Improving Patient Care with better Blood Gas Preanalytics

By Anne Skurup,
Clinical and Scientific Affairs Manager,
Radiometer Medical Aps, Denmark
Agenda

- Impact on patient care
- Needle-stick and safety
- Patient ID
- Bias on results due to sampling device
- Sample contamination
- Importance of mixing
- Resources for how to:
  - Get into the details
  - Troubleshooting
  - Skill test
Learning Objectives

- Review the reasons why careful attention to the preanalytical phase helps to avoid risk to patients
- Identify the steps for healthcare provider to help avoid preanalytical errors
- Discuss how preanalytical errors can effect patient results and how these errors can be avoided
The preanalytical phase of arterial blood gas sampling

Preanalytical errors are said to be the reason for up to 62% of all errors in laboratory medicine [1].

“Several aspects of blood pH and gas analysis are unique among clinical and laboratory determinations, and, at the same time, no other test results have more immediate impact on patient care” [2]  

CLSI

Error rate

Preanalytical phase  62%
Analytical phase  15%
Post-analytical phase  23%

Preanalytical quality management works!

- Examples:

  - “Introduction of recommendations regarding proper blood collection enabled a decrease in the ratio of hyperkalemic samples from 16% to < 5% [1]”

  - “Impact of the implementation on the process after modification of the preanalytical process...the bias for hemoglobin concentration was drastically reduced...−2 [−10; 5] g/L instead of −19 [−64; 27] g/L [2]”

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Question A

- How often do you have clots in a blood gas sample?

- Answers:
  A. Several times a day
  B. Once a week
  C. Once a month
  D. Never
  E. Don’t know/is not registered
Question B

- For how long do you mix the sample before analysis?

- Answers:

A. 3 minutes
B. 2 minutes
C. 1 minute
D. < 1 minute
E. Operator decides on sample-by-sample basis
F. Is not mixed before analysis
G. Don’t know
Will it impact patient care?

- Which results are you to trust?

<table>
<thead>
<tr>
<th>ctHb</th>
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</tr>
</thead>
<tbody>
<tr>
<td>10.0 g/dL</td>
<td>7.2 g/dL</td>
</tr>
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</table>

| $pO_2$ | 100 mmHg |
| $pCO_2$ | 41 mmHg |
| $sO_2$ | 98 % |

| $pO_2$ | 90 mmHg |
| $pCO_2$ | 42 mmHg |
| $sO_2$ | 97.4 % |

| $cK^+$ | 4.1 mmol/L |
| $cNa^+$ | 141 mmol/L |
| $cCl^-$ | 100 mmol/L |

| $cK^+$ | 3.4 mmol/L |
| $cNa^+$ | 147 mmol/L |
| $cCl^-$ | 110 mmol/L |

| $cCa^{2+}$ | 1.15 mmol/L |
| $cCa^{2+}$ | 1.08 mmol/L |
Operator Safety

- Consider:
  - Use a safety device that limits contact with patient blood
  - Use a protection device for the safe removal of needles
  - Ensure procedure for operator safety is established and followed
Operator Safety

- Needle-stick injury and unwanted contact with patient blood are daily risks for operators taking blood gas samples.

- From the literature[1]:
  
  "A total of 10,441 percutaneous injuries were reported from 1998 to 2002"

  "7 % occurred in ICUs/CCUs, ORs (29 %) and EDs (9 %)"

Needle-stick injury

- Can be caused by:
  - Unavailability of sampling safety devices for operators
  - Lack of dedicated procedure for operator safety
  - Procedures for safety not followed

- Can lead to:
  - Operator concern over own safety
  - Needle-stick injury
  - Infection by blood-borne pathogens
Patient and sample ID

- Consider:
  - Use at least two patient identifiers [2]
  - Make sure the arterial syringe has a patient ID label attached or
  - Use a prebarcoded arterial syringe
  - Always enter a patient ID into the analyzer before analysis
  - Use barcode readers
Patient and sample ID

- Incorrect or missing patient and sample IDs are some of the most frequent – and critical – preanalytical errors [1].

From the literature [1]:

“Average specimen mislabeling 250/month

Key staff determined average total cost per mislabeling incident is USD 500

- The annual cost: $3000 \times \text{USD} 500 = \text{USD} 1.5 \text{ million}
- Excludes any "downstream" medicolegal or liability costs”

“Bedside barcode labeling system...... reported to reduce specimen labeling errors by 41 % “.

Patient and sample ID

- Errors can be caused by:
  - Lack of patient identification and/or sample labeling
  - Transcription errors due to manual data entry
  - Lack of a procedure for identifying patient and samples

- Errors can lead to:
  - Noncompliance
  - Misdiagnosis
  - Incorrect treatment of a patient
  - Need for resampling
  - Lost billing opportunities
What preanalytical error?

- Same sample
- A: Correct
- B: WITH preanalytical error

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<tr>
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<tbody>
<tr>
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</tr>
<tr>
<td></td>
<td></td>
<td>1.08 mmol/L</td>
</tr>
</tbody>
</table>
Heparin induced bias

- Bias on electrolytes may be caused by:
  - Use of heparin that is not formulated to reduce bias on electrolytes
Heparin induced bias

- Some facts:
  - Clots in the sample may interfere with the analyzer and produce inaccurate values [1]
  - Anticoagulation is needed to reduce the clotting of the sample
  - Heparin is the only anticoagulant that is recommended for blood gas analysis [2]

Poll responses

- How often do you have clots in a blood gas sample?
Heparin

- The higher heparin concentration, the better anticoagulation
  - “10 IU/mL may not eliminate clotting and 150 IU/mL may also not be enough” [1]
  - “When below 200 IU/mL there is no effect on the blood gases but on electrolytes” [2]
- In 1960 the conventional heparin concentration adopted was 40 IU/mL [3]
Heparin

- Heparin binds positively charged ions

### Bias on iCa using non-balanced heparin

<table>
<thead>
<tr>
<th>IU/mL Heparin</th>
<th>Bias on cCa(^{2+})[1,2]</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>-0.03</td>
</tr>
<tr>
<td>50</td>
<td>-0.15</td>
</tr>
<tr>
<td>100</td>
<td>-0.19</td>
</tr>
</tbody>
</table>

- Avoided by using electrolyte-balanced heparin

The choice of device makes a difference

“Taken together, two out of the three syringes tested here introduced a clinically significant negative bias” [1]

CLSI and heparin induced bias

- **CLSI C46-A2:**

  - 5.2.1. “..special preparations of heparin are available, which virtually eliminate the interference form heparin binding of these electrolytes.”

  - 5.2.1. “The ideal collection device for arterial blood sampling is....containing a small amount of anticoagulant such as lyophilized heparin”

  - 5.2.5: “Although a low concentration of ordinary heparin will reduce the error, it will not eliminate it, and the special heparin preparations discussed above (balanced or dispersed) are preferable”
What preanalytical error?

- Same sample
- A: Correct
- B: WITH preanalytical error

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>pO₂</td>
<td>100 mmHg</td>
<td>90 mmHg</td>
</tr>
<tr>
<td>pCO₂</td>
<td>41 mmHg</td>
<td>41.5 mmHg</td>
</tr>
<tr>
<td>sO₂</td>
<td>98 %</td>
<td>97.4 %</td>
</tr>
</tbody>
</table>
Sample contamination

- **Consider:**

  - Use self-filling syringes:
    - Fill readily when puncturing an artery

  - Use short-beveled needles
    - Easier to position inside the artery

  - Reduce the risk of puncturing the opposite artery wall

  - Make the puncture at an angle of 45° for better positioning

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Sample contamination

- Arterial puncture
  - When doing arterial punctures, there is a risk of accidentally puncturing a vein.
  - Even a few drops of venous blood mixed with the arterial sample can cause bias on the patient results.
  - Venous blood in an arterial sample can lead to bias on $O_2$- and $CO_2$-related parameters
What preanalytical error?

- Same sample
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<td>141 mmol/L</td>
<td>147 mmol/L</td>
</tr>
<tr>
<td>cCl⁻</td>
<td>100 mmol/L</td>
<td>110 mmol/L</td>
</tr>
</tbody>
</table>
Sample contamination and arterial line sampling

- **Consider:**

  - Check the specific catheter package for the exact volume of dead space
  
  - Rule of thumb: discard at least three times the dead space
  
  - Draw the blood gas sample with a dedicated blood gas syringe containing dry electrolyte-balanced heparin

  - If in doubt, consider resampling
Sample contamination and arterial line sampling

- Risk of diluting the blood gas sample with flush solution
  - Highly dependent on the specific catheter.

- Insufficient removal of flush solution
  - Will cause increased $c\text{Na}^+$ and $c\text{Cl}^-$ values as flush solution contains sodium chloride

- The bias affecting $pO_2$ will depend on the actual patient $pO_2$ values.

- Other parameters will typically be negatively biased (dilution).
What preanalytical error?

- Same sample
- A: Correct
- B: WITH preanalytical error

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<th></th>
<th>A</th>
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</tr>
</thead>
<tbody>
<tr>
<td>$pO_2$</td>
<td>70 mmHg</td>
<td>90 mmHg</td>
</tr>
<tr>
<td>$pCO_2$</td>
<td>45.6 mmHg</td>
<td>45.4 mmHg</td>
</tr>
<tr>
<td>$sO_2$</td>
<td>94.0%</td>
<td>96.9%</td>
</tr>
</tbody>
</table>
Room air contamination

- Consider:
  - Visually inspect the sample for air bubbles
  - Expel any bubbles by gently tapping the sides of the syringe right after sampling and before mixing
  - Use arterial blood gas syringes with tip caps that are vented
    - Allows you to expel air and seal the syringe without getting in contact with blood
Room air contamination

- Room air contamination of a blood gas sample may alter the values.

- The actual bias introduced will have
  - Most impact on $pO_2$
  - Minor effect on $pCO_2$ and pH [1]

- The bias on $pO_2$ is dependent on
  - Volume of room air
  - Initial $pO_2$ value
  - Hemoglobin concentration, mixing of sample
  - Pneumatic tube transport etc. [1, 2]

Calculated and measured changes in blood $pO_2$ when 20 or 40 $\mu$L air (atmospheric $pO_2$) was added to blood. Data points are based on changes in $pO_2$ as measured on 19 blood specimens as air was sequentially introduced and equilibrated with the blood in a syringe.

Room air contamination

- Room air contamination and pneumatic tube transport
  - 0.2 mL of air is added to a blood gas sample and transported via pneumatic tube
  - The initial $pO_2$ value is 105 mmHg
  - After the pneumatic tube transport $pO_2$ increases to 150 mmHg [1].

CLSI and Room air contamination

- **CLSI C46-A2:**
  
  5.3.2: “…exposure to the atmosphere can markedly affect the pH, pCO₂ and pO₂”

  5.3.3: “During pneumatic transport, the blood sample is very rapidly accelerated and decelerated, which vigorously agitate the blood in a syringe....... It can have noticeable effect on the pO₂.....Consequently it is very important to continually emphasize to....removing all air bubbles from a blood gas syringe prior to pneumatic transport”
What preanalytical error?

- Same sample
- A: Correct
- B: WITH preanalytical error

A
ctHb 6.2 mmol/L (10.0 g/dL)

B
ctHb 4.5 mmol/L (7.2 g/dL)
Sample mixing

- **Consider:**

  - Mix the sample for one minute in two dimensions by rolling the syringe between the hands AND inverting it vertically.
    - Red blood cells tend to stack one on top of the other. Stacking is prevented by mixing in two dimensions [3].
  
  - If the sample is visibly sedimented, it needs mixing for several minutes [2, 3].
  
  - Ensure a dedicated procedure for sufficient mixing is established and followed in your facility

  - Use arterial blood gas syringes with an integrated mixing ball when available [1] and a blood gas analyzers with automatic mixing [4].

Poll Responses

- For how long do you mix the sample before analysis?
Sample mixing

- Nonhomogeneous samples can be caused by:
  - Sedimentation of red blood cells
  - No standardized procedure for mixing
  - Sampling devices used are not optimal for mixing e.g. syringes with a narrow diameter may make mixing more difficult
Effect of automated mixing

Automated mixing reduced mean ctHb difference (g/dL):

<table>
<thead>
<tr>
<th>From</th>
<th>To</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 min</td>
<td>0.6</td>
</tr>
<tr>
<td>20 min</td>
<td>0.3</td>
</tr>
<tr>
<td>30 min</td>
<td>0.6</td>
</tr>
</tbody>
</table>

What preanalytical error?

- Same sample
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<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>$pO_2$ 90 mmHg</td>
<td>$pO_2$ 96 mmHg</td>
</tr>
</tbody>
</table>
Storage temperature

The recommended storage temperature of a sample is dependent on the material of the sampling device:

- Plastic sampling devices should be stored at room temperature [1,2]
- Glass sampling devices can be stored in ice slurry water or at room temperature [1,2]

CLSI and Storage Temperature

- **CLSI C46-A2:**
- 5.2.1 "...it is recommended that plastic syringes should not be iced, but kept at room temperature as long as the blood is analyzed within 30 minutes of collection"
Storage time

- **Consider:**

- Measure the sample immediately [1,2]

- If storage is unavoidable, measure the sample within 30 minutes [1,2]

- Measure special samples within 5 minutes:
  - high \( pO_2 \), high leukocyte count, shunt studies etc; consider using glass sampling devices [1,2]

- Use a blood gas analyzer that can keep track of sample age

- Follow the package insert

Biochemistry predicts the following changes of heparinized arterial blood gas samples obtained anaerobically and stored at room temperature [1]:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Change</th>
<th>Because......</th>
</tr>
</thead>
<tbody>
<tr>
<td>$pO_2$</td>
<td>↓</td>
<td>The cells that utilize oxygen continue to do so</td>
</tr>
<tr>
<td>$pCO_2$</td>
<td>↑</td>
<td>$CO_2$ is a product of the metabolism</td>
</tr>
<tr>
<td>pH</td>
<td>↓</td>
<td>Combined effect:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1) Increase in $CO_2$ causes a decrease in pH</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2) Increase in hydrogen-ion concentration</td>
</tr>
<tr>
<td></td>
<td></td>
<td>due to continued glycolysis</td>
</tr>
<tr>
<td>Glucose</td>
<td>↓</td>
<td>Due to continued glycolysis</td>
</tr>
<tr>
<td>Lactate</td>
<td>↑</td>
<td>Due to continued glycolysis</td>
</tr>
</tbody>
</table>

More into the details on preanalytics?
Blood gas preanalytics app
Preanalytics app structure

Handbook with video demonstrations

Skill test

Interactive troubleshooting guide

Sample mixing

Samples that are thoroughly mixed and recentered homogenous are a prerequisite for reflecting correct patient results [1].

Mixing prior to analysis is performed to achieve a uniform distribution of red blood cells. Insufficient mixing may cause erroneous hemoglobinemia and Hct values and bias on calculated parameters derived from cHb.

Some studies recommend automatic mixing for consistently achieving homogenous samples [2].

Nonhomogeneous samples can be caused by

- Sedimentation of red blood cells
- No standardized procedure for mixing
- Sampling devices used are not optimal for mixing e.g. syringes with a narrow diameter may make mixing more difficult

Example

Two samples are stored for 10 minutes before analysis. Red blood cell sedimentation is visible. One sample is mixed thoroughly, the other just long enough to make it appear homogenous. This may alter patient results as shown below.

<table>
<thead>
<tr>
<th>Patient results from a sample that has been thoroughly mixed</th>
<th>Patient results from a sample that has been briefly mixed</th>
</tr>
</thead>
<tbody>
<tr>
<td>cHb</td>
<td>6.2 mmol/L (10.0 g/dL)</td>
</tr>
</tbody>
</table>

Skill test

Question 1/7

The recommended storage temperature of a blood gas sample is dependent on the material of the sampling device.

Plastic sampling devices should be stored at:

- Slightly warmer than room temperature
- On ice
- Room temperature

Table:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>1</td>
</tr>
<tr>
<td>pHCO₂</td>
<td>1</td>
</tr>
<tr>
<td>pO₂</td>
<td>1</td>
</tr>
<tr>
<td>cNa⁺</td>
<td>1</td>
</tr>
<tr>
<td>cK⁺</td>
<td>1</td>
</tr>
<tr>
<td>cCa²⁺</td>
<td>1</td>
</tr>
<tr>
<td>cCl⁻</td>
<td>1</td>
</tr>
<tr>
<td>cHb</td>
<td>1</td>
</tr>
<tr>
<td>cO₂</td>
<td>1</td>
</tr>
<tr>
<td>cGlucose</td>
<td>1</td>
</tr>
<tr>
<td>cLactate</td>
<td>1</td>
</tr>
</tbody>
</table>
Useful tips to avoid preanalytical errors in blood gas testing: pH, pCO₂ and pO₂

By Chris Higgins

The measurement of the parameters pH, pCO₂ and pO₂ is vulnerable to a number of preanalytical errors and tips to help avoid these errors, ensuring that the results of analysis accurately reflect the patient’s acetylene status. The tips include the removal of air bubbles, ...

Pneumatic tube transport of blood samples – an update

By Chris Higgins

The significance of good practice during the preanalytical phase of clinical laboratory investigation cannot be overemphasized. One aspect of the preanalytical phase – the transport of samples – is considered here; in particular the transport of samples via pneumatic tube systems. This is an update of a previous...

Effect of small air bubbles on changes in blood pO₂ and blood gas parameters: calculated vs. measured effects

By John G. Teffetelli, Elizabeth H. McDonnell

When blood samples are collected, it is important to remove air bubbles from syringes to avoid erroneous results. The potential magnitude of the interference to pO₂ by air bubbles. In this pO₂...

Preanalytical errors in Point-Of-Care Testing

By Ana-Maria Simundic

Preanalytical errors are quite frequent in the area of point-of-care testing (POCT testing is usually performed by clinical staff (i.e. nurses and physician laboratory work as laboratory professionals. Moreover,...

Capillary blood gases - to arterialize or not

Blood gas testing and related measurements: National recommendations on behalf of the Croatian Society of Medical Biochemistry and Laboratory Medicine

By Lara Dukić, Lara Milesej Kopelović, Adrijana Đorđević, Ivana Radoč
Will it impact patient care?

- A: Correct  B: WITH preanalytical error

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<td>100 mmHg</td>
<td>90 mmHg</td>
</tr>
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<td>42 mmHg</td>
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- Resources for how to:
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Note: This slide deck is made from: Blood gas preanalytics app, “On the safe side” and “High Five for safe arterial blood gas sampling”, Articles from acutecaretesting.org