Advanced Blood Gas Analysis From Physiology to Practice

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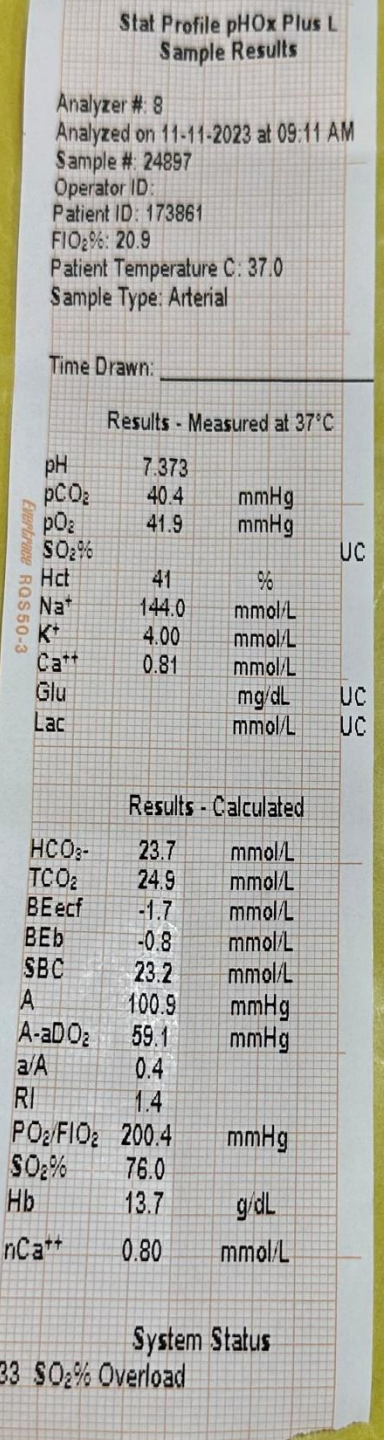
OBJECTIVES

- Indications for BGA
- Composition of a BG report
- Sample types
- Pitfalls in BGA
- Steps in BG interpretation
- Case scenarios
- Clinical Mx of acid base abnormalities

Indications for BG analysis

- To obtain information about ventilation (PCO2) oxygenation (PO2)
- To obtain information about acid base balance or electrolyte disturbance
- To evaluate response to a clinical intervention


Stat Profile pHOx Plus L
Sample Results

Analyzer #: 8
Analyzed on 11-11-2023 at 09:11 AM
Sample #: 24897
Operator ID:
Patient ID: 173861
FIO_2%: 20.9
Patient Temperature C: 37.0
Sample Type: Arterial

Time Drawn: _____

Results - Measured at 37°C

pH	7.373		
pCO_2	40.4	mmHg	
pO_2	41.9	mmHg	
SO_2%			UC
Hct	41	%	
Na^+	144.0	mmol/L	
K^+	4.00	mmol/L	
Ca^{++}	0.81	mmol/L	
Glu		mg/dL	UC
Lac		mmol/L	UC

Results - Calculated

HCO_3-	23.7	mmol/L
TCO_2	24.9	mmol/L
BEecf	-1.7	mmol/L
BEb	-0.8	mmol/L
SBC	23.2	mmol/L
A	100.9	mmHg
A-aDO_2	59.1	mmHg
a/A	0.4	
RI	1.4	
PO_2/FIO_2	200.4	mmHg
SO_2%	76.0	
Hb	13.7	g/dL
nCa^{++}	0.80	mmol/L

System Status

33 SO_2% Overload

Composition of BG report

Directly measured variables

- pH
- pCO_2
- pO_2
- SpO_2
- Electrolytes –Na/K/Ca/Cl
- Hct
- Glucose
- Lactate

Indirectly/Calculated variables

- HCO_3/Std HCO_3
- Base Excess-Blood/ECF (Std)
- Hb
- a/A
- P/F

Actual Bicarbonate

- Derived from pH and pCO_2 using the Henderson-Hasselbach equation.
- Normal range 21 - 26 mmol.
- **H-H equation**: **$pH = 6.1 + \log [HCO_3^-] / 0.03\ pCO_2$**
- 6.1 is the pKa (negative logarithm of the acid dissociation constant) for carbonic acid (H_2CO_3)

Standard Bicarbonate

- The calculated concentration of HCO_3^- if the sample it were at 'standard conditions'.
- At a temperature of 37°C and a pCO_2 of 5.3 kPa (40mmHg; the middle of the pCO_2 reference range).
- By assuming a pCO_2 of 5.3kPa, the standard bicarbonate compensates for any abnormality in HCO_3^- caused by a respiratory cause.

Base Excess (Buffer Base)

- Base excess and base deficit refer to an excess or deficit, respectively, in the amount of base present in the blood.
- Usually reported as a concentration in units of mEq/L (milliequivalents of solute per litre of solvent).
- Positive numbers indicating an excess of base and negative a deficit.

Base Excess (Buffer Base)

- Base excess beyond the reference range indicates:
- **metabolic alkalosis** if too high (more than +2 mEq/L)
- **metabolic acidosis** if too low (less than −2 mEq/L)

Base Excess : Amount of Acid or Alkali required to return plasma **in vitro** to normal pH under standard conditions.

Standard BE: BE calculated for Anaemic Blood (Hb = 5Gm%).

- Since Hb effectively buffers plasma & ECF to a large extent.

- Quantity of Acid or Alkali required to return plasma **in-vivo** to a normal pH under standard conditions

Types of samples

- Arterial
- Venous –peripheral/central
- Capillary

What should be your choice?

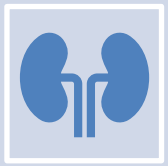
Disadvantages of Arterial Puncture

- Failure and/or pain
- Haematoma or haemorrhage
- Arteriospasm
- Arterial occlusion
- Vasovagal response
- Pseudoaneurysm

Self Fill Syringe


16G
40mm
1.6mm
18G
38mm
1.2mm
19G
25mm
1.1mm
19G
38mm
1.1mm
20G
25mm
0.9mm
20G
38mm
0.9mm
21G
25mm
0.8mm
21G
38mm
0.8mm
22G
32mm
0.7mm
23G
25mm
0.6mm
23G
30mm
0.65mm
25G
16mm
0.5mm
26G
13mm
0.45mm
27G
13mm
0.4mm
29G
13mm
0.33mm
30G
8mm
0.30mm

Venous Blood Gas



Done when you need to determine mainly pH,pCO_2,HCO_3

Peripheral

Drawn without a tourniquet

Central

ICU/HDU setting to determine $ScvO_2$

	Arterial	Venous	Arterio-venous (A-V) difference
pH	7.35-7.45	7.31-7.41	~ 0.04
pCO_2 (kPa)	4.7 - 6.0	5.5 - 6.8	~ 0.6
pCO_2 (mmHg)	35 -45	41 - 51	~ 6
Bicarbonate (mmol/L)	22-28	23-29	~ 1
PO_2 (kPa)	10.6 - 13.3	4.0 -5.3	~ 8.0
pO_2 (mmHg)	80-100	30 -40	~ 55
sO_2 (%)	> 95	75	> 20

ABG vs VBG ?

pH

- Good correlation

pCO_2

- Good correlation in normocapnia
- Correlation dissociates when $PaCO_2$ >45mmHg

HCO_3

- Good correlation

Lactate

- Good correlation,dissociates >2

PO_2

- PO_2 values compare poorly

When do we need ABG ?

- To accurately determine PaO_2 / PaCO2 in a ventilated patients

- To accurately determine parameters in a haemodynamically unstable patients

What are the preferred sites for ABG sampling

- Radial
- Brachial
- Femoral
- Preferably arterial line

Pitfalls in BG Analysis

- Pre analytical
- Analytical
- Post analytical

Pre analytical errors

- Patient factors
- Sampling and storage factors
- Transport factors

Table III: A summary of the sources of error and their consequences during blood gas analysis

Error	Consequences
Pre-analytical phase	
Test over-utilisation	Iatrogenic anaemia
Entrainment of air bubbles	PO_2/PCO_2 equilibration with environment False hypocalcaemia
Storage on ice	PO_2 equilibration with environment
Excessive time to analysis	Significant deviations in PO_2/PCO_2
Excessive/incorrect heparin	Analyte dilution Deviations in cation measurements
Aspiration of sample from IV fluid containing catheter	Dilution of analytes Falsely elevated or reduced lactate level depending on fluid type
Haemolysis	False hyperkalaemia, hyponatraemia, hypocalcaemia
Transport via pneumatic tube system	PO_2/PCO_2 equilibration with air bubbles Haemolysis
Analytical phase	Amplification of errors from previous phase
Improper QC/maintenance	Unreliable results
Electrolytes with ionisation similar to standard electrolytes	Falsely elevated electrolyte with similar ionisation
Antifreeze intoxication	False hyperlactataemia
Aspirin intoxication	False hyperchloraemia
Post analytical phase	Amplification of errors from previous phases
Use of different analysers for serial analysis	Improper trends in pH, PO_2, PCO_2
Application of traditional approach (Henderson-Hasselbalch)	Amplification of errors from previous phases Too simple to identify complex acid-base disturbances
Application of physicochemical and semiquantitative approaches (Stewart and Fencl)	Amplification of errors from previous phases Cumbersome May only be applicable to critical patients
Use of incorrect reference range for species	Incorrect interpretation of results

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Interpretation of Blood Gases

1. Look at the **pH**
2. What is the **primary disorder**
3. In **Respiratory disorder** compensation **acute or chronic**
4. In **Metabolic disorder ,**is the compensation **pure**
5. Is there a **mixed** metab/resp.disorder
6. In MA -Is there a **HAGMA**
7. If HAGMA calculate -**Delta ratio**
8. Final **Interpretation**/Clinical diagnosis

Case 1 :Known COPD on inhalers , presents with 3 days history of worsening SOB

pH	6.95
pCO2	80
HCO3	40.2
Na	134
Cl	102
PaO2	78

1. Look at the pH
2. What is the primary disorder
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Step 1

- **Look at the pH**

<7.35- acidosis

>7.45-alkalosis

Normal 7.35-7.45 –does not rule out a complex acid base disorder

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Step 2

What is the primary disorder

Look at pH and pCO_2 –

moved same direction-Metabolic

moved opposite direction-Respiratory

This is not true always !!

Mixed Met/Res acidosis ↓ pH–(↓HCO_3)+ (↑CO_2)

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Step 3 – Is the compensation acute/chronic

- **Acute-** starts in 5-10 min ,modest
- **Chronic**-Starts in 3-5 days

- **Respiratory acidosis**

Acute- ↑1 HCO_3 for every 10 rise in pCO_2
Chronic - ↑4 HCO_3 for every 10 rise in pCO_2

- **Respiratory alkalosis**

Acute - ↓ 2 HCO_3 for every 10 decrease in pCO_2
Chronic- ↓ 5 HCO_3 for every 10 decrease in pCO_2

(Respiratory 1,4-2,5 Rule)

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Step 8–Interpretation/Clinical diagnosis

- Determining the final interpretation of BGA

a) Partially compensated high anion gap pure metab. acidosis

b)Partially compensated chronic respiratory acidosis

c)Mixed metab./respiratory acidosis

- Clinical diagnosis

a) DKA

b) COPD exacerbation

c) Severe pneumonia with sepsis

A1

- Partially compensated CO_2 retaining chronic respiratory acidosis

- COPD exacerbation

Management

1. V 28 Oxygen
2. Start EWS chart
3. Reassess WOB
4. Start BiPAP IPAP -15 EPAP -5
5. Repeat BGA

Case 2: Advanced level female student was brought by schoolteachers with acute SOB

pH	7.56
pCO2	20
HCO3	19.8
Na	131
Cl	101

1. Look at the pH
2. What is the primary disorder
3. In Respiratory disorder compensation acute or chronic
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A2

- Partially compensated acute respiratory alkalosis
- Voluntary hyper ventilation

What's your Management

- Breath into a paper bag ?
- Reassure

Case 3: Known type 1 diabetic off insulin for 3 days presents with vomiting and altered behavior.

pH	**7.03**
pCO_2	18.9
HCO_3	7.1
Na+	134
Cl-	96

1. Look at the pH
2. What is the primary disorder
3. In Respiratory disorder compensation acute or chronic
4. In Metabolic disorder compensation is pure or mixed
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Step 4 – In MA is the compensation pure

- **Metabolic acidosis** (Winters formula)

Expected pCO_2- (1.5 x HCO_3)+8 (+/- 2)

- **Metabolic alkalosis**

Expected pCO_2- (0.7 x HCO_3)+20 (+/- 5)

Lowest pCO_2 - 8-12

Maximum pCO_2 - 55

Interpretation of Blood Gases

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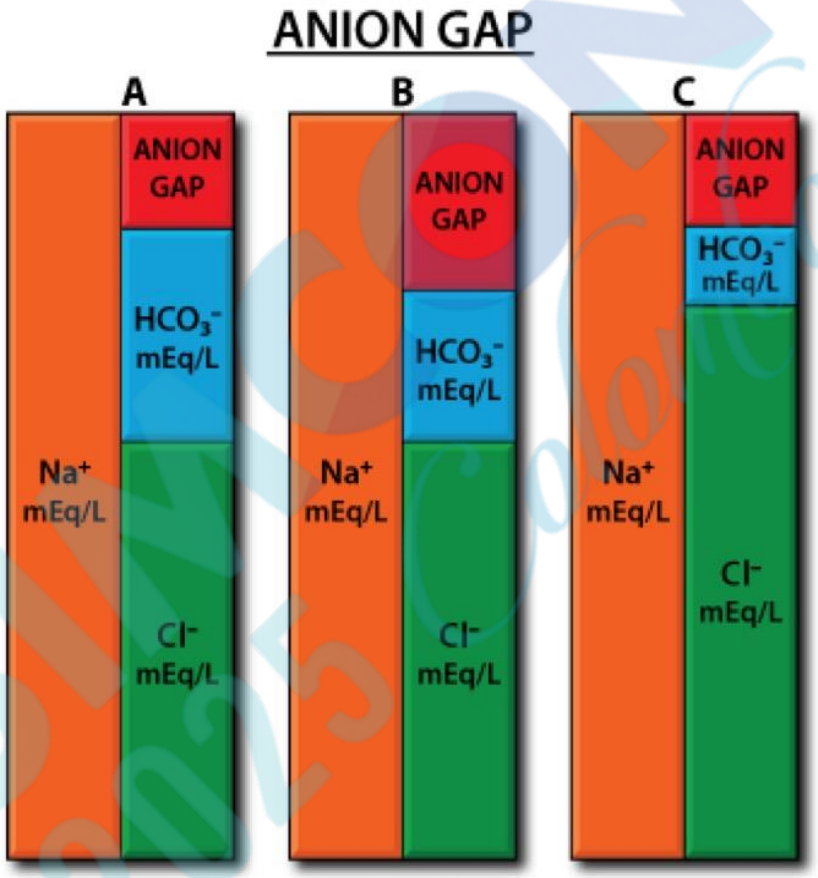
Anion Gap



A. NORMAL ION DISTRIBUTION

B. METABOLIC ACIDOSIS due to acid accumulation; decreased HCO_3^-, increased anion gap

C. METABOLIC ACIDOSIS due to HCO_3^- loss; decreased HCO_3^-, normal anion gap, increased Cl^-

Step 5 –In MA calculate anion gap

- Metabolic acidosis

Anion Gap = $(Na^+) – (Cl^-) - (HCO_3^-)$

Normal 10-14 (12)

Anion Gap

- $AG = (Na^+) - (HCO_3^- + Cl^-)$
- Three clinical applications
  1) Presence or absence of an AG assists in determining the cause of the metabolic acidosis.
  2) The AG is useful in determining the presence of a mixed acid/base disturbance by calculating the Delta Ratio
  3) The AG can be useful in detecting selected disorders that occur with a low, not high AG. (Lithium toxicity, Multiple Myeloma with production of cationic paraproteins)

CAUSES OF INCREASED ANION GAP METABOLIC ACIDOSIS

- **M**: **M**ethanol
- **U**: **U**remia
- **D**: **D**KA
- **P**: **P**araldehyde
- **I**: **I**ron / Isoniazid
- **L**: **L**actic acidosis
- **E**: **E**thylene glycol
- **S**: **S**alicylates

"MUDPILES"

Interpretation of Blood Gases

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7.In HAGMA Calculate Delta ratio

- Used in HAGMA to see whether change in HCO3- is appropriate (i.e. whether there is a coexistent NAGMA or metabolic alkalosis)
- Delta ratio = Increase in Anion Gap/ Decrease in HCO3-
- (change in anion gap) / (change in bicarbonate)

(AG-12)/(24-Bicarbonate)

Calculate Delta ratio

(change in anion gap) / (change in bicarbonate)

(AG-12)/(24-Bicarbonate)

- Value 1-2 -Uncomplicated HAGMA
- Value <1 –Combined HAGMA plus NAGMA
- Value >2- Combined HAGMA/Metab Alkalosis

Interpretation of Blood Gases

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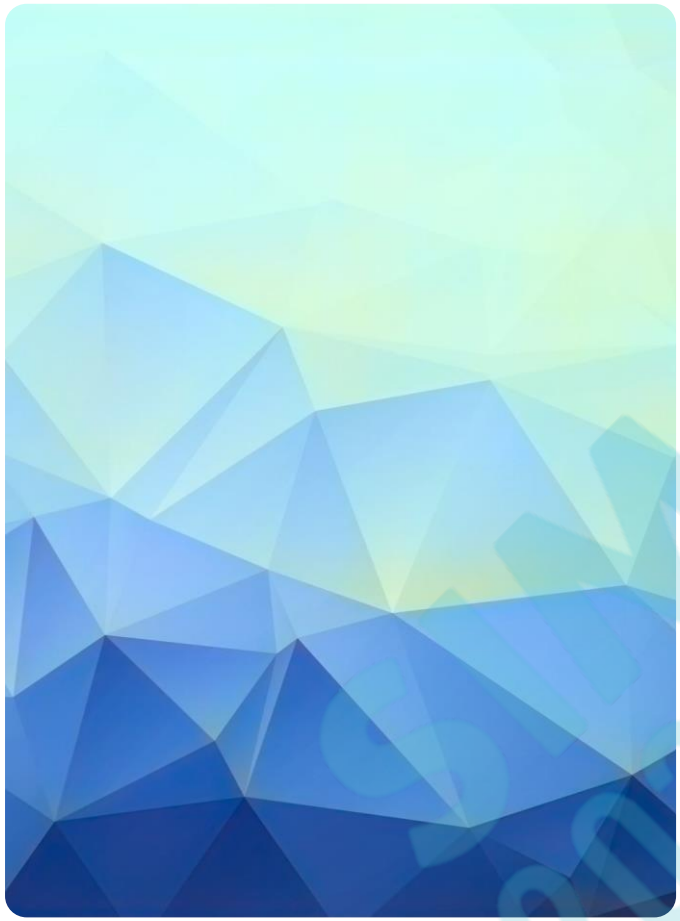
A3

- Partially compensated high anion gap pure metabolic acidosis
- DKA



Management

- IV Fluids
- IV Insulin
- Potassium replacement
- Treat the precipitant
- Role of IV HCO_3 ?

- Always treat the aetiology
- Role of HCO3
- Indications ?
- Disadvantages?
- Bolus/Infusion ?
- Concentration -8.4% vs 1.26%
- Role of RRT

Treatment of Metabolic acidosis

- Always treat the aetiology
- Role of HCO3
- Indications ?
- Disadvantages?
- Bolus/Infusion ?
- Concentration -8.4% vs 1.26%
- Role of RRT

Case 4: Known patient with CKD presents with SOB and diarrhoea.

pH	7.12
pCO_2	31
HCO_3	15
Na	131
Cl	108

1. Look at the pH
2. What is the primary disorder
3. In Respiratory disorder compensation acute or chronic
4. In Metabolic disorder is the compensation pure
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- **Metabolic acidosis** (Winters formula)

Expected pCO2- (1.5 x HCO3)+8 (+/- 2)

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Step 5 –In MA calculate anion gap

- Metabolic acidosis

Anion Gap = $(Na^+) – (Cl^-) - (HCO_3^-)$

Normal 10-14 (12)

Causes of Non-Anion Gap Metabolic Acido

USED PART

U: Urinary diversion/ Ureteroentero

S: Small Bowel Fistula

E: Extra Chloride

D: Diarrhea

P: Pancreatic fistula

A: Addison, Acetazolamide

R: RTA

T: Tenofovir, Topiramate

Interpretation of Blood Gases

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A4

- Partially compensated non anion gap metabolic acidosis
- Secondary to diarrhoea

Causes of Low Anion Gap

- Increased ‘unmeasured’ cations
- • Hypermagnesemia
- • Lithium toxicity
- • Paraproteinemia
  - Myeloma
  - Waldenstrom’s macroglobulinaemia

Case 5 :Known CCF on large doses of frusemide was brought in with SOB, generalized weakness.

pH	7.51
pCO_2	47
HCO_3	40
Na	128
Cl	102
K	2.8

1. Look at the pH
2. What is the primary disorder
3. In Respiratory disorder compensation acute or chronic
4. In Metabolic disorder is compensation pure
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A5

- Partially compensated pure metabolic alkalosis
- Diuretic induced hypokalaemia

Case 6 :Known COPD and DM presents with fever, cough and SOB with reduced LOC.

pH	**6.84**
pCO_2	71
HCO_3	18
Na	134
Cl	92
CBS	141
Lactate	08

1. Look at the pH
2. What is the primary disorder
3. In Respiratory disorder compensation acute or chronic
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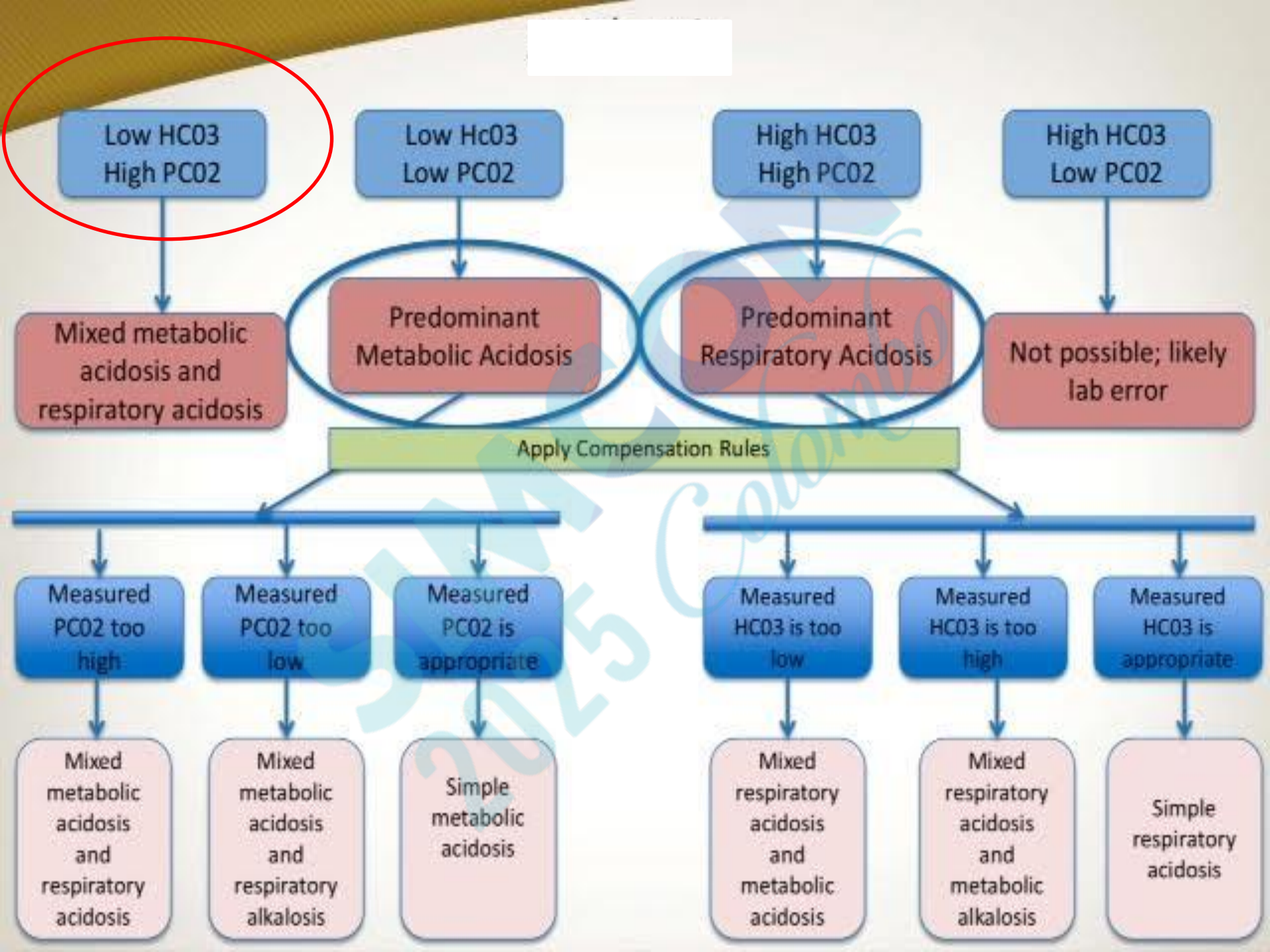

Low HC03
High PC02
Low Hc03
Low PC02
High HC03
High PC02
High HC03
Low PC02
Mixed metabolic acidosis and respiratory acidosis
Predominant Metabolic Acidosis
Predominant Respiratory Acidosis
Not possible; likely lab error
Apply Compensation Rules
Measured PC02 too high
Measured PC02 too low
Measured PC02 is appropriate
Measured HC03 is too low
Measured HC03 is too high
Measured HC03 is appropriate
Mixed metabolic acidosis and respiratory acidosis
Mixed metabolic acidosis and respiratory alkalosis
Simple metabolic acidosis
Mixed respiratory acidosis and metabolic acidosis
Mixed respiratory acidosis and metabolic alkalosis
Simple respiratory acidosis

Step 4-Is there a mixed Metab./Resp. disorder

- Mixed acidosis (metab.+ resp.)
- Metab. acidosis with resp. alkalosis
- Metabolic alkalosis with respiratory acidosis
- Mixed alkalosis
- Metabolic alkalosis with metabolic acidosis

Table 6: Selected mixed and complex acid-base disturbances

Disorder	Characteristics	Selected situations
Respiratory acidosis with metabolic acidosis	↓ in pH ↓ in HCO_3 ↑ in $PaCO_2$	• Cardiac arrest • Intoxications • Multi-organ failure
Respiratory alkalosis with metabolic alkalosis	↑ in pH ↑ in HCO_3- ↓ in $PaCO_2$	• Cirrhosis with diuretics • Pregnancy with vomiting • Over ventilation of COPD
Respiratory acidosis with metabolic alkalosis	pH in normal range ↑ in $PaCO_2$, ↑ in HCO_3-	• COPD with diuretics, vomiting, NG suction • Severe hypokalemia
Respiratory alkalosis with metabolic acidosis	pH in normal range ↓ in $PaCO_2$ ↓ in HCO_3	• Sepsis • Salicylate toxicity • Renal failure with CHF or pneumonia • Advanced liver disease
Metabolic acidosis with metabolic alkalosis	pH in normal range HCO_3- normal	• Uremia or ketoacidosis with vomiting, NG suction, diuretics, etc.

A6

- Mixed metabolic and respiratory acidosis
- High anion gap metabolic acidosis (lactic acidosis)
- COPD exacerbation

Management

- Fluid Resuscitate
- IV Antibiotics
- V Oxygen
- BiPAP
- Repeat ABG

Case 7. Known diabetic off treatment for 2 weeks presents with fever with chills and rigors and a red swollen warm right lower limb. He was tachypnic / hypotensive and receiving a fluid bolus

pH	**7.37**
pCO_2	27
HCO_3	18
Na	134
Cl	92
CBS	341
Lactate	06

1. Look at the pH
2. What is the primary disorder
3. In Respiratory disorder compensation acute or chronic
4. In Metabolic disorder compensation is pure or mixed
5. Is there a mixed metab/resp.disorder
6. In MA -Is there a HAGMA
7. If HAGMA calculate (Delta ratio)
8. Final Interpretation/Clinical diagnosis

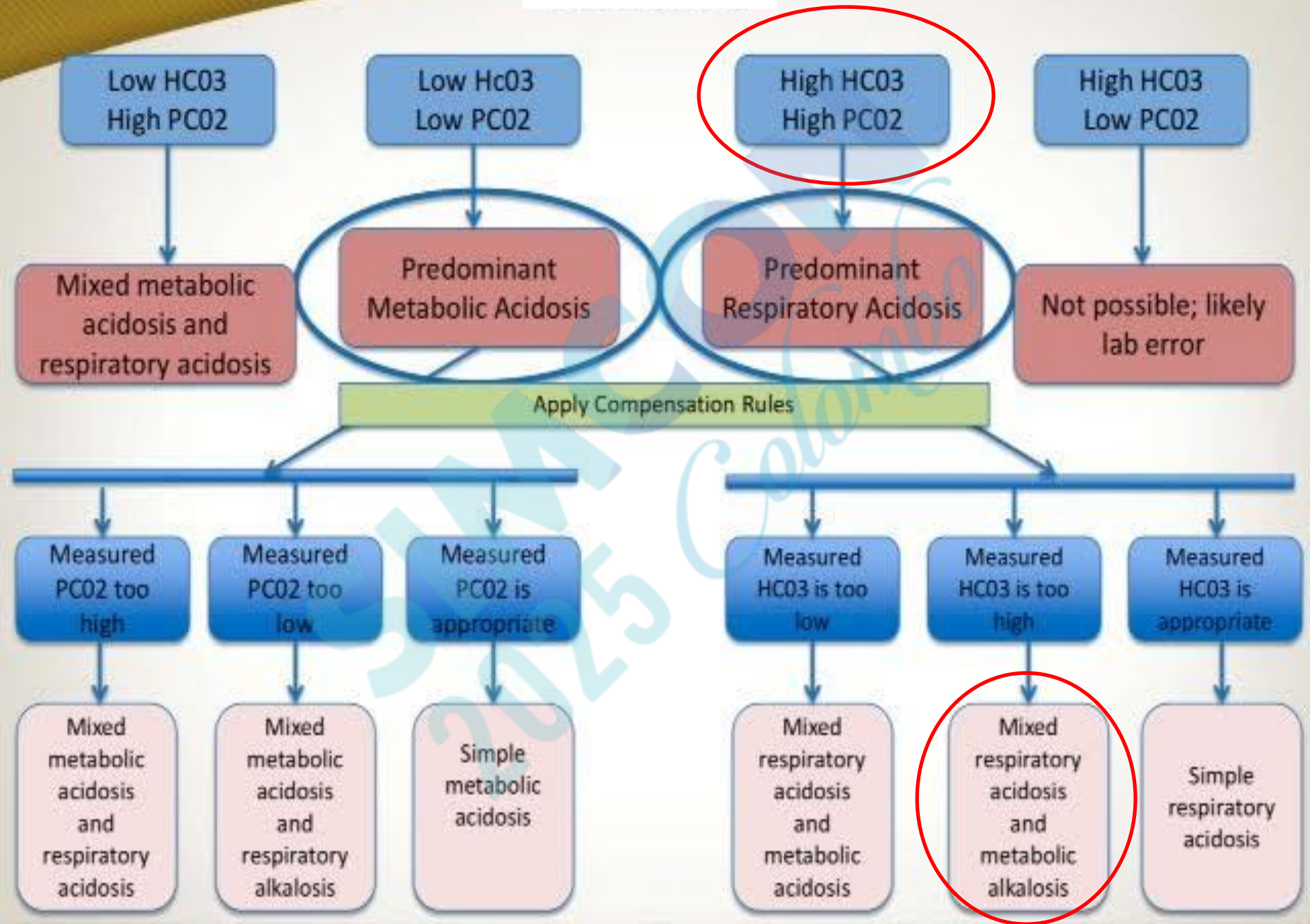
A7

- Metabolic acidosis with respiratory alkalosis

Case 8. Known COPD patient admitted with worsening SOB and abdominal fullness .He had a NG tube inserted which drained out 800 ml within 6hrs

pH	7.38
pCO_2	61
HCO_3	36
Na	134
Cl	92
K	2.8

1. Look at the pH
2. What is the primary disorder
3. In Respiratory disorder compensation acute or chronic
4. In Metabolic disorder compensation is pure or mixed
5. Is there a mixed metab/resp.disorder
6. In MA -Is there a HAGMA
7. If HAGMA calculate (Delta ratio)
8. Final Interpretation/Clinical diagnosis


Low HC03
High PC02
Low Hc03
Low PC02
High HC03
High PC02
High HC03
Low PC02
Mixed metabolic acidosis and respiratory acidosis
Predominant Metabolic Acidosis
Predominant Respiratory Acidosis
Not possible; likely lab error
Apply Compensation Rules
Measured PC02 too high
Measured PC02 too low
Measured PC02 is appropriate
Measured HC03 is too low
Measured HC03 is too high
Measured HC03 is appropriate
Mixed metabolic acidosis and respiratory acidosis
Mixed metabolic acidosis and respiratory alkalosis
Simple metabolic acidosis
Mixed respiratory acidosis and metabolic acidosis
Mixed respiratory acidosis and metabolic alkalosis
Simple respiratory acidosis

A8

- Respiratory acidosis and metabolic alkalosis

Management

- V O2
- BiPAP
- IV K replacement
- Repeat BG

Summary

Know the basics of blood gas analysis

Minimize errors in the blood gas sampling process

Develop a systematic approach of your own to analyse blood gases

Apply compensation formulas that are familiar to you and Delta ratio to find out complex mixed gas disorders

Mixed gas disorders are the commonest that you see in clinical practice

Plan evidence-based management and repeat BGA