Approach to the Patient with Acid-Base Problems

Maintenance of Normal pH

- normal pH = 7.40 --> $[H^+]$ = 40 neq / L
- $H_2O + CO_2$ <--> H_2CO_3 <--> $H^+ + HCO_3^-$

dietary breakdown of protein
(about 80 meq / d normally)

13,000 to 20,000 mM CO2 produced per day

Henderson - Hasselbach Equation

- $H_2O + CO_2$ <--> H_2CO_3 <--> $H^+ + HCO_3^-$
  is equivalent to:
- $pH = 6.1 + \log \{[HCO_3^-] / [H_2CO_3]\}$
  is equivalent to:
- $pH = 6.1 + \log \{[HCO_3^-] / (.03 \times pCO_2)\}$

which can be approximated by the formula

$[H^+] = 24 \times pCO_2 / [HCO_3^-]$

- Normally, $[H^+]$ = 40 neq / L
- Normally, pCO_2 = 40 mm Hg
- Normally, $[HCO_3^-]$ = 24 meq / L

- Remember this formula !!!!!

$[H^+] = 24 \times pCO_2 / [HCO_3^-]$

- This formula is easy to remember

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- This formula is easy to remember
- The constant is easy to remember (same as the usual [HCO3] level
- And…most importantly →

$[H^+] = 24 \times pCO_2 / [HCO_3^-]$

This formula shows that it is the RATIO of CO2 and HCO3 which determines pH

$\underline{pCO_2} / \underline{[HCO_3^-]}$

$[H^+] = 24 \times pCO_2 / [HCO_3^-]$

- Getting from [H+] to pH (or back)
- Converting from [H+] to pH can be easy if you are a savant, if you carry a calculator, or if you take advantage of the fact that, over the range of physiologic pH, the relationship between [H+] and pH is almost linear

$[H^+] = 24 \times pCO_2 / [HCO_3^-]$

- This formula is usable because, in the range of pH values we usually deal with, there is a nearly linear relationship between pH and $[H^+]$

pH	actual $[H^+]$	estimated$[H^+]$
7.10	79	70
7.20	63	60
7.30	50	50
7.50	32	30

Regulation of pH – 3 mechanisms

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- Buffering

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- Respiratory regulation of pCO_2

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- Respiratory regulation of pCO_2
- Renal regulation of $[H^+]$ and $[HCO_3^-]$

Regulation of pH – 3 mechanisms

Different Mechanisms

Different Speeds

Regulation of pH -- mechanisms

- Buffering -- OCCURS IMMEDIATELY
  - No semipermeable membranes to cross
  - No enzyme activation necessary
  - Everything needed is right at hand

Regulation of pH -- mechanisms

- Buffering -- OCCURS IMMEDIATELY
- Respiratory changes OCCUR OVER HOURS
  - Brainstem response to pH
  - Delay in CSF pH changes

Regulation of pH -- mechanisms

- Buffering -- OCCURS IMMEDIATELY
- Respiratory changes are INTERMEDIATE
- Renal changes OCCUR MORE SLOWLY
  - Physiologic changes in renal H+ excretion

Buffering

- Extracellular
  - almost entirely through bicarbonate
    - » it's concentration is highest
  - small contribution from phosphate
- $H_2O + CO_2$ <--> H_2CO_3 <--> $H^+ + HCO_3^-$
- Intracellular

Buffering

- Extracellular
- Intracellular
  - hemoglobin can directly buffer protons
    - » H^+ entry into RBC matched by exit of Na^+ and K^+
    - » **relationship between pH and measured [K+]**
  - hemoglobin can directly buffer dissolved CO_2
  - intracellular conversion of CO_2 (and H_2O) to H^+ and HCO_3^- -> generation of HCO_3^-
    - » H^+ buffered by Hb; HCO_3^- exchanges for Cl^-

Respiratory regulation of pCO_2

- pCO_2 is inversely proportional to VENTILATION
- Ventilation increases in response to a drop in pH, and falls when pH rises
  - respiratory center in medulla
  - responds to pH "intermediate" between that of CSF and plasma
  - response is rapid (though not instantaneous)
  - response is more predictable for falls in pH than for increases

Renal Regulation of $[H^+]$ and $[HCO_3^-]$

A DUMB KIDNEY WILL
USUALLY DO BETTER
THAN A SMART DOCTOR

Renal Regulation of $[H^+]$ and $[HCO_3^-]$

TWO MAJOR FUNCTIONS OF THE KIDNEY (regarding acid-base reg.)

Renal Regulation of $[H^+]$ and $[HCO_3^-]$

TWO MAJOR FUNCTIONS OF THE KIDNEY

- Reclamation of filtered bicarbonate

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- Excretion of Acid

Renal Regulation of $[H^+]$ and $[HCO_3^-]$

TWO MAJOR FUNCTIONS OF THE KIDNEY

- Reclamation of filtered bicarbonate
  - a normal occurrence
  - 4000 meq / day in normal persons
  - by far the greatest use of secreted acid
- Excretion of Acid

Renal Regulation of $[H^+]$ and $[HCO_3^-]$

TWO MAJOR FUNCTIONS OF THE KIDNEY

- Reclamation of filtered bicarbonate
- Excretion of Acid
  - titratable acidity
  - ammonium formation
  - free H^+ excretion

Renal Regulation of $[H^+]$ and $[HCO_3^-]$

Factors which effect renal acid excretion (bicarbonate reclamation)

ACID EXCRETION IS STIMULATED BY:

- Acidemia

Renal Regulation of $[H^+]$ and $[HCO_3^-]$

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ACID EXCRETION IS STIMULATED BY:

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- Hypercapnea

Renal Regulation of $[H^+]$ and $[HCO_3^-]$

Factors which effect renal acid excretion (bicarbonate reclamation)

ACID EXCRETION IS STIMULATED BY:

- Acidemia
- Hypercapnea
- Volume depletion (?mediated by angiotensin II)
  - "Contraction alkalosis"

Renal Regulation of $[H^+]$ and $[HCO_3^-]$

Factors which effect renal acid excretion (bicarbonate reclamation)

ACID EXCRETION IS STIMULATED BY:

- Acidemia
- Hypercapnea
- Volume depletion (?mediated by angiotensin II)
- Chloride depletion
- ?? Hypokalemia
- Aldosterone

Renal Regulation of $[H^+]$ and $[HCO_3^-]$

Factors which effect renal acid excretion (bicarbonate reclamation)

ACID EXCRETION IS INHIBITED BY:

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Renal Regulation of $[H^+]$ and $[HCO_3^-]$

Factors which effect renal acid excretion (bicarbonate reclamation)

ACID EXCRETION IS INHIBITED BY:

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- Elevated $[HCO_3^-]$

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- Elevated $[HCO_3^-]$
- Hypocapnea
- ? Hyperkalemia

Renal Regulation of $[H^+]$ and $[HCO_3^-]$

Remember:

Compared to BUFFERING and RESPIRATORY adaptation, RENAL compensatory mechanisms take a bit longer.

Definitions

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- Metabolic alkalosis = loss of $[H^+]$ or addition of $[HCO_3^-]$

- Respiratory acidosis = increase in pCO_2
- Respiratory alkalosis = decrease in pCO_2

The ANION GAP

- Na^+ - Cl^- - HCO_3^- = 8-12 normally
  - mainly proteins, phosphates, and sulfates

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- BRAINSTEM REFLEX

High Anion Gap Metabolic Acidosis

USUALLY FROM ADDITION OF ACID

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High Anion Gap Metabolic Acidosis

USUALLY FROM ADDITION OF ACID

- Ketoacidosis
  - DKA, Alcoholic KA, Starvation
- Lactic acidosis
  - hypoperfusion; other causes
- Ingestions
  - ASA, Ethylene glycol, methanol
- Renal insufficiency
  - inability to excrete acid

Normal Anion Gap Metabolic Acidosis

- Rise in Chloride matches the decrease in HCO3

Normal Anion Gap Metabolic Acidosis

- Renal Disease
  - proximal or distal RTA
  - renal insufficiency (HCO_3^- loss)
  - hypoaldosteronism / K^+ sparing diuretics

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  - ureterosigmoidostomy
- Ingestions
  - carbonic anhydrase inhibitors

Compensation

A "simple" acid-base disturbance is one with a primary problem (respiratory or metabolic, acidosis or alkalosis) leading to a compensation in the other arm.

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Primary metabolic problem – respiratory compensation

Primary respiratory problem – metabolic compensation

Compensation

THREE THINGS TO REMEMBER

Compensation

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1) Compensation is not immediate

Compensation

THREE THINGS TO REMEMBER

1) Compensation is not immediate
2) Compensation is not complete

Compensation

THREE THINGS TO REMEMBER

1) Compensation is not immediate
2) Compensation is not complete
3) The pCO_2 and HCO_3 move in the same direction

Compensation - Rules

These formulas are EMPIRICALLY DERIVED from observation and measurement.

Compensation - Rules

Respiratory Compensation for Metabolic Changes

- Metabolic acidosis
  - pCO_2 decreases by 1.2 x the drop in $[HCO_3^-]$ — important !!
- Metabolic alkalosis
  - pCO_2 increases by .7 x the rise in $[HCO_3^-]$
  - less predictable than the comp. for acidosis

COMPENSATION IS USUALLY NOT COMPLETE

Compensation - Rules

Metabolic Compensation for Respiratory Changes

- Respiratory Acidosis
  - ACUTE: $[HCO_3^-]$ increases by .1 x the rise in pCO_2
  - CHRONIC: $[HCO_3^-]$ increases by .35 x the rise in pCO_2
- Respiratory Alkalosis
  - ACUTE: $[HCO_3^-]$ decreases by .2 x the fall in pCO_2
  - CHRONIC : $[HCO_3^-]$ decreases by .5 x the fall in pCO_2

COMPENSATION IS USUALLY NOT COMPLETE

Approach to the Patient

- History and Physical Examination
  - In the majority of cases you should be able to predict, qualitatively, the type of disturbance
- Examples:
  - a patient with septic shock (hypoperfusion)
  - a patient with severe COPD
  - a patient with one day of worsening asthma

Approach to the Patient

- Is the patient ACIDEMIC or ALKALEMIC ?
- What is the $[HCO_3^-]$?
  - elevated ---- metabolic alkalosis
  - decreased -- metabolic acidosis
- What is the Anion Gap
- What is the pCO_2 ?
  - elevated --- respiratory acidosis
  - decreased -- respiratory alkalosis
- Is the degree of compensation what you expect?

Notation for Laboratory Values

Na+	Cl-	BUN	Glu
K+	HCO3-	Cr.	

pH / pCO2 / pO2 / base excess ON FIO2

Case 1 - History and Physical

The patient is a 73 year-old man admitted with profuse diarrhea. Stool culture later grows *Salmonella*. On admission his blood pressure is 100/60 mm Hg when lying. Upon sitting it drops to 70/40 mm Hg. Skin turgor is reduced.

WHAT ABNORMALITIES WOULD YOU EXPECT BASED ON THIS INFORMATION ??

Salmonella diarrhea -- Lab values

133	118
2.5	5

ABG on Room Air
7.11 / 16 / 96

[H+] = 77 neq / L

Case 1) *Salmonella* diarrhea -- Answers

133	118
2.5	5

7.11 / 16 / 96

[H+] = 77 neq / L

The patient is profoundly acidemic. The very low bicarbonate clearly indicates that the acidosis is, at least in part, metabolic.
The anion gap is NORMAL, pointing us in the direction of a limited number of possible causes.
The expected decrement in CO2 is --> 1.2 x (25-5) = 1.2 X 20 = 24, and this is actually what we see in this case.
The potassium is low because of loss in the diarrheal fluid.

Case 2 -- History and Physical

A 26 year-old man with IDDM stopped taking his insulin because he was depressed. His family brought him to the emergency room the next day in a semi-comatose state.

On physical examination he was obtunded. His HR was 130, RR 24 and deep, BP 110/60 mm Hg.

WHAT ABNORMALITIES WOULD YOU PREDICT ???

IDDM without Insulin -- Predictions

- Lack of insulin --> KETOGENESIS and Hyperglycemia
- Obligate urination (osmotic diruesis) --> dehydration --> hypoperfusion --> inadequate oxygen delivery --> LACTIC ACIDOSOS
- Effect on K+
  - net loss of K b/o urination
  - possible high plasma K+ -- for what reason??

Diabetic -- Lab Values

140	105	51	470
4.8	6	2.3	

ABG on RA: 7.10 / 20 / 92

urine dipstick: large ketones

Case 2) DKA -- Interpretation

140	105	51	470	ABG on RA:
4.8	6	2.3		7.10 / 20 / 92

The patient is profoundly acidemic. The very low HCO3- is c/w a metabolic acidosis.
The anion gap is 19 -- above normal. From our list, the two most obvious candidates for are DKA and LACTIC ACIDOSOS.
The measured K+ is normal, though we strongly suspect that total body K+ is low.
The respiratory response is a little bit less than predicted, perhaps b/o fatigue.

Case 3 -- History and Physical

A young woman with a seizure disorder suffers a grand-mal seizure in the waiting room of the Emergency Department. She has been waiting to have a laceration evaluated.

She is promptly brought to the treatment area.

WHAT ABNORMALITIES WOULD YOU EXPECT TO SEE BASED ON THIS INFORMATION ???

Seizure Disorder -- Predictions

- She might have difficulty with ventilation during her seizure, leading to hypercapnea and a respiratory acidosis.
- The intense muscle activity might exceed her anaerobic threshold, leading to a lactic acidosis.

Seizure Victim -- Lab Values

140	98
4.0	17

ABG on RA: 7.14 / 45 / 86

Case 3) Seizure Victim -- Interpretation

140	98
4.0	17

ABG on RA: 7.14 / 45 / 86

The patient has a profound acidemia.

The cause of this problem is a COMBINATION of a high-anion-ga
METABOLIC ACIDOSIS (AG = 25), and a moderate
RESPIRATORY ACIDOSIS.

Case 4 -- History and Physical

- A 52 y/o man with longstanding COPD is admitted to the hospital with a lower extremity cellulitis. His COPD is clinically stable.

WHAT ABNORMALITIES MIGHT YOU EXPECT TO SEE ??

COPD -- Predictions

- We have no reason to expect the cellulitis to effect the pateint's pulmonary problem.
- COPD patients MAY have a chronic respiratory acidosis.
- A chronic respiratory acidosis will induce some metabolic compensation

COPD -- Lab Values

139	98	19
4.9	31	1.0

ABG on RA: 7.34 / 60 / 60

Case 4) COPD -- Interpretation

139	98	19
4.9	31	1.0

ABG on RA: 7.34 / 60 / 60

The patient has a moderate acidemia.
The bicarbonate is HIGH, and the anion gap is normal.
The pCO2 is VERY HIGH, consistent with our prediction about a patient with COPD. THE PRIMARY DISTURBANCE IS PROBABLY RESPIRATORY

The expected rise in HCO3- is: .35 x (60-40) = .35 X 20 = 7 meq/L

Case 5 -- Lab Values

139	102	19
4.9	25	1.0

ABG on RA 7.24 / 39 / 86

WHAT IS THE PROBLEM IN THIS CASE ??

Case 5 -- Interpretation

139	102	19
4.9	25	1.0

ABG on RA 7.24 / 39 / 86

The patient has a moderate acidemia.
The bicarbonate is normal, as is the anion gap.
The pCO2 is normal as well.

REMEMBER THE EQUATION:

$$[H^+] = 24 \times pCO_2 / [HCO_3^-]$$

Case 5 -- Interpretation

Plugging in the values from the case, we get:

[H+] =~ 56 neq / L ..... our estimate
HCO3- = 25 meq / L
pCO2 = 39 mm Hg

56 = 24 X (39 / 25)

The numbers do not fit. Some piece of data is incorrect !!!!!!!

Case 5 -- Interpretation

139	102	19
4.9	25	1.0

ABG on RA 7.24 / 39 / 86
ABG on RA 7.42 / 39 / 86

Perhaps someone in the lab wrote down the pH incorrectly.

If the pH were 7.42 instead of 7.24, the [H+] would be 38, and the equation would be an identity.

ONE CAN USE THE FORMULA RELATING [H+], [HCO3-], AND pCO2 TO CHECK FOR CONSISTENCY

Case 6 -- Lab Values

139	110	19
3.0	18	1.0

ABG on RA: 7.36 / 33 / 95

WHAT IS THE ACID-BASE DISTURBANCE ??
WHAT MIGHT BE CAUSING IT ??

Case 6 -- Interpretation

139	110	19
3.0	18	1.0

ABG on RA: 7.36 / 33 / 95

The pH is slightly low -- slightly acidemic
The HCO3- is slightly low, c/w a metabolic acidosis
The anion gap is normal. One cause of a normal anion gap metabolicacidosis is a RENAL TUBULAR ACIDOSIS.
The hypokalemia is something commonly seen with RTA's
The respiratory compensation is appropriate.

Case 7 -- Lab Values

139	110	19
4.0	20	1.0

ABG on 40% O_2: 7.44 / 30 / 55

WHAT IS THE ACID-BASE DISTURBANCE ??

WHAT MIGHT BE CAUSING IT ??

Case 7 -- Interpretation

139	110	19
4.0	20	1.0

ABG on 40% O_2: 7.44 / 30 / 55

The pH is slightly alkalemic.
The bicarbonate is low, c/w a metabolic acidosis.
The pCO2is also low, c/w a respiratory alkalosis.
pH CHANGES USUALLY REFLECT THE PRIMARY PROBLEM , therefore:
The changes are most c/w a primary resp. alkalosis with a metabolic compensation.

Case 7 -- Interpretation

139	110	19
4.0	20	1.0

ABG on 40% O_2: 7.44 / 30 / 55

The expected compensation for a primary respiratory alkalosis is given by the formula:

- Respiratory Alkalosis
  - –ACUTE: $[HCO_3^-]$ decreases by .2 x the fall in pCO_2
  - –CHRONIC : $[HCO_3^-]$ decreases by .5 x the fall in pCO_2

The expected decrease in HCO3- is 5 meq/L

Case 8 -- History and Physical

- A 54 y/o man with COPD is admitted with a two-day history of progressive shortness of breath and increasing sputum production.
- He is diffusely wheezing on examination, and his air movement is poor.
- His CXR shows a LLL pneumonia

Case 8 -- Labs

139	100	19
4.0	30	1.0

ABG on RA: 7.25 / 70 / 50

Case 8 -- Interpretation

139	100	19
4.0	30	1.0

ABG on RA: 7.25 / 70 / 50

The clinical scenario is c/w some degree of respiratory acidosis, either acute or chronic.
The pH is acidemic, the pCO2 elevated, and the HCO3- elevated, c/w a compensated respiratory acidosis, BUT...
The degree of compensation is NOT what we would expec
The most likely explanation is a baseline chronic respirator acidosis with a superimposed worsening resp. acidosi

Case 9 -- History

- A 63 y/o man with insulin-requiring diabetes mellitus but a history of poor compliance with his diet and treatment is brought to the emergency room after passing out.
- His finger-stick glucose in the field was 40

Case 9 -- Labs

132	117	43
5.2	9	3.3

ABG on RA: 7.23 / 28 / 107

Case 9 -- Interpretation

132	117	43
5.2	9	3.3

ABG on RA: 7.23 / 28 / 107

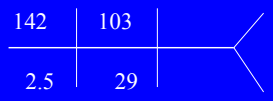
He has a normal-anion-gap metabolic acidosis. The predicted respiratory compensation would result in a pCO_2 of 20.8 mm Hg, so there is a second process involved.
Clinically, this could be either a decrease in his respiratory drive due to his altered state of consciousness, or an acute-on-chronic metabolic acidosis, without enough time for further compensation.

Case 10 - History and Physical

The patient is a middle aged man with arthritis of his knee. He was referred to Loyola. Medications include HCTZ and Furosemide, for ankle edema. In his clinic visit, he was noted to be tachycardic. He was otherwise asymptomatic.

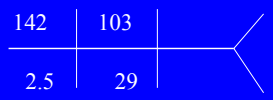
In the ER, they were concerned about the possibility of PE.

Tachycardic OA pt. -- Lab values



ABG on Room Air
7.66 / 24 / 116
BUN 39
Creatinine 1.3

Tachycardic OA pt. -- Answers



ABG on Room Air
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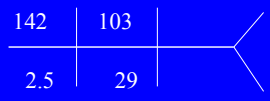
BUN 39
Creatinine 1.3

He has a “contraction alkalosis” with hypokalemia, from the diuretic.

Tachycardic OA pt. -- Answers



ABG on Room Air

7.66 / 24 / 116

He has a “contraction alkalosis” with hypokalemia, from the diuretic.

He was told to “breathe deeply” before they drew his ABG, because it would hurt.