Hyperinflation: What is it and what does it mean? The role of high-frequency ventilation (HFV) in 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.

"Wean the MAP/PEEP; the baby is hyperinflated." It is the recurring waking nightmare of NICU respiratory therapists everywhere. Before having a "knee jerk" reaction to a chest film (CXR) with a (insert arbitrary number here) rib count, it is imperative that clinicians understand what is happening with the patient before reacting to the CXR.

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Why is a baby hyperinflated? Unfortunately, the standard CXR does not differentiate between lungs that are showing air trapping from ones in which the lung is actually over inflated. There are, however, signs to watch for when dealing with this situation. There are situations where moderate hyperinflation may help the patient and attempts to "fix" it do more harm than good.

There are many reasons for which we consider decreasing MAP/PEEP, the interpretation of a CXR being just one of them. In addition to the CXR, blood pressure issues and/or suspected impairment of venous return are the most common reasons for decreasing MAP. Hemodynamic compromise may or may not be improved by decreasing MAP, depending on what is happening within the lungs. While intrathoracic pressure is most commonly blamed for blood pressure problems, we tend to forget that pulmonary vascular resistance (PVR) is highest at both ends of the pulmonary compliance curve and lowest at optimal compliance. Poorly and/or non-recruited lungs press against pulmonary vasculature and result in increased PVR. In this case, decreasing MAP will not help and may well make matters worse. Cerebral blood return will also be impaired if PVR is high.

In clinical practice, the most useful indicators of optimal pulmonary compliance are oxygen saturation (SpO_2) and oxygen requirements (FiO_2) since optimal compliance is the point at which adequate oxygenation occurs with the lowest FiO_2 (and the lowest ventilating pressures).

A baby with FiO_2 of 0.21 and SpO_2 100% is quite simply not hyperinflated, regardless of what a CXR may show at this point, but if the current picture is the result of air trapping, they may become hyperinflated over time. Impaired blood flow through the lungs impacts oxygenation, as does impaired blood pressure. Neither of these factors is present in this situation. In clinical practice, the precursor to hyperinflation is often air trapping. In its insidious progression, air trapping increases expansion and, counterintuitively, FiO_2/SpO_2 may improve as inadvertent PEEP approaches optimal PEEP.

It is very unlikely that a baby with a MAP of 7-9 cmH_2O is actually hyperinflated, and a CXR showing this is actually a warning NOT to decrease MAP/PEEP. Doing so might make matters worse as it leads to more gas trapping and ultimately collapse and derecruitment.

A study in gas trapping

Figure 1 day 1

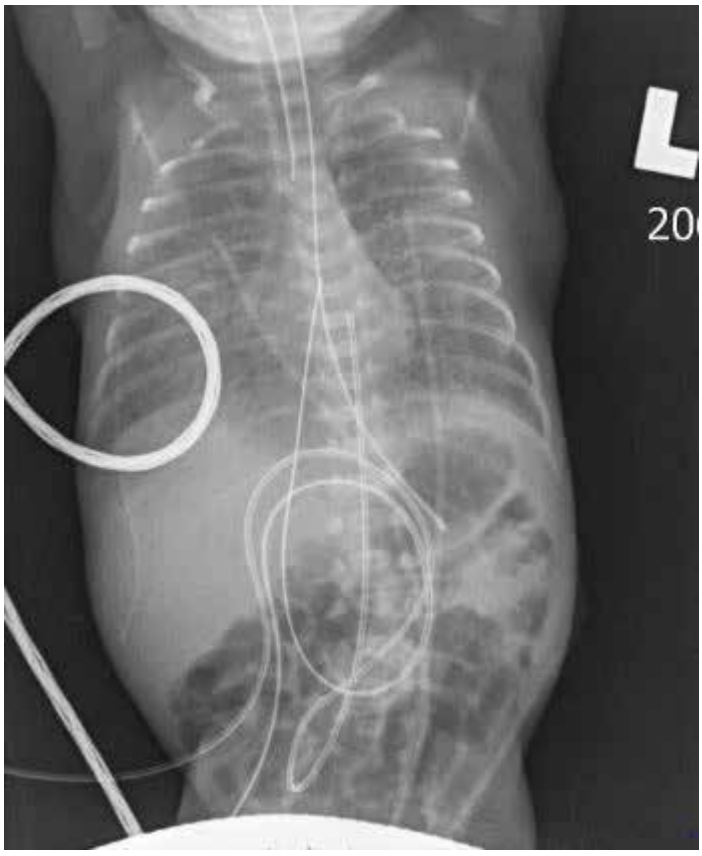

Figure 1

Figure 1 is a CXR of a 648-gram baby, day one of life, being oscillated (HFO) at 9 Hz, maximum amplitude of 20 cmH_2O (on volume guarantee using 18 cmH_2O) at a MAP of 10 cmH_2O. Several things jump out here that warn of impending trouble. The grossly "hyperinflated" picture actually shows gas trapping. We do not think of PEEP when using HFO, but the effective PEEP at these settings is 2 cmH_2O. (MAP minus ½ amplitude). Such a low PEEP is likely not adequate to maintain airway stability. (See figure 5, courtesy of Bunnell Inc)

Figure 2 Day 1

Figure 2 is the same infant, now on HFJV the same day. Ventilator settings are rate of 300, pressures of 28/10 (HFJV reading PEEP 9.8 cmH_2O) and HFJV inspiratory time (JTi) of 0.02 seconds, and FiO2 0.39. PEEP is then weaned to 9 with HFJV PEEP measuring 8.8 cmH_2O. The picture is arguably worse. In the face of air trapping, this patient would benefit from a decrease in HFJV rate and higher PEEP. Instead, the PEEP was further decreased to 8 cm$H_2$0. Numerous adjustments were made, and by day 4 (figure 3) FiO_2 had climbed to 0.67 after PEEP had been reduced from 10 to 8 cmH_2O, and recruitment maneuvers were started at 6 cmH_2O above PEEP with a 2-second inspiratory time (Ti) and rate of 10 in an attempt to decrease FiO_2 and optimize lung volume.

By day 5 the team decided to leave the PEEP, now increased back to 10 cmH_2O, as is and stay the course as the patient's condition and CXR had improved. Between adjustments in JTi and recruitment maneuvers, FiO_2 had decreased to 0.37.

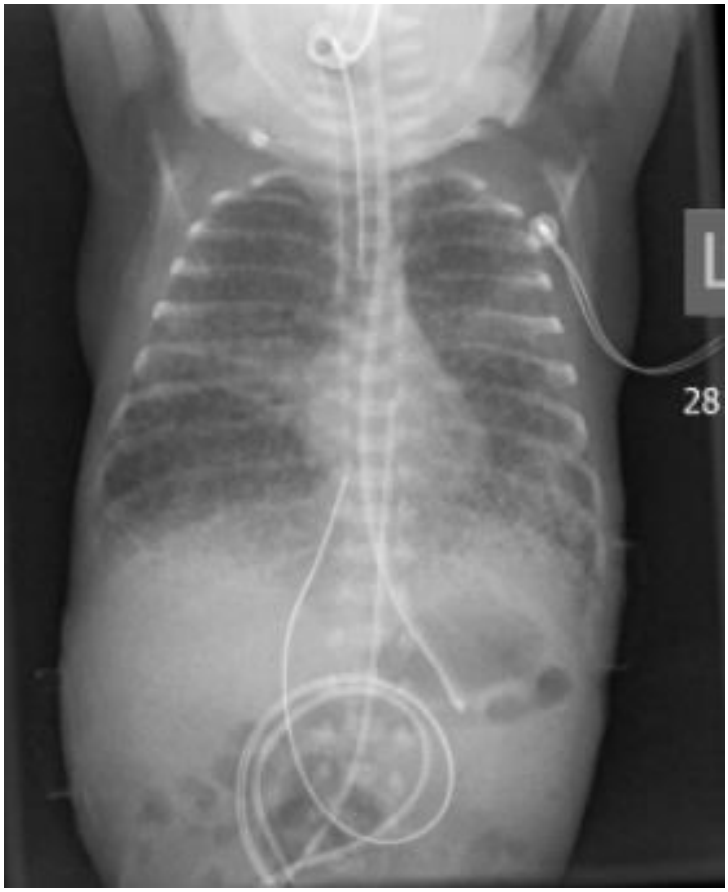

Figure 3 Day 4

Figure 4 Day 5

"This case of patient management is an example of a team failing to recognize gas trapping and being led astray by rib counting. When "hyperinflation" worsens with decreased PEEP/MAP clinicians are well advised to head in the opposite direction. "

This case of patient management is an example of a team failing to recognize gas trapping and being led astray by rib counting. When "hyperinflation" worsens with decreased PEEP/MAP clinicians are well advised to head in the opposite direction. HFJV is the best way to mitigate air trapping by virtue of a possible I:E ratio of 1:12 and the nature of the HFJV breath in relation to conducting airways. In this case, it did not eliminate it, but it did not help that the team failed to utilize maximum I:E ratio by decreasing the HFJV rate to its minimum of 240, although this was done eventually. It is also interesting to note in this case that increasing JTi (as high as the maximum of 0.034 seconds) did not result in a change in HFJV measured PEEP, the standard indicator of systemic gas trapping. I surmise that since the larger jet breath must displace more gas in its path, increased concurrent expiration mitigated the decreased time for passive exhalation. The greater momentum combined with increased time also allows the breath to travel further down the distal airways.

Adjustments to jet inspiratory time are great physics, but the fine-tuning in clinical practice is, I think, evolving and sometimes patient specific. As an admittedly jet-biased clinician, one of the things I like about the machine is the ability to micro-tune breaths and MAP for airway resistance, respiration, and ventilation.

Managing hyperinflation/gas trapping with HFO

Raising MAP in HFO can help prevent air trapping, as can low-

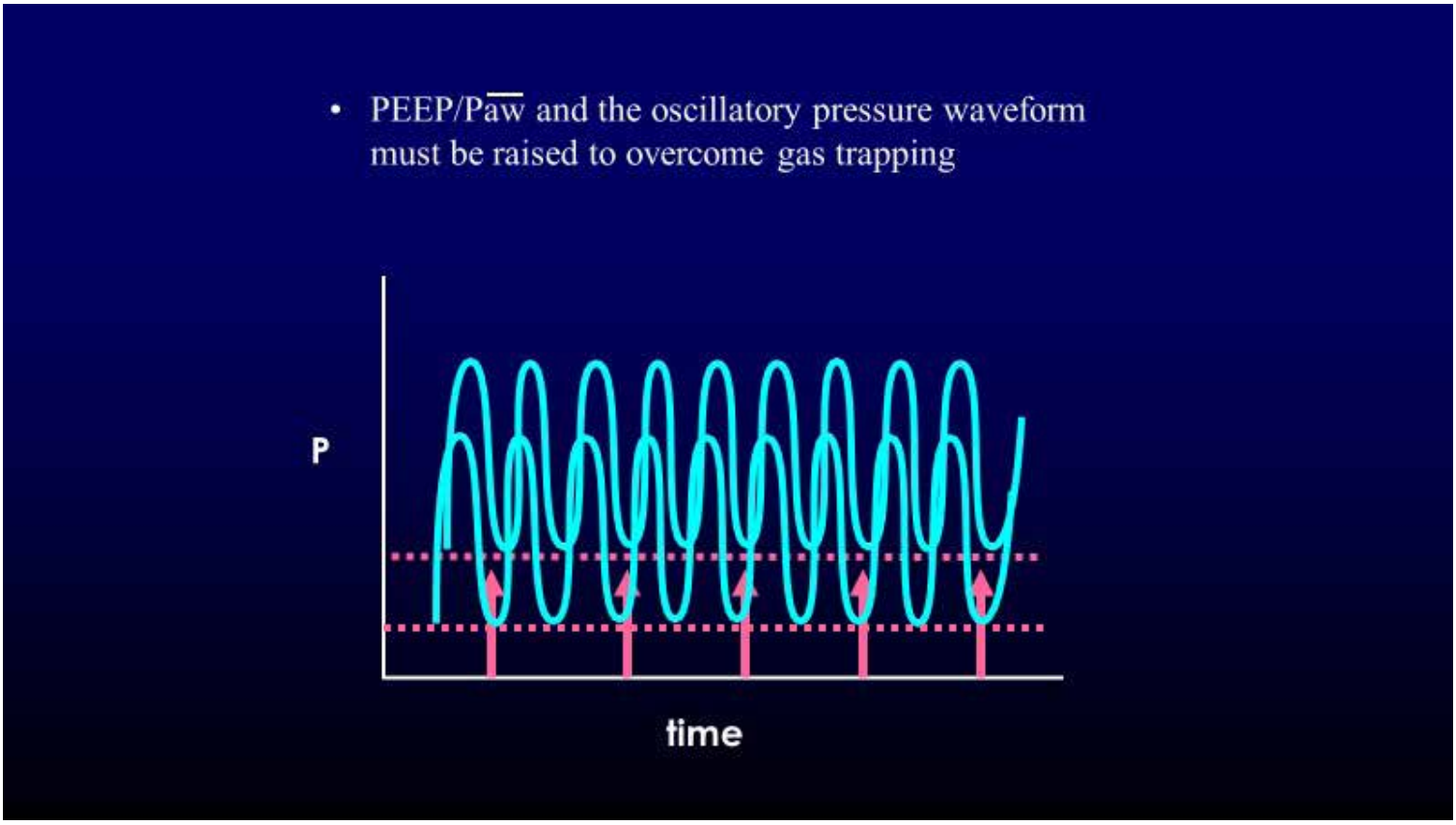

Figure 5 courtesy Bunnell Inc

ering frequency. Lowering frequency may allow for maintenance of minute volume while using lower amplitude. This will be much easier to do if the next generation ventilators with volume targeting and measurement are available. Using the lowest frequency possible with the lowest amplitude possible to maintain ventilation may be useful in the absence of HFJV or in milder cases. Be very cautious as amplitude approaches double the MAP, which can set the stage for airway instability and gas trapping especially in smaller babies with inherent high airway resistance.

Hyperinflation and chronic lung disease

We have all witnessed babies who, while appearing hyperinflated on CXR, get much worse when MAP/PEEP is decreased. These babies are telling us that they are not effectively hyperinflated, rather they are at a place on the compliance curve optimal to their own physiology. The familiar histology slide in figure 6 shows the problems associated with CLD: decreased surface area due to lack of secondary crests, and thickened membranes resulting from absent or inadequate apoptosis. This impacts gas exchange as there is both a lack of real estate available (aka surface area), increased airway resistance, and an increased diffusion gradient. How might some hyperinflation benefit these patients? As long as volutrauma is avoided by using HFO or HFJV, moderate hyperinflation stretches these surfaces and may result in a decreased diffusion gradient while increasing available surface area for gas exchange.

If decreasing (or increasing) MAP/PEEP necessitating increased amplitude or HFJV PIP to maintain ventilation, it is an indicator of lost compliance and the move should be reconsidered, as should it be if the baby's condition deteriorates. Increased FiO_2 should also be considered as a deterioration.

"As long as volutrauma is avoided by using HFO or HFJV, moderate hyperinflation stretches these surfaces and may result in a decreased diffusion gradient while increasing available surface area for gas exchange."

Avoiding "The MAP Trap"

- Air trapping first appears as hyperinflation on CXR

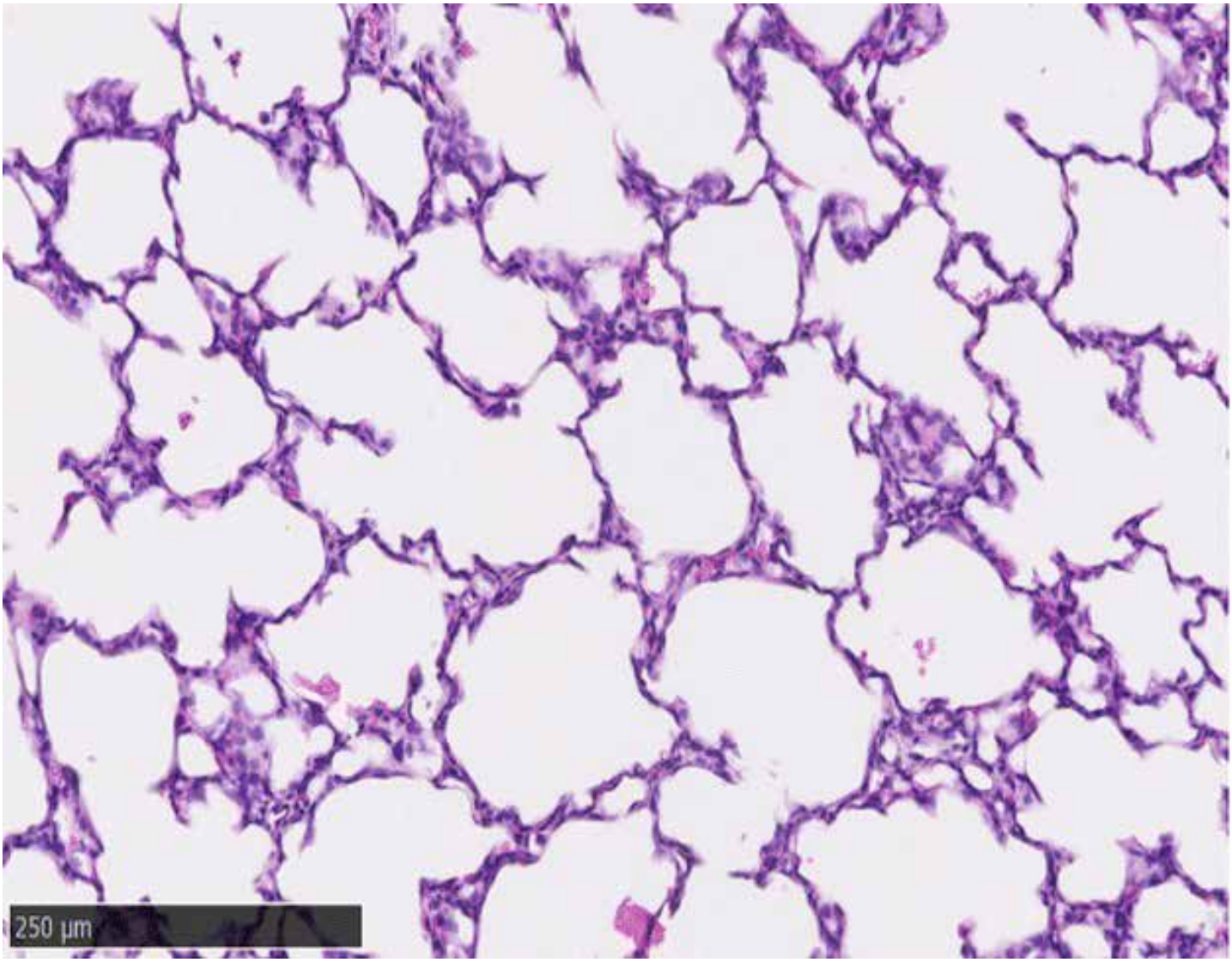

Figure 6 with permission Hyperoxia-induced lung structure–function relation, vessel rarefaction, and cardiac hypertrophy in an infant rat model. (2)

- Intuitive response is to wean MAP/PEEP
- "Hyperinflation" on CXR is unchanged or worse
- Decrease the MAP/PEEP more
- CXR progresses to "hyperinflated" but hazy with chronic changes
- By this time the damage is beginning, and the lungs will only improve with higher MAP/PEEP!
- Once the damage is done the HFJV can only do so much!

Remembering these points can help clinicians avoid this trap:

- Infants in 21% oxygen are likely NOT hyperinflated no matter what the CXR shows
- Infants with no apparent cardiovascular impairment are likely not hyperinflated
- Infants who show "hyperinflation" and crump when MAP is decreased are telling you they are not hyperinflated
- CLD may benefit from hyperinflation
- An underinflated lung will affect blood pressure as much as an overinflated lung

Air trapping is a precursor to hyperinflation. Guard against it by being mindful of:

- "Hyperinflation" on relatively low MAP/PEEP
- "Hyperinflation" that worsens when MAP/PEEP is decreased
- If using HFJV measured PEEP approaches or exceeds set PEEP
- Strongly suspect air trapping in all micro-prems!
- Copious secretions/meconium lead to air trapping
- Higher rates/frequencies can lead to or worsen air trapping
- Small airway diameter and its effect on time constants

We cannot change the nature of the patients we treat, but we can keep ourselves from using treatment strategies that exacerbate the problems associated with that nature and learning to listen to the language these patients speak: SpO_2 and FiO_2.

Next month: Non-Invasive Nasal HFJV Assisted (NINJA) Ventilation. Hint: it's this patient.

References:

1. *Bunnell Inc*
2. *Greco F, Wiegert S, Baumann P, Wellmann S, Pellegrini G, Cannizzaro V. Hyperoxia-induced lung structure–function relation, vessel rarefaction, and cardiac hypertrophy in an infant rat model. Journal of Translational Medicine. 2019;17(1):91.*

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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
416-967-8500
Rob Graham <rcgnrcp57@yahoo.ca>