Original Article

# Comparison of Blood Gas Values in Arterial and Venous Blood

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**Abstract.** ***Objective :*** To compare pH and $PCO_2$ values of simultaneously obtained arterial, arterialized capillary, and venous blood samples and also to compare oxygen saturation ($ASaO_2$) measured in arterial blood and oxygen saturation by pulse oximetry ($PSaO_2$). ***Methods :*** Prospective study was done in the children admitted in the Pediatric Intensive Care Unit of Christian Medical College Hospital Vellore, requiring critical care. All the three blood gas samples (arterial, capillary and venous) were taken simultaneously and analyzed. Oxygen saturation by pulse oximetry was also recorded. ***Results :*** 50 children aged 14 days to 12 years were included in the study. Arterial and capillary pH values were highly correlated ($r^2$=0.9024, p<0.0001). Out of 16 children with arterial acidosis 9(56%) were identified by capillary blood gas. Arterial and venous pH values also showed good correlation ($r^2$=0.8449, p<0.0001). The $PCO_2$ values of arterial and capillary blood gases were found to be highly correlated ($r^2$=0.9534, p<0.0001). The capillary blood gas accurately reflected the arterial $PCO_2$ in 41 (82%) patients. Arterial and venous blood gas $PCO_2$ values had less correlation ($r^2$=0.5917, p=0.011). The arterial oxygen saturation ($ASaO_2$) and oxygen saturation by pulse oximetry ($PSaO_2$) were correlated moderately ($r^2$=0.7241, p<0.0001). ***Conclusion :*** Even though arterial blood gas analysis is the gold standard, and when an arterial blood gas sample cannot be obtained, a combination of arterialized capillary blood gas and pulse oximetry can be effectively used in acutely ill children of all ages. Venous samples have a good correlation with arterial samples for pH but are not useful for monitoring blood gas status in acutely ill children.
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Blood gases contain a wealth of information about oxygenation, ventilation and acid-base status of the body and should be routinely monitored in critically ill children.

The determination of pH, partial pressure of oxygen ($PaO_2$), partial pressure of carbondioxide ($PaCO_2$) and saturation of oxygen ($ASaO_2$) from a sample of arterial blood is the gold standard. Arterial puncture or cannulation requires technical expertise and is not without risks. Therefore, technically simpler and less invasive method is preferable in infants and young children.

There is a general agreement that capillary blood gas (CBG) pH values are reliable predictors of arterial pH though CBG values may be of little use in predicting arterial $PO_2$.[1] Opinion varies regarding CBG $PCO_2$.[1] Capillary Blood Gas values are reported to be more accurate in adults.[1,2] A number of studies have compared simultaneous capillary and arterial blood gases in the newborn. But there is little information regarding the correlation in older children.

Pulse oximetry is another valuable adjunct for oxygen monitoring but it does not assist to monitor pH or $PCO_2$.

This study prospectively compared simultaneously obtained arterial, arterialized capillary and venous blood gases measurements and also assessed the correlation between oxygen saturation by pulse oximetry ($PSaO_2$) and arterial oxygen saturation ($ASaO_2$).

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## MATERIALS AND METHODS

Children with various diseases who were admitted between August 1998 to January 1999 in the Pediatric Intensive care unit requiring oxygen therapy, assisted ventilation and any critical illness requiring blood gas monitoring were enrolled. The exclusion criteria were cyanosis, poor peripheral perfusion, peripheral oedema and hypothermia. The Institutional Review Board of Christian Medical College, Vellore, approved this study.

Clinically meaningful value of reliability coefficient 0.6 was fixed, as Landis and Koch (1977) have recommended this statistic as substantial. The value for the null hypothesis was fixed at .02, as this is better than 0 and less likely to provide false positive results (Donner and Eliasziw 1987). In order to get the reliability coefficient 0.6, which is significantly greater than 0.2 with alpha and beta errors at 5% and 20% respectively, the sample size needed is 50 subjects.[3,4]

The demographic data, vital parameters, relevant investigations and primary diagnosis of all the subjects were recorded in a specified proforma. The same

investigator took all the blood samples. Arterial blood samples were collected from radial artery or brachial artery by an arterial puncture or from an indwelling arterial cannula if present. The arterial punctures were done by No.24 or 26-gauge needle connected to 2-ml glass syringes which contained sodium heparinate 0.1ml as an anticoagulant.

Arterialized capillary blood samples were collected from the prewarmed heel or fingertip using a heparinized capillary tube. Milking or squeezing of the area was avoided. The venous blood collection was done from the superficial peripheral veins, especially in the antecubital fossa and dorsum of the hand. All the three blood samples taken by the same investigator were sent immediately to the laboratory and analyzed in the Radiometer ABL 300 Acid-Base laboratory at the temperature of 37° ± 0.1°C. In all instances less than 180 seconds separated completion of arterial, capillary and venous blood collection. The oxygen saturation by the Nellcor Purittan Bennette pulse oximeter was also recorded simultaneously. All the documented data were analyzed in the SPSS Software program using Pearson correlation co-efficient. Bland-altman plots and 95% limits of agreement were used to determine clinical utility of capillary blood gases.

## RESULTS

A total of fifty children from 14 days to 12 years of age were included. Majority of the patients was under one year of age 30(60%). The primary diagnoses included Bronchiolitis 15(30%), CNS disorders including viral encephalitis and TB meningitis 10(20%), Septicemia 9(18%), Pneumonia 7(14%), Bronchial asthma 2(4%), Empyema 2(4%) and miscellaneous 5(10%).

Arterial (ABG) and capillary blood gases (CBG) pH values were highly correlated ($r^2$=0.9024 and p <0.001). The regression equation for parameters arterial and capillary blood gas pH was Y(APH)=0.52+0.93(CPH) (Figs. 1a and 1b). The other validity parameters like sensitivity, specificity and accuracy were also calculated and the values were 56% 97% and 84% respectively. In 82% (41 out of 50 patients) of cases, the absolute value of difference between the arterial (APH) and capillary pH (CPH) was <0.05 which was clinically acceptable (Table 1). The highest difference between capillary and arterial pH was 0.102. The mean absolute value of difference between CPH and APH was 0.03.

**TABLE 1. Shows Correlation Between Capillary (CPH) and Arterial (APH) Blood Gas pH Values**

| | | APH | | |
|---|---|---|---|---|
| | | < 7.35 | 7.35–7.45 | > 7.45 |
| CPH | < 7.35 | 9 | 1 | 0 |
| | 7.35–7.45 | 6 | 20 | 2 |
| | > 7.45 | 1 | 3 | 8 |

CPH - Capillary Blood pH
APH - Arterial Blood pH
Positive Predictive Value of CPH < 7.35 for APH < 7.35 = 90%
Negative predictive Value of CPH > 7.35 for APH > 7.35 = 82.5 %

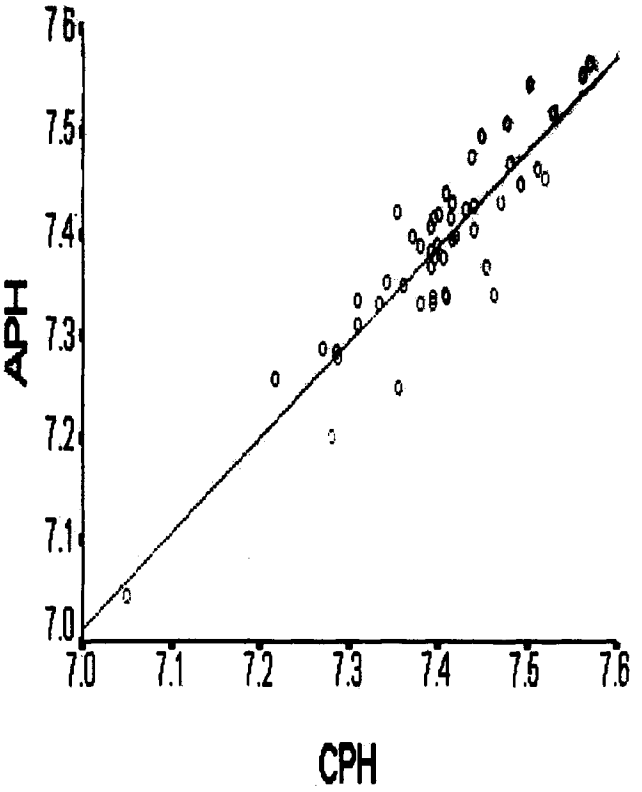


**Fig. 1a.** Scattergram of Arterial versus Capillary pH (CPH)

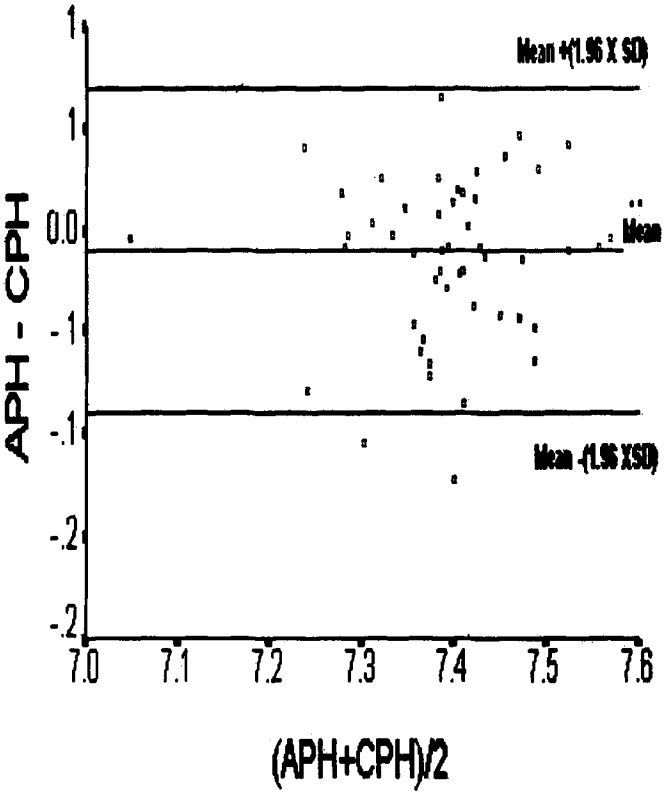


**Fig. 1b.** Bland-Altman Plot of pH data

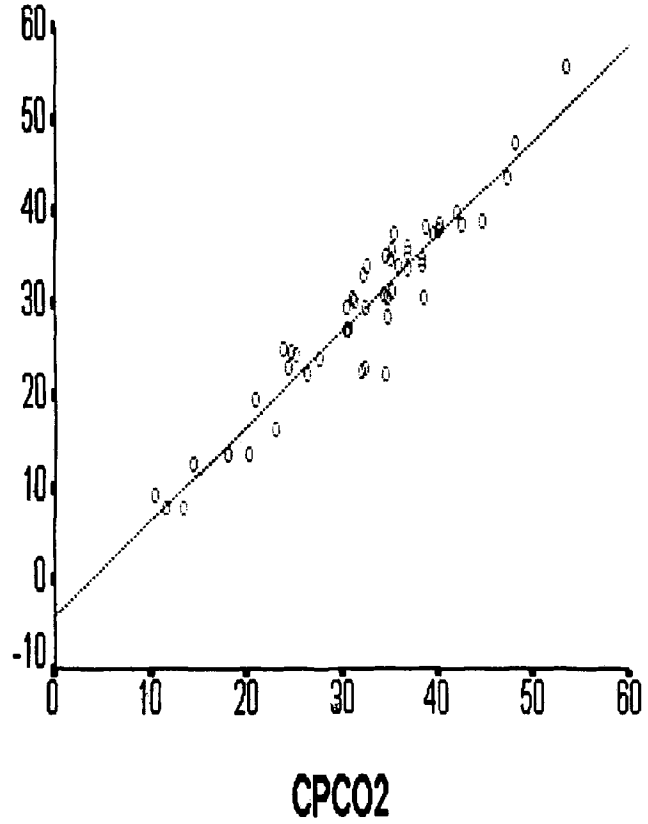


**Fig. 2a.** Scattergram of Arterial ($APCO_2$) Versus Capillary $PCO_2$ ($CPCO_2$)

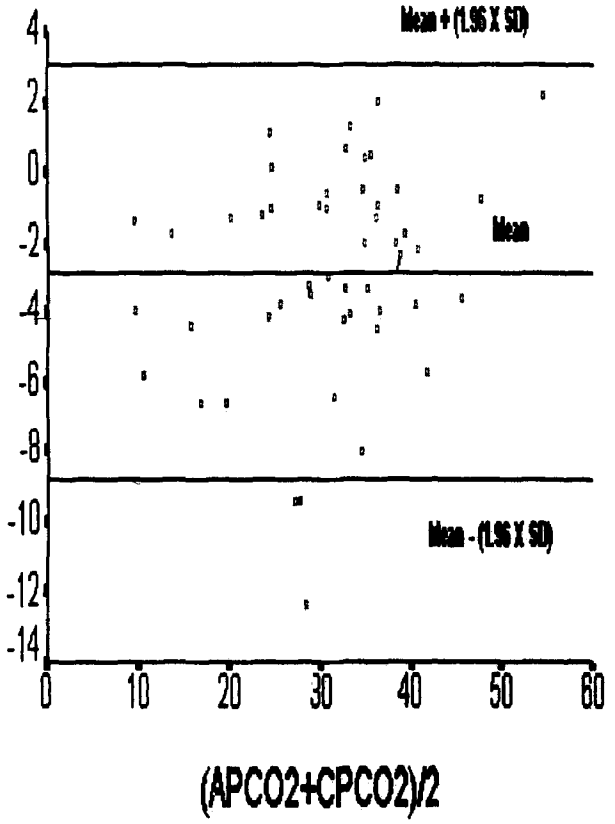


**Fig. 2b.** Bland-Altman plot of $PCO_2$ Data

Of 16 patients with arterial acidosis (pH<7.35) capillary blood gas identified 9. The range of arterial pH values with acidosis was from 7.047 to 7.34 and that of capillary pH was from 7.057 to 7.343. The range of CBG pH values of the 7 patients where the CBG did not identify the acidosis was 7.35 to 7.38. Their corresponding APH was 7.27 to 7.35.The capillary blood gas also identified 8 out of 10 patients with arterial alkalosis (pH >7.46).

A statistically significant correlation was observed in $PCO_2$ values of arterial ($APCO_2$) and capillary ($CPCO_2$) blood gases ($r^2$=0.9534, p<0.001). The regression equation of these parameters was Y ($APCO_2$) =–3.83+1.03 ($CPCO_2$) (Figs. 2a and 2b).

The sensitivity, specificity and accuracy of the correlation were 80%, 93% and 84 % respectively. In 88% (44 out of 50) of patients the difference between arterial and capillary $PCO_2$ was < 6.5mm of Hg. Capillary $PCO_2$ ($CPCO_2$) was higher than arterial $PCO_2$ ($APCO_2$) in 8(16%) out of 50 patients and lower in 1(2%) patient (Table 2).

The capillary blood gas identified the two patients with arterial hypercarbia ($PaCO_2$ > 46mmg Hg) (Table 2). The values of hypercarbia with arterial blood gas were 47.40 and 55.60 and the corresponding capillary $PCO_2$ values were 48.10 and 58.40. The $PO_2$ values of arterial and capillary blood gas showed moderate correlation ($r^2$=0.6698, p<0.001). The capillary $PO_2$ correlated well with arterial $PO_2$ when it was less than 65 mmg Hg. The capillary $PO_2$ identified all 4 patients with arterial hypoxemia ($PO_2$ < 65). The negative predictive value of $CPO_2$ > 65 for $APO_2$ > 65 was 100% thereby showing very good correlation when there is hypoxemia.

**Table 2. Correlation Between Arterial and Capillalry $PCO_2$ Values ($APCO_2$ and $CPCO_2$)**

| | | $APCO_2$ | | |
|---|---|---|---|---|
| | | ≤ 34 | 35–45 | ≥ 46 |
| $CPCO_2$ | ≤ 34 | 28 | 1 | 0 |
| | 35–45 | 7 | 11 | 0 |
| | ≥ 46 | 0 | 1 | 2 |

$CPCO_2$ – Arterial Blood $PaCO_2$
$CPCO_2$ – Capillary Blood $PaCO_2$

Arterial and venous pH values also had good correlation ($r^2$=0.8449, p<0.001). In 62%(31 out of 50) of patients the absolute value of difference was < 0.05. The venous pH was higher than arterial pH in 4(8%) patients and lower in 11(22%) patients. The mean absolute value of difference between venous and arterial pH was 0.04. Maximum venous pH was higher than arterial pH by 0.117. Of 16 patients with arterial acidosis and 10 patients with arterial alkalosis, venous blood gas identified 12 and 6 respectively.

The arterial oxygen saturation ($ASaO_2$) and oxygen saturation by pulse oximetry ($PSaO_2$) correlated

moderately ($r^2$ =0.724 and p<0.001). The sensitivity, specificity and accuracy of the correlation were 50%, 98% and 96% respectively. There were 48 patients with arterial $O_2$ saturation ($ASaO_2$) >90%), pulse oximetry identified 47 of these. It also identified one of the two patients with arterial oxygen saturation ($ASaO_2$) < 90% (Table 3).

**TABLE 3. Correlation Between Arterial Oxygen Saturation ($ASaO_2$) And Oxygen Saturation By Pulse Oximetry ($PSaO_2$)**

| | | $ASaO_2$ | |
|---|---|---|---|
| | | < 90 | < 90 |
| $PSaO_2$ | < 90 | 1 | 1 |
| | > 90 | 1 | 47 |

$ASaO_2$ – Arterial Oxygen Saturation
$PSaO_2$ – Oxygen Saturation by Pulse Oximetry
Positive Predictive Value of $PSaO_2$ <90 for $ASaO_2$ < 90 = 50%
Negative predictive Value of $PsaO_2$>90 for $ASaO_2$ > 90 = 94%

## DISCUSSION

In the present study arterialized capillary and venous blood gas values were compared to arterial blood gas values which is the gold standard. Several studies in the neonates have shown that arterialized capillary pH and $PCO_2$ were clinically useful estimates comparable with arterial values.[5,6,7] Yet other studies report that capillary pH, $PCO_2$ and $PO_2$ are subject to wide variation from arterial blood gas samples.[8,9,10] There is only one report comparing ABG and CBG in children beyond neonatal period.[11]

The present study shows a good correlation for pH values in arterial and capillary blood samples. In 74% patients pH assessment by capillary blood sample was accurate. Similar to this, the study done by Harrison *et al* in older children also showed good correlation for pH.[11] Hence uniformly across the age pH values are comparable in ABG and CBG.

Siggard-Anderson reports that capillary pH, $PaCO_2$ and $PaO_2$ are more accurate in adults than in children. [2] But in the present study and the Study by Harrison *et al* good correlation between arterial and capillary blood pH, $PaCO_2$ and $PaO_2$ values are seen in children of all ages.

We analyzed $APCO_2$ and $CPCO_2$ values and found a very strong correlation. In 82% of patients $PCO_2$ was accurately predicted by capillary blood gas. The negative predictive value of $CPCO_2$ for $APCO_2$ < 46 was 100%. No patient had a false underestimate of $PCO_2$ by CBG. The accuracy of the correlation was 84%.The only other study in older children as reported by Harrison *et al* showed similar strong correlation ($r^2$=0.955).[11] In the studies in neonates reported by Karna *et al*, Saili *et al*, Glasgow *et al* and Desai *et al* the correlation co-efficient for $PCO_2$ was statistically significant.[5,6,7,12] But in contrast, Banister *et al*, Thomsen *et al* and Usher *et al* had reported poor correlation for arterial and capillary $PCO_2$ values in infants.[13,14,15]

Bland-Altman plots compare two methods of measurement in a more rigorous fashion. Bland and Altman stated that if the mean difference between measurements ± 1.96 SD (95% limits of agreement) is not clinically important, we could use the two measurement methods interchangeably.[11,16] In this study the 95% limits of agreement for pH and $PCO_2$ fall within the parameters for clinical utility (Figs. 1b and 2b).

We compared $PO_2$ values between capillary and arterial blood gases and found good correlation when there was hypoxemia ($r^2$=0.6917, p<0.0001). The negative predictive value of $CpO_2$ > 65 for $ApO_2$ > 65 was 100%. There was less correlation when there was hyperoxemia ($PO_2$ > 101 mmHg). Similarly, the studies done by Hunt *et al*, Usher *et al* and Glasgow *et al* in the neonates showed good correlation when arterial $PO_2$ < 65 mmHg there by showing hypoxia will not be missed.[13,14,15,17] Other studies in the neonates report poor correlation for $PO_2$ values.[11,13,18]

The present study also compared venous blood gas (VBG) values with arterial blood gas (ABG) values. There was a high correlation between venous and arterial pH values. The mean absolute value of difference was 0.04. In the literature review, the studies done by Linderman *et al* and Brandenburg *et al* showed significant correlation between arterial and venous pH values during exercise and in patients with diabetic ketoacidosis.[19,20]

Pulse oximetry identified 94% of subjects with arterial oxygen saturation ($ASaO_2$) more than 90%. Only one of the two patients who had arterial oxigen saturation less than 90% was missed by pulse oxymetry and the correlation is statistically significant. In the literature review, the studies done by Russell *et al* and Swedlow *et al* showed good correlation for oxygen saturation by pulse oximetry and arterial oxygen saturation.[21,22] Similarly Southall *et al* studied 43 children and found good correlation between arterial and pulse oximeter oxygen saturation.[23]

## CONCLUSION

Arterialized capillary blood gases accurately reflect arterial pH and $PCO_2$ in children who are critically ill. Capillary samples did not underestimate arterial hypercarbia or hypoxemia. Oxygen saturation by pulse oximetery also correlated well with arterial oxygen saturation. Thus when an arterial blood gas sample cannot be obtained a combination of arterialized capillary blood gas analysis and pulse oximetry can effectively be used in acutely ill children of all ages. However, hyperoxemia is not very accurately estimated by both these modalities. Venous samples though have a good correlation for pH are not useful for monitoring blood gas status in acutely ill children.

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