BLOOD GAS ANALYSIS

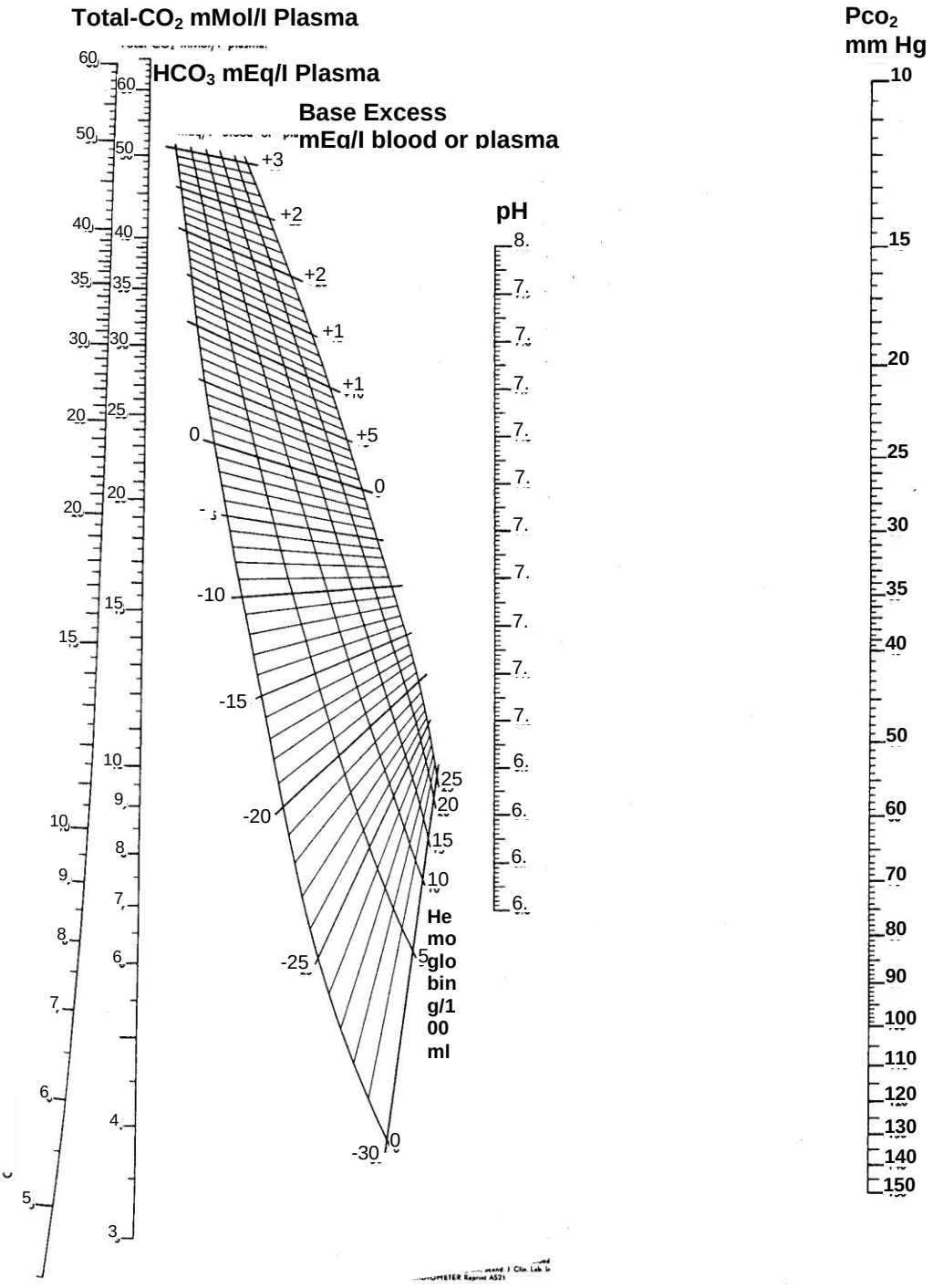
Contents

Abbreviations

ABE	Actual base excess
ABG	Arterial blood gas
$AaDO_2$	Alveolar to arterial oxygen gradient
Baro/PB	Barometric pressure
BB	Buffer base
BE	Base excess
BEecf	Base excess in extracellular fluid
BPD	Bronchopulmonary dysplasia
CH+	Concentration of hydrogen ion
CO_2	Carbon dioxide
ECMO	Extra corporeal membrane oxygenation
FiO_2	Fraction of inspired oxygen
HCO_3	Bicarbonate
H_2CO_3	Carbonic acid
MAP	Mean airway pressure
O_2CT	Oxygen content of blood
$PaCO_2$	Partial pressure of carbon dioxide in arterial blood
PaO_2	Partial pressure of oxygen in arterial blood
pAO_2	Partial pressure of oxygen in alveoli
pH_2O	Water vapour pressure
PPHN	Persistent pulmonary hypertension in newborn
RBC	Red blood corpuscles

RQ	Respiratory quotient
Sat	Saturation
SBE	Standard base excess
St HCO^-_3/SBC	Standard bicarbonate
TCO_2	Total carbon dioxide content of blood
THbA	Total haemoglobin concentration
UAC	Umbilical artery catheter

The terminology of arterial blood gas (ABG) is complex and confusing. It is made worse by the printouts generated by recent microprocessors. Basically the machines



measure pH, carbon dioxide and oxygen. All other parameters are derived based on software in machine which can be obtained manually if one knows how to use Siggaard ndersen Nomograms (given above).

Goals of ABG in newborn is to characterize the type of disorder, quantify the magnitude and assess the nature and extent of compensation.

Indications for ABG

(1) Severe respiratory or metabolic disorders

(2) Clinical features of hypoxia or hypercarbia

(3) Shock

(4) Sepsis

(5) Decreased cardiac output

(6) Renal failure

(7) Ideally any baby on oxygen therapy

(8) Inborn errors of metabolism

Collection of Samples

Ideal artery for sampling in newborn is radial or umbilical artery. One must perform "Allen Test" to ensure collateral blood supply by ulnar artery before puncturing radial artery. If sample from umbilical artery catheter (UAC) is being taken, one should assure free flow of blood and remove three to four times dead space volume before sample is taken. Indwelling arterial line may only be put if round the clock facilities for ABG estimation are available considering this as a potent source of infection.

Arterialised capillary samples are comparable to arterial blood (Table I). If capillary sample (100-150 micro L) is being taken from prewarmed heel, let the capillary fill from the tissue site from where blood is oozing out (figure I). Avoid squeezing and first drop of blood. Rotate the capillary in palm . to mix anticoagulant with blood. Care should be taken not to include any air bubble in the capillary.

Venous blood is good for HCO^-_3 estimation but bad for pH, pCO_2 and pO_2. While drawing venous sample make sure that no tourniquet is applied, artery is not compressed and sample is drawn against the flow of blood towards heart.

Table I : Comparison of Blood Gas Analysis at different sites

	Arterial	Capillary	Venous
PH	Same	----------	Lower
PO_2	Higher	⟶	Lower
PCO_2	Lower	⟶	Higher
HCO^-_3	Same	----------	Same
Recommendation	Good	Fair	Bad

Precautions for collection of blood sample

(1) Heparin is acidic and lowers pH. Use heparin of lower strength (1000 units per ml instead of 5000 units per ml) or heplock solution.

(2) Use small volume of heparinised saline just for lubricating syringe and plunger. If volume is more, dissolved oxygen in haparinised saline may increase pO_2.

(3) Avoid air bubble and let syringe fill spontaneously.

(4) It is desirable to use a glass syringe as plastic syringes are permeable to air.

(5) Sample may be collected in a heparinised capillary from hub of needle used to puncture artery.

The sample should be processed immediately, preferably within 30 minutes. Blood is a living medium. The cells consume oxygen and produce CO_2. Drop in pO_2 depends on initial pO_2. If the latter is very high, significant drop may be noticed. The changes are as depicted in Table II. Slush of ice (not cubes) should be used for storing samples till processing. The sample should be shaken, homogenised before putting in machine.

Table II: Changes in ABG every 10 minutes in vitro

	37°C	4°C
pH	0.01	0.001
pCO_2	0.1 mm Hg	0.01 mm Hg
pO_2	0.1 mm Hg	0.01 mm Hg

* It is obvious that blood sample should be stored at 4°C, if it cannot be processed immediately for minimal error.

Terminology of ABG

Acidosis	pH <7.3
Alkalosis	pH>7.5
Hypercapnia	pCO_2 > 50 mm Hg
Hypocapnia	pCO_2 <30 mm Hg
Hypoxia	pO_2 < 50 mm Hg
Hyperoxia	pO_2 > 70 mm Hg

*Acidemia and alkalemia refer to blood while acidosis, alkalosis to tissue pH.

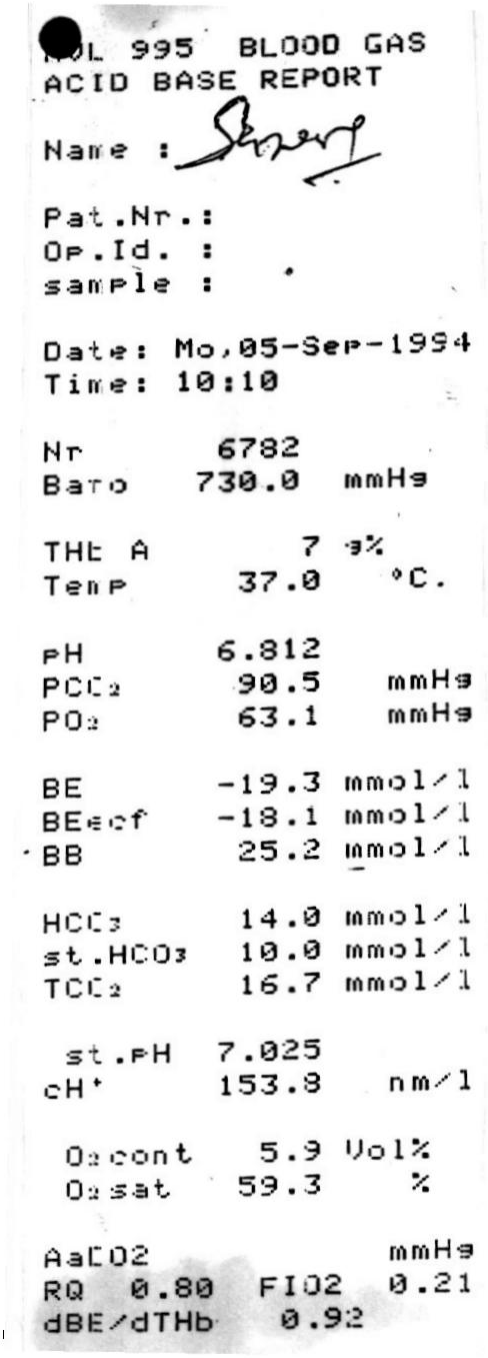
Normal Neonatal ABG values

PH	7.35 – 7.45
pCO_2	35 – 45 mm Hg
pO_2	50 – 70 mm Hg
HCO_3	20 – 24 mEq/L
BE	± 5

ABG values vary with age of neonate and even with gestational age (Table III, IV).

Table III: ABG values based on neonatal age

	Pre-birth (Scalp)	5 min after birth	1-7 days after birth
pH	>7.20	7.20-7.34	7.35-7.45
pCO_2	<50	35-45	35-45
pO_2	25-40	49-73	70-75
Sat%	>50	>80	>90
HCO_3	>15	16-19	20



ABL 995 BLOOD GAS
ACID BASE REPORT

Name : Shyam

Pat.Nr.:
Op.Id. :
sample :

Date: Mo,05-Sep-1994
Time: 10:10

Nr	6782	
Baro	730.0	mmHg
THb A	7	g%
Temp	37.0	°C.
pH	6.812	
PCO_2	90.5	mmHg
PO_2	63.1	mmHg
BE	-19.3	mmol/l
BEecf	-18.1	mmol/l
BB	25.2	mmol/l
HCO_3	14.0	mmol/l
st.HCO_3	10.0	mmol/l
TCO_2	16.7	mmol/l
st.pH	7.025	
cH^+	153.8	nm/l
O_2cont	5.9	Vol%
O_2sat	59.3	%
AaDO2		mmHg
RQ 0.80	FIO2	0.21
dBE/dTHb	0.92	

Printout generated by blood gas machine

Table IV: Target blood gas values

	<28 wks	28-40 wks	Term infant with PFC	Infant with BPD
PaO_2	45-65	50-70	80-100	60-80
$PaCO_2$	40-50	40-60	35-45	45-70
PH	>7.25	>7.25	7.50-7.60	7.35-7.45

Understanding the printout (Appendix – II).

BARO:

It denotes barometeric pressure at site where machine is installed. It varies from place to place and it is determined by automated barometer in the machine. **Barometric pressure is required for calculation of alveolar oxygen pressure.**

THb A:

Haemoglobin (Hb) of patient. A few machines measure haemoglobin, others need this information to be fed. If no information is fed, machine may assume any Hb or it may be at mercy of technician. **Haemoglobin is required to calculate oxygen content (O_2 CT) of blood.**

Temp:

Patient temperature has to be fed into machine because the machine measures all values at 37°C. **Temperature affects pH, pCO_2 and pO_2. Hence, it is desirable to have values corrected for patient temperature.**

BE (ABE); BeEcf (SBE); BB

BE refers to actual base excess in variance from (above or below) total buffer base (BB). Normal BB is 48-49 mmol/L. If BB is 40, it means buffer base is reduced by nearly 8

mmol/L, or BE is –8 (also called base deficit). If BB is 60, it means buffer base is increased by nearly 12 mmol/L, or BE is +12.

BB is dependent on haemoglobin, as 25% of BB is constituted by haemoglobin buffer. Fifty percent of BB is contributed by bicarbonate and 25% by other buffers (proteins, phosphate, sulphate).

HCO_3 (ABC); st HCO_3 (SBC); TCO_2

TCO_2 is sum of HCO^-_3 and amount of CO_2 dissolved in plasma. For each mm Hg pCO_2 , 0.03 ml CO_2 is dissolved per 100 ml of plasma. As HCO^-_3 values change with CO_2 levels, st HCO^-_3 is used to denote value of HCO^-_3 , independent of CO_2 changes (i.e. at pCO_2 of 40 and temperature of 37°C).

St. pH:

It is the pH adjusted for temperature of 37°C and pCO_2 of 40 mm of Hg. This would represent pH value purely due to metabolic status.

CH+:

Concentration of hydrogen ion in nmol/L at 37°C and patients temperature.

O_2 CT:

It is the sum of oxygen bound to haemoglobin + oxygen dissolved in plasma. For each gm saturated Hb, 1.34 ml O_2 is bound to hemoglobin and for each mm Hg pO_2 0.003 ml oxygen is dissolved per 100 ml of plasma.

O_2 sat:

Proportion/percentage of hemoglobin which is saturated with oxygen.

Aa DO_2 :

Alveolar to arterial oxygen gradient. Normal value is 5 to 15 mm Hg.

RQ:

Amount of CO_2 liberated per minute divided by amount of O_2 utilised per minute. Normal values are 200 ml/250 ml =0.8.

FiO_2:

Inspired oxygen fraction concentration. This value has to be fed to machine, it is required for calculation of alveolar oxygen concentration.

DBE/dTHB:

It is called hemoglobin indicator. The normal value of this parameter is 0.32. If this value is more than 0.32 then it indicates, the hemoglobin of the patient should be measured accurately in order to calculate exact base excess.

Details about pH

$pH=pK + \log (HCO_3/H_2 CO_3)$ **(Henderson-Hasselbach euqation)**

pK=constant, it is the pH value at which H_2CO_3 is 50% dissociated i.e. concentration of HCO_3^- and carbonic acid in body are equal.

PK=6.1 for H_2CO_3.

Normal ratio HCO^-_3/H_2CO_3 = 20/1 and hence

pH = 6.1 + log 20

= 6.1 + 1.3 = 7.4

pH Normal 7.35-7.45

Ideal 7.4± 2 S.D.

Alkalosis>7.5

Acidosis <7.3

Severe acidosis <7.2

If pH is <7.25 stimulation of respiratory centre occurs but if <7.0 depression will occur.

Relationship of pH and pCO_2

pCO_2 elevation of 10 mm Hg decreases pH by 0.08, while pCO_2 decrease of 10 mmHg increase pH by 0.08.

The effect of buffers on pH

Buffers stabilize pH. Hemoglobin, bicarbonate and protein are the principal buffers of blood. Extravascular space does not have hemoglobin and hence the buffering capacity is less than that of blood. Because we have no measure of extra and intracellular buffering capacity, it is difficult to predict how much pH will change when the concentration of acid or CO_2 changes. The equation $CO_2 + H_2O = H_2CO_3 = H^+ + HCO^-_3$ shows that any addition or subtraction of H^+ or of HCO^-_3 ions causes a change in CO_2 level. By changing ventilation, CO_2 concentration can be altered. The Henderson Hasselbach equation can be used to calculate one variable only if the other two are known; for example, we can calculate (HCO^-_3) if pH and (H_2CO_3) are known. The equation cannot be used to predict what will happen if only one variable changes and if we know nothing about the other two. Although, we can estimate what might happen in response to an acid-load or ventilatory change, we cannot be accurate.

Oxygenation

Normal values of arterial oxygen tension in term neonates is 50-70 mm of Hg and in children 70-100 mm of Hg. Spurious hypoxia may be noted in situations with increased cells (polycythemia), delay in processing, venous blood or in a febrile patient. Although universally used, paO_2 monitoring has recognized shortcoming. Validity of values are optimal when blood gas samples are obtained from indwelling catheters under quiet,

resting conditions. In a crying neonate due to pain of percutaneous puncture values obtained may not reflect steady state conditions. paO_2 values vary considerably throughout the day in sick neonates. Intermittent sampling produces only a limited view of a single point in time. Transcutaneous ($TcPO_2$) monitors are useful for judging trends in oxygenation during management of acute lung disease. These monitors measure skin surface pO_2 (not paO_2), which under proper conditions is closely correlated with arterial pO_2. The $TcPO_2$ sensor combines a miniature blood gas electrode with a servo controlled probe. The sensor is applied to the skin in a way that excludes any effects of environmental air on values measured. The technique depends on heating the skin at the sensor site to 43.5°C to 44°C. This increases the tissues pO_2 as oxygen diffuses to the skin surface. With these operating temperatures and proper calibration, skin surface pO_2 at the electrode site correlates closely with central arterial pO_2.

In certain clinical circumstances, however, correlation is poor and $TcPO_2$ may underestimate paO_2. Such conditions include circulatory insufficiency, inadequate electrode temperature, improper calibration and lack of user expertise, patient age greater than 10 weeks (skin thickness factor), and use of vasodilator agents. Maturation and thickening of skin with increasing postnatal age limits the use of transcutaneous monitoring to neonates. All of these artifacts of measurement result in underestimation of arterial pO_2.

Under usual circumstances $TcPO_2$ should be in the 40 to 80 mm Hg range. There is a time lag between measured $TcPO_2$ and paO_2 values. As a result, oxygen concentration should not be continuously raised and lowered in attempts to “chase” fluctuating $TcPO_2$

values. The FiO_2 and management plan selected should be designed to minimize fluctuations of $TcPO_2$ values as much as possible without constant manipulations of FiO_2.

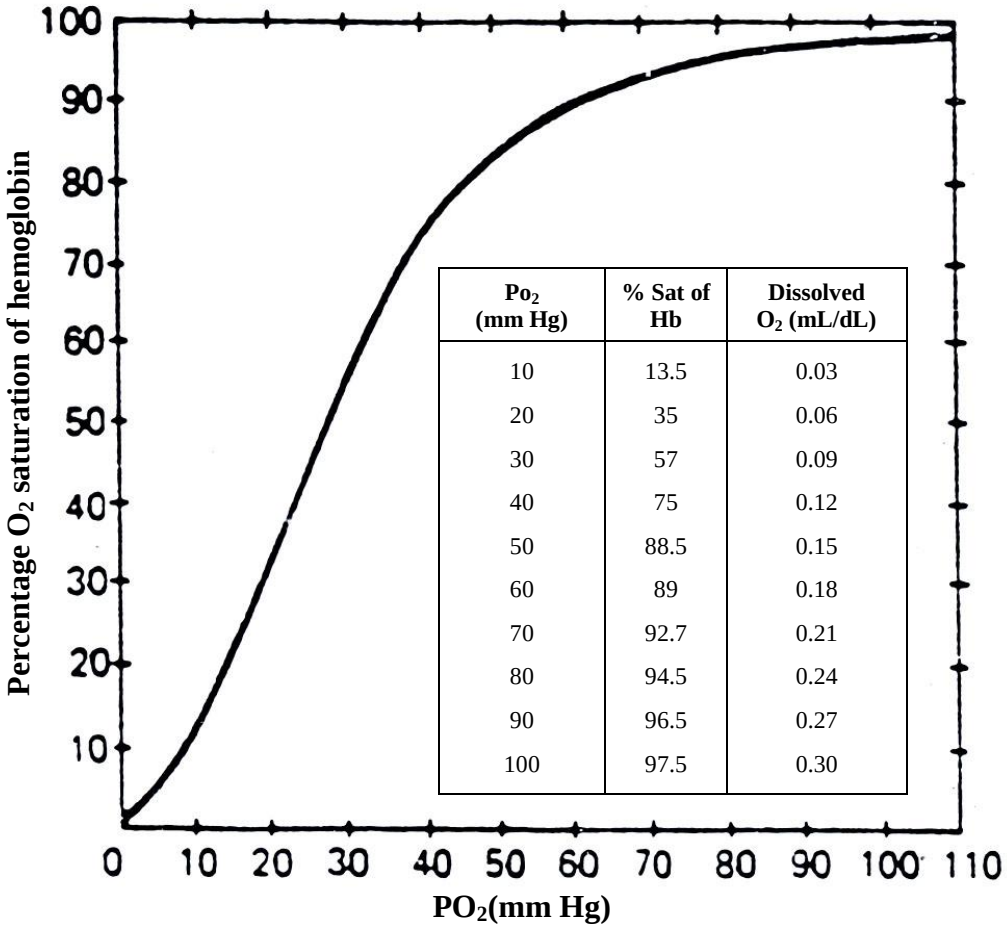
Table VI: Causes of hypoxemia

Causes of Hypoxemia	Disorders
Hypoventilation	Loss of respiratory drive, Mechanical interference with lung inflation
Ventilation/perfusion mismatch	Parenchymal lung disease
Right-to-left shunt	Congential heart disease, Persistent pulmonary hypertension
Methemglobinemia	Abnormal hemoglobin, Nitrate toxicity (following No)

Oxygen saturation

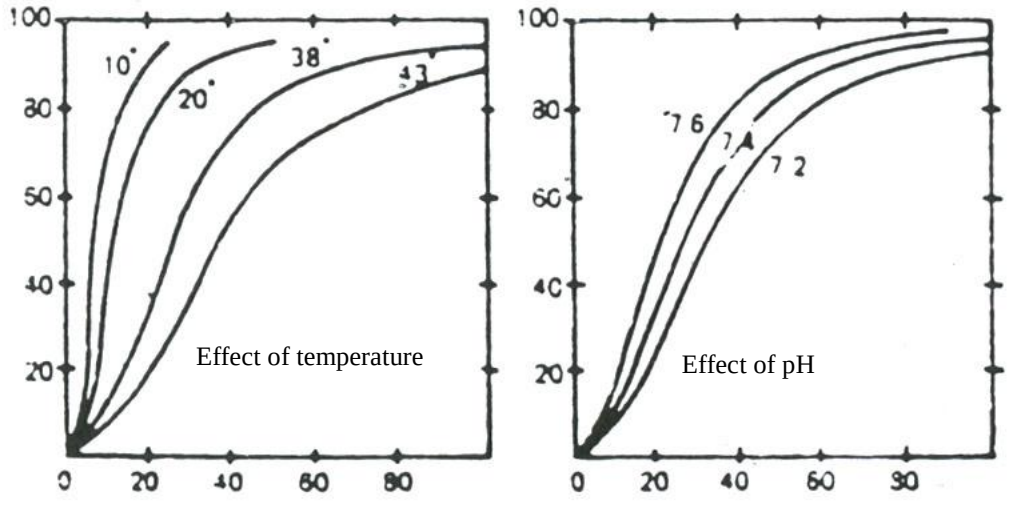
Amount of oxygen that is combined with hemoglobin divided by the amount of O_2 that can be combined with Hb i.e. % of saturation of Hb. Pulse oximetry is useful for monitoring trends in oxygenation. This technique is less complex and does not require calibration or the level of user sophistication that $TcPO_2$ monitors do. The technique measures peripheral hemoglobin O_2 saturation (SaO_2). Movement artifacts may at times, severely limit the applicability of this techniques. Artifacts of saturation measurement may also occur in the presence of high-intensity light, >50% fetal Hb, .Pulse oximetry does not measure the paO_2 and, **thus is relatively insensitive in detecting hyperoxemia**. This is particularly important in the small premature. In acute lung disease, the range of desirable hemoglobin saturation as measured by the pulse oximeter is 88 to 93%. **Normal saturation being 95-98%**.

Clinical cyanosis becomes evident if saturation is <75%. At paO_2 of 40 mm Hg 75% of hemoglobin A is saturated, while at paO_2 27 mm Hg 50% of hemoglobin A is saturated (P50) and at paO_2 of 60 mm Hg 90% of hemoglobin A is saturated.



Po_2 (mm Hg)	% Sat of Hb	Dissolved O_2 (mL/dL)
10	13.5	0.03
20	35	0.06
30	57	0.09
40	75	0.12
50	88.5	0.15
60	89	0.18
70	92.7	0.21
80	94.5	0.24
90	96.5	0.27
100	97.5	0.30

OXYGEN DISSOCIATION CURVE



Effects of Temperature and pH on Oxygen Dissociation Curve

Oxygen dissociation curve is sigmoid shaped which plateaus off at pO_2 > 70 mm Hg. Thus a patient with very high pO_2 may have saturation 97-99% (Figure II). The position of the oxy-hemoglobin dissociation curve is affected by changes in type of hemoglobin, pH, temperature, and concentrations of 2,3-diphosphoglycerate (2,3-DPG) (Table V). Fetal hemoglobin binds O_2 more avidly than does adult hemoglobin and tends to shift the curve to the left. As a result, the paO_2 at which hemoglobin is 50% saturated (P50) is decreased. This shift benefits the fetus since it favors O_2 uptake at the low O_2 tensions in placenta. During the first months after birth, the oxy-hemoglobin dissociation curve begins to shift to the right, and between 4 and 6 months of age it is similar to that of the adult.

Table V: Factors affecting the position of the oxyhemoglobin dissociation curve

Shift Curve to the Left and ↓ P50 (Impair Oxygen Delivery)	**Shift Curve to the Right and ↑ P50** (Improve Oxygen Delivery)
- Alkalosis	- Acidosis
- ↓ Temperature	- ↑ Temperature
- ↓ 2, 3 – DPG concentrations	-↑ 2, 3 –DPG concentrations
- ↑ Fetal hemoglobin	-↑ Adult hemoglobin

The curve may shift to right due to ↓ pH, ↑ pCO_2 , ↑ temperature, ↑ 2-3 DPG and adult haemoglobin indicating less firm affinity of oxygen to haemoglobin while it may shift to left due to ↑ pH, ↓ pCO_2, ↓ temperature, ↓ 2-3 DPG and ↑ HbF thus indicating more firm binding of oxygen to haemoglobin thus resulting in tissue hypoxia (Figure-III).

O_2 Content (O_2 CT and significance)

It is concentration of total oxygen in the blood (expressed as vol. %).

1 gm of Hb combines with 1.34 ml of oxygen. Each 100 ml of blood has 0.003 ml of dissolved oxygen for each 1 mm Hg of O_2 tension.

O2CT = O_2 in saturated Hb + Dissolved O_2 in plasma

Patient with anemia may have normal saturation because of cardiac compensation but decreased oxygen content as less hemoglobin is available for transporting oxygen.

Oxygen delivery.

Oxygen delivery to the tissues is the product of arterial oxygen content and cardiac output, and it is directly affected by changes in paO_2,. Hemoglobin concentration, and cardiac output. A decrease in any one of these components can be offset to some extent by increases in the others.

Oxygen consumption is equal to the cardiac output times the difference between arterial O_2 content and venous O_2 content. Oxygen consumption can be affected by both O_2 delivery and by the ability of the tissues to extract O_2 from blood. The difference between arterial O_2 content and venous O_2 is a measure of effectiveness of O_2 delivery to tissues. An increase in the gradient between arterial and venous O_2 contents infers that delivery is inadequate and that the tissues are increasing extraction to maintain O_2 tension and increase extraction is limited, since a minimum gradient of oxygen tension must be maintained to facilitate diffusion of oxygen into cells and mitochondria. If mixed venous O_2 tension is too low, O_2 delivery to mitochondria will be compromised and O_2consumption will decrease as the cell switches from aerobic to anaerobic metabolism. This inefficiency results in ATP depletion and ultimate cell death. In addition, anaerobic metabolism generates two molecules of lactic acid for every molecule of glucose metabolized, resulting in tissue lactic acidosis. Therefore, the appearance of significant amounts of lactic acid in arterial blood (> 3 umol/L) is indicative of inadequate O_2 delivery to the cellular mitochondria.

Calculation of oxygen content difference of arterial blood and venous blood at right atrial level tells how much oxygen is being utilized by tissue. Because of total shut down in cellular enzymatic function in septic shock, no oxygen utilization occurs. Hence, the oxygen content of venous blood is same as that of arterial.

Alveolar Gas Equation ($AaDO_2$)

Alveolar oxygen can be calculated by following formula

$$pAO_2 = PiO_2 - PACO_2 \left(FiO_2 + \frac{(1-FiO_2)}{} \right)$$

R

Where PiO_2 is partial inspired oxygen pressure and equals $(PB-H_2O)$ (FiO_2). For most clinical purposes, R is assumed to be 0.8 and a modified equation given below is used

$$pAO_2 = (PB-PH_2O) \times (FiO_2) - \frac{PaCO_2}{0.8}$$

or when FiO_2 is greater than 0.6

$$PAO_2 = (PB - PH_2O) \times (FiO_2) - PaCO_2$$

(PB: Barometric pressure; PH2O : Water vapour pressure).

Alveolar oxygen partial pressure in an individual breathing room air (FiO_2 0.21) with arterial pCO_2 of 40 mm of Hg is (760-47) (0.21) –40/0.8

= 713 × 0.21 – 40/0.8

= 149-50 = 99 mm Hg.

In an infant who is breathing 50% oxygen, (FiO_2 0.5) and has an arterial pO_2 of 150 and pCo_2 of 36, the calculated Alveolar pO_2 will be:

$$0.5 \times (760 \text{ mm Hg} - 47 \text{ mm Hg}) - \frac{36}{0.8} = 311 \text{ mm Hg}$$

$AaDO_2$ will be 311 – 150 = 161 mm Hg while the arterial to alveolar pO_2 ratio, will be 150/311 = 0.48.

In normal person breathing room air, the $AaDO_2$ is less than 10 mmHg. But in a neonate due to higher physiological dead space , this may be upto 25-35 mm of Hg . It is about 200 while breathing 100% oxygen. Large gradients (high $AaDO_2$) are noted in congenital cyanotic heart disease with shunts exceeding 50%, meconium aspiration

syndrome and persistence of fetal circulation. $AaDO_2$ > 620 for 12 hr on FiO_2 100% is an indication for ECMO in West, because risk of mortality is > 80%.

An advantage of using arterial pO_2 to alveolar pO_2 ratio (a/ApO_2) instead of $AaDO_2$ is that the ratio does not change with varying inspired oxygen concentration. In healthy adult the ratio a/ApO_2 is more than 0.8.

In infants with the severe RDS the a/ApO_2 ratio could fall to as low as 0.1 to 0.2. In addition, high arterial pCO_2 values indicate reduced ventilation. As baby recovers from RDS the a/ApO_2 improve gradually from low (0.1 to 0.3) to normal (0.7 to 0.9). A value of < 0.22 of arterial to alveolar oxygen ratio is indication for administering surfactant.

Oxygenation Index

$$\frac{MAP \times FiO_2 \times 100}{\text{Postductal } pO_2}$$

40 – mortality risk > 80-90%

25-40 – Moratlity risk 50-60%

If oxygenation index >40, it is a indication for use of ECMO

Carbon dioxide transport

Carbon dioxide transport helps in excreting large amounts of CO_2 continuously from high body concentrations to low atmospheric concentrations. Carbon dioxide is carried in several forms: dissolved in plasma as bicarbonate in equilibrium with dissolved CO_2, is in the form of plasma or red cell bicarbonate. Carbon dioxide is 20 times more soluble in blood than oxygen and its dissociation curve is nearly linear over physiologic ranges. As a result, large amounts of CO_2 can be carried in blood and removed from the body with relatively small changes in partial pressure of carbon dioxide in blood.

Carbon dioxide and oxygen interact in the blood to enhance each other's loading and unloading capabilities where concentration extremes exist. The bindings of CO_2 to hemoglobin in the tissues augments unloading of oxygen from capillary blood-**the Bohr effect**. On the other hand, the binding of oxygen to hemoglobin in the alveolar capillary bed augments CO_2 unloading from capillary blood into the alveolar **the Haldane effect**.

$PaCO_2$

Partial pressure of carbon dioxide in arterial blood. Normal value is 35-45 mm Hg (Ideal 40 mm Hg).

Normal $paCO_2$ of venous blood = 45 mmHg

$paCO_2$ is indicative of alveolar ventilation.

If $paCO_2 < 30$ =Respiratory alkalosis

$paCO_2 > 50$ = Respiratory acidosis

High CO_2 is the most important respiratory centre stimulant. If $paCO_2 > 65$ the respiratory centre becomes insensitive to CO_2. In persistent pulmonary hypertension of newborn (PPHN) values of pCO_2 40-50 mm of Hg with normal pH and pO_2 50-70 mm of Hg are acceptable but not ideal. . In bronchopulmonary dysplasia a high pCO_2 (45-55 mm of Hg) may be acceptable as long as pH is >7.25 and oxygenation normal. In situation of pCO_2 rise, partial tube blockage, decreased minute ventilation or ventilation – perfusion mismatch should be thought.

CO_2 content

The partial pressure of CO_2 (the pCO_2) is measured in torr (mm Hg). Torr is then converted into millimoles of H_2CO_3 by assuming that for every torr of pCO_2 at 37°C, there is 0.03 mmol of H_2CO_3. The sum of bicarbonate and carbonic acid is the CO_2 content.

CO_2 content = HCO^-_3 + H_2CO_3
(at pCO_2 of 40 mmHg and HCO_3 – of 24 mmol/L)
= 24 + 40 X 0.03
= 24 + 1.2
= 25.2 mmol/L

Measuring the CO_2 content in blood

Majority (95%) of CO_2 is inside RBC in form of HCO^-_3 and carbamino-compound, only 5% is dissolved in plasma.

In clinical practice, CO_2 content is assumed to be largely bicarbonate (which is usually true) and, therefore; it reflects a base excess (if CO_2 content is high) or deficit (if CO_2 content is low). Note that there is a problem with this way of interpretation. Assume one gets a report that the CO_2 content is 12 mEq/1. These 12 mEq/1 are the sum of (HCO^-_3) and (H_2 CO_3).

Table VII: CO_2 content can mislead

	(HCO^-_3)	pCO_2 x 0.03	pH
A	10	2	6.79
B	11.8	0.2	7.87

A- Represents a mix respiratory metabolic acidosis

B- is a respiratory alkalosis insufficiently compensated

A CO_2 content, therefore, has to be interpreted cautiously. A simultaneous determination of pCO_2 or pH eliminates the uncertainty.

CO_2 content is a more complete measure of CO_2 present in the plasma in various forms, but it has no additional advantage over HCO^-_3 and it follows the same changes of HCO^-_3 , which is more accurately measured in acid base disorders.

Actual bicarbonate (HCO^-_3)

HCO^-_3 in plasma

(n) 22-24 mEq/L

< 20 Acidosis

> 24 Alkalosis

CO_2 up and down rule

Partial pressure of carbon dioxide may change the levels of bicarbonate depending on degree and duration of CO_2 rise.

Relationship between HCO^-_3 & $PaCO_2$

(1) For acute elevation in $PaCO_2$ over 40 mmHg, HCO^-_3 increases by 1 mEq/L for each 10 mmHg $paCO_2$.

(2) For acute decrease in $paCO_2$ below 40 mmHg, HCO^-_3 decreases by 2mEq/L for each 10 mm of Hg decrease in $paCO_2$.

(3) For chronic elevation in $paCO_2$ over 40 mm of Hg HCO^-_3 increases 4 mEq/L for each 10 mm of Hg increase in $paCO_2$.

Standard bicarbonate concentration (SBC)

(22-26) mEq/L

It is the concentration of the HCO^-_3 in the plasma from blood l which is equilibrated to bring the $paCO_2$ to 40 mm of Hg at 37°C i.e. it overcomes the changes in HCO^-_3 due to respiratory causes and reflects a non-respiratory acid-base change.

Under ideal condition SBC=HCO_3 (n) variation = ± 2 mEq/L. If respiratory acidosis is present, HCO_3 > SBC (because this blood will have a pCO_2 > 40 mm of Hg and therefore

when equilibrated to 40 mmHg, some of the CO_2 will leave the blood. Hence SBC will be lowered).

If respiratory alkalosis is present HCO_3 < SBC (because during equilibration to 40 mm some CO_2 gets absorbed and therefore SBC increases).

Remember following

(1) SBC Low – Metabolic acidosis

High – Metabolic alkalosis

(2) Difference between actual HCO_3^- and SBC indicates

- respiratory acidosis if HCO_3 > SBC
- Respiratory alkalosis if HCO_3 < SBC

(3) When HCO_3 = SBC then respiratory balance is present

- When both are low but equal then compensated metabolic acidosis

(4) When SBC is ↑/↓ then HCO_3 must also ↑/↓

But ↑/N/↓ HCO_3 - may be associated with (n) SBC

Actual base excess (ABE)

Refers to actual base excess above or below total buffer base (BB). It is in-vitro expression which mainly reflects non respiratory portion of acid-base.

When CO_2 accumulates as a result of impaired respiration, the following reactions occur

$CO_2 + H_2O = H_2CO_3 = HCO_3^- + H^+$

Hb - + H+ = HHb

The decrease in amount of Hb^- buffer is equal to the amount of HCO_3^- released in the reaction. Therefore, total amount of buffer anion content will not change. Therefore, changes in the $paCO_2$ will not change base excess.

Hence, ABE is a indicator of metabolic status. It attempts to quantify the patients total base excess or deficit. Expressed as mmol/L of base above or below the (n) buffer base range. The base excess allows an estimate how much base (if BE is negative) or acid (if BE is positive) is necessary to bring a liter of blood to pH 7.4.

Standard base excess (SBE) buffer base (BB)

SBE is same as ABE except that it is an in-vivo measurement which is dependent on the equilibration of the interstitial or ECF compartment of the body and not only the blood with CO_2.

Unlike the ABE – which is the BE in the whole blood in vitro, where buffering capacity is due to bicarbonate and hemoglobin, the in-vivo buffering capacity is less than in vitro because actually equilibration to the new level CO_2 takes place not only in the blood but also in the interstitial space. Since the extra-cellular volume of the body contains about three times more extra-vascular (free of hemoglobin buffer) than intravascular (rich in hemoglobin buffer) volume, some clinicians like to report the standard base excess, a base excess assuming hemoglobin of 5 g/dl. This represents the average buffering capacity of the total extra-cellular volume. Intracellular buffers play an important role after a disturbance has persisted for some time, particularly in severe acid-base derangements. In such situations, standard base excess does not provide a useful guide to therapy, one has to titrate until the desired result is achieved.

Microprocessors in modern automated analyzers use algorithms that automatically calculate variables such as bicarbonate and standard base excess by deriving the blood's buffering capacity from known hemoglobin values. If an apparatus displaying BE is not available the Siggaard-Andersen Alignment Nomogram allows us to use either CO_2 content with pCO_2 or pH, or pH and pCO_2 to find bicarbonate. Additionally, it can be used to determine a base excess for well or poorly buffered systems. It is simple to use. Just draw a straight line through any two of the known variables (pH, pCO_2, CO_2 content) and read off not only the actual bicarbonate, but also BE for any appropriate hemoglobin concentration. For standard BE, use 5g hemoglobin/dl blood, unless the patient is severely anemic (Appendix-I)

Significance of base excess

Total buffer base (BB) in a neonate is 48-49 mmol/L. Half of this is due to HCO_3^-, 25% due to haemoglobin buffer and another 25% due to protein, sulfate, phosphate buffers.

A value of BE of ± 5 is considered normal. Abnormal pH with BE> -5 (based deficit <5) without any decompensation in a stable neonate does not need treatment. Abnormal pH with BE<-5 (base deficit >5) with significant imbalance needs treatment. Treatment of neonatal metabolic acidosis consists of general supportive care and specific measures directed to treat underlying cause. Treatment of hypothermia, hypovolemia, (anemia, hypoxia and electrolyte disturbances) will usually correct metabolic acidosis secondary to asphyxia or poor tissue perfusion. Antibiotics should be given if sepsis is suspected. Many infants require ventilatory support. Bicarbonate is considered by some to be unnecessary and even harmful,

leading to changes in cerebral blood flow and paradoxically to increased cerebrospinal fluid or intracellular acidosis.

Simple disorder

In simple acid base disorder pCO_2 and HCO_3^- levels change in the same direction.

Simple disorder	pH	pCO_2	HCO_3^-
Metabolic acidosis	↓	↓	↓
Metabolic alkalosis	↑	↑	↑
Respiratory acidosis	↓	↑	↑
Respiratory alkalosis	↑	↓	↓

The Mixed Disturbance

If a patient with respiratory insufficiency develops metabolic acidosis, he loses his ability to compensate and a mixed respiratory-metabolic acidosis supervenes. Correspondingly, a mixed respiratory-metabolic alkalosis is also possible.

Mixed Disturbances*

	pH	Bicarbonate	pCO2
Mixed			
Acidosis	↓↓	↓	↑
Alkalosis	↑↑	↑	↓

- This table demonstrates that compensation cannot take place when respiratory and metabolic (renal) disturbance conspire. In mixed disturbances, both metabolic (bicarbonate) and respiratory (pCO_2) factors pull in the same direction and pH changes are exaggerated (double arrows).

Compensation mechanism

Compensation for Acid –Base imbalances

When disturbances in acid-base balance perisist, the body can call into play compensatory efforts through an organ not primarily affected; for example, pulmonary disturbances resulting in respiratory acidosis or alkalosis will lead to compensation by the kidney. Conversely, primary disturbances of renal function or metabolism with acid-base imbalance lead to compensation by the lungs.

The body's compensatory efforts are governed by complex intracellular and extracellular stimuli and responses. Assume that a respiratory acidosis triggers a renal compensatory effort. Compensation will return the abnormal pH toward normal. It does not re-establish completely normal values or when complete compensation and correction of a respiratory acidosis succeeds, the drive that sustains the compensatory effort would cease.

The direction of compensatory mechanism, bicarbonate, and PCO_2.

	PH	Bicarbonate	PCO_2	Compensation*
Respiratory				
Acidosis	↓	↑↑	↑	
Alkalosis	↑	↓↓	↓	Renal effect on bicarbonate
Metabolic				
Acidosis	↓	↓	↓↓	
Alkalosis	↑	↑	↑↑	Respiratory effect on CO_2.

- Double arrows show direction of compensation. The pH change will be less pronounced in the presence of compensatory mechanism than in their absence.

Anion Gap

Measurement of anion gap gives a clue to the cause of metabolic acidosis. Anion gap is the difference between the unmeasured anions and cations. This is calculated as difference between measured cations and anions.

Serum $(Na^+ + K^+) - (Cl^- + HCO_3^-)$

Normal values are 5 to 12 mmol/L. A normal anion gap acidosis suggests a HCO_3^- loss or rapid dilution of ECF. Chloride is proportionately increased in such conditions – GIT, Renal loss of HCO_3^-. Increased anion gap suggest an addition of strong acid in the system as occurs in lactatemia, ketonemia, renal failure, excessive salt therapy (ringer lactate, acetate), ingestion of slicylates, methanol glycol. A decrease in serum K+, Ca++, Mg++ or falsely high Na+ or serum protein can also increase the anion gap. A decrease in anion gap does not help in diagnosis of acid base disorder. This may occur with low serum protein or increase plasma chloride due to bicarbonate loss by intestine or kidneys.

Remember 50% of sick patients with hyperlactatemia may present as no anion gap metabolic acidosis because of hyperchloremia and hypoalbuminemia.

Approach to ABG and exercises

Approach to ABG (Back page)

Interpretation of ABG should be systematic. Look at pH, pCO_2, HCO_3^- / BE and pO_2, (where lungs control CO_2/O_2 while kidneys HCO_3^-). Try to answer following

1. Is acidosis or alkalosis present?
2. Is the imbalance respiratory (pCO_2) or metabolic (HCO_3^-) in origin?
3. Is any compensation present?
4. What is paO_2?

5. Identify possible cause of the acid-base imbalance
6. What is the management for the imbalance?

   Keep clinical condition, previous ABG and therapeutic interventions in mind while interpreting the ABG report. Compensation by kidneys is slow in neonate with which while a sick neonate with respiratory disease has limitation for CO_2 excretion and kidneys may be ineffective for HCO_3^- conservation.

   Let us look at arterial blood gas level for different simple disorders.

PH	7.35	7.22	7.49	7.18	7.60
PCO_2	42	55	30	40	45
BE	-2	-4	0	-10	10
HCO_3^-	23	21	22	16	32
pO_2	60	58	65	55	70
Interpretation	**Normal**	**Respiratory Acidosis**	**Respiratory Alkalosis**	**Metabolic Acidosis**	**Metabolic Alkalosis**

ABG exercises:

For following ABG (A to F) confirm the values of TCO_2, O_2 content, $AaDO_2$. Are these correctly derived by machine?

	A	B	C	D	E	F
Baro Pr.	747	737	747	730	747	747
Water vap. pr.	47	47	47	47	47	47
Hb	15	10	12	10	10	10
pH	7.418	6.881	7.322	7.516	7.516	7.531
pCO_2 mmHg	28.8	51.1	36.4	21.4	21.4	29.7
pO_2 mmHg	43.8	29.5	96.3	112.1	112.1	139.0
BE (ABE) mmol/L	-3.9	-22.2	-6.7	-2.7	-2.7	+3.5
Beecf (SBE) mmol/1	-5.4	-21.1	-6.8	-4.9	-4.9	+2.2
BB mmol/L	44.0	23.4	41.1	45.3	45.3	51.5
HCO_3 mmol/L	18.1	9.3	18.3	17.4	17.4	25.0
$StHCO_3$ mmol/L	20.3	8.2	18.8	21.1	21.1	27.5
TCO_2 mmol/L	19.0	10.8	19.4	18.0	18.0	25.9
O_2 ct vol %	15.1	6.8	16.1	13.7	13.6	13.8
O_2 sat %	81.0	50.0	96.6	98.6	98.6	99.2
FiO_2	0.50	1.0	0.30	0.30	0.30	0.30
Aa DO_2	270.6	619.5	70.0	72.1	72.1	35.3

What are possible for simple disorders in newborn ?

Metabolic acidosis

(i) Underperfusion

(ii) Hypothermia

(iii) Anemia

(iv) Hypoxemia

(v) Sepsis

(vi) Increased protein load > 3g/kg/day while on parentaral nutrition.

(vii) Renal immaturity – loss of bicarbonate

(viii) Late metabolic acidosis – immaturity of kidney to handle high solute load especially sulphur containing aminoacids.

(ix) Metabolic disorder -IEM

(x) Decreased cardiac output

(xi) Acetazolamide (diamox) use

(xii) Use of excessive PEEP ,increase work of breathing

Metabolic alkalosis

(i) Iatrogenic – bicarbonate therapy

(ii) Use of diuretics

(iii) Following blood transfusion – citrate in blood gets converted to bicarbonate

(iv) Persistent vomiting – Congential adrenal hyperplasia

(v) Prolonged gastric aspiration

(vi) Urea cycle disorder

Respiratory Acidosis

Due to decreased minute ventilation

(i) Tube block

(ii) Tube dis-lodgement

(iii) Increased dead space – long endotracheal tube, adapters, and small bore tube

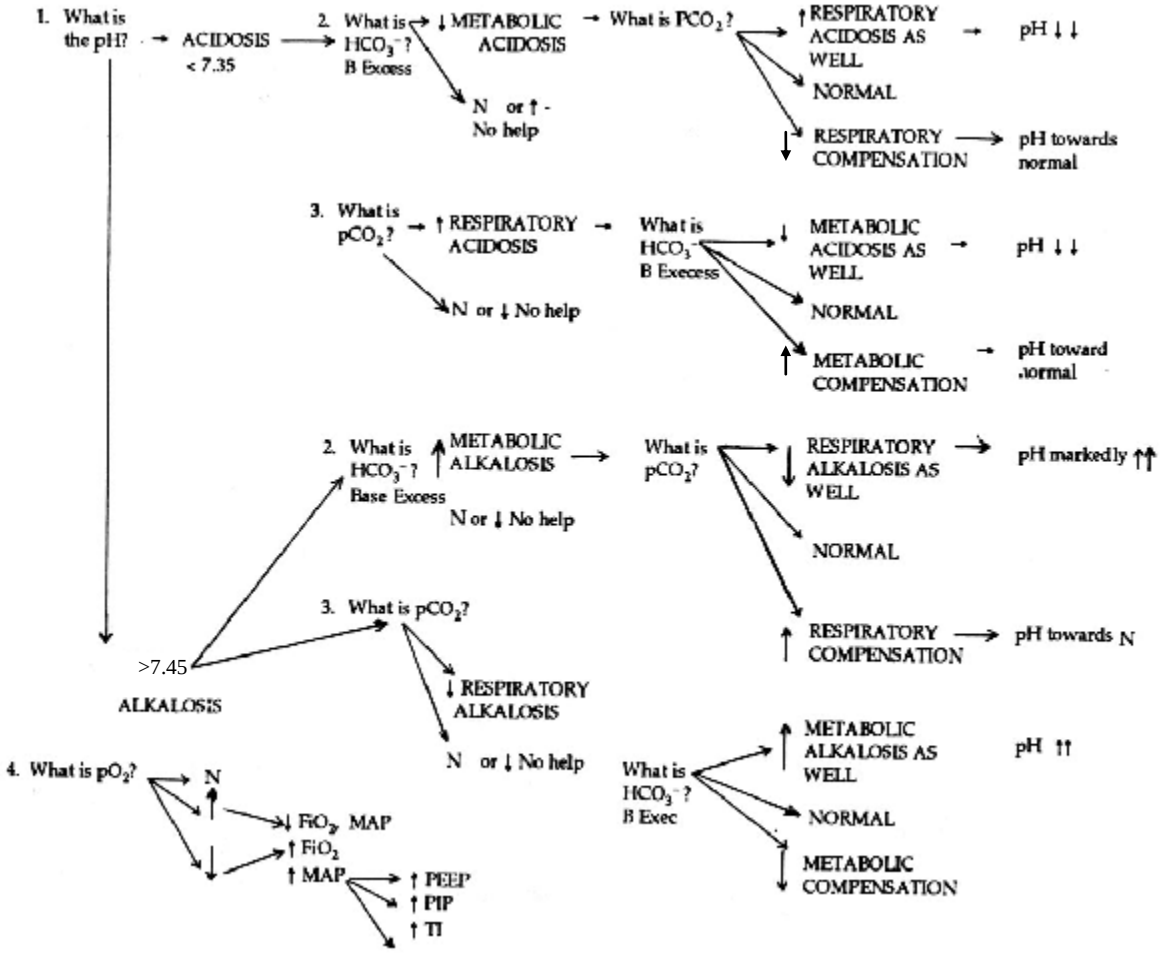
(iv) Opening of ductus (PDA)

(v) Pulmonary interstitial edema

(vi) Pulmonary air leak

(vii) Collapse, consolidation

Arterial blood gases decision tree



Practical tips for sampling for blood gas analysis

- Wait for a steady-state before sampling: Wait 30 minutes after any change in the ventilatory setting
- The frequency in which the blood gases should be drawn is dependent upon the severity and the progress of the disease.
- The following are recommendations which may be useful.

  Arterial blood gases should be drawn:

  - Within 30 minutes of initiating mechanical ventilation or making a parameter change
  - Every 2-4 hours during acute phase of illness
  - Every 4-6 hours on stable infants requiring minimal ventilator manipulations
  - Every 1-7 days in infants with chronic lung disease
  - Whenever clinical condition indicates

Use low strength heparin enough to obtain a final concentration in the sample between 50 and 100 IU/ml or heplock solution..

- Use minute volume of liquid heparin so as to avoid dilution of blood specimen.
- If Ca++ has to be determined on the same sample, use a special "buffered" heparin to avoid the chelating effect of standard heparin on calcium ions.
- Try to use dry heparin (powder or better crystallized or better still, lyophilized). The available commercial kits or sets use mostly crystallized form for capillaries and lyophilized for syringes.

- Always carefully mix the blood after sampling by rotating the syringe between your hands and swirling it gently up and down, to assure a good mixing with heparin. Do it again.
- Avoid accidental introduction of air bubbles into the syringe. Tighten it carefully immediately after sampling.
- Use sampling equipment allowing spontaneous ascension of blood in it, without requirement of pulling on the plunger.
- Eliminate immediately and carefully any air bubble present inside the syringe before sending it to the laboratory.
- Use glass syringe, if the measurement cannot be done immediately.
- Try to reduce delay to a minimum between sampling and measurement. Do not keep sample in ice if measurement can be done within 30 min. after sampling.
- If the delay is, or is presumed, to be more than 30 min. , immerse sample in a slush of iced water and keep it so until measurement can be done. Maximum allowable delay in these conditions is two hours, and even then, pO_2 value is doubtful.
- Be very careful when interpreting the blood gas values measured either between 30 minutes and 2 hours on non iced sample or measured after two hours on an iced sample.
- In case of hyperleucocytosis, polycythemia, consider results (mostly pO_2) with a critical eye because these may result in spurious hypoxemia
- Homogenize blood sample before introduction into the analyzer, particularly if hemoglobin/hematocrit have to be determined simultaneously with $pH/pCO_2/pO_2$.

- Expel the first drops of blood from the syringe before introduction into the analyzer. Inject slowly and carefully when using such a procedure.
- Make a perfect local vasodilation and puncture the appropriate site for capillary sampling with adequate material. Do not try capillary sampling from an hypotensive neonate. Take great care of the risks of local contamination by ambient air. Do not forget to help heparin powder dissolution in the sample in an appropriate way. If a metal flea is required, do not forget to eliminate it before presenting the capillary to the analyser.
- Before sampling from a catheter, aspirate a blood volume four times dead space slowly. Take the sample in desired syringe. Re-infuse the blood withdrawn after the sampling.

Desired blood gas status and the possible change(s) in ventilator settings which will achieve it (using pressure-type ventilator)

Desired status	Ventilator settings				
	Rate	PIP	PEEP	Ti	FiO_2
Increase $PaCO_2$	↓	↓			
Decrease $PaCO_2$	↑	↑			
Increase PaO_2		↑	↑	↑ *	↑
Decrease PaO_2		↓	↓	↓ *	↓

* Fine tuning, sparingly employed