

# Gas Trapping and Hyperinflation

Rob Graham, R.R.T./N.R.C.P.

*I dedicate this column to the late Dr. Andrew (Andy) Shennan, the founder of the perinatal program at Women's College Hospital (now at Sunnybrook Health Sciences Centre). To my teacher, my mentor and the man I owe my career as it is to, thank you. You have earned your place where there are no hospitals and no NICUs, where all the babies do is laugh and giggle and sleep.*

***“Gas trapping invariably leads to hyperinflation, which may lead to interstitial lung disease, pneumothorax, and cardiopulmonary compromise.”***

When the treatment is worse than the disease, prevention is key

“All micro-preemies are gas trapping or are about to.” A colleague made this statement during a discussion on malignant hyperinflation, often seen in this patient group. Gas trapping invariably leads to hyperinflation, which may lead to interstitial lung disease, pneumothorax, and cardiopulmonary compromise.

Technological advances notwithstanding, this phenomenon has plagued clinicians ever since we started ventilating premature babies almost 60 years ago. For over 25 years, “conventional” ventilation (CV) was the sole option in the NICU. The inherently high resistance of small conducting airways ( $R_{a/w}$ ) combined with decreased compliance of developing lungs necessitates using high ventilating pressures and rates to provide sufficient minute volume to clear  $CO_2$ . Since airway diameter decreases during the expiration, their resistance increases further such that there may be insufficient time for delivered tidal volume to escape, et voila, gas trapping occurs.

This was not a big problem when we treated “larger” 30+ week post-gestational age (PGA) infants, where poor compliance and oxidative stress rather than airway resistance were our primary concerns. While surfactant markedly decreased  $FiO_2$  needs (and presumably oxidative stress), the problems inherent with high  $R_{a/w}$  increased as the PGA and size of our patients decreased. Older ventilators did not indicate impending problems nor modes to mitigate them; rather, the first indication of gas trapping was

usually seen on a chest film (CXR).

The advent of synchronisation, assist/control (A/C) and pressure support (P/S) modes, flow graphics, and volume-targeted ventilation gave us some tools to recognise gas trapping. The Drager Babylog® 8000+ displayed a calculated value, an indicator of overdistention called “C20/C”. This compared volume delivered during the last 20% of the inspiratory cycle to that of the first 80% (1), essentially a numeric representation of “beaking” (see figure 1) on a pressure/volume curve. Since less inspiratory time ( $T_i$ ) is required to deliver less volume at a given respiratory rate, this will increase available expiratory time ( $T_e$ ) and may decrease gas trapping if present.

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The use of high-frequency ventilation (HFV) in the NICU has increased and is gaining acceptance as a first intention mode rather than a “rescue” strategy and is no longer considered experimental. Under the HFV label, it is important to distinguish between high-frequency oscillation (HFO) and high-frequency jet ventilation (HFJV); the two are very different.

In HFO, very high rates are used to deliver very small, sub-anatomical dead space tidal volumes ( $V_{tHF}$ ). Airway patency and maintenance of functional residual capacity (and by function oxygenation) are achieved with mean airway pressure (MAP), while ventilation is primarily a function of oscillating amplitude, which directly influences  $V_{tHF}$ . In the absence of volume targeting (VG), oscillatory rate ( $f$ ) has an inverse relationship to  $V_{tHF}$ ; thus, at a fixed amplitude, decreasing  $f$  increases  $V_{tHF}$ , and increasing  $f$  decreases  $V_{tHF}$ . This is because as  $f$  decreases, the driving device (diaphragm or piston) is in the inspiratory phase longer, giving more volume and vice versa.

If VG is used in conjunction with HFO, then  $f$  has a direct and linear relationship to ventilation, **providing increased  $f$  is not contributing to gas trapping**. Using VG also may allow for maintenance of minute volume using higher  $V_{tHF}$  and lower  $f$  while using less amplitude. Gas trapping can occur with HFO under

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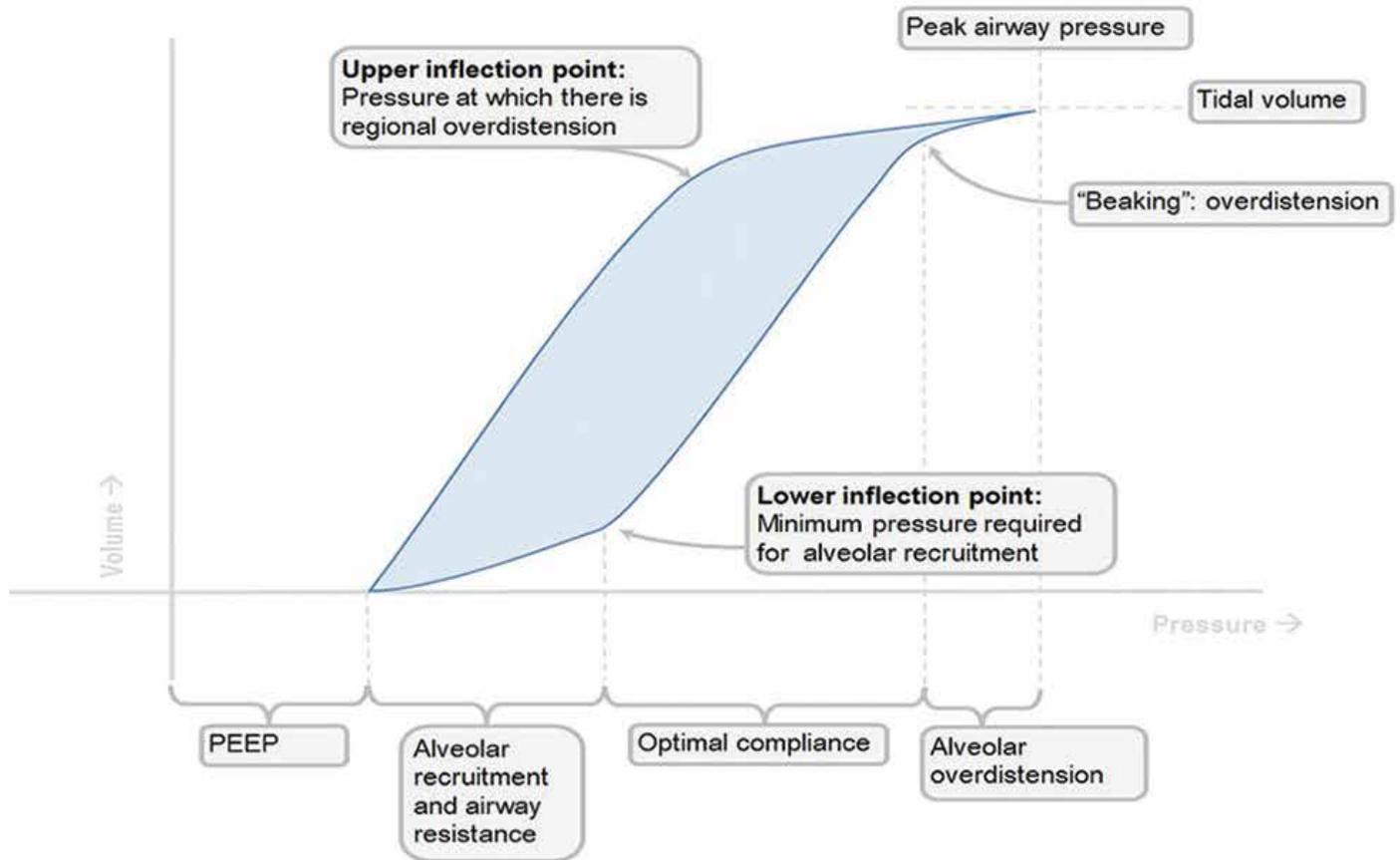


Figure 1: pressure-volume curve showing beaking (2)

two circumstances: one, as mentioned, is high  $f$  not providing sufficient time for exhalation, and the other is if MAP is not high enough to maintain airway patency. The latter is exacerbated by high amplitude since in a 1:2 I:E ratio, approximately 1/3 of it is below set MAP. As the lowest point of the amplitude, waveform gets lower, the risk of airways losing patency increases, possibly to the point of collapse. This phenomenon is known as a pinch point and prevents gas distal to the obstruction from escaping.

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Some HFO capable ventilators allow I:E ratio to be adjusted as high as 1:3. This may decrease the potential for gas trapping, but the increase in amplitude necessitated by a shorter inspiratory phase may offset any gains made. Using lower frequencies (if tolerated and  $V_{tHF}$  does not need to be increased too much) is a better bet, but active expiration necessitated by the mode makes gas trapping likely.

Several characteristics of HFJV make it the mode least likely to create or exacerbate gas trapping. While the principles of ventilation and oxygenation are similar ( $V_{tHF}$  being the primary determinant of ventilation and PEEP the primary determinant of oxygenation), HFJV's passive expiration eliminates the possibility of airway instability and pinch points as ventilating pressure increases; increased PIP in HFJV is always felt above-set PEEP since there is no oscillating waveform. It is vital to provide enough PEEP to maintain airway patency and FRC. The fact that  $T_i$  is very short (0.02 – 0.034 seconds) and is set rather than a fixed percentage of the total ventilating cycle means I:E ratios (and absolute  $T_e$ ) are greater with HFJV, as high as 1:12.

During inspiration, the HFJV breath is delivered as a high-velocity spike of gas that travels more or less down the centre of the airways. In doing so, incoming gas displaces the gas in its path, forcing it to the sides of the airway, where it exists in a spiral fashion. While the bulk of gas exits during the expiratory phase, some does so concomitantly with inspiration.

This is not to say that gas trapping does not occur during HFJV; rather, that is less likely. One of the features of the Bunnell Life-Pulse® is the ability of the machine to very accurately measure distal endotracheal tube pressure; peak inspiratory pressure, PEEP, and MAP are displayed. We have traditionally been taught that if the measured PEEP displayed on the machine was higher than the set PEEP, it was a clear indication of gas trapping. This is true; however, since the value displayed indicates what is happen-

ing in the lungs as a whole, regional gas trapping may be present without the jet giving us any obvious indication thereof. Since a brief pressure deflection occurs initially with the jet breath, it is safer to suspect gas trapping as measured PEEP approaches set PEEP and indeed with all micro-prems. Ensuring I:E ratios of 1:4 or greater have been a guide to avoiding gas trapping, but as our patients have become ever smaller, that is likely no longer the case; as high an I:E ratio as possible with these babies, preferably 1:12 provided by a rate of 240 is recommended.

Being warned and aware of gas trapping doesn't mean we can do anything about it; clear signs are often present in tiny babies, even at a jet rate of 240. If PEEP is not high enough to keep airways open, gas trapping initially shows up as increasing lung volumes. That this almost invariably leads clinicians to decrease PEEP is not helpful. The trouble is apparent hyperinflation from low PEEP is indistinguishable from too much PEEP and treating one when the problem is the other worsens the situation. If PEEP is already low, the culprit is likely gas trapping, and increased PEEP is more likely to help.

Once the lungs are recruited, and adequate FRC is established, it is important to decrease PEEP/MAP to the lowest point to provide stasis. Any de-recruitment should be corrected expeditiously as gas trapping can rapidly result in gross hyperinflation, air leak, and an escalation of support and  $\text{FiO}_2$ .

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Once hyperinflation is established, it can be very difficult to manage. Increasing PEEP/MAP to stent airways open and (hopefully) decrease gas trapping can be a tough sell when a CXR shows 10+ ribs of inflation, especially since doing so may not immediately improve. Conversely, the “old school” practice of drastically reducing PEEP/MAP to facilitate collapse can be disastrous, mainly if gas trapping is the culprit. As the lungs collapse and become atelectatic several things happen. Gas exchange is reduced in areas of relatively good function resulting in higher  $\text{FiO}_2$ , which increases oxidative stress. Pulmonary vascular resistance is markedly elevated in areas of atelectasis, further taxing the heart, and an inflammatory response is elicited locally. The pulmonary structure is also damaged since alveoli are interdependent for structural integrity (3). Given the precarious clinical state these babies are

often in, this may represent trading the proverbial frying pan for the fire.

Given the consequences of treating hyperinflation, it behooves us to determine the necessity of doing so. If the baby is stable ( $\text{FiO}_2$  and blood pressure acceptable), hyperinflation may be physiologically insignificant, and some babies are more stable left alone. Indeed, if a baby significantly deteriorates while one is trying to “fix” them, the treatment may be worse than the disease.

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**Disclosures:** The author receives compensation from Bunnell Inc for teaching and training users of the LifePulse HFJV in Canada. He is not involved in sales or marketing of the device nor does he receive more than per diem compensation. Also, while the author practices within Sunnybrook H.S.C. This paper should not be construed as Sunnybrook policy per se. This article contains elements considered “off label” as well as maneuvers, which may sometimes be very effective but come with inherent risks. As with any therapy, the risk-benefit ratio must be carefully considered before they are initiated.

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*Corresponding Author*



*Rob Graham, R.R.T./N.R.C.P.  
Advanced Practice Neonatal RRT  
Sunnybrook Health Science Centre  
43 Wellesley St. East  
Toronto, ON  
Canada M4Y 1H1  
Email: [rcgnrcp57@yahoo.ca](mailto:rcgnrcp57@yahoo.ca)  
Telephone: 416-967-8500*