# THE USE OF FREE FLOWING PERIPHERAL VENOUS BLOOD IN ASSESSING ACID-BASE STATUS

by

Leslie Ingersoll Carveth, B.S.

A THESIS

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APPROVED:

[redacted]

Wilma E. Peterson, Ph.D., Associate Professor, Thesis Advisor

[redacted]

Jack L. Keyes, Ph.D., Associate Professor, First Reader

[redacted]

Barbara Gaines, D.Ed., Associate Professor, Second Reader

[redacted]

John M. [illegible], Ph.D., Chairman of Graduate Council

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# CHAPTER I

## INTRODUCTION

Blood-gas analysis is an essential tool used in the management of critically ill patients. The $pO_2$, $pCO_2$, and pH of arterial blood provide vital information regarding cardiopulmonary function and acid-base status. Nurses are required to understand the results of acid-base measurements and their implications in the care and treatment of the patient. Acid-base and respiratory status are often in critical balance and frequent measurements of blood-gas composition may be needed for proper management.

Blood from arteries is used since arterial blood is more completely oxygenated than venous blood and is usually of uniform composition throughout the body (Slonim and Hamilton, 1976). In contrast, the blood-gas composition of venous blood varies with: 1) the metabolic activity of the tissue from which it comes, 2) the rate of blood flow through the area, and 3) any underlying metabolic disturbances of the organ or tissue from which the venous blood drains (Harrison and Galloon, 1965; Paine, Boutwell and Soloff, 1961).

However, arterial punctures pose certain disadvantages to patients. Obtaining an arterial sample may be difficult, painful, and the number of times samples may be drawn from the same site are limited (Goldschmidt and Light, 1925; Brooks and Wynn, 1959; Hofford, Dowling and Pell, 1973). Repeated arterial punctures or those done by inexperienced hands involve the potential hazards of occlusion, hematoma, ruptured arteries, thrombosis and embolization (Stern and Furman, 1973; Sabin, Taylor and Kaplan

1976; Hoffman, 1977; Skiendzielewski, 1977). Patients receiving anticoagulant therapy may develop complications such as: spontaneous or post-traumatic hemorrhage, hematomas, infected hematomas necessitating incision and drainage, muscle ischemia with resultant contracture and necrosis, peripheral neuropathies, median nerve neuropathy after brachial artery puncture, and femoral nerve palsy following femoral arterial puncture (Neviaser, Adams and May, 1976; Macon and Futrell, 1973). Situations where it may be especially difficult to obtain arterial blood include sampling from arteries of premature infants, pediatric patients, and patients with extensive burns of the body which interfere with direct arterial puncture. Blood obtained by venipuncture for determining acid-base balance would be an advantage in the above situations since venous blood is easier to obtain than arterial blood and may often be available via an indwelling intravenous catheter or needle which is already in place.

Many of the hazards and problems described above could be eliminated if peripheral venous blood could be used in lieu of arterial blood. The present project describes the results of a study of free flowing peripheral venous blood to assess specific kinds of metabolic acid-base disorders.

## Theoretical Framework

The following model illustrates the relationship between venous and arterial blood.

Figure 1 shows that arterial blood is pumped from the pulmonary circulation in the lungs to the parallel components of the systemic circulation and surrounding tissues. The circulation to the fingers and

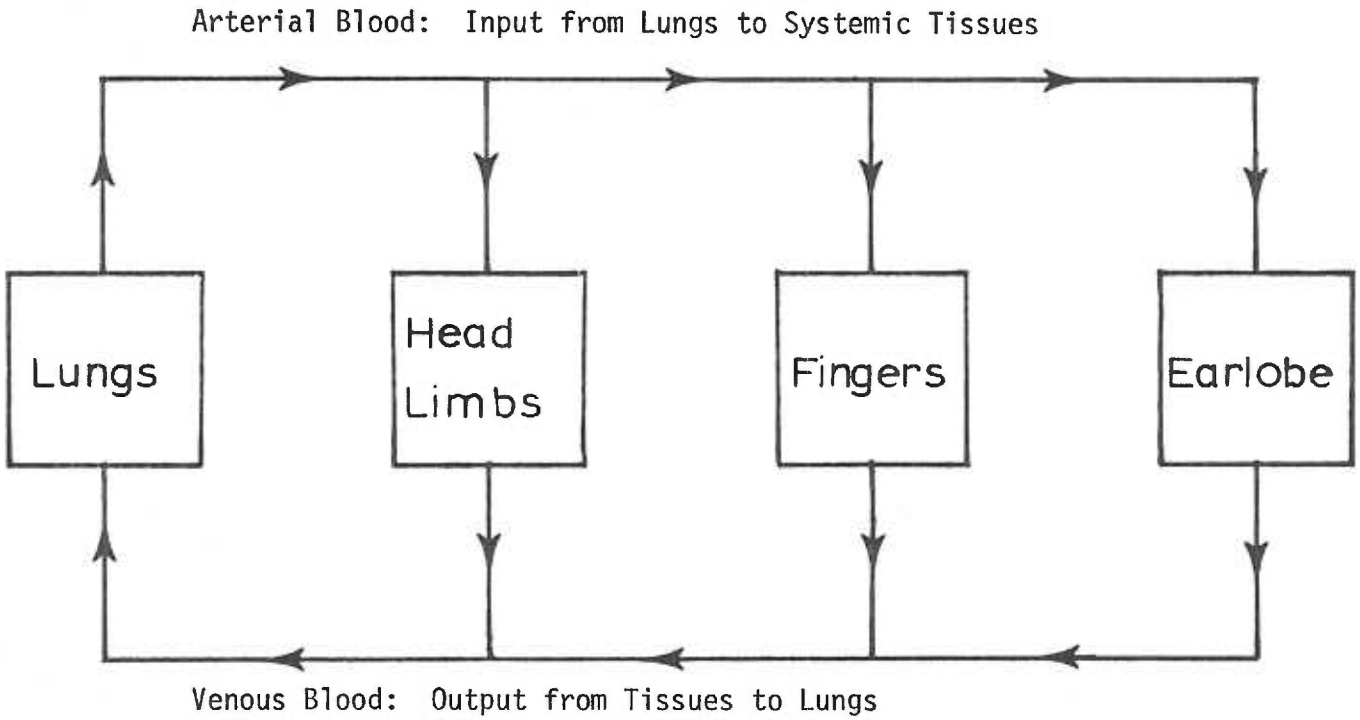


Figure 1. The relationship between arterial and venous blood is shown diagramatically. Head, fingers and earlobes are shown as examples of the many parallel circuits.

earlobe represent separate parallel circuits in the model. Venous blood leaving the systemic circulation flows back through its respective veins to the lungs where $O_2$ and $CO_2$ are exchanged with the environment. Arterial blood differs from venous blood by what the lungs add and remove, i.e., $O_2$ and $CO_2$ respectively. Arterial blood is uniform in composition throughout the systemic circulation whereas venous blood composition varies depending on blood flow and metabolic activity of the surrounding tissues. This can be shown in the following equations:

$$\dot{Q}\ \{O_2\}_a = \dot{Q}\ \{O_2\}_v + \dot{V}O_2 \quad (1)$$

where

$\dot{Q}$ = flow,

$\dot{V}O_2$ = oxygen consumption,

$\{O_2\}_a$ = the concentration of oxygen in the arteries, and

$\{O_2\}_v$ = the concentration of oxygen in the veins.

$$\dot{Q}\ \{O_2\}_a - \dot{Q}\ \{O_2\}_v = \dot{V}O_2 \quad (2)$$

$$\dot{Q}\{\{O_2\}_a - \{O_2\}_v\} = \dot{V}O_2 \quad (3)$$

$$\{O_2\}_a - \{O_2\}_v = \frac{\dot{V}O_2}{\dot{Q}} \quad (4)$$

From equation 4, it can be seen that for any given value of $O_2$ uptake and hence, metabolic rate, as flow ($\dot{Q}$) increases the difference between arterial and venous $O_2$ concentration will diminish. Therefore, if flow can be increased disproportionately to the metabolic activity in the tissue then the $O_2$ concentration of the venous blood from that tissue will more closely reflect $O_2$ concentration of the arterial blood.

This statement can apply to $CO_2$ and acid production as well, which are described by the following equations:

$$\{CO_2\}_v - \{CO_2\}_a = \frac{\dot{V}CO_2}{\dot{Q}} \quad (5)$$ where,

$\dot{V}CO_2$ = $CO_2$ production,

$\{CO_2\}_a$ = the concentration of $CO_2$ in the arteries, and

$\{CO_2\}_v$ = the concentration of $CO_2$ in the veins.

$$\{H+\}_v - \{H+\}_a = \frac{\text{H+ production}}{\dot{Q}} \quad (6)$$ where,

$\{H+\}_a$ = the concentration of acid in the arteries, and

$\{H+\}_v$ = the concentration of acid in the veins.

It is not always necessary to measure the total concentration of $O_2$, $CO_2$, and H+ concentration. Instead, parameters are measured that are proportional to concentration, i.e., $pO_2$, $pCO_2$, and pH.

Use of Peripheral Venous Blood

Convenience, safety, and ease of venous sampling offer advantages over use of arterial sampling if certain conditions can be met. In order to use venous blood in lieu of arterial blood, venous blood must be arterialized. Arterialization occurs when the site where the venous blood is to be obtained is warmed, thereby producing vasodilation with increasing circulation to that area. Blood flow through an area increases rapidly as the temperature of the surroundings rises in the range of 35-45$^{o}$ C (Collis and Neaverson, 1967). The increased flow, disproportionate to the metabolic activity of the surrounding tissues, and the subsequent increased oxygen ($O_2$) delivery will allow the venous blood to have a composition similar to that of arterial blood (arterialized venous blood).

Methods to Produce Arterialization

Different methods have been described in the literature as a means of producing arterialized venous blood. The hand or finger to be used to obtain arterialized venous blood is dipped into a water bath with an average temperature of 45-47$^{o}$ C for varying lengths of time, usually 5-20 minutes (Meakin and Davies, 1920; Goldschmidt and Light, 1925; Paine, Boutwell and Soloff, 1961; Gambino, 1961; Collis and Neaverson, 1967; Koch, 1968). Heating the extremity with a hot towel (Paine, Boutwell and Soloff, 1961; Begin, Racine and Roy, 1975) or a hot water bottle (Hofford, Dowling and Pell, 1973) has also been used to produce arterialized venous blood. Electric warming pads ranging from 40$^{o}$ to a maximum of 60$^{o}$ C have been used to warm the extremities (Harrison and Galloon, 1965; Brooks and Wynn, 1959). In studies using warm earlobe blood, various techniques have been devised to accomplish arterialization. Application of either histamine cream, thurfyl nicotinate cream, or Trafuril paste to the earlobe results in hyperemization (Dorcat and Kenny, 1965; Koch, 1968; MacIntyre, Norman and Smith, 1968; Maas and Van Heijst, 1961; Spiro Dowdeswell, 1976). Radiant heat by electric heaters of incandescent heat lamps results in arterialization of blood in the earlobe (Lilienthal and Riley, 1944 and 1946; Laughlin, McDonald and Bedell, 1964; Gambino, 1961).

Research has been done on both arterialized venous blood and arterialized capillary blood in comparison to arterial blood. Although this investigator used only arterialized venous blood many of the principles outlined in the studies focusing on arterialized capillary blood are relevant and will be discussed.

# CHAPTER II

## REVIEW OF THE LITERATURE

### Arterialized Venous Blood

Meakin and Davies (1920) compared oxygen ($O_2$) saturation of arterial and venous blood in various normal and abnormal conditions. In one phase of their study, these investigators studied the relationship of local temperature variations on both arterial and venous oxygen saturation ($O_2$ sat.). Throughout a wide range of temperature conditions arterial oxygen saturation remained about 96.1 per cent. Venous $O_2$ sat., on the other hand, varied widely with changes in local temperature. At normal temperatures venous $O_2$ sat. was 56.4 per cent. When the arm was exposed to colder temperatures the venous oxygen saturation steadily declined. When the arm was immersed in a water bath of $45^{o}$ C for ten minutes the venous blood was 94.2 per cent saturated with oxygen. The venous blood saturation remained 94.2 per cent, even when the warming experiment was repeated and the arm was immersed for 20 minutes. From these results Meakins and Davies concluded that using venous $O_2$ sat. as an estimate of arterial $O_2$ sat. was subject to error due to the wide variation of venous $O_2$ sat. with changes in local peripheral temperature. However, Meakins and Davies did not hypothesize that in situations where venous blood was warmed it might indeed be similar to arterial blood in terms of $O_2$ saturation.

Following the work of Meakins and Davies, Goldschmidt and Light (1925) investigated the use of venous blood in lieu of arterial blood for measurement of oxygen content (vol. %), oxygen capacity of hemoglobin,

$O_2$ sat., and carbon dioxide content (vol.%).

The hand and wrist were placed in a water bath set at a temperature of 45-47° C. At the end of ten minutes the hand was removed from the water and a venous blood sample was obtained from the back of the hand. The arterial blood was withdrawn from either the radial or brachial artery. These investigators found $O_2$ content, capacity, saturation, and $CO_2$ content of the venous blood indistinguishable from that of arterial blood when the warming procedures were followed.

It should be noted that $O_2$ sat. is not linearly related to $pO_2$. The oxyhemoglobin dissociation curve is S shaped with the steep portion of the curve between 10 and 40 mmHg $pO_2$ and the flat portion of the curve above 70 mmHg $pO_2$. Therefore, small changes in $O_2$ sat. at the flat portion of the curve may reflect large changes in $pO_2$, e.g., a change in $O_2$ sat. from approximately 93 to 97 per cent saturation (% sat.) reflects a change in $pO_2$ of 30 mmHg (70-100 mmHg). Small changes in $O_2$ sat. at the steep portion of the curve reflect only small changes in $pO_2$, e.g., a change in $O_2$ sat. from approximately 40 to 45 % sat. reflects a change in $pO_2$ of approximately 2 mmHg (22 to 24 mmHg) (Slonim and Hamilton, 1976). Therefore, caution should be exercised when comparing difference in per cent saturation between venous and arterial blood.

In 1959, Brooks and Wynn used venous blood in lieu of arterial blood for assessment of pH and carbon dioxide ($CO_2$) status. Arterialization of venous blood was brought about by heating one hand and forearm with two electric heating pads for 15 minutes. The temperature at the sample site did not exceed 40° C. Venous blood was then taken from the heated limb, the unheated limb and an arterial sample was obtained from either the brachial or femoral artery. Results showed that arteriovenous

differences in the heated extremity were small while those from the unheated extremity were quite large. Hence, they concluded that heating the extremity was necessary to obtain arterialization of venous blood.

Using nonambulatory patients, Brooks and Wynn found that arteriovenous differences in the heated extremity were smaller if the subjects were confined to bed. Confining the patient to bed did not reduce the differences between arterial and unwarmed venous blood.

Brooks and Wynn concluded that if their criteria were met, i.e., patient in bed, warm and skin temperature over the dorsum of the hand at least $35^{o}$ C, then venous $pCO_2$ and pH would be a reliable indicator of arterial $pCO_2$ and pH. Their results showed that venous $pO_2$ was significantly different from arterial $pO_2$. They hypothesized that if the temperature used to heat the extremities was higher, the differences in $pO_2$ and $O_2$ saturation would also be negligible.

Paine, Boutwell and Soloff (1961) explored the use of arterialized venous blood for estimating arterial pH and $pCO_2$. The pH range in this study varied from 7.269 to 7.484. Blood was drawn from a vein on the dorsum of the hand that had been previously warmed by either a hot towel or by immersion in a hot water container. Arterial blood was drawn and used as the control sample. Various techniques for obtaining the blood samples were used. In 15 patients, tourniquets were placed above the elbow prior to sampling. In 6 of these 15 patients a vacuum tube was used for collection of the blood sample, while the other 9 patients had their blood withdrawn into a heparinized syringe. The 14 remaining patients had a tourniquet placed above the wrist and were encouraged to flex their fingers before venipuncture. All arterial blood samples were drawn into heparinized syringes.

Results were reported as mean differences between arterialized venous blood and arterial blood. Results are as follows:

1. Use of vacuum tubes gave mean pH differences of 0.05 pH units, and mean $pCO_2$ differences of 4.9 mmHg.
2. The group with constriction above the elbow where heparinized syringes were used had mean differences in pH of 0.038 pH units and $pCO_2$ of 8.5 mmHg.
3. The group with constriction above the wrist and samples drawn into heparinized syringes had mean differences in pH of 0.022 pH units and $pCO_2$ of 2.86 mmHg.

These investigators concluded that the pH of arterialized venous blood could be used as a reliable estimate of arterial pH. They drew no conclusions on the use of $pCO_2$ from arterialized venous blood.

Harrison and Galloon (1965) studied the use of venous blood as an alternative to arterial blood for the measurement of $CO_2$ tensions. The study groups was comprised of 13 patients, 12 of which were undergoing surgical procedures with general anaesthesia and one patient who was on the ward receiving artificial ventilation.

Arterialization was achieved by wrapping the hand in an electric warming pad which had a maximum temperature of $60^{o}$ C. A total of 146 paired venous samples were taken under a variety of conditions at the beginning of and during anesthesia. First the venous sample was withdrawn and then the arterial sample was obtained within 30 seconds. Samples were drawn anaerobically into heparinized syringes and analyzed within 3½ hours.

Results showed the smallest difference in samples taken at the beginning of anesthesia. These researchers attributed the smaller differences at the beginning of anesthesia to initial vasodilation caused by the anesthetic agent. They also found that when ideal sampling conditions

were maintained, i.e., blood taken from the dorsum of the warmed hand with no stasis or obstruction to the flow of blood in the vein, the difference between arterial and venous $pCO_2$ was not greater than 2 mmHg, the mean difference being 0.5 mmHg.

These investigators felt that venous blood was an acceptable substitute for arterial blood in measuring carbon dioxide tensions when the sampling conditions they described were followed.

Collis and Neaverson (1967) investigated the use of arterialized venous blood as an accurate estimation of acid-base status in 23 conscious patients. Arterialized blood samples were taken from veins on the dorsum of the hand immediately before or after arterial puncture. Arterialization was achieved by placing the hand in a $45^{o}$ C water bath for 5 minutes. Samples were drawn anaerobically into heparinized syringes, and analyzed immediately.

These authors reported their results as mean differences comparing arterialized venous blood to arterial blood. Mean pH differences of .0052 pH units (SD 0.0075) and mean $pCO_2$ differences of .76 mmHg (SD0.81) were recorded. These authors stated that individual readings of $pO_2$ differed as much as 40 mmHg, and at levels of 60 mmHg and greater the arterialized venous blood was useless as an estimation of arterial blood.

Based on these results these researchers stated that pH and $pCO_2$ of arterialized venous blood could be used as a reliable estimate of pH and $pCO_2$ in arterial blood.

It is of interest to note that the authors report that pH was repeatable to within 0.005 pH units, yet they found a difference of 0.0052 units significant. In addition, they could measure $pCO_2$ to within only

2 mmHg and found that a venous-arterial $pCO_2$ difference of $0.76 \pm 0.81$ was highly significant.

Summary of the Use of Arterialized Venous Blood

In the studies reviewed thus far the pH ranged from 7.267 to 7.484. Arterialized venous blood samples were drawn from the dorsum of the hand in the majority of cases. The two exceptions to this were from the studies of Brooks and Wynn (1959) who also drew venous samples from the wrist and Harrison and Galloon (1965) who infrequently used other sites. The hand veins drain tissues which normally have relatively low rates of metabolism, and are easily dilated by heating to increase the rate of blood flow throughout the hand (Harrison and Galloon, 1965). By using the dorsum of the hand as the preferred sample site the problem of controlling increased metabolism with heat is virtually eliminated. A summary of the results of studies in which arterialized venous blood was compared with arterial blood is given in Table 1.

Arterialized Capillary Blood

Lilienthal and Riley (1944) studied the oxygen saturation of arterialized capillary blood and compared it with $O_2$ saturation of arterial blood. The earlobe was used as the source of capillary blood. The earlobe was warmed by radiant heat for a few minutes to produce full vasodilatation, then punctured and a blood sample obtained. These investigators devised and described a virtually anaerobic technique for collecting arterialized capillary blood.

Their experiments indicated that there was no significant difference between the oxygen saturation of blood obtained from a warmed ear and that

TABLE 1

Summary of Studies Using Arterialized Venous Blood

| PARAMETERS MEASURES | MEAN DIFFERENCES (ARTERIAL VERSUS VENOUS) | INVESTIGATORS |
|---|---|---|
| $pCO_2$ (mmHg) | 1.2 | (Brooks and Wynn, 1954) |
| pH (pH units) | 0.005 | |
| $pCO_2$ (mmHg) | 0.5 (SD 0.70) | (Harrison and Galloon, 1965) |
| Vacuum tubes | | (Paine, Boutwell and Soloff, 1971) |
| pH (pH units) | 0.05 | |
| $pCO_2$ (mmHg) | 4.9 | |
| Constriction above elbow--heparinized syringes | | |
| pH (pH units) | 0.038 | |
| $pCO_2$ (mmHg) | 8.3 | |
| Constriction above wrist--heparinized syringes | | |
| pH (pH units) | 0.022 | |
| $pCO_2$ (mmHg) | 2.86 | |
| pH (pH units) | 0.0052 (SD 0.0075) | (Collis and Neaverson, 1967) |
| $pCO_2$ (mmHg) | 0.76 (SD 0.81) | |

of arterial blood that had been obtained simultaneously from the brachial artery. The range of oxygen saturations measured was from 75.7 to 97.7% saturation.

As discussed previously small changes in oxygen saturation may reflect marked changes in $pO_2$. Therefore, it may not be possible to accurately predict a relationship between values of $pO_2$ in arterial blood from arterialized capillary blood even when $O_2$ saturations are similar.

Lilienthal and Riley (1946) followed their study of oxygen saturations in arterialized capillary blood with one that compared the carbon dioxide content of arterial blood with that of arterialized capillary blood. The methods used in this study were similar to that followed in the previous study. In these experiments, Lilienthal and Riley developed a correction factor to account for possible dilution of the samples because of the use of a wet anticoagulant in the syringe. The carbon dioxide content (vol. %) of earlobe blood exceeded that of arterial blood in 11 of 12 comparisons. After the correction factors had been applied 9 of the 12 capillary samples showed a difference in $CO_2$ concentrations of 1 vol. % or less. From this experiment Lilienthal and Riley concluded that the $CO_2$ content of arterial blood could be estimated from the $CO_2$ content of blood obtained from the warmed ear.

Gambino (1961) used the Lilienthal and Riley method of collecting arterialized capillary blood. He obtained arterialization of the venous blood in two ways. One in which he dipped the finger into water which had a temperature of $45^{o}$ C for 5 minutes and the other by heating the ear for 5 minutes with a 75 watt light bulb held 2 inches from the ear. The parameters he selected to study were pH, $pCO_2$, $CO_2$ content (vol. %),

and $O_2$ saturation. These parameters were tested with paired samples of arterialized capillary blood and brachial artery blood under varying physiologic conditions. These conditions were: comparison of capillary and arterial values at rest, comparison of capillary and arterial values after one minute of step-up exercise, and comparison of capillary and arterial values after 15 minutes of 40 per cent oxygen. No significant differences were observed between paired samples for the parameters measured when the results were analyzed by the Fishers' T table.

A comparison of the pH and $pCO_2$ of arterial blood with arterialized blood from the earlobe was done by Maas and Van Heijst (1961a). In this study pH ranged from 7.308 to 7.51. Earlobe blood was arterialized by rubbing the earlobe with Trafuril paste, an irritant which causes hyperemia. They found in comparing pH of arterial blood and the blood from the arterialized earlobe that the average difference between the two was insignificant, (0.002 pH units). They concluded that arterialized earlobe blood was a good substitute for arterial blood when determining pH.

In comparing $pCO_2$ of blood in arterialized capillaries and arteries, simultaneous samples of blood were obtained from the earlobe and brachial artery in 20 patients. The mean $pCO_2$ difference when comparing arterialized capillary blood to arterial blood was 0.16 mmHg (SD 1.2 mmHg). They concluded from these results that the $pCO_2$ of blood from the earlobe was similar to the $pCO_2$ of arterial blood (Maas and Van Heijst, 1961b).

Laughlin, McDonald and Bedell (1964) attempted to determine if there was a relationship between $pO_2$ of arterial blood and $pO_2$ of samples obtained from a warmed ear or fingertip. Using 33 patients, the earlobe

was warmed by a specially designed electric heater and the fingertip warmed in a water bath of 46° C for 5 to 10 minutes. The $pO_2$ of arterial blood from the brachial artery served as the control.

The blood from the warmed ear had a mean $pO_2$ of 79 mmHg compared with a mean arterial $pO_2$ of 82 mmHg. The standard deviation of the mean difference between arterial and arterialized capillary blood was $\pm$ 5 mmHg. The mean $pO_2$ of blood drawn from the unwarmed ear was 63 mmHg and the corresponding mean arterial blood $pO_2$ was 72 mmHg. The mean $pO_2$ of blood drawn from the warmed hand was 56 mmHg while simultaneously drawn arterial blood had a mean $pO_2$ of 67 mmHg.

These investigators concluded that the warmed earlobe was a satisfactory site for measurement of arterial $pO_2$. They also mentioned that when patients were in circulatory collapse or had a compromised peripheral circulation the earlobe $pO_2$ was not a reliable estimate of arterial $pO_2$.

Dorcat and Kenny (1965) investigated the accuracy of using values obtained from capillary samples to predict the pH, $pCO_2$, and bicarbonate concentration of arterial blood in 50 patients undergoing abdominal surgery. Capillary samples were obtained from an earlobe that had been arterialized by the topical application of histamine cream followed by vigorous rubbing. Capillary and arterial samples were withdrawn simultaneously. The arterial pH ranged from 7.248 to 7.530. They reported mean differences between arterial and arterialized capillary blood of 0.003 pH units (SD 0.007), 0.5 mmHg (SD 1.2 mmHg) for $pCO_2$ and 0.018 (SD 0.4) for bicarbonate concentration. These results concur with the hypothesis that capillary sampling is sufficiently accurate for clinical use for these parameters.

MacIntyre, Norman and Smith (1968) found that capillary blood specimens obtained from the earlobe after it had been massaged with the irritant Thurfyl nicotinate, for 3 minutes gave reliable measurements of arterial $pO_2$. This study was performed on normal, hyperoxic and hypoxic subjects. The $pO_2$ ranged from 2 to 2,100 mmHg. In order to obtain $pO_2$ values up to 2,100 mmHg subjects were placed in hyperbaric chambers. These authors reported their results as means and standard deviations (SD). When $pO_2$ values ranged from 0 to 300 mmHg with a mean arterial $pO_2$ of 80.0 (SD 20.6) the earlobe blood withdrawn at the same time had a mean $pO_2$ of 78.7 (SD 21.0). These authors did not give either raw data or results for $pO_2$ values greater than 300 mmHg.

Koch (1968) investigated the use of $pO_2$ and $pCO_2$ measurements in capillary blood as a substitute for arterial $pO_2$ and $pCO_2$. These parameters were studied under differing conditions. Both the earlobe and fingertip were used as sites for obtaining capillary blood. Arterialization of the capillary blood was brought about by rubbing the earlobe with the irritant Trafuril paste, or dipping the fingertip in water which had a temperature of $45^{o}$ C for 10 minutes.

The mean difference between arterial and arterialized capillary blood (earlobe) at rest during air breathing was .16 mmHg (SD 3.3 mmHg) while $pO_2$ obtained from the warmed fingertip showed a mean difference of 6.4 mmHg (SD 6.4 mmHg). At rest during oxygen breathing the $pO_2$ obtained from either site had a mean difference of 90 mmHg (SD 42 mmHg). During exercise and air breathing the $pO_2$ obtained from the warmed earlobe had a mean difference of 0.7 mmHg (SD 3.7 mmHg). The mean difference between arterial and arterialized capillary $pCO_2$ (earlobe) at rest during air breathing was .3 mmHg (SD 1.5 mmHg). The $pCO_2$ of capillary blood when

obtained from the heated fingertip showed a mean difference of .02 mmHg (SD 2.4 mmHg). Close agreement regardless of sample site was found for $pCO_2$.

Koch stated that in situations such as circulatory collapse or when oxygen tensions are greater than 200 mmHg, the $pO_2$ of capillary blood is not a valid substitute for $pO_2$ of arterial blood.

Wallman, Arora, Allen and Hyde (1968) compared measurements of arterialized capillary blood (ACB) with arterial blood during the breathing of both room air and 100 per cent oxygen. Since measurement of $pO_2$ during the breathing of 100 per cent oxygen makes possible the detection of right-left shunting,these investigators felt that measurement of $pO_2$ from arterialized capillary blood would be a simple method for detecting right-left shunting. Their study compared $pO_2$, $pCO_2$ and pH of blood obtained from a warmed earlobe with that of arterial blood from the brachial artery during room air and 100 per cent oxygen breathing.

The earlobe was warmed for at least 15 minutes with a 7-watt night-lamp bulb. Patients breathing 100 per cent oxygen were instructed to take 3 to 4 deep breaths immediately before the specimen was withdrawn. All specimens were placed in an ice bath until they were analyzed. Table 2 gives a summary of their results.

These investigators concluded that the large variance in $pO_2$ while breathing 100 per cent oxygen could be attributed to incomplete arterialization of the earlobe blood and by loss of oxygen because of brief exposure of the sample to room air. They also concluded that $pCO_2$ and pH of ACB was a reliable estimate of arterial blood during both room air breathing and 100 per cent oxygen breathing. The $pO_2$ of ACB was in close agreement with arterial $pO_2$ during room air breathing, but not a reliable

estimate of arterial $pO_2$ during breathing of 100 per cent oxygen.

TABLE 2

Summary of Results Reported by Wallman, et al.

| | ACB* | | | Arterial | | |
|---|---|---|---|---|---|---|
| | pH | $pO_2$ | $pCO_2$ | pH | $pO_2$ | $pCO_2$ |
| Airbreathing (mean value) | 7.41 | 79 mmHg | 41.3 mmHg | 7.41 | 80.3 mmHg | 40.8 mmHg |
| 100 percent oxygen breathing (mean value) | 7.42 | 437 mmHg | 40.1 mmHg | 7.42 | 542 mmHg | 38.8 mmHg |

* Arterialized Capillary Blood

Olivia, Spellman, Podgainy and Gittleman (1973) replicated MacIntrye, Norman and Smiths' research (1968) of earlobe capillary blood for estimating arterial oxygen tension in a larger number of subjects. Significant levels of correlation occurred between arterialized capillary blood and arterial blood in the oxygen pressure range from 46 to 130 mmHg, r-0.91. However, in the range of 450 to 650 mmHg there was poor correlation.

Hofford, Pell and Dowling (1973) also evaluated the use of arterialized capillary blood samples in a sample of 20 subjects. The earlobe and finger pulp were used as the sampling sites. Arterialization of the hand or earlobe was obtained by applying a hot water bottle with an average temperature of $50^{o}$ C to the site for 10 minutes.

With $pO_2$ measurements in the range of 0 to 100 mmHg the mean difference between arterialized capillary blood and arterial blood was 0.50 mmHg using blood obtained from the finger and 0.60 mmHg using blood obtained from the earlobe. At $pO_2$ levels above 100 mmHg mean differences ranged

from 64 to 172 mmHg (finger) and 5 mmHg (earlobe). The mean differences for $pCO_2$ were 0.8 mmHg (finger) and 1.40 mmHg (earlobe). Mean differences for pH were 0.007 (finger) and 0.008 (earlobe).

They concluded that in patients breathing room air, the $pO_2$ of arterialized capillary blood was acceptable in lieu of arterial determinations. In patients on supplemental $O_2$, the $pO_2$ of arterialized capillary blood was not an accurate reflection of arterial $pO_2$.

Spiro and Dowdeswell (1976) investigated the use of arterialized blood samples from the earlobe in place of true arterial samples. Simultaneous samples of arterial blood and warmed earlobe blood were drawn with the subjects at rest and during exercise. The mean differences between arterial and earlobe blood samples at rest for $pO_2$ was .72 mmHg and 1.00 mmHg for $pCO_2$. The mean differences of samples taken during exercise was .95 mmHg for $pO_2$ and .53 mmHg for $pCO_2$. The results showed no significant differences for $pO_2$ or $pCO_2$ between arterial blood and arterialized earlobe blood under these conditions.

## Summary of the Use of Arterialized Capillary Blood

In the studies reviewed for arterialized capillary blood, the pH ranged from 7.18 to 7.53. Arterialized capillary blood samples were withdrawn from either the earlobe or the fingertip. A summary of the results of studies in which arterialized capillary blood was compared with arterial blood is given in Table 3.

## Summary of the Review of the Literature

The review of the literature from 1920 through 1976 described various methods for using arterialized venous or capillary blood in

TABLE 3

Summary of Studies Using Arterialized Capillary Blood

| INVESTIGATION | PARAMETERS MEASURES AND CONDITIONS | SITE | COMPARISON TO ARTERIAL PARAMETERS |
|---|---|---|---|
| Lilienthal and Riley (1944) | $O_2$ | Earlobe | No significant difference |
| Lilienthal and Riley (1946) | $CO_2$ content (Vol.%) | Earlobe | No significant difference |
| Gambino (1961) | pH, $pCO_2$ content (Vol.%) $O_2$ saturation (at rest and exercise) Low $O_2$ | Finger or Earlobe | No significant difference |
| Maas and Van Heijst (1961a) | pH | Earlobe | No significant difference |
| Maas and Van Heijst (1961b) | $pCO_2$ | Earlobe | No significant difference |
| Laughlin, McDonald and Bedell (1964) | $pO_2$ | Earlobe and Finger | No significant difference in Earlobe Significant difference in Finger |
| Dorcat and Kenny (1965) | pH, $pCO_2$, and $HCO_3$ | Earlobe | No significant difference |
| McIntyre, Norman and Smith (1968) | $pO_2$ at low, medium high $pO_2$ | Earlobe | No significant difference |
| Koch (1968) | $pO_2$ | Earlobe and Fingertip | No significant difference |
| Wellman, Arora, Allen and Hyde (1968) | $pO_2$, pH, $pCO_2$ | Earlobe | No difference in room air |

assessing acid-base status. These studies had the following limitations:

1. Investigators dealt only with human subjects and were, therefore, unable to change acid-base status as an independent variable.

2. Many of the subjects had either a mild acid-base disorder or no acid-base disorder.

3. The widest range of pH investigated was from 7.18 to 7.49 (Wallman, Arora, Allen and Hyde, 1968).

In the following study, the above limitations were overcome.

## Problem Statement

The following study was designed to evaluate the use of arterialized venous blood rather than arterial blood for assessment of acid-base status. This investigator expanded the above studies in a controlled laboratory setting using animal models. This allowed changing the acid-base status in the subjects over a wide pH range. The pH, $pCO_2$ and $pO_2$ of arterial, warmed and unwarmed venous blood were determined in metabolic acidosis and alkalosis.

The variables in this study were the pH, the partial pressure of oxygen ($pO_2$), and the partial pressure of carbon dioxide ($pCO_2$) in the samples of collected blood (See Appendix A for definition of terms).

In this study, the following hypotheses were tested:

1. There is no physiologically significant difference between pH, $pCO_2$ and $pO_2$ of arterialized venous blood obtained from an indwelling venous catheter and that of blood obtained simultaneously from the femoral artery of the same animal, regardless of acid-base status.

2. There is a physiologically significant difference between pH, $pCO_2$, and $pO_2$ of non-arterialized venous blood obtained from an indwelling venous catheter and that of blood obtained simultaneously from the femoral artery of the same animal, regardless of acid-base status.

# CHAPTER III

# METHODS

## Reliability of Measurements

A Radiometer BGA3 Blood-Gas Analyzer was used to measure pH, $pCO_2$ and $pO_2$. According to the BGA3 Instrument Manual this analyzer has been shown to have a reproducibility of $\pm$ 0.001 pH units, $\pm$ 0.1 mmHg $pCO_2$ and $\pm$ 1.0 mmHg $pO_2$.

Preliminary reproducibility studies on this blood-gas analyzer were done to become familiar with the equipment and techniques used in blood-gas analysis.

Calibration of the blood-gas analyzer and procedures used for measurements followed the protocol outlined in the BGA3 Instrument Manual (Appendix B). To assess the accuracy of the calibrating technique and the GMA2 Precision Gas Mixer, electrode calibrations with gas mixtures of known $O_2$ and $CO_2$ concentrations were performed (See Appendix B).

Calibration of the blood-gas analyzer took place before any samples were run. Checks of stability were made after each sample set had been measured.

## Procedure and Controls

Eight healthy mongrel dogs of both sexes were used as the experimental animals. Weights ranged from 10 to 22.3 Kg with a mean weight of 14.9 Kg. The dogs were anesthetized with sodium pentobarbital (30mg/Kg) intravenously and the trachea was cannulated. A femoral vein was catheterized for infusion of maintenance anesthesia and ammonium chloride

($NH_4Cl$) or sodium bicarbonate ($NaHCO_3$). The femoral artery was catheterized to obtain arterial blood samples. Prior to each experiment, the hind paw which was going to be used as the site of the arterialized venous blood (warmed) was randomly selected, while the remaining paw was used as the control site (unwarmed). Then,a vein in each hind paw was catheterized with an appropriate sized polyethylene catheter to obtain free flowing peripheral blood. The catheters were inserted with the tip directed distally in the extremity, against the venous flow, to facilitate obtaining a free-flowing blood sample. After the catheters were in place a thermometer was inserted under the skin of the paw which was to be warmed.

Arterialization of venous blood was accomplished as follows: 5-10 minutes prior to drawing blood samples, a goose neck lamp with a 60 watt bulb was placed approximately 10 cm from the paw. The heat source remained in place until the warmed paw temperature was approximately $5^{o}$ C higher than the pre-heating paw temperature. After the paw reached the desired temperature samples were drawn.

Approximately 1 ml samples of arterial, warmed and unwarmed venous blood were drawn simultaneously under anaerobic conditions (Slonim and Hamilton, 1976; Severinghaus, 1965). The syringes used to collect the samples were prepared in the following manner: 1) the barrels were lubricated with stopcock grease to eliminate blood and gas leakage around the barrel, 2) the syringes were heparinized with 1000 units/cc sodium panheparin, and 3) a mercury plug was placed in the syringe to facilitate obtaining samples under anaerobic conditions and to aid in the mixing of the sample. Samples were drawn at approximately 30 minute intervals,

placed in crushed ice and analyzed within 30 minutes of aspiration. The results of the arterial blood and unwarmed venous blood analyses served as the control values, while those of the arterialized venous blood served as the experimental values.

Prior to infusion of solutions baseline or initial conditions for pH, $pCO_2$ and $pO_2$ were established. Blood samples were obtained from the femoral artery, the unwarmed venous and warmed venous sample sites and analyzed as described above.

After baseline values were determined, various degrees of metabolic acid-base disturbances were induced in the animals.

Metabolic acidosis was induced in the first four dogs by a continuous intravenous infusion of approximately 5-7 mEq/kg·two hour of 0.3M $NH_4Cl$ (Russell, Illickal, Maloney, Roeher and Deland, 1972). Advancing acidosis was developed in varying degrees and samples were obtained at approximately 30 minute intervals over the decreasing pH range until the pH reached approximately 6.8 pH units. A minimum of seven sample points during acidosis were obtained.

Metabolic alkalosis was induced in the last four dogs by a continuous intravenous infusion of approximately 7-10 mEq/kg·hour of 1.0M $NaHCO_3$ (Russell, Illickal, Maloney, Rocher and Deland, 1972). Sampling procedures and number of samples taken were similar to that described for dogs being given ammonium chloride. Advancing alkalosis was produced until the pH of arterial blood reached values greater than 7.6.

# CHAPTER IV

# RESULTS

## General Information

The pH, $pCO_2$ and $pO_2$ in peripheral venous and arterial blood have been compared during various stages of metabolic acidosis and alkalosis. One hundred ninety-two samples were taken from a total of eight dogs, 4 male and 4 female. Table 4 shows the ranges of the blood-gas parameters studied.

Table 4

Ranges of Blood-gas Parameters

| | pH | $pCO_2$ mmHg | $pO_2$ mmHg | $HCO_3^-$ mEq/L |
|---|---|---|---|---|
| RANGE | 6.87-7.67 | 18-101 | 15-126 | 5-80 |

The temperature of the paw prior to heating ranged from $31^{o}$ - $36^{o}$ C. After heating took place, the range of temperatures in the warmed paw was $38^{o}$ - $42^{o}$ C. In each case the paw temperature was elevated by at least $5^{o}$ C during warming.

Throughout the experiments, the animals rectal (core) temperature, heart rate and respiratory rates were monitored. A summary of these measurements is found in Table 5.

In this study the limits of reproducibility for each sample were 0.005 for pH, 1.0 mmHg $pCO_2$ and 1.0 mmHg $pO_2$. All pH values were within the 0.005 reproducibility limit. From the 192 samples for $pCO_2$ only 3

Table 5

Summary of the Mean of Means and Standard Error of the Mean for Temperature, Heart Rate and Respiratory Rate.

| | TEMPERATURE | HEART RATE | RESPIRATORY RATE |
|---|---|---|---|
| Mean of Means | 37.9 | 145 | 22 |
| S.E.M. | $\pm$0.34 | $\pm$6.5 | $\pm$2.0 |

exceeded the 1.0 mmHg limit, the highest value being 1.5 mmHg. Five of the 192 samples for $pO_2$ exceeded the 1.0 mmHg limit, the highest being 2.2 mmHg.

Figures 2 through 9 show the results of blood-gas analysis obtained from 192 samples of blood taken from 8 animals. The warmed and unwarmed venous blood samples were taken under free flowing (without stasis) conditions from indwelling venous catheters. The arterial blood sample was obtained simultaneously via the femoral artery. The identity line at $45^{o}$ to the axes in Figures 2 through 9 indicates where the values would lie if the warmed or unwarmed venous blood-gas parameters were identical to the arterial blood-gas parameters.

A number of statistical tests were used to analyze the differences between the blood-gas parameters of warmed venous blood vs arterial blood, and unwarmed venous blood vs arterial blood. Raw data from which the data in Tables 6 through 10 was computed may be found in Appendix C.

The rest of the results of this study are organized and discussed under the following headings: pH, $pCO_2$, $pO_2$ and $\{HCO_3^-\}$ .

pH

Figures 2 and 3 show the relationship of the pH of warmed and unwarmed venous blood as a function of the pH of arterial blood.

In Figure 2 it appears from visual inspection that the values from all 8 animals cluster around the identity line. The mean of the mean difference of all warmed venous points from the identity line in Figure 2 is 0.014 $\pm$ 0.003 S.E.M. (Table 6). The mean 'r' value for the data in Figure 2 is 0.992 $\pm$ 0.012 SD (Table 7). The mean of the slopes computed from the data obtained from all 8 animals is 0.965 $\pm$ 0.045 SD, with an average 'Y' intercept of 0.249 $\pm$ 0.326 SD (Tables 8 and 9).

Figure 3 shows the relationship of the pH of unwarmed venous blood to that of arterial blood. Again it appears from visual inspection that the points cluster around the identity line until the pH reaches approximately 7.50, then the points deviate to the right of the identity line.

The calculated mean of the mean differences of all unwarmed venous points from the identity line in Figure 3 is 0.046 $\pm$ 0.008 S.E.M.(Table 6).

The mean 'r' for data shown in Figure 3 is 0.959 $\pm$ 0.05 SD (Table 7). The mean of the slopes (arterial vs unwarmed venous blood) computed from the data of the 8 animals is 0.82 $\pm$ 0.21 SD, with a mean 'Y' intercept of 1.30 $\pm$ 1.54 SD (Tables 8 and 9).

Significant differences were found in the pH identity relationship between warmed and unwarmed venous blood for both slopes and 'Y' intercepts (Tables 8 and 9). There is a significant difference between the mean of means for all 8 animals as shown in Table 6. The difference listed is computed as follows:

Difference = (A-W)- (A-UnW) (7) where,

A is the pH of arterial blood,
W is the pH of warmed venous blood, and
UnW is the pH of unwarmed venous blood.

## $pCO_2$

Figures 4 and 5 depict the relationship between the $pCO_2$ of warmed and unwarmed venous blood as a function of the $pCO_2$ of arterial blood. In both figures the points from all 8 animals appear to distribute around a line nearly parallel to and to the left of the identity line.

The calculated mean of the mean differences of the warmed and unwarmed venous points from the identity line in Figures 4 and 5 is -2.7 mmHg $\pm$ 0.6 S.E.M. and -6.2 mmHg $\pm$ 1.3 S.E.M., respectively (Table 6).

The mean value for 'r' in all 8 animals is shown in Table 7. For the $pCO_2$ of warmed and unwarmed venous blood as a function of arterial $pCO_2$ the mean 'r' is 0.923 $\pm$ 0.054 SD and 0.801 $\pm$ 0.306 SD, respectively.

The mean of the slopes computed from the data of the 8 animals shown in Figure 4 is 0.9 $\pm$ 0.1 SD, with an average 'Y' intercept of 4.5 mmHg $\pm$ 6.0 SD (Tables 8 and 9). For Figure 5 the mean of the slopes computed from the data obtained from all 8 animals is 0.8 $\pm$ 0.4 SD, with the mean 'Y' intercept of 10.5 mmHg $\pm$ 18.5 SD (Tables 8 and 9).

## $pO_2$

Figures 6 and 7 show the relationship of the $pO_2$ of warmed and unwarmed venous blood as a function of the $pO_2$ of arterial blood.

Except for one point in each figure all the points from the 8 animals in both figures fall below the identity line. The mean of mean differences between the points and the identity line in Figure 6 (warmed venous blood)

for all 8 animals is 15.6 mmHg $\pm$ 2.0 S.E.M. and in Figure 7 (unwarmed venous blood) is 23.3 mmHg $\pm$ 2.7 S.E.M. (Table 6).

Data for the calculated mean values of 'r' for all 8 animals is reported in Table 7. The mean values for 'r' for the $pO_2$ of warmed and unwarmed venous blood in relation to the $pO_2$ of arterial blood are 0.826 $\pm$ 0.152 SD and 0.556 $\pm$ 0.37 SD, respectively.

Tables 8 and 9 contain the data from the computed mean of the slopes and 'Y' intercepts. The calculated mean of the slopes for $pO_2$ in warmed venous blood vs $pO_2$ in arterial blood is 0.7 $\pm$ 0.2 SD with a mean 'Y' intercept of 11.1 mmHg $\pm$ 7.6 SD. For the $pO_2$ of unwarmed venous blood vs $pO_2$ of arterial blood the mean of the slopes is 0.5 $\pm$ 0.3 SD, with an average 'Y' intercept of 16.5 mmHg $\pm$ 30.1 SD.

$HCO_3^-$

The relationship of the $\{HCO_3^-\}$ of warmed and unwarmed venous blood as a function of the $\{HCO_3^-\}$ of arterial blood is found in Figures 8 and 9.

From visual inspection it appears that the values from all 8 animals cluster around the identity line in Figure 8. Figure 9, on the other hand, shows the same relationship until the $\{HCO_3^-\}$ reaches approximately 40 mEq/L. At that point the values deviate to the right of the identity line.

The mean of mean differences of all warmed venous points from the identity line in Figure 8 is - 0.04 mEq/L $\pm$ 0.23 S.E.M. (Table 6). The mean 'r' value for the data in Figure 8 is 0.991 $\pm$ 0.013 SD (Table 7). The mean of the slopes (warmed vs arterial) computed from the data obtained from all 8 animals is 1.0 $\pm$ 0.05 SD, with a mean 'Y' intercept of 0.6 mEq/L $\pm$ 1.4 SD (Tables 8 and 9).

The calculated mean of mean differences of all unwarmed venous points

from the identity line in Figure 9 is 1.0 mEq/L $\pm$ 0.7 S.E.M. (Table 6). The mean 'r' for data shown in Figure 9 is 0.992 $\pm$ 0.008 SD (Table 7). The mean of the slopes (arterial vs unwarmed venous blood) computed from the data of the 8 animals is 0.9 $\pm$ 0.1 SD, with an average 'Y' intercept of 3.9 mEq/L $\pm$ 3.7 SD (Tables 8 and 9).

Significant differences between mean slopes were found in the $\{ HCO_3^- \}$ identity relationship between warmed and unwarmed venous blood (Table 8).

The numbers shown in Table 10 are the Standard Errors of Estimate that were obtained from all 8 animals. These values give the standard error that can be expected if the values from warmed or unwarmed venous blood-gases are used to predict the arterial blood-gas values.

A summary of all results can be found in Table 11.

Figure 2: Arterial blood vs warmed venous blood pH in all 8 animals. The straight line at $45^{o}$ to the axes indicates where the values would lie if the pH of warmed venous blood were identical to the pH of arterial blood.

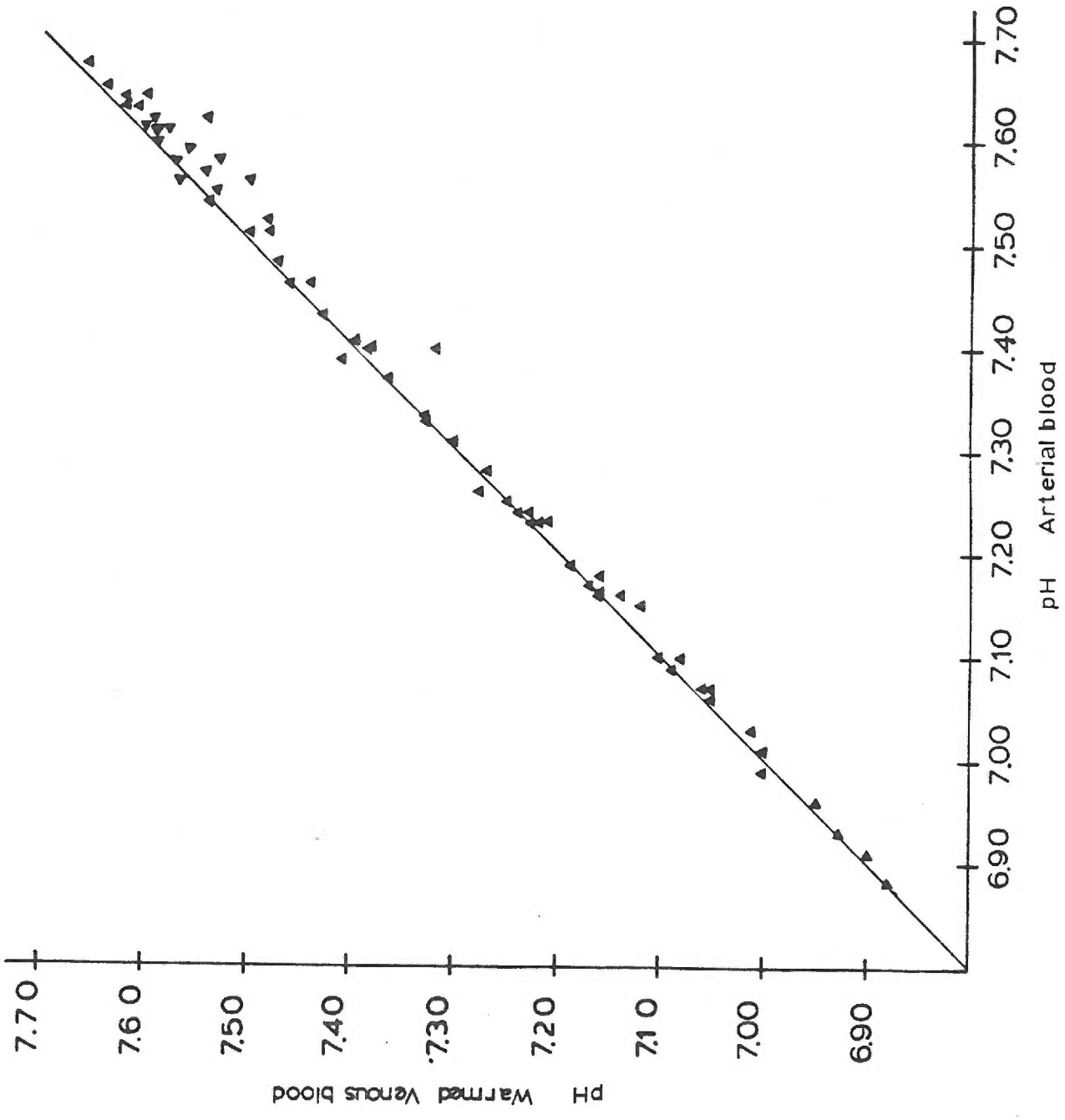
7.70
7.60
7.50
7.40
7.30
7.20
7.10
7.00
6.90
pH Warmed Venous blood
6.90
7.00
7.10
7.20
7.30
7.40
7.50
7.60
7.70
pH Arterial blood

Figure 3: Arterial blood vs unwarmed venous blood pH in all 8 animals. The straight line at $45^{o}$ to the axes indicates where the values would lie if the pH of unwarmed venous blood were identical to the pH of arterial blood.

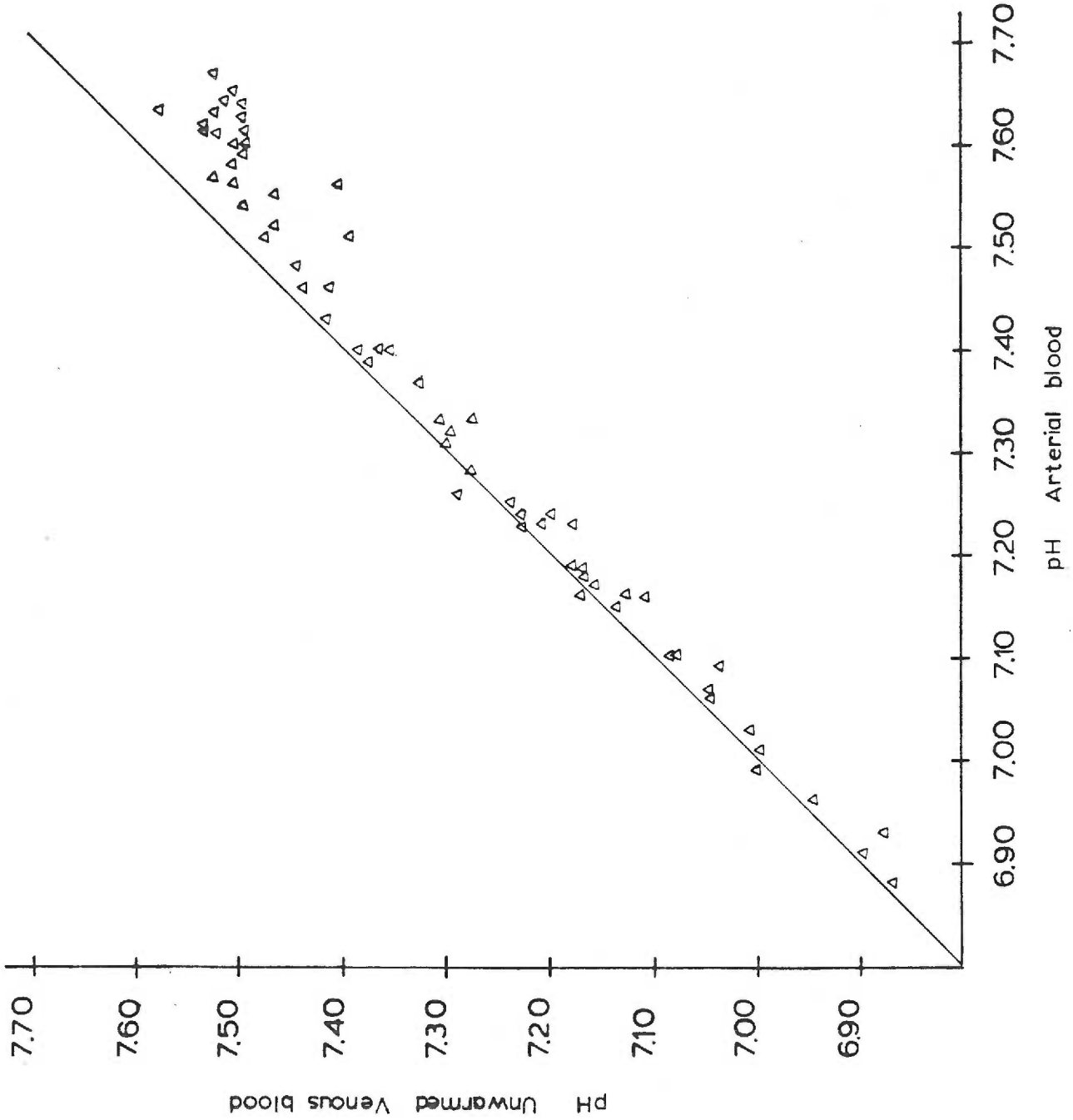
7.70
7.60
7.50
7.40
7.30
7.20
7.10
7.00
6.90
pH Unwarmed Venous blood
6.90
7.00
7.10
7.20
7.30
7.40
7.50
7.60
7.70
pH Arterial blood

Figure 4: $pCO_2$ of arterial blood vs the $pCO_2$ of warmed venous blood in all 8 animals. The straight line at $45^{o}$ to the axes indicates where the values would lie if the $pCO_2$ of warmed venous blood were identical to the $pCO_2$ of arterial blood.

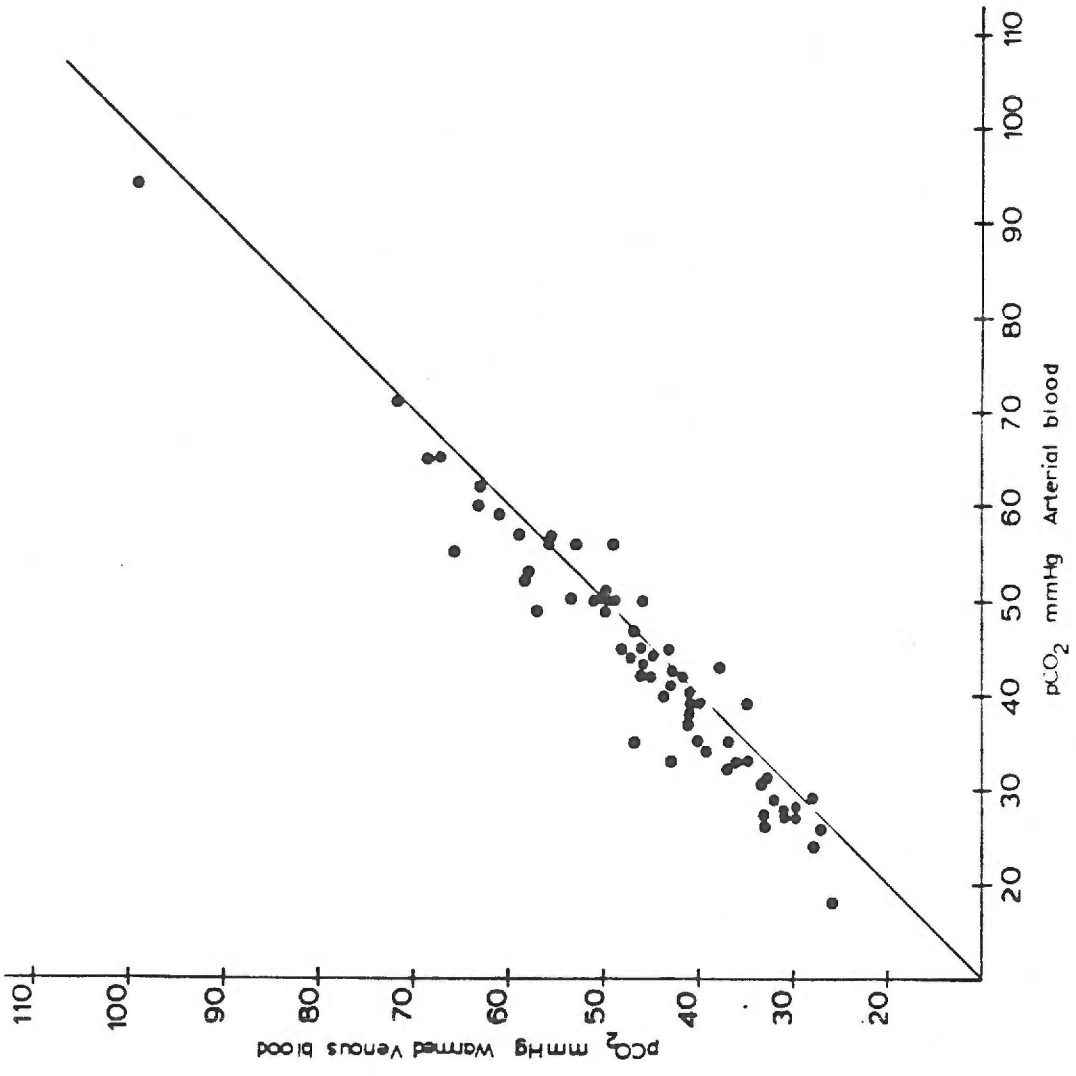
$pCO_2$ mmHg Arterial blood
$pCO_2$ mmHg Warmed Venous blood
20
30
40
50
60
70
80
90
100
110

Figure 5: $pCO_2$ arterial blood vs the $pCO_2$ of unwarmed venous blood in all 8 animals. The straight line at $45^o$ to the axes indicates where the values would lie if the unwarmed venous blood $pCO_2$ were identical to the arterial blood $pCO_2$.

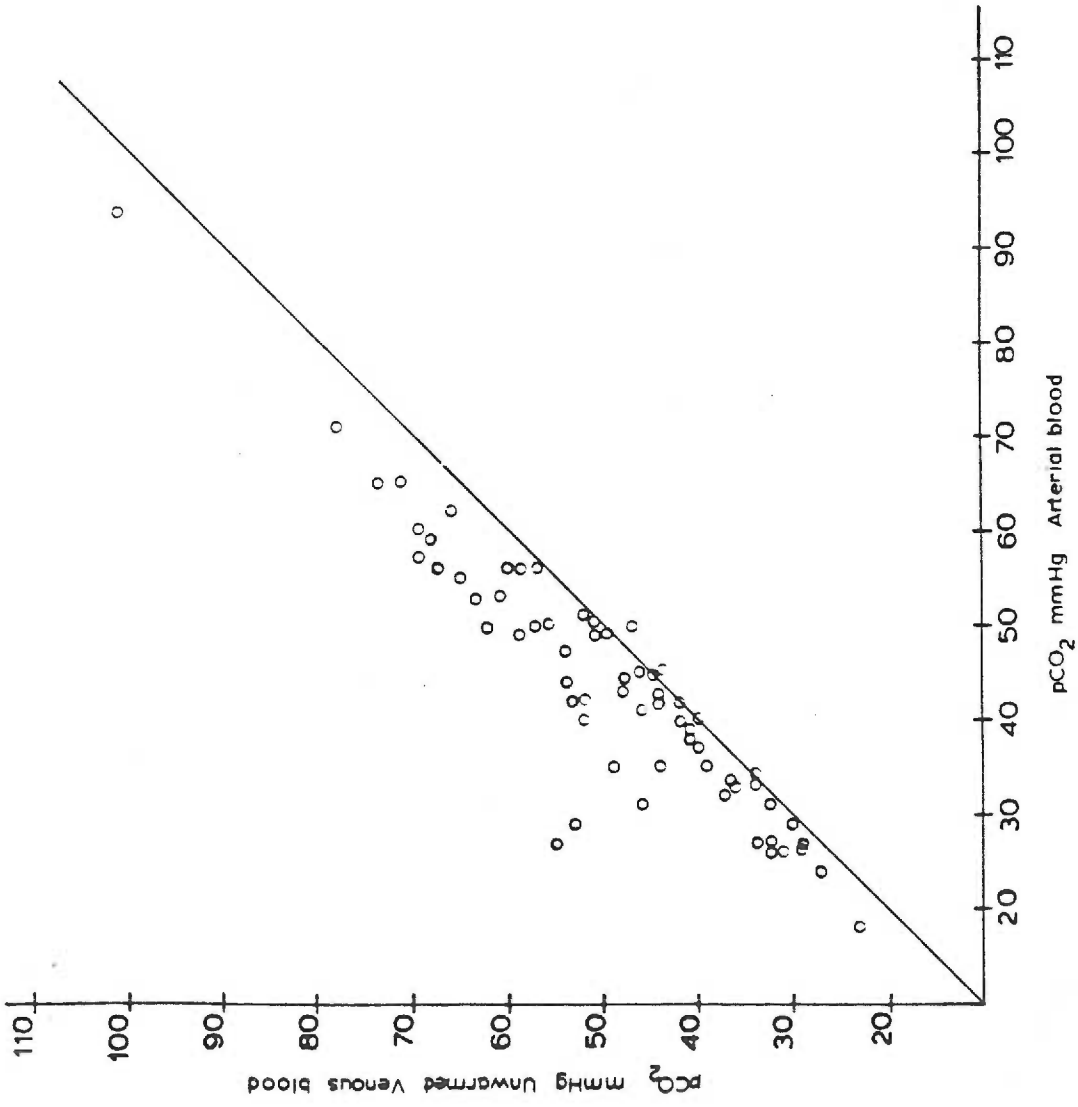
$pCO_2$ mmHg Arterial blood
$pCO_2$ mmHg Unwarmed Venous blood
20
30
40
50
60
70
80
90
100
110

Figure 6: An identity plot of the $pO_2$ of arterial blood vs the $pO_2$ of warmed venous blood in all 8 animals. The straight line at $45^{o}$ to the axes indicates where the values would lie if the $pO_2$ of warmed venous blood were identical to that of arterial blood.

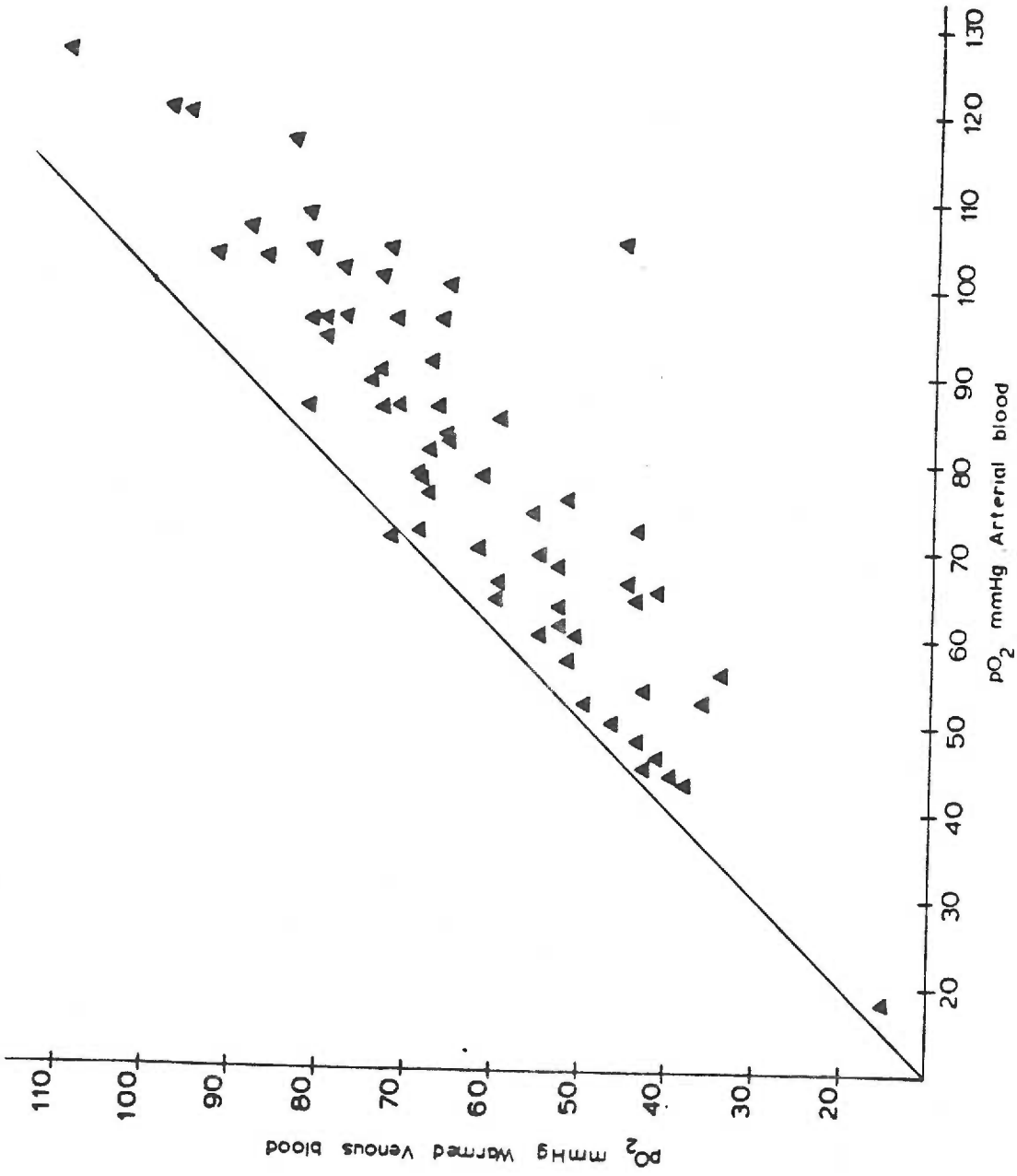
$pO_2$ mmHg Arterial blood
20
30
40
50
60
70
80
90
100
110
120
130
$pO_2$ mmHg Warmed Venous blood
20
30
40
50
60
70
80
90
100
110

Figure 7: An identity plot of the $pO_2$ of arterial blood vs the $pO_2$ of unwarmed venous blood in all 8 animals. The straight line at $45^{o}$ to the axes indicates where the values would lie if the $pO_2$ of unwarmed venous blood were identical to that of arterial blood.

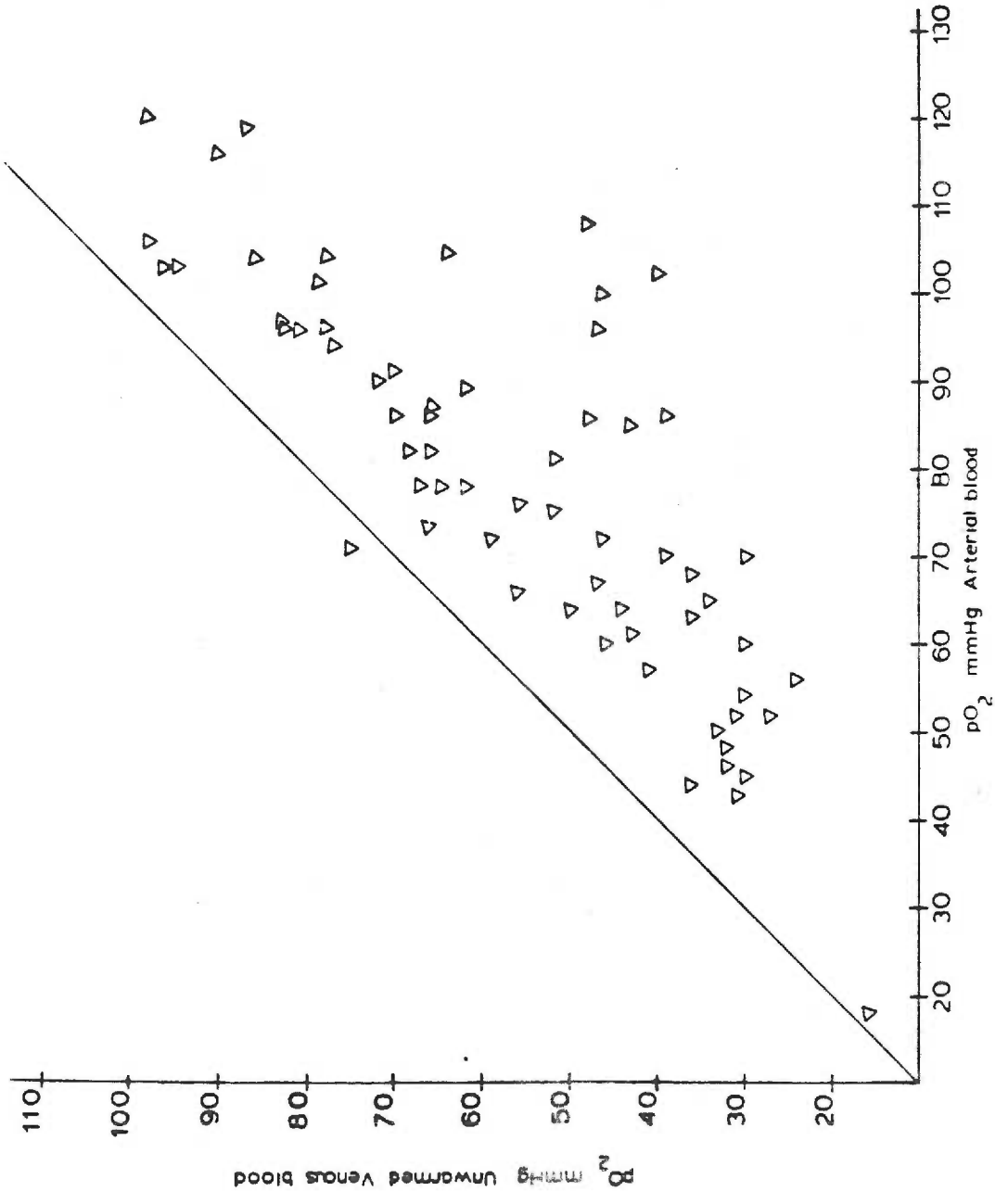
$pO_2$ mmHg Arterial blood
20
30
40
50
60
70
80
90
100
110
120
130
$pO_2$ mmHg Unwarmed Venous blood
20
30
40
50
60
70
80
90
100
110

Figure 8: $HCO_3^-$ concentration of arterial blood vs the $HCO_3^-$ concentration of warmed venous blood in all 8 animals. The straight line at $45^o$ to the axes indicates where the values would lie if the $HCO_3^-$ concentration of warmed venous blood were identical to that of arterial blood.

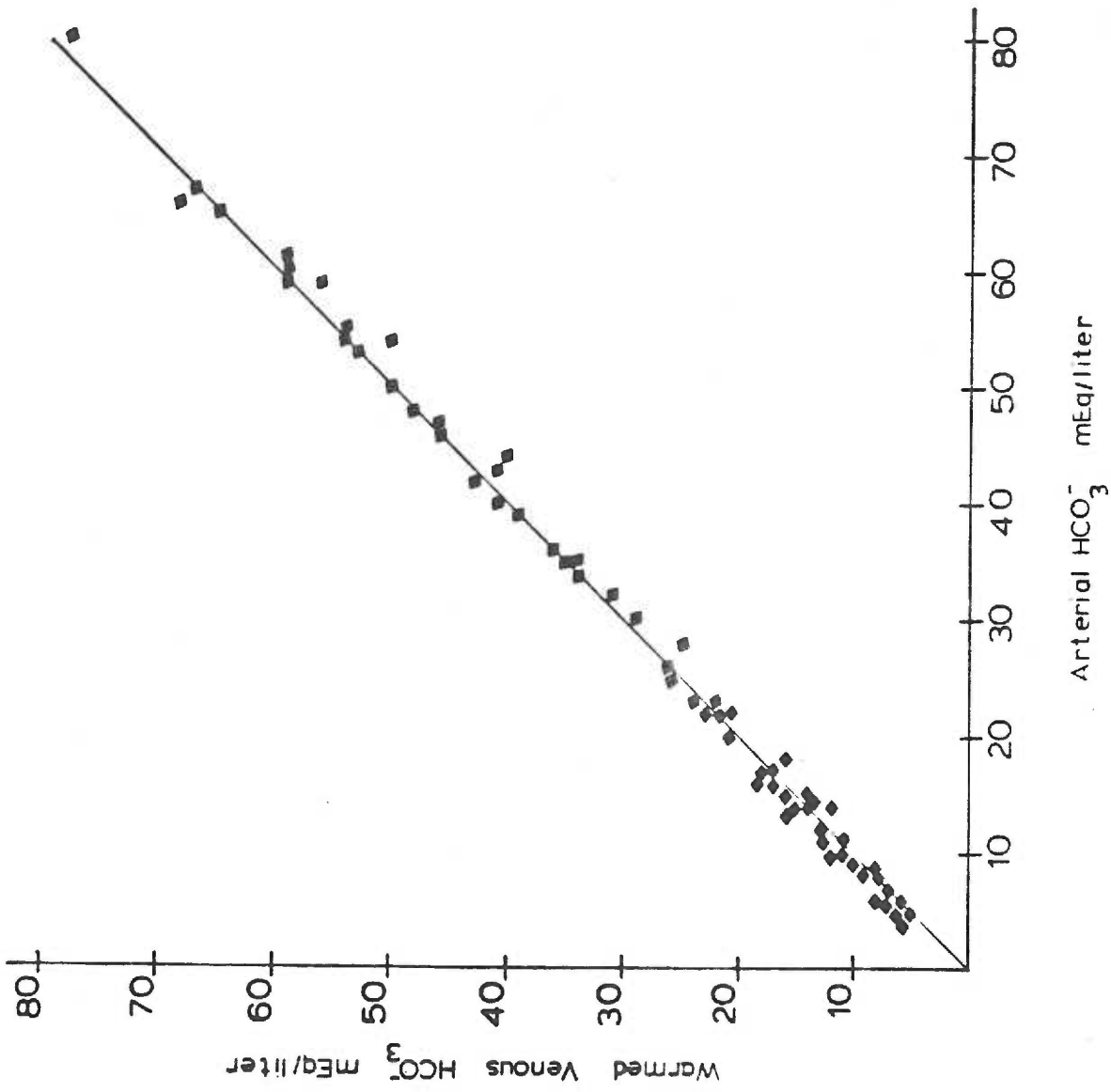
Warmed Venous $HCO_3^-$ mEq/liter
80
70
60
50
40
30
20
10
10
20
30
40
50
60
70
80
Arterial $HCO_3^-$ mEq/liter

Figure 9: $HCO_3^-$ concentration of arterial blood vs the $HCO_3^-$ concentration of unwarmed venous blood in all 8 animals. The straight line at $45^o$ to the axes indicates where the values would lie if the $HCO_3^-$ concentration of unwarmed venous blood were identical to that of arterial blood.

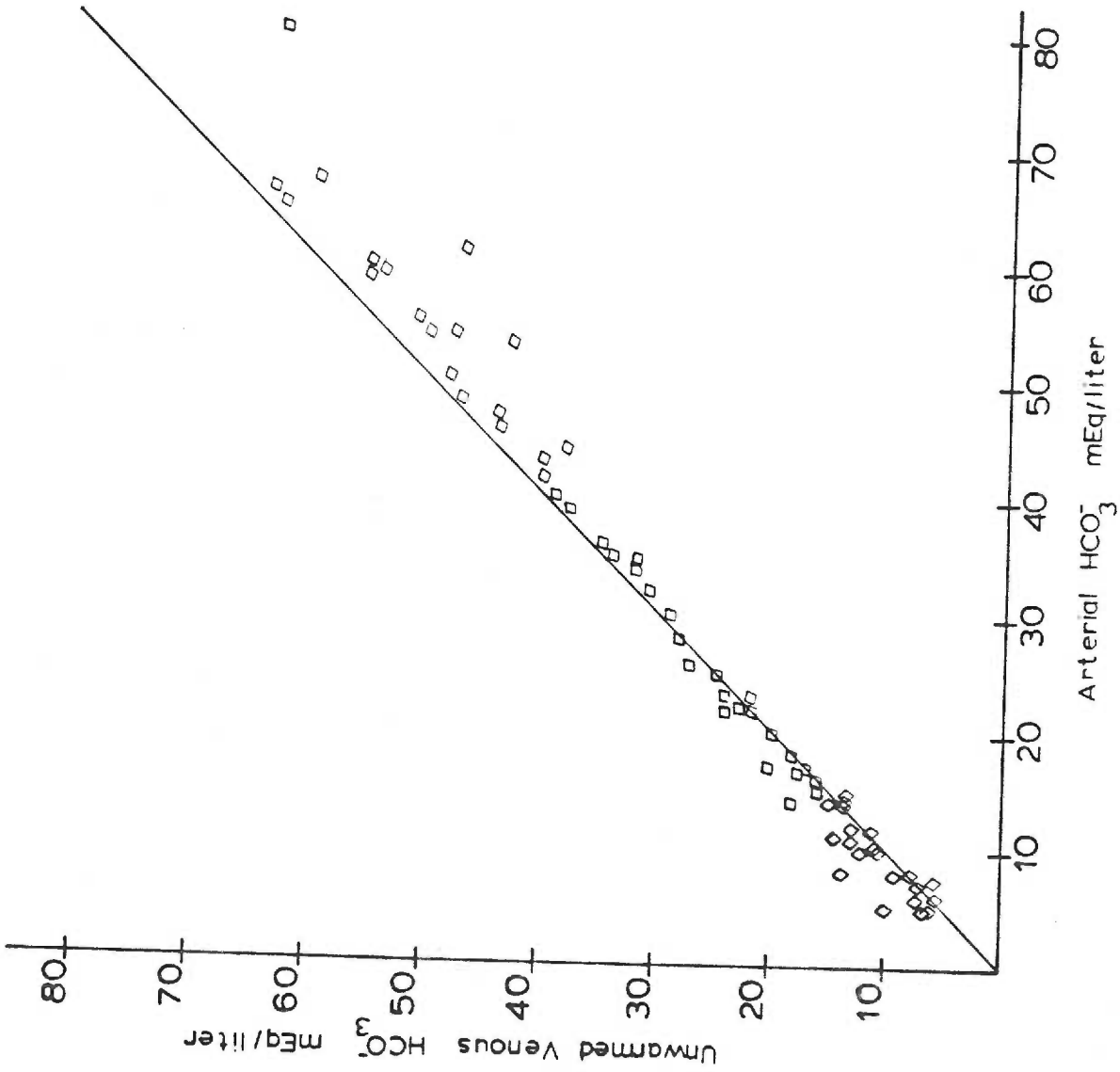
Unwarmed Venous $HCO_3^-$ mEq/liter
Arterial $HCO_3^-$ mEq/liter
10
20
30
40
50
60
70
80

TABLE 6

Comparison of Mean Differences.
Arterial Blood minus Warmed Venous Blood and Arterial Blood minus Unwarmed Venous Blood

| | pH | | $pCO_2$ mmHg | | $pO_2$ mmHg | | $HCO_3^-$ mEq/L | |
|---|---|---|---|---|---|---|---|---|
| | A - W* | A - UnW** | A - W | A - UnW | A - W | A - UnW | A - W | A - UnW |
| | | | Animals Receiving $NH_4$ CL (Acid Dogs, n=4) | | | | | |
| Mean of Means | 0.008 | 0.019 | -3.5 | -6.8 | 20.3 | 25.4 | -0.7 | -1.3 |
| S.E.M. | 0.003 | 0.009 | 0.8 | 3.9 | 3.6 | 7.5 | 0.2 | 0.7 |
| 't' | -1.187 | | 0.886 | | -0.789 | | 0.741 | |
| | | | Animals Receiving $NaHCO_3$ (Base Dogs, n=4) | | | | | |
| | 0.021 | 0.072 | -1.8 | -5.6 | 10.8 | 21.1 | 0.6 | 3.4 |
| | 0.008 | 0.005 | 1.4 | 0.6 | 3.0 | 2.9 | 0.4 | 0.9 |
| | -4.193* | | 3.192* | | -2.970 | | -5.441** | |
| | | | All animals (Acid plus Base, n=8) | | | | | |
| Mean of Means | 0.014 | 0.046 | -2.7 | -6.2 | 15.6 | 23.3 | -0.04 | 1.0 |
| S.E.M. | 0.003 | 0.008 | 0.6 | 1.3 | 2.0 | 2.7 | 0.23 | 0.7 |
| 't' | -3.013** | | 1.964 | | -2.016 | | -1.368 | |

p* < 0.05 p** < 0.02
'p' is the probability that the two values tested are identical

S.E.M. is Standard Error of Means
A minus W* is Arterial Blood minus Warmed Venous Blood
A minus UnW** is Arterial Blood minus Unwarmed Venous Blood

"t" is the value obtained when the difference between means from warmed and unwarmed venous blood was tested for significance.

TABLE 7

Comparison of Pearson's 'r'.
Arterial Blood vs Warmed Venous Blood and Arterial Blood vs Unwarmed Venous Blood

| | pH | | $pCO_2$ mmHg | | $pO_2$ mmHg | | $HCO_3^-$ mEq/L | |
|---|---|---|---|---|---|---|---|---|
| | A vs W * | A vs UnW** | A vs W | A vs UnW | A vs W | A vs UnW | A vs W | A vs UnW |
| | | | Animal Receiving $NH_4Cl$ (Acid Dogs, n=4) | | | | | |
| Mean | 0.993 | 0.966 | 0.904 | 0.726 | 0.754 | 0.354 | 0.986 | 0.995 |
| Std.Div. | 0.007 | 0.003 | 0.055 | 0.409 | 0.181 | 0.448 | 0.018 | 0.002 |
| 't' | -0.698 | | 0.783 | | 1.330 | | -0.938 | |
| | | | Animals Receiving $NaHCO_3$ (Base Dogs, n=4) | | | | | |
| Mean | 0.990 | 0.923 | 0.942 | 0.876 | 0.892 | 0.759 | 0.996 | 0.988 |
| Std.Div. | 0.016 | 0.046 | 0.053 | 0.190 | 0.097 | 0.103 | 0.003 | 0.011 |
| 't' | 2.943 | | 0.925 | | 3.009* | | 1.729 | |
| | | | All animals (Acid plus Base, n=8) | | | | | |
| Mean | 0.992 | 0.959 | 0.923 | 0.801 | 0.826 | 0.556 | 0.991 | 0.992 |
| Std.Div. | 0.012 | 0.050 | 0.054 | 0.306 | 0.152 | 0.370 | 0.013 | 0.008 |
| 't' | 1.897 | | 1.085 | | 1.825 | | -0.040 | |

p* = 0.05
'p' is the probability that the two values tested are identical

A vs W* is Arterial Blood vs Warmed Venous Blood
A vs UnW** is Arterial Blood vs Unwarmed Venous Blood

"t" is the value obtained when the difference between means from warmed and unwarmed venous blood was tested for significance

TABLE 8

Comparison of Mean Slopes
Arterial Blood vs Warmed Venous Blood and Arterial Blood vs Unwarmed Venous Blood

| | pH | | $pCO_2$ mmHg | | $pO_2$ mmHg | | $HCO_3^-$ mEq/L | |
|---|---|---|---|---|---|---|---|---|
| | A vs W* | A vs UnW** | A vs W | A vs UnW | A vs W | A vs UnW | A vs W | A vs UnW |
| | | | | Animals Receiving $NH_4Cl$ (Acid Dogs, n=4) | | | | |
| Mean | 1.0 | 1.01 | 0.8 | 0.6 | 0.6 | 0.3 | 1.0 | 0.9 |
| Std.Div. | 0.04 | 0.04 | 0.1 | 0.4 | 0.1 | 0.4 | 0.06 | 0.1 |
| 't' | | -3.857* | | 0.875 | | 1.820 | | 0.896 |
| | | | | Animals Receiving $NaHCO_3$ (Base Dogs, n=4) | | | | |
| Mean | 0.93 | 0.63 | 1.0 | 1.1 | 0.7 | 0.7 | 1.0 | 0.8 |
| Std.Div. | 0.01 | 0.05 | 0.1 | 0.2 | 0.2 | 0.1 | 0.04 | 0.1 |
| 't' | | 10.899** | | 0.925 | | -0.343 | | 2.553 |
| | | | | All animals (Acid plus Base, n=8) | | | | |
| Mean | 0.96 | 0.82 | 0.9 | 0.8 | 0.7 | 0.5 | 1.0 | 0.9 |
| Std.Div. | 0.04 | 0.21 | 0.1 | 0.4 | 0.2 | 0.3 | 0.05 | 0.1 |
| 't' | | 2.377* | | 1.158 | | 1.269 | | 2.377* |

p* < 0.05 p** < 0.01
'p' is the probability that the two values tested are identical

A vs W* is Arterial Blood vs Warmed Venous Blood
A vs UnW** is Arterial Blood vs Unwarmed Venous Blood

"t" is the value obtained when the difference between means from warmed and unwarmed venous blood was tested for significance

TABLE 9

Comparison of "Y" Intercepts.
Arterial Blood vs Warmed Venous Blood and Arterial Blood vs Unwarmed Venous Blood

| | pH | | $pCO_2$ mmHg | | $pO_2$ mmHg | | $HCO_3^-$ mEq/L | |
|---|---|---|---|---|---|---|---|---|
| | A vs W* | A vs UnW** | A vs W | A vs UnW | A vs W | A vs UnW | A vs W | A vs UnW |
| | | | Animals Receiving $NH_4Cl$ (Acid Dogs, n=4) | | | | | |
| Mean | -0.003 | -0.10 | 8.4 | 19.4 | 14.0 | 38.1 | 1.2 | 2.4 |
| Std.Div. | 0.266 | 0.26 | 3.6 | 20.7 | 8.0 | 28.9 | 0.7 | 2.4 |
| 't' | 3.102* | | -0.909 | | -2.227 | | -0.876 | |
| | | | Animals Receiving $NaHCO_3$ (Base Dogs, n=4) | | | | | |
| Mean | 0.50 | 2.72 | 0.6 | 1.7 | 8.2 | -5.0 | 0.1 | 5.4 |
| Std.Div. | 0.09 | 0.40 | 5.6 | 12.6 | 7.0 | 6.0 | 1.8 | 4.4 |
| 't' | -11.114** | | -0.212 | | 2.882 | | -1.920 | |
| | | | All animals (Acid plus Base, n=8) | | | | | |
| Mean | 0.25 | 1.30 | 4.5 | 10.5 | 11.1 | 16.5 | 0.6 | 3.9 |
| Std.Div. | 0.33 | 1.54 | 6.0 | 18.5 | 7.6 | 30.1 | 1.4 | 3.7 |
| 't' | -2.36* | | -0.949 | | -0.612 | | -2.01 | |

p* = 0.05 p** < 0.01
'p' is the probability that the two values tested are identical

A vs W* is Arterial Blood vs Warmed Venous Blood
A vs UnW** is Arterial Blood vs Unwarmed Venous Blood

"t" is the value obtained when the difference between means from warmed and unwarmed venous blood was tested for significance

TABLE 10

Comparison of the Standard Error of Estimate.
Arterial Blood vs Warmed Venous Blood and Arterial Blood vs Unwarmed Venous Blood

| | pH | | $pCO_2$ mmHg | | $pO_2$ mmHg | | $HCO_3^-$ mEq/L | |
|---|---|---|---|---|---|---|---|---|
| | A vs W* | A vs UnW** | A vs W | A vs UnW | A vs W | A vs UnW | A vs W | A vs UnW |
| | All Animals (Acid plus Base, n=8) | | | | | | | |
| Mean | 0.012 | 0.025 | 2.8 | 3.6 | 6.0 | 9.1 | 1.0 | 1.4 |
| Std.Div. | 0.008 | 0.018 | 1.0 | 2.1 | 2.6 | 4.1 | 0.4 | 1.1 |
| 't' | -1.716 | | -0.874 | | -2.414* | | -1.093 | |

p* < 0.05
'p' is the probability that the two values tested are identical

A vs W* is Arterial Blood vs Warmed Venous Blood
A vs UnW** is Arterial Blood vs Unwarmed Venous Blood

"t" is the value obtained when the difference between means from warmed and unwarmed venous blood was tested for significance

TABLE 11

Summary of Results

| Parameters | Range | Mean of the Mean Differences* | Standard Error of Estimate | 'r' | Slope | 'Y' Intercept |
|---|---|---|---|---|---|---|
| | | Warmed Venous Blood vs Arterial Blood | | | | |
| pH | (6.87-7.67) | 0.014±0.003 | 0.012±0.008 | 0.992±0.012 | 0.96±0.04 | 0.25±0.33 |
| $pCO_2$ mmHg | (18-101) | -2.7 ±0.6 | 2.8 ±1.0 | 0.923±0.054 | 0.9 ±0.1 | 4.5 ±6.0 |
| $pO_2$ mmHg | (15-126) | 15.6 ±2.0 | 6.0 ±2.6 | 0.826±0.152 | 0.7 ±0.2 | 11.1 ±7.6 |
| $HCO_3$ mEq/L | (5-80) | -0.04 ±1.0 | 1.0 ±0.4 | 0.991±0.013 | 1.0 ±0.05 | 0.6 ±1.4 |
| | | Unwarmed Venous Blood vs Arterial Blood | | | | |
| pH | (6.87-7.67) | 0.046±0.008 | 0.025±0.018 | 0.959±0.05 | 0.82±0.21 | 1.30±1.54 |
| $pCO_2$ mmHg | (18-101) | -6.2 ±1.3 | 3.6 ±2.1 | 0.801±0.306 | 0.8 ±0.4 | 10.5 ±18.5 |
| $pO_2$ mmHg | (15-126) | 23.3 ±2.7 | 9.1 ±4.1 | 0.556±0.37 | 0.5 ±0.3 | 16.5 ±30.1 |
| $HCO_3$ mEq/L | (5-80) | 1.0 ±0.7 | 1.4 ±1.1 | 0.992±0.008 | 0.9 ±0.1 | 3.9 ± 3.7 |

Mean of the Mean Differences is defined as Difference = (A-W)- (A-UnW) where

A is the value of Arterial Blood,
W is the value of Warmed Venous Blood, and
UnW is the value of Unwarmed Venous Blood.

# CHAPTER V

# DISCUSSION

## Warmed vs Unwarmed Venous Blood

The results of this study show that for the determination of pH, $pCO_2$, $pO_2$ and $\{HCO_3^-\}$ the use of warmed venous blood provides a better estimate of arterial blood than unwarmed venous blood.

From inspection of the identity plots (Figures 2-9) it is apparent that in general points obtained from warmed venous blood vs arterial blood cluster closer to the identity lines than those of unwarmed venous blood vs arterial blood.

The mean 'r' values for all blood-gas parameters, with the exception of$\{HCO_3^-\}$are consistently higher for the warmed vs arterial blood than the unwarmed vs arterial blood. In the case of$\{HCO_3^-\}$the mean 'r' value calculated from the data in Figure 8 (warmed venous blood) was $0.991 \pm 0.013$ and that from unwarmed venous blood (Figure 9) was $0.992 \pm 0.008$.

The mean of the slopes calculated for each blood-gas parameter is closer to the value of 1.0 when warmed venous blood rather than unwarmed venous blood is plotted as a function of arterial blood. In addition, the intercepts for all parameters are closer to the intercept of the identity line when warmed rather than unwarmed venous blood is used (Table 11).

The mean of mean differences and standard error of the mean are consistently less for arterial minus warmed venous blood than arterial minus unwarmed venous blood (Equation 7, Table 11). Normally, pH varies within the range of 7.37-7.43 (Keyes, 1976). If warmed venous blood is used

to estimate arterial pH a difference (arterial minus warmed venous pH) of approximately 1/6 the normal pH range may be seen, while using unwarmed venous blood a difference (arterial minus unwarmed venous pH) of approximately 5/6 of the normal pH range is observed (Table 11).

The standard error of estimate provides information with regard to the error that can be expected in measuring a blood-gas parameter using warmed or unwarmed venous blood in lieu of arterial blood. A smaller standard error is seen when blood-gas values of warmed rather than unwarmed venous blood are used to estimate blood-gas values of arterial blood (Table 11).

Differences Observed Between Acid and Base Dogs

When grouping the 8 animals into those who received $NH_4Cl$ (acid dogs) and those who received $NaHCO_3$ ( base dogs) specific differences were noted. For example, in Table 6, when 't' tests were performed between the mean of mean differences of the arterial minus warmed venous blood and arterial minus unwarmed venous blood significant difference was found only in the base group. All differences with the exception of that for $pO_2$ were significant at the 0.05 level. For $pO_2$ the probability that the difference was equal to zero was between 0.05 and 0.1. No significant differences were seen in the acid group.

There are several possibilities that might explain the observed differences between the acid and base dogs.

1) In metabolic alkalosis there is an increase in pH which causes the oxyhemoglobin dissociation curve to shift to the left. A shift to the left increases the affinity between hemoglobin (Hgb) and oxygen ($O_2$). An increased affinity causes Hgb to bind more tightly with $O_2$. This shift

to the left probably occurred in the base dogs because of the rapid transfer of $HCO_3^-$ across the red cell membrane. Therefore, as $HCO_3^-$ increases in the plasma, pH of red cell water increases. Thus, in metabolic alkalosis the $pO_2$ must be reduced to much lower values to cause Hgb to release the same amount of $O_2$ than is released at a higher $pO_2$ in acidosis or in normal acid-base balance. When there is less $O_2$ available to the tissues anaerobic metabolism may ensue with a subsequent increase in lactic acid production. An increase in lactic acid production will cause a widening of the difference in pH between peripheral venous blood and arterial blood in metabolic alkalosis. This widening phenomena was observed in this study as shown in Figure 3. After the pH reached approximately 7.50 the points deviated to the right of the identity line causing a widening between the points and the identity line. This widening was not as apparent or as great in Figure 2 (warmed venous blood).

For the base dogs there are at least two possible explanations why the values of blood-gas parameters in warmed venous blood mimicked those in arterial blood more closely than those from unwarmed venous blood. First, increased temperature at the peripheral site causes a decreased affinity between Hgb and $O_2$ (Slonim and Hamilton, 1976). The reduced affinity for $O_2$ causes an increase in $O_2$ unloading into the surrounding tissues at a higher $pO_2$ than occurs in unwarmed tissues at the same pH. Secondly, increasing the flow to the sample site causes wash out of the lactic acid that may have built up during anaerobic metabolism. In addition, increased flow causes an increased delivery of $O_2$ to the peripheral tissues thereby making more $O_2$ available to the tissues for metabolism.

According to Figure 1 (Introduction), and the equations that follow,

changes in blood-gas composition of blood as it flows through the tissues are a function of both blood flow and metabolic demands of the surrounding tissues. Therefore, if blood flow increases sufficiently, because of warming, the blood in the superficial paw veins should not be measurably different from arterial blood in terms of pH, $pCO_2$, $pO_2$ and $\{HCO_3^-\}$. This argument could account for the significant difference found in the group of base dogs when comparing arterial minus warmed venous blood to arterial minus unwarmed venous blood.

If the above discussion is valid it can be hypothesized that in metabolic alkalosis the blood-gas composition of warmed venous blood is approximately the same as that of arterial blood, while unwarmed venous blood becomes more unlike arterial blood.

2) A similar argument to that presented above further supports the findings of significant differences between acid and base dogs. In metabolic acidosis there is a decrease in pH which causes the oxyhemoglobin dissociation curve to shift to the right. A shift to the right will decrease the affinity between Hgb and $O_2$, therefore Hgb will unload $O_2$ more readily into the peripheral tissues. Thus, at constant temperatures, in metabolic acidosis Hgb will release the same amount of $O_2$ at higher levels of $pO_2$ than occurs in alkalosis or in normal acid-base balance. With sufficient amounts of $O_2$ at the cellular level the problems associated with anaerobic metabolism will not be as likely to occur. Therefore, the widening that was seen at pH values about 7.5 will not necessarily be seen in metabolic acidosis. Therefore, warming the paw during stages of acidosis may not change the pH, $pCO_2$, $pO_2$ and $\{HCO_3^-\}$, composition of the warmed peripheral venous blood as dramatically as was noted during stages

of increasing metabolic alkalosis.

3) Another explanation for the significant difference seen between acid and base dogs could be experimental error. Since acidosis was induced in the first four dogs in this study and alkalosis was induced in the last four dogs improvement in experimental technique could be a possible explanation for the significant difference noted in the latter group of animals. This explanation is not as likely to be correct since the investigator had developed considerable skill with the use of the equipment and procedures prior to the beginning of this study.

Comparisons With Results Reported in Literature Review

The results of this study compare favorably with those reported by Dorcat and Kenny (1965); Paine, Boutwell and Soloff (1961); and Gambino (1961). In the present study results showed a mean of mean differences of 0.014 $\pm$ 0.003 SD for pH, -2.7 mmHg $\pm$ 0.6 SD for $pCO_2$, 15.6 mmHg $\pm$ 2.0 SD for $pO_2$ and -0.04 mEq/L $\pm$ 1.0 SD for $HCO_3^-$ (arterial minus warmed venous blood). These results, with the exception of $pCO_2$ concur with those of Dorcat and Kenny who defined their limits of acceptability as a difference in capillary and arterial measurements of $\pm$ 0.025 for pH; $\pm$ 2.0 mmHg for $pCO_2$, and $\pm$ 0.5 mEq/L for $HCO_3^-$. The overall mean of mean difference for $pCO_2$ in this study was 0.7 mmHg greater than their limit of acceptability. Dorcat and Kenny did not report $pO_2$.

The use of $pO_2$ from warmed venous or capillary blood as a reliable estimate of arterial $pO_2$ has not been consistently proven (Lilienthal and Riley, 1944; Gambino, 1961; MacIntyre, Norman and Smith, 1968; Collis and Neaversen, 1967; Koch, 1968; Wallman, Arora, Allen and Hyde, 1968; Spiro and Dowdeswell, 1976).

# CHAPTER VI

## SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

### Summary and Conclusions

Blood-gas analysis is an essential tool used in the management of critically ill patients. Blood-gas parameters (pH, $pCO_2$, $pO_2$) are usually measured from arterial rather than venous blood. Arterial blood is used since it is more completely oxygenated than venous blood and is usually of uniform composition throughout the body.

However, arterial punctures pose certain disadvantages to patients, such as, hemorrhage, occlusion, hematoma, thrombosis and embolization.

Since 1925 researchers have investigated the use of blood-gas values measured from either peripheral venous or capillary blood as a reliable estimate of these parameters in arterial blood.

In order to use venous blood in lieu of arterial blood, the venous blood must be arterialized. Arterialization occurs when the site where the venous blood is to be obtained is warmed, thereby producing vasodilation with increasing flow to that area. The increased flow, disproportionate to the metabolic activity of the surrounding tissues, and subsequent oxygen delivery will allow the venous blood to have a composition similar to that of arterial blood (arterialized venous blood). The principles behind 'arterialization' were described in a theoretical framework. Both a model and equations describing the relationship between flow and metabolic rate substantiate the theory of arterialization.

Different methods have been described in the literature as a means of

producing arterialized (warmed) venous blood.

The purpose of this study was to evaluate the use of arterialized (warmed) venous blood as a reliable substitute for arterial blood in assessing acid-base status.

Eight healthy mongrel dogs of both sexes were used as the experimental animals. Samples of arterial, warmed and unwarmed venous blood were drawn simultaneously under anaerobic conditions. Arterial blood was drawn from a femoral catheter, unwarmed venous blood was drawn from an unheated paw, and warmed venous blood was drawn from a warmed paw.

In this study arterialization (warming) of the venous blood was produced in the following manner: a goose neck lamp with a 60 watt bulb was placed approximately 10 cm. from the paw. The heat source remained in place until the warmed paw temperature was at least $5^{o}$ C higher than the pre-heated paw temperature.

Various degrees of metabolic acid-base disturbances were induced in the animals. One-hundred-ninety-two samples of blood were taken which had a pH range of 6.87 to 7.67.

A number of statistical tests were used to analyze the differences between the blood-gas parameters of warmed venous blood vs arterial blood, and unwarmed venous blood vs arterial blood.

The result of this study show that for the determination of pH, $pCO_2$, $pO_2$ and $\{HCO_3^-\}$ the use of warmed venous blood provides a better estimation of arterial blood than unwarmed venous blood.

It was noted in this experiment that when metabolic alkalosis was induced in the experimental animals the values of arterial minus warmed venous blood were significantly different from arterial minus unwarmed

venous blood. This significant difference was not observed in those dogs in which metabolic acidosis was induced.

The results of this study concur with other studies reviewed, that reliable estimates of pH, $pCO_2$, $pO_2$ and $\{HCO_3^-\}$ in arterial blood can be made from these same parameters measured from warmed venous blood.

Recommendations

1) Studies done at high values of $pO_2$ (100 to 300 mmHg) have shown that the $pO_2$ of arterialized (warmed) capillary blood is not a reliable estimate of the $pO_2$ of arterial blood (MacIntyre, Norman and Smith, 1968; Wallman, Arora, Allen and Hyde, 1968; Olivia, Spellman, Podgainy and Gittleman, 1973). The $pO_2$ values in this study ranged from 15 to 126 mmHg. A future study which compares the $pO_2$ of warmed venous blood to the $pO_2$ of arterial blood at high values of $pO_2$ would be useful.

2) This study dealt only with metabolic acid-base disturbances. A similar study which looks at both respiratory and mixed acid-base disturbances would have significant usefulness. With this information a more complete picture could be obtained concerning the reliability of using blood-gas values measured from warmed venous blood as a substitute for arterial blood in assessing acid-base status.

3) This study was done in a controlled laboratory setting using healthy mongrel dogs. The results of this study showed that values obtained from warmed venous blood can be a reliable estimate of those values in arterial blood. An important follow-up study would be to use this information in a clinical setting.

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## DEFINITION OF TERMS AND VARIABLES

pH — The pH of a solution is defined as the negative logarithum of the hydrogen ion concentration in that solution (Slonim and Hamilton, 1976; Keyes, 1976; Filley, 1969, 1971).

$pCO_2$ — The $pCO_2$ is the partial pressure of $CO_2$ in a solution and is proportional to the amount of $CO_2$ that is physically dissolved in the solution (Slonim and Hamilton, 1976; Keyes, 1976).

$pO_2$ — The $pO_2$ is the partial pressure of $O_2$ in a solution and is proportional to the amount of $O_2$ that is physically dissolved in the solution (Slonim and Hamilton, 1976; Keyes, 1976).

$\{HCO_3^-\}$ — Bicarbonate concentration was calculated using the Henderson-Hasselback equation:

$$pH = pK'a + \log \frac{\{HCO_3^-\}}{S.\ pCO_2} \qquad (1)$$

$$\text{therefore, } \{HCO_3^-\} = \{10^{(pH-pKa)}\} \cdot \{S.\ pCO_2\} \qquad (2), \text{ where}$$

$pK'a = 6.1$ at $37^oC$, and

$S = 0.0301$ mm of $CO_2$/mmHg $pCO_2$ (Selkurt, 1976).

Acidosis - Acidosis is a term describing an acid-base disturbance that reflects an increase in the plasma hydrogen ion concentration. This can occur from an increase of acids and/or a loss of bases (Slonim and Hamilton, 1976; Keyes, 1976; Vander, 1975).

Alkalosis - Alkalosis is a term describing an acid-base disturbance that reflects a decrease in plasma hydrogen ion concentration. This can occur from a loss of acids and/or increase in bases (Slonim and Hamilton, 1976; Keyes, 1976; Vander, 1975).

# APPENDIX B

## Protocol for Calibration of Electrodes

## CALIBRATION PROTOCOL

The BMS3 Mark 2 is comprised of three units. The $BGA_3$ component houses the electrodes. The $GMA_2$ precision gas supply is used for the calibration of the blood-gas electrodes and for the equilibration of blood to known $pCO_2$ values. Pure $CO_2$ carbon dioxide entering the $GMA_2$ is infused at a constant rate where it is mixed with atmospheric air to produce two measurable gas concentrations. The two gas mixtures enter the $BGA_3$ component where they are humidified.

The PHM 73 pH blood-gas monitor provides a digital readout for pH, $pCO_2$ and $pO_2$. Known blood-gas parameters, as measured by the electrode are calibrated with the controls on this component.

## CALIBRATION TECHNIQUE

### Preparation for calibration

The BMS3 Mark 2 system was turned on at least one hour prior to calibration. This allowed the water bath to reach and maintain a temperature of $37^{o}$ C. Barometric pressure was measured with a mercury barometer. This information is necessary for calibration of the $pCO_2$ and $pO_2$ electrodes. Membranes for the $pCO_2$ and $pO_2$ electrodes were changed weekly prior to calibration.

### pH calibration

A two-buffer calibration technique with precision buffers of pH 7.383 ($\pm$ 0.005) and 6.841 ($\pm$ 0.005) were used to calibrate the pH electrode.

The electrode was calibrated with the high pH buffer followed by the low pH buffer. The electrode was rechecked with the high pH buffer to ensure precision.

The two-buffer calibration technique was carried out prior to sample analysis. A one-buffer calibration technique (pH buffer 7.383) was used between sample analysis. If this calibration check showed that the reading was not within $\pm$ 0.001 pH units, then the electrode was re-calibrated using both buffers.

## $pCO_2$ calibration

Pure carbon dioxide was infused into the $GMA_2$ precision mixer at a constant rate. The carbon dioxide was mixed in precise amounts with air to give two gas mixtures of high and low concentrations of carbon dioxide. The concentrations of carbon dioxide in the mixtures were measured in a mass spectrometer. They were found to have concentrations of 5.61% and 11.22% for the low and high concentrations respectively. Tables of values were used to determine the $pCO_2$ from the barometric pressure and the known carbon dioxide concentrations in the gas mixtures. The $pCO_2$ values obtained were verified using the following equation:

$$pCO_2 = \frac{(BP-W)\text{mmHg}}{100} \times X\%$$

BP = barometric pressure

W = vapor pressure of water (47 mmHg)

X = the percent of carbon dioxide in the gas mixture

Once the $pCO_2$ values were determined, the PHM 73 was calibrated using these values. A gas selector was used which allowed either high or low

carbon dioxide concentrations to flow in contact with the $pCO_2$ membrane, and hence the electrode. Calibration was done using the low gas concentration first followed by the high gas concentration. To ensure precision, the low gas concentration was rechecked.

Between samples, the calibration was rechecked using the low gas concentration. If this calibration check showed that the reading was not within $\pm$ 0.1 mmHg, then the electrode was recalibrated using both high and low concentrations.

$pO_2$ calibration

The $pO_2$ electrode was calibrated using both high and low concentrations of oxygen. The high $pO_2$ was obtained by using a sample of thermostat water that had been in equilibrium with atmospheric air for at least one hour at a temperature of $37^{o}$ C. Tables of values were used to determine $pO_2$ measurements based on barometric pressure. The $pO_2$ value was verified using the following equation:

$$pO_2 = \frac{(BP-W)}{100} \text{ mmHg} \times X\%$$

BP = barometric pressure

W = vapor pressure of water (47 mmHg)

X = the oxygen concentration in the atmosphere (20.93%)

Using the gas selector in the low $pCO_2$ position, a reference $pO_2$ was obtained. Between samples the calibration for $pO_2$ was rechecked using the reference $pO_2$. If this calibration check was not within $\pm$ 1 mmHg, then recalibration was carried out using thermostat water.

# APPENDIX C

Raw Data From All 8 Experimental Animals

DOG #1 January 9th
Weight - 18 kg.

| TIME SAMPLES DRAWN | pH | | | $PCO_2$ mmHg | | | $PO_2$ mmHg | | | $HCO_3^-$ mEq/L | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Arterial | Warmed Venous | Unwarmed Venous | Arterial | Warmed Venous | Unwarmed Venous | Arterial | Warmed Venous | Unwarmed Venous | Arterial | Warmed Venous | Unwarmed Venous |
| 1155 | 7.307 | 7.302 | 7.300 | 28.6 | 32.2 | 29.6 | 77.5 | 62.2 | 67.1 | 13.9 | 15.4 | 14.1 |
| 1235 | 7.249 | 7.252 | 7.241 | 42.8 | 38.3 | 44.2 | 82.6 | 65.7 | 66.4 | 18.2 | 16.4 | 18.4 |
| 1305 | 7.193 | 7.186 | 7.178 | 43.2 | 46.4 | 47.7 | 82.2 | 66.4 | 67.6 | 16.7 | 17.0 | 17.2 |
| 1340 | 7.160 | 7.164 | 7.169 | 44.8 | 46.2 | 45.7 | 77.6 | 69.0 | 61.8 | 15.5 | 16.1 | 16.1 |
| 1410 | 7.168 | 7.174 | 7.158 | 38.8 | 34.8 | 41.3 | 77.9 | 68.7 | 65.2 | 13.6 | 12.4 | 14.2 |
| 1425 | 7.147 | 7.120 | 7.137 | 35.1 | 40.4 | 39.3 | 85.9 | 72.7 | 66.5 | 11.8 | 12.7 | 12.9 |
| 1515 | 7.098 | 7.085 | 7.075 | 32.2 | 36.6 | 37.4 | 90.0 | 74.3 | 72.6 | 9.6 | 10.6 | 10.6 |
| 1550 | 7.071 | 7.061 | 7.046 | 27.5 | 30.8 | 32.0 | 93.7 | 79.9 | 77.5 | 7.7 | 8.5 | 8.5 |
| 1620 | 7.013 | 7.003 | 6.998 | 26.7 | 29.8 | 29.4 | 95.7 | 79.6 | 78.2 | 6.6 | 7.2 | 7.0 |
| MEAN | 7.156 | 7.150 | 7.145 | 35.5 | 37.3 | 38.5 | 84.8 | 70.9 | 69.2 | 12.6 | 12.9 | 13.2 |
| SD | 0.090 | 0.094 | 0.094 | 7.2 | 6.2 | 6.9 | 7.0 | 6.2 | 5.6 | 4.0 | 3.6 | 3.9 |

DOG #2 January 16th
Weight - 16 kg.

| TIME SAMPLES DRAWN | pH | | | $PCO_2$ mmHg | | | $PO_2$ mmHg | | | $HCO_3^-$ mEq/L | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Arterial | Warmed Venous | Unwarmed Venous | Arterial | Warmed Venous | Unwarmed Venous | Arterial | Warmed Venous | Unwarmed Venous | Arterial | Warmed Venous | Unwarmed Venous |
| 1201 | 7.260 | 7.279 | 7.289 | 50.5 | 49.4 | 47.1 | 71.1 | 72.0 | 75.1 | 22.0 | 22.4 | 21.9 |
| 1248 | 7.239 | 7.232 | 7.227 | 42.1 | 45.2 | 41.8 | 95.6 | 81.3 | 82.3 | 17.4 | 18.4 | 16.8 |
| 1331 | 7.161 | 7.155 | 7.133 | 41.4 | 42.6 | 46.2 | 96.5 | 77.7 | 82.1 | 14.4 | 14.6 | 15.0 |
| 1416 | 7.073 | 7.047 | 7.046 | 34.8 | 47.2 | 44.0 | 102.7 | 87.4 | 94.7 | 9.8 | 12.6 | 11.7 |
| 1454 | 6.994 | 7.003 | 7.005 | 39.5 | 41.1 | 40.1 | 102.8 | 93.5 | 95.7 | 9.3 | 9.9 | 9.7 |
| 1534 | 6.956 | 6.947 | 6.946 | 33.0 | 34.8 | 33.9 | 120.5 | 98.1 | 97.9 | 7.1 | 7.4 | 7.2 |
| 1610 | 6.908 | 6.903 | 6.904 | 30.9 | 33.3 | 31.8 | 119.4 | 95.7 | 87.0 | 6.0 | 6.4 | 6.1 |
| 1632 | 6.881 | 6.883 | 6.869 | 26.1 | 26.6 | 32.4 | 125.6 | 110.0 | 78.5 | 4.7 | 4.8 | 5.7 |
| MEAN | 7.059 | 7.060 | 7.052 | 37.3 | 40.0 | 39.7 | 104.3 | 89.5 | 86.6 | 11.3 | 12.1 | 11.8 |
| SD | 0.148 | 0.148 | 0.152 | 7.6 | 7.8 | 6.2 | 17.7 | 12.3 | 8.6 | 6.0 | 6.2 | 5.8 |

DOG #3 January 23rd
Weight - 10 kg

| TIME SAMPLES DRAWN | pH | | | $PCO_2$ mmHg | | | $PO_2$ mmHg | | | $HCO_3^-$ mEq/L | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Arterial | Warmed Venous | Unwarmed Venous | Arterial | Warmed Venous | Unwarmed Venous | Arterial | Warmed Venous | Unwarmed Venous | Arterial | Warmed Venous | Unwarmed Venous |
| 1247 | 7.366 | 7.365 | 7.330 | 47.1 | 47.2 | 53.6 | 80.9 | 67.6 | 51.6 | 26.2 | 26.2 | 27.4 |
| 1330 | 7.331 | 7.320 | 7.278 | 42.3 | 42.9 | 52.4 | 85.3 | 59.7 | 43.2 | 21.6 | 21.4 | 23.7 |
| 1405 | 7.242 | 7.235 | 7.205 | 40.3 | 43.7 | 51.9 | 85.8 | 66.9 | 47.7 | 16.8 | 17.9 | 19.9 |
| 1437 | 7.229 | 7.222 | 7.180 | 35.4 | 37.1 | 48.8 | 96.4 | 66.9 | 47.3 | 14.3 | 14.8 | 17.7 |
| 1514 | 7.161 | 7.145 | 7.113 | 31.0 | 33.1 | 46.5 | 100.1 | 65.6 | 46.0 | 10.7 | 11.0 | 14.4 |
| 1555 | 7.088 | 7.092 | 7.037 | 28.8 | 28.3 | 53.1 | 102.0 | 77.9 | 40.1 | 8.4 | 8.4 | 13.8 |
| 1630 | 6.971 | 6.966 | | 36.6 | 37.7 | | 93.5 | 73.0 | | 8.2 | 8.3 | |
| 1709 | 6.929 | 6.928 | 6.884 | 26.8 | 30.5 | 54.8 | 108.0 | 82.5 | 47.5 | 5.4 | 6.2 | 10.0 |
| MEAN | 7.165 | 7.159 | 7.147 | 36.0 | 37.5 | 51.6 | 94.0 | 70.0 | 46.2 | 14.0 | 14.3 | 18.1 |
| SD | 0.159 | 0.157 | 0.151 | 7.0 | 6.7 | 2.9 | 9.4 | 7.3 | 3.7 | 7.2 | 7.1 | 6.0 |

DOG #4 January 30th
Weight - 22.3 kg

| TIME SAMPLES DRAWN | pH | | | $PCO_2$ mmHg | | | $PO_2$ mmHg | | | $HCO_3^-$ mEq/L | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Arterial | Warmed Venous | Unwarmed Venous | Arterial | Warmed Venous | Unwarmed Venous | Arterial | Warmed Venous | Unwarmed Venous | Arterial | Warmed Venous | Unwarmed Venous |
| 1145 | 7.394 | 7.407 | 7.376 | 42.4 | 42.4 | 43.9 | 74.2 | 55.9 | 66.1 | 25.1 | 25.7 | 24.9 |
| 1235 | 7.395 | 7.320 | 7.358 | 33.1 | 43.2 | 36.1 | 105.3 | 46.1 | 64.3 | 19.6 | 21.6 | 19.7 |
| 1310 | 7.284 | 7.269 | 7.278 | 34.4 | 39.4 | 34.4 | 91.4 | 68.3 | 69.7 | 15.8 | 17.5 | 15.6 |
| 1335 | 7.234 | 7.226 | 7.230 | 33.0 | 35.9 | 35.8 | 95.7 | 72.3 | 80.8 | 13.5 | 14.4 | 14.9 |
| 1410 | 7.226 | 7.210 | 7.212 | 26.8 | 32.6 | 33.9 | 100.6 | 73.8 | 79.1 | 10.8 | 12.6 | 13.2 |
| 1445 | 7.182 | 7.164 | 7.167 | 26.4 | 33.1 | 30.8 | 104.5 | 73.4 | 77.7 | 9.6 | 11.5 | 10.8 |
| 1525 | 7.099 | 7.095 | 7.090 | 26.8 | 31.1 | 29.4 | 103.9 | 82.1 | 86.2 | 8.0 | 9.2 | 10.0 |
| 1600 | 7.060 | 7.051 | 7.053 | 23.6 | 28.0 | 26.9 | 106.3 | 88.7 | 97.9 | 6.5 | 7.5 | 7.3 |
| 1635 | 7.028 | 7.007 | 7.011 | 18.1 | 25.6 | 22.7 | 116.3 | 84.2 | 89.7 | 4.6 | 6.2 | 5.6 |
| MEAN | 7.211 | 7.194 | 7.197 | 29.4 | 34.5 | 32.6 | 99.8 | 71.6 | 79.1 | 12.6 | 14.0 | 13.4 |
| SD | 0.134 | 0.130 | 0.129 | 7.1 | 6.1 | 6.0 | 11.9 | 13.6 | 11.2 | 6.6 | 6.5 | 6.2 |

DOG #5 February 6th
Weight - 11.4 kg.

| TIME SAMPLES DRAWN | pH | | | $PCO_2$ mmHg | | | $PO_2$ mmHg | | | $HCO_3^-$ mEq/L | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Arterial | Warmed Venous | Unwarmed Venous | Arterial | Warmed Venous | Unwarmed Venous | Arterial | Warmed Venous | Unwarmed Venous | Arterial | Warmed Venous | Unwarmed Venous |
| 1220 | 7.328 | 7.333 | 7.312 | 45.4 | 43.1 | 44.8 | 88.7 | 75.5 | 62.2 | 23.1 | 22.2 | 22.0 |
| 1250 | 7.430 | 7.425 | 7.416 | 49.3 | 49.6 | 49.8 | 85.9 | 82.5 | 70.1 | 31.7 | 31.5 | 31.0 |
| 1335 | 7.514 | 7.504 | 7.403 | 44.0 | 45.1 | 53.9 | 85.9 | 72.0 | 38.7 | 34.4 | 34.4 | 32.6 |
| 1410 | 7.475 | 7.472 | 7.452 | 51.2 | 50.2 | 52.3 | 75.7 | 68.5 | 55.6 | 36.5 | 35.6 | 35.4 |
| 1445 | 7.564 | 7.568 | 7.411 | 49.7 | 45.6 | 61.6 | 69.8 | 62.1 | 30.1 | 43.5 | 40.3 | 38.0 |
| 1520 | 7.608 | 7.597 | 7.541 | 56.1 | 53.0 | 57.4 | 61.5 | 53.1 | 43.4 | 54.4 | 50.1 | 47.7 |
| 1600 | 7.644 | 7.621 | 7.495 | 50.3 | 53.2 | 57.1 | 60.3 | 54.6 | 30.1 | 53.0 | 53.1 | 42.7 |
| 1645 | 7.653 | 7.639 | 7.509 | 56.4 | 56.4 | 60.5 | 51.6 | 50.0 | 31.1 | 60.6 | 58.7 | 46.7 |
| MEAN | 7.527 | 7.520 | 7.442 | 50.3 | 49.5 | 54.7 | 72.4 | 64.8 | 45.2 | 60.6 | 40.7 | 37.0 |
| SD | 0.113 | 0.106 | 0.073 | 4.4 | 2.5 | 5.6 | 13.8 | 11.7 | 15.7 | 12.1 | 12.3 | 8.6 |

DOG #6 February 20th
Weight - 16 kg.

| TIME SAMPLES DRAWN | pH | | | $PCO_2$ mmHg | | | $PO_2$ mmHg | | | $HCO_3^-$ mEq/L | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Arterial | Warmed Venous | Unwarmed Venous | Arterial | Warmed Venous | Unwarmed Venous | Arterial | Warmed Venous | Unwarmed Venous | Arterial | Warmed Venous | Unwarmed Venous |
| 1155 | 7.403 | 7.381 | 7.386 | 36.8 | 40.8 | 39.6 | 74.7 | 52.2 | 51.5 | 22.3 | 23.5 | 23.0 |
| 1235 | 7.515 | 7.475 | 7.473 | 37.8 | 41.2 | 41.0 | 71.6 | 43.8 | 45.5 | 29.6 | 29.4 | 29.1 |
| 1315 | 7.508 | 7.478 | 7.479 | 45.5 | 48.6 | 44.3 | 66.6 | 44.9 | 46.8 | 35.0 | 34.9 | 31.9 |
| 1400 | 7.558 | 7.500 | 7.512 | 48.6 | 57.4 | 51.0 | 64.6 | 43.8 | 44.5 | 42.0 | 43.4 | 39.6 |
| 1455 | 7.580 | 7.532 | 7.508 | 52.7 | 58.4 | 60.7 | 65.4 | 41.7 | 33.8 | 47.9 | 47.5 | 46.8 |
| 1545 | 7.616 | 7.538 | 7.505 | 54.6 | 65.6 | 65.2 | 55.5 | 34.3 | 24.5 | 53.9 | 54.2 | 49.8 |
| 1625 | 7.638 | 7.598 | 7.518 | 56.7 | 58.9 | 68.7 | 52.0 | 36.0 | 27.0 | 58.9 | 55.8 | 54.1 |
| 1700 | 7.627 | 7.614 | 7.577 | 65.4 | 68.7 | 71.2 | 44.0 | 39.5 | 35.6 | 66.3 | 67.5 | 64.2 |
| MEAN | 7.556 | 7.514 | 7.495 | 49.8 | 54.9 | 54.9 | 61.8 | 42.0 | 38.6 | 44.5 | 44.5 | 38.8 |
| SD | 0.079 | 0.074 | 0.054 | 9.7 | 10.4 | 12.4 | 10.4 | 5.6 | 9.9 | 15.1 | 14.7 | 12.9 |

DOG #7 February 27th
Weight - 12 kg.

| TIME SAMPLES DRAWN | pH | | | $PCO_2$ mmHg | | | $PO_2$ mmHg | | | $HCO_3^-$ mEq/L | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Arterial | Warmed Venous | Unwarmed Venous | Arterial | Warmed Venous | Unwarmed Venous | Arterial | Warmed Venous | Unwarmed Venous | Arterial | Warmed Venous | Unwarmed Venous |
| 1145 | 7.325 | 7.328 | 7.305 | 55.9 | 48.9 | 57.2 | 71.8 | 68.9 | 58.8 | 28.2 | 24.9 | 27.6 |
| 1240 | 7.464 | 7.456 | 7.435 | 50.1 | 49.8 | 51.5 | 64.3 | 59.2 | 50.0 | 34.8 | 34.0 | 33.5 |
| 1320 | 7.551 | 7.531 | 7.473 | 50.4 | 50.7 | 56.0 | 67.6 | 53.1 | 36.3 | 42.8 | 41.2 | 39.8 |
| 1350 | 7.540 | 7.535 | 7.495 | 55.6 | 55.6 | 59.4 | 57.2 | 52.2 | 41.4 | 46.1 | 45.5 | 44.4 |
| 1425 | 7.585 | 7.566 | 7.496 | 59.4 | 61.1 | 67.7 | 62.7 | 53.1 | 35.6 | 54.6 | 53.8 | 50.7 |
| 1500 | 7.609 | 7.588 | 7.536 | 61.6 | 63.3 | 66.5 | 69.4 | 54.8 | 39.5 | 59.8 | 58.6 | 54.6 |
| 1540 | 7.632 | 7.616 | 7.531 | 65.2 | 67.7 | 74.2 | 50.1 | 46.7 | 33.2 | 66.8 | 66.8 | 60.2 |
| 1615 | 7.668 | 7.656 | 7.528 | 71.4 | 72.0 | 78.4 | 45.2 | 42.7 | 30.3 | 79.5 | 77.9 | 63.2 |
| MEAN | 7.547 | 7.534 | 7.475 | 58.7 | 58.6 | 63.8 | 61.0 | 51.3 | 40.6 | 51.6 | 50.4 | 46.8 |
| SD | 0.109 | 0.103 | 0.077 | 7.3 | 8.7 | 9.4 | 9.4 | 10.8 | 9.5 | 17.0 | 17.5 | 12.7 |

DOG #8 March 6th
Weight - 13.6 kg

| TIME SAMPLES DRAWN | pH | | | $PCO_2$ mmHg | | | $PO_2$ mmHg | | | $HCO_3^-$ mEq/L | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Arterial | Warmed Venous | Unwarmed Venous | Arterial | Warmed Venous | Unwarmed Venous | Arterial | Warmed Venous | Unwarmed Venous | Arterial | Warmed Venous | Unwarmed Venous |
| 1130 | 7.398 | 7.385 | 7.373 | 39.3 | 41.0 | 42.1 | 66.3 | 59.9 | 55.7 | 23.5 | 23.8 | 23.7 |
| 1250 | 7.571 | 7.537 | 7.528 | 44.1 | 47.2 | 47.7 | 60.5 | 51.1 | 45.8 | 39.3 | 38.9 | 38.5 |
| 1330 | 7.606 | 7.578 | 7.493 | 41.5 | 45.7 | 52.7 | 54.4 | 43.1 | 29.6 | 40.1 | 41.4 | 39.2 |
| 1410 | 7.602 | 7.582 | 7.500 | 48.8 | 50.1 | 58.7 | 48.4 | 44.4 | 32.5 | 46.7 | 45.8 | 44.4 |
| 1445 | 7.592 | 7.563 | 7.506 | 53.2 | 57.6 | 62.5 | 46.3 | 41.5 | 32.4 | 49.7 | 50.3 | 47.9 |
| 1525 | 7.612 | 7.587 | 7.528 | 59.9 | 63.4 | 68.8 | 43.2 | 38.0 | 30.6 | 58.6 | 58.6 | 55.4 |
| 1605 | 7.460 | 7.445 | 7.420 | 94.5 | 97.7 | 100.6 | 18.3 | 15.2 | 15.7 | 65.1 | 65.1 | 63.3 |
| MEAN | 7.549 | 7.525 | 7.478 | 54.5 | 57.5 | 61.9 | 48.2 | 41.9 | 34.6 | 46.1 | 46.2 | 44.6 |
| SD | 0.085 | 0.079 | 0.059 | 19.0 | 19.2 | 19.3 | 15.5 | 13.8 | 12.8 | 13.7 | 13.6 | 12.8 |

SUMMARY TABLE OF 'r', SLOPE, AND INTERCEPT FOR EACH ANIMAL

| 1979 | pH | | $PCO_2$ mmHg | | $PO_2$ mmHg | | $HCO_3^-$ mEq/L | |
|---|---|---|---|---|---|---|---|---|
| | A vs W | A vs Unw | A vs W | A vs Unw | A vs W | A vs Unw | A vs W | A vs Unw |
| January 9th | | | | | | | | |
| r | .9947 | .9955 | .8677 | .9721 | .9021 | .9302 | .9601 | .9974 |
| slope | 1.0412 | 1.0511 | .7453 | .9375 | .7960 | .7499 | .8766 | .9664 |
| intercept | - .3014 | - .3772 | 10.9457 | 5.2092 | 3.4612 | 5.6362 | 1.8605 | 1.0277 |
| January 16th | | | | | | | | |
| r | .9961 | .9924 | .8568 | .8472 | .9243 | .4199 | .9900 | .9929 |
| slope | 1.0152 | 1.0228 | .8743 | .6889 | .6445 | .2037 | 1.0100 | .9495 |
| intercept | - .1101 | - .1676 | 7.4442 | 13.9843 | 22.2640 | 65.4182 | .6088 | .9990 |
| January 23rd | | | | | | | | |
| r | .9992 | .9990 | .9774 | .1182 | .7214 | - .3832 | .9981 | .9972 |
| slope | .9883 | 1.0105 | .9374 | .0455 | .5646 | - .1384 | .9836 | .8182 |
| intercept | .0783 | - .1210 | 3.7722 | 49.9407 | 17.0936 | 59.2329 | .5365 | 6.0337 |
| January 30th | | | | | | | | |
| r | .9839 | .9977 | .9143 | .9645 | .5110 | .6076 | .9974 | .9939 |
| slope | .9530 | .9637 | .7846 | .8294 | .5859 | .5717 | .9806 | .9289 |
| intercept | .3220 | .2477 | 11.4869 | 8.2810 | 13.1609 | 22.0041 | 1.6654 | 1.6397 |
| February 6th | | | | | | | | |
| r | .9981 | .8646 | .8701 | .5917 | .9576 | .7194 | .9930 | .9742 |
| slope | .9393 | .5582 | .9087 | .7550 | .8090 | .8131 | .9427 | .6507 |
| intercept | .4496 | 3.2407 | 3.8232 | 16.7098 | 6.2121 | -13.7262 | 1.0103 | 9.5734 |
| February 20th | | | | | | | | |
| r | .9652 | .9073 | .9540 | .9580 | .7784 | .7342 | .9954 | .9950 |
| slope | .9116 | .6230 | 1.0303 | 1.2689 | .4184 | .6962 | .9724 | .9185 |
| intercept | .6268 | 2.7875 | 3.6546 | -7.9591 | 16.1795 | -4.3776 | 1.2491 | 1.4665 |
| February 27th | | | | | | | | |
| r | .9985 | .9689 | .9469 | .9703 | .8472 | .6733 | .9986 | .9837 |
| slope | .9411 | .6795 | 1.1307 | 1.2489 | .7069 | .6744 | 1.0268 | .7349 |
| intercept | .4320 | 2.3470 | -7.7245 | -9.4500 | 10.6780 | - .5210 | -2.6250 | 8.8400 |
| March 6th | | | | | | | | |
| r | .9979 | .9499 | .9982 | .9856 | .9859 | .9079 | .9986 | .9988 |
| slope | .9309 | .6613 | 1.0104 | 1.0010 | .8785 | .7490 | .9893 | .9313 |
| intercept | .4979 | 2.4864 | 2.4960 | 7.3549 | - .4311 | -1.4816 | .6083 | 1.6770 |

A vs W is arterial blood versus warmed venous blood.

A vs Unw is arterial blood versus unwarmed venous blood.

AN ABSTRACT OF THE THESIS OF

LESLIE INGERSOLL CARVETH

For the MASTER OF NURSING

Date Receiving This Degree: June 8, 1979

Title: THE USE OF FREE FLOWING PERIPHERAL VENOUS BLOOD IN ASSESSING ACID-BASE STATUS

Approved: [redacted]
Wilma Peterson, Ph.D. Thesis Advisor

One-hundred-ninety-two samples of blood taken from 8 mongrel dogs were analyzed to determine if peripheral venous blood could be used in lieu of arterial blood for assessment of metabolic acid-base disorders. Various stages of metabolic acidosis and alkalosis were induced in these animals. The pH ranged from 6.87 to 7.67.

When peripheral venous blood was arterialized by warming the paw from which blood was obtained to a temperature at least $5^{o}$ C greater than the pre-heated temperature then the blood-gas composition of warmed venous blood mimicked that of arterial blood. In contra t, unwarmed venous blood did not mimic arterial blood as closely as that of warmed venous blood.

From the results of this study it was concluded that the pH, $pCO_2$, $pO_2$ and $\{HCO_3^-\}$ of warmed venous blood could be used as a reliable estimate of arterial blood in the assessment of metabolic acid-base disturbances.