13):817-822.
7. Nourdine K, Combes P, Carton MJ, Beuret P, Cannamela A, Ducreux JC. Does noninvasive ventilation reduce the ICU nosocomial infection risk? A prospective clinical survey. Intensive Care Med 1999;25(6):567-573.
8. Hess DR. Noninvasive positive-pressure ventilation and ventilator-associated pneumonia. Respir Care 2005;50(7):924-929; discussion 929-931.
9. Kohlenberg A, Schwab F, Behnke M, Geffers C, Gastmeier P. Pneumonia associated with invasive and noninvasive ventilation: an analysis of the German nosocomial infection surveillance system database. Intensive Care Med 2010;36(6):971-978.
10. Storre JH, Bohm P, Dreher M, Windisch W. Clinical impact of leak compensation during non-invasive ventilation. Respir Med 2009;103(10):1477-1483.
11. Nava S, Ambrosino N, Clini E, Prato M, Orlando G, Vitacca M, et al. Noninvasive mechanical ventilation in the weaning of patients with respiratory failure due to chronic obstructive pulmonary disease. A randomized, controlled trial. Ann Intern Med 1998;128(9):721-728.
12. Celikel T, Sungur M, Ceyhan B, Karakurt S. Comparison of noninvasive positive pressure ventilation with standard medical therapy in hypercapnic acute respiratory failure. Chest 1998;114(6):1636-1642.
13. L'Her E, Roy A, Marjanovic N. Bench-test comparison of 26 emergency and transport ventilators. Crit Care 2014;18(5):506.
14. Gay PC. Complications of noninvasive ventilation in acute care. Respir Care 2009;54(2):246-257; discussion 257-258.
15. De Keulenaer BL, De Backer A, Schepens DR, Daelemans R, Wilmer A, Malbrain ML. Abdominal compartment syndrome related to noninvasive ventilation. Intensive Care Med 2003;29(7):1177-1181.
16. Carron M, Freo U, BaHammam AS, Dellweg D, Guarracino F, Cosentini R, et al. Complications of non-invasive ventilation techniques: a comprehensive qualitative review of randomized trials. Br J Anaesth 2013;110(6):896-914.
17. Thille AW, Lyazidi A, Richard JC, Galia F, Brochard L. A bench study of intensive-care-unit ventilators: new versus old and turbine-based versus compressed gas-based ventilators. Intensive Care Med 2009;35(8):1368-1376.
18. Aslanian P, El Atrous S, Isabey D, Valente E, Corsi D, Harf A, et al. Effects of flow triggering on breathing effort during partial ventilatory support. Am J Respir Crit Care Med 1998;157(1):135-143.
19. Chiumello D, Pelosi P, Croci M, Biqatello LM, Gattinoni L. The effects of pressurization rate on breathing pattern, work of breathing, gas exchange and patient comfort in pressure support ventilation. Eur Respir J 2001;18(1):107-114.
20. Bonmarchand G, Chevron V, Chopin C, Jusserand D, Girault C, Moritz F, et al. Increased initial flow rate reduces inspiratory work of breathing during pressure support ventilation in patients with exacerbation of chronic obstructive pulmonary disease. Intensive Care Med 1996;22(11):1147-1154.
21. Vignaux L, Vargas F, Roeseler J, Tassaux D, Thille AW, Kossowsky MP, et al. Patient-ventilator asynchrony during non-invasive ventilation for acute respiratory failure: a multicenter study. Intensive Care Med 2009;35(5):840-846.
22. Itagaki T, Chenelle CT, Bennett DJ, Fisher DF, Kacmarek RM. Effects of leak compensation on patient-ventilator synchrony during premature/neonatal invasive and noninvasive ventilation: a lung model study. Respir Care 2017;62(1):22-33.
23. Itagaki T, Bennett DJ, Chenelle CT, Fisher DF, Kacmarek RM. Performance of leak compensation in all-age ICU ventilators during volume-targeted neonatal ventilation: a lung model study. Respir Care 2017;62(1):10-21.