Preanalytical errors are said to be the reason for up to 62% of all errors in laboratory medicine [1]. Here are some tips on how to avoid the most frequent errors.

Agenda

- Introduction
- Why the preanalytical phase is important
- High Five for safe arterial blood gas sampling
- Additional educational resources
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: "Vision: To be the leader in clinical and laboratory standards to improve the quality of medical care” [3]

High Five for safe arterial blood gas sampling:

Path of workflow:

1. **Patient preparation** – patient assessment and correct data registration to maximize patient safety
2. **Blood collection device** – greater sample integrity and operator safety
3. **Sample collection** – maximum safety for patient and operator
4. **Sample handling** – key steps for greater sample integrity
5. **Sample transport** – minimum time to patient results

Workflow based on CLSI international guidelines [1] [2]

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1. Patient preparation
Patient assessment and correct data registration to **maximize patient safety**

Accurate **patient identification** is fundamental for patient safety
- Use at least two patient identifiers [1]
- Always enter a patient ID into the analyzer before analysis

Thorough **patient assessment** is the foundation for reliable clinical interpretation of blood gas results
- Clarify and assess the clinical indication of the patient
- Stabilize patient for 20-30 min if applicable
- Add additional patient characteristics and other relevant information

Proper **sample labeling** ensures the right result for the right patient
- Attach patient ID label to the syringe before leaving the patient

Careful selection of **sampling site** with optimal access and blood flow
- Radial artery
- Brachial artery
- Femoral artery
- Arterial line

Specimen labeling errors have significant consequences for patient care, for healthcare management and for increasing costs that are often unaccounted for [2]

**Tips!**

Use **pre-barcoded** syringe

Use a barcode reader to **register at bedside**

Establish a **dedicated procedure** for identifying patient and sample

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1. Patient preparation

Patient assessment and correct data registration to **maximize patient safety**

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

**Errors can lead to:**
- Non-compliance
- Misdiagnosis
- Incorrect treatment
- Resampling
- Lost billing opportunities
2. Blood collection device
Greater sample integrity and operator safety

Dedicated ABG collection device ensures greater sample integrity
- Select a 1-3 mL self-filling, plastic, disposable syringe pre-filled with an anti-coagulant
- Choose short-bevel needles
- Choose luer-tip cap
- Heparin is the only anti-coagulant recommended for blood gas analysis

Dry electrolyte-balanced heparin is the foundation for a result you can trust
- Use an anti-coagulant to reduce clotting of the sample
- Use an anti-coagulant which eliminates the interference from binding electrolytes
- Use dry anti-coagulant to prevent dilution effect

An ABG collection device with sharps injury protection prevents needlestick injuries
- Use one-hand operated sharps injury protection

Heparin amount and type is important:
- Too much heparin can bias electrolyte results - too little heparin may not be sufficient to prevent clotting
- Non-compensated heparin may interfere with electrolyte results

Tips!
- Use a syringe with integrated needle shield device and tip cap

Facts:
- At some point in their career 48% of nurses had sustained an injury by a needle or sharp and 10% had been stuck in the last year [1]
- The risk of infection by a contaminated needle is 1 in 3 for Hepatitis B, 1 in 30 for Hepatitis C, 1 in 300 for HIV [2]

References:
Greater sample integrity and operator safety

Heparin-induced bias can be caused by:

- Use of heparin that is not formulated to reduce bias on electrolytes
- The use of liquid heparin

This can lead to:

- Erroneous electrolytes and metabolites results
- Clots in the sample that may interfere with the analyzer and produce inaccurate value [1]
- Incorrect patient treatment [2]

Sharps injury can be caused by:

- Unavailability of sampling safety devices for operators
- Lack of a dedicated procedure for operator safety
- Dedicated procedures for operator safety are not followed

This can lead to:

- Operator concern over own safety
- Needlestick injury
- Infection by blood-borne pathogens

3. Sample collection
3. Sample collection

**Maximum safety** for patient and operator

**A-puncture procedure**

Use of **short-bevel needles** eases the placement of needle in artery

- Minimize the risk of puncturing opposite arterial wall

**Self-filling syringes** fill readily indicating an artery has been punctured

- Rapid appearance of the blood flash indicates an artery has been punctured

An ABG collection device with **sharps injury protection** prevents needlestick injuries

- Use one-hand operated sharps injury protection

**Arterial line procedure**

**Removing sufficient flush solution** prevents sample contamination

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The recommendations shown in the video are based on best practice and international guidelines. Be sure to follow local procedure and guidelines for sample collection.
3. Sample collection

**Maximum safety** for patient and operator

Sample contamination can be caused by:

- Mixing venous blood with arterial blood
- Diluting the sample with flush solution if an insufficient amount of flush solution has been removed

This can lead to:

- Contaminating the sample with either venous blood or flush solution will alter the values of the sample so that it no longer represents the patient status

Operator safety can be compromised by:

- Unavailability of samplers with integrated safety device
- Lack of dedicated procedure for operator safety

This can lead to:

- Needlestick injury
- Operator concern over own safety
- Infection by blood-borne pathogens
4. Sample handling
Key steps for greater sample integrity

Thorough removal of air bubbles minimizes room air contamination of the sample
- Visually inspect the sample for air bubbles
- Expel any air bubbles before mixing

Proper mixing of the sample immediately post draw for a clot-free sample
- Mix immediately after air bubbles have been expelled
- Mix to dissolve the heparin to prevent clots to form

Mixing – again – prior to analysis to obtain a homogeneous sample
- Thoroughly mix the sample by inverting the syringe several times and rolling it between the palms of your hands

Tips!
Use syringes with vented tip caps that seal the sample and remove air without getting in contact with blood
Establish a dedicated mixing procedure in your facility
Gentle mixing of the sample is required to avoid the risk of hemolysis

A visibly sedimented sample needs mixing for several minutes [1, 2]

Exposure to room air can lead to:

- Sample values no longer representative of patient status
- \( pO_2 \) will be most impacted – there will be minor effects on \( pCO_2 \) and pH [1]

Clots in the sample can lead to:

- Blocking the sample pathway and lead to analyzer downtime
- Inaccurate measurements – both for the current sample, but also for successive samples

A sedimented sample can lead to:

- Erroneous hemoglobin and Hct values and bias on calculated parameters derived from cTnHb

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1. Toffaletti J. Effect of small air bubbles on changes in blood \( pO_2 \) and blood gas parameters: Calculated vs. measured effects. www.acutecaretesting.org July 2012.
5. Sample transport
Immediate analysis of sample for greater sample integrity and short TAT

- If storage is unavoidable, store the sample for maximum 30 minutes
- Glass syringes should be used if analysis will be delayed (more than 30 minutes after collection)

NB!
Analyze special samples within 5 minutes: high $pO_2$, high leucocyte count, shunt studies

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

Store plastic sampling devices at room temperature to minimize any effect on sample values

- Glass sampling devices can be stored in ice slurry water or at room temperature
5. Sample transport

**Minimum time**

to patient results

**Prolonged storage time can lead to:**

- Continuous metabolism alters values in the sample so they no longer represent patient status, for example: \( pO_2 \), \( pCO_2 \), pH, glucose and lactate are affected

**Wrong storage temperature can lead to:**

- Wrong storage temperature can alter the values in the sample so they no longer represent patient status
High Five for safe arterial blood gas sampling:

Path of workflow:

1. **Patient preparation** – patient assessment and correct data registration to maximize patient safety
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More educational resources
Radiometer’s blood gas preanalytics app:
- Handbook with video demonstrations
- Skill test
- Interactive troubleshooting guide

Available for iPhone, Android, Windows Phone
In depth on: Heparin
In depth on: Heparin

3 important points about heparin

1. Sufficient concentration of heparin is needed
2. Electrolyte-balanced heparin minimizes bias on positive ions like Ca$^{2+}$, Na$^{+}$ and K$^{+}$
3. Heparin needs to be provided in a dry format to avoid dilution errors

1. Heparin concentration

What is a sufficient concentration of heparin?

- The higher heparin concentration, the better anticoagulation

- Exact concentration for effective anticoagulation not possible to give:
  - “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]

### 3 important points about heparin

- Sufficient concentration of heparin is needed
- Electrolyte-balanced heparin minimizes bias on positive ions like Ca^{2+}, Na^{+} and K^{+}
- Heparin needs to be provided in a dry format to avoid dilution errors

**IMPORTANT:**
The anticoagulation effect is also dependent on how fast heparin is dissolved (see clots and mixing)

2. Heparin interference

- Heparin binds positively charged ions
- A high heparin concentration is desirable, however heparin binds to positive ions like calcium...

### 3 important points about heparin

- Sufficient concentration of heparin is needed
- Electrolyte-balanced heparin minimizes bias on positive ions like Ca²⁺, Na⁺ and K⁺
- Heparin needs to be provided in a dry format to avoid dilution errors

### Bias on ionized calcium with the use of non-balanced heparin

<table>
<thead>
<tr>
<th>IU/mL Heparin</th>
<th>Bias on cCa²⁺[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>

2. Heparin interference

According to international guidelines:

- **CLSI C46-A2**
  - **5.2.1** “...special preparations of heparin are available, which virtually eliminate the interference from heparin binding of these electrolytes.”
  - **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”
  - **5.2.5** "Therapeutic heparin used for systemic anticoagulation should not be used....because of its very high concentration"

### 3 important points about heparin

- **Sufficient concentration of heparin is needed**
- **Electrolyte-balanced heparin minimizes bias on positive ions like Ca^{2+}, Na^{+} and K^{+}**
- **Heparin needs to be provided in a dry format to avoid dilution errors**
3. Heparin formulation

- Liquid heparin will inevitably lead to dilution and impact electrolyte and metabolite values.

- The dilution effect will vary and depends on the volume of liquid heparin versus the volume of the blood gas sample.

### 3 important points about heparin

- Sufficient concentration of heparin is needed.
- Electrolyte-balanced heparin minimizes bias on positive ions like Ca^{2+}, Na^+ and K^+.
- Heparin needs to be provided in a dry format to avoid dilution errors.

From the literature:

“The danger from nonstandardized blood collection into syringe washed with liquid heparin should be carefully assessed. For preventing serious medical errors due to nonstandardized blood gas sampling, electrolyte balanced dry heparin may be recommended.” [1]

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3. Heparin formulation

**Example**
- If the volume of liquid heparin is 0.05 mL and 1 mL whole blood is sampled (Hct 45 %) it will dilute the plasma phase by approx. 10 %. [1]

3. Heparin formulation

According to international guidelines:

- **IFCC [1]:**
  - “…a 5% dilution may be acceptable for the blood gases, but not for the electrolytes”

- **CLSI [2]:**
  - 5.2.1 “The ideal collection device for arterial blood sampling is…containing a small amount of anticoagulant such as lyophilized heparin”

From the literature:

“Excess liquid heparin statistically exaggerated or produced false results consistent with metabolic acidosis with respiratory compensation” [3]

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Radiometer’s solution

First and only to market with fully balanced heparin

Dry electrolyte-balanced heparin

Bias on $\text{Ca}^{2+}$ leading to low $\text{cCa}^{2+}$

No bias on $\text{Ca}^{2+}$

Radiometer facts:
First to market with high sensitive calcium measurement
First to market with balanced heparin
Radiometer’s dry electrolyte-balanced heparin – minimum bias on electrolytes proven

Studies prove Radiometer’s dry electrolyte-balanced heparin has minimum bias on electrolyte and pH values

“The biases introduced by Radiometer syringes were minimal” [1]

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

In depth on heparin

Radiometer’s dry electrolyte-balanced heparin – superiority confirmed by additional studies

Scientific insight
Dry electrolyte-balanced heparin

This paper provides a brief insight into three scientific studies evaluating Radiometer arterial blood gas samplers.

Radiometer samplers (POC and saBIOPOC) are precalibrated with an appropriate concentration of dry electrolyte-balanced heparin in order to avoid preanalytical error caused by inappropriate heparin concentration, dilution effect from liquid heparins and heparin effect on positively charged ions.

Several studies evaluating Radiometer samplers have been published over the years, for example...

Radiometer samplers provided correct ionised calcium results whereas non-heparinised venous blood samples did not. Van Berk et al.[1] compared electrolyte concentrations in non-anticoagulated blood with concentrations measured in electrolyte-balanced blood gas syringes. Venous blood from 6 healthy individuals was collected into plain tubes. Remaining blood was collected into three different electrolyte-balanced heparin blood gas syringes: Prolabo (BD), Monovette (Sarstedt) and POC050 diaplanoter.

Lensed calcium, potassium, sodium and hydrogen ions were analysed directly using a blood gas analyser.

The comparison showed that ionised calcium concentrations were significantly lower in blood collected in syringes from BD (Becton Dickenson) and SI (Sarstedt) compared to ionised calcium concentrations in standard heparinised blood (p<0.0001).

"The negative bias is clinically relevant for most subjects since it exceeds the total allowable error (15%) of 2.0% for ionised calcium. In contrast, ionised calcium measured in blood collected in RM (Radiometer) syringes was identical to values obtained from SI blood (p>0.5). "IO syringes introduced the most pronounced bias in concentrations of all electrolytes, whereas the biases introduced by RM (Radiometer) syringes were minimal. Similarly, the 95% limits of agreement were the narrowest and displayed no obvious zero bias with RM (Radiometer) syringes."

Radiometer samplers with dry balanced heparin provided stable calcium and sodium concentrations. Calaf N et al.[2] compared the different arterial blood gas sampler kits in a clinical study evaluating preanalytical factors. They collected arterial blood gas samples from respectively 160 and 50 patients and concluded that "blood samples collected by the POC 70 and the Pro-Stat were of superior quality." Some of the samples kits "consistently provided calcium and sodium concentrations that were higher than the mean due to the type of heparin that the device contained (liquid sodium heparin)." Whereas "the other kits provided more stable samples." The POC 70 and a dry trithemium ionium balanced heparin that had to effect on hemoglobin and POC70, "valium" and "Radiometer's POC 70 and SIAM, or NaCl Euritine fulfilled the largest number of requirements."

References

Radiometer’s portfolio of arterial blood gas syringes
Arterial blood gas syringes

**PICO**
Arterial puncture and arterial line sampling

**safePICO70**
Arterial puncture sampling with integrated needle shield device

**safePICO**
Premium solution for arterial blood gas sampling

PICO70

PICO50

safePICO self-fill

safePICO aspirator
Arterial blood gas syringes

Radiometer’s PICO line – features

PICO syringe
- Available as aspirator for arterial line procedures and vented for arterial puncture procedure
- Pre-heparinized with dry electrolyte-balanced heparin coated on fiber disc
- TipCap to seal sample during transport
- Fill volume: PICO70 0.3-1.5 mL, PICO50 0.5-2 mL

safePICO70 syringe
- Arterial puncture draw
- Same features as PICO line
- Integrated needle shield device – single handed activation and audible “click” when activated correctly
- Fill volume: 0.3-1.5 mL

Needle assortment
For self-filling syringes:
Broad assortment of needles to suit puncture site and patient characteristics

Outer diameter
<table>
<thead>
<tr>
<th>Length</th>
<th>25G Orange</th>
<th>23G Blue</th>
<th>22G Clear</th>
</tr>
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<tbody>
<tr>
<td>16 mm</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25 mm</td>
<td></td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>32 mm</td>
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Preferably short-bevel 20-25 gauge needles with a length of 16-38 mm are acceptable for arterial puncture [1]

Radiometer’s **PICO line** – benefits

**Dry electrolyte-balanced heparin**
- Specially prepared heparin that minimizes bias on all electrolytes, Na⁺, K⁺, Ca²⁺ as recommended by CLSI guidelines
- Minimal bias on electrolytes even at smaller sample volumes
- Heparin superiority proven by independent study

**Vented plunger system on self-filling syringe**
- Vented plunger designed to minimize bubbles in sample

**Needles with short bevel**
- Easy placement of needle in artery; prevent puncture of opposite arterial wall
- Minimize the risk of mixing venous blood with arterial blood

**Needles with super-thin needle wall**
- Larger inner diameter compared to regular needles
- Faster filling and reduced patient discomfort

**TipCap**
- Minimize room air: The special design of the Radiometer TipCap leaves no room for air in the luer tip
- Anaerobe sample: The TipCap is designed to expell air from the sample before sealing
Radiometer’s **needle safety mechanism**

**safePICO70 syringe**

**Maximum operator safety**

- Onboard safety mechanism → always where needed
- Single handed activation → allows operator to take care of patient while disposing of needle
- Audible “click” signals correct activation → ensure correct usage every time
- Full encapsulation of needle → safe disposal of needle and optimal prevention of stick injury
- Robust and irreversible once activated → maximum user safety
Radiometer’s premium safePICO line – features

**safePICO syringe**
Maximum safety and sample integrity
- safePICO aspirator for arterial line draw
- safePICO self-fill for arterial puncture draw
- Pre-heparinized with dry electrolyte-balanced heparin coated on fiber disc
- safeTIPCAP for safe and easy removal of air bubbles; seals the sample during transport
- Integrated mixing ball for easy and efficient mixing of sample
- Pre-barcoded to enable automatic match of patient ID and sample ID
- safePICO self-fill available with integrated needle shield device
- Fill volume: safePICO self-fill 0.7-1.5 mL, safePICO aspirator 0.7-1.7 mL

**Needle assortment** – for self-filling syringes
Broad assortment of needles to suit puncture site and patient characteristics

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Radiometer’s premium safePICO line – benefits

**safeTIPCAP**
Greater sample integrity and operator safety
- Allows for easy expelling of air while preventing exposure to blood
- Seals the sample during transport
- Stays on during measurement; forms a closed system once attached

**Mixing ball**
Greater sample integrity
- Gold plated metal mixing ball ensures easy, quick and efficient mixing
- Dissolves heparin to prevent clotting
- Ensures homogenous sample for correct hemoglobin results

**Pre-barcoded**
Maximum data accuracy
- Pre-attached barcode on syringe for automatic match of patient ID and sample ID