What is new in ventilation - New modes of ventilation and new Anesthesia Machine Technology

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General Review:

-Differences between pressure control and volume ventilation.

-Monitoring ventilation in pediatric patients.

-Can an adult anesthesia machine bellows and circle system be used to ventilate infants and children, and if so, how should it be set up?

-Is there an advantage to bringing an "ICU-type" ventilator into the OR for pediatric -- patients with non-compliant lungs?

-Are the technical advances of two newly available anesthesia ventilators sufficient to provide adequate ventilation for all pediatric patients with non-compliant lungs?

-What is High Frequency Oscillatory Ventilation? Do we need to know HFOV?

-What new developments are there that soon may become available for pediatric ventilation in the operation room?

Volume Control vs. Pressure Control:

Pressure limited or pressure control ventilation (PCV) is frequently applied to infants and children. There are several advantages to this mode of ventilation. Limiting the peak inflating pressure delivered by the ventilator will limit the transalveolar pressure produced, thereby reducing ventilator-induced lung injury. (1) The decelerating flow used to produce PCV is thought to improve the distribution of gas flow. (2) When compared to volume control ventilation there is a more rapid improvement in lung compliance and oxygenation. (3) Lastly, setting anesthesia ventilators to deliver accurate small tidal volumes is difficult because of the proportionately large compression volume loss in the ventilator and circuit. (4)

Pressure Control Ventilation	**Volume Control Ventilation**

Advantages

• Prevents excess inflating pressure	• Maintain minute ventilation, constant tidal volume
• Decrease risk of barotraumas	• Changes in compliance or resistance reflected in PIP
• Better V/Q matching in diseases with low compliance	

Disadvantages

• Delivered tidal volume is variable	• Small children with changing lung compliance have altering compression volume (lost volume)
• Changes in compliance or resistance are difficult to detect	• May deliver high PIP
	• May increase risk of barotramuma

Monitoring Ventilation

Ventilation is the tidal exchange of gas between lungs and the atmosphere, and is measured by the concentration of CO_2 in arterial blood. In the operating room, the most common non-invasive method of measuring CO_2 is with capnography, which closely reflects changes in arterial CO_2 among patients without lung disease. When ventilating an infant, capnography is frequently less accurate because there may be a leak around the uncuffed endotracheal tube or because the fresh gas flow washout of the small volume of CO_2 sampled (5,6). Another measurement of alveolar ventilation is the measurement of exhaled tidal volumes (V_t). However, in infants the measured exhaled V_t may be grossly inaccurate. Exhaled V_t is usually measured by a spirometer located at the end of the expiratory limb and will over estimate the patient's V_t because it reflects the patient's exhaled V_t and the compression volume in the breathing circuit. If there is a leak around the endotracheal tube, the spirometer will underestimate the exhaled gas. Without reliable $ETCO_2$ monitoring or exhaled V_t measurements, the pediatric anesthesiologist must rely on chest expansion and PIP to make ventilator adjustments. This technique is commonly used by most pediatric anesthesiologists. However, drapes that cover the chest make the assessment of chest excursion more difficult; and because adult anesthesia ventilators have large compression volumes, only profound changes in lung compliance are reflected as changes in PIP.

Adult vs. Pediatric Bellows/Circle

Badgwell et al. (4) evaluated the Ohmeda 7800 in 80 infants, ASA I-IV, undergoing a variety of surgical procedures. In this non-randomized study, the anesthesia system used was whatever was set up by the technician before the case, and included five different circuits: an adult circle with adult bellows, adult circle with pediatric bellows, Bain circuit with pediatric bellows, pediatric circle with adult bellows, and pediatric circle with pediatric bellows. Tidal volume was set to appropriate chest expansion (PIP about 20 cm H_2O), 20 breaths/min, fresh gas flow 3 L/min, and adjusted to appropriate end tidal CO_2 and SpO_2. The main findings were as follows: 79 of 80 infants could be adequately ventilated, regardless of the system used. The one exception was a newborn with congenital diaphragmatic hernia, and very non-compliant lungs, who was better ventilated with an ICU ventilator brought into the OR, and who later required ECMO. The compliance volume of all systems was 7-9 ml per cm H_2O pressure, requiring a set tidal volume ranging from 250-300 ml/kg for a 1 kg infant, to 25 ml/kg if the infant weighed 10 kg or more. Considering the compliance volume losses, the wasted Vt would be between 152 and 188 ml for every breath when a peak inflating pressure of 20 cm H_2O is reached. If the delivery of a 30ml Vt breath required a PIP of 20 cm H_2O, the ventilator must be set to deliver between 180 and 220 ml. If the infant's lung compliance worsened, requiring a PIP of 25 to deliver this breath, the ventilator would have to be reset to deliver between 220 and 265 ml. Without adjustment, the delivered Vt would be less than 8 ml. A 20% change in PIP would lead to a 75% loss in delivered ventilation. It is clear from their data that the ratio of compression volume to delivered Vt is very high; and therefore changes in lung compliance have a profound effect on delivered Vt in infants.

The question of how best to "set up" an adult bellows with an adult circle system to ventilate infants was addressed in a study by Tobin et al. (7). They used a Narkomed 2B system and an infant lung model, targeting the same PIP and RR. They achieved this in three different ways: A = time-cycled, volume-controlled using bellows excursion to control delivered volume; B = time-cycled, pressure-controlled using inspiratory pressure limit adjustment to control delivered volume; C = time-cycled, pressure-controlled using the inspiratory flow adjustment to control delivered volume. They found that in the normal compliance lung model, method B consistently gave a higher delivered tidal volume, but that there was no difference in the low compliance model. The main point was that delivering the desired PIP for pressure control ventilation was the most important factor, not the specific method employed. Recommendations were about how to set up an adult system for this use by setting the inspired tidal volume at 10-15 ml/kg, with a minimum of 100 ml, setting the popoff at 20, and increasing this limit, or inspiratory flow, or bellows expansion until adequate gas exchange was achieved based on chest expansion, breath sounds, and non-invasive ventilatory monitoring.

Features of some of the ventilators:

Ohmeda 7800

Mode of Ventilation   Volume Control Only

Compliance Volume   7 – 9 ml/cm H2O Pressure
(V_t Wasted for 20 cms of PIP = 152-188 ml)

20% change in PIP   = 75% loss in V_t

ratio of compression volume:delivered V_t = High

Allows the user to selct Inspiratory flow, which alters the 1:E ratio

<u>Narkomed 2B</u> :

Delivering the Peak Inspiratory Pressure in the pressure control mode is the most important factor, and NOT the specific method employed (Tobin et al).

<u>Siemens Servo 300:</u>

When compared to standard anesthesia ventilators was found to deliver slightly more (2 –13%) minute ventilation, otherwise no significant difference was noticed (Stevenson et al)

New Anesthesia Ventilators:

Stayer et al compared (9) the Drager Narkomed NAD 6000 ventilator to the Siemens Servo 900C anesthesia system in an infant test lung. It has conventional flowmeters, vaporizers, controls, CO2 absorption, and gas scavenging systems, and thus retains all of the advantages of a standard anesthesia machine (familiarity, convenient spontaneous manual and spontaneous ventilation), with the advantages of an ICU type ventilator (volume or pressure control mode, set tidal volumes down to 20 ml, rates of 4-100 BPM, high inspired flows, adjustable PEEP and I:E ratio). The 900C is the prototypical ICU ventilator, capable of very high working flows and pressures, and ventilating even the most non-compliant lungs of patients of all sizes. The anesthesia system consists of a vaporizer setup on the inspiratory port, and a manual ventilation valve on the expiration port. It is a non-rebreathing system, with fresh gas flow equal to the minute ventilation of the patient, and no C02 absorber. At high minute ventilation, much anesthetic gas is wasted. In addition, there is no popoff valve, making manual and spontaneous ventilation difficult. Lastly, the ventilator controls are foreign and non-intuitive to most anesthesiologists. The 900C is no longer manufactured, so the experiment was designed to test whether the new ventilator would function as well as the ICU ventilator. Both systems delivered adequate, precise tidal volumes when set in the volume control mode under a variety of conditions; when the PIP increased above 40, both ventilators could

only deliver about 50% of the set tidal volume. One possible advantage of the NAD 6000 is that because it performs a circuit compliance check, it more accurately determined the reduced delivered tidal volumes in the low lung compliance situations, whereas the 900C did not. The basic conclusion was that both ventilators continued to deliver adequate ventilation, even under the most extreme conditions of fast rate, low compliance, and small tidal volumes that would be expected with even small infants.

Stevenson et al. (10) compared the NAD 6000 to the Narkomed GS (a standard anesthesia ventilator, previously found to be fairly equivalent to the Servo 300 ICU ventilator) in the same infant lung model under a wide variety of conditions. The NAD 6000 was superior for the following reasons-the Narkomed GS could not be set to deliver any tidal volume less than 50 ml, or a tidal volume over 200 ml with the low compliance model at 20 breaths per minute or higher; minute ventilation did not vary at all with fresh gas flow with the NAD 6000, whereas it was directly proportional with the Narkomed GS. The NAD 6000 partially compensated for a sudden change from normal to low compliance, whereas the Narkomed GS did not. This compliance compensation is incomplete because it is intentionally limited by the manufacturer to prevent delivery of excessive tidal volume and peak inspiratory pressure to small patients (11).

Stayer et al also compared the new Datex-Ohmeda Aestiva 3000 anesthesia machine ventilator to the NAD 6000 and the Servo 900C in an infant test lung (12) in the pressure control mode. The Aestiva 3000 incorporates the SmartVent 7900 ventilator, which is a conventional bellows style, pneumatically driven but microprocessor controlled ventilator, capable of being set to a wide range of tidal volumes, or the pressure control mode. This ventilator compensates for changes in compliance or fresh gas flow by determining changes in ventilator output from a spirometer on the inspiratory limb of the circuit. It has all the advantages of a standard anesthesia machine coupled with an excellent user interface design. Under conditions of high respiratory rates and high inflating pressures, the Aestiva 3000 delivered lower tidal volumes than did the other two ventilators. The primary reason was that it delivered less than 50% of the inspiratory flow of the other machines.

Finally, in a study in infants under 5 kg undergoing surgery for congenital heart disease (13), Stayer et al compared the performance of the Servo 900C and the NAD 6000 for volume controlled ventilation before incision in a randomized, crossover study design. The leak around the endotracheal tube was minimized in this study. At identical volume controlled settings, the NAD 6000 delivered slightly greater minute ventilation, as evidenced by lower EtCO2, PaCO2, and measured tidal volumes. It generated higher PIP and peak inspiratory flows to do so, as well as a slightly higher mean airway pressure. The indicated exhaled tidal volume as measured by the flow transducer inside the NAD 6000, however, was significantly greater than the measured tidal volume, as indicated by a spirometer attached to the end of the patients' endotracheal tube. This suggests that the compliance compensation feature on this machine may not be accurate for these small infants.

Anesthesia Machine Comparisons	Narkomed AV2+	Ohmeda 7800	6400	Fabius GS 1.3	Aestiva/5
Does fresh gas flow increase Vt?	Yes	Yes	No	No	Initially
Is the pre-use system leakage measured?	No	No	Yes	Yes	No
Is there compensation for a proximal leak?	No	No	No	No	Yes
Is leakage measured during the case?	No	No	Yes	No	No
Is the hose compliance compensated?	No	No	Yes	Yes	No
Is the system compliance compensated	No	No	Yes	Yes	Yes
Is the reported exhaled Vt adjusted for hose?	No	No	Yes	Yes	No
At low FGF, exh, what gas fills the reservoir bag?	Exhaled	Exhaled	Scrubbed	Scrubbed	Exhaled
What is the mechanism of VCV?	Mech. Limit	Metered	Displacement	Displacement	Metered/servo
How is PCV controlled?	P-limited	None	Flow/ P-limited	Flow/ P-limited	P-limited
Is the SIMV mode offered?	No	No	Yes	No	No
What is the specified minimum Vt?		18	10	20	20
How is fresh gas measured?	Flow tubes	Flow tubes	Flow tubes	Electronic	Flow tubes
Is there a backup flow tube?	N/a	N/a	N/a	Yes	N/a
Is there integrated capnography?	No	No	Yes	No	No

Is there integrated anesthetic gas monitoring?	No	No	Yes	No	No
What is the effect of lost oxygen pressure on FGF?	No FGF	No FGF	No FGF	Air available	Air available
Return of sampled gas to circuit?	No	No	No	No	No
Is there a mechanical Paw gauge?	Yes	Yes	No	Yes	Yes
Can you remove the absorber during VCV?	No	No	No	Yes	No
Likely to entrain room air with a circuit leak?	No	No	Yes	Yes	No
Might it entrain room air with inadequate FGF?	No	No	No (version)	Yes	No
Can you provide CMV without any FG pressure?	No	No	No	Yes	No
Effect of O_2 flush during VCV inspiration?	>Vt, held at P-limit	>Vt, held at P-limit	None	None	>Vt, held at P-limit
Can it provide zero PEEP in CMV?	No	No	Yes	Yes-pneumatic	No
How do you convert from VCV to PCV?	Mechanical	N/A	Automatic	Automatic	Electronic reset
How can you find a low pressure (vaporizer) leak?	Positive pressure	Negative pressure	Auto, vap open	Auto, vap open	Negative pressure

High Frequency Oscillatory Ventilation:

Utilizes highest frequencies
Smallest volumes
Active expiratory phase
Oscillation achieved by piston pump or diaphragm
Volatile anesthetics can be delivered accurately

Indications:
Almost always initiated in ICU, When conventional ventilation doesnot provide adequate gas exchange(14,15). When a patient is brought to the OR who is on HFOV one may elect to Continue HFOV or more commonly the patient is switched to conventional ventilator By ICU team prior to transport. When first HFOV is initiated a lag time of upto 45 minutes is needed for recruiting alveoli and for effective ventilation. This adds to the limitation placed in it's use in the operating.

Inverse ratio ventilation.

Modern anesthesia ventilators have recently offered inverse ratio ventilation (IRV) as a means of increasing mean airway pressure without increasing peak airway pressure (16,17). IRV is defined as an I:E ratio greater than 1:1, and has physiological effects similar to the inspiratory pause described above. The ratio may be inverted in ventilators utilizing a flow generator (FG) mode or in those utilizing a pressure generator (PG) mode. When FG-IRV is used, the I:E ratio can only be inverted by decreasing the mean inspiratory flow or by adding an end-inspiratory pause. For the same minute ventilation and I:E ratio, the inspiratory pause provides a greater mean airway pressure than does the lower lower flow rate of the first option22. When using IRV, caution is advised to prevent breath stacking and auto-peep. This could occur if there is inadequate time for exhalation. Using IRV with a pressure generator merely prolongs the inspiratory time.

Future Developments in Pediatric Anesthesia Ventilators

Pressure regulated volume control ventilation (PRVC) is available on some ICU ventilators such as the Siemens Servo 300. Its major advantage is that it will deliver the set tidal volume at the lowest achievable peak airway pressure by using a decelerating inspiratory flow pattern (like conventional pressure control mode). The advantage of this is that adverse cardiorespiratory interactions are minimized. This is particularly important with single venticle patients who lack a right-sided cardiac chamber (i.e. after the Fontan operation), or in patients with non-complaint lungs requiring high-pressure ventilation. Siemens Corporation produces the Kion anesthesia system, with a future option for PRVC that is not yet available. This machine, however, has a standard bellows, and thus would be expected to have a higher compression volume than non-bellows ventilators, and so it performance would need to be carefully evaluated before it could be recommended for use in small infants.

Newer monitoring systems allow for measurement of flow and pressure at the endotracheal tube. Incorporating this data into the anesthesia system is helpful in determining optimal ventilation in patients with poorly compliant lungs.

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