

# AARC Clinical Practice Guidelines: Capillary Blood Gas Sampling for Neonatal and Pediatric Patients

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In the absence of an indwelling arterial catheter, capillary blood gas sampling may be used to evaluate the acid/base and ventilation status of neonatal and pediatric patients with cardiorespiratory conditions. These guidelines were developed from a comprehensive review of the literature to provide guidance for the collection, handling, and interpretation of blood obtained from an arterialized capillary sample. Capillary and venous blood gas measurements are a useful alternative to arterial blood gas measurements for neonatal and pediatric patients who do not require close monitoring of  $P_{aO_2}$ . In the presence of alterations in body temperature, blood pressure, or peripheral perfusion, agreement between a capillary blood gas with an arterial sample is recommended to determine whether changes in these physiologic conditions reduce reliability. Perfusion to the sample site should be assessed and preference given to blood sampling from a well perfused site, and blood should be analyzed within 15 min of sampling to minimize the propensity for pre-analytical errors. Clinicians should consider re-collecting a blood sample, obtained from an artery, vein, or capillary, when the blood gas or analyte result interpretation does not align with the patient's clinical presentation. A pneumatic tube system can be reliably used to transport blood gas samples collected in a syringe and capillary tube to a clinical laboratory for analysis. To reduce the cumulative pain effect and risk of complications, the capillary puncture procedure should be minimized when possible. Non-pharmacologic interventions should be used to reduce pain associated with capillary blood gas sampling. Automatic lancets are preferred to puncture the skin for capillary blood gas collection. *Key words: blood gas analysis; blood draw; capillary; point of care; neonatal; pediatrics; acid-base.* [Respir Care 2022;67(9):1190–1204. © 2022 Daedalus Enterprises]

## Introduction

Evaluating acid/base balance and ventilation through pH and blood gas analysis are essential to the care of infants and

children with cardiorespiratory impairment. Measurement of pH,  $P_{CO_2}$ , and  $P_{O_2}$  have diagnostic and prognostic value, and are used to guide the respiratory plan of care.<sup>1</sup> Although obtaining a blood sample from a percutaneous arterial

puncture or an indwelling arterial catheter provides a reliable assessment of the adequacy of ventilation, acid/base balance, and oxygenation, the procedures can be painful<sup>2</sup> and carry the risk of sepsis, blood loss, and vascular complications.<sup>3-5</sup> Capillary blood sampling provides an alternative to arterial blood sampling. Compared with a percutaneous arterial puncture, capillary blood collection is less technically challenging and carries fewer risks of harm.<sup>6</sup>

This intermittent procedure collects blood by puncturing the fleshy or palmar surface of the foot, fingers, or earlobe.<sup>7</sup> For infants and small children, preference is often given for sample collection from the posterolateral aspect of the foot, located just anterior to the heel because there is minimal risk to inadvertently puncture the posterior tibia artery or bone as the skin is pierced for sample collection.<sup>8</sup> In addition, there is a higher risk for nerve damage when fleshy surfaces of fingers and toes are used for capillary blood gas sampling in neonates and newborn infants.<sup>9</sup> The palmar surfaces of fingers and toes, and the earlobe offer acceptable collection sites for children from which the extremity can be stabilized and a small sample of arterialized capillary blood can be safely obtained for analysis.<sup>10</sup>

Meticulous attention to the patient's physiologic status, the integrity of the puncture site, collection technique, and preparation of the sample for analysis are essential to obtaining a quality sample and reducing the potential for pain or injury. Alterations in blood pressure, temperature, and peripheral perfusion have the potential to reduce reliability of capillary blood gas and pH results.<sup>11</sup> Poor-quality samples contribute to pre-analytical errors that interfere with effective medical management and contribute to poor patient outcomes. A paucity of published studies and a lack of standardized research protocols make it difficult to identify factors that contribute to these pre-analytical errors and to develop recommendations to mitigate the potential for harm.

Unlike former American Association for Respiratory Care Clinical practice guidelines<sup>12,13</sup> on this subject, this

guideline links essential components of care to clinical and process outcomes. The purpose of this guideline is to provide guidance for determining sample accuracy and reliability, identify factors that contribute to harm, and provide recommendations for collection and preparation of a good-quality sample for analysis. The guidelines that were developed from this systematic review focus on the following questions related to neonatal and pediatric patients:

1. How do blood gas and pH results from a blood sample obtained from a capillary site differ from results obtained from venous or arterial sites?
2. How does the collection and handling of blood obtained from a capillary site affect the results and interpretation of blood gas and pH values versus an arterial or venous sample?
3. What impact do pre-analytic errors have on blood gas and pH errors?
4. What impact does the collection technique have on the incidence of patient complication?
5. What impact does the presence of dyshemoglobins have on blood gas and pH results?

### Committee Composition

A committee was selected by the American Association for Respiratory Care leadership based on their known experience related to the topic, interest in participating in the project, and their commitment to the process details. The committee first met face-to-face, where they were introduced to the process of developing clinical practice guidelines. At that time, the committee selected a chair and wrote a first draft of the research questions in the population intervention-comparator-outcome (PICO) format. Subsequent meetings occurred as needed by conference call. Frequent e-mail communications occurred among committee members and the American Association for Respiratory Care staff. The committee members received no remuneration for their participation in the process, although their expenses for the face-to-face meeting were reimbursed by the American Association for Respiratory Care.

### Search Strategy

A literature search was conducted by using the PubMed, CINAHL via EBSCO host, and Scopus.com databases for studies on capillary blood gas sampling techniques and outcomes in pediatric populations. The search strategies used a combination of relevant controlled vocabulary (ie, Medical Subject Headings and CINAHL Headings) and

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Ms Volsko has disclosed relationships with First Energy Corporation and Neotech. The remaining authors have disclosed no conflicts of interest.

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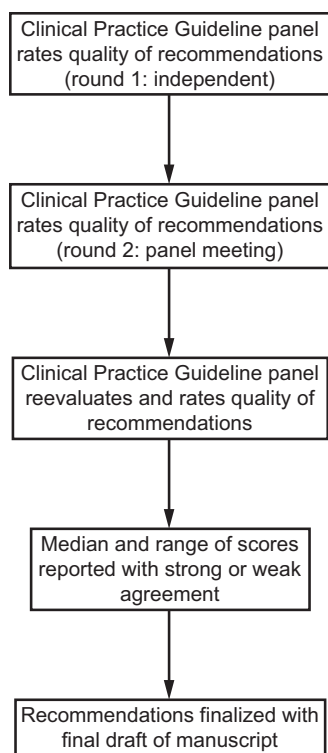


Fig. 1. Literature appraisal process.

keyword variations that related to pediatrics, capillaries, blood gas, techniques, complications, and outcomes. The searches were limited to English language studies about human populations. The searches were also designed to filter out citations indexed as commentaries, editorials, interviews, news, or reviews. No date restrictions were applied to the searches (see the supplementary materials at <http://www.rcjournal.com>). The original search was completed on January 18, 2018, and a repeated search was completed on August 30, 2021. Duplicate citations were identified and removed by using the EndNote X7 citation management software (Clarivate Analytics, Philadelphia, Pennsylvania).

### Study Selection

At least two reviewers (DLE, TAV, SLS) independently assessed study eligibility in the Covidence systematic review software. Inclusion criteria used to assess eligibility were the following: (1) pediatric population, (2) capillary sample, and (3) pH,  $P_{CO_2}$ ,  $P_{O_2}$  measures. The exclusion criteria used were the following: (1) adult population, (2) fetal population, (3) electrophoresis, (4) placenta or placental, (5) extracorporeal membrane oxygenation, (6) arterial sample, and (7) not empirical research (eg, theory or opinion articles).

### Development of Recommendations

By using a standardized multi-round rating process, a modification of the RAND/UCLA Appropriateness Methodology, the committee reviewed the evidence collected, along with its collective experience to derive recommendations for each of the PICO questions.<sup>14</sup> The literature was collapsed into evidence tables according to each PICO question. Individual committee members were assigned the task of writing a systematic review of the topic, drafting  $\geq 1$  recommendations, and suggesting the level of evidence supporting the recommendation:

- A. Convincing scientific evidence based on randomized controlled trials of sufficient rigor
- B. Weaker scientific evidence based on lower levels of evidence such as cohort studies, retrospective studies, case-control studies, and cross-sectional studies
- C. Based on the collective experience of the committee

Committee members reviewed the first draft of evidence tables, systematic reviews, recommendations, and evidence levels. They individually rated each recommendation for those supported by evidence levels A and B by using a Likert scale of 1 to 9, with 1 meaning expected harms greatly outweigh the expected benefits and 9 meaning expected benefits greatly outweigh the expected harms. The scores were returned to the committee chair. Because the first ratings were done with no interaction among the committee members, a conference call was convened, during which time the individual committee rankings were discussed. Particular attention was given to the discussion and justification of any outlier scores. Recommendations and evidence levels were revised with committee member input.

After discussing each PICO question, the committee members re-rated each recommendation. The final median and range of committee members' scores are reported. Strong agreement required all committee members to rank the recommendation  $\geq 7$ . Weak agreement meant that one or more members rated the recommendation  $< 7$ , but the median vote was at least 7. For recommendations with weak agreement, the percentage of those who rated  $\geq 7$  was calculated and reported after each weak recommendation. The process flow that the committee used to rate the appropriateness and quality of the literature selected through the search process is illustrated in Figure 1. Drafts of the report were distributed among the committee members in several iterations. When all the committee members were satisfied, the document was submitted for publication. The report was subjected to peer review before the final publication.

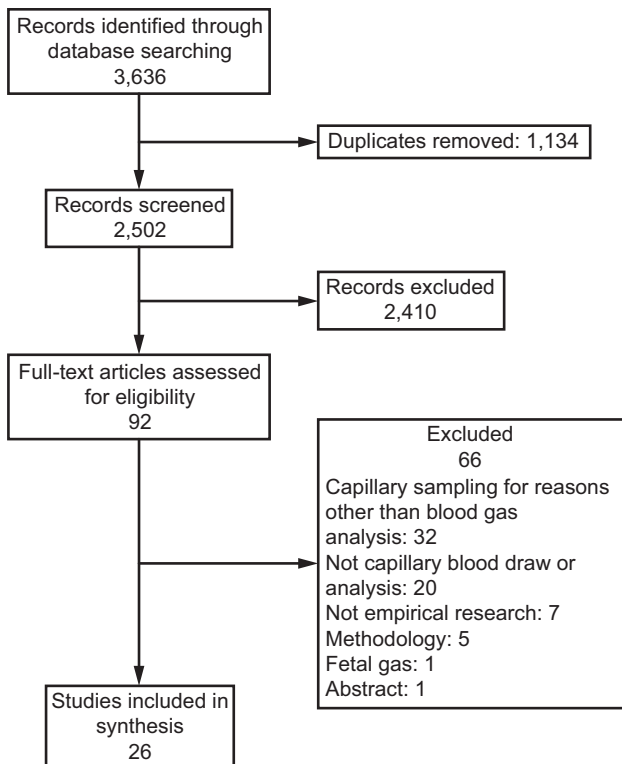


Fig. 2. Flow chart.

### Assessment and Recommendations

The search strategies retrieved 3,636 peer-reviewed articles (Fig. 2). After removal of duplicates, 2,502 articles remained for screening, of which, 2,410 were excluded at the title and abstract level. After a full-text review of 92 articles, 26 studies met the inclusion criteria. A summary of the key findings for each PICO question addressed in this review is provided in Table 1.

### Arterial, Venous, and Arterialized Capillary Blood Gas Values

Venous and arterialized capillary blood sampling provides an alternative to arterial blood sampling in infants and children that requires assessment of their ventilatory status. The reliability of venous and capillary blood gas values as surrogates for arterial blood gas values must be established before use in clinical decision making to avoid the propensity for harm. Few studies address the reliability of these alternative methods in pediatrics across a range of ages, from preterm neonates to children. There were no studies identified that compared arterial versus venous blood gas results in preterm infants admitted to a neonatal ICU. Three studies evaluated the differences in arterial blood gas values and those obtained from an arterialized capillary sample obtained from the most medial or lateral

portion of the plantar surface of the heel.<sup>15-17</sup> When an indwelling arterial catheter was not available, a percutaneous sample was obtained. Paired sampling was used, and samples from the artery and the heel were either obtained simultaneously<sup>15</sup> or within 3 to 5 min of the arterial sample.<sup>15-17</sup>

In a comparison of 158 samples obtained from an indwelling umbilical catheter to arterialized capillary heel blood samples simultaneously collected from 41 normothermic, hemodynamically stable neonates in the first week of life, McLain et al<sup>15</sup> reported arterial and arterialized capillary pH and  $P_{CO_2}$  satisfactorily represented arterial values. A mean  $\pm$  SD discrepancy for pH and  $P_{CO_2}$  of  $0.007 \pm 0.002$  and  $-0.37 \pm 4.8$  mm Hg, respectively, was noted when arterial blood was compared with that obtained from the heel, which was prewarmed to  $40^\circ\text{C}$  before blood collection in a capillary tube.<sup>15</sup> Limited clinical utility and a poorer association between arterial and arterialized capillary  $P_{O_2}$  mean  $\pm$  SD discrepancy of  $20.25 \pm 9.37$  mm Hg was noted.<sup>15</sup>

Saili et al<sup>16</sup> reported statistically significant differences ( $P < .05$ ) for all blood gas values when arterialized capillary blood obtained from a warmed heel were compared with arterial blood specimens percutaneously sampled from the right radial artery of 51 normotensive, well perfused, preterm neonates within the first 72 h after birth. The mean  $\pm$  SD  $P_{aCO_2}$  was significantly lower,  $29 \pm 15$  mm Hg, compared with capillary blood,  $40 \pm 18$  mm Hg. The mean  $\pm$  SD arterial pH was  $7.36 \pm 0.14$  mm Hg versus  $7.31 \pm 0.14$  mm Hg, and mean  $\pm$  SD  $P_{aO_2}$  was  $71 \pm 41$  mm Hg versus  $52 \pm 65$  mm Hg when compared with the capillary samples.<sup>16</sup> Topical anesthetics were not used during percutaneous arterial sampling, and the impact of factors that may affect the results, such as pain and changes in breathing frequency during the procedure, were not accounted for in this study. It is difficult to determine whether heel preparation adequately arterialized the capillary collection site because the heel was warmed by a 5-min heated water submersion, from which the temperature was not recorded. Yang et al<sup>17</sup> evaluated differences in arterial and capillary pH,  $P_{CO_2}$ , and  $P_{O_2}$  obtained from samples of 33 infants with a birthweight of 635 to 2,500 g who were admitted to the neonatal ICU. The mean  $\pm$  SD for  $P_{aO_2}$ ,  $101 \pm 79$  mm Hg, and for arterial oxygen saturation ( $S_{aO_2}$ ),  $93 \pm 8.4\%$ , were significantly higher in arterial samples compared with  $P_{O_2}$ ,  $46 \pm 13$  mm Hg, and  $S_{aO_2}$ ,  $81 \pm 9.3\%$ , obtained by a heel puncture. No clinically relevant differences were noted between capillary and arterial pH and  $P_{CO_2}$ .<sup>17</sup>

Four clinical studies<sup>18-21</sup> evaluated differences in arterial and capillary blood gas values, 50% of which included a comparison with samples obtained from a peripheral vein.<sup>20,21</sup> In a study of 75 paired samples obtained from children 0.6 – 134 months of age admitted to the pediatric ICU, Escalante-Kanashiro and Tantaleán-Da-Fieno<sup>18</sup>

Table 1. Summary of Evidence for Each PICO Question Included in the Systematic Review

PICO Question	Study	Intervention	Outcome
How do blood gas and pH results from a blood sample obtained from a capillary site differ from results obtained from venous or arterial sites?	Escalante-Kanashiro et al, <sup>18</sup> 2000	Capillary blood gas sample vs arterial blood gas sample	Mean differences of arterial and arterialized capillary blood gas samples were negligible for pH and P <sub>CO<sub>2</sub></sub> ; only values for pH were unaffected by changes in body temperature, peripheral perfusion, or blood pressure
	Fauchère et al, <sup>22</sup> 2002	Capillary lactate concentrations	Capillary blood lactate measurements in newborns were comparable with arterial measurements, providing less invasive methods of evaluating tissue oxygenation
	Harrison et al, <sup>19</sup> 1997	Capillary blood gas sample vs arterial blood gas sample	Arterial and capillary samples are reliable (good agreement) for the measurement of pH and P <sub>CO<sub>2</sub></sub>
	Kirubakaran et al, <sup>20</sup> 2003	Capillary blood gas sample vs arterial blood gas sample	Arterial and capillary samples were reliable (good agreement) for the measurement of pH and P <sub>CO<sub>2</sub></sub>
	McLain et al, <sup>15</sup> 1988	Warmed heel capillary sample vs unwarmed heel capillary sample compared with arterial sample	Arterial and arterialized capillary pH and P <sub>CO<sub>2</sub></sub> satisfactorily represented arterial values; limited clinical utility and a poorer association between arterial and arterialized capillary P <sub>O<sub>2</sub></sub>
	Saili et al, <sup>16</sup> 1992	Capillary blood gas sample vs arterial blood gas sample	Significantly lower P <sub>CO<sub>2</sub></sub> and P <sub>O<sub>2</sub></sub> values when blood was sampled from an arterialized capillary; the difference between capillary and arterial samples for the measurement of pH were not significant
	Tan et al, <sup>21</sup> 2018	Capillary blood gas sample vs venous blood gas sample	Venous and capillary samples are reliable (strong agreement) for measurement of metabolic and gas exchange variables but not for oxygenation
	Yang et al, <sup>17</sup> 2002	Capillary blood gas sample vs arterial blood gas sample	The mean values for P <sub>O<sub>2</sub></sub> obtained from an artery were significantly higher compared with blood obtained from an arterialized capillary sample
	McLain et al, <sup>15</sup> 1988	Warmed heel capillary sample vs unwarmed heel capillary sample compared with an arterial sample	Warming the heel produced no significant change in blood gas results
	Patel et al, <sup>25</sup> 1988	Unwarmed heel capillary sample compared with an arterial sample with a 1.0-mL flush and arterial sample with a 0.5-mL flush	The smaller the flush volume of arterial blood, the greater the dilution, which may impact sample results; capillary samples significantly overestimated P <sub>CO<sub>2</sub></sub> values compared with the control (a 2-mL flush)
What impact do pre-analytic errors have on blood gas and pH errors?	Pupek et al, <sup>26</sup> 2017	Comparison of sample delivered by pneumatic tube system vs manual transport	No significant difference between delivery methods, indicated that both arterial and capillary samples can be transported by pneumatic tube without blood gas or pH alteration
	No evidence		
What impact does the collection technique have on the incidence of patient complication?	Aguilar Cordero et al, <sup>40</sup> 2014	Ingestion of breast milk, 24% oral glucose, or no ingestion during a heel lance	Administration of breast milk during the heel lance procedure improved changes in heart rate, S <sub>pO<sub>2</sub></sub> , and the length of time to recover after the procedure; non-pharmacologic methods to reduce pain during the heel lance procedure may be effective
			(Continued)



Table 1. Continued

PICO Question	Study	Intervention	Outcome
	Barker et al, <sup>47</sup> 1994	Heel puncture vs incision	For larger samples, the incision method demonstrated a shorter collection time, which could reduce pain
	Davari et al, <sup>36</sup> 2019	Effect of the tucking position on pain severity during a heel stick	Although the severity of pain increased significantly during the intervention for both groups, the mean severity of pain did not differ between the groups, which indicated that the tucking position did not significantly decrease the pain intensity compared with the supine position
	Erkut and Yildiz, <sup>34</sup> 2017	The effect of swaddling vs no swaddling during a heel lance on pain, vital signs, and crying	Swaddling reduced the crying time and neonatal infant pain scores and can be used to mitigate pain associated with a heel lance
	Gao et al, <sup>39</sup> 2018	Impact of non-nutritive sucking and sucrose alone, and in combination on pain during a heel stick	The combination of sucrose and non-nutritive sucking provided better pain relief than either intervention alone; this combination could be used for repeated pain exposure in preterm infants
	Gokulu et al, <sup>50</sup> 2016	Impact of repeated painful stimuli on the pain response during a heel prick	Infants who received repeated painful stimuli in the first few days of life were more likely to display the pain response to a routine heel prick than infants who were not exposed to the painful stimuli before the heel prick
	Gonsalves and Mercer, <sup>33</sup> 1993	The impact of painful procedures on the physiologic response of infants	Physiologic responses seem to be indices of an infant's response to painful stimuli and, in the absence of crying, may be useful for clinical evaluation
	Herrington and Chiodo, <sup>42</sup> 2014	The impact of a gentle human touch on the pain response across all phases (baseline, warming, heel stick, and recovery) of the procedure	Gentle human touch reduced the pain response across all phases of a capillary blood sampling procedure for heart rate (did not decrease), breathing frequency (did not decrease), and crying time (did not increase)
	Hwang and Seol, <sup>45</sup> 2015	Comparison of the effect of manual vs automatic lancet on pain response	The automatic lancet elicited a lower pain score during the procedure over the use of the manual lancet; it also reduced the number of heel pricks and squeezes as well as the duration of the procedure, which could reduce the pain felt by the infant during the heel prick procedure
	Im et al, <sup>37</sup> 2008	The impact of touch vs non-nutritive sucking vs no intervention on the pain experience during the heel stick procedure	No difference was noted in neonatal infant pain scores and heart rate among the groups, although S <sub>PO<sub>2</sub></sub> was better maintained with the touching and non-nutritive sucking interventions
	Jain et al, <sup>41</sup> 2006	The impact of a 2- min leg massage before a heel stick	The application of a 2-min leg massage before a heel stick reduced the neonatal infant pain score and the heart rate, which indicated that the pain may be reduced with this intervention
	Leng et al, <sup>38</sup> 2016	The impact of sucrose vs sucrose and non-nutritive sucking vs sucrose and swaddling vs sucrose, swaddling, and non-nutritive sucking on the pain response during shallow heel stick and deep heel stick procedures	The combination of non-nutritive sucking, swaddling, and oral sucrose was most effective for analgesia during deep heel stick procedures, whereas oral sucrose alone was sufficient for shallow heel stick procedures
	Marofi et al, <sup>43</sup> 2015	The impact of melody on physiologic response to a heel stick	No significant differences in physiologic outcomes were noted between the 2 groups at different points in the procedure (before, during, and after); although the melody could assist in maintaining physiologic balance compared with no intervention

(Continued)

Table 1. Continued

PICO Question	Study	Intervention	Outcome
What impact does the presence of dyshemoglobins have on blood gas and pH results?	Merter and Bolişik, <sup>46</sup> 2021	A comparison of the effect of manual vs an automatic lancet on the pain response	Automatic lancets for heel punctures reduced the pain response in neonates compared with manual heel stick lancets
	Shao-Hui et al, <sup>35</sup> 2014	The impact of swaddling and heel warming on the pain response to a heel stick	Both swaddling and heel warming may reduce the impact of pain on physiologic measures and speed of recovery from the procedure, although heel warming resulted in a lower pain response than swaddling
	Usta et al, <sup>44</sup> 2021	The impact of lavender oil via aromatherapy on the pain response to a heel stick	Mean pain scores during and after the heel stick procedures were lower in the group that received lavender oil via aromatherapy (drops on cotton bud placed near the infant's nostrils) 3 min before a heel stick compared with no lavender oil administration, which indicated that the use of lavender oil via aromatherapy may reduce pain intensity associated with the procedure
	No evidence		

PICO = population, intervention, comparator, outcome

reported the mean difference between arterial and capillary blood was 0 for pH, 0.44 mm Hg for P<sub>CO<sub>2</sub></sub>, and 51 mm Hg for P<sub>O<sub>2</sub></sub>. Only the values for pH were unaffected by changes in body temperature, peripheral perfusion, or blood pressure.<sup>18</sup> Hypotension and poor peripheral perfusion profoundly impacted the reliability with which capillary blood reflected P<sub>aO<sub>2</sub></sub> and P<sub>aCO<sub>2</sub></sub>. Similar findings were reported by Harrison et al<sup>19</sup> in a sample of 50 children 1–220 months of age (median, 56 months). Ninety-five percent limits of agreement between arterial and capillary samples were good for both pH ( $\pm 0.032$ ) and P<sub>CO<sub>2</sub></sub> ( $\pm 4.5$  mm Hg). The absolute difference between arterial and capillary values for pH and P<sub>CO<sub>2</sub></sub> were  $\leq 0.05$  and 1.6 mm Hg, respectively. The absolute difference between arterial and capillary values was much higher for P<sub>O<sub>2</sub></sub> and was reported as  $> 6.5$  mm Hg. Ninety-five percent limits of agreement were lower for P<sub>O<sub>2</sub></sub> ( $\pm 43.6$  mm Hg).<sup>19</sup>

Kirubakaran et al<sup>20</sup> assessed reliability, sensitivity, specificity, and accuracy in 50 children, ages 14 d to 12 years, who required treatment in the pediatric ICU. The mean absolute value of the difference in pH between the arterial and capillary blood samples did not exceed 0.05, with the highest difference reported as 0.102 and 95% limits of agreement of  $\pm 0.032$ . The mean absolute value difference between venous and arterial pH was 0.04, with the greatest difference between venous and arterial pH values was reported as 0.117. The absolute mean difference between arterial and capillary P<sub>CO<sub>2</sub></sub> was  $\leq 6.5$  mm Hg and 95% limits of agreement of  $\pm 4.5$  mm Hg. P<sub>O<sub>2</sub></sub> values were lower for capillary blood compared with arterial blood, with the mean difference of  $\geq 6.5$  mm Hg and 95% limits of agreement of  $\pm 43.6$  mm Hg.<sup>20</sup> Differences between arterial and venous P<sub>CO<sub>2</sub></sub> and P<sub>O<sub>2</sub></sub> values were not reported.

The use of venous blood as an alternative to arterialized capillary blood gas monitoring for evaluating gas exchange and oxygenation was investigated by Tan et al<sup>21</sup> in a cohort of 93 preterm infants with a median (interquartile range) gestational age of 31 (29–34) weeks in a single institution's neonatal ICU. This investigation was narrower in scope and only included blood gas samples simultaneously collected by venipuncture and heel puncture. Strong agreement as determined by the intraclass coefficient correlation (ICC) was noted for pH (ICC = 0.87), CO<sub>2</sub> (ICC = 0.802), bicarbonate (ICC = 0.928), and base excess (ICC = 0.946) was found.<sup>21</sup> These results are similar to the previously mentioned studies,<sup>16,19,20</sup> which compared the interchangeability of venous and arterialized capillary samples as a substitute for an arterial blood gas sample. Similarly, a weak agreement between arterialized capillary and venous P<sub>O<sub>2</sub></sub> was found (ICC = 0.364).<sup>21</sup>

None of the included studies demonstrated agreement in P<sub>O<sub>2</sub></sub> among capillary, venous, and arterial samples. Using capillary samples to assess oxygenation status may not be

practical. However, Fauchère et al<sup>22</sup> noted that capillary blood lactate levels are comparable with arterial blood lactate levels ( $P < .001$ ). This may be useful in assessing tissue oxygenation in infants. Low-level evidence supports capillary and venous blood gas measurements as a useful alternative in the absence of an indwelling arterial catheter for infants and children who require close monitoring of pH and  $P_{CO_2}$ , but not  $P_{O_2}$  measurements (evidence level B; mean appropriateness score, 8 [range, 7 – 8]). Low-level evidence also supports the correlation of a capillary or venous blood gas with an arterial sample when there are alterations in body temperature, blood pressure, or peripheral perfusion to determine whether changes in these physiologic conditions reduce reliability (evidence level B; all committee members responded 8).

### Sample Collection and Handling

The quality of the sample obtained from an artery, vein, or arterialized capillary is an essential component of the pre-analytical phase of blood gas and analyte measurement. Pre-analytical test variables include patient preparation, the specimen collection technique, amount of specimen collected, and specimen transport.<sup>23</sup> Poor-quality samples have the potential to produce inaccurate results.<sup>24</sup> Two studies addressed the impact sample collection and handling had on sample quality and on interpretation of the results. Patel et al<sup>25</sup> evaluated the effect that 2 different flush volumes had on arterial samples obtained from an indwelling arterial line and the effect volume collected from a capillary sample had on the measurements of electrolyte concentrations and blood gas values.

Simultaneous samples of 0.2 mL each were obtained by percutaneous puncture from an un-warmed heel and withdrawn from an indwelling arterial line of 40 neonates. The subjects ranged from 26 to 42 weeks of gestation at birth and did not have clinical evidence of right-to-left ductal shunting.<sup>25</sup> The investigators report concordance between capillary and arterial pH when the blood sample obtained from the arterial line was preceded by a 1-mL flush volume. The investigators also noted that potassium and  $P_{CO_2}$  in capillary samples were significantly higher than potassium and  $P_{CO_2}$  in arterial samples with a low-flush volume (mean  $\pm$  SD difference of  $1.22 \pm 0.96$  mmol/L,  $P < .001$ ; and mean  $\pm$  SD difference of  $4 \pm 6.2$  mm Hg,  $P < .001$ , respectively). In addition, capillary  $P_{O_2}$  was significantly lower than  $P_{O_2}$  (mean  $\pm$  SD difference of  $18 \pm 11.6$  mm Hg;  $P < .001$ ).<sup>25</sup>

Heel and/or finger warming is considered a standard practice for capillary puncture-site preparation in many facilities.<sup>15</sup> One crossover study compared simultaneously obtained arterial and capillary blood gas samples in preterm infants.<sup>15</sup> Half of the capillary samples were obtained from a pre-warmed site (40°C) and half were obtained from a

site that was unwarmed. Warming the heel showed no significant impact on the discrepancy ( $P > .1$ ) between capillary pH (mean  $\pm$  SD discrepancy of  $0.005 \pm 0.035$  for unwarmed heels and  $0.003 \pm 0.033$  for warmed heels, 95% CI),  $P_{CO_2}$  (mean  $\pm$  SD discrepancy of  $2 \pm 5.3$  mm Hg for unwarmed heels and  $0.4 \pm 4.9$  mm Hg for warmed heels, 95% CI), or  $P_{O_2}$  (mean  $\pm$  SD discrepancy of  $20.2 \pm 9$  mm Hg for unwarmed heels and  $16.2 \pm 9.4$  mm Hg, 95% CI) results when compared with arterial results.<sup>15</sup>

A pneumatic tube system is commonly used in acute care institutions instead of manually delivering specimens to a clinical laboratory. The pneumatic tube system is often used to save staff time through the mechanical transfer of specimens from the collection site (eg, clinical unit) to the laboratory for processing or analysis. Pupek et al<sup>26</sup> evaluated the impact that transporting arterial and capillary blood gas samples through a low-carrier velocity and controlled acceleration pneumatic tube system had on sample integrity. Non-airtight padded cannisters were used to transport 20 arterial blood sample from 20 healthy adult volunteers and 20 capillary samples from neonates admitted to a neonatal ICU. The investigators reported a negligible difference in pH (mean difference,  $-0.00049$ , average percent bias,  $-0.0064$ ;  $P = .83$ ),  $P_{CO_2}$  (mean difference  $-0.17$ , average percent bias  $-0.28$ ;  $P = .72$ ), and  $P_{O_2}$  (mean difference,  $0.95$ , average percent bias,  $3.52$ ;  $P = .39$ ) when arterial samples were transported by a pneumatic tube system compared with manual specimen delivery to the clinical laboratory for analysis.

Similarly, no significant difference in  $P_{O_2}$  (mean difference,  $0.95$ ; percent average bias,  $1.99$ ;  $P = .26$ ) was reported when blood samples, collected in a capillary tube, were transported by a pneumatic tube system compared with manual specimen delivery to the clinical laboratory for analysis. The investigators did not report the impact transport by a pneumatic tube system had on the pH or  $P_{CO_2}$  from a capillary sample. Statistically significant differences in potassium (mean difference,  $0.095$ ; average percent bias,  $0.22$ ;  $P = .01$ ), total hemoglobin (mean difference,  $1.5$ ; average percent bias,  $1.38$ ;  $P = .033$ ), and deoxyhemoglobin (mean difference,  $-0.345$ ; average percent bias,  $-3.8$ ;  $P = .041$ ) were noted when blood collected in a capillary tube was transported by a pneumatic tube system compared with a manual specimen delivery.<sup>26</sup> Although statistically significant, differences in potassium, total hemoglobin, and deoxyhemoglobin were not clinically relevant.

Previous clinical practice guidelines reported that squeezing of the puncture site could result in contamination of the capillary blood gas sample with venous and or lymphatic fluid.<sup>12,13</sup> Unfortunately, no studies extracted from the systematic review directly addressed the impact of squeezing. For this reason, no recommendation on squeezing the puncture site can be made. Additional research is needed to



understand the impact of squeezing on capillary blood gas results. Low-level evidence supports the assessment of perfusion at the sample site and preference given to blood gas sampling from a well perfused site to minimize the propensity for pre-analytical errors (evidence level B; median appropriateness score, 8 [range, 6–8]). Low-level evidence also supports the need to consider redrawing the blood gas sample from any sampling site (ie, arterial, venous, capillary) when blood gas or analyte result interpretation does not align with the patient's clinical presentation before clinical decision making occurs (evidence level B; median appropriateness score, 9 [range, 8–9]). In addition, low-level evidence supports the use of a pneumatic tube system to reliably transport blood gas samples collected in a syringe and capillary tube to a clinical laboratory for analysis (evidence level B; median appropriateness score, 9 [range, 8–9]).

### Pre-Analytic Errors

Historically, there are some knowns in clinical practice for handling capillary blood samples. Unfortunately, this systematic review found no studies that directly addressed the impact of post-collection capillary blood specimen handling techniques on the resulting pH,  $P_{CO_2}$ , and  $P_{O_2}$  results in the neonatal and pediatric population. Literature focused on blood sampling for gas analysis in the adult population may be used to guide practice. Heparinized plastic syringes and tubes are typically used to collect blood specimens. In comparison with the heparinized glass tubes, plastic devices are less permeable to gases at room temperature. However, when the plastic is cooled to 0–4°C, it has been theorized that the plastic molecules contract, opening pores large enough to allow oxygen to diffuse into the sample, although not large enough to allow carbon dioxide to diffuse out of the sample.<sup>27,28</sup>

In a study of arterialized blood samples, Knowles et al<sup>27</sup> studied the effect of syringe material, storage time, and temperature on blood gas results. They found that the sample in a plastic device had no change in pH and  $P_{CO_2}$  at 30 min after collection at both room temperature and on ice. However, there were significant changes in  $P_{O_2}$  values at 30 min for both the iced sample and the room temperature sample. The glass syringe samples showed no significant change in pH,  $P_{CO_2}$ , or  $P_{O_2}$ . Similarly, other researchers found that, when iced in glass tubes, the sample can be stored for up to 30 min without a significant change in pH or  $P_{CO_2}$ .<sup>29,30</sup> In light of this information, most resources recommend that samples are analyzed within 15 min of collection and are stored at room temperature.<sup>12,13,28,30</sup> After 15 min of storage time,  $P_{O_2}$  values may be affected.<sup>31</sup>

During the collection process, an air bubble may be introduced into the sample. Because ambient air contains a  $P_{O_2}$  larger than that in the capillary sample and a  $P_{CO_2}$  of

nearly zero, exposure to the air bubble will alter the  $P_{O_2}$  of the sample (increase  $P_{O_2}$  if the sample is < 150 mm Hg or decrease  $P_{O_2}$  if the sample is > 150 mm Hg) and decrease the  $P_{CO_2}$  of the sample. Removal of the air bubble will avoid this artificial result.<sup>32</sup> Mixing the sample has been recommended by previous guidelines to properly distribute the heparin in the syringe to prevent clots.<sup>12,13,31</sup> Some sources report that mixing the sample does not have an impact on the pH,  $P_{CO_2}$ , and  $P_{O_2}$ .<sup>28</sup> Regardless, the presence of a clot will prevent proper introduction of the sample into the analyzer. Gently rolling or inverting the sample back and forth after collection and before analyzing should be sufficient anticoagulation of the sample. Shaking the sample is not recommended; this practice may hemolyze the red blood cells.<sup>32</sup> If a clot is present, then a metal shard (also called a flea) can be introduced into the sample and moved with a magnet on the outside of the barrel of the tube to remove the clot.<sup>31</sup> Some blood gas analyzer manufacturers recommend against this practice; therefore, referencing the policy and procedure manual that accompanies the analyzer is vital.

The collective knowledge and experience of the committee, along with the literature derived from other populations and sample types support the use of gentle mixing of the sample at the time of collection and immediately before analyzing for effective coagulation (evidence level C; median appropriateness score, 8 [range, 7–8]), expelling all air bubbles at the time of collection (evidence level C; all committee members responded 7), and analyzing samples within 15 min of collection to avoid pre-analytic errors (evidence level C; all committee members responded 8). In addition, the collective knowledge and experience of the committee and the literature derived from other populations and sample types do not support icing a capillary sample that can be analyzed within 15 min of collection (evidence level C; median appropriateness score, 8 [range, 7–8]).

### Collection Technique and Patient Complications

Capillary sampling for blood gas analysis has been associated with less-serious patient complications compared with arterial catheterization or puncture.<sup>15</sup> Despite this, effort should be made to mitigate the risks associated with capillary sampling however mild. Of the complications that are associated with capillary blood sampling, the most researched is pain. Capillary sampling for blood gas and pH analysis is a common procedure and can cause pain response. Assessing pain in the neonate can be a challenge, although several physiologic measures can be used. Gonsalves and Mercer<sup>33</sup> conducted a prospective, observational study that compared the physiologic response to both the painful and non-painful procedures. Heart rate, breathing frequency, and  $S_{pO_2}$  were monitored before, during, and after the procedure. Univariate analysis indicated significant differences

in heart rate, breathing frequency, and hemoglobin oxygen saturations with painful procedures ( $P < .001$ ), which suggest that physiologic indices can be used to identify pain response in the neonate.<sup>33</sup> This literature search yielded 14 clinical studies<sup>34-47</sup> that evaluated methods to reduce pain associated with capillary puncture and sampling.

Eleven studies<sup>34-44</sup> evaluated non-pharmacologic interventions, including swaddling, heel warming, non-nutritive sucking, breast milk, oral sucrose, touch and/or massage, music therapy, and aromatherapy to reduce pain associated with heel puncture. Theoretically, non-pharmacologic interventions distract the neonate or infant from pain, thus lessening pain response. Erkut and Yildiz<sup>34</sup> conducted a randomized control trial that compared the pain response during heel puncture in swaddled infants versus in non-swaddled infants. Neonatal infant pain scores (a measure composed of 6 assessments, including facial expression, cry, arousal, activity of arms, activity of legs, and breathing pattern),<sup>34</sup>  $S_{pO_2}$ , total crying time, and total time for procedure were monitored. The mean  $\pm$  SD neonatal infant pain scores were lower in the swaddled group versus the non-swaddled group both during the procedure ( $5.43 \pm 1.19$  vs  $6.57 \pm 5.5$ ;  $P = .001$ ) and after the procedure ( $1.56 \pm 0.82$  vs  $3.29 \pm 1.47$ ;  $P = .001$ ). Duration of total crying time was significantly lower in the swaddled group versus in the non-swaddled group ( $55 \pm 27$  seconds vs  $82 \pm 31$  seconds;  $P = .001$ ) and postprocedure  $S_{pO_2}$  were significantly higher in the swaddled group versus in the non-swaddled group ( $97 \pm 2$  vs  $95 \pm 2$ ;  $P = .006$ ).<sup>34</sup>

Shao-Hui et al<sup>35</sup> conducted a randomized control trial that compared swaddling versus heel warming versus no intervention in infants and concluded that both swaddling and heel warming reduce pain response in pre-term neonates during heel puncture. Heel warming was more effective than swaddling in reducing pain-associated changes in  $S_{pO_2}$  and heart rate recovery time. After a heel puncture, no difference was noted in heart rate. Changes in  $S_{pO_2}$  (reduced,  $P = .01$ ) and pain score (increased,  $P = .03$ ) were significant between the groups. Post hoc analysis found that reductions in  $S_{pO_2}$  were greater with swaddling than with heel warming. The pain recovery time was also significant between the groups for heart rate,  $S_{pO_2}$ , and crying time ( $P = .03$ ,  $P = .02$ , and  $P < .01$ , respectively). The heart rate recovery time was significantly longer in the control group and the swaddling group compared with the heel warming group.<sup>35</sup>  $S_{pO_2}$  recovery time was significantly longer in the control group when compared with the heel warming group.<sup>35</sup> Crying time was longer in the control group than in the swaddling and heel warming groups.<sup>35</sup>

Davari et al<sup>36</sup> conducted a clinical crossover trial that compared the impact of facilitated tucking (a process in which the caregiver, using warmed hands, holds the infant with the legs and arms tucked in toward the torso) and

with supine positioning during heel puncture. Pain intensity in both positions was increased during sampling ( $P = .0001$ ), although comparisons before, during, and after a heel puncture demonstrated no significant difference ( $P > .05$ ).<sup>36</sup> This suggests that facilitated tucking is not an effective method of pain reduction during heel puncture in infants. Non-nutritive sucking has also been found to be an effective non-pharmacologic intervention for pain response during heel puncture.<sup>37,38</sup> Im et al<sup>37</sup> found that non-nutritive sucking led to smaller reductions in  $S_{pO_2}$  ( $P = .001$ ), although no differences were noted in the pain score or heart rate with non-nutritive sucking. Leng et al<sup>38</sup> conducted a randomized control trial, seeking to evaluate the impact of adding additional non-pharmacologic interventions to oral sucrose. Each neonate received 2 mL of 24% sucrose solution with either non-nutritive sucking or swaddling, or a combination of oral sucrose, non-nutritive sucking, and swaddling.<sup>38</sup> The investigators found that both non-nutritive sucking and swaddling reduced pain but, when combined, had a synergistic effect on pain reduction.

The group with all 3 non-pharmacologic interventions experienced the most significant reduction in the pain response.<sup>38</sup> Gao et al<sup>39</sup> conducted a randomized controlled trial that evaluated the impact of routine care (no intervention), non-nutritive sucking alone, oral sucrose alone (0.2 mL/kg of 20% sucrose), and non-nutritive sucking in combination with oral sucrose during nonconsecutive heel punctures in 86 preterm infants. The non-nutritive sucking with the oral sucrose group had lower pain scores, lower heart rate, higher  $S_{pO_2}$ , and a reduced crying time when compared with the routine care, the non-nutritive sucking alone group and the oral sucrose alone group.<sup>39</sup> Aguilar Cordero et al<sup>40</sup> compared the impact of breast milk versus 24% oral sucrose versus a control group on the pain response during a heel puncture. The investigators found that administration of breast milk during the heel puncture procedure improved changes in heart rate,  $S_{pO_2}$ , and the length of time to recover after the procedure ( $P < .001$ ). Oral sucrose also led to improvements in these 3 measures but less than those found with breast milk.<sup>40</sup>

Three studies<sup>37,41,42</sup> evaluated the impact of touch and/or massage to reduce pain. Im et al<sup>37</sup> found that touch resulted in smaller reductions in oxygen saturation when compared with a control ( $P = .008$ ) in full-term neonates. Jain et al<sup>41</sup> conducted a randomized, double crossover trial of preterm neonates that evaluated the use of a 2-min leg massage before heel puncture. After a heel puncture, the pain score ( $3.5 \pm 1.6$  vs  $1.5 \pm 0.9$ ;  $P < .001$ ) and heart rate ( $P = .03$ ) were higher when massage was not used.<sup>41</sup> A small, randomized crossover study conducted by Herrington and Chiodo<sup>42</sup> also evaluated the impact of gentle touch in preterm neonates, found statistically significant differences in heart rate,

breathing frequency, and crying time when touch was used during capillary puncture ( $P = .01$ ,  $P = .02$ , and  $P = .033$ , respectively).

One quasi-experimental study of 50 infants evaluated the effect of music to reduce the pain response in neonates.<sup>43</sup> Music was played before, during, and after the heel puncture procedure (the sound was placed 1 mm away and at 65 dB). Heart rate, breathing frequency, and  $S_{pO_2}$  were measured before, during, and after heel puncture. Increases in breathing frequency were less significant in the melody group ( $P < .05$ ), no change was noted in heart rate or  $S_{pO_2}$ .<sup>43</sup> Additional evidence is needed to determine the impact of music on pain in neonates. Usta et al<sup>44</sup> conducted a double-blinded randomized control trial of 61 premature neonates to evaluate aromatherapy as a method to reduce the pain response during heel puncture. Infants who were exposed to the scent of lavender oil had a lessened pain response both during ( $P = .008$ ) and after a heel puncture ( $P = .030$ ).<sup>44</sup> This contrasts with previously published studies conducted by Kawakami et al<sup>48</sup> and Malachowska et al,<sup>49</sup> both by using different variations of aromatherapy found no impact on the pain response. Additional studies by that use aromatherapy to reduce pain response should be conducted before conclusions are drawn.

The selection of lancet style can also have an impact on pain during heel puncture. Two studies evaluated the impact of lancet selection (manual vs automatic) on the pain response.<sup>45,46</sup> Hwang and Seol<sup>45</sup> compared manual and automatic lancets impact on the pain score, heart rate,  $S_{pO_2}$ , and regional cerebral oxygenation measured by near-infrared spectroscopy in premature neonates. In the manual lancet group, the pain score was significantly higher during ( $P = .004$ ) and after the procedure ( $P = .048$ ).<sup>45</sup> No significant differences in heart rate were noted between the groups during ( $P = .57$ ) or after ( $P = .81$ ) the procedure.<sup>45</sup>  $S_{pO_2}$  was slightly higher in the automatic lancet group ( $P = .05$ ) during the procedure, although no difference was noted afterward ( $P = .061$ ).<sup>45</sup> Measures of cerebral oxygenation (regional cerebral oxygenation [rScO<sub>2</sub>] and cerebral fractional tissue oxygen extraction [cFTOE]) were impacted by lancet selection. In the manual lancet group, the reduction in mean  $\pm$  SD rScO<sub>2</sub> was significantly greater ( $-7.64 \pm 6.46\%$ ) vs the automatic lancet group ( $2.48 \pm 5.02\%$ ;  $P = .01$ ) and the increase in mean  $\pm$  SD cFTOE was significantly greater in the manual lancet group ( $0.08 \pm 0.07$ ) compared with the automatic lancet group ( $0.03 \pm 0.05$ ,  $P = .04$ ).<sup>45</sup>

Merter and Bolişik<sup>46</sup> conducted a parallel-group prospective randomized controlled and observational trial that compared the pain response with automatic vs manual lancets. After the heel puncture, the automatic lancet group had a higher mean  $\pm$  SD higher  $S_{pO_2}$  ( $96\% \pm 3\%$  vs  $90\% \pm 7\%$ ;  $P < .001$ ), a lower mean  $\pm$  SD heart rate ( $139.8 \text{ bpm} \pm 14.8 \text{ bpm}$  vs  $151.7 \text{ bpm} \pm 18.6 \text{ bpm}$ ;  $P = .008$ ), and a lower mean  $\pm$  SD pain score ( $1.6 \pm 1.5$  vs

$6.5 \pm .5$ ,  $P < .0001$ ) versus the manual lancet group.<sup>46</sup> The automatic lancet group also had fewer incidences of crying ( $P < .001$ ) during the procedure.<sup>46</sup> Three studies compared automatic lancets and manual lancets for effectiveness (number of heel punctures, number of squeezes, and duration of procedure).<sup>45-47</sup> More-effective techniques may result in less patient complication. Hwang et al<sup>45</sup> found that the mean  $\pm$  SD number of heel punctures ( $1.08 \pm 0.29$  vs  $2.5 \pm 1.73$ ;  $P = .09$ ), number of squeezes ( $12.5 \pm 2.88$  vs  $23.58 \pm 5.65$ ;  $P < .001$ ), and duration of the procedure ( $62.91 \pm 15.54$  s vs  $81.42 \pm 11.52$  s;  $P = .002$ ) were significantly less with the automatic lancet versus the manual lancet. Barker et al<sup>47</sup> found that an automatic lancet resulted in shorter collection times ( $P < .05$ ) and fewer repeated heel punctures ( $P < .005$ ) were required to obtain the sample. Merter and Bolişik<sup>46</sup> also concluded that the use of automatic lancets led to shorter collection times compared with manual lancets ( $11 \pm 3.7$  s vs  $28.4 \pm 14.6$  s;  $P < .001$ ) and fewer repeated heel punctures ( $P < .001$ ). These investigators also noted that automatic lancets were less likely to cause redness ( $P = .03$ ) and bruising ( $P < .001$ ).<sup>46</sup>

It was demonstrated that infants who were exposed to repeated painful procedures (eg, heel puncture) early in life showed an increased response to pain with subsequent heel punctures, which suggests a cumulative pain effect with repeated painful stimuli.<sup>33</sup> In a study conducted by Gokulu et al,<sup>50</sup> 60 term infants (20 large-for-gestational age infants and 40 term average-for-gestational age infants) were monitored after repeated pain exposure via a heel puncture. The large-for-gestational age infants had previously received at least 5 painful procedures and were considered the study group, whereas the average-for-gestational age infants received standard care only and were considered the control group.<sup>50</sup> The pain score,  $S_{pO_2}$ , heart rate, and crying time were monitored. After a heel puncture,  $S_{pO_2}$  was significantly reduced ( $P = .009$ ), whereas the pain score ( $P = .01$ ) and crying time ( $P = .02$ ) were significantly increased in the study group. No difference in heart rate ( $P = .98$ ) was observed.<sup>50</sup>

Previous clinical practice guidelines reported additional potential for patient complications, including burns (from overheating during the warming procedure), hematoma, nerve damage, and scarring.<sup>12,30</sup> No studies extracted from the systematic review addressed the above complications. For this reason, no recommendations can be made with regard to these concerns. Low-level evidence supports minimizing the capillary puncture procedure, when possible, to reduce the cumulative pain effect and risk of complications (evidence level B; all committee members responded 9) as well as the use of non-pharmacologic interventions when performing heel puncture for capillary blood sampling to reduce the pain response (evidence level B; median appropriateness, 7 [range 7–8]). Higher level evidence supports the preferential use of automatic lancets rather than manual

lancets to reduce pain response, procedure time, number of heel punctures, and bruising (evidence level A; all committee members responded 8). The collective knowledge and experience of the committee supports the use of caution when applying heat to a capillary puncture site to avoid cutaneous burns (evidence level C; all committee members responded 9).

### Dyshemoglobins and Results

The accuracy of the hemoglobin concentration measurement is important because it reflects the oxygen-carrying capacity of blood. Hemoglobin derivatives or dyshemoglobins reduce oxygen-carrying capacity and oxygen use at the tissue level. Dyshemoglobins can occur after exposure to chemical agents such as anesthetics (eg, benzocaine and lidocaine)<sup>51</sup> and anti-infectives (eg, sulfonamide and sulfoxone),<sup>52</sup> inhalation of toxic substances that contain carbon monoxide,<sup>53</sup>

and contact with sulfur compounds and pollutants.<sup>54</sup> Interference with the oxygen-hemoglobin binding capacity can also occur with illness such as during a vaso-occlusive crisis in association with sickle cell disease<sup>55</sup> or as a function of the development and transition to extrauterine life.<sup>56</sup> Assessment of oxygenation depends on the ability to adequately measure the effect with which the dyshemoglobin disrupts oxygenation cellular processes and inhibits aerobic metabolism.

In 14 children with sickle cell disease, Needleman et al<sup>57</sup> evaluated the accuracy of  $S_{pO_2}$ , benchtop blood gas analyzer, and a CO-oximeter. The investigators reported elevated levels of methemoglobin saturation (mean  $\pm$  SD, 2.3  $\pm$  1.4%) and carboxyhemoglobin (mean  $\pm$  SD, 4.7  $\pm$  1.3%). The mean  $\pm$  SD values for oxygen saturation were greater when obtained by both pulse oximetry (96.3  $\pm$  1.6%) and arterial blood gas analysis (94  $\pm$  3.1%)

Table 2. Summary of the Recommendations for Each PICO Question

PICO Question	Recommendation
How do blood gas and pH results from a blood sample obtained from a capillary site differ from the results obtained from venous or arterial sites?	In the absence of an indwelling arterial catheter, capillary and venous blood gas measurements may be useful alternatives to arterial blood samples for infants and children who require close monitoring of pH and $P_{CO_2}$ , but not $P_{O_2}$ measurements (evidence level B; median appropriateness score, 8 [range, 7 – 8]); in the presence of alterations in body temperature, blood pressure, or peripheral perfusion, a correlation of a capillary or venous blood gas with an arterial sample is needed to determine whether changes in these physiologic conditions reduce reliability (evidence level B; all committee members responded 8)
How does the collection and handling of blood obtained from a capillary site affect the results and interpretation of blood gas and pH values vs blood obtained intravascularly (arterial and/or venous)?	Perfusion to the sample site should be assessed, and preference given to blood gas sampling from a well-perfused site to minimize the propensity for pre-analytical errors (evidence level B; median appropriateness score, 8 [range, 6 – 8]); regardless of the sampling site (ie, arterial, venous, capillary), when the blood gas or analyte result interpretation does not align with the patient’s clinical presentation, consideration to redrawing the blood gas sample should be given before clinical decision making occurs (evidence level B; median appropriateness score, 9 [range, 8 – 9]); a pneumatic tube system can be reliably used to transport blood gas samples collected in a syringe and capillary tube to a clinical laboratory from analysis (evidence level B; median appropriateness score, 9 [range, 8 – 9])
What impact do pre-analytic errors have on blood gas and pH errors?	Samples should be analyzed within 15 min of collection to avoid pre-analytic errors (evidence level C; all committee members responded 8); samples collected in plastic capillary tubes should not be iced (evidence level C; median appropriateness score, 8 [range, 7 – 8]); gentle mixing of the sample at the time of collection and immediately before analyzing for effective coagulation (evidence level C; median appropriateness score, 8 [range, 7 – 8]); expel all air bubbles at the time of collection (evidence level C; all committee members responded 7)
What impact does the collection technique have on the incidence of patient complication?	The capillary puncture procedure should be minimized when possible to reduce the cumulative pain effect and risk of complications (evidence level B; all committee members responded 9); non-pharmacologic interventions should be used when performing heel puncture for capillary blood sampling to reduce the pain response (evidence level B; median appropriateness score, 7 [range, 7 – 8]); automatic lancets are preferred to manual lancets to reduce the pain response, procedure time, number of heel sticks, and bruising (evidence level A; all committee members responded 8); use caution when applying heat to avoid cutaneous burns (evidence level C; all committee members responded 9)
What impact does the presence of dyshemoglobins have on blood gas and pH results?	Because there were no studies extracted from the systematic review that directly related to the impact that the presence of dyshemoglobins have on pH, $P_{CO_2}$ , and $P_{O_2}$ , there are no recommendations at this time

PICO = population, intervention, comparator, outcome



when compared with CO-oximetry ( $89.1 \pm 3.8\%$ ).<sup>57</sup> Overestimation of oxygen saturation occurred in this small cohort due to the presence of dyshemoglobin and a shifted oxyhemoglobin dissociation curve. Because there were no studies extracted from the systematic review that directly related to the impact, the presence of dyshemoglobins on pH,  $P_{CO_2}$ , and  $P_{O_2}$ , there are no recommendations at this time.

### Summary

Invasively monitoring the adequacy of ventilation and oxygenation requires meticulous attention to detail to minimize the propensity for injury or harm to the infant or child during sampling or errors associated with the sampling technique, preparation, and analysis. The PICO questions for this systematic review were developed to provide guidance for the collection, handling, and use capillary blood samples to evaluate the acid/base balance, ventilation, and oxygenation in lieu of an arterial blood sample. The agreement with which blood sampled from an artery, vein, and arterialized capillary is clinically relevant and essential to the accurate interpretation of blood obtained from an arterialized capillary sample for the purposes of blood gas analysis in the neonatal and pediatric population.

Our literature search revealed that there is a paucity of rigorous information available on many aspects of this topic. The results of our systematic review are summarized in Table 1. Several studies used correlations to compare differences in blood gas parameters sampled from an artery, vein, or arterialized capillary. These studies were excluded because the statistical measures used did not allow for a determination of agreement between the values reported through blood gas analysis. Many of the recommendations provided through this clinical practice guideline were based on low-level information evidence or committee experience. Much of the evidence gleaned from the literature was from clinical trials conducted more than 20 years ago. In some cases, no literature was available and the collective experience of the committee was insufficient, so no recommendation could be directly made. A summary of recommendations is in Table 2.

Acid/base balance and oxygenation assessment through blood gas sampling and analysis is vital in guiding the plan of care for children with cardiorespiratory illness. Capillary blood gas samples are an acceptable less-invasive alternative to a percutaneous sample obtained from an artery or vein for evaluating pH and  $P_{CO_2}$  (vs arterial or venous puncture) in neonatal and pediatric patients. Blood obtained from an arterialized capillary significantly underestimates  $P_{O_2}$  compared with blood obtained from an artery. Because  $P_{O_2}$  obtained from an arterialized capillary does not satisfactorily represent that of an arterial value, there is limited

utility for its use in clinical decision making. To obtain a more comprehensive assessment of an infant or child's clinical status, use of noninvasive monitoring of  $S_{pO_2}$  should be used to evaluate oxygenation when capillary and venous blood gas measurements are used to monitor acid/base balance.<sup>58</sup>

This clinical practice guideline provides practical recommendations for the collection, handling, and transportation of samples collected from an arterialized capillary. These recommendations provide guidance to improve the quality of the sample obtained and to reduce harm in terms of the complications, pain, and stress that an infant or child experiences during the procedure. Improving the integrity of the sample during collection and preparation for analysis reduces the propensity for error. A good-quality sample provides the clinical team with results that accurately reflect the infant or child's acid/base status, which, in turn enhances decision making. Although no evidence met the inclusion criteria for the impact of pre-analytic errors on capillary blood sampling and analysis, some findings from the adult population literature can guide clinical practice. Preventing processes that affect the original state of the sample, such as extended periods of time between collection and analysis, air bubbles, temperature, and blood clots, is vital to obtaining accurate results to guide clinical practice. Because capillary blood sampling will likely continue to be used to assess the pH and  $P_{CO_2}$  of infants, future research into these pre-analytic errors would be helpful.

The use of a pneumatic tube system to transport samples to a laboratory for analysis can reduce transportation waste or the travel time that the collector incurs in manual delivery (walking the sample) from the patient care area to the laboratory for analysis. No statically significant or clinically relevant differences in values were noted when blood samples collected in a syringe or capillary tube were transported by a pneumatic tube system compared with manual delivery.<sup>25</sup> A pneumatic tube system can be reliably used to transport blood samples collected in a syringe and capillary tube to a clinical laboratory for analysis. However, some facilities may not allow blood and body fluids to be transported to the laboratory for analysis by a pneumatic tube system. Clinicians are encouraged to follow individual organizational policies.

Pain is a common complication associated with capillary blood sampling. Several studies met the inclusion criteria for this systematic review<sup>33-50</sup> and focused on a variety of interventions to mitigate pain. Interventions such as breastfeeding,<sup>39</sup> oral sucrose,<sup>38-40</sup> non-nutritive sucking,<sup>37-39</sup> swaddling,<sup>34,35,38</sup> gentle human touching,<sup>37,42</sup> massage,<sup>41</sup> melody,<sup>43</sup> and aromatherapy<sup>44</sup> demonstrated a reduction in pain associated with the heel puncture procedure compared with no intervention. However, safety of the infant is paramount, and these interventions should be considered in context with the other medical needs for



each individual patient. Other methods to mitigate pain caused by the heel puncture procedure include evaluating how the procedure is performed. Manual procedures, in which the pressure used to puncture the skin is variable, has the potential to cause more pain than when using an automated lancet.<sup>45,46</sup> Repeated procedures, either due to frequent heel punctures or multiple attempts to retrieve the sample, can lead to a cumulative pain effect.<sup>50</sup> Therefore, reducing the number of heel punctures inflicted on the patient is important for the overall well-being of the infant.

Similar to the findings related to pre-analytic errors, this systematic review found no literature related to the impact of dyshemoglobins that met inclusion criteria. However, it is important to consider conditions that may shift the oxyhemoglobin dissociation curve, such as methemoglobinemia, fetal hemoglobin, and body temperature, and result in over- or underestimated oxygenation. When considering the inability of the capillary blood sample to accurately reflect the oxygenation status of the patient, an arterial blood sample may be warranted in situations in which evaluation of  $P_{aO_2}$  is important to guide the plan of care. Although there was a general lack of strong evidence to develop recommendations, this guideline highlights when a capillary blood sample may be used as an alternative to an arterial sample for clinical decision making. It also brings to light the gaps in the literature, from which future research can be focused to better guide our clinical practice.

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