Pre-Analytical Errors in Capillary Blood Gas Sampling

MARTHA E LYON, PHD, DABCC, FACB
ROYAL UNIVERSITY HOSPITAL
SASKATOON HEALTH REGION
SASKATOON, SASKATCHEWAN, CANADA
Where in the World is Saskatchewan?

Springtime in Saskatchewan

+ Fall
+ Winter
Objectives

Discuss the unique challenges involved in the identification and collection of capillary blood specimens from neonates

Describe the effect of body temperature, specifically hypothermia, on the measurement of blood gases

Analyze the limitations of arterialization of capillary blood specimens on the measurement of blood gases

Review the ways in which heparin based anticoagulants can influence the measurement of electrolytes, specifically ionized calcium

Assess the effect of small air bubbles and transporting blood through the pneumatic tube on the measurement of oxygen
Potential Errors in Obtaining and Reporting a Blood Gas Result

- Pre-Analytical
- Analytical
- Post-Analytical
Potential Errors in Obtaining and Reporting a Blood Gas Result

Problems that can occur prior to the actual analysis of the specimen

Pre-Analytical

Analytical

Post-Analytical
Potential Errors in Obtaining and Reporting a Blood Gas Result

Pre-Analytical
Patient Identification, Specimen Collection, Handling and Transport

Analytical

Post-Analytical
Potential Errors in Obtaining and Reporting a Blood Gas Result

Pre-Analytical

Patient Identification, Specimen Collection, Handling and Transport

Specimen Preparation Prior to Analysis

Analytical

Post-Analytical
Potential Errors in Obtaining and Reporting a Blood Gas Result

- **Pre-Analytical**
  - Patient Identification, Specimen Collection, Handling and Transport
  - Partially clotted specimen
  - Specimen Preparation Prior to Analysis

- **Analytical**

- **Post-Analytical**
Potential Errors in Obtaining and Reporting a Blood Gas Result

Pre-Analytical

Analytical

Post-Analytical

62% Lab Associated Errors

Potential Errors in Obtaining and Reporting a Blood Gas Result

Pre-Analytical

Analytical

Post-Analytical

Problems that can occur during the actual analysis of the specimen
Potential Errors in Obtaining and Reporting a Blood Gas Result

15% Lab Associated Errors

Pre-Analytical  Analytical  Post-Analytical

Potential Errors in Obtaining and Reporting a Blood Gas Result

Pre-Analytical

Analytical

Results reported without reference range

Post-Analytical

Transcription (LIS) errors in result reporting
Potential Errors in Obtaining and Reporting a Blood Gas Result

Potential Errors in Obtaining and Reporting a Blood Gas Result

Potential Errors in Obtaining and Reporting a Blood Gas Result

- Pre-Analytical
- Analytical
- Post-Analytical

62% Lab Associated Errors
Pre-Analytical Errors in Capillary Blood Gas Sampling

Special Emphasis on Neonates
Survey 204 clinical labs in Croatia (174:85%)

Objectives

1) Prevalence of CBS for different patient populations

2) Compliance of protocols with international guidelines

1. Prevalence of CBS for different patient populations

2. Compliance of protocols with international guidelines

Original papers

Nationwide survey of policies and practices related to capillary blood sampling in medical laboratories in Croatia

Jasna Lenicak Kileza
Children's Hospital Zagreb, Department of Laboratory Diagnostics, Zagreb, Croatia

Corresponding author: jlenicek@gmail.com

Abstract

Introduction: Capillary sampling is increasingly used to obtain blood for laboratory tests in volumes as small as necessary and as non-invasively as possible. Whether capillary blood sampling is also frequent in Croatia, and whether it is performed according to international laboratory standards is unclear.

Materials and methods: All medical laboratories that participate in the Croatian National External Quality Assessment Program (N = 204) were surveyed on-line to collect information about the laboratory's parent institution, patient population, types and frequencies of laboratory tests based on capillary blood samples, choice of reference intervals, and policies and procedures specifically related to capillary sampling. Sampling practices were compared with guidelines from the Clinical and Laboratory Standards Institute (CLSI) and the World Health Organization (WHO).

Results: Of the 204 laboratories surveyed, 174 (85%) responded with complete questionnaires. Among the 174 respondents, 155 (89%) reported that they routinely perform capillary sampling, which is carried out by laboratory staff in 118 laboratories (76%). Nearly half of respondent laboratories (48%) do not have a written protocol including order of draw for multiplet sampling. A single puncture site is used to provide capillary blood for up to two samples at 49% of laboratories that occasionally or regularly perform such sampling. Most respondents (88%) never perform arterialisati- on prior to capillary blood sampling.

Conclusions: Capillary blood sampling is highly prevalent in Croatia across different types of clinical facilities and patient populations. Capillary sampling procedures are not standardized in the country, and the rate of laboratory compliance with CLSI and WHO guidelines is low.

Key words: capillaries; blood specimen collection; standardisation; diagnostic techniques and procedures

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Introduction

Capillary blood sampling allows much smaller blood volumes to be drawn in a much less invasive manner than venous sampling. Capillary blood samples are primarily arterial blood, though they also contain unknown proportions of blood from venules, arterioles, and capillaries, as well as from interstitial and intracellular fluid (1). Together with technological advances that allow multiple blood tests to be performed quickly and easily with small sample volumes, capillary sampling is helping to drive the widespread use of point-of-care (POC) diagnostics. POC analyzers are meant to allow clinical staff, rather than laboratory staff, to perform a variety of tests quickly and easily in the ward rather than in the laboratory (2).

Although capillary blood sampling has several advantages over venous sampling, it also carries greater risk of giving incorrect test results. This is because hemolysis and lipemia cannot be detected in capillary-sampled blood, and both can significantly affect test results. In addition, analyte concentrations can differ between capillary and venous blood, potentially invalidating standard reference ranges based on venous blood. Indeed, differences between the two sampling methods mean that clinicians must be careful to perform
Capillary Blood Gas Analysis

- Not just blood gases!
  - (pO$_2$, pCO$_2$, pH)
- Hemoglobin derivatives
  - (carboxy-Hb, met-Hb, oxy-Hb, and reduced Hb)
- Electrolytes
  - (Na$^+$, K$^+$, Cl$^-$, iCa$^{2+}$, iMg$^{2+}$)
- Metabolites
  - (glucose, lactate, creatinine, TBIL)
Outline

Patient Info
- Age
- Body Temp

Puncture Site
- Heel
- Earlobe

Arterialization

Identification Issues

Method and Conditions of Specimen Transport

Sample Handling

Clinical Laboratory

Anticoagulant
Pre-analytical events were most commonly (81.1%) reported
- 18.7% specimen not labelled
- 16.3% specimen mislabelled
- 13.2% improper collection

Top 3 problems
Patient Identification

(CLSI GP33-A Accuracy in Patient and Sample Identification)

- Two unique patient identifiers
  - Full name
  - Assigned ID number
  - Date of Birth
  - Photo ID on government approved card (ie driver’s licence)
Patient Identification – At Birth

- First ID band (mother’s information)
- Within 1 hr of birth, baby issued with personal health number (second ID band)

When baby arrives in Post Partum – 2 ID bands
Patient Identification

Normal Newborn Nursery

- First ID band (mother’s information)
- Within 1 hr of birth, baby issued with personal health number (second ID band)
  - Date of Birth
  - No given name yet – will happen after birth registration forms filled out
Patient Identification Challenges

- Mother’s surname (at birth) Father’s surname (after birth registration)
- Identification of twins, triplets etc.
  - Twin A Baby Girl
  - Twin B Baby Boy
Identification Issues

Patient Info
- Age
- Body Temp

Puncture Site
- Heel
- Earlobe

Arterialization

Anticoagulant

Method and Conditions of Specimen Transport

Sample Handling

Clinical Laboratory
Patient Assessment Information (CLSI C46-A2)

- “Steady state” ventilation (20-30 min acceptable for most patients post ventilator change)
- Patient age & Location
- Body Temperature
- Time of sampling
- FIO₂ or actual flow rate and method of delivery
- Ventilatory status (spontaneous breathing or assisted/controlled ventilation)
- Mode of Ventilation (pressure support)
- Site of Sampling
- Position and/or activity (rest, exercise)
Gestational & Post-Natal Age: Pre-analytical Error?

- Analysis of blood gases, basic biochemistry, coagulation, CBC, urinalysis and microbiology should be available in all units where babies are delivered.

- Pediatric and Neonatal patients are not just little adults.

- Acquiring Gestational Age (& Post-Natal Age) reference ranges is a huge challenge.
<table>
<thead>
<tr>
<th>Post-Natal Age</th>
<th>Gestational Age (28 weeks)</th>
<th>Gestational Age (32 weeks)</th>
<th>Gestational Age (36 weeks)</th>
<th>Gestational Age (40 weeks)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 days</td>
<td>40 - 220</td>
<td>27 - 175</td>
<td>23 - 143</td>
<td>18 - 118</td>
</tr>
<tr>
<td>7 days</td>
<td>23 - 145</td>
<td>19 - 119</td>
<td>16 - 98</td>
<td>13 - 81</td>
</tr>
<tr>
<td>14 days</td>
<td>18 - 118</td>
<td>15 - 97</td>
<td>12 - 80</td>
<td>10 - 66</td>
</tr>
<tr>
<td>21 days</td>
<td>16 - 104</td>
<td>14 - 86</td>
<td>11 - 71</td>
<td>9 - 57</td>
</tr>
<tr>
<td>28 days</td>
<td>15 - 95</td>
<td>12 - 78</td>
<td>10 - 64</td>
<td>9 - 53</td>
</tr>
</tbody>
</table>
Patient Assessment Information (CLSI C46-A2)

- "Steady state" ventilation (20-30 min acceptable for most patients post ventilator change)
- **Patient age** & Location
- **Body Temperature**
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- FIO₂ or actual flow rate and method of delivery
- Ventilatory status (spontaneous breathing or assisted/controlled ventilation)
- Mode of Ventilation (pressure support)
- Site of Sampling
- Position and/or activity (rest, exercise)
Robin Knobel, PhD, RN, assistant professor at the Duke University School of Nursing in Durham North Carolina, and a Robert Wood Johnson Foundation nurse faculty scholar, shared her research at the conference. In a telephone interview with Medscape Medical News, she discussed what nurses can learn from this type of monitoring.

Medscape: What prompted you to study temperature regulation in extremely low-birthweight infants?

**Dr. Knobel:** I worked as a NICU [neonatal intensive care unit] and a neonatal nurse practitioner. We did a lot of transport, and it would always impress me how cold the babies were when we would pick them up. Nurses would take care of everything — blood pressure, ventilation, all those vital things — but many times they would forget about the temperature.

Once I picked up a really cold baby who ended up dying because he was so hypothermic in the beginning. I also saw many hypothermic babies coming from the delivery room who would be cold from the delivery experience. I decided that I wanted to do something to improve temperatures for babies.
Body Temperature & Premature Babies

- All infants up to ~ 1 yr generate heat by non-shivering thermogenesis
  - Thermogenin
    - mitochondrial protein (brown adipose tissue)
    - Used to generate heat
  - Infants < 32 wks do not warm themselves effectively (relative deficiency of thermogenin)

Henry’s Law
- The partial pressure of a gas is proportional to its concentration at a given temperature and pressure
Hypothermia has become an important novel neuroprotective strategy for asphyxiated neonates. Most of these neonates will receive mechanical ventilation. Hypothermia affects blood gas parameters such as pH and PCO2. At lower temperatures pH increases and PCO2 decreases. This is relevant, because Pao2 is known to affect oxygen tension and, hence, cerebral perfusion. In addition, cerebral blood flow decreases during hypothermia, which increases the risk of insufficient blood flow during hypocapnia.

Most blood gas instruments, whether a central laboratory or point-of-care device, contain a temperature-controlled sample chamber specified to be 37°C. It is at that temperature that all measurements of pH and partial pressure of gases are performed. In the a-stat strategy, uncorrected values are used to keep the pH and PCO2 close to the 37°C reference value. However, most instruments can calculate and present temperature-corrected pH and PCO2 values. In the so-called pH-stat method, the measured pH is corrected to the actual body temperature of the patient. Ventilator settings can be adjusted to keep the actual pH as close to 7.4 as possible.

At present, it is unclear whether the a-stat or pH-stat theory should be used in the neuroprotective strategy for asphyxiated term neonates.

In the 2 large randomized, controlled trials on therapeutic hypothermia in term neonates with perinatal asphyxia, attending physicians were advised to correct blood gases and pH for rectal temperature. Here we will summarize the relevance of blood gas values in and the effects on cellular function during hypothermia.

**HYPOTHERMIA, PCO2, AND pH**

Physical laws determine that the solubility of a gas within a liquid decreases when lowering the temperature. During hypothermia, arterial PCO2 decreases and pH increases compared with 37°C when measurements are made at the actual body temperature (Fig 1). In healthy subjects with a body temperature of 37°C, pH and Paco2 should approach 7.4 and 5.3 kPa (40 mm Hg), respectively. During hypothermia (33°C), pH will rise to 7.5 and Paco2 will decrease to 4.5 kPa (34 mm Hg).

**Paco2 AND CEREBRAL BLOOD FLOW**

Under normal conditions, term neonates autoregulate their cerebral blood flow in response to changes in systemic arterial pressure, but this mechanism can be impaired during neonatal distress. In particular, changes in Paco2 have a well-recognized effect on cerebral blood flow. Hypocapnia induces cerebral vasoconstriction and may decrease cerebral tissue high-energy phosphates. This effect has been extensively investigated in experiments in neonatal animals. In preterm neonates, profound hypocapnia below values of 4 kPa (30 mm Hg) was related to periventricular leukomalacia. There is little reason to assume that hypocapnia could not damage the brain in the sick term neonate. Klinger et al reported that in asphyxiated term neonates early hypocapnia was independently associated with adverse outcome. Others have reported an association between neurodevelopmental sequelae and profound hypocapnia in infants who were referred for extracorporeal membrane oxygenation because of severe cardiopulmonary failure. Substantial hypocapnia and, in particular, hypocapnia must therefore be considered to be potentially dangerous for the sick asphyxiated term infant.

**PH AND CELLULAR ENZYMATIC PROCESSES**

There is some evidence that intracellular pH changes with temperature such that the intracellular pH remains at or close to the pH of neutrality (the state when [H+] = [OH-]). Experimental work has shown that protein buffering, largely because of the imidazole group of histidine, is responsible for maintaining this temperature-pH relationship (aided by phosphate and bicarbonate buffering). The idea that the degree of dissociation (known as α) of imidazole remains constant despite changes in temperature is known as the "α-stat hypothesis." The net charge on all proteins is kept constant despite changes in temperature. It is hypothesized that as a result, all proteins can function optimally despite temperature changes. The a-stat strategy is often used for pediatric and adult cardiac surgery, although there are no good data to support this practice. In contrast, in the pH-stat strategy, pH and Pao2 are maintained at constant values during cooling such that in vivo hypothermic blood is at a pH of 7.40 and the Paco2 is 5.3 kPa (40 mm Hg), whereas the blood measured at 37°C is hypercapnic and acidic. Studies of hypothermic circu...
In conclusion, variations in body temperature significantly affect the results of important and frequently used monitoring techniques in intensive care, anesthesia and emergency medicine. The knowledge of physical and technical changes during hypothermia and hyperthermia is necessary to avoid pitfalls in monitoring of blood gases...."
Identification Issues

Patient Info
• Age
• Body Temp

Puncture Site
• Heel
• Earlobe

Arterialization

Anticoagulant

Method and Conditions of Specimen Transport

Sample Handling

Clinical Laboratory
Capillaries are the smallest blood vessel connecting arterioles and venules.

Capillary wall is a single cell thick which promotes the release of O₂ and nutrients and capture of CO₂ and waste.

Blood collected by skin puncture represents a mixture of arteriole, capillary and venule blood.
Figure 1: Capillary network

<table>
<thead>
<tr>
<th>Arterial blood</th>
<th>AV Difference</th>
<th>Venous Blood</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>7.40</td>
<td>pH</td>
</tr>
<tr>
<td>$pCO_2$</td>
<td>5.3 kPa</td>
<td>$pCO_2$</td>
</tr>
<tr>
<td>$pO_2$</td>
<td>13.0 kPa</td>
<td>$pO_2$</td>
</tr>
</tbody>
</table>

Higgins C. Capillary-blood gases: To arterialize or not. MLO. November 2008:42-47
Differences between Arterial, Capillary and Venous Glucose Concentrations

- Arterial Glucose ~ Capillary Glucose
- Capillary Glucose > Venous Glucose

Venous glucose = capillary glucose (fasting specimens)

Capillary glucose can be up to 20 – 25% higher than venous glucose
- After a meal
- Glucose load
- Glucose clamping studies

WHO guidelines on drawing blood: best practices in phlebotomy, Geneva, Switzerland, 2010
• Single deep puncture
• Heel (< 1 y)
• Earlobe (> 1y)

Numerous Conditions where Capillary Blood Sampling is Unsuitable, including
• Dehydrated Patients
• Edematous Patients
• Poor peripheral perfusion

Do not “milk” the puncture site
• May cause hemolysis
• Contamination with tissue fluid
Hemolysis in Serum Samples Drawn in the Emergency Department

Edward R. Burns, Noriko Yoshikawa
Department of Pathology, Albert Einstein College of Medicine and Montefiore Medical Center, New York, NY.

4,021 patients (ED = 2,992  Med Ward = 1,029)

Both collected by Laboratory Phlebotomists

Rates of hemolysis:  12.4% in ED
1.6% in a Medical Ward
How do we currently detect hemolysis?

• Visual inspection of plasma

• Problems:
  ▫ time consuming (requires centrifugation)
  ▫ manual qualitative assessment
  ▫ between observer variability
How do we currently detect hemolysis?

- Hemolysis Index (Automated Clinical Chemistry Systems)

- Spectrophotometric assessment
  - Blanked bichromatic measurements
    - 405 nm and 700nm

- Problems:
  - Some time consumed
Can we detect hemolysis in a whole blood specimen?

Not yet!
Distribution of H Index (NICU, Well Baby Nursery)

N = 852

Percentile

<table>
<thead>
<tr>
<th>Percentile</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0th</td>
<td>7</td>
</tr>
<tr>
<td>25th</td>
<td>53</td>
</tr>
<tr>
<td>50th</td>
<td>97</td>
</tr>
<tr>
<td>75th</td>
<td>158</td>
</tr>
<tr>
<td>100th</td>
<td>1246</td>
</tr>
</tbody>
</table>
75-80% of all specimens are visually hemolyzed.
Effect of Hemolysis of Blood Gases and Electrolytes

- pH (-0.2%)
- *pO₂ (-4.9%)
- sO₂ (-4.9%)
- COHb (-11%)
- *Ca²⁺ (-7%)
- *pCO₂ (+4.1%)
- HCO₃⁻ (+1.4%)
- *K⁺ (+152%)

* Clinically Meaningful Bias

Arterial Blood = Gold Std Sample

Immerse heel in warm water
- 40-45°C
- 5-10 min

“The clinical value of capillary-blood gas results depends, however, on the extent to which pH, pCO2, and pO2 of capillary blood accurately reflect pH, pCO2, and pO2 of arterial blood”

Capillary-blood gases: To arterialize or not

By Chris Higgins

The gold-standard sample for blood-gas analysis is arterial blood obtained via an indwelling arterial catheter or by arterial puncture. For a number of reasons, capillary blood is an attractive substitute sample that is routinely used in some clinical settings. The purpose of this article is to examine the evidence that blood-gas parameter values (pH, pCO2, and pO2) obtained from a capillary-blood sample accurately reflect arterial blood. There is conflicting opinion that increasing local blood flow (by warming or application of vasodilating agent) prior to capillary-blood sampling is necessary for most accurate results and this controversial issue will be addressed. [Notes: The unit of pCO2 and pO2 measurement used in this article is kPa — to convert kPa to mmHg divide by 0.133.]

Blood-gas analyzers measure blood pH, and the oxygen and carbon-dioxide tensions of blood (pCO2 and pO2). These measurements, along with parameters (bicarbonate, base excess, and so on) derived by calculation from these measurements, allow evaluation of acid-base status and adequacy of ventilation and oxygenation. Thus, blood-gas analysis is helpful for assessment and monitoring of patients suffering a range of metabolic disturbances and respiratory diseases, both acute and chronic. It is an important component of the physiological monitoring that critically ill patients, particularly those being mechanically ventilated, require.

The gold-standard sample for blood-gas analysis is arterial blood obtained anerobically via an indwelling arterial catheter (most often sited at the radial artery in adults and the umbilical artery in neonates), or arterial puncture. In an intensive-care setting where patients may require frequent (perhaps two hourly) blood-gas analysis, arterial catheters become a serious threat to infection control policies for other samples.

The arterial blood sample is obtained directly from the femoral artery in the groin. Although arterial puncture does not place patients at risk of the serious complications associated with arterial catheterization, it is potentially hazardous and certainly not risk free. Furthermore, it is a procedure that is reported by patients to be significantly more painful than venous puncture. Specialist training in arterial puncture is essential for patient safety and comfort; and, in many countries, obtaining arterial blood is the almost exclusive preserve of medically qualified staff.

Capillary blood can be obtained by near-painless skin puncture using a lancet or automated incision device that punctures the skin to a depth of just 1 millimeter. It is the least-invasive and safest blood-collecting technique, and can be performed by all healthcare personnel after minimal training. The relative simplicity and safety profile of capillary-blood sampling and the necessity for only small volumes (100 µL to 150 µL) of blood for pH and gas analysis make capillary blood an attractive substitute for arterial blood, particularly among neonates and infants but also adults. The clinical value of capillary-blood gas results depends, however, on the extent to which pH, pCO2, and pO2 of capillary blood accurately reflect pH, pCO2, and pO2 of arterial blood.

Capillary and arterial blood: theoretical considerations

With a diameter of just 8 µm, capillaries are the smallest blood vessels. They are the connection between arterioles (the smallest artery) and venules (the smallest vein) and, thus, between the arterial and venous sides of the circulatory system. The capillary network (see Figure 1) is the site of nutrient and waste exchange between blood and tissue cells, made possible by the single-cell (1-µm) thickness of the capillary wall. Oxygenated arterial blood arriving via arterioles at the capillary network yields its oxygen and other essential nutrients to tissue cells as carbon dioxide and other waste products of metabolism are released and the tissue cells take them up (from difference. 13 kPa, venous PA. The order is 0.02. In arterial blood, pO2 is similar to pO2 of arterial blood, and there is a small (from difference. 20 mmHg difference. Capillary pH was similar to Arterial pH
- <0.05 difference
- Clinically insignificant

Capillary pCO2 was similar to Arterial pCO2
- <3-5 mmHg difference
- Clinically acceptable

Capillary pO2 was different from Arterial pO2
- 20 mmHg difference
- Clinically UNacceptable

Capillary pO2 decreases so does the arterial capillary difference
Arterial pO2 increases so does the arterial capillary difference
“There is really no substitute for arterial blood if accuracy of pO2 measurement is important, for example, for the prescription of long-term oxygen therapy”

Higgins C. Capillary-blood gases: To arterialize or not. MLO. November 2008:42-47
Identification Issues

Patient Info
- Age
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Puncture Site
- Heel
- Earlobe

Arterialization

Anticoagulant

Method and Conditions of Specimen Transport

Sample Handling

Clinical Laboratory
Anticoagulants

- Calcium chelators (ie. EDTA, Sodium Citrate)
- Vitamin K Antagonist (ie. Warfarin)
- Cofactor (ie. Heparin+antithrombin III)
Heparin

- Natural occurring polysaccharide
- Different sizes
- Different degrees of sulfation
- Different formulations
Different Formulations of Heparin

Balanced Heparin
- Lithium and Zinc
- Lithium, Zinc and Calcium
- Lithium, Sodium, Potassium and Calcium

Depending upon formulation of heparin used, biases in the measurement of ionized calcium, ionized magnesium and sodium could be seen.
The adult human body contains approx 1100gm (27.5mol) of Calcium. 99% of Calcium is in bones. Blood Calcium levels are normally 9-10.2mg/dL (2.25-2.55mmol/L).
Congenital Analbuminemia is rare

50 cases reported since 1954

12 local cases identified from First Nations Community near Saskatoon

Will the lack of albumin influence the measurement of ionized calcium?
Identification Issues

Patient Info
• Age
• Body Temp

Puncture Site
• Heel
• Earlobe

Arterialization

Anticoagulant

Method and Conditions of Specimen Transport

Sample Handling

Clinical Laboratory
Glass versus Plastic Syringe or Capillary Tube

Historical
Glass versus Plastic Syringes or Capillary Tube

1) Immediately place on ice slurry
Glass versus Plastic Syringes or Capillary Tube

1) Immediately place on ice slurry

2) Negligible permeability to oxygen and carbon dioxide (due to diffusion)
Glass versus Plastic Syringes Or Capillary Tube

- Cost
- Safety
- Convenience

New Standard
Glass versus Plastic Syringes or Capillary Tube

- Clinical Laboratory Standards Institute (CLSI) (C-46 A2)
  - Specimen collection devices
  - Sample handling
  - Specimen transport
  - Specimen storage

Recommendation:
Arterial specimens collected into a plastic syringe should be stored at room temperature and must be analyzed within 30 minutes
How do temperature and time affect ABG results with a plastic syringe?

- Clinical Laboratory Standards Institute (CLSI)
  - Specimen collection devices
  - Sample handling
  - Specimen transport
  - Specimen storage

Recommendation:
Arterial specimens collected into a **plastic syringe** should be stored at **room temperature** and must be analyzed within **30 minutes**
Changes in Oxygen Measurements When Whole Blood Is Stored in Iced Plastic Glass Syringes

John J. Mahoney, James A. Harvey, Ronald J. Wong, and Antonius L. Van Kessel

Table 1. Change in $\rho_{O_2}$ of Whole Blood and Plasma in Glass Syringes after Storage in Ice Water

<table>
<thead>
<tr>
<th></th>
<th>Whole blood</th>
<th></th>
<th>Plasma</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>Time 0</td>
<td>60 min</td>
<td>Delta</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>103.3 ± 1.4</td>
<td>102.9 ± 1.4</td>
<td>-0.5 ± 1.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(13.77 ± 0.19)</td>
<td>(13.72 ± 0.19)</td>
<td>(-0.07 ± 0.15)</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>41.1 ± 1.9</td>
<td>41.8 ± 1.6</td>
<td>0.7 ± 0.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(5.48 ± 0.25)</td>
<td>(5.57 ± 0.21)</td>
<td>(0.09 ± 0.09)</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>110.2 ± 1.6</td>
<td>111.4 ± 1.8</td>
<td>1.2 ± 2.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(14.69 ± 0.21)</td>
<td>(14.85 ± 0.24)</td>
<td>(0.16 ± 0.27)</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>64.3 ± 2.4</td>
<td>66.4 ± 2.8</td>
<td>2.1 ± 2.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(8.57 ± 0.32)</td>
<td>(8.85 ± 0.37)</td>
<td>(0.28 ± 0.29)</td>
<td></td>
</tr>
</tbody>
</table>
Changes in Oxygen Measurements When Whole Blood Is Stored in Iced Plastic Glass Syringes

John J. Mahoney, James A. Harvey, Ronald J. Wong, and Antonius L. Van Kessel

Table 2. Change in $p_{O_2}$ of Whole Blood and Plasma In Plastic Syringes after Storage in Ice Water

<table>
<thead>
<tr>
<th></th>
<th>Mean ± SD, $p_{O_2}$, mmHg (and kPa)</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Time 0 / 30 min / Delta</td>
<td>P</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Whole blood (n = 10 each)</td>
<td>101.0 ± 1.7 / 109.7 ± 4.1 / 8.4 ± 3.3</td>
<td>&lt;0.0001</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(13.46 ± 0.23) / (14.62 ± 0.55) / (1.12 ± 0.44)</td>
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<td></td>
<td>70.9 ± 1.3 / 71.7 ± 1.4 / 0.8 ± 0.6</td>
<td>&lt;0.002</td>
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<td></td>
<td>(9.45 ± 1.30) / (9.56 ± 0.19) / (0.11 ± 0.08)</td>
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<tr>
<td></td>
<td>42.8 ± 0.8 / 43.1 ± 0.4 / 0.4 ± 0.5</td>
<td>NS</td>
<td></td>
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<td></td>
<td>(5.71 ± 0.80) / (5.75 ± 0.05) / (0.05 ± 0.07)</td>
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<tr>
<td>Plasma (n = 8 each)</td>
<td>106.7 ± 2.2 / 119.3 ± 2.1 / 12.6 ± 2.4</td>
<td>&lt;0.0001</td>
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<td></td>
<td>(14.22 ± 0.29) / (15.90 ± 0.28) / (1.68 ± 0.32)</td>
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<td></td>
<td>79.1 ± 3.3 / 92.9 ± 2.2 / 13.8 ± 3.7</td>
<td>&lt;0.0001</td>
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<tr>
<td></td>
<td>(10.54 ± 0.44) / (12.38 ± 0.29) / (1.84 ± 0.49)</td>
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<tr>
<td></td>
<td>67.2 ± 3.7 / 88.1 ± 5.0 / 20.9 ± 2.3</td>
<td>&lt;0.0001</td>
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<tr>
<td></td>
<td>(8.96 ± 0.49) / (11.74 ± 0.67) / (2.79 ± 0.31)</td>
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Effect of small air bubbles on changes in blood $pO_2$ and blood gas parameters: calculated vs. measured effects

Jul 2012

John G. Toffaletti

Elizabeth H. McDonnell

• Background: Important to remove air bubbles from syringes (to avoid errors)

• Calculate expected theoretical changes in $pO_2$ (20 µL or 40 µL of air are added)

• Confirm validity of these calculations by measuring blood gas & Co-ox parameters (19 patients after equilibration with similar increments of air)
Remove Bubbles

Introduce air by visually pulling back on syringe plunger until tip was half full of air (20 μL) or completely full (40 μL)

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</thead>
<tbody>
<tr>
<td>Bubble vol (μL)</td>
<td>0</td>
<td>40</td>
<td>80</td>
<td>120</td>
<td>160</td>
<td>200</td>
</tr>
<tr>
<td>pH</td>
<td>7.243</td>
<td>7.241</td>
<td>7.241</td>
<td>7.244</td>
<td>7.248</td>
<td>7.255</td>
</tr>
<tr>
<td>pCO₂ (mmHg)</td>
<td>34.5</td>
<td>34.1</td>
<td>33.7</td>
<td>32.9</td>
<td>32.0</td>
<td>30.9</td>
</tr>
<tr>
<td>pO₂ (mmHg)</td>
<td><strong>69.4</strong></td>
<td><strong>85.1</strong></td>
<td><strong>105</strong></td>
<td><strong>127</strong></td>
<td><strong>159</strong></td>
<td><strong>183</strong></td>
</tr>
<tr>
<td>ΔpO₂ (mmHg)</td>
<td>16</td>
<td>20</td>
<td>22</td>
<td>32</td>
<td>24</td>
<td>----</td>
</tr>
<tr>
<td>Hb (g/dL)</td>
<td>13.7</td>
<td>13.6</td>
<td>13.5</td>
<td>13.6</td>
<td>13.6</td>
<td>13.6</td>
</tr>
<tr>
<td>%O₂ Hb</td>
<td>89.7</td>
<td>93.3</td>
<td>95.0</td>
<td>95.8</td>
<td>96.1</td>
<td>96.2</td>
</tr>
<tr>
<td>sO₂ %</td>
<td><strong>92.6</strong></td>
<td><strong>96.2</strong></td>
<td><strong>97.8</strong></td>
<td><strong>98.8</strong></td>
<td><strong>99.1</strong></td>
<td><strong>99.3</strong></td>
</tr>
<tr>
<td>O₂ ct (mL/mL)</td>
<td>0.173</td>
<td>0.179</td>
<td>0.182</td>
<td>0.185</td>
<td>0.187</td>
<td>0.187</td>
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</tbody>
</table>

**TABLE V:** Blood gas and CO-oximetry measurements on a representative arterial blood sample as 40 μL increments of room air were added to 1.2 mL blood. The ΔpO₂ is the difference between the pO₂ values before and after addition of each 40 μL increment of air. O₂ ct = oxygen content.
FIG. 1: Calculated and measured changes in blood $pO_2$ when 20 or 40 μL 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.
Purpose:
To characterize the potential interference to pO$_2$ measurement when blood contamination with air is sent through a pneumatic tube system.
Introduce air by visually pulling back on syringe plunger until tip was half full of air (20 μL) or completely full (40 μL).

<table>
<thead>
<tr>
<th>Bubble Size, mL:</th>
<th>7% O₂</th>
<th>12% O₂</th>
<th>20% O₂</th>
<th>50% O₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>PO₂, (mm Hg)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>65</td>
<td>68</td>
<td>65</td>
<td>339</td>
</tr>
<tr>
<td>PTS transport—no liner</td>
<td>67</td>
<td>82</td>
<td>129</td>
<td>329</td>
</tr>
<tr>
<td>PTS transport—with liner</td>
<td>63</td>
<td>78</td>
<td>108</td>
<td>322</td>
</tr>
</tbody>
</table>

* Whole blood was tonometered at 37°C with either 7%, 12%, 20%, or 50% oxygen. Samples were sent at ambient temperature via PTS transport either with or without a liner. The control sample was left undisturbed at ambient temperature for 2 minutes. Results are single determinations. PTS indicates pneumatic tube system.
• Air contamination showed almost no effect on the control samples (walked to the lab for analysis)
• Specimens sent by PTS showed large erroneous increases in samples tonometered at 7% and 12%
• Specimens sent by PTS showed little interference in specimens tonometered at 20% oxygen
• Specimens sent by PTS showed large erroneous decreases in samples tonometered at 50% oxygen

<table>
<thead>
<tr>
<th>Table 1.—Effect of Pneumatic Transport on PO₂ (mm Hg) in tonometered Blood Transported With and Without a Tube Liner*</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bubble Size, mL:</strong></td>
</tr>
<tr>
<td><strong>PO₂, (mm Hg)</strong></td>
</tr>
<tr>
<td>Control</td>
</tr>
<tr>
<td>PTS transport—no liner</td>
</tr>
<tr>
<td>PTS transport—with liner</td>
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</tbody>
</table>

*Whole blood was tonometered at 37°C with either 7%, 12%, 20%, or 50% oxygen. Samples were sent at ambient temperature via PTS transport either with or without a liner. The control sample was left undisturbed at ambient temperature for 2 minutes. Results are single determinations. PTS indicates pneumatic tube system.
Identification Issues

Patient Info
- Age
- Body Temp

Puncture Site
- Heel
- Earlobe

Arterialization

Method and Conditions of Specimen Transport

Sample Handling

Clinical Laboratory
Sample Handling

- Mixing necessary to dissolve heparin
- Necessary to achieve uniform distribution of RBCs
  - Hemoglobin measurement
Hematocrit in 434 In-patients <7d, October 2007, RRL

P. D’Orazio, M. Erdosy, J. Cervera, S. Mansouri, H. Visnick, L. Boone
Instrumentation Laboratory, Lexington, MA

Abstract

Systems for whole blood analysis in critical care and point-of-care (POC) settings are frequently affected by the presence of blood clots in the sample. Partially coagulated blood may result from pre-analytical error or certain pathophysiological conditions. Miniaturized sensors and fluidic pathways, especially in systems for POC testing, increase the likelihood of trapping blood clots on sensors and interfering with sample analysis, often without knowledge of the user. The GEM Premier™ 3000 critical care analyzer (Instrumentation Laboratory) measures pH, pCO2, pO2, Na+, K+, Ca++, glucose, lactate and hematocrit in 150 mL of whole blood. Electrochemical sensors are incorporated in a disposable measurement cartridge for analysis of 75, 150, 300, 450 or 600 samples over a three-week period. Recently, Intelligent Quality Management (iQM™) has been added to the system. iQM is an active, real-time, quality-control system which includes checks for the presence of blood clots on sensors using failure-pattern recognition. Upon detecting a blood clot on a sensor, the system automatically begins corrective action, including vigorous rinsing of the sensor surface. If the clot is not immediately removed, the sensor becomes disabled and results for that channel suppressed until the system verifies removal of the clot. To demonstrate the importance of iQM in flagging errors due to clots, we evaluated the magnitude of errors produced by clots on sensors for blood gases, pH, and electrolytes. Clots were purposely formed by adding thrombogenic compounds to blood samples collected from healthy volunteers. Samples were analyzed on several GEM Premier 3000 instruments with iQM until a particular sensor was disabled. Then, blood samples without clots were analyzed both on the system with the disabled sensor and on a control system. Raw signals from the disabled sensor were retrieved and used to calculate what the reported result would have been, had the sensor not been disabled and the result reported while a clot was present on the sensor. Bias was calculated by comparison to the control instrument, and measured against total allowable error using CLIA 88 limits. The sensors with the largest clot-related errors were pH, pCO2, and pO2. For pH, 50% of the samples (range: 7.0 – 7.4); for pCO2, 59% of the samples (range: 25 – 106 mmHg); and for pO2, 89% of the samples (range: 26 – 46 mmHg) exceeded the allowable error. In the case of pCO2 and pO2, the magnitude and direction of the error indicate that the presence of clots interferes with diffusion of analyte across the outer sensor membrane, resulting in sluggish response. For pH, the direction and magnitude of the error are more complex. The presence of a clot not only causes sluggish response, but also appears to shift the local pH at the sensor in the alkaline direction. We conclude that the iQM system for the GEM Premier 3000 is effective in avoiding erroneous results due to the presence of blood clots on sensors, especially for pH and blood gases, the most important critical care analytes.

Introduction

Systems for whole blood analysis in critical care and POC settings are affected by the presence of blood clots in samples. Many traditional laboratory-based systems for critical-care analysis have built-in “clot catchers” to prevent clots from entering the systems fluidics. Clots which are not stopped by the clot catcher, or if a clot catcher is not present, may block fluidic lines and disable the system. The result is system down-time while the lines are removed and cleared by the user. Clots which are stopped by the clot catcher also result in increased maintenance while the clot catcher is replaced or cleaned. Miniaturized sensors and fluidics in unit-use and multi-use, cartridge-based systems for POC applications are particularly problematic in the presence of clots because often no user-performed maintenance is possible. If a clot causes cartridge fluidic problems, the cartridge must be discarded and replaced, a time-consuming and costly process. In addition to increased maintenance, system down-time, and expense, there is risk of incorrect reporting of analytical results if a clot becomes trapped on the surface of a sensor and the system has no mechanism for detecting or removing the clot. In this case, the clot may interfere with normal functioning of the sensor and the system may continue to report incorrect results.

Sensors with largest clot related errors
- pH (50%)
- pCO2 (59%)
- pO2 (89%)

Exceeded total allowable error using CLIA 88 limits

Magnitude & direction of the error with pCO2 & pO2 showed that clots interfere with the diffusion of analyte across the outer sensor membrane (sluggish response)
Conclusions

• Pre-analytical phase of the blood gas testing process represents unique challenges for the neonatal population

• Capillary blood sampling is a common method used to collect a blood specimen in neonates
Thank you for your time
Questions?