Dräger

Babylog 8000 –
Flow Wave and Volume Monitoring

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Introduction

The Dräger Babylog 8000 works in just the same way as other conventional neonatal ventilators (i.e. it is continuous flow, pressure limited, time-cycled). It also has additional features which have not been routinely available before in the field of neonatal ventilation. The aim of this booklet is to describe these »extras« and explain their value.

A device named a »flow sensor« has been incorporated into the wye piece which connects to the endotracheal (ET) tube. The purpose of this flow sensor is to detect gas flow into and out of the baby's lungs throughout the respiratory cycle. We can derive useful information from both the pattern of the flow waveforms and from the conversion of flow measurements into **volumes**.

How do we interpret the Flow Wave?

Figure 1 represents a basic flow pattern on the Babylog screen.

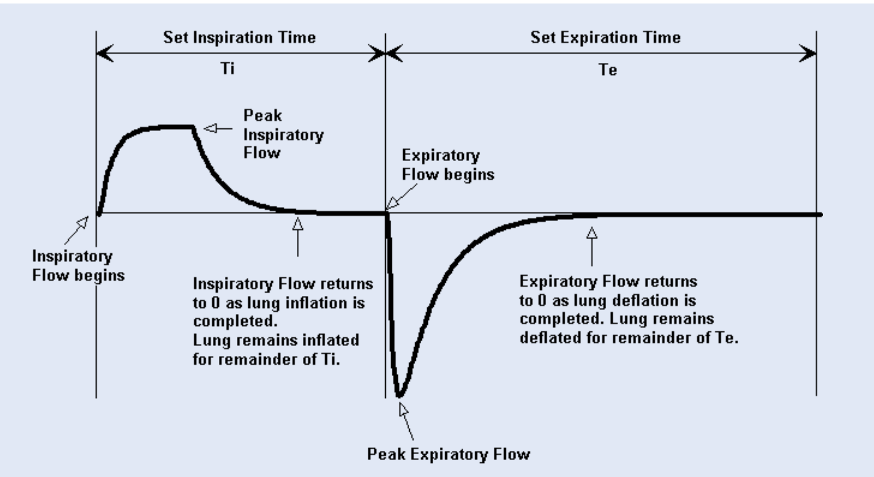

Fig 1: Flow during a respiratory cycle

Timing and the Flow Wave

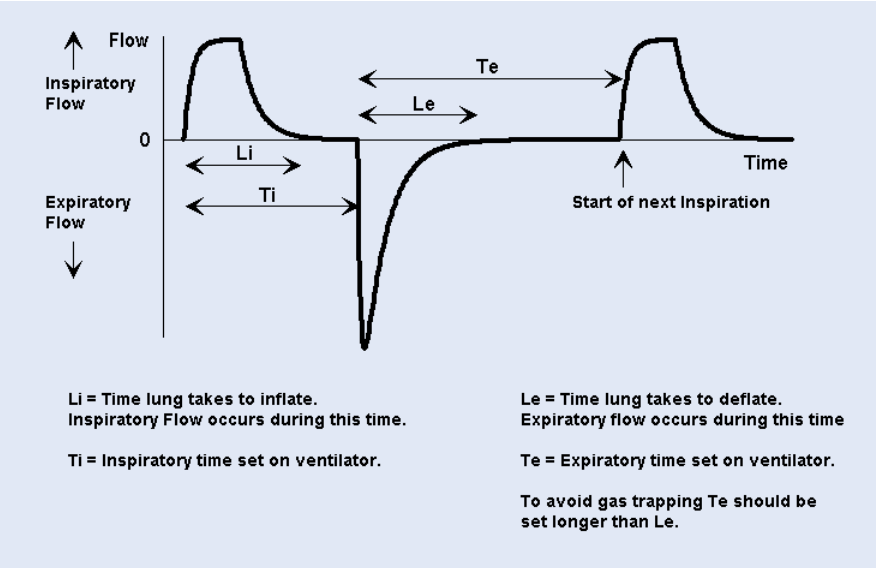

Fig 2: Flow during lung inflation and deflation

In figure 2 lung inflation and deflation time can be compared with set inspiratory and expiratory time. The horizontal line represents zero or no flow i.e. there is no gas moving into or out of the baby's lungs.

The wave you see **above** this line results from flow occuring during **inspiration**. The wave **below** this line represents flow occurring during **expiration**. Lung inflation (denoted as Li) is complete when the flow curve has come back to the zero flow line. Lungs fill at different rates, according to their particular **time constant**, which depends mainly on their condition and disease state.

You will notice in this example that Ti, the inspiratory time set on the ventilator, exceeds the time the lungs actually take to fill. This is often the case, as we deliberately increase Ti in order to improve the mean airway pressure (MAP) and thus the baby's oxygenation. During this time, the lungs cannot begin to deflate, as the peak pressure is maintained in the circuit, and the lungs are thus held in inflation.

At the end of Ti (when the expiratory valve in the ventilator opens) the circuit pressure falls and the lungs begin to empty. The time taken to empty is shown as Le, and this is usually slightly longer than Li, due to resistance during expiration.
Again, in Fig 2, Te, the expiratory time setting on the ventilator exceeds Le. In this case there is a gap or time interval between the completion of lung emptying and delivery of the next breath.
We shall look at different examples of flow waves and at ways of manipulating them to our advantage.

How can we Recognise Compromise of Inspiratory Flow?

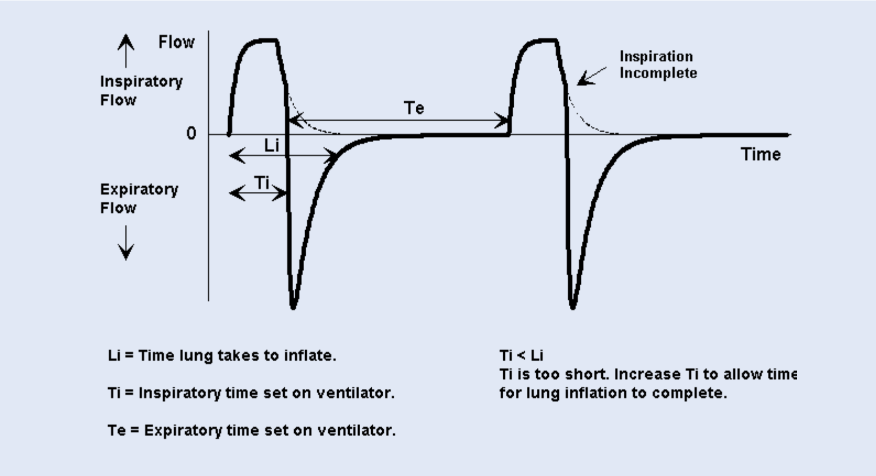

Fig 3: Compromised inspiratory flow

Here you can see that there is »clipping« of the flow wave before inspiration has quite finished. This happens when the Ti (set on the ventilator) is shorter than the time required for the lung to expand fully. It may or may not be significant, depending on the circumstances and the clinical situation. For example, if clipping only just precedes the cessation of flow, then very little flow will be lost, and this may not matter. However, if Ti is much too short (relative to Li), gas flow into the lungs may be significantly reduced, and this could be clinically important.

How can we Optimise Ti?

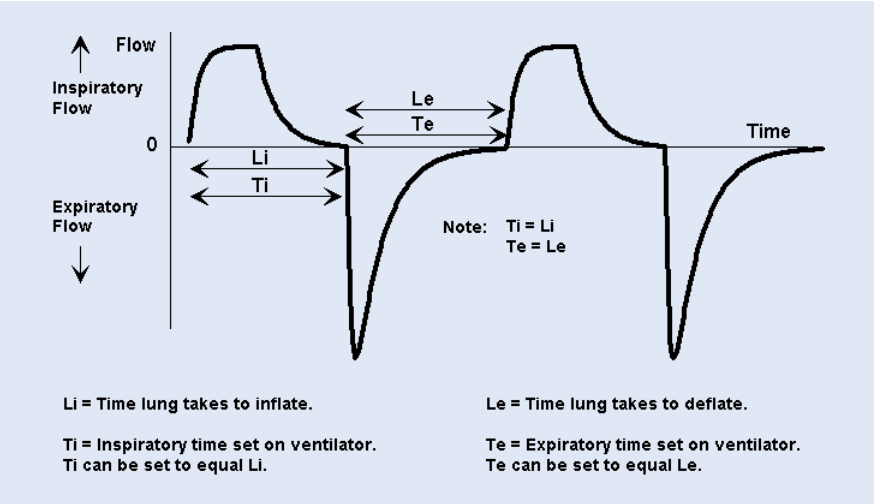

Fig 4: Using the flow wave to maximise respiratory rate

One way of approaching this situation is to start by matching Ti to the lung's own timing, and ensure inspiration is just complete before the expiratory phase begins. You can do this easily by adjusting Ti on the ventilator and watching the effect on the flow tracing. When oxygenation is a problem, you may wish to manipulate the MAP by first increasing Ti, in preference to increasing the pressures, whilst still ensuring adequate time is left for expiration (see p 9).

How can we Detect Compromise of Expiratory Flow and Inadvertent PEEP?

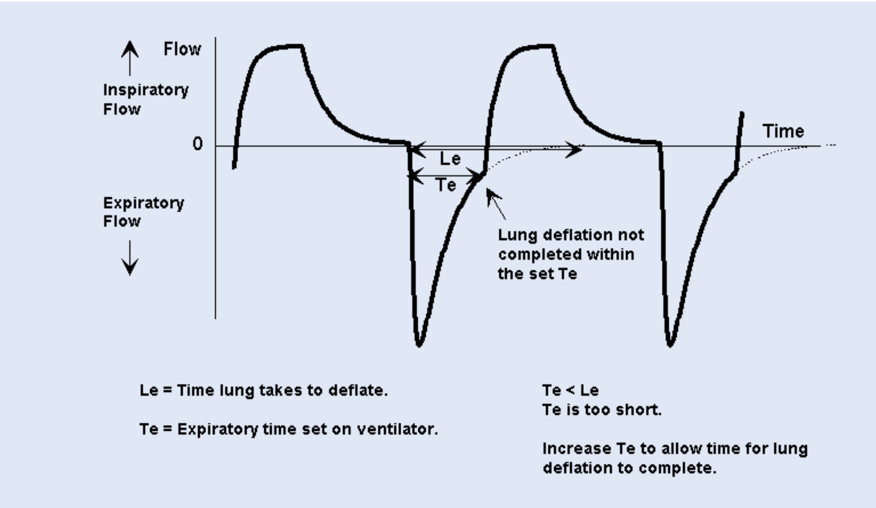

Fig 5: Compromised expiratory flow

Expiratory time (Te) should be long enough to allow expiratory flow to be completed, and the airway pressure to fall to the value set for PEEP.

Clipping of expiratory flow occurs when Te is too short relative to the time the lung needs to empty, and this results in incomplete emptying before the next breath is delivered by the ventilator. Small amounts of »gas trapping« occur during successive breaths, leading to equilibrium at a higher level of thoracic gas volume and pressure. The latter is termed inadvertent PEEP, (also known as occult, intrinsic, and auto-PEEP). Theoretically, this may be beneficial in some circumstances, but in practice it is difficult to measure and may easily result in compromise of ventilation and the need to use higher pressures in order to compensate.

If one wishes to avoid the above situation, Te should always be set just beyond the point where expiratory flow ceases.

If the respiratory rate needs to be increased and Te is longer than it needs to be, it can be shortened to the point where expiratory flow has ceased (fig 4). This will avoid wasted time after the end of a respiratory cycle, and enables the next breath to be delivered as soon as possible, without compromise of the preceding breath. (The I:E ratio and MAP will automatically increase as well. If this is not a desired effect, other parameters may have to be readjusted to maintain the status quo.)

What are VT and MV?

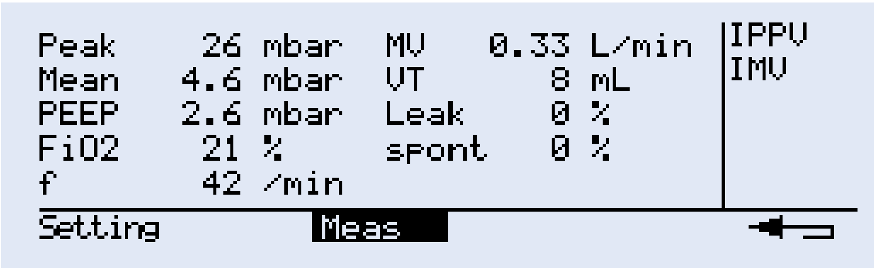

Fig 6: Example of the Babylog »measurements« screen

In the top right-hand corner of the screen (set on measurements, not settings) there are two values called VT and MV. These are both measurements of volume and are derived from the flow sensor by automatic processing within the ventilator.

VT stands for **Tidal Volume**. A tidal volume is the amount of gas or air breathed in or out in one breath. It is measured in millilitres (ml), and in this case it is the expired gas that is measured, i.e. what actually comes out of the lungs.

MV stands for **Minute Volume** or **Minute Ventilation**. This is the amount of gas that is breathed in or out over one minute. Again, it is the expired gas that is measured but now the units are in **litres/min (L/min)**. This is why the number appears smaller than the value for a single breath or tidal volume.

Multiplying tidal volume by the number of breaths per minute gives the minute volume:

MV = VT x Rate

This formula is accurate when each tidal volume is the same size. In practice though, there is considerable breath-to-breath variation in tidal volumes unless a baby is paralysed. This averages out over a minute, and the MV displayed by the ventilator is measured continuously and remains more stable than VT under constant conditions. The figure shown is a rolling average depicting the measured MV.

What is the »Normal« VT ?

There may be a wide range of VT in a spontaneously breathing baby. Spontaneous breaths tend to be smaller and triggered or ventilator breaths larger.

VT depends on several factors, including the size of the lungs (or baby), their compliance/stiffness, and the pressure and other ventilator settings used (figure 7).

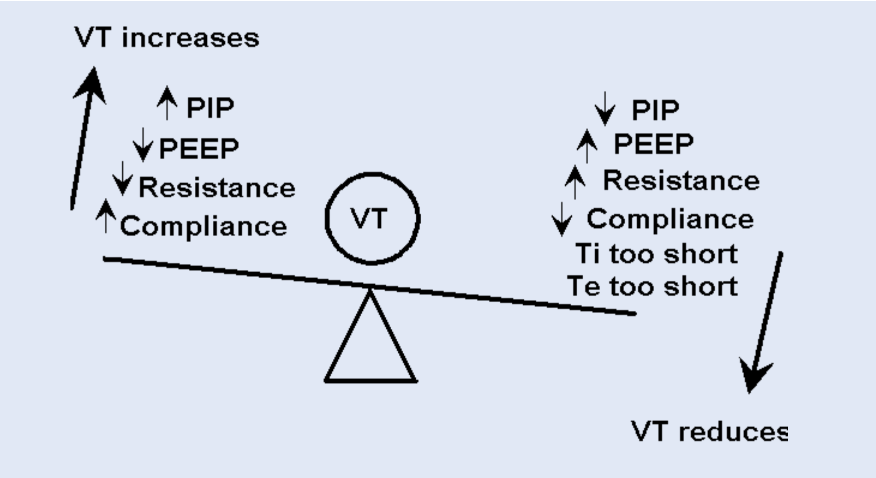

Fig 7: Factors affecting tidal tolume

There is no real agreement or proof of exactly what size VT should be but many clinicians aim for a range of **4-7ml/kg**. The reasoning behind this relates to the entity of dead space and the concept of lung overdistension.

Dead Space

Ventilation with small tidal volumes, even at high rates, can lead to ineffective CO_2 exchange. This is because about 2ml/kg of each breath does not reach the alveoli, but remains in the bronchial tree, and consequently does not participate in gas exchange. This is called the anatomical dead space. In addition there is usually additional dead space, physiological (lung units that are ventilated but not perfused) and mechanical (ET tube, especially if too long!).

Overdistension

Over-inflation may damage even normal, mature lungs. It is still not clear whether this is the result of high pressures, excessive volumes, or a combination of both. The situation in the structurally immature lung, particularly in the absence of surfactant is critical in this respect. As we know, barotrauma causes pulmonary airleak, resulting in either acute pneumothorax or the more insidious pulmonary interstitial emphysema (PIE). In the same way chronic lung disease /broncho-pulmonary dysplasia (BPD) is also partly due to the use of high ventilator pressures. The effects of pressure and volume are difficult to differentiate from one another, but we can speculate that preventing overdistension by controlling VT may result in less damage to the lung. For this reason, we would not advocate delivery of VT in excess of 10 ml/kg in most circumstances.

What is the »Normal« MV?

Again this depends upon several factors: the size of the baby, the condition of the lungs and the quantity of CO_2 produced by the body for excretion via the lungs. We have found the published values to be of relatively little practical help when ventilating preterm babies with respiratory distress.

However the measurement and monitoring of MV has proved extremely useful for the following reasons:

1. CO_2 control

CO_2 exchange is inversely proportional to MV (in accordance with the Alveolar Ventilation Equation, see footnote1). This means that if a baby is hypercapnic, the logical way to reduce the $PaCO_2$ is to increase the MV. Conversely, if a baby is hypocapnic, the MV can be **decreased** to correct it.

It is especially useful if there is a record of a recent MV value during a period of normocapnia, as this provides a figure to aim for. There are many ways in which one can manipulate the MV, and of course this must be appropriate to the other clinical conditions such as oxygenation and MAP. In order to successfully manipulate MV, a working knowledge of the determinants of VT is essential. This will be discussed in more detail along with the clinical examples.

2. Warning Alarms

MV alarms can provide warning of changing clinical conditions, providing the alarm limits are appropriately set. The most common reason for these alarms sounding is failure to reset them when the MV has deliberately been altered!

MV alarms may reflect a change in the VT. An increase or »MV high« alarm can alert one to improving lung compliance, say after treatment with exogenous surfactant, and this situation demands reduction in ventilation pressures if overdistension is to be avoided. A reduction or »MV low« alarm can warn of impending deterioration such as worsening of compliance during the initial phases of respiratory distress. This indicates the need to re-check arterial blood gases and make ventilator adjustments if appropriate.

MV alarms may reflect changes in respiratory rate, such as an increase during periods of spontaneous activity, or a reduction if no activity occurs for a while.

1) Alveolar Ventilation Equation, $PaCO_2 = VCO_2 / MVA + K$, where VCO_2 is the rate of CO_2 production, MVA is the alveolar MV and K is a constant.

How should the MV alarms be set?

The answer is: according to the clinical condition. In a sick baby with stiff lungs in whom gas exchange demands the use of high pressures and high inspired oxygen fraction, the titration of VT and MV are obviously more important than in a baby who is breathing spontaneously with very little help from the ventilator.

In the first case, it would be advisable to set the MV alarms at +/-10% around the appropriate MV, that is the MV at which the baby is normocapnic and the VT is within the normal range.

Clearly, as clinical improvement begins, one can afford to relax the MV alarms, say to +/-20%, and then to +/-30% during weaning.

Common Reasons for MV Alarms Sounding

»MV low«	»MV high«
Incorrectly set alarm limits	Improving lung conditions
Deteriorating lung conditions	Increased triggering in SIPPV
Endobronchial intubation	Incorrectly set alarm limits
	Increased respiratory rate

Leaks

The **magnitude** of leak around the ETT is calculated from the measurements of inspiratory and expiratory flow. The **direction** is not indicated, i.e. whether the leak is occurring during inspiration or expiration.

The significance of this is that in the presence of sizeable leaks, exceeding 20-30%, one cannot be confident of the accuracy of the measured VT. Leaks of less than 10% are not displayed.

Warning: - regarding failure to achieve set peak pressure (or disparity between pressure readings on settings and measurements screens).
If the working flow rate is inadequate you will see that the pressure wave has a slow rise and may fail to reach a plateau, looking triangular in shape. Under these circumstances the flow rate must be increased in order to achieve the desired peak pressure. This is analogous to »squaring« the pressure wave for the purpose of increasing the mean airway pressure and arterial oxygenation at any given ventilator settings.

Clinical Examples

We have chosen three examples which illustrate the use of VT and MV in different ways. You can assume in each case that the flow waves are not compromised before or after the ventilation changes.

We shall assume the following as normal ranges for arterial blood gases:

pH 7.30 - 7.40 pCO_2 4.0 - 5.5 kPa pO_2 5.5 - 8.0 kPa

If you are more familiar with mmHg, multiply these values by 7.6 (or x 8 as a rough guide).

Units of measurement

The units of pressure displayed by the Babylog are millibars. These are almost identical to cmH_2O and can be used interchangeably.

Ti and Te are shown in seconds, or fractions thereof.

Inspired oxygen is in percentage.

Volumes are shown in ml for VT and litres/min for MV.

Example 1: Respiratory acidosis in a baby with RDS

Case history:
Baby T. 28 weeks gestation, birth weight 0.80kg. Ventilated from birth for hyaline membrane disease, now 48hrs of age. Arterial blood gases and ventilator settings as follows:

Arterial Blood Gases				Settings					Volumes		
pH	pCO_2	pO_2	bic	Pip/ Peep	MAP	rate	Ti	Te	O_2	Vt	MV
7.19	8.1	8.7	19	26/5	13	66	.45	.45	66	2.1	.14

Fig 8: Initial arterial blood gases, ventilator settings and measurements

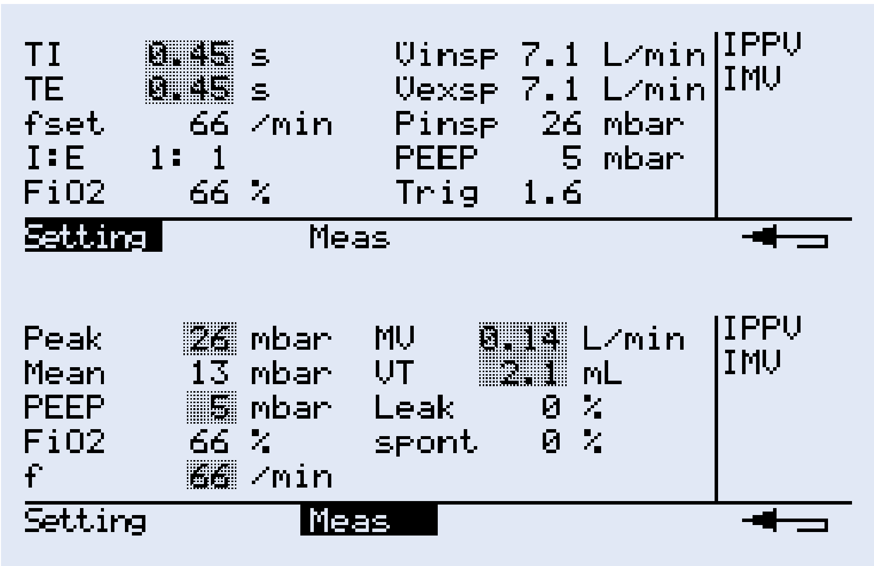

Fig 9: Settings and measurements as shown on Babylog screen

Comments

CO_2 retention causing acidosis (no metabolic component).

VT is on the low side, working out at only 2.6 ml/kg.

Flow tracings show a short lung time constant, with the lungs filling and emptying in about 0.3s, and no compromise of flow.

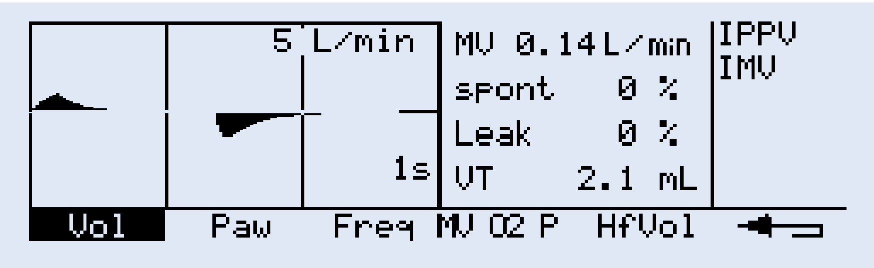

Fig 10: Flow tracing showing a short lung time constant

Aims

– Keep pO_2 as it is, by maintaining MAP and O_2 the same.
– Reduce pCO_2 by increasing MV: we shall need quite a large increase in MV as the CO_2 is quite high.

1st step - improve VT

In this case VT is so low per kg, the first step should be to optimise it (aiming for around 5ml/kg) in order to overcome the effect of dead space. As flow is not compromised here, we can try increasing the peak pressure a bit and dropping the PEEP a bit. Both of these manoeuvres will increase VT per se. The MAP will stay roughly the same.

2nd step - increase rate

Optimising VT may not be enough on its own to get the pCO_2 down, so we should also consider increasing the rate to further increase the MV. Checking the flow tracings, we can shorten Ti and Te a little, deliberately maintaining the I:E ratio so as not to change the MAP.

Now check the MAP: if it has altered a bit we may have to compensate by adjusting the inspired oxygen.

Here are the settings these manipulations have brought about:

Settings						Volumes	
Pip/Peep	MAP	rate	Ti	Te	O_2	Vt	MV
28/3	13	75	.4	.4	66	3.5	0.63

Fig 11: Ventilator settings and measurements adjusted according to therapeutic aims

Note: VT is now 4.3 ml/kg which is within the recommended range.

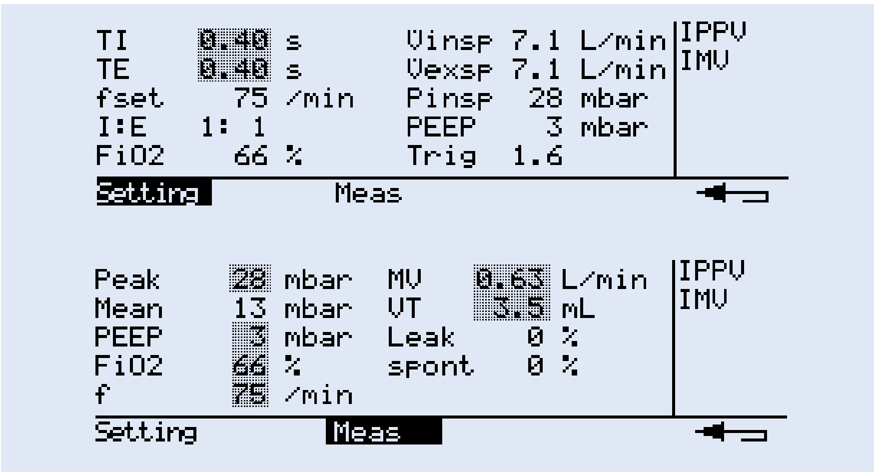

Fig 12: Settings and measurements as shown on the Babylog screen

Here are the blood gases half an hour later:

Arterial Blood Gases			
pH	pCO_2	pO_2	bic
7.32	5.6	8.6	20

Fig 13: Improved arterial blood gases resulting from ventilator adjustments

This is the flow tracing half an hour later:

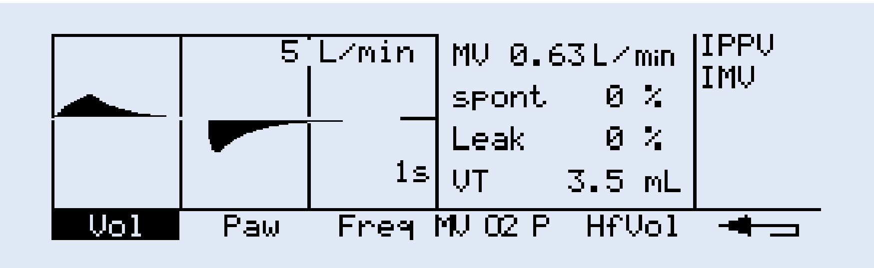

Fig 14: Flow tracing showing a longer lung time constant yet still without compromise of flow

Example 2: Respiratory alkalosis in a baby with BPD following a PDA ligation

Case history:
Baby D. Born at 26 weeks gestation, birth weight 0.650kg. Ventilated from birth for RDS, now 29 days old (0.7kg) with BPD. Still ventilator-dependent, despite two courses of steroids. Planned surgical ligation of patent ductus arteriosus.

Ventilation stable prior to surgery:

Arterial Blood Gases				Settings					Volumes		
pH	pCO_2	pO_2	bic	Pip/ Peep	MAP	rate	Ti	Te	O_2	Vt	MV
7.40	4.7	8.8	22	22/3	7.8	35	.5	1.2	35	4.3	.15

Fig 15: Initial arterial blood gases, ventilator settings and measurements

```
TI      0.50 s        Vinsp 7.1 L/min  IPPV
TE      1.20 s        Vexsp 7.1 L/min  IMV
fset      35 /min     Pinsp   22 mbar
I:E     1: 2.4        PEEP     3 mbar
FiO2      35 %        Trig  1.6
Setting         Meas

Peak      22 mbar    MV    0.15 L/min  IPPV
Mean     7.8 mbar    VT     4.3 mL     IMV
PEEP       3 mbar    Leak     0 %
FiO2      35 %       spont    0 %
f         35 /min
Setting          Meas
```

Fig 16: Settings and measurements as shown on the Babylog screen

Following transfer, anaesthesia and surgery the baby returned to the neonatal unit with these gases and ventilator settings:

Arterial Blood Gases				Settings					Volumes		
pH	pCO_2	pO_2	bic	Pip/ Peep	MAP	rate	Ti	Te	O_2	Vt	MV
7.58	2.2	10	16	27/4	9.0	30	.5	0.65	50	6.7	.20

Fig 17: Arterial blood gases, ventilator settings and measurements past surgery

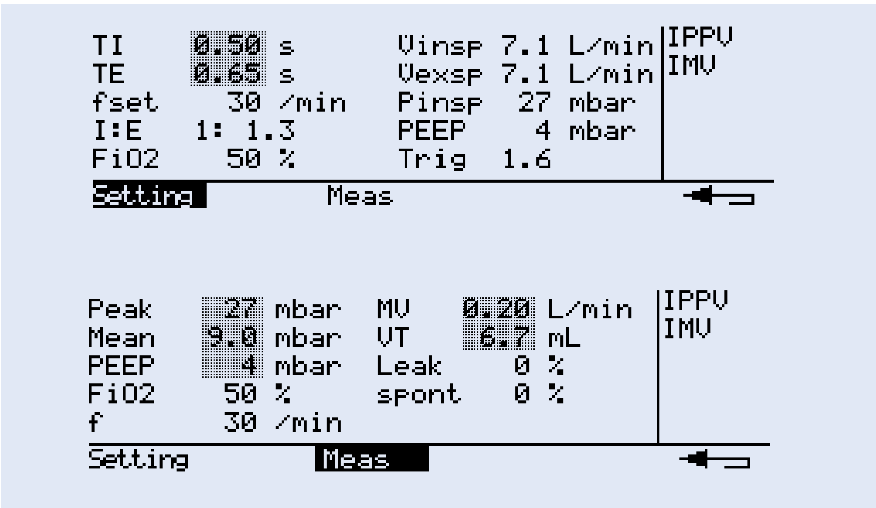

Fig 18: Settings and measurements as shown on the Babylog screen

Comments
pCO_2 very low leading to a respiratory alkalosis. PO_2 high.

VT high, almost 10ml/kg. Ventilator settings have been altered to compensate for peri-operative changes. Lung compliance and oxygen requirements are likely to have changed since surgery.

Flow tracings show Ti matches lung inflation time well, with no compromise, either in inspiration or expiration.

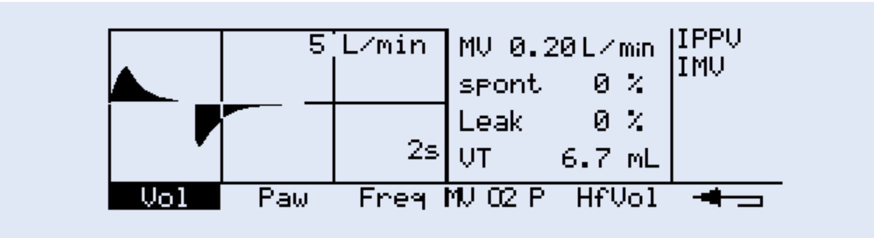

Fig 19: Flow trace showing no compromise in inspiratory or expiratory flow

Aims

– Reduce pO_2 either by maintaining MAP and reducing inspired oxygen or vice versa, or a bit of each.
– Allow pCO_2 to rise by decreasing MV: as the CO_2 is so low the MV may have to be considerably reduced. The pre-operative value will probably no longer be appropriate in this case, as a lot has changed in a few hours.

1st step - reduce VT

Aim for 5-6ml/kg, by reducing the pressures. It is likely that less peak pressure will be required to maintain the same VT as previously, because lung compliance has probably improved.

Let's consider Peep first - a Peep of 4 is probably no longer needed as oxygenation is good, thus the Peep can be reduced a little. However, this will **increase**, rather than diminish the VT.

So now the peak pressure needs to be reduced to balance out the increase resulting from the Peep change as well as the large starting VT. Slowly reduce Pip until the measured VT comes within the required range. As long as you are monitoring the VT, it is safe to make relatively large pressure changes over the course of several minutes. If you could not see the effects of these changes (in the absence of VT monitoring) you would probably have to accomplish this in multiple small steps over a longer time period.

2nd step - reduce the rate

Now that VT has been optimised, we probably also need to reduce the MV a bit further by reducing the rate. We can do this by lengthening Te a bit, and leaving Ti as it is (especially if it already matches lung inflation time).

Now take note of the MAP: it has decreased as a result of the changes we have made, which fits in with our intentions regarding pO_2.

Here are the settings these manipulations have brought about:

Settings					Volumes		
Pip/ Peep	MAP	rate	Ti	Te	O_2	Vt	MV
20/3	6.5	25	.5	1.9	50	4.1	0.11

Fig 20: Ventilator settings and measurements adjusted according to therapeutic aims

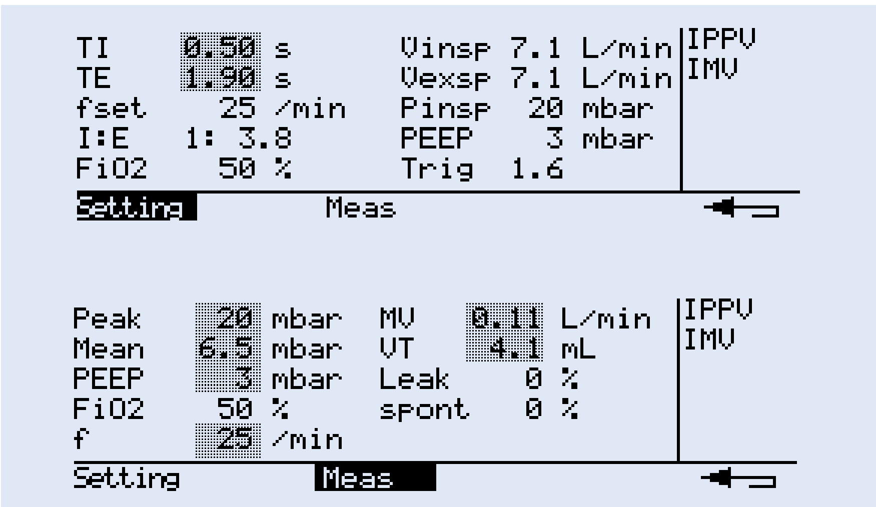

Fig 21: Settings and measurements as shown on the Babylog screen

Here are the blood gases twenty-five minutes later:

Arterial Blood Gases			
pH	pCO_2	pO_2	bic
7.39	4.5	8.5	20

Fig 22: Improved arterial blood gases resulting from ventilator adjustments

Example 3: Normal arterial blood gases but excessive tidal volume in a preterm baby

Case history:
Baby K, born at 26 weeks gestation weighing 700g. Maternal steroids given during 48hrs prior to delivery. Poor Apgar scores at birth intubated immediately and ventilated. Now 10 hrs old with good oxygen saturation and CXR looks almost clear.

Arterial Blood Gases				Settings					Volumes		
pH	pCO_2	pO_2	bic	Pip/ Peep	MAP	rate	Ti	Te	O_2	Vt	MV
7.35	5.0	8.0	20	22/3	6.0	23	.5	2.1	35	7.9	.18

Fig 23: Initial arterial blood gases, ventilator settings and measurements

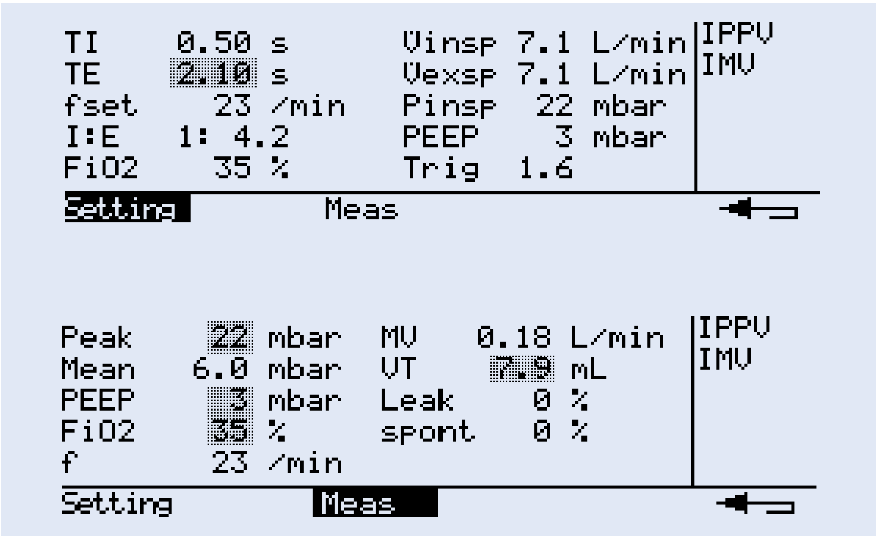

Fig 24: Settings and measurements as shown on the Babylog screen

Comments

This baby's blood gases are normal at reasonable ventilation settings. However, he is receiving a VT of about 12 ml/kg. This is because his lungs are relatively compliant now. If this overdistension is allowed to continue, the lungs may become damaged solely as a result of the ventilation.

Aims

- Reduce the VT
- Maintain the same MV and normal gases.

1st step - reducing VT

This can be done as in the previous example, by slowly reducing the Pip whilst watching the effect on VT, and aiming for about 6ml/kg. Remember that while you are doing this the MAP will fall and you may need to temporarily increase the inspired oxygen until you have finished all the manipulations.

Do not use increases in Peep for the purpose of reducing VT, unless you also need to increase the MAP, as this will not make any difference to lung overdistension.

2nd step - compensation for MV

Now that we have reduced VT, in order to maintain the MV at its previous level we need to increase the frequency. (Remember, MV = VT x rate).

So, by reducing Te (and checking the flow tracing) we can both increase the rate (and MV) and also boost the MAP again by increasing the I:E ratio. We may need to increase the inspired oxygen slightly to compensate for any small loss in MAP.

Here are the ventilator settings resulting from these changes:

Settings					Volumes		
Pip/ Peep	MAP	rate	Ti	Te	O_2	Vt	MV
15/3	5.7	40	.5	1.0	40	4.5	0.18

Fig 25: Ventilator settings and measurements adjusted according to therapeutic aims

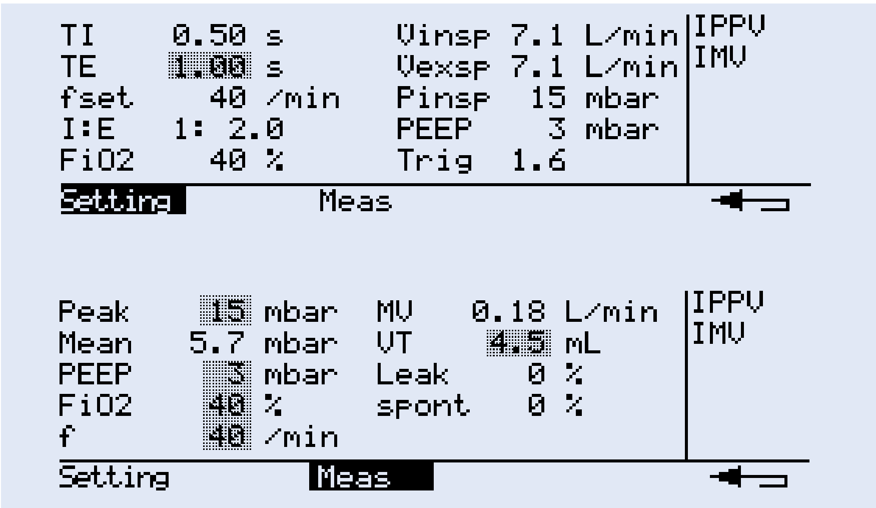

Fig 26: Settings and measurements as shown on the Babylog screen

Here are the next set of gases, one hour after the changes:

Arterial Blood Gases			
pH	pCO_2	pO_2	bic
7.39	4.7	8.2	21

Fig 27: Improved arterial blood gases resulting from ventilator adjustments

Suggested Guidelines for Use of Flow waves, VT and MV

- Record VT and MV on a regular basis, ideally at the same time as the hourly observations, along with the ventilator settings.

- Note the VT and MV before you sample arterial blood for gas analysis, and record the changes you make to them as a result of any ventilator manipulations.

- Get used to looking at flow waves regularly until they become familiar to you.

- Get into the habit of setting and using MV alarms.

- Aim to ensure both the inspiratory and expiratory time settings are of sufficient duration to allow inspiratory and expiratory flow to be complete.

- Aim to maintain VT between 4-6ml/kg. Try not to exceed 10 ml/kg as this may cause trauma to the lung. If blood gases are good, VT < 5ml/kg is perfectly acceptable.

- If $PaCO_2$ > 5.5kPa, reduce by increasing MV, by altering rate and/or VT as appropriate, bearing the above points in mind. Your manipulations must also take account of the desired mean airway pressure, depending on PaO_2.

- If $PaCO_2$ < 4kPa, attempt to increase it by reducing the MV accordingly, using VT and/or rate adjustments as judged most appropriate in light of the above constraints.

- In the event of marked hypo or hypercarbia, it would be useful to look back and find a recent blood gas result demonstrating normocarbia, and the accompanying MV at the time. This will provide a landmark to aim for, unless lung conditions have changed rapidly since.

Caveat: Normal gases may not mean optimal ventilation!

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