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Flying Blind
Why Are We Not Recognizing Air Trapping (Even with "The Jet")

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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.

The path to chronic lung disease (CLD) in the premature infant is not a path at all; it is a map. As in ancient times, all roads lead to CLD, the Rome of pulmonary outcomes. While some of these paths can be avoided some of the time, and (one hopes) some paths can be avoided all of the time, rarely does one path alone lead to CLD.

We can leave runaway inflammatory responses to pharmacists and physiologists to treat or one day prevent, but mechanical ventilation is a key trigger in that response. As clinicians, we often have little training and relatively crude tools at our disposal to assess the presence of gas trapping. Along with inadequate evidence to support what become "gut feelings" about mechanical ventilation over the course of a career, and then there are institutional biases.

Medicine has used and learned from the aviation industry to improve safety, emulating checklists, for example. What we have been slower to adopt is the attitude in the proverbial cockpit; that is speaking up when something is wrong or does not look right, even if it means taking over from the right-hand seat.

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This change from the culture of "the Captain is God" was necessitated by many crashes which, when analyzed, could have been prevented if a subordinate, seeing something wrong, had voiced their concern and/or taken over flying the plane. The military, top-down style of leadership in medicine lingers even today; trainees and new hires are reluctant to question the "old guard" even when their guts are telling them they should be. In the vernacular of respiratory therapy, we call it "drinking the Kool-Aid®." There is all too much of the drink to go around; it is nutritionally void, an impediment to safety and progress, and serves the field of medicine no better than it did aviation.

My tombstone will undoubtedly read, "It is gas trapping," for the words cross my lips more times than I can count. July has arrived with its requisite new crop of fellows and residents. I will sound like a broken record.

It is my firm belief that gas trapping is one of the most significant contributors to CLD. Physics dictate how much gas can travel through a tube in a given amount of time; playing with pressure will increase volume, but will not change the time at which it can deliver it. That is the time constant.

A myriad of factors contributes to gas trapping in the micro-premature infant. The predominant one is the tiny radius of their airways; another is the minute volume required to ventilate and oxygenate using conventional modes of ventilation (CV). As the rate is increased, the ventilation cycle shortens, leaving less time both to fill the lungs and to empty them. If the volume is increased either by adjusting target volume or increasing pressure, the time required for that volume to exit remains constant, but the time available for that to happen gets shorter. Larger volumes create shear stress, which in turn triggers an inflammatory cascade. High pressures easily damage fragile conducting airways, creating places for gas to escape on entry where it lies trapped in the pleural cavity without contributing to ventilation. Eventually, it forces the diaphragm down, giving the appearance of hyperinflation on chests films. (figure 1)

Figure 1: Chest film showing hyperinflation, however, note the haziness of the lung fields. Decreasing PEEP resulted in a marked increase in FiO2 requirements, which dramatically decreased when PEEP was increased, suggesting gas trapping. MAP <10 (Image used with permission.)

Adherence to proper lung-protective ventilation strategies can mitigate this damage. The most important is the "open lung" approach to ventilation. This ideal can only be achieved by assessing and providing sufficient mean airway pressure (MAP) to maintain functional residual capacity (FRC), which maintains optimum compliance. It is important to revisit this regularly, as even the most careful CV causes damage that may impact compliance. As compliance decreases, more MAP is required to maintain it and to maintain airway patency. This only works until cardiovascular compromise occurs, and as MAP increases, so does the risk of impairing cerebral blood return.

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In CV, the problem with increasing MAP (usually by increasing PEEP) is that peak inspiratory pressures often rise as well, increasing the risk of airway rupture. This is where high-frequency modes offer help. Both high-frequency oscillation (HFO) and high-frequency jet ventilation (HFJV) pressures rapidly attenuate as they progress down the airways, and both modes are effective in removing CO_2.

Time is not on our side when ventilating with HFO. Here gas trapping is the most common problem, whether from "pinch points" created using high amplitude and inadequate MAP or because the typical 1:2 inspiratory/expiratory (I:E) ratio does not provide enough time for gas to exit, even with active exhalation. (figure 2) Decreasing frequency can help, but without the ability to monitor delivered volumes, it is risky; careful adjustment of amplitude is required so as not to give too much volume. If I:E ratio can be adjusted independently, increasing to 1:3 may help if it is a matter of expiratory time, provided the resulting increased amplitude does not create pinch points.

What about HFJV? With a fixed inspiratory time (Ti) and I:E ratio as high as 1:12, much more time is available both for expiration and spontaneous breathing. Gas traveling in both directions simultaneously (called bi-directional double-helical flow) in HFJV also helps.

Speaking of spontaneous breathing, it is worth noting that air trapping can occur on nasal CPAP and even a spontaneously breathing infant, as can CLD.

The proximity of the jet ventilator's pressure port and the algorithm used to interpret it provide us an approximation of what positive end-expiratory pressure (PEEP) is at the distal endotracheal tube (ETT). As the value of PEEP measured on the jet ventilator approaches the value set on the slave ventilator, gas trapping is highly suspected. Should jet-measured PEEP be higher than set, gas trapping is definitely occurring.

With these extra tools, why do I say we are flying blind? In HFJV, the machine reports estimated distal ETT pressure, which gives an average view of the situation. It cannot, however, tell you if re-

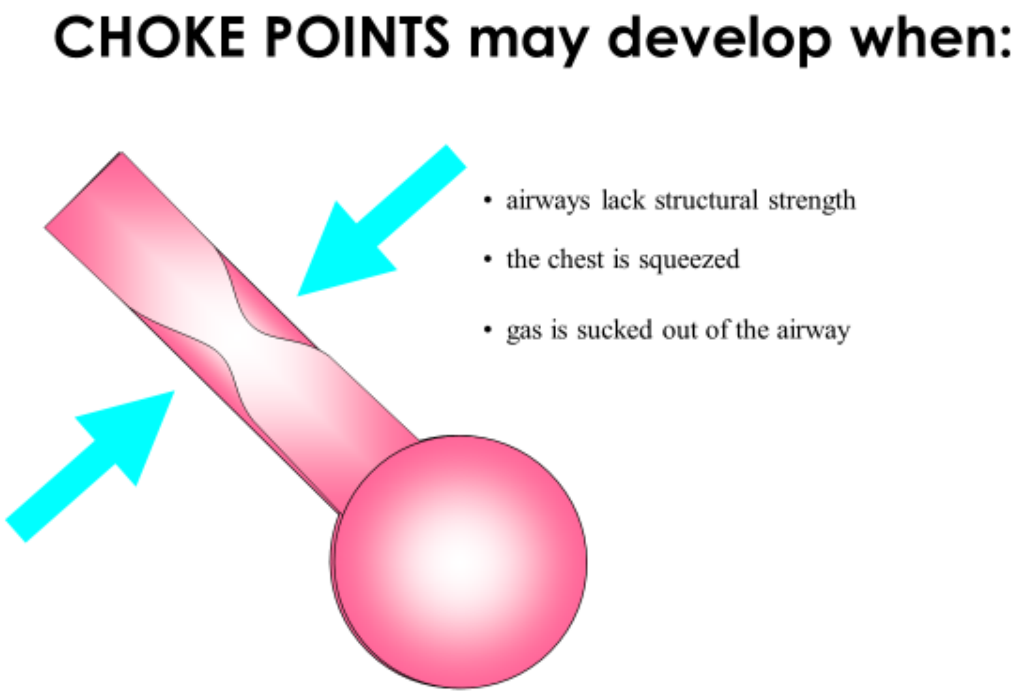

Figure 2: courtesy Bunnell Inc.

gional gas trapping is occurring. Regional gas trapping eventually leads to the same outcome as overall gas trapping; regional hyperinflation impedes upon adjacent areas. This, in turn, collapses airways (particularly on expiration) and creates gas trapping in them as well. In the end, the picture is the same.

A new ventilator (Drager VN-500®) used as a slave for the jet ventilator perplexed users because the slave machine's measured PEEP was lower than set PEEP. It was thought at first that there was a flaw in the jet ventilator, an unseen leak in the circuit, or a problem with the slave machine itself. It turned out none of those were the case.

PEEP is, by definition, the pressure at the end of expiration, and before inspiration occurs, the lowest pressure present. This is what the slave machine was accurately reporting; the lowest pressure sensed in the circuit. Why was this so different than what the jet was reporting?

The jet measures the pressure between jet breaths. The slave machine reports the lowest pressure it senses. Because the jet breath creates a momentary decrease in pressure behind it, entrainment occurs, much like a truck passing by with a tail of debris swept up and briefly following it. There is no broom; it is the relative vacuum created as the truck passes. This raises the possibility that gas trapping is occurring earlier than we have previously thought.

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That an extreme micro-prem is experiencing gas trapping should be assumed unless proven otherwise; the consequences are too dire. Anti-gas trapping measures should be taken early, predominantly lower rates with HFJV and preferably lower frequencies in HFO if available devices provide volume monitoring. Sufficient PEEP in HFJV and MAP in HFO are vitally important.

Chest imaging is a clumsy tool in the assessment of air trapping. At first, the lungs may look wonderful, even over-inflated, as trapped volume steadily increases. The appearance of hyperinflation often leads clinicians to decrease distending pressure. This is only helpful if the lungs are actually hyperinflated from that pressure; if gas trapping is the culprit, the results are not good. As extra-luminal gas collects in the pleural space, it begins to compress airways and alveoli alike. Compromised airways lead to more gas trapping and more apparent hyperinflation, creating a vicious cycle. Eventually, imaging shows completely de-recruited "whited out" lungs. It is a double whammy at this point since the lungs are most prone to injury during the re-recruitment process, and atelectasis will likely have triggered a cytokine cascade.

There are clinical signs when gas trapping may be occurring. The appearance of hyperinflation with low PEEP/MAP (PEEPS < 7 – 8 in HFJV or MAP < 8 – 9 with HFO) is one. These pressures are unlikely to cause hyperinflation: consider MAP in CV is considerably higher. Paradoxically, it is probably more PEEP/MAP the lungs require, not less. Another is amplitude or inspiratory pressure. Should more amplitude or peak pressure be required to maintain ventilation after PEEP/MAP has been decreased, it is a clear sign that compliance has been compromised, and previous settings should be restored.

Fear of pressure remains common in clinical practice. It is worth remembering that there is a considerable difference in MAP between CV and HVO or HFJV. In the "old days," infants were typically started on a rate of 60, peak pressure of 20 cmH_2O, PEEP of 5 cmH_2O, and Ti of 0.4 seconds. These settings produce a MAP of approximately 11 cmH_2O. A MAP of 10 cmH_2O is a typical starting point using HFO, lower than pressures previously used initially with CV. Furthermore, with high-frequency modes of ventilation, the lungs are subjected to far lower shear forces due to rapid pressure attenuation and smaller volumes. In a unit using high-frequency modes exclusively, such as the one I practice in, we have forgotten about the typical CV MAP. The way MAP is achieved is more relevant when discussing lung damage than the number itself, particularly if aiming for ventilatory efficiency. (see June's column) PEEP is the safest, most effective way of providing, maintaining, and increasing MAP.

It is unlikely we will ever be able to eliminate gas trapping in our tiniest patients. The best we can do is acknowledge it and the danger it presents, and act appropriately to minimize injury.

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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