Crystalloids:
What they do to acid-base

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Luciano Gattinoni, MD, FRCP
Università di Milano
Fondazione IRCCS- Cà Granda -
Ospedale Maggiore Policlinico
Milan, Italy
The players

<table>
<thead>
<tr>
<th>Player</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>55000 mmol/L</td>
</tr>
<tr>
<td>Strong Ion(^+)</td>
<td>150 mmol/L</td>
</tr>
<tr>
<td>Strong Ion(^-)</td>
<td>110 mmol/L</td>
</tr>
<tr>
<td>Weak acid(^-)</td>
<td>40 mmol/L</td>
</tr>
<tr>
<td>H(^+)</td>
<td>0.00000004 mmol/L</td>
</tr>
</tbody>
</table>
Plasma electroneutrality

\[ \text{BB} = [\text{HCO}_3^-] + [A^-] \]

i.e.

the negative charge

\[ \text{SID} = [\text{Na}^+] + [\text{K}^+] + [\text{Ca}^{2+}] - [\text{Mg}^{2+}] - [\text{Cl}^-] - [\text{XA}^-] \]

i.e.

\[ \text{BB} = \text{SID} \]
Measured and calculated values (mean +/- SD) at the different measuring points. Saline group = white dots; Ringer's group = black dots. Star = intragroup differences, P < 0.05; triangle = intergroup differences, P < 0.05.

Infused nearly 4.5-5 L  
Dilution nearly 30%  
Initial $V_{\text{ext}}$ nearly 15 L
1 BASELINE

2 Dilution Closed System

3 Dilution Open System

Plasma

Higher CO₂% Lower CO₂%

Distilled water 0.9% NaCl Lactated Ringer’s
Closed System

Normal SID = 42 mEq/L
Normal Atot = 19 mEq/L
Normal PCO$_2$ = 40 mmHg
pH = 7.409

if we double the volume (ex. 1 L to 2 L)

SID = 21 mEq/L
Atot = 9.5 mEq/L
PCO$_2$ $\approx$ 20 mmHg
pH = 7.409
Open System

Normal SID = 42 mEq/L
Normal Atot = 19 mEq/L
Normal PCO$_2$ = 40 mmHg
pH = 7.409

if we double the volume (ex. 1 L to 2 L)

SID = 21 mEq/L
Atot = 9.5 mEq/L
PCO$_2$ = 40 mmHg
pH = 7.134
Effects of infusion SID

(in vitro experimental data
PCO$_2$ = 35 mmHg)

<table>
<thead>
<tr>
<th>pH</th>
<th>Baseline</th>
<th>0</th>
<th>12</th>
<th>24</th>
<th>36</th>
<th>48</th>
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<tbody>
<tr>
<td>7.0</td>
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<td>7.1</td>
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<td>7.2</td>
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<td>7.3</td>
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<td>7.4</td>
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<td>7.5</td>
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<td>7.7</td>
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</table>

Effects observed:

- Dilution 25%
- Dilution 50%
- Dilution 75%
- Dilution 100%

$pH$ values decrease from baseline to 24 hours and then increase towards 48 hours for all dilutions except 25%.

HCO$_3^-$ changes:

- Baseline: $18.3 \pm 0.3$ mEq/L

References:

How to avoid acidosis at whatever dilution?
Consider a volume of water equilibrated at different PCO$_2$ values…

\[
\frac{[\text{HCO}_3^-] \times [\text{H}^+]}{[\text{CO}_2 \text{ dissolved}]} = K_c
\]

\[
\text{pH} = pK + \log_{10} \frac{[\text{HCO}_3^-] \times [\text{H}^+]}{[\text{CO}_2 \text{ dissolved}]} 
\]

Electroneutrality

\[
[\text{HCO}_3^-] = [\text{H}^+] 
\]
PCO$_2$ and water
Consider a volume of water equilibrated at different PCO$_2$ values... with a strong ion difference higher than zero...

\[
\frac{[\text{HCO}_3^-][\text{H}^+]}{[\text{CO}_2 \text{ dissolved}]} = K_c \quad \text{H-H equation}
\]

\[
\text{pH} = \text{pK} + \log_{10} \frac{[\text{HCO}_3^-][\text{H}^+]}{[\text{CO}_2 \text{ dissolved}]}
\]

Electroneutrality

\[
[\text{HCO}_3^-] = [\text{SID}] + [\text{H}^+]
\]
PCO$_2$ and water

- SID 20 mEq/l
- SID 15 mEq/l
- SID 10 mEq/l
- SID 5 mEq/l
- SID 0 mEq/l

[HCO$_3^-$] (mmol/l)

PCO$_2$ (mmHg)
To avoid acidosis the infusion must be such that at whatever volume and constant $\text{PCO}_2$

$\text{HCO}_3/\text{CO}_2$ ratio remains constant
Effects of infinite dilution in open system (constant PCO$_2$)

\[ \text{pH} = \text{pK}_c + \log_{10} \frac{\text{HCO}_3^-}{\alpha \text{PCO}_2} \]

- SID$_D$ = HCO$_3^-$
- SID = HCO$_3^-$
- pH unmodified
- pH increase
- pH decrease
As in saline \( \text{SID} = 0 \ \text{mEq/L} \)
Always acidotic
+ 
Chlorine change
Effects of infusion

(12 pigs)

Effects of infusion
(12 pigs)

Effects of infusion

(12 pigs)

- Polysaline RIII
- Lactated Ringer’s
- Normal Saline

Time from infusion (min):
0 30 60 90 120 150 180 210 240 270 300 330 360

Plasma Chlorine variations (mEq/L):
-8 -6 -4 -2 0 2 4 6 8 10 12 14

Infusion
Washout

Tubulo-glomerular feedback

Increased Cl⁻ load → Macula densa → Afferent aa constriction
Development of kidney failure

Figure 1. Development of Stage 2 or 3 Acute Kidney Injury (AKI) While in the Intensive Care Unit (ICU)

No. at risk
2008 761
2009 772

2008
2009

Log-rank P = .001

Stage 2 or 3 defined according to the Kidney Disease: Improving Global Outcomes clinical practice guideline.

Development of kidney failure

Figure 2. Renal Replacement Therapy (RRT) in the Intensive Care Unit (ICU)

Summarizing

- The dilution affects pH as function of infusion SID and baseline HCO$_3$-

- Normal saline always causes acidosis

- Increase Cl$^-$ may cause kidney impairment