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Blood Gas and Ventilator Manual for House Staff on Pulmonary Service

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**Blood Gas and
Ventilator Manual
for
House Staff
on
Pulmonary Service**

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ARTERIAL BLOOD GASES

pH	=	7.38 to 7.42
pCO ₂	=	40 MM HG
PO ₂	=	70 to 100 mm Hg
HCO ₃	=	23 to 25 meq./l.

pH

1. Definition: A measure of acidity in relation to body bases.
2. Determined by the Henderson-Hasselbalch relationship:

$$\text{pH} + \frac{\text{HCO}_3}{\text{pCO}_2} = \frac{\text{kidney}}{\text{lung}}$$

pCO₂

1. Definition: Pressure exerted by CO₂ (not a direct measurement of amount)
2. Determined by and is equal to the Alveolar Ventilation Equation:

$$\dot{V}_A = (T.V. - D.S.) R$$

where \dot{V}_A = alveolar ventilation or that volume of air reaching the alveoli.
T.V. = tidal volume
D.S. = dead space, the volume of air in the tracheobronchial tree which is not available for gas exchange.
R. = rate

USEFUL TERMS REGARDING THE pCO₂:

1. Hyperventilation: pCO₂ ↓ 35 mmHg
2. Hypoventilation: pCO₂ ↑ 45 mmHg

These are blood gas diagnoses (lab), do not confuse with "TACHYPNEA" which means an increase in respiratory rate and is a physical diagnosis.

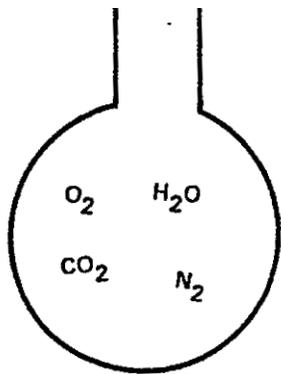
BICARBONATE ION HCO₃

1. Definition: Direct measurement of base solute in a solvent (blood) - - - a measurement of amount.
2. Control of this ion is by the kidney which excretes or retains it.

P_aO₂ (Determined by Blood Analysis)

1. Definition: The pressure exerted by O₂ in the alveolus, is not a direct measurement of amount.
- A - a Gradient: The difference between the O₂ pressure in the alveolus and the capillary.

CALCULATION OF THE A - a GRADIENT:



$$\begin{aligned}
 pA_{O_2} &= pI_{O_2} - \frac{pCO_2}{.8} \\
 pI_{O_2} &= (pB - 47) Fi_{O_2} \\
 pI_{O_2} &= \text{pressure of inspired } O_2 \\
 pB &= \text{barometric pressure} \\
 47 &= \text{pressure of water vapor} \\
 Fi_{O_2} &= \text{the fraction of inspired } O_2 \\
 &= \text{(express as decimal)}
 \end{aligned}$$

CALCULATION OF THE A - a GRADIENT:

What is the A - a Gradient if the $fIO_2 = .21$ (air), $pCO_2 = 40$ and the $PaO_2 = 60$?

$$\begin{aligned} pAO_2 &= pIO_2 - \frac{pCO_2}{.8} \\ &= (760 - 47) .21 - \frac{40}{.8} \\ &= 150 - 50 \\ pAO_2 &= 100 \\ &= 100 - 60 \\ A - a &= 40 \end{aligned}$$

O₂ IN GENERAL

Carried in the blood in two forms: dissolved and in combination with Hb.

1. Dissolved: Obeys Henry's Law - - the amount dissolved is proportional to the partial pressure.
There is .003 ml O₂/100 ml blood for each mmHg PaO₂ so that arterial blood with a PaO₂ of 100 mmHG contains .3 ml O₂/100 ml (or .3 vols%).
2. In combination with Hb:
1 gm Hb can combine with 1.39 ml O₂ so 15 gm Hb can combine with 20.8 ml O₂/100 ml blood.

O₂ TERMS

1. O₂ Capacity: max amount of O₂ that can combine with Hb at full saturation.
2. % Saturation:
$$= \frac{O_2 \text{ combined with Hb}}{O_2 \text{ Capacity}} \times 100$$
3. O₂ Content: O₂ combined with Hb plus O₂ dissolved in the plasma.

CLINICAL APPLICATION:

Bleeding patient with 7.5 gm Hb. The patient has severe dyspnea (labored breathing), but the PaO₂ is 100 mmHg.

$$\begin{array}{rclcl} \text{O}_2 \text{ combined} & = & 7.5 & \times & 1.39 & = & 10.4 \\ \text{O}_2 \text{ combined} & = & 100 & \times & .003 & = & \underline{.3} \\ \text{O}_2 \text{ content} & = & & & & & 10.7 \text{ ml O}_2/100 \text{ ml blood} \end{array}$$

The normal O₂ content is 21 ml O₂/100 ml blood.

The above patient demonstrates severe dyspnea in a hemorrhagic situation and although the PaO₂ is 100 mmHg, the patient is dyspneic because the amount of O₂ measured as content is markedly decreased 10.7 ml O₂/100 ml blood.

Remember, the PaO₂ reflects dissolved PaO₂ in plasma. The important O₂ is carried by hemoglobin.

CAUSES OF HYPOXEMA (West - Pulmonary Pathophysiology)

1. Hypoventilation
2. Diffusion Impairment
3. Shunt
4. Ventilation - perfusion inequality
5. Low Oxygen Environment

ACID BASE DIAGNOSIS

DEFINITIONS:

RESPIRATORY ACIDOSIS
 RESPIRATORY ALKALOSIS
 METABOLIC ACIDOSIS
 METABOLIC ALKALOSIS

pH	PCO ₂	HCO ₂
↓	↑	
↑	↓	
↓		↓
↑		↑

The above chart illustrated four categories of blood gas diagnosis. If you think of your patient as falling into one or another category, therapy can be simplified. Combinations can occur and require multiple regimens.

Metabolic or HCO₃ problems are handled naturally via the kidney. These problems do cause shifting of electrolytes so that electrolytes are either excreted or retained by the kidney.

ACID BASE EFFECT ON ELECTROLYTES

METABOLIC ALKALOSIS
 METABOLIC ACIDOSIS

pH	H ⁺	Na ⁺	K ⁺	Cl ⁻	HCO ₃ ⁻
↑	↓	↑	↓		↓
↓	↑	↓	↑		↑

KEY

A1 K⁺ loss is

Compensatory mechanisms are opposite so alkalosis corrects by acidosis and vice versa. Na⁺ exchanges for H⁺ or K⁺ in the kidney pCO₂ regulated by alveolar ventilation of the lung.

There are three major positive ions H⁺, Na⁺, K⁺, and two major negative ions Cl⁻, HCO₃⁻ that must be considered.

Consequently, looking at the chart above on electrolyte effects of Metabolic Acidosis and Metabolic Alkalosis, you can see retention or excretion by the kidney of these ions.

A good way to memorize the effects is to look at the term Metabolic Alkalosis. The term AL K⁺ Loss demonstrates K⁺ Loss. Also, metabolic alkalosis by definition is increased pH with increased HCO₃⁻. This leaves only two ions to account for Cl⁻ and Na⁺.

In order to balance out the negative compartment, since HCO₃⁻ is increased, then Cl⁻, is decreased. The same applies to the positive compartment. If pH is increased (definition of alkalosis), the H⁺ must be decreased. The K⁺ is down because of AL K⁺ Loss is so in order to balance out the positive compartment, the Na⁺ must decrease. So what then could be a possible treatment for Metabolic Alkalosis -- H⁺ ion in the form of arginine. H⁺, Cl⁻ or KCl.

Metabolic Acidosis follows exactly opposite that of metabolic alkalosis, so that the treatment is Na⁺ and HCO₃⁻.

COMMON CAUSES OF METABOLIC ACIDOSIS

pH ↓ HCO₃ ↓

1. Diabetes
2. Renal Failure
3. Lactic Acidosis
4. Diarrhea

COMMON CAUSES OF METABOLIC ALKALOSIS

pH ↑ HCO₃ ↑

1. Vomiting
2. N-G Suction
3. Drugs (diuretics, steroids, antacids)
4. Hypokalemia Al K⁺ loss

CORRECTION OF METABOLIC ACIDOSIS

pH ↓ HCO₃ ↓

$$\text{Meq. of NaHCO}_3 = 0.2 \times \text{kg (body weight)} \times \Delta \text{Base}$$

EXAMPLE:

$$\text{pH} = 7.02$$

$$\text{HCO}_3 = 10 \quad \text{QUESTION: Correct the pH to calculated 7.4}$$

Patient weighs 70 kg.

$$\text{pCO}_2 = 40$$

Determination of the Δ B from Siggard-AnJerssen Alignment Nomogram:

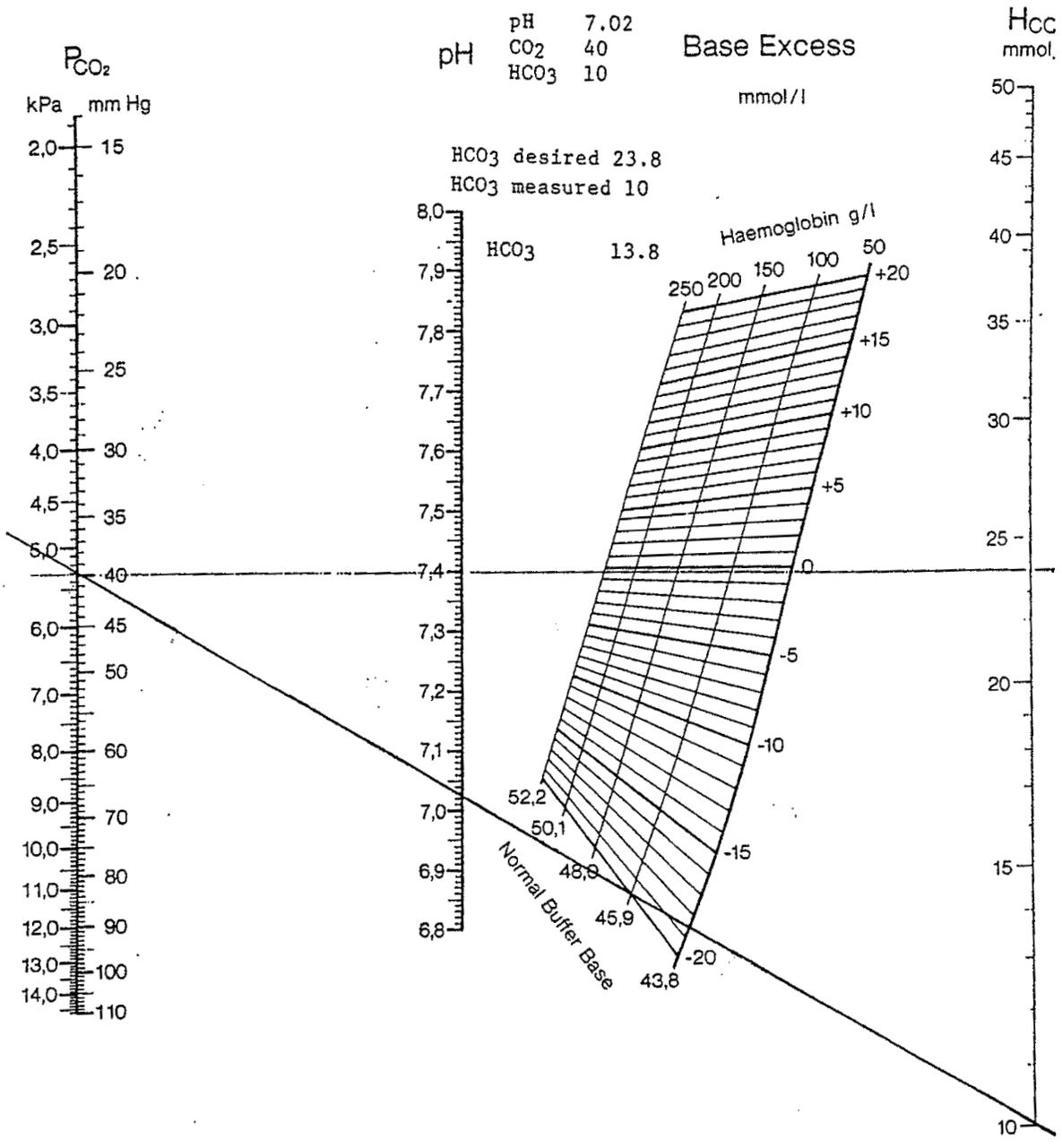
1. First draw a straight line between the above blood gas parameters.
2. Second, draw a straight line from the pCO₂ through the pH you want the patient to have, say for example, 7.4. The line will intersect an HCO₃ level of 23.8
3. You have 10 meq/L of HCO₃ on board for a pH of 7.02 want to increase the level of HCO₃ to 23.8 or planned pH of 7.4

So:

HCO ₃ desired	23.8
HCO ₃ on board	10
<hr/>	
Δ B	13.8

$$\begin{aligned} \text{And: Meq. of NaHCO}_3 &= 0.2 \times 70 \times 13.8 \\ &= 193 \text{ meq. needed to correct to a pH of 7.4} \end{aligned}$$

METABOLIC ACIDOSIS



CORRECTION OF METABOLIC ALKALOSIS

pH ↑ HCO₃ ↑

$$\text{Meq. of Arginine} \bullet \text{HCl} = 0.2 \times \text{kg (body weight)} \times \Delta \text{Base}$$

EXAMPLE:

$$\text{pH} = 7.7$$

$$\text{HCO}_3 = 44.5$$

$$\text{pCO}_2 = 40$$

QUESTION: Correct the pH to calculated 7.4
Patient weighs 70 kg.

Determination of the Δ B from Siggard-AnJerssen Alignment Nomogram:

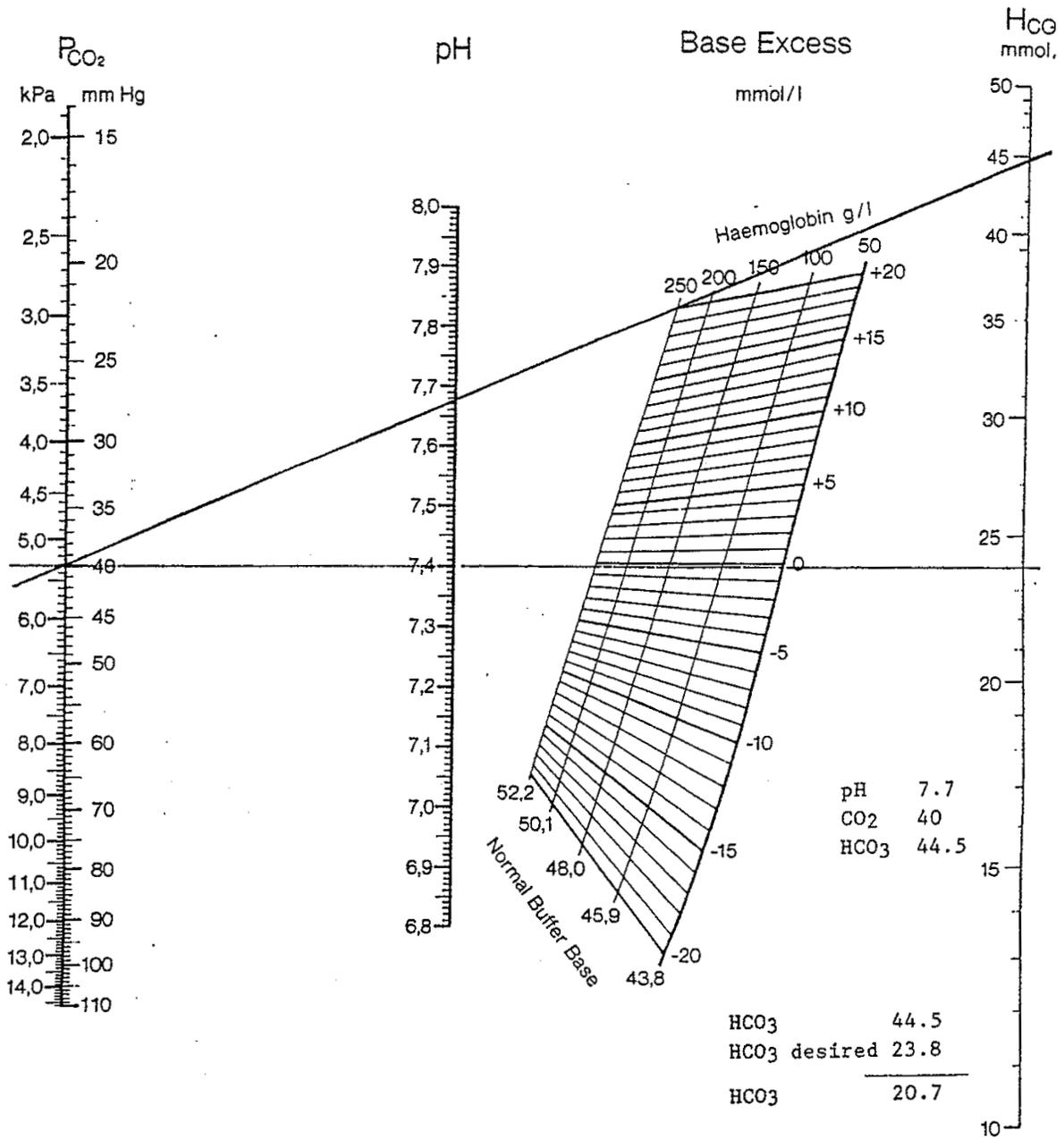
1. First draw a straight line between the above blood gas parameters.
2. Second, draw a straight line from the pCO₂ through the pH you want the patient to have, say for example, 7.4. The line will intersect an HCO₃ level of 44.5
3. You have 44.5 meq/L on board for a pH of 7.7, and you want to decrease the level of HCO₃ to 23.8 or planned pH of 7.4

So:

HCO ₃ on board	44.5
HCO ₃ desired	<u>23.8</u>
Δ B	20.7

And: $\text{Meq. of Arginine} \bullet \text{HCl} = 0.2 \times 70 \times 20.7$
= 290 meq. of Arginine • HCl needed to correct
to a pH of 7.4

METABOLIC ALKALOSIS



COMMON CAUSES OF RESPIRATORY ACIDOSIS

pH ↓ pCO₂ ↑

1. COPD - asthma, bronchitis, emphysema
2. Depression of the respiratory center -- anesthesia, drugs
3. Traumatic - flail chest
4. Polio

COMMON CAUSES OF RESPIRATORY ALKALOSIS

pH ↑ pCO₂ ↓

1. Emotion or pain
2. Pneumonia
3. CHF
4. Pulmonary Embolism

Respiratory acidosis and alkalosis are based on the CO₂ level and treatment must be directed at the etiology. Since artificial ventilation is the final pathway of hypoventilation, all modes of improving ventilation should be attempted prior to intubation and ventilation. In some cases, only experience can teach you when intubation is necessary. Let the pH that the pCO₂ produces, serve as a guide. Now, look at the patient - does he have progressive disease or one which can be reversed?

Usually, the obstructive pulmonary problems causing respiratory acidosis can be readily treated with IV and inhaled bronchodilators. IV steroids may also be useful, though in the acute phase, they play a more complementary role. There is another trick for lowering CO₂ which will be explained in the ventilator section.

Drug overdose and anesthesia take time to leave the body, and intubation and ventilation are necessary until detoxification occurs.

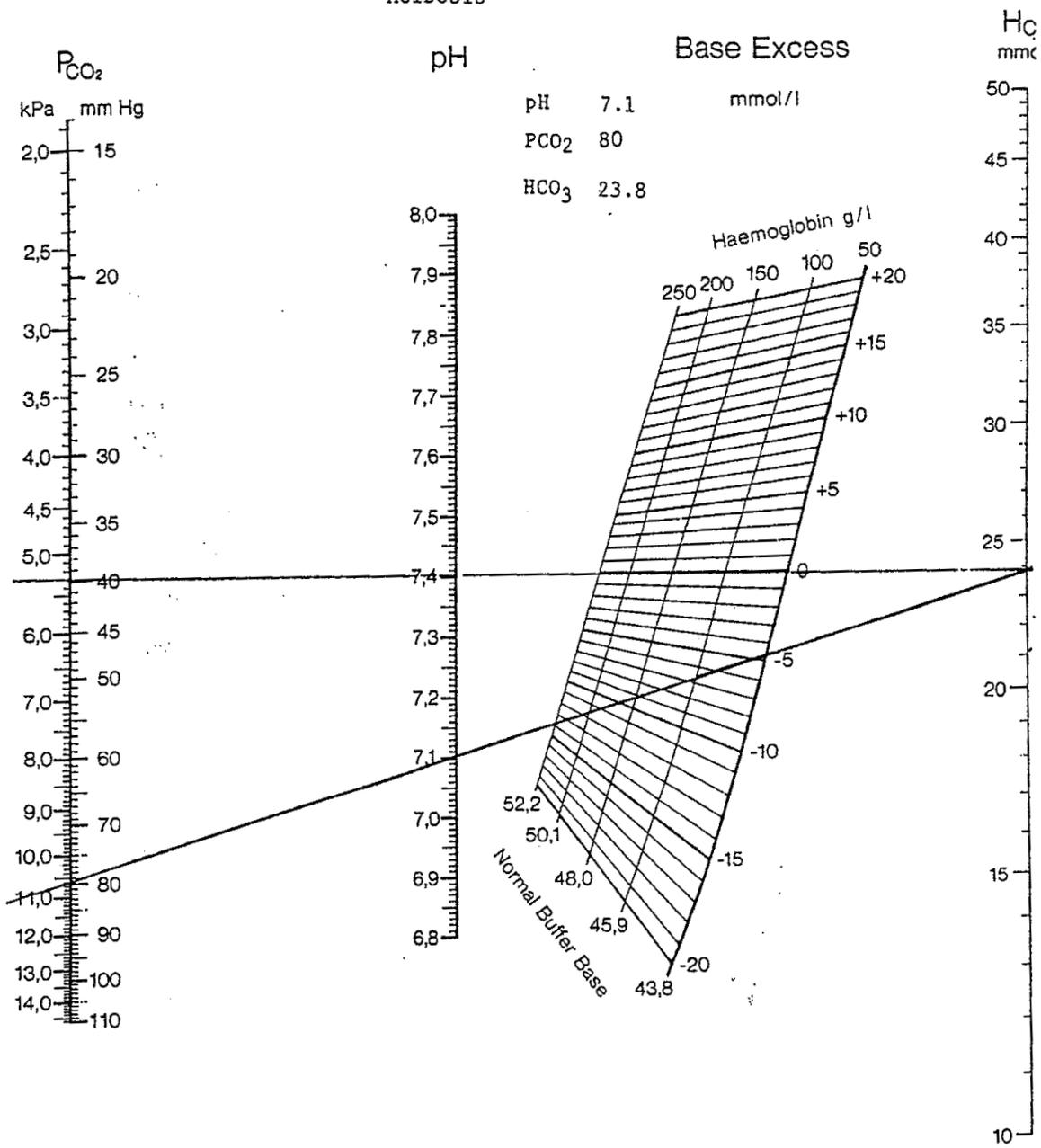
Traumatic flail chest injury is also another reason for intubation and ventilation, but there is also another indication for the ventilator to stabilize the chest from within.

Neurological diseases, polio, myasthenia gravis, Gullain-Barre and CVA also can produce respiratory failure. Obviously, this would demand initial ventilator support until the disease resolves.

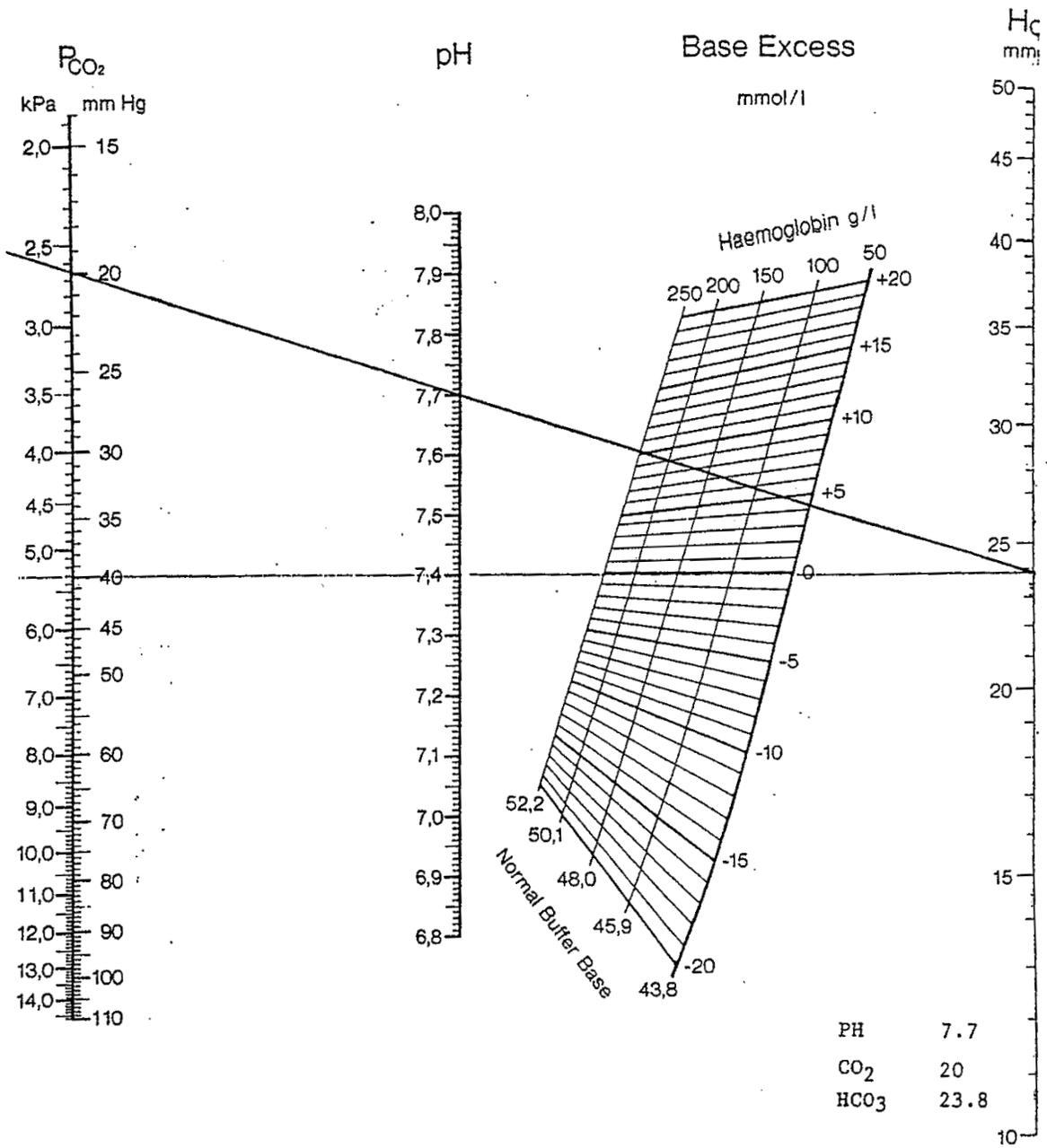
Respiratory alkalosis represents another problem, in that patients with increased respirations can tire and become apneic, causing the pCO₂ to rise, producing respiratory acidosis.

The next section on ventilators would be viewed for those problems of apnea, and hypoventilation can not be corrected in a reasonable amount of time --- seconds!

RESPIRATORY
ACIDOSIS



RESPIRATORY
ALKALOSIS



Shipping Weight (approx):

Ventilator module: 79.4 kg (175 lb).

(335 lb) - heavy packing

Ventilator module with Compressor Pedestal:

172 kg (380) - heavy packing

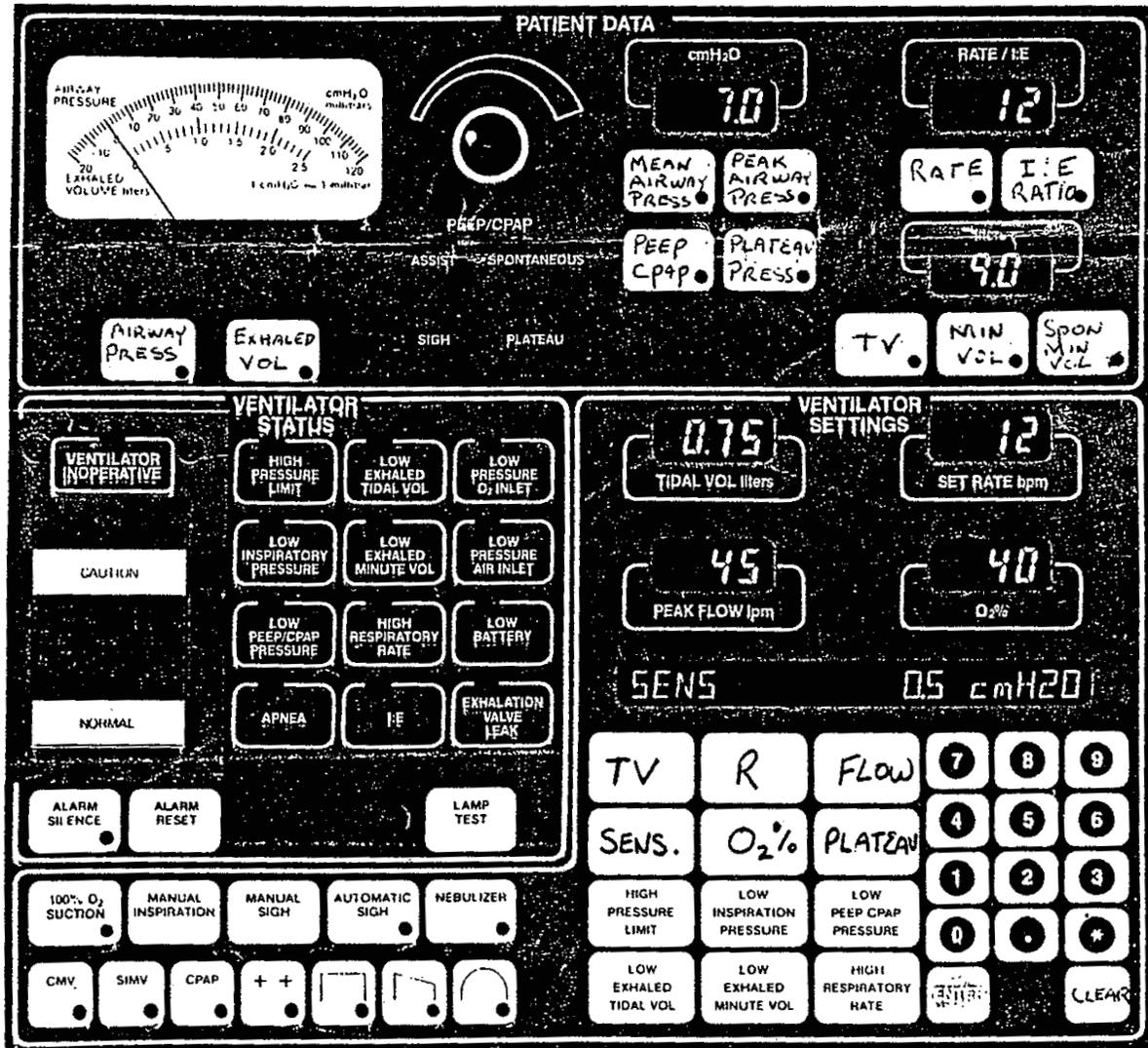
Pedestal 72.6 kg (160 lb)

Cleaning and Sterilization

- Body to control panel: Wipe clean with standard disinfectants

Exchange Autoclavable main flow bacteria filter and heated exhalation bacteria filter

All elements in the patient circuit except the O₂ sensor are autoclavable



VENTILATORS

A. pCO₂ Control

1. pCO₂ is controlled by the alveolar gas equation
$$p\text{CO}_2 \text{ A} = (\text{TV} - \text{DS}) \text{ R}$$
2. Pressure and Flow Concept
3. Difference between Volume and Pressure Ventilators (graphs)
4. Modes of Ventilation
 - CMV
 - SIMV
5. CO₂ adjusting equation
6. Setting up the ventilator
7. Hyperventilation on ventilator

B. pO₂ Control

1. pO₂ is controlled by PaO₂ which is a function of the percentage of O₂ or FiO₂
2. Shunt chart
3. How to increase PaO₂ and decreased FiO₂
 - Importance:
 - a. CPAP
 - b. PEEP

VENTILATORS

A. Think of a model ventilator as a device which controls the $p\text{CO}_2$. This is done by producing a TV (tidal volume) as a certain R (rate). This process is governed by the alveolar gas equation

$$p\text{CO}_2 \dot{A} = (\text{TV} - \text{DS}) R$$

However, in order to get the TV out of the machine and into the patient, some force must be present. This force is known as P (pressure) and the ratio of the volume per unit is F (flow).

Diagrammatically

$$p\text{CO}_2 = \begin{array}{ccc} \text{TV} & \text{X} & \text{R} \\ | & \diagdown & | \\ \text{P} & & \text{F} \end{array}$$

So on the model ventilator, the most important control for $p\text{CO}_2$ is the TV and R with P and F helping the delivery.

Consequently, any change in rate, pressure or flow will inadvertently affect the overall tidal volume, which change the $p\text{CO}_2$. The TV, P, F and R will now be called the four parameters of ventilation.

B. Difference between Volume and Pressure Ventilators

The model ventilator in paragraph A does not exist, but there are two types of ventilators in clinical use today which employ three of the four parameters of ventilation and by a delicate balance of these three parameters, the fourth parameter is accomplished.

PRESSURE VENTILATORS

Set a Pressure, Flow and Rate to obtain a certain Volume. This is a good system as long as the patient is apneic and airway pressure is stable. If the patient begins to trigger the ventilator or if more pressure is needed because of bronchospasm or secretions, the TV will change. Since man breaths and maintains his $p\text{CO}_2$ by TV, then the $p\text{CO}_2$ will change.

Pressure ventilators are not employed in the ICU area. However, for transport or a drug overdose with respiratory depression in the emergency room, this type of ventilator is satisfactory, as long as a volume ventilator is on the way.

If a pressure ventilator is used, then a respiratory therapist should be present constantly, balancing the P, F, and R, so that the TV stays constant. These machines are cheap. By the way, a bag, endotracheal tube and respiratory therapist are just as good!

VOLUME VENTILATORS

These are the state-of-the-art ventilators.

Set a Volume and Rate, give the machine enough Flow to meet the Tidal Volume and the CO₂ will be controlled.

What about Pressure? – The pressure control does not control pressure because the ventilator will generate as much pressure as it needs to deliver the pre-set volume. The pressure control is really a “blow off” device in that if one sets a volume a certain amount of pressure will be necessary to force that volume into the lungs. This amount of pressure will be regulated by the ventilator and correspond to that volume which is set. The pressure control, then, sets the highest pressure you want to deliver. If the pre-set volume needs more pressure than what is set, the pressure alarm will sound and only the volume corresponding the set pressure level will be delivered. Consequently, the patient will not receive the prescribed volume and hypoventilation with an increase in paCO₂ may results.

This protects the lung from barotrauma, such as pneumothorax. Usually, this alarm means airway obstruction, such as secretions (easily handled with suctioning). There is one critical situation in which a tear occurs in the pleura, resulting in pneumothorax. Since the patient is being ventilated with a forceful pressure, Tension Pneumothorax can occur in seconds. The pressure gauge will sound and sometimes subcutaneous emphysema will be noted. Auscultation should be performed immediately, and the side with decreased breath sounds should have a need, 20 gauge, placed in between the lateral intercostal space and open to air. Air will rush out in a hissing manner. Unfortunately, you will not have time to call for a chest film. A chest tube can then be inserted, and you will note the ventilator pressure gauge reading lower levels.

IN SUMMARY

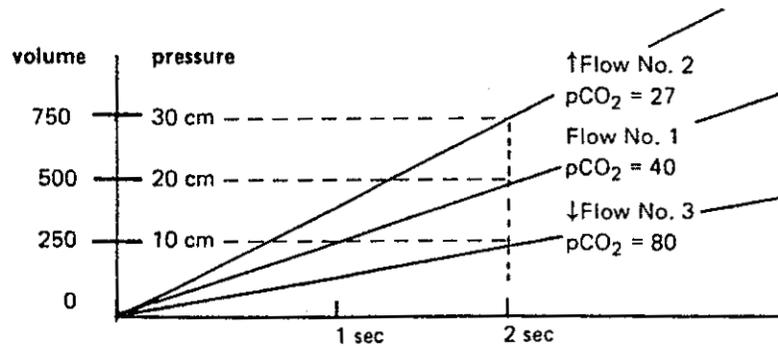
Pressure Ventilators – Set P, F, and R	TV varies
Volume Ventilators – Set TV, F and R	P varies

C. Graphic illustrations of Pressure and Volume Ventilators with regard to the four parameters of ventilation.

5. This brings us to the basic rule of the four factors of ventilation:
 “The volume, pressure, flow and rate are all interrelated. Consequently, if you change one factor, the other factors will change. Thus an alteration in \dot{A} will occur.”

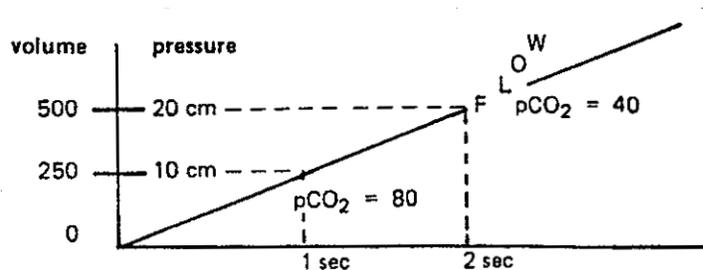
The overall effect will be a change in the $p\text{CO}_2$.

6. Example of changing the flow holding the rate constant in a pressure ventilator



Considering a TV of 500 at 20 cm with Flow No. 1 producing an \dot{A} with a $p\text{CO}_2$ of 40. Increasing the Flow to No. 2 would result in an increase in the volume to 750 with an increase in delivery pressure to 30 cm. Consequently, an increase in \dot{A} resulting in a decrease in $p\text{CO}_2$ to 27, thus causing alveolar hyperventilation. Likewise, to decrease the Flow to No. 3, a TV of 250 ml at a delivery pressure of 10 would be achieved and an increase in $p\text{CO}_2$ to 80 thus causing alveolar hypoventilation.

7. Example of changing the timing of inspiration, holding the flow constant on a pressure ventilator.



At 2.0 seconds, inspiratory time with flow constant of TV of 500 ml and a delivery pressure of 20 cm is achieved for a $p\text{CO}_2$ of 40. If you decrease the time of inspiration, the TV will decrease to 250 cc and delivery pressure to 10 cm with a resultant alveolar hypoventilation and a rise in the $p\text{CO}_2$ to 80.

8. Pressure Ventilator versus Volume Ventilator

Rule: "Man maintains his pCO₂ as a result of A."

- a. Pressure Ventilator: set the delivery pressure, the volume achieved will depend on the airways.

PROBLEM: If the airways change, that is, undergo bronchoconstriction or become full of secretions, the effective volume will fall causing alveolar hypoventilation and a rise in the pCO₂.

- b. Volume Ventilator: set the volume to be delivered and the pressure necessary to deliver this all important volume will be internally compensated by the machine.

EXAMPLE: Set a volume at 500 cc. The delivery pressure is recorded at 20 cm. If this patient develops bronchospasms, or the airways become full of secretions, more pressure will be needed, say 30 or 35 cm H₂O. The ventilator will raise the pressure automatically so that the 500 cc TV is maintained. The highest pressure the ventilator can generate will be limited by the pressure limiting control.

9. Demonstration of Pressure and Volume Ventilators

- a. Bird Pressure Ventilator d. MA-2 Volume Ventilator
b. PR-2 Pressure Ventilator e. MA-7200 Volume Ventilator
c. MA-1 Volume Ventilator

D. There are two modes of volume ventilation for pCO₂ control.

CMV (continuous mandatory ventilation)

SIMV (synchronous intermittent mandatory ventilation)

The best way to differentiate these two is with the following mathematical expression:

$$\text{CMV} = (\text{TV}_m \times \text{R}_m) + (\text{TV}_m \times \text{R}_{pt})$$

$$\text{SIMV} = (\text{TV}_m \times \text{R}_m) + (\text{TV}_{pt} \times \text{R}_{pt})$$

In the expression, I have divided the total ventilation into what is set on the ventilator and what the patient initiates. In CMV, a volume is set (TV_m), and a Rate is set (R_m). This is the only constant ventilation. If you examine the second part, you set the addition of another TV_m times the rate the patient can trigger. This is nothing more than allowing the patient to take minimal to maximal negative pressure inspiration. Thus, opening the interval valve or allowing the ventilator to give an additional full pre-set TV.

This trigger is set by the sensitivity control, and is based on how hard or how easy you want the patient to receive the extra pre-set TV.

In SIMV mode, the TV is set, the R_m is set, but the second part of the expression $TV_{pt} + R_{pt}$ is the TV of the patient and the rate of the patient.

QUESTION: When is SIMV like CMV?

ANSWER: When the R_{pt} is zero. Remember this for future use!

So why two modes?

Older ventilators (MA-1) have only CMV mode. The problem here was weaning. How do you let someone up from total ventilator support? There was only one way – take the patient off the ventilator and let them go on their own. We refer to this as the classical wean and orders written were as follows:

10/1/71 – take patient off ventilator and allow to breath through a 35% Briggs (tube filled with air and oxygen) for one hour, then place back on ventilator. (I could not write CMV because we did not have this term.) rotate this through the day.

Not a bad order. Relatively easy to follow but impossible to accomplish.

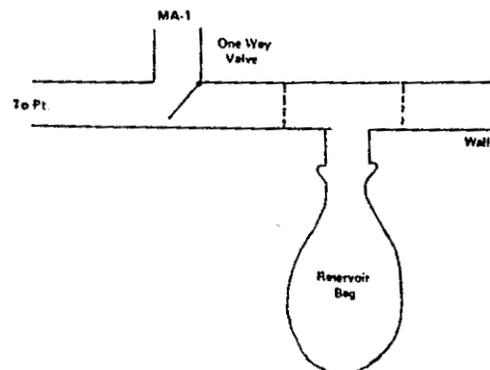
It always seemed that when it was time to take these patients off, Mr. Jones, in the next bed, would decide to have a cardiopulmonary arrest. Consequently, weaning classically never went according to schedule, since nursing and respiratory therapists were working on Mr. Jones.

I would like to add, when a patient was completely off, he had to be watched continuously, since there were no apnea alarms and the only indication for any possible trouble was the eye of the nurse or respiratory therapists.

Pulmonologists, attacked this problem with the development of the IMV circuit. Examine this diagram:

IMV - Patient breaths on his own and MA-1-Sighs
Patient at frequent intervals
(A Bionic Nurse)

USE: Hard weaning problems
Patient with severe emphysema who needs to be signed
so as to lower the pCO_2 .
Remember $pCO_2 = (TV - DS) R$



Well this worked quite well, but had two problems.

If the patient took a deep breath on his own and it was time for the ventilator to cycle, he received not only his volume but also the TV_m . This obviously could cause hyperinflation and barotrauma could result. Another problem was in low IMV rates with patients becoming apneic. If the IMV was set on one or two breaths/minute, that is all the patient would get if apnea occurred. Again, there were no alarms.

This situation was corrected with the development of synchronous IMV or SIMV. It works exactly as IMV, except that if the patient takes a deep breath, the ventilator will wait until he exhales before giving a breath. Also, if he went apneic, an alarm sounded and the ventilator would switch into GMV mode to a rate and volume compatible with life.

E. CO₂ CMV Adjustment Equation

$$CO_{2_1} \times TV_1 \times R_1 = CO_{2_2} \times TV_2 \times R_2$$

This is a practice formula in the apneic patient. In CMV remember the R_1 is total rate ($R_m + R_{pt}$) and not that which is set R_m .

In SIMV, the formula can be applied. However, you must assume the patient's R will be equal before the change and after. Results are less exact but it does serve as a guide.

CORRECTION OF RESPIRATORY ACIDOSIS AND ALKALOSIS WHILE ON VENTILATOR:

Since \dot{A} ventilation produced a certain CO_2 as determined by blood gas analysis, it was possible to calculate what new \dot{A} is necessary to produce a new CO_2 .

$$p\text{CO}_2_1 \times \text{TV}_1 \times \text{R}_1 = p\text{CO}_2_2 \times \text{TV}_2 \times \text{R}_2$$

Example: $p\text{CO}_2 + 50$ NEED $p\text{CO}_2 = 40$

$$\text{TV}_1 = 500 \qquad \qquad \qquad \text{TV}_2$$

$$\text{R}_1 = 10 \qquad \qquad \qquad \text{R}_2$$

$$50 \times 500 \times 10 = 40 \times \text{TV}_2 \times \text{R}_2$$

$$6250 \qquad \qquad = \text{TV}_2 \times \text{R}_2$$

$$625 \times 10 \qquad \qquad = \text{TV}_2 \times \text{R}_2$$

$$520 \times 12 \qquad \qquad = \text{TV}_2 \times \text{R}_2$$

$$415 \times 15 \qquad \qquad = \text{TV}_2 \times \text{R}_2$$

TV_1 – set volume R_1 – set rate $p\text{CO}_2$ – present $p\text{CO}_2$
 TV_2 – new volume R_2 – new rate $p\text{CO}_2_2$ – desired $p\text{CO}_2$

HIGH RATES WITH LOW VOLUMES ON SIMV

Occasionally, you will see a patient on low machine SIMV rates with unbelievably high rates – 40's. If you look at the expiratory spirometer, it will be noted extremely low exhaled volumes.

What is occurring?

Obviously, this is a situation which does not occur in healthy patients. NOTE: A good rule to follow in ventilating any patient is to make the machine breathe for them as close as possible Rates and Volumes generated in normal patients. (Use yourself as an example.)

The patient described above is not ready for SIMV wean and should be placed back on CMV. This is done for two reasons:

1. Not many patients can maintain high rates and low volumes for any period of time before they “poop-out” and become apneic.
2. In CMV mode (see graph #4) you will note that it takes a certain amount of time to pump a tidal volume into a patient. While this volume is inflating the lung, the “urge” to breathe is shut off. You cannot inspire while you are already inspiring – TRY IT! Consequently, your rate on CMV will drop to a level more acceptable. What will be the rate? This depends on the CMV formula.

$$\text{CMV} = (\text{TV}_m \times R_m) + (\text{TV}_m \times R_{pt})$$

HYPERVENTILATION ON THE VENTILATOR OR LOW CO₂

We have seen that CO₂ is proportional to \dot{A} and is governed by
 $\text{CO}_2 \approx \dot{A} = (\text{TV} - \text{DS}) R$

What happens when you have a patient who may be on CMV and triggering the ventilator at high rates – 30's? Since he is in CMV mode, then every respiratory cycle given by the machine or initiated by himself is associated with a full predetermined TV which is set on the ventilator. Decreasing the machine rate will do absolutely nothing since the patient is triggering at his own rate.

Example

$$\text{CMV} = (\text{TV}_m \times R_m) + (\text{TV}_m \times R_{pt})$$
$$700 \times 10 + 700 \times 20$$

Overall rate is 30!

Cut down rate to 2

$$CMV = (TV_m \times R_m) + (TV_m \times R_{pt})$$

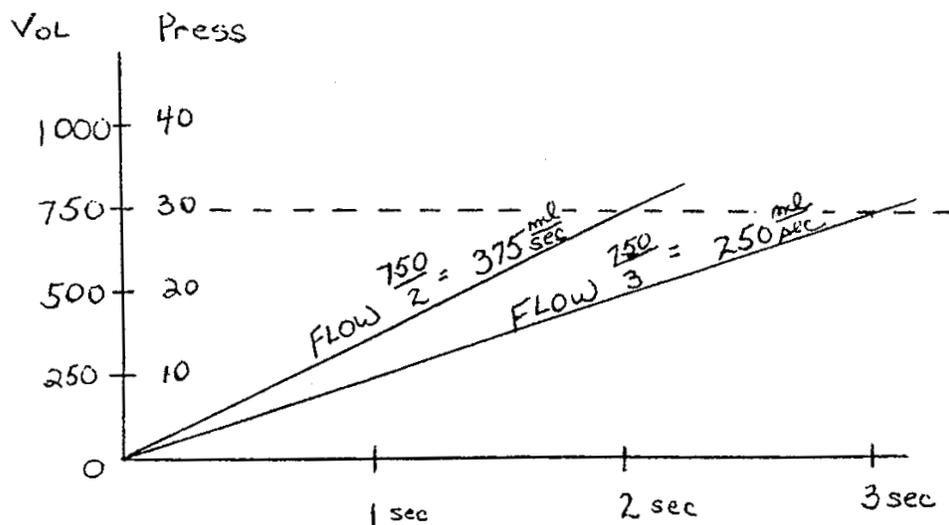
$$700 \times 2 \quad \quad \quad 700 \times 28$$

Overall rate is still 30!

Cutting down on the volume will only drop the time of inspiration and increase the time of expiration, thus allowing the patient to breathe and trigger at faster rate in the time of expiration. (Remember, you cannot breathe while you are breathing!)

So what can you do?

By lowering the flow rate, you will provide the same volume. Since your delivery time is more, your overall rate will drop. Consequently, CO₂ will rise. This trick works well, but if the patient does not respond and is severely ill, then you may elect to use Pavulon (a muscle paralyzer).



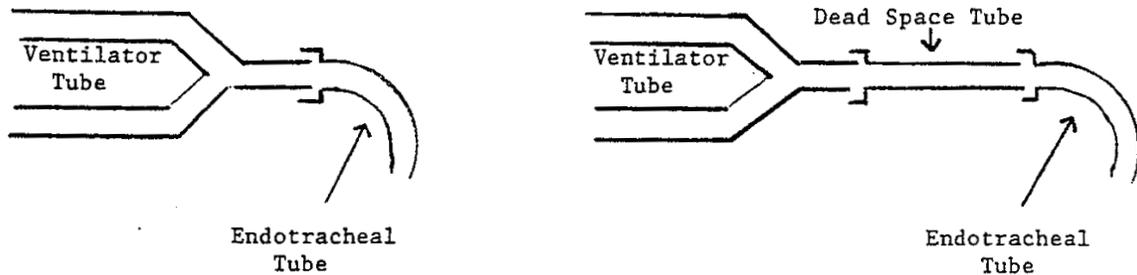
Effect of decreasing the FLOW on a Vol. Ventilator

For example:

Examine the above diagram. You see the volume ventilator set at 750 cc. The flow is set at 375 ml/second. This gives you an overall inspiratory rate of 2 seconds. In a patient hyperventilating or triggering the ventilator at an increased rate, you can lower the flow as in the example above from 375 ml/second to 250 ml/second giving a total time of inspiration of 3 seconds. This small increase, although seems miniscule, will drop the total respiratory rate of the patient which is hyperventilating on the ventilator.

Lowering the flow in CMV mode to increase the timing of inspiration consequently decreasing the overall rate is a good trick. However, there are times when it does not work. There are two other tricks which can be utilized.

If the patient continues to hyperventilate and a low CO_2 continues with a high pH, one can install extra tubing in the ventilator circuit so that the patient will inhale a mixture of expired gases (CO_2). Please see diagram. I will call this the addition of “Dead Space Tube”.



I start usually with a 6 inch “Dead Space Tube” and can add small increments until the desired pCO_2 is achieved. I rarely utilize more than 10 inches of “Dead Space Tubing”.

There is one last trick with patients who continue to hyperventilate (decrease pCO_2), and that is to place them in CMV mode and paralyze the respiratory muscles with Pavulon.

Obviously, these patients cannot be weaned when on Pavulon.

OXYGEN CONTROL VENTILATOR

Clinical Use of the Shunt Chart:

1. Now able to reduce FiO_2 to a precalculated PaO_2 . This helps avoid oxygen toxicity at high FiO_2 .
2. Locate FiO_2 (Fraction of Inspired Oxygen or Percentage of O_2), then locate PaO_2 . Where the two parameters intersect is the percentage shunt.
3. As long as there are no major hemodynamic changes such as cardiopulmonary arrest, hemorrhagic shock, etc., the shunt will hold.
4. Please note – this is a calculated value and not a true value, but can be utilized quite well in clinical practice.
5. EXAMPLE:

Patient is on a ventilator and the FiO_2 is 1.00 (100%). The PaO_2 is 400. The calculated shunt is 17%. Now, suppose you want a PaO_2 of 100. All you do is locate the PaO_2 of 100 and read horizontally until you get the shunt of 17%, then read vertically to FiO_2 of 0.39. In effect, you have decreased the FiO_2 from 1.0 to 0.39.

PaO_2	FiO_2	.35	.39	.42	.45	.49	.53	.56	.60	.63	.66	.70	.74	.77	.81	.84	.88	.91	.95	.98	1.00
	PiO_2	250	275	300	325	350	375	400	425	450	475	500	525	550	575	600	625	650	675	700	725
	PAO_2	200	225	250	275	300	325	350	375	400	425	450	475	500	525	550	575	600	625	650	675
30		65	65	65	65	66	66	66	66	67	67	67	67	67	68	68	68	68	68	69	69
40		53	53	54	54	55	55	55	56	56	57	57	57	58	58	58	59	59	59	59	60
50		41	42	43	43	44	45	45	46	46	47	47	48	48	49	49	50	50	51	51	52
60		34	34	35	36	37	38	38	39	40	40	41	42	42	43	44	44	45	45	46	47
70		26	27	28	29	30	31	32	33	34	35	35	36	37	38	39	39	50	41	41	42
80		23	24	26	27	28	29	30	31	32	32	33	34	35	36	37	37	38	39	40	40
90		19	20	21	22	24	25	25	27	28	29	30	31	32	33	33	34	35	36	37	37
100		15	17	18	19	20	22	23	24	25	26	27	28	29	30	31	32	33	34	35	35
120		10	11	13	14	15	17	18	19	21	22	23	24	25	26	27	28	29	30	31	32
140		10	11	13	14	15	17	18	19	21	22	23	24	25	26	27	28	29	30	31	32
160		7	9	11	12	14	15	16	18	19	20	21	22	24	25	26	27	28	29	30	31
180		5	7	9	10	12	13	15	16	17	19	20	21	22	23	25	26	27	28	29	30
200		5	7	9	10	12	13	15	16	18	19	20	21	22	23	26	26	27	28	29	30
225				2	4	5	7	9	10	12	13	15	16	18	19	20	21	22	24	25	26
250				0	1	3	5	7	8	10	11	13	14	16	17	18	20	21	22	23	24
275					0	1	3	4	6	8	9	11	13	14	15	17	18	19	21	22	23
300						1	3	4	6	8	9	11	13	14	15	17	18	19	21	22	23
325							2	4	6	7	9	11	12	14	15	16	18	19	20	21	21
350								2	3	5	7	9	10	12	13	15	16	17	19	20	20
375									1	3	5	6	8	10	11	13	14	16	17	18	18
400												2	4	6	8	9	11	12	14	15	17

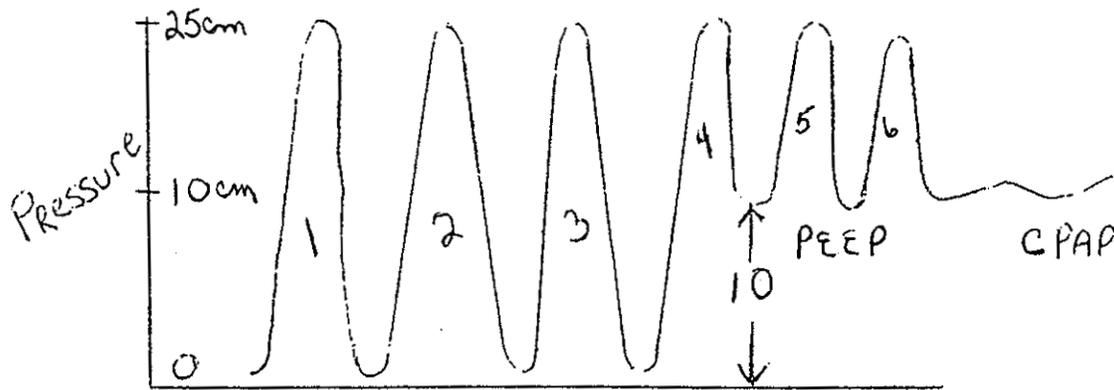
TABLE OF SHUNTS - Hb. = 15; A.V. O_2 = 4; pH = 7.5

Now you have seen the clinical adaption of the shunt. What happens if the patient has an extremely large shunt, despite 100% O₂ (FiO₂ = 1.0).

There are two tricks available –

Continuous Positive Airway Pressure (CPAP) and Positive End Expiratory Pressure (PEEP).

Examine the following graph of Pressure and Rate during mechanical ventilation:



Looking at Breath #1, you can see as the ventilator cycles, the pressure raises from 0 to 25 cm H₂O during inspiration and decreases from 25 cm H₂O to 0 during expiration.

This situation is true of Breath #1, 2 and 3. On Breath #4, the ventilator cycles from 0 to 25 cm during inspiration, but as the patient exhales, PEEP is applied so that exhalation, although starts at 25, now is abruptly at 10 cm H₂O. The ventilator then on Breath #4 starts inspiration at 10 cm H₂O until 25 cm H₂O and exhalation again at 25 cm down to 10 cm H₂O. This is the same for Breath #6.

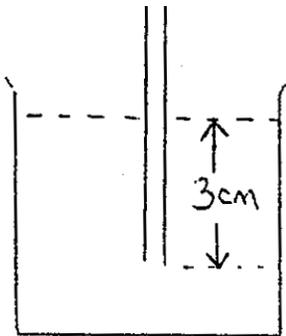
HOW TO INSTALL PEEP:

The new ventilators have an ungraduated knob which is turned until the appropriate PEEP is reached. The level of PEEP is read directly off of the pressure dial on the ventilator.

What would happen if the ventilator does not have a PEEP adjustment?

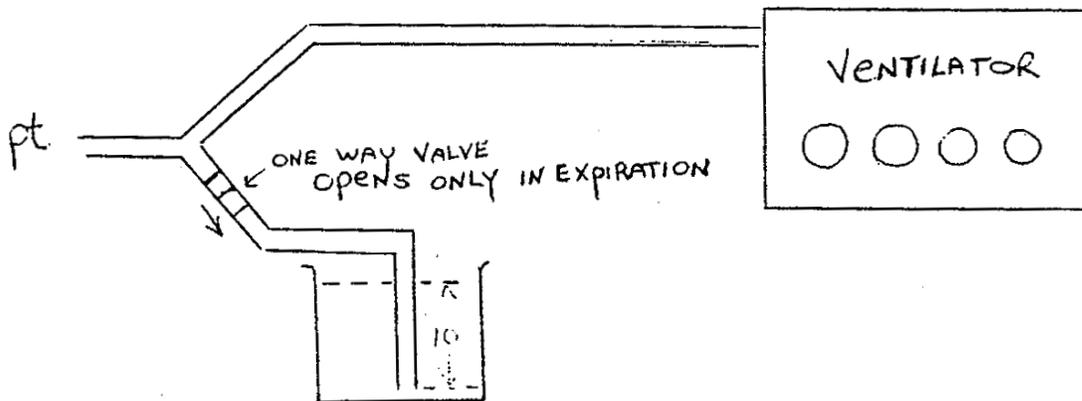
You use a system popular in the early days of ventilators which you can make. Before I show this system, I am going to ask a question.

If I take a straw and submerge it in a glass of water so that the straw is 3 cm below the water line and I blow air through the straw so that bubbles are formed, what then is the pressure in the straw?



The pressure is 3. If I blow harder, the pressure is still 3. As long as the bubbles are forming, the pressure is 3.

What then would happen if I took the ventilator's expiratory hose and place it 10 cm under water? The effect is the same as the straw, and 10 cm of pressure will remain in the system at the end of expiration producing 10 cm of PEEP.



Any container can be used (trash can, bottle, etc) as long as the expiratory tube is fixed 10 cm under water. This is a noisy system, but it works. Maintain multichecks on the pressure gauge on the ventilator. It is also dangerous because hospital personnel tend to knock the container over. (I also saw trash thrown into the container.)

WHAT IS THE EFFECT OF PEEP ON THE ALVEOLUS?

Because of this increased pressure at the end of expiration, the alveolar volume never fully deflates and consequently stays inflated a bit longer. Whether or not this is the action which causes the PaO_2 to rise is not known BUT since it works it is being used.

There is the use of SUPER PEEP (20 cm) and MEGA PEEP (30 cm) in clinical medicine in extremely hard oxygenating cases. These cases are few and the outlook is usually poor.

In shock lung, alveolar surfactant is lost. Remember surfactant is a proteinaceous material which by virtue of its surface tension allows the alveolus to stay open at end expiration. PEEP does the very thing which may be considered artificial surfactant.

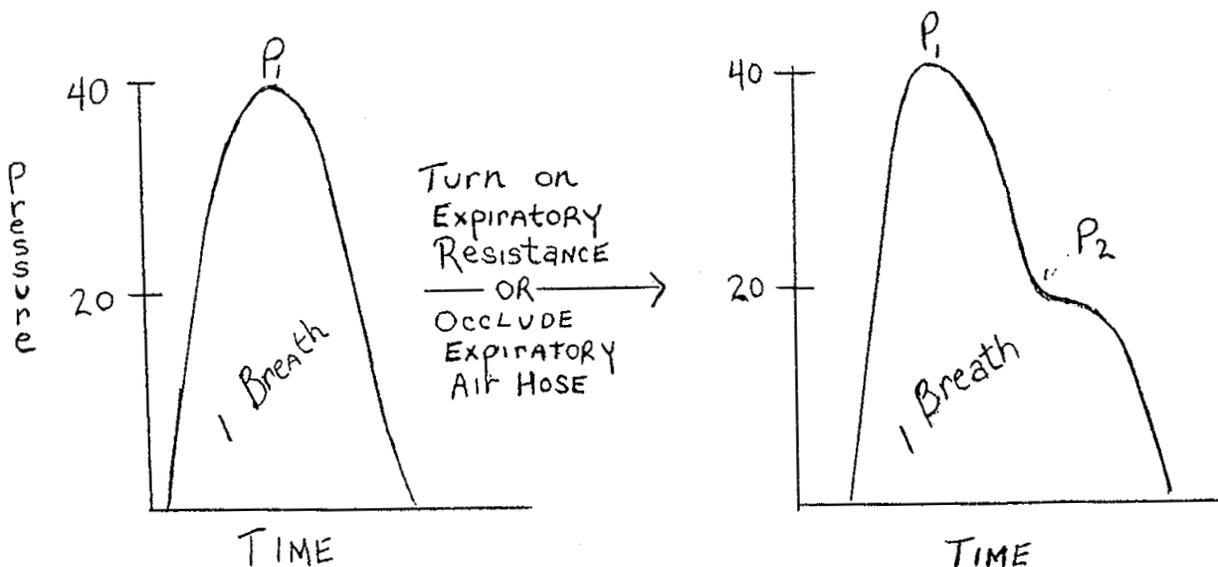
Pulmonary function-wise, the effect of PEEP is to increase the FRC. Patients with severe emphysema already have an increased FRC and may not respond well to PEEP.

If high PEEP is used, venous return to the heart may be impaired producing low cardiac output. There is even a bigger problem of alveolar rupture producing pneumothorax. Volume loading may help the venous return problems and prophylactic bilateral chest tubes may be inserted to avoid tension.

HOW TO GET THE RIGHT LEVEL OF PEEP?

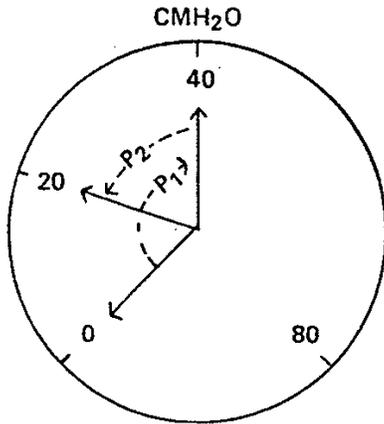
It has been shown that the PEEP level which gives the best compliance will give the best PaO_2 . Compliance is nothing more than the measurement of the lungs elasticity. The lower the compliance, the “stiffer” the lung.

Examine the following pressure time curve:



By turning on expiratory resistance or obstructing an air hose, you see a “dent” in the expiratory descending limb. This “dent” is the plateau pressure P_2 . This measurement is obtained by observing the pressure gauge.

COMPLIANCE MEASUREMENT ON VENTILATOR

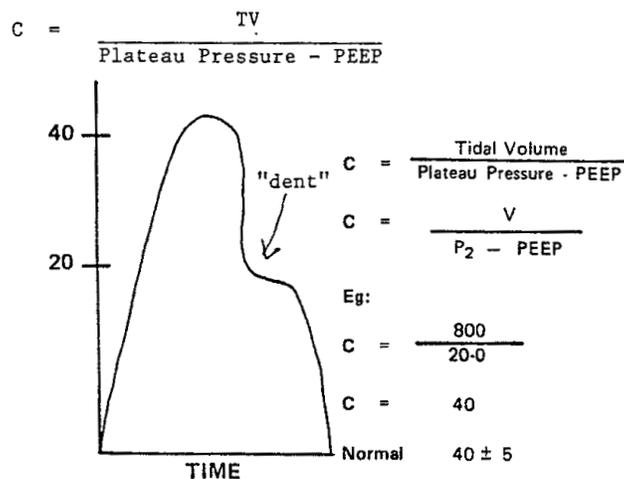


40 represents the total pressure necessary to overcome the tubing on the ventilator and expansion of the chest wall (rib motion and lung inflation).

Compliance is the measurement of the lung inflation and deflation only. By turning on the expiratory resistance or occluding the expiratory hose, you generate a notch on the graph. If you are looking at the dial, a “hang up” of the needle on the Pressure gauge for a split second occurs. This “hang up” is equal to the plateau pressure and represents only one point of the compliance in expiration. This one-point compliance is known as the static compliance.

The dynamic compliance is a measurement made in the Pulmonary Lab over the total inspiratory and expiratory volume pressure curve.

Static compliance can be calculated by the following:



1. Respiratory Cycle

NB

1. Turn on Expiratory Resist. Control
- or
2. Obstruct the Expir. Hose

If you take multiple compliance measurements over increasing values of PEEP 0, 2, 4, 6, 8, etc., you get the following example:

BEST PEEP - PEEP at which Compliance is closest to 40

EG	PEEP	COMPLIANCE	=	$\frac{\text{T.V.}}{\text{PLATEAU PRESSURE} - \text{PEEP}}$
	0	$\frac{500}{20 - 0}$	=	25
	2	$\frac{500}{18 - 2}$	=	31
	4	$\frac{500}{16 - 4}$	=	40 "Best PEEP"
	6	$\frac{500}{22 - 6}$	=	30
	8	$\frac{500}{26 - 8}$	=	27

Normal compliance runs about 35 to 45 with 40 being ideal. Consequently, the closest PEEP measure to 40 compliance is the best PEEP.

There are situations, shock lung, where the best compliance is much lower than 40. The best PEEP would then be the compliance closest to 40.

Another Way to Adjust Best PEEP:

With the indwelling oxygen sensor, right heart catheter a continuous $\bar{Sv}O_2$ can be measured. Levels of PEEP are applied and $\bar{Sv}O_2$ noted. The highest $\bar{Sv}O_2$ will correspond to the best PEEP.

Shunt Chart and PEEP:

As long as you maintain the PEEP at a constant level, the shunt chart can be applied.

GETTING THE PATIENT OFF PEEP:

Once the best PEEP is applied, it should not be touched until the FiO_2 is lowered to around .3 (30%), then it should be cut in small increments with blood gas or SVO_2 monitoring.

CPAP

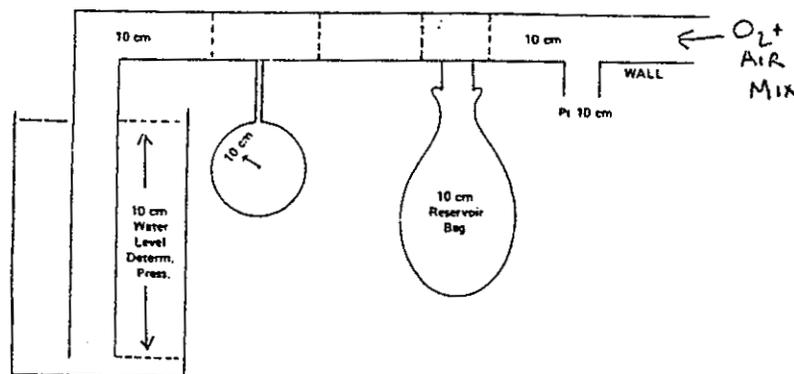
Overall, PEEP is best used in pO_2 problems and CO_2 problems (patient cannot breathe on his own, so patient must be ventilated). What happens if a patient is able to maintain a good CO_2 and is fully awake but unable to maintain a PaO_2 ? (Example – Pulmonary Embolism). We then can try CPAP.

Consider the following example:

Air and O_2 are sent through tubing to the “old water container”. Again, if the tube is submerged 10 cm below the water level and bubbles are noted – What is the pressure in the system?

As long as the bubbles are formed, the pressure is 10 during inspiration and expiration.

EXAMPLE: P.E.



**Wall Flow –
Extremely High Flow
Air or Air + O_2 or O_2
30 - 50 L/min**

CPAP - To maintain + pressure in the alveoli during inspiration and expiration. Patient must breathe on his own - he must be able to control his pCO_2 .

USE: Oxygenation problems only

CPAP ADJUSTMENT

First, select the FiO_2 you wish to work with, then apply 5 cm increments of CPAP until a desired paO_2 is achieved. Rarely, more than 15 cm will be necessary as these patients will also have CO_2 problems requiring PEEP.

As long as the applied CPAP is constant, the Shunt Chart will hold so that FiO_2 can be selected to give the proper paO_2 .

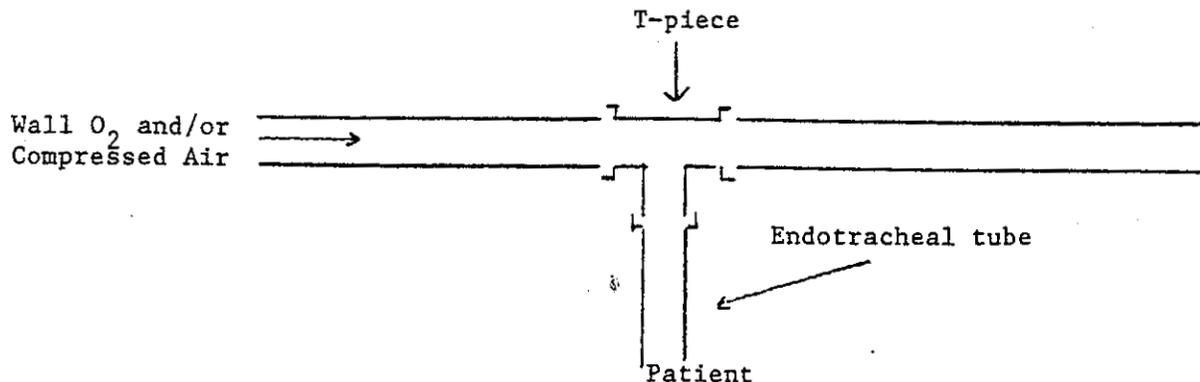
CPAP = 0 OR CPAP – ZERO

Since there is no TV_m or R_m in the CPAP mode, the patient must be breathing on his own. If the patient suddenly stops breathing, he will have to be placed back on CMV or SIMV. Obviously, some alarm or some person must recognize this.

On the modern ventilators, this is electronically performed.

We can made use of this protective device when weaning a patient.

Suppose we have a patient on a low SIMV, say a Rate of 1. The next step would be to take him off the ventilator and apply a Briggs set-up (see diagram) or T-piece



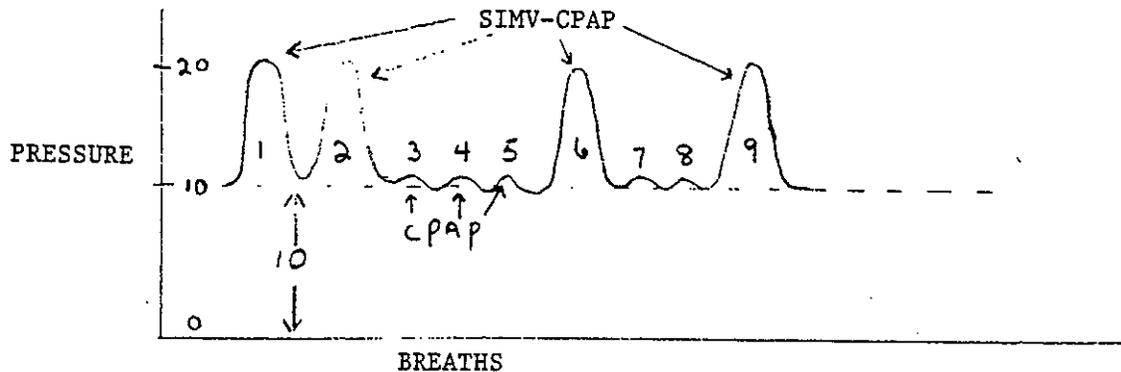
From the diagram, there exists no alarm or back-up system.

Utilizing the modern ventilator, the patient can be placed on Zero "0" pressure CPAP. breathing will occur as illustrated through the T-piece set-up built into the ventilator which senses TV or R . In the event of apnea or low patient generated alveolar ventilation, the ventilator will automatically sound the alarm and switch to CMV mode at a predetermined TV , R and FiO_2 .

SIMV AND CPAP MODE

Occasionally, a patient will need CO₂ support and O₂ support. That is, he is breathing on his own but not enough to control his CO₂ or pO₂.

A breathing diagram would appear as follows:



Breaths 1, 2, 6, 9 represent the cycling of the ventilator in the SIMV mode ($TV_m \times R_m$) which resembles PEEP since the patient never drops below 10 cm H₂O pressure in expiration.

In these breaths, the machine controls the pCO₂ and the machine end expiratory Pressure will control the pO₂.

Breaths 3, 4, 5, 7, 8 represent the patient breathing on his own but at a continuous positive airway of 10 cm H₂O.

In these breaths, the patient controls the pCO₂, while the machine's continuous positive airway pressure controls the pO₂.

VD/VT RATIOS:

During each breath a certain volume of air ventilates the dead space and the remainder, the alveolar space where gas exchange occurs. The ratio of dead space ventilation to total ventilation (VD/VT) is a reflection of efficiency of ventilation. Normally, the VD/VT = .35 or less. When the dead space increases so there are abnormally large areas which are being ventilated but which are not exchanging gas, the VD/VT increases. VD/VT is calculated from the following equation:

$$\frac{VD}{VT} = \frac{PaCO_2 - PeCO_2}{PaCO_2} \quad \begin{array}{l} PaCO_2 = \text{arterial carbon dioxide tension} \\ PeCO_2 = \text{carbon dioxide tension in expired air} \end{array}$$

Above $\frac{VD}{VT}$ of .6 patient cannot be weaned off ventilator

EXAMPLE:

What is the VD in a patient who has a tidal volume of 800, PaCO₂ of 50, and PeCO₂ of 30?

What is the VD/VT?

$$\frac{VD}{800} = \frac{50 - 30}{50}$$

$$VD = 320$$

$$\frac{VD}{VT} = \frac{320}{800} = .4$$

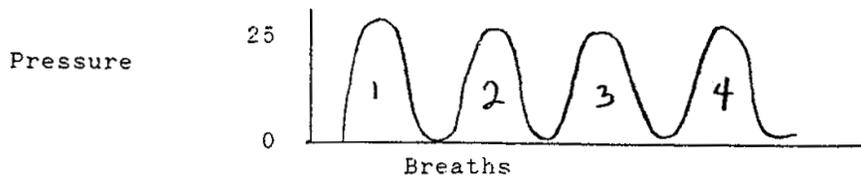
WEANING

Modalities used in weaning

- CMV
- CMV + PEEP
- SIMV
- CPAP
- Pressure Support

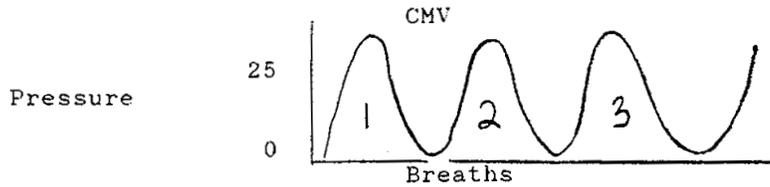
} Or any combination

Consider the CMV diagram as we will alter this with the various weaning modalities.



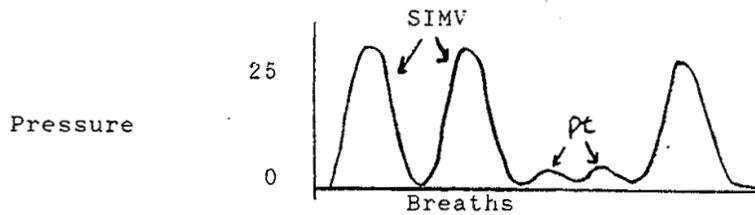
We have already presented CMV and SIMV and CPAP and the following is a review of those modalities.

CMV



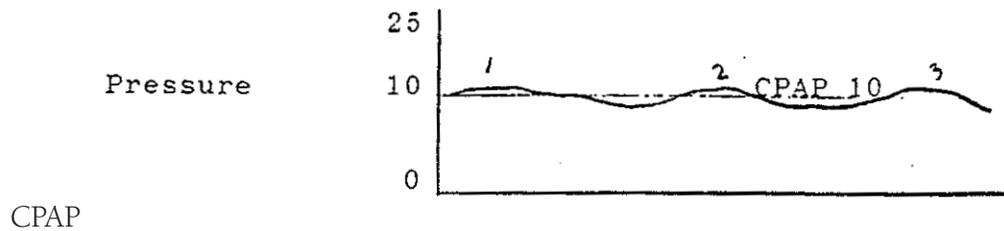
$$CMV = (TV_m \times R_m) + (TV_m \times R_{pt})$$

SIMV



$$SIMV = (TV_m \times R_m) + (TV_{pt} \times R_{pt})$$

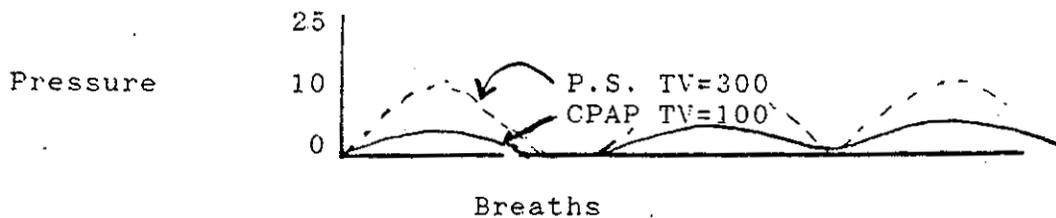
CPAP = O2 problems only (utilized for alarms and CMV backup)



Example: A patient with CPAP = 10 or 10 cm H2O pressure during inspiration and expiration

Pressure Support (P.S.)

P.S. A new modality used to support or make easy inspiration and increased volume (a CO2 thing). Consider a patient on CPAP = 0 (solid line) --



Example: Patient on CPAP = 0 has a TV of 100 which corresponds to a CO2 of 50. You wish to increase the patient's TV so the CO2 decreases

P.S. Helps the patient breath by making it easier to inspire. The TV will increase to 300. One thing you must know is that ring. As soon as the patient stops breathing or reaches full inspiration, P.S. shuts off. Unfortunately, there is no way to calculate how much volume will equal how much pressure support so that we start P.S. and observe the TV until it goes to a reasonable level. Obviously, the proof of the pudding is in the ABG which is still the only way to tell if your vent changes are effective.

Where does it work ---- Only when the patient is breathing on their own in CPAP or SIMV

$$\text{SIMV} = (\text{TV}_m \times \text{R}_m) = (\text{TV}_{pt} \times \text{R}_{pt})$$

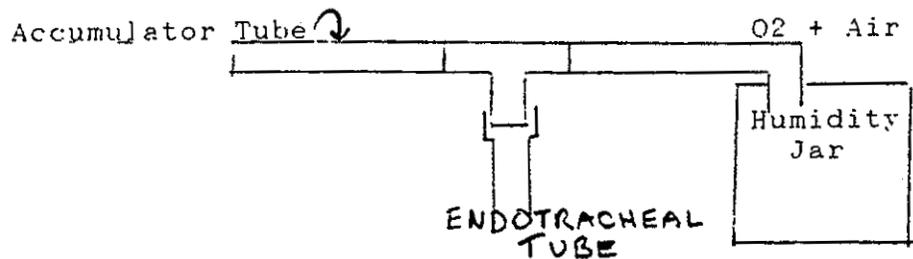
not here P.S. ← Here
 ↗ ↑ ↘

If the patient continues to breath and receive P.S., this modality becomes like a pressure cycle vent.

Different modes of Weaning with Diagram:

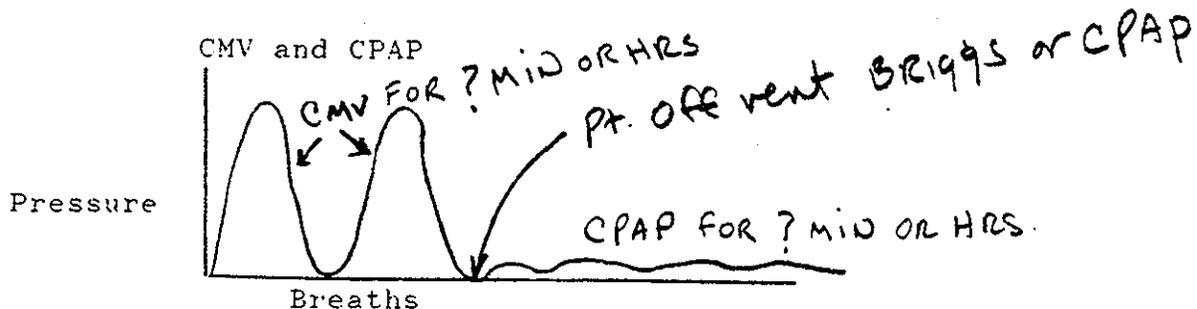
1. Classical wean or the CMV wean: The patient on CMV then at certain times is taken off the vent and able to breath on their own. Standard order would be like this --

CMV 500 R 10 FIO2 30 for two hours followed by 30 minutes on Briggs set up
(A Briggs is a standard vent tube connected to a high humidity plus oxygen source)



As you can see, if the patient stops breathing there is no back up vent or alarm. In modern vents we place the patient on CPAP = 0 FIO2 whatever. Now if the patient stops breathing, the back up alarm and ventilation in CMV occurs so that the patient is automatically ventilated and oxygenated.

The idea with CMV and Briggs or CMV and CPAP is to gradually increase Briggs time or CPAP time until the patient is off the vent completely. Sometimes patients will fail or crash after two hours of CPAP or Briggs. This is usually manifested by apnea, tachypnea, tachycardia, etc and represents some problem -- secretions, sepsis, arrhythmia, nutrition problems, etc. You need to address these problems first prior to wean.

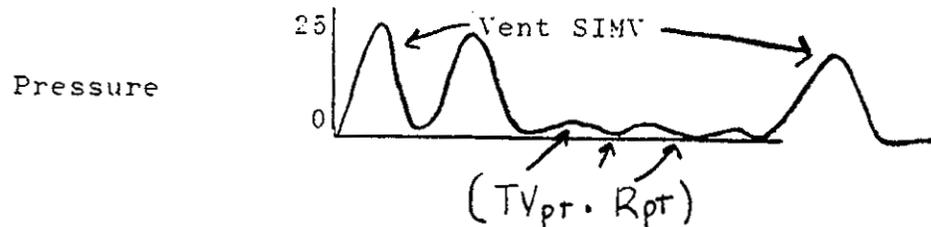


2. Convention Wean SIMV Wean: Currently state-of-the-art.

Consider:

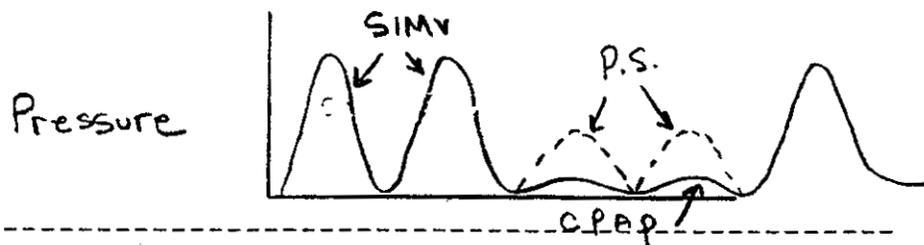
$$\text{SIMV} = (\text{TV}_m \times \text{R}_m) + (\text{TV}_{pt} \times \text{R}_{pt})$$

Again, the idea is to decrease R_m so that the R_{pt} patient rate and TV_{pt} increases to a point so that $\text{TV}_m + \text{R}_m$ is 0.



3. CPAP wean -- usually with CMV and SIMV (see above)

4. P.S. wean - usually with SIMV or CPAP

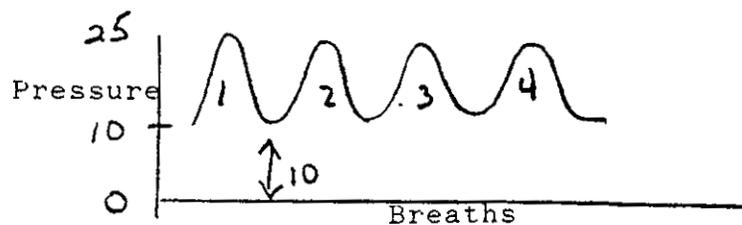


Problem:

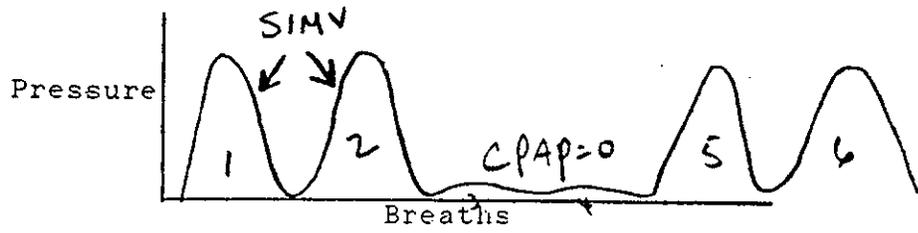
Diagram a patient on CMV and CPAP = 0



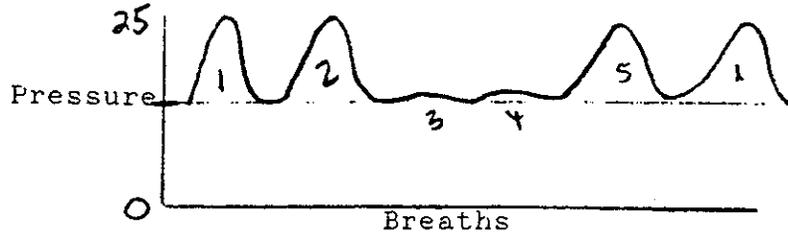
$$\text{CMV} + \text{CPAP} = 10 \quad (\text{CPAP} + \text{CMV} = \text{PEEP})$$



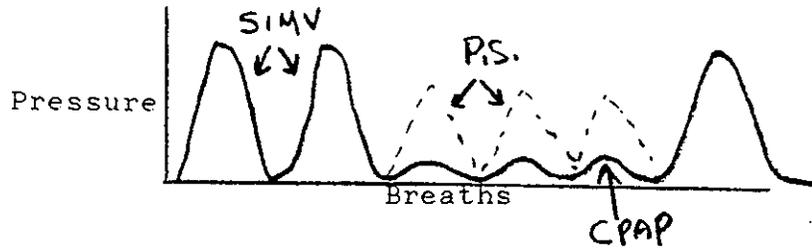
SIMV + CPAP = 0



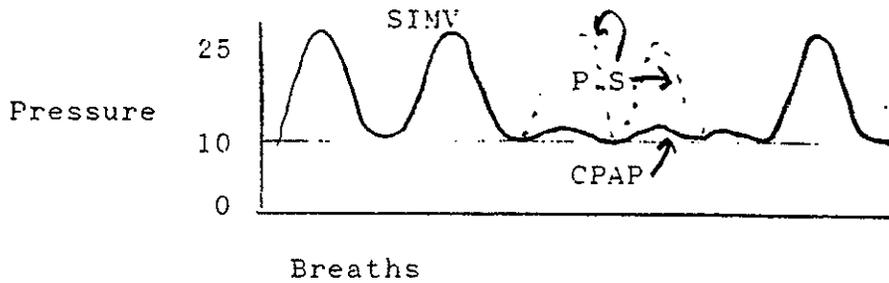
SIMV + CPAP = 10



SIMV + CPAP = 0 + P.S. 10



SIMV + CPAP = 10 + P.X. 15



TROUBLESHOOTING GUIDE

Troubleshooting the pCO₂

PROBLEM

SOLUTION

Normal

None

Hypoventilation

{ Increased TV
or
Increased R

Hyperventilation –

1. { Decreased TV
or
Decreased R }

in apneic patient – use CO₂
adjusting formula

2. Decreased Flow in patient with increased R

3. Pavulon

Troubleshooting the pO₂

PROBLEM

SOLUTION

pO₂ Normal

None

pO₂ High

Shunt chart and dial down FiO₂

pO₂ Low

Shunt chart and dial up FiO₂

pO₂ Really Low

{ CPAP
PEEP

PULMONARY QUESTIONS

Problems for ABG

1. 15 year old with Valium overdose:

pH	pCO ₂	HCO ₃	R.R.
7.1	84	25	4

- Acidosis or alkalosis?
- is tachypnea present?
- level of ventilation: increased normal decreased
- hyperventilation, normal ventilation, hypoventilation
- metabolic or respiratory

2. 55 year old male with nasogastric suction for 4 days.

Intern forgot to add potassium to this patient's I.V.

pH	pCO ₂	HCO ₃	R.R.
7.7	40	50	15

- Acidosis or alkalosis
- level of ventilation: increased normal decreased
- is tachypnea present?
- amount of buffer: increased normal decreased
- metabolic or respiratory
- why is the buffer changed?
- metabolic or respiratory
- what would you expect the serum K level to be: inc. norm. dec.

3. 25 year old hysterical person:

pH	pCO ₂	HCO ₃	R.R.
7.7	20	(figure it out)	30

- Acidosis or alkalosis
- level of ventilation: increased normal decreased
- hyperventilation, normal ventilation, hypoventilation
- is tachypnea present?
- why is the level of base unchanged?
- metabolic or respiratory

PULMONARY QUESTIONS

4. 32 year old female with renal failure Kg = 70

pH	pCO ₂	HCO ₃	R.R.
7.0	40	9.5	20

- Acidosis or alkalosis
- level of ventilation: increased normal decreased
- hyperventilation, normal ventilation, hypoventilation
- amount of buffer: increased normal decreased
- metabolic or respiratory
- how much bicarb is needed to restore this patient to a pH of 7.4?

5. Patient on a ventilator receiving FiO₂ of .5 (50% O₂)

What is the A – a gradient if the paO₂ = 90 mm Hg and the pCO₂ = 40 mm Hg?

6. Patient on a ventilator receiving FiO₂ of 1.00 (100% O₂)

What is the A – a gradient if the paO₂ = 300 mm Hg and the pCO₂ = 50 mm Hg?

7. How is the pCO₂ controlled?

8. How is the HCO₃ controlled?

9. A patient has Hb = 12 gm/100 ml blood, the paO₂ = 150, so that the blood is fully saturated

-- What is the arterial oxygen content?

-- Is this patient hypoxemic? (O₂ low in the blood)

-- Does this patient have tissue hypoxia? (O₂ low in the tissue)

10. A patient with sickle cell anemia has an Hb of 4 gm/100 ml blood, the paO₂ = 150 mm Hg (patient on nasal O₂) so that the blood is fully saturated.

-- What is the arterial oxygen content?

-- Is this patient hypoxemic? (O₂ low in the blood)

-- Does this patient have tissue hypoxia? (O₂ low in the tissue)

11. What is the shunt, if the paO₂ = 40 mm Hg and the fiO₂ = .49 (49% O₂)

(Use Shunt Chart)

12. What is the shunt if the paO₂ = 400 and the fiO₂ = 1.00 (100% O₂)

(Use Shunt Chart)

PULMONARY QUESTIONS

16. continued

Weight = 60 kg

What is the shunt??

Propose a treatment for HCO_3^- of 25 with a PCO_2 of 40 mmHg and PO_2 of 80 mmHg

17. PNEUMONIA

This is a 64 year old male with past history of COPD. His normal PCO_2 when stable is 45. He develops pneumonia and goes into acute CO_2 retention and is placed on the ventilator.

Patient weighs 60 kg.

ABG's prior to ventilator

pH – 7.1	}	ROOM AIR
PCO_2 – 88		
PO_2 – 40		
HCO_3^- – 28		

What is the diagnosis?

ABG's one hour on Ventilator

pH – 7.28	}	MA-1
PCO_2 – 60		TV – 600
PO_2 – 100		R – 10
HCO_3^- – 28		FIO_2 – .60

1. What is the diagnosis?
2. What is the shunt?
3. Adjust MA-1 – so $\text{PCO}_2 = 45$ (Remember this is his stable PCO_2)
4. Adjust MA-1 – so $\text{PO}_2 = 75$

18. CHEST WOUND

A thirty year old post cardiac arrest following thoracic surgery for a bullet wound of the chest. He is on a volume ventilator and weight 65 kg.

PULMONARY QUESTIONS

18. continued

pH – 7.2		MA-1
PCO ₂ – 40		TV – 600
PO ₂ – 100		R – 14
HCO ₃ – 15		FIO ₂ – .5

1. What is the diagnosis?
2. What is the blood gas diagnosis?
3. What is the shunt?
4. Adjust the pH to 7.38

19. AORTIC ANEURYSM

This is a seventy year old female who underwent abdominal aortic aneurysm resection. She is post operative and unable to breath. She is on the MA-1 ventilator.

ABG's		MA-1
pH – 7.24		TV – 500
PCO ₂ – 60		R – 12
PO ₂ – 70		FIO ₂ – .35

1. What is the blood gas diagnosis?
2. QS/QT X 100% = (shunt)?
3. Adjust the MA-1 so the pH is 7.42 and the paO₂ is 90.

20. POST CODE 99

A sixty year old male post Code 99 was given too much NaHCO₃ during Code. On MA-2 volume ventilator. Patient is completely apneic. Patient weighs 60 kg.

ABG's		MA-2
pH – 7.70		TV – 800
PCO ₂ – 40		R – 10
PO ₂ – 100		FIO ₂ – 50%

PULMONARY QUESTIONS

20. continued

1. What is the diagnosis?
 2. Bring the pH to 7.45
-
21. A. Construct an IMV circuit
 - B. Construct a CPAP circuit
 - C. What is the difference between SIMV and CMV (formula)

ABDOMINAL TRAUMA

22. A patient with abdominal trauma is finally stabilized in CMV mode, his ventilator settings are:

pH – 7.36	}	MA-7200	Diagnosis:
PCO ₂ – 35		CMV 10 (set)/15 overall rate	
PO ₂ – 92		TV – 600	
HCO ₃ – 19		FIO ₂ – 50%	

You decide to wean conventionally (SIMV) - after five minutes the following parameters are noted:

No gas performed	}	MA-7200	Diagnosis:
		SIMV 10 (set)/40 overall rate	
		TV – 600	
		FIO ₂ – .30	

Is weaning a good idea?

STAPH PNEUMONIA

23. A patient with Staph Pneumonia on the ventilator. He is quite stable and arterial blood gases are within normal range. Inflation pressure is 30 cm H₂O with a TV of 500. The pressure alarm is set at 40 cm H₂O. Suddenly with each ventilator cycle, the pressure increases by 5-10 cm H₂O. The pressure alarm begins to sound and TV begins to drop. Pressure now is 80 cm and exhaled volumes of 100 ml.

1. Explain what the pressure alarm denotes;
2. What are the clinical conditions associated with high pressures and what treatments should be started.

ANSWERS TO PROBLEMS FOR ABG

1. pH = 7.1

pCO₂ = 84

HCO₃ = 25

R.R. = 4

- a. Acidosis
- b. No. Bradypnea with rate of 4/minute
- c. Ventilation level decreased
- d. Hypoventilation
- e. Respiratory

2. N-G Suction for four days

pH = 7.7

pCO₂ = 40

HCO₃ = 50

R.R. = 15

- a. Alkalosis
- b. Normal level of ventilation
- c. Normal ventilation
- d. No tachypnea
- e. Amount of buffer is increased
- f. HCL is lost from stomach so CL decreases and HCO₃ increases
- g. Metabolic
- h. K⁺ level decreased due to N-G suction without replacement

3. pH = 7.7

pCO₂ = 20

R.R. = 30

HCO₃ = 23.5, totally respiratory problem

- a. Alkalosis
- b. Increased level of ventilation
- c. Hyperventilation
- d. Tachypnea present (respiratory rate of 30/minute)
- e. Alkalosis is a result of increased blow-off of CO₂ with hyperventilation; patient is hyperventilating due to hysterical condition.
- f. Respiratory

ANSWERS

4. A thirty-two year old with renal failure;

weight 70 kg

pH = 7.03

pCO₂ = 40

HCO₃ = 23.5

R.R. = 20

a. Acidosis

b. Normal level of ventilation

c. Normal ventilation (although the respiratory rate is 20/minute, Hypoventilation and hyperventilation are defined by the pCO₂. Therefore, the patient is tachypneic but ventilating normally).

d. Amount of buffer decreased

e. Metabolic (2° to renal failure)

f. Diagnosis: metabolic acidosis we choose NaHCO₃ to bring pH to 7.4

First: Line up ABG's on Sig-Ander Nomogram

Second: Holding pCO₂ at 40, move straight edge to give a pH of 7.4, the HCO₃ necessary to give a pH of 7.4 is 24. We have on board 10 meq and want to increase to 24 meq.

Using the formula, we can calculate:

$$\begin{aligned}\text{meq Na HCO}_3 &= (\Delta B) \times .2 \times (\text{kg}) \\ &= (24-10) \times .2 \times 70 \\ &= 198 \text{ meq Na HCO}_3\end{aligned}$$

Suggest half the dose to be given IV push and the rest hung as a drip over two hours.

5. A - a gradient with PaO₂ = 90 mm Hg and pCO₂ = 40 mm Hg

$$p\text{AO}_2 = p\text{IO}_2 - \frac{p\text{CO}_2}{.8}$$

$$\begin{aligned}p\text{IO}_2 &= (p\text{B} - 47) f\text{IO}_2 \\ &= (760 - 47) .5\end{aligned}$$

$$p\text{IO}_2 = 356.5$$

$$p\text{AO}_2 = 356.5 - \frac{40}{.8}$$

$$= 356.5 - 50$$

$$p\text{AO}_2 = 306.5$$

$$A - a = 306.5 - 90 + \underline{216.5}$$

ANSWERS

6. $\text{PaO}_2 = 300 \text{ mm Hg}$, $\text{pCO}_2 = 50 \text{ mm Hg}$, $\text{fIO}_2 = 1.00$

$$\begin{aligned}\text{pAO}_2 &= \text{pIO}_2 - \frac{\text{pCO}_2}{.8} \\ &= [(760 - 47) 1.00] - \frac{50}{.8}\end{aligned}$$

$$\text{pAO}_2 = 650.5$$

$$\text{A} - \text{a} = 650.5 - 300 = \underline{\underline{350.5}}$$

7. pCO_2 is controlled by respiration

8. HCO_3 is controlling by kidneys

9. Blood fully saturated, $\text{Hb} = 12 \text{ gm}$, $\text{PaO}_2 = 150$

a. Arterial O_2 content:

$$\begin{aligned}\text{O}_2 \text{ content} &= 1.39 \times \text{Hb} + .003 \times \text{PaO}_2 \\ &= (1.39 \times 12) + (.003 \times 150)\end{aligned}$$

$$\begin{aligned}\text{O}_2 \text{ content} &= 16.68 + .45 \\ &= 17.13\end{aligned}$$

b. No

c. Tissue hypoxia defined as $20 \pm 3 \text{ O}_2$ content. Therefore, patient does not have tissue hypoxia.

10. Sickle cell anemia, $\text{Hb} = 4 \text{ gm}$, $\text{PaO}_2 = 150$

$$\begin{aligned}\text{a. O}_2 \text{ content} &= 1.39 \times \text{Hb} + .003 \times \text{PaO}_2 \\ &= (1.39 \times 4) + (.003 \times 150) \\ &= 5.56 + .45\end{aligned}$$

$$\text{O}_2 \text{ content} = 6.01$$

b. No

c. Yes, the patient has tissue hypoxia (remember, the normal is O_2 content of 20 ± 3).

$$\begin{array}{l} 11. \text{PaO}_2 = 40 \text{ mm Hg} \\ \text{fIO}_2 = .49 \end{array} \quad \left. \begin{array}{l} \diagup \\ \diagdown \end{array} \right\} \frac{\text{QS} \times 100}{\text{QT}} = 55\%$$

$$\begin{array}{l} 12. \text{PaO}_2 = 400 \\ \text{fIO}_2 = 1.00 \end{array} \quad \left. \begin{array}{l} \diagup \\ \diagdown \end{array} \right\} \frac{\text{QS} \times 100}{\text{QT}} = 17\%$$

ANSWERS

13. N-G Suction

H⁺, CL⁻, K⁺ ions are most likely to be lost/metabolic alkalosis.

14. Chronic Respiratory Failure

pCO₂ = 75 mm Hg

If pH = 7.4, use Sig-Ander to line up HCO₃. The HCO₃ value from the nomogram is 45 meq. The bicarbonate is increased

15. ANSWERS TO FLAIL CHEST

1. Diagnosis;

pH - 7.18

PCO₂ - 70

PO₂ - 45

HCO₃ - 25



Room Air



1. Respiratory Acidosis

2. Hypoxemia

2. pH - 7.52

PCO₂ - 32

PO₂ - 180

HCO₃ - 25



MA - 1

RV - 900

R - 15

FiO₂ = 1.0



Respiratory
Alkalosis

3. $\frac{QS}{QT} \times 100 = 30\%$

4. For PaO₂ of 90, drop FiO₂ to 70%

5. $(PCO_2)_1 \times TV_1 \times R_1 = (PCO_2)_2 \times TV_2 \times R_2$
 $32 \times 15 \times 900 = 41 \times (TV_2 R_2)$
 $10536 = TV_2 R_2$

Assign the rate you want = $\left\{ \begin{array}{l} \text{If } R_2 = 15, \text{ then } TV_2 = 702 \\ \text{If } R_2 = 13, \text{ then } TV_2 = 810 \\ \text{If } R_2 = 10, \text{ then } TV_2 = 1053 \end{array} \right.$

16. ANSWERS TO POST CODE 99 - CVA

1. Diagnosis

pH - 7.45	MA-1	Metabolic Alkalosis
pCO ₂ - 47	TV - 900	
pO ₂ - 53	R - 15	
HCO ₃ - 32	FiO ₂ - 45	Hypoxemia

2. $QS \times 100 = 40\%$
QT

3. For a PaO₂ of 80, an FiO₂ of 1.0 is necessary.

4. $(PCO_2)_1 \quad TV_1 \quad R_1 = (PCO_2)_2 \quad TV_2 \quad R_2$
 $47 \quad 900 \quad 15 = 40 \quad (TV_2 \quad R_2)$
 $15862 = TV_2 \quad R_2$

Pick the TV you want = If TV = 900, then R = 17.6
If TV = 800, then R = 19.8
If TV = 700, then R = 22.7

5. For a HCO₃ of 25 ----

First - Line up ABG on Sig-Ander Nomogram

Next - Read pH - 7.4 This means after Arginine Infusion a pH of 7.4 will be expected.

16. ANSWERS TO POST CODE 99

Next - Using the formula, we can calculate the MEQ of Arginine to get a pH of 7.4

meg of Arginine = $\Delta B \times .2 \times (60)$
= $(32-28) .2 (60)$
= 48 Meg of Arginine to be infused over 2-3 hours.

17. ANSWERS TO PNEUMONIA

pH = 7.28	}	MA - 1	}	Respiratory Acidosis
pCO ₂ = 60		TV = 600		
pO ₂ = 100		R = 10		
HCO ₃ = 38		Fio ₂ = .60		

$$1. \frac{QS}{QT} \times 100 = 24\%$$

2. To get paO₂ of 75 at 24% Shunt Decrease
FiO₂ to .35

3. To get pCO₂ of 45 - use S.A. Normogram to see what pH the patient will have ----- 7.4 (perfect)

$$\begin{aligned} \therefore TV_1 R_1 (pCO_2)_1 &= TV_2 R_2 (pCO_2)_2 \\ 600 \cdot 10 \cdot 60 &= (TV_2 R_2) \cdot 45 \\ 8000 &= TV_2 R_2 \end{aligned}$$

Assign the rate you want

$$\left\{ \begin{array}{l} \text{If } R_2 = 14, \text{ then } TV_2 = 571 \\ \text{If } R_2 = 12, \text{ then } TV_2 = 666 \\ \text{If } R_2 = 10, \text{ then } TV_2 = 800 \end{array} \right.$$

18. PULMONARY ANSWERS TO CHEST WOUND

ABG Diagnosis: Metabolic Acidosis

Shunt: 20%

Adjust the pH to 7.38 -

First, line up the ABG on Sig.-Ander. Normogram

Next, holding the CO₂ at 40, move the straight edge until the pH reads 7.38. The new HCO₃ necessary to give a pH of 7.38 is 23.5.

Using the formula, we can calculate the meg of NaHCO₃.

$$\begin{aligned} \text{meg of NaHCO}_3 &= (\Delta B) \cdot .2 (65) \\ &= (22.5 - 15) \cdot .2 (65) \\ \text{meg of NaHCO}_3 &= 97.5 \end{aligned}$$

Suggest half the dose be given IV and the rest hung as a drip over two hours.

19. ANSWER TO AORTIC ANEURYSM

Write Pulmonary Service Note:

<u>ABG</u>		<u>Equipment</u>	<u>DX</u>
pH 7.24	↓	MA -1	Respiratory Acidosis
pCO ₂ 60	↑	Ventilator	
pO ₂ 70		V _t = 500	
HCO ₃ 25		R = 12	
		F ₁ O ₂ = .35	

$$\frac{QS}{QT} \times 100 = 26\% \text{ Shunt}$$

To get paO₂ of 90 at 26% shunt increase
fiO₂ to .56

To get pH at 7.42 - use S.A. Normogram

1. Set up given ABG pH 7.24 pCO₂ 60 HCO₃ 25
 2. Hold HCO₃ at 25 and move straight line up pH scale until 7.42 is read.
 3. Read new pCO₂ off straight line = 40
- ∴ TV₁ R₁ (pCO₂)₁ = TV₂ R₂ (pCO₂)₂
 500 12 60 = (TV₂ R₂) 40
 9000 = (TV₂ R₂)

Assign the rate you want $\left\{ \begin{array}{l} \text{If } R_2 = 12 \text{ then } TV_2 = 750 \text{ ml} \\ \text{If } R_2 = 14 \text{ then } TV_2 = 642.8 \text{ ml} \end{array} \right.$

20. ANSWERS TO POST CODE

ABG Diagnosis - Metabolic Alkalosis due to overuse of NaHCO₃.

Since pH 7.7 is too alkalotic we must bring down pH. We choose 7.45.

Patient Needs Arginine - HCL

First, Line up ABG's on Sig. Ander. Normogram. Next, holding CO₂ at 40, move straight edge until pH reads 7.45. The HCO₃ necessary to give a pH of 7.45 is 26.5. We have 47 on board and want to decrease to 26.5. Using the formula, we can calculate the megs necessary:

20. continued

$$\begin{aligned}\text{meg Arginine} \cdot \text{HCL} &= (\Delta B) \cdot 2 \text{ (kg)} \\ &= (47 - 27) \cdot 2 \text{ (60)} \\ &= 240 \text{ meg Arginine} - \text{HCL}\end{aligned}$$

Suggest IV drip of 240 meg of Arginine - HCL over 3-4 hours. Of course, a blood gas will be drawn after completing drip.

21. ANSWERS - SEE TEXT

22. ANSWERS TO ABDOMINAL TRAUMA

No, weaning is not a good idea -

The patient's rate on a set rate of SIMV 10 is 40. This means the ventilator is giving a 10 rate at a volume of 600 ml. The patient is attributing a rate of 30 (40 patient - 10 machine).

If you would measure the volumes of the patient at rates around 30, you would probably see small volumes. This is a common situation and signifies some underlying etiology. The HCO_3 may serve as a guide since it is decreased. The following must be eliminated and if found treated before a successful wean can be accomplished:

1. Sepsis - check WBC's, cultures
2. Renal failure - check BUN, creatinine and urinary output
3. Sodium acetate in hyperalimentation solution

23. ANSWERS TO STAPH PNEUMONIA

As explained earlier, there is present some mechanism which is resisting this set volume. Since this is a volume ventilator the ventilator will draw from the set 40 cm H_2O so that a TV of 500 is delivered. If more pressure, above 440 cm H_2O is needed, the alarm will sound and the patient will only receive that volume which corresponds to that 40 cm H_2O . If you would compensate by turning up the pressure alarm (a dangerous maneuver) it will be noted more and more pressure is needed to give the desired volume. Eventually it would be impossible to increase pressure enough so that the volume of 500 can be given and we end with marked increase in pressure with a drop in TV.

The clinical conditions in decreasing importance which can be an etiology are:

1. Tension Pneumothorax - STAT chest tube or needle
2. Secretions - Therapy
 - a. Endotracheal suction in airways of endotracheal tube or tracheal tube
 - b. Bronchoscopy - if nurses unable to aspirate

PaO ₂	FiO ₂	.35	.39	.42	.45	.49	.53	.56	.60	.63	.66	.70	.74	.77	.81	.84	.88	.91	.95	.98	1.00
PiO ₂		250	275	300	325	350	375	400	425	450	475	500	525	550	575	600	625	650	675	700	725
PAO ₂		268	293	318	343	368	393	418	443	468	493	518	543	568	593	618	643	668	693	718	743
30		65	65	65	65	66	66	66	66	66	67	67	67	67	68	68	68	68	68	69	69
40		53	53	54	54	55	55	55	56	56	57	57	57	58	58	58	59	59	59	60	60
50		41	42	43	43	44	45	45	46	46	47	47	48	48	49	49	50	50	51	51	52
60		34	34	35	36	37	38	38	39	40	40	41	42	42	43	44	44	45	45	46	47
70		26	27	28	29	30	31	32	33	34	35	36	37	37	38	39	39	40	41	41	42
80		23	24	26	27	28	29	30	31	32	32	33	34	35	36	37	38	39	40	40	40
90		19	20	21	22	24	25	26	27	28	29	30	31	32	33	33	34	35	36	37	37
100		15	17	18	19	20	22	23	24	25	26	27	28	29	30	31	32	33	34	35	35
120		10	11	13	14	15	17	18	19	21	22	23	24	25	26	27	28	29	30	31	32
140		10	11	13	14	15	17	18	19	21	22	23	24	25	26	27	28	29	30	31	32
160		7	9	11	12	14	15	16	18	19	20	21	22	24	25	26	27	28	29	30	31
180		5	7	9	10	12	13	15	16	17	19	20	21	22	23	25	26	27	28	29	30
200		5	7	9	10	12	13	15	16	18	19	20	21	22	23	26	26	27	28	29	30
225		2	4	5	7	9	10	12	13	15	16	18	19	20	22	24	25	26	27	28	29
250		0	1	3	5	7	8	10	11	13	14	16	17	18	20	21	22	23	24	25	26
275		0	1	3	5	7	8	10	11	13	14	16	17	18	20	21	22	23	24	25	26
300		0	1	3	5	7	8	10	11	13	14	16	17	18	20	21	22	23	24	25	26
325		0	1	3	5	7	8	10	11	13	14	16	17	18	20	21	22	23	24	25	26
350		0	1	3	5	7	8	10	11	13	14	16	17	18	20	21	22	23	24	25	26
375		0	1	3	5	7	8	10	11	13	14	16	17	18	20	21	22	23	24	25	26
400		0	1	3	5	7	8	10	11	13	14	16	17	18	20	21	22	23	24	25	26

TABLE OF SHUNTS - Iib. = 15; A.V.O₂ = 4; pH = 7.5

