Changes in Transcutaneous Oxygen Tension During Capillary Blood-Gas Sampling

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With a Radiometer TCM-1 oxygen monitor, we followed the fluctuations in transcutaneous oxygen tension (pₐO₂) during capillary blood collection from a heel prick. Thirty premature infants who presented with some respiratory compromise showed unpredictably increased (43 of 125 observations) or decreased (82 of 125 observations) values during this blood-sampling process. The fluctuation exceeded 10 mmHg in 61 observations and represented as much as −67% relative change. In general, pₐCO₂ values exceeded capillary pO₂ values determined by standard blood-gas analysis. We investigated several aspects of capillary blood sampling to explain these observations. Because the induced response is a dynamic change, which continues throughout the collection process, we conclude that successive specimens will have different O₂ tensions. Even if the capillary blood pO₂ truly reflected pₑO₂, the magnitude and direction of deviation from the patient’s uncompromised O₂ tension could lead to inappropriate management. We conclude that capillary blood specimens should not be used for pO₂ determinations in newborns.

Additional Keyphrases: blood gases · newborns · variation, source of · “arterialization” of capillary blood

Clinical management of the sick premature infant frequently includes blood-gas analysis (1, 2). The specimen of choice for blood-gas determination is arterial blood. In the newborn, umbilical artery catheterization provides convenient access to a specimen. However, because of the risks of arterial catheterization (3) and the complications of repeated arterial punctures (4), “arterialized” (i.e., local hyperemia induced by heat or chemicals) capillary blood from the heel is frequently substituted as the specimen for blood-gas analysis. There are conflicting reports on the suitability of this specimen for pO₂ determinations (5–20). Several investigators have reported that the use of capillary blood for pO₂ determinations is particularly contraindicated for the newborn population. Koch and Wendel (5) and Gandy et al. (6) have suggested that poor arterial pressure and perfusion of a newborn’s heel are possible sources of discrepancy in the blood-gas measurement. Compounding these physiological limitations, capillary pO₂ analysis may be compromised by incomplete “arterialization” before sampling (7) and by the mechanics of the sampling itself (8–10). Nevertheless, the Committee on Pediatric Clinical Chemistry of the American Association for Clinical Chemistry states that pO₂ determinations on capillary blood may be useful if they are “judiciously ordered, obtained by highly skilled personnel, and interpreted cautiously” (21).

Here, we present evidence that the arterial oxygen tension (pₐO₂) changes during the capillary blood-sampling process. Such a change alone could explain the reported discrepancies between arterial and capillary blood pO₂ measurements. Transcutaneous oxygen measurements (pₑO₂) were used to follow the pₑO₂ changes. Although some investigators question the identity of pₑO₂ and pₑO₂ (22, 23), studies in this laboratory and elsewhere (24–28) have established the equality of pₑO₂ with arterial O₂ tensions determined by conventional measurements.

Materials and Methods

The transcutaneous pO₂ measurement system used in this study consisted of a Radiometer TCM-1 oxygen monitor, a Radiometer TCM101 calibrating unit (The London Co., Cleveland, OH 44145), and a modified Omniscribe Model B5217-5 dual-pen recorder (Houston Instruments, Austin, TX 78753). The recorder was set up so that pₑO₂ was continuously displayed on the lower half of the chart and the heater power output on the upper. The heater power output is an indicator of blood-flow changes (29), so we used a modified recorder (28) to enhance this channel’s signal.

All of the above items were transported on a laboratory cart especially equipped with hospital-grade electrical receptacles and a single 3-meter power cord. In practice, this system is easily transported, requires little space, and is operated from a single electrical outlet in the intensive-care unit.

The pₑCO₂ equipment was used according to the manufacturer’s instructions, except for contact-gel composition and instrument calibration, as described elsewhere (28). All transcutaneous measurements were made at 44 °C.

Specimens for comparative studies were transported to the laboratory within 5 min of collection and were analyzed within 10 min. The IL 213 blood-gas analyzer (Instrumentation Laboratory, Inc., Lexington, MA 02173) was used in these experiments. Its performance and quality control have been described elsewhere (30, 31).

The patients (n = 30) ranged in gestational age from 24 to 38 weeks and weighed 595 to 3300 g at birth. The most frequent primary diagnosis of these patients was prematurity. Blood-gas measurements were performed for the following reasons: respiratory distress, bronchopulmonary dysplasia, hyaline membrane disease, apnea of prematurity, or Wilson–Mikity syndrome.

The capillary blood-sampling procedure was performed by the Neonatal Intensive Care Unit nursing staff. So that the capillary bed might be arterialized, the infant’s heel was wrapped with a warm cloth 10 min before the blood was sampled. The lateral aspect of the heel was punctured to start a good flow of blood, from which three 120-μL heparinized capillary tubes (Sherwood Medical Industries, St. Louis, MO 63103; no. 8889-307008) were filled. Both ends of the capillaries were plugged with “Critoseal” (Sherwood Medical In-

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Results

Figure 1 shows the \( p_{CO_2} \) and heater power consumption recorded during a typical blood-sampling. \( p_{CO_2} \) changes were unremarkable during the interval A–B while the infant’s heel was warmed. \( p_{CO_2} \) rarely changes at A, but usually there was a significant change at B when the heel was lanced. The last of the three capillary tubes was filled at point D. The sampling interval is therefore defined as the interval B–D, which averaged 2.8 min. Approximately 30 s after point B, the \( p_{CO_2} \) began to decline. The initial rate of change was 20 mmHg/min. Such a rate of change is commonly observed, although the magnitude and direction of change varies.

The patient contact was terminated before E, by which point the \( p_{CO_2} \) had returned to the pre-intervention values (A–B). Point C is defined as the point of maximum change. Sometimes the pressure changes associated with capillary blood-sampling were positive rather than negative; i.e., \( p_{CO_2} \) increased, and C exceeded B. The heater power always increased during the capillary sampling process.

In the instance illustrated, the variations in heater power consumption shown here do not coincide with opening the incubator or other activities that could disturb the incubator temperature. (Environment-associated temperature changes may not be significant because the ambient temperature of the patient-care area is about 32 °C.)

Sampling-induced changes in \( p_{CO_2} \) (similar to those shown in Figure 1) were simultaneously measured with the monitor’s electrodes placed against the upper right chest and against the inside of the lower left calf (approximately 3.5 cm above the heel) of a 30-hour-old infant. The results from the extremity were all lower than those measured on the chest. The range of differences between sites was 4–24 mmHg. The \( p_{CO_2} \) depression associated with capillary blood sampling occurred simultaneously at both sites, but the magnitude and rate of change were not as pronounced as the values observed on the chest. Arterial blood-gas specimens from an umbilical artery catheter (high placement) were taken before and during (at point C of Figure 1) capillary blood-specimen collection. The ratio of the \( p_{CO_2}/p_{aCO_2} \) observed before specimen collection was used to predict the \( p_{aCO_2} \) from the observed \( p_{CO_2} \) during this procedure. The predicted \( p_{aCO_2} \) was 50 mmHg; the observed \( p_{aCO_2} \) was 49 mmHg.

Studies of several subjects confirm that changes at the chest and leg sites parallel one another during sampling. However, statistical analysis of results did not confirm a consistent bias between measurement sites, and this inconsistency was not ascribable to interinstrument bias, because the calibration points and control-gas determinations were identical before and after the test was performed.

In separate experiments, no significant changes in chest and leg \( p_{CO_2} \) were caused by elevating the patient’s leg 10 cm above the heart (the average elevation during capillary blood-sampling) without blood sampling.

The variation in \( p_{CO_2} \) associated with capillary blood sampling can be seen in Figure 2, in which the measured capillary \( p_{aCO_2} \) is compared to the range of \( p_{CO_2} \) observed during the interval B–C. The bias toward \( p_{aCO_2} \) values higher than capillary \( p_{aCO_2} \) is apparent. The magnitude of variations did not correlate with \( p_{aCO_2} \). At a given capillary \( p_{aCO_2} \), the range of measured \( p_{CO_2} \) was not consistent (i.e., at 48 mmHg capillary \( p_{aCO_2} \), the range of \( p_{CO_2} \) was 71−78, 42−48, 62−80, 52−78, and 48−64 mmHg in five different individuals). The mean value for the midpoints of observed \( p_{CO_2} \) ranges was 55 mmHg. The mean value for the capillary \( p_{aCO_2} \) data was 43 mmHg.

When 125 cases were examined for the maximum percentage change associated with capillary specimen collection, i.e., \( [(C - B)/B] \times 100 \), the results ranged from −67 to +63% relative change. The overall mean was −8%, the SD +23.5%. The mean of positive changes was +17%; the mean of negative changes was −21%. In only one observation was there no change. The change (C − B) was negative in 66% of these observations, positive in 34% of them. The direction of change in a given patient was unpredictable. In 61 of 125 cases, the observed change exceeded 10 mmHg. The maximum absolute \( p_{CO_2} \) change observed was a drop from 88 to 34 mmHg.

Discussion

The blood-gas response of sick newborns to capillary blood sampling described here seems to be unique and not associated with on-going dynamic changes. This response was readily identified in all cases except those of extreme \( p_{CO_2} \) instability when frequent or rapid variations mask these changes, or in instances of limited responsiveness associated with moribund infants. The parallelism of leg and chest \( p_{CO_2} \) determinations with coincidentally determined \( p_{aCO_2} \) and the predictability of \( p_{aCO_2} \) from \( p_{CO_2} \) determinations indicate that transcutaneous \( O_2 \) sensors are monitoring true physiological

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3 1 mmHg = 133 Pa = 133 N/m².
changes in O2 tension. Distinct pCO2 changes have been described to occur with other patient manipulations such as suctioning, feeding, etc. (32). Thus, this report and others point to the very labile O2 status of sick newborns.

As indicated in Figure 1, the pCO2 changes throughout the collection of a capillary blood specimen. The pO2 determined on any given capillary blood specimen by conventional analysis would be the average of changing O2 tensions in circulating blood during its collection interval. Moreover, two or more capillary blood specimens taken during the total interval would be expected to have different O2 tensions.

Because of these differences, the analysis of two or more samples of capillary blood with different blood-gas instruments is ineffective as a quality-control technique in this circumstance, even though it is a powerful technique otherwise.

The observation illustrated in Figure 1 also suggests that arterial vs capillary pO2 comparisons made by earlier investigators (5–20) may be compromised, because an overall negative bias could be obtained if specimens were not collected simultaneously.

In theory, the induced physiological phenomena described here should have been equally reflected in capillary pO2 and pCO2 values, but Figure 2 demonstrates that pCO2 results are consistently greater than capillary pO2 results, irrespective of the direction of change. We initially hypothesized that the capillary pO2 vs pCO2 bias identifiable in Figure 2 would be the sum of peripheral perfusion (chest to leg) bias plus orthostatic (leg elevation) bias plus methodology-associated bias. In the small series described here, the existence of a peripheral perfusion bias could not conclusively be demonstrated by simultaneous transcutaneous O2 measurements on the chest and leg. This agrees with the findings of Jacobson and Lofgren (33), who measured no difference between the thigh and the chest in infants. In other investigations we have shown that infants less than 24 h old may constitute a peculiar subpopulation and that such a bias may exist for them (28). The suspected orthostatic bias was not demonstrable but may be present under some circumstances of low blood pressure or aortic atresia. Because the hypothesized perfusion and orthostatic biases were not supported by our data, we conclude that methodology-associated phenomena are responsible. One methodology-associated bias which could account for these observations is incomplete "arterialization" before capillary-blood collection. Only a detailed investigation of arterIALIZATION mechanisms that directly measure heel-skin temperature and coincidentally determine pCO2 will elucidate the origin of the bias.

Perhaps the most serious limitation to the use of capillary blood specimens for pO2 determinations is the potential for misinterpreting a patient's O2 status by over-reliance on results that have been compromised by the collection process. Even if the capillary pO2 truly reflected the pO2, the magnitude and direction of deviation from the patient's uncompromised O2 tension could lead to inappropriate management. In these studies, 66% of capillary blood specimens represent falsely lower pO2 values. In 49% of our observations, pCO2 changes exceeded 10 mmHg. In our hospital, changes of this magnitude in values below 50 mmHg or above 75 mmHg would make a difference in the management of the case. The most extreme change noted (from 88 to 34 mmHg) would clearly change the patient's evaluation. We conclude that capillary blood specimens from the heel should not be used for pO2 determinations in newborns. We believe that, under most circumstances, the transcutaneous measurement of O2 tension is a valid alternative to the pO2 analysis of a capillary blood specimen.

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References