Neonatal Pressure Support Ventilation: Are We Doing What We Think We Are Doing?

Assisted modes of mechanical ventilation, including synchronous intermittent mandatory ventilation, pressure support ventilation (PSV), continuous mandatory ventilation, neurally adjusted ventilatory assist, and volume guarantee ventilation, are widely used in neonates, infants, and small children to achieve improved short-term and long-term outcomes.[1-3] Specifically, evidence is accumulating that the various assisted modes of ventilation are associated with increased patient comfort, decreased work of breathing, decreased diaphragmatic dysfunction, less risk of air leak, shorter duration of weaning, and significant reduction in bronchopulmonary dysplasia.[3-6] Despite these improvements in ventilatory modes and their associated technology, pulmonary complications of prematurity, including bronchopulmonary dysplasia, pneumothorax, pulmonary interstitial emphysema, and need for long-term mechanical ventilation, remain agonizingly common, suggesting that we have significant room for improvement in our ability to provide optimal ventilatory support for our patients.[7,8]

SEE THE ORIGINAL STUDY ON PAGE 1463

The premise underlying all assisted forms of ventilation is that the ventilator is technologically capable of a number of actions that will reliably occur in rapid succession when a neonate attempts to take a breath. First, the ventilator must accurately observe and determine that the neonate is indeed engaging in respiration, typically by detecting a change in air flow. Then, the ventilator must rapidly achieve pressurization sufficient to deliver the desired volume of air to the infant within a reasonable interval after a breathing attempt is noted. Next, the ventilator must be able to determine that the neonate has terminated the breathing effort (and presumably now desires to exhale) and must cease providing pressure above PEEP within a reasonable interval after inspiratory efforts have ended. In addition, the ventilator must be capable of engaging this sequence of events only when the neonate attempts a breath while ignoring all of the various artifactual changes in respiratory properties that may occur in ventilator circuits in the absence of an intended breath. Finally, the ventilator must be capable of making these determinations and engaging these actions in patients who likely have an air leak present, potentially further complicating measurement and control of air flow. Whether individual ventilators can reliably achieve this sequence of events may impact the short-term and long-term outcomes of neonates, infants, and small children; however, until now, these data have been notably incomplete.

In this issue of RESPIRATORY CARE, Vignaux et al[9] attempt to improve our understanding of pressure support breathing in a variety of adult and neonatal ventilators using an ingenious bench model designed to simulate the specific characteristics of neonates and infants that make ventilation particularly challenging. Specifically, they tested 6 adult and 4 neonatal ventilators in 3 patient scenarios: a preterm infant with relatively high resistance, low compliance, and low inspiratory effort; a full-term infant with moderate resistance, moderate compliance, and higher inspiratory effort; and a child with lower resistance, higher compliance, and substantially higher inspiratory effort. These scenarios were chosen to mimic commonly encountered patients within neonatal and pediatric ICUs. In addition, to better mimic real-life clinical care, each of these scenarios was tested both with and without an added air leak. Finally, the authors tested the ventilators in noninvasive modes to determine whether the potentially detrimental effects of air leaks on ventilator performance could be countered using existing algorithms.

The authors then measured end points to test each of the critical aspects of PSV, including trigger delay time, pressure-time product at 300 ms, and inspiratory time in excess of respiratory effort. These measurements addressed whether the ventilator could adequately identify and respond to respiratory effort, deliver the desired amount of air, and stop inhalation when the patient did, respectively. Finally, the authors measured the accuracy of displayed tidal volumes (V_T) to determine whether each ventilator

---

The authors have disclosed no conflicts of interest.

Correspondence: Edward G Shepherd MD, Division of Neonatology, Department of Pediatrics, Nationwide Children's Hospital, The Ohio State University College of Medicine, 700 Children's Drive, Columbus, OH 43205. E-mail: edward.shepherd@nationwidechildrens.org.

DOI: 10.4187/respcare.03616

was capable of accurately reflecting the volume of air delivered to model patients.

So how did the tested ventilators perform? The short answer is not very well. The longer answer is that all the tested ventilators performed well in some tests and poorly in others, and no ventilator performed well in all areas. For example, only 4 ventilators (3 neonatal and one adult) had acceptable trigger delays for neonates, and only 3 ventilators had acceptable delays for children. Furthermore, some ventilators had substantially different trigger delay values between patient types. Similarly, pressurization capacities ranged across ventilators and patient types from 15 to 70% of ideal; indeed, only 2 ventilators, both adult-type, achieved adequate pressurization across all patient types. Finally, nearly all the ventilators tested had high inspiratory time in excess values in some or all of the patient scenarios, and 4 had values $> 100\%$ of the patient's inspiratory time in at least one scenario; these model patients were essentially receiving ventilator breaths for at least twice as long as they were inhaling.

In general, introducing leaks to the system further complicated the picture. Only 2 ventilators, for instance, successfully avoided autotriggering after leaks were introduced. Fortunately, either increasing the inspiratory trigger or activating the noninvasive mode corrected this in all ventilators except one. Leak-associated trigger delays increased in 5 ventilators, only 2 of which corrected with activation of the noninvasive ventilation (NIV) mode. Pressurization capacity was minimally affected in the 4 neonatal ventilators when leaks were introduced, but 2 adult ventilators had substantial pressurization loss, with adequate NIV compensation in only one.

Finally, in the absence of leaks, 6 ventilators accurately displayed measured V_T (within ~10%). Interestingly, there was no difference detected between proximal versus distal flow sensors. When leaks were introduced, the displayed V_T was typically too low, although activation of the NIV mode corrected the differences in some, but not all, ventilators.

So, when we provide PSV to neonates, infants, and small children, are we providing the support we think we are? The data presented by Vignaux et al[9] suggest that in some cases we are and in some cases we are not. The variability in ventilator performance reported here is consistent with previous reports on other ventilator characteristics, lending weight to their findings.[10-12] These data also begin to suggest an explanation for the fact that assisted ventilation is not always successful in reducing work of breathing and ventilator-patient asynchrony. Naturally, these data need to be understood in the context of a bench model designed to test ventilator-patient interactions that are much more complex in real life, and thus, further in vivo testing is warranted. Nevertheless, the authors present meaningful data that help inform us of the implications of our practice.

Michael A Hokenson MD
Edward G Shepherd MD
Division of Neonatology
Department of Pediatrics
Nationwide Children's Hospital
The Ohio State University College of Medicine
Columbus, Ohio

REFERENCES

1. Ålander M, Peltoniemi O, Saarela T, Anttila E, Pokka T, Kontiokari T. Current trends in paediatric and neonatal ventilatory care—a nationwide survey. Acta Paediatr 2013;102(2):123-128.
2. Dani C, Bresci C, Lista G, Martano C, Messina F, Migliori C, Vento G. Neonatal respiratory support strategies in the intensive care unit: an Italian survey. Eur J Pediatr 2013;172(3):331-336.
3. Wheeler K, Klingenberg C, McCallion N, Morley CJ, Davis PG. Volume-targeted versus pressure-limited ventilation in the neonate. Cochrane Database Syst Rev 2010(11):CD003666.
4. Betensley AD, Khalid I, Crawford J, Pensler RA, DiGiovine B. Patient comfort during pressure support and volume controlled-continuous mandatory ventilation. Respir Care 2008;53(7):897-902.
5. Futier E, Constantin JM, Combaret L, Mosoni L, Roszyk L, Sapin V, et al. Pressure support ventilation attenuates ventilator-induced protein modifications in the diaphragm. Crit Care 2008;12(5):R116.
6. Greenough A, Dimitriou G, Prendergast M, Milner AD. Synchronized mechanical ventilation for respiratory support in newborn infants. Cochrane Database Syst Rev 2008(1):CD000456.
7. Ali Z, Schmidt P, Dodd J, Jeppesen DL. Bronchopulmonary dysplasia: a review. Arch Gynecol Obstet 2013;288(2):325-333.
8. Peng W, Zhu H, Shi H, Liu E. Volume-targeted ventilation is more suitable than pressure-limited ventilation for preterm infants: a systematic review and meta-analysis. Arch Dis Child Fetal Neonatal Ed 2014;99(2):F158-165.
9. Vignaux L, Piquilloud L, Tourneux P, Jolliet P, Rimensberger PC. Neonatal and adult ICU ventilators to provide ventilation in neonates, infants, and children: a bench model study. Respir Care 2014: 59(10):1463-1475.
10. Abbasi S, Sivieri E, Roberts R, Kirpalani H. Accuracy of tidal volume, compliance, and resistance measurements on neonatal ventilator displays: an in vitro assessment. Pediatr Crit Care Med 2012; 13(4):e262-268.
11. Park MA, Freebairn RC, Gomersall CD. Bench performance of ventilators during simulated paediatric ventilation. Anaesth Intensive Care 2013;41(3):349-358.
12. Sharma A, Milner AD, Greenough A. Performance of neonatal ventilators in volume targeted ventilation mode. Acta Paediatr 2007; 96(2):176-180.