Respiratory Potpourri: Recruitment Maneuvers During High-Frequency Jet Ventilation (HFJV): High, Low, Long, or Short?

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.

Those who have been utilising high-frequency jet ventilation (HFJV) for some time have most likely used conventional breaths (CMV)) superimposed on HFJV either to reverse atelectasis or for initial lung recruitment. Traditionally the term conventional breath was an apt description as their parameters were just that; relatively high peak inspiratory pressure (PIP) of 20 cmH_2O (or higher) and inspiratory time (Ti) of 0.5 seconds or so.

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The past debate has revolved around whether to set CMV PIP below HFJV PIP, or above. The difference between the two, aside from the obvious difference in pressure, is with the jet itself. CMV PIP set higher than HFVJ PIP will cause the jet ventilator to pause for the duration of the CMV breath, while CMV PIP set below HFJV PIP will not; HFJV breaths will be superimposed on CMV breaths.

PIP differences aside, clinicians were instructed to use CMV during initial HFJV to recruit the lungs since the low PIP and short Ti of HFJV are not powerful enough to do so on their own. These were started at rates of 5-10 and were reduced as FiO_2 improved with the aim to stop them entirely and run HJFV in CPAP mode. CMV breaths were (and still are) advised to help determine optimal PEEP settings. If FiO_2 increases when CMV rate is reduced or CMV breaths are discontinued, PEEP is increased until FiO_2/SpO_2 is stable when CMV is discontinued. This approach seems to work, and it is still the standard practice in many NICUs.

The burning question behind the use of CMV with HFJV is "why?". After all, if the benefit of HFJV is its gentleness, why use high PIP CMV breaths at all? This strategy works in the short term, but there are known sequelae associated with CMV, mainly inflammatory response and lung injury stemming from sheer forces, volutrauma, and conducting airway/alveolar duct rupture or tears. The short-term gain from the use of CMV may come at the cost of pulmonary damage later.

I do not use the traditional style CMV breaths in my personal practice. Initially, rather than use CMV to recruit the lung, I prefer to start with higher PEEP instead. This has worked well for me and is how HFJV is done in the NICU I practice in. I believe it is one of the reasons our CLD rates are remarkably low.

There are clinical situations, however, which do not respond well enough to increasing PEEP. Regional atelectasis is one, and unilateral collapse is another. The question is how to manage these pathologies clinically without causing further damage to the lung, and without over-distending well -functioning areas of higher compliance.

Physics dictate that gas takes the path of least resistance; compliant areas accept volume more readily, and gas will preferentially fill these areas until they become less compliant from over-distention. Once this happens, gas will begin to enter less compliant/higher resistance areas.

There is an inherent problem with the standard CMV breath in this situation: time. Time constants dictate how long it takes for gas to fill a space, and the most compliant areas of the lung take the longest to fill; a standard Ti of 0.5 seconds likely does not afford enough time for this to happen, let alone time for pendelluft to redistribute volume within the lung. The result is areas of higher compliance being over-distended, resulting in volutrauma, and collapsed/atelectatic areas suffering damage from the inflammatory response with surfactant impairment that follows atelectasis. (1,2) The clinical response may be good, but it comes at a cost.

Contrast this with a different form of CMV, one which ostensibly protects compliant areas while gently opening up areas of collapse. How is this accomplished? A combination of relatively low CMV PIP combined with a longer CMV Ti.

Limiting PIP reduces the volume that enters compliant areas, thus giving some protection against volutrauma while increasing the CMV Ti gives more time for pendelluft to occur once compliant areas have accepted as much volume as they will at a given PIP. The lower PIP also slowly and gently exerts a force against collapsed areas and eventually recruits them. I refer to these breaths as recruitment maneuvers (RMs) to differentiate from the standard CMV breaths of old.

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We know that the lung is at greatest risk of damage when being recruited, be it on the admission table or after de-recruitment. Appropriate PEEP/MAP should prevent atelectasis; however, what that level is may not be provided by clinicians suffering from "PEEPaphobia" or "MAPaphobia." The modified CMV breath (I prefer to

use the term “recruitment maneuver” (RM)) may offer gentler recruitment and be less apt to damage or further damage the lungs.

Not to be confused with sustained inflations (there is evidence these are not a good idea) (3), RMs have shorter Ti and usually lower PIP, and have been gaining favour within the unit I work in, and have been a personal standard of practice for over ten years. From a clinical perspective, they can work “like magic” or produce less dramatic results. The goal is to decrease FiO_2 and provide more lung volume to work with. Similar to CMV breaths, RMs should be used only when necessary for as short a period as possible. PEEP should be increased when they are discontinued to prevent derecruitment.

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One scenario in which RMs work very well is complete unilateral collapse. Whether from a mainstem intubation or surfactant being inadvertently given to one lung only, initiating RMs while positioning the baby collapsed side up has, in my experience, worked very well, and generally within 8-12 hours. Regional atelectasis is more challenging to treat, and RMs may take longer to work, but they too respond to this treatment.

Settings:

There is some variation within the clinical practice when it comes to RMs. Some use slightly shorter Ti, some longer; some use a respiratory rate of 5 while some use more; some use slightly higher PIP and some less.

It is my practice to use PIP of 5-6 above PEEP, a rate of 10, and Ti of 2 seconds. PIP settings on most ventilators are limited to a minimum delta P, although the utility of pressures below 5 above is limited though there may be situations where lower delta P may succeed. The slave ventilator used with most of the jets in my NICU has a maximum Ti of 2 seconds. I do not believe it prudent to exceed Ti of more than 3 seconds. If these settings do not achieve positive results within an hour or so, then PIP may be increased; a PIP 5-6 above PEEP may be insufficient to re-inflate non-compliant areas. The goal is to use as low a PIP as will do the job, though it stands to reason the higher the PIP, the less protective the RM is. The use of a rate of 5 is likely adequate for most situations; higher rates should be reflective of the urgency of improving clinical status. If inspiratory and expiratory flow rates are independently adjustable, I will decrease inspiratory flow rate to soften the waveform of the RM, otherwise lengthening slope or rise time will have a similar effect.

Management:

Once the desired effect is achieved RMs may be discontinued, or their frequency decreased if a more cautious approach is taken. Either way, the goal is the same: the discontinuation of RMs.

As the lung is recruited, ventilation may improve as well as oxygenation. Initially, CO_2 may rise, followed by a precipitous drop as the recruitment occurs, and ventilation-perfusion matching (VQ) improves. Conversely, ventilation may decrease as the RM decreases HFJV ΔP for the duration of the RM; increasing HFJV PIP may be required temporarily. Either way, the dynamics of ventilation change during RMs and must be accommodated. The monitoring of $PaCO_2$ during RMs is de rigueur.

Caveats:

This style of RM is relatively new. As such, there is anecdotal evidence of their effectiveness but no proper clinical trials. I have never seen a baby suffer a pneumothorax as a result of RM use, but higher Ti has been associated with an increase of pneumothorax4. The chance of air leak is always present and should be high on the clinician’s troubleshooting list should acute deterioration occur. In my workplace, there is a needle aspiration kit attached to each ventilator.

As a final note on the subject, it is worth noting that third-generation ventilators providing oscillation along with conventional modes may also give the option of sigh breaths during oscillation (HFO) This style RM may benefit some patients on HFO as well.

2.0 ETT: A way to buy time?

The use of 2.0 mm ETT’s is controversial, to say the least. The unit where I work stocks them, but they are not meant to be used for ventilation. Rather, they are used (rarely) in emergent situations involving post extubations edema to buy time for dexamethasone to do its job. There is no way at present to ventilate through this small an ETT, partially because the resistance is too high for conventional ventilators to work. The small lumen leads to severe gas trapping, and there is no way to properly suction. Although it is possible to pass a 6 Fr suction catheter through a 2.0 ETT (with some difficulty) straight from the package, once the tube is in situ and secured, this becomes impossible. The tape securing the ETT creates a stricture preventing passage. Even if it were possible, the catheter completely occludes the airway, and suctioning results in removal of lung volume along with whatever secretions the small catheter is capable of removing. Even if 5 Fr catheters are available, their inherent high resistance makes them useless for tracheal toilet.

I recently cared for a 23+5-week gestation infant weighing 499 grams. The resuscitation team was unable to intubate with a 2.5 ETT. The decision was made to place a 2.0 ETT orally. Initially, the infant did very well on oscillation with volume guarantee (HFO/VG) using remarkably low amplitude and was in 21% O2 post-surfactant.

Initial settings were frequency of 10 Hz, maximum amplitude of 20 cmH_2O (using 15), mean airway pressure (MAP) of 10 cmH_2O, I:E ratio of 1:2, and volume targeted at 1 mL. The frequency was decreased to 8 Hz, and I:E ratio increased to 1:3, both in an attempt to mitigate presumed gas trapping. Volumes were weaned as low as 0.6 mLs, but rising CO_2 necessitated increasing back to 1 mL. At 15 hours of life, the baby was placed on HFJV as FiO_2 was increasing, as was CO_2. (This should have been the initial mode of ventilation in my opinion). Initial settings were a rate of 240, PIP of 20, PEEP of 9, and Ti 0.02 seconds. Prior to the switch, monitoring HFO/VG with the jet on standby mode showed a higher MAP than set on the ventilator, confirming the presence of inadvertent PEEP. PEEP, as measured on the jet ventilator in operation, was 9.2. Shortly thereafter, the decision was made to reintubate with a 2.5 ETT under rapid sequence induction.

Previously, a 2.5 ETT was passed through the left nare using a small amount of lubricating jelly, and a 6 Fr suction catheter as an introducer. Initially, the nose blanched but pinked up nicely in a short time. A 6 Fr suction catheter was passed through the ETT using a small amount of lubricating jelly and used as an introducer as previously. The suction catheter was then passed through the vocal cords using Magill forceps under direct laryngoscopy and advanced as deeply as possible. The ETT was then passed through the vocal cords over the catheter with gentle pressure while rotating the ETT. The patient was then placed back on HFJV. Once the ETT was up-sized, FiO_2 returned to 0.21.

Having the 2.0 ETT in situ for approximately 15 hours may have dilated the glottis making it possible to pass the larger tube. Lesson? A tiny baby may be successfully ventilated for a short time with a 2.0 ETT in order to buy time for inflammation to subside and possible dilation of the glottis.

Life Pulse® Play:

Please note any modification of the Life Pulse® circuit is not sanctioned by Bunnell Inc., and this "investigation" is purely academic.

Colleagues have mused about the suitability of HFJV for the treatment of COVID-19 refractive to traditional ventilation options. The ability of HFJV to overcome airway resistance and the double-helical bidirectional flow characteristics of the mode also facilitates clearance of secretions. The question of whether or not the Life Pulse® has enough driving pressure to accomplish this task in a larger patient is the biggest question.

The maximum servo pressure (the driving pressure required to achieve set PIP) available on the machine is 20 psi; however, the accumulator inside holds 500 mls of gas under pressure. This may not be sufficient to keep up with the demands of larger patients depending on rate, Ti, and PIP.

Modifying the circuit, I have been able to achieve PIP of up to 107 cmH_2O (using a Sechrist® Airway Pressure Monitor Model 400) and a servo pressure just over 20 psi using a jet rate of 240 and Ti 0.034. This may be sufficient for a small adult; however, the largest LifePort® adaptor is a 5 mm, smaller than a typical adult endotracheal tube. This may not be an insurmountable problem as I am quite sure a resourceful clinician could figure out a way to make it fit. My next exercise will be to determine if there is a way to estimate pressure delivered by the machine with the modification made. Stay tuned.

While on the topic of unorthodox use of the Life Pulse® I should mention I have not had the opportunity to investigate further "NINJA" (Non-Invasive Nasal Jet Assisted ventilation). I look forward to updating readers on this mode.

"As with the rest of the world, ensuring PPE availability is still a challenge, and the first wave of this pandemic is not yet over. How any of us fair with the predicted second wave is at this point unknown and will largely depend on our collective ability to ramp up production of PPE to ensure all involved in the care of COVID-19 patients are properly protected."

It is fortunate that here in Ontario as in California, closing down non-essential businesses and institutions as well as social distancing and stay at home advisories have thus far prevented our system from being overwhelmed. Knock wood, but at this point, we in Ontario have a surplus of adult ICU bed capacity and no shortage of ventilators. As with the rest of the world, ensuring PPE availability is still a challenge, and the first wave of this pandemic is not yet over. How any of us fair with the predicted second wave is at this point unknown and will largely depend on our collective ability to ramp up production of PPE to ensure all involved in the care of COVID-19 patients are properly protected.

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