THE USE OF FEMORAL VENOUS BLOOD FOR ASSESSMENT OF ACID-BASE STATUS IN STATES OF DECREASED CARDIAC OUTPUT

by

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CHAPTER I

INTRODUCTION

The purpose of this study is to analyze femoral venous blood-gas composition during states of decreasing cardiac output. In order to understand the need for such an investigation, a brief historical perspective is necessary.

Arterial blood has been traditionally used in the clinical setting to determine the acid-base status of critically ill patients. Arterial blood has been used for assessment of acid-base status for two reasons: 1) Its composition is basically uniform throughout the systemic circulation, and 2) its oxygen content reflects certain aspects of cardiopulmonary function (Slonim & Hamilton, 1976). Venous blood, although it represents tissue acid-base status, has not been used because 1) metabolic activity varies in different organs and tissues, and 2) blood flow varies to different organs and tissues, consequently the blood-gas composition of venous blood is non-uniform and thought to be too variable for clinical use (Smith & Kampine, 1980).

There are, however, many problems and complications that can arise from obtaining arterial samples. The most universal problem is the pain involved especially with repeated samples. The literature is replete with examples of the complications associated with arterial puncture and arterial catheters inserted for obtaining samples. Major examples from numerous

sources include: hematoma formation, bleeding complications, nerve damage, and sepsis from catheterization (Carveth, 1979; Puri, Carlson, Bander & Weil, 1980; Schriver, 1980; Sise, Hollingsworth, M., Brim, J., Peters, R., Virgilio, R., Shackford, S., 1981).

In recent years many studies have been conducted on the efficacy of using venous blood for assessment of acid-base disorders (Bieber, 1979; Carveth, 1979; Griffith, 1980; Schriver, 1981; Murphy, 1982; & Feldon, 1982). Initially, mixed-venous blood-gas composition was studied as a substitute for arterial blood. Arterial blood, as noted previously, reflects cardiopulmonary function. Later, however, mixed-venous blood became recognized for its own unique contribution to acid-base assessment. When all potential sampling sites are considered, mixed-venous blood theoretically provides the most accurate representation of systemic tissue acid-base status of any potential venous site (Murphy, 1982).

Unfortunately, obtaining mixed-venous blood entails insertion of a pulmonary artery (PA) catheter. A PA catheter is primarily inserted for monitoring left ventricular function and only secondarily used for the purpose of obtaining mixed-venous blood. Insertion of a PA catheter also has its associated risks, discomfort, and expense as noted by Feldon (1982). In addition, obtaining a sample of mixed-venous blood from an already existing PA catheter can be plagued with difficulty as discussed in a recent review by Feldon (1982). Because of the problems associated with sampling mixed-venous blood, other alternative venous sites have been studied. The most promising alternative site for mixed-venous blood has been peripheral venous blood (Carveth, 1979, Schriver, 1981; & Feldon, 1982).

Both mixed-venous and peripheral-venous blood-gas composition have

been studied under a wide variety of conditions. Wide ranges of metabolic and respiratory acid-base disturbances have been studied as well as analyzing mixed-venous and peripheral venous blood-gas composition during states of decreased cardiac output. Problems arise, however, in obtaining either mixed-venous or peripheral venous blood when cardiac output is severely reduced. For the above reasons an alternative to mixed-venous blood during severe reductions in cardiac output is necessary. Therefore, the purpose of this study, as mentioned in the beginning, is to analyze femoral venous blood-gas composition during progressively decreasing states of cardiac output.

THEORETICAL FRAMEWORK

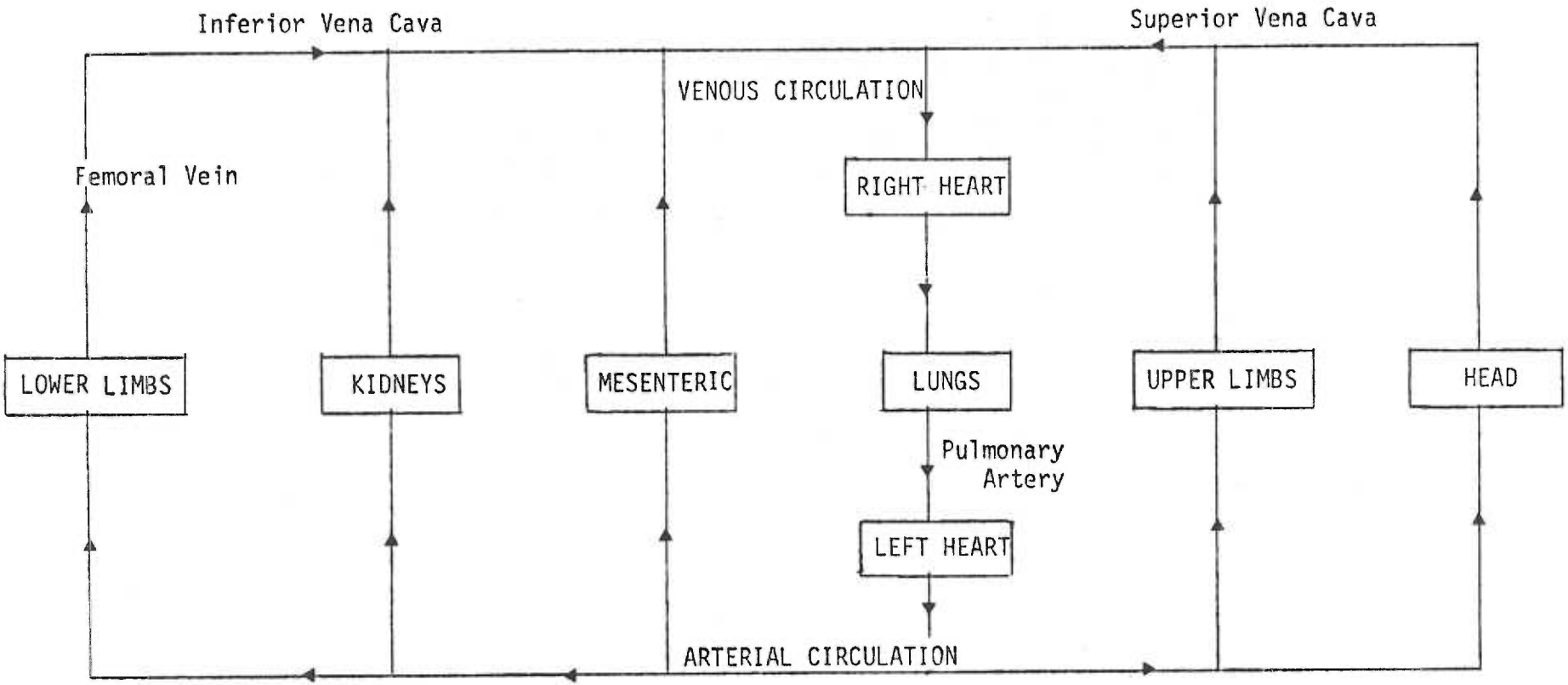
To understand the rationale for using femoral venous blood it is necessary to discuss the theoretical background for the use of mixed-venous blood in acid-base assessment. First, a physiological model showing the relationship between arterial, mixed venous, and femoral venous blood will be presented. Next, an in-depth explanation is presented explaining why blood-gas composition of a particular venous site is dependent on metabolic rate and blood flow. Last, in-vivo and in-vitro CO_2 titration curves will be discussed since they provided the theoretical impetus for first analyzing mixed-venous blood-gas composition.

1) Physiological Model

Arterial blood-gas composition, which represents output from the lungs is a better indicator of pulmonary function than venous blood-gas composition. Venous blood-gas composition, however, is a better indicator of tissue acid base status than arterial blood-gas composition. The following model adapted from Bieber (1979) supports these considerations (see Page 5).

It can be seen from the model (Figure 1) that arterial and venous blood flow in opposite directions. Arterial blood represents input from the lungs to the various organs and tissues of the body. Venous blood represents outflow from the organs and systemic tissue to the lungs. Each of the subdivisions represent parallel circuits within the systemic circulation.

Arterial and venous blood differ in blood-gas composition. In the normal lung exchange of O_2 and CO_2 occurs. This exchange is dependent on



THEORETICAL MODEL OF ARTERIAL AND VENOUS CIRCULATION

FIGURE 1. Arrows illustrate the direction of blood flow through arterial and venous circulations. Arterial circulation represents output from heart and lungs. The venous circulation represents output of separate but parallel circuits from systemic tissues and organs. Blood in the pulmonary artery represents the flow weighted average of all circuits. The femoral vein represents blood from the lower limbs (modified from Bieber, 1979).

the balance between pulmonary capillary perfusion and alveolar ventilation. Therefore, any abnormalities in either pulmonary capillary perfusion, alveolar ventilation, or both can alter arterial blood-gas composition.

There is also a small fraction of blood that nourishes the lung parenchyma, especially the bronchial tree, before returning to the left side of the heart. There blood equilibrates with interstitial fluid of the lung parenchyma. However, the amount by which this small fraction of shunted blood alters arterial blood-gas composition in normal people is minimal. (Only in severe pulmonary disease will shunts of sufficient magnitude exist that could significantly alter arterial blood-gas composition.) Once blood is returned to the left side of the heart it becomes well mixed. This mixed blood of uniform composition is then pumped through the arteries to the various tissues and organs of the body. Therefore, arterial blood may be obtained from any of the systemic arteries and its composition will reflect the matching of ventilation rate to alveolar capillary perfusion, plus any effects of pulmonary shunting. It is for this reason that arterial blood-gas composition is used to assess cardiopulmonary function. It is also why arterial blood-gas composition will be uniform when drawn from any available arterial site.

In systemic tissues blood in capillaries equilibrates with interstitial fluid. Oxygen is taken up and CO_2 is given off by the cells. Additionally, buffering of volatile acid (CO_2) and fixed acids generated by tissue metabolism also occurs in the blood of the capillaries. Each of these constituents directly affects the blood-gas composition of venous blood. It therefore follows that analysis of venous blood-gas composition

might have significant value in assessment of systemic tissue acid-base disturbances.

2) Metabolic Rates and Blood Flow

As mentioned previously, there are some important factors to note before drawing a sample for venous blood-gas analysis. Metabolic rates and blood flows of specific tissues or organs vary throughout the body. Under normal conditions venous blood-gas composition can vary considerably from site to site (Smith & Kampine, 1980). For example, kidney and skeletal muscle each receive about 20 percent of the total blood flow or cardiac output. A more realistic picture unfolds if one divides the flow to each organ by the weight of that organ. The "vascularity" or blood flow per unit weight is then obtained. The kidneys receive about 300 ml/min/100 gm of tissue compared to "resting" skeletal muscle which receives about 5 ml/min/100 gm of tissue.

According to Smith and Kampine (1980), resting skeletal muscle and tissues such as bone, skin, cartilage, and fat have high resistance and therefore low flow per unit weight. Organs, such as liver, heart, kidneys, and brain, have comparatively low vascular resistance and therefore high flow per unit weight.

Metabolic rates also differ in individual organs. Oxygen consumption is an indicator of metabolic rate. Another way to express O_2 consumption is by the O_2 extraction ratio. The O_2 extraction ratio is simply the fraction of the total O_2 delivered that is taken up by the tissues. The following equation will help clarify the definition of O_2 extraction ratio:

$$\frac{\dot{V}\,O_2}{\dot{Q}\cdot Ca\,O_2} = E$$

For the whole body:

$$E = \frac{200\text{ ml }O_2/\text{min}}{5\text{L/min}\cdot 20\text{ ml }O_2/\text{dl}} = \frac{200\text{ ml }O_2/\text{min}}{5\text{L/min}\cdot 200\text{ ml }O_2/\text{L}} = 0.20$$

$\dot{V}\,O_2$ = O_2 Uptake in ml/min.

$\dot{Q}$ = Blood Flow in ml/min.

CaO_2 = Concentration of O_2 in a volume of blood (ml O_2/100 ml blood).

E = Extraction Ratio of O_2.

The O_2 extraction rates vary from one organ to the next. For example, the O_2 extraction ratio would 0.55 in the heart while for skeletal muscle it would be 0.25 in healthy adults at rest (Smith & Kampine, 1980). It is clear the pO_2 of venous blood samples depend on the oxygen extraction ratio and, therefore, the site one chooses from which to draw the venous blood.

3) In-Vivo and In-Vitro Buffer Curves

In order to understand the theoretical background for examining venous blood-gas composition, it is necessary to understand the difference between in-vitro and in-vivo CO_2 titration curves. Several concepts need explanation to understand buffer curves before discussing the differences between them. The preceding discussion is organized according to the following outline: 1) review of key principles of acid-base balance, 2) the construction of a CO_2 titration curve, 3) the effect of hemoglobin on CO_2 titration curves, 4) an example of a CO_2 titration curve used in acid-base assessment, 5) the difference between in-vivo and in-vitro CO_2

titration curves, and 6) implications for studying venous blood-gas composition.

3a) Review of Key Principles of Acid-Base Balance

There are two types of acid produced in the body, non-volatile or fixed acids and volatile acid or CO_2. Non-volatile acids are waste products of metabolism in the body. During periods of imbalance these acids can cause metabolic acid-base disturbances.

Volatile acid (CO_2) is also a waste product of metabolism. The concentration of CO_2 is determined by the alveolar ventilation rate. Normally ventilation rate is adjusted to maintain a partial pressure of arterial CO_2 ($PaCO_2$) of 40 torr. Through hyperventilation the body can eliminate extra CO_2 and through hypoventilation the body retains CO_2. Excess CO_2 in body fluids leads to respiratory acidosis, while excessive loss of CO_2 leads to respiratory alkalosis.

Acidosis is characterized by an elevated free H^+ concentration in the blood and is measured as a lower than normal pH. Alkalosis is characterized by a decreased free H^+ concentration in the blood and is measured by a higher than normal pH. During acid-base disturbances there are three ways that the body handles pH shifts caused by decreased or increased acid loads. They are: 1) buffering, 2) respiratory compensation through alterations in alveolar ventilation rate, and 3) renal compensation via regulation of $[HCO_3^-]$. Buffering will be the main focus of this discussion.

A buffer is a combination of a weak acid and a weak base that act to minimize pH shifts. It should be emphasized that a buffer cannot prevent a pH change but only reduces the magnitude of the change. Each body

compartment has its own predominant buffers. The main buffer in the blood compartment is hemoglobin, but other proteins as well as the H_2CO_3/HCO_3^- system are present. The interstitial fluid compartment has very little protein, therefore the H_2CO_3/HCO_3^- system is predominant. The intracellular compartment has proteins and phosphates as primary buffers (see Figure 2).

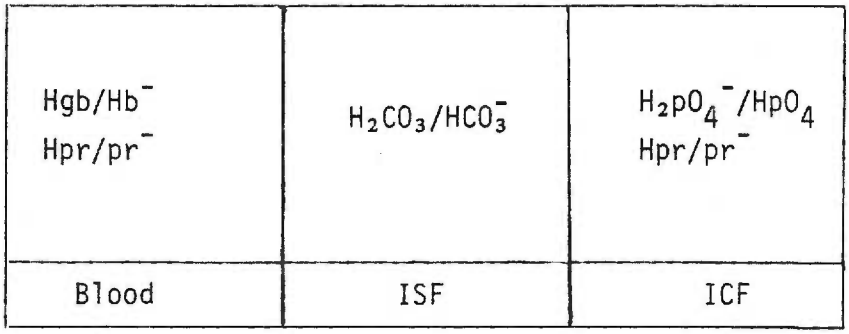
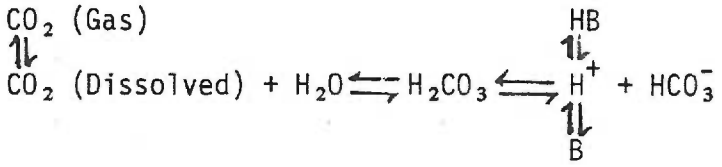


FIGURE 2

Major buffers for each body fluid compartment are depicted above. Hemoglobin is the predominant buffer in the blood compartment, but protein and the carbonic acid/bicarbonate system also contribute. The carbonic acid/bicarbonate system is the main buffer in the intersitial fluid compartment. Phosphorus and proteins are main buffers in the intracellular fluid compartment. The above illustration is a model of major buffers and not representative of the different proportions of each fluid compartment.

There is an interrelationship between each of these buffer systems of the body. Each buffer system is in equilibrium or balance with one another with H^+ as the fulcrum. It should be remembered that acids are H^+ donors while bases are H^+ acceptors. The following equation illustrates this concept:



EQUATION 1. (Buffering)

HB/B^- system represents non-volatile buffer system where HB represents H^+ in combination with other body buffers besides H_2CO_3/HCO_3^- and B^- represents other body buffers without H^+, i.e., buffer bases. H_2CO_3/HCO_3^- represents the volatile buffer system.

If H^+ is added to the blood in the form of non-volatile acids, then two buffering reactions will take place. One reaction will be the combination of H^+ and B^- forming HB. The other reaction will be the combination of H^+ with HCO_3^- forming carbonic acid (H_2CO_3). Carbonic acid then is dehydrated into H_2O and CO_2. Carbon dioxide is excreted via the lungs. Both of these reactions help reduce free H^+ concentration and thereby help minimize pH shifts to possible dangerously low values.

If non-volatile acid is decreased or base is added, then the reactions are reversed. The first buffering step is a dissociation of HB into B^- and H^+. Additionally, CO_2 and H_2O combine to form H_2CO_3 which in turn dissociates into HCO_3^- and H^+. The end result is replacement of some of the free H^+ lost when base was added to the blood. Again, these buffering steps minimize dangerous pH shifts in an alkaline direction.

If CO_2 is added to blood via hypoventilation or intentionally inhaling high concentrations of CO_2, then the entire horizontal reaction shown in Equation 1 will shift to the right. Carbon dioxide will combine

with H_2O forming H_2CO_3. Carbonic acid will then dissociate into HCO_3 and H^+. Some of the excess hydrogen ions formed will then combine with B^- (body buffers other than H_2CO_3/HCO_3^-) to form HB again reducing possible dangerous pH shifts to an acidotic state.

If the CO_2 content of blood is decreased as occurs in hyperventilation, then the reaction in Equation 1 will shift from right to left. The buffering reaction involves a dissociation of HB to form B^- and H^+ thereby replacing some of the H^+ lost when CO_2 was excreted.

3b) Constructing a CO_2 Titration Curve

A titration curve is a graphic illustration of the ability of a solution to buffer an acid. A titration curve could be constructed for any acid such as hydrochloric acid or sulfuric acid. Generally, however, the more important titration curves for clinical assessment are those for organic acids, especially carbonic acid which comes from the hydration of CO_2. Because carbonic acid can be added to blood by adding CO_2 the curve obtained is called a CO_2 titration curve. Since CO_2 is in equilibrium with the H_2CO_3/HCO_3^- buffer system, a CO_2 titration curve is therefore a type of buffer curve and very valuable in acid-base assessment.

In order to construct a CO_2 titration curve, varying concentrations of CO_2 are allowed to equilibrate with blood. When different amounts of CO_2 are allowed to equilibrate with blood the buffering reaction explained in Equation 1 occurs. If increasing concentrations of CO_2 are allowed to equilibrate with blood then the pH will progressively decrease (Equation 2). When each increasing level of CO_2 is plotted as a point on a $pH/[HCO_3^-]$ diagram the points fall on a straight line. The slope of this line is always

negative. This line is called a CO_2 titration or buffer curve.

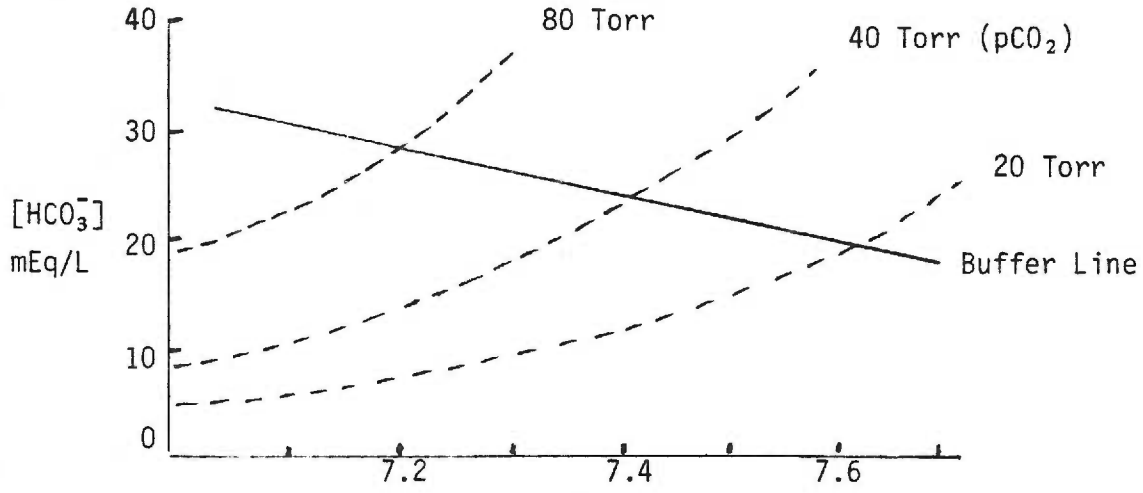


FIGURE 3. (Buffer Curve)

pH/$[HCO_3^-]$ diagram illustrating the construction of a CO_2 titration curve or buffer line at various concentrations of CO_2. The dashed curves represent values of constant pCO_2 (isobars).

3c) Effect of Hemoglobin Concentration on the CO_2 Titration Curve

The buffer capacity of blood is the slope of the CO_2 titration curve and is dependent on hemoglobin concentration. Hemoglobin, as mentioned before, is a major buffer of the blood compartment. Hemoglobin is a buffer because it contains a large number of acidic and basic groups. High concentrations of hemoglobin are able to buffer more CO_2 than low concentrations of hemoglobin. When CO_2 is added to blood with higher hemoglobin concentrations, more HCO_3^- will be generated than in blood with lower hemoglobin concentrations (Equation 1). The buffer curve therefore has a steeper slope with high hemoglobin concentrations. For example, a blood sample with a normal pH, pCO_2, and $[HCO_3^-]$ is allowed to equilibrate with a high concentration of CO_2 (pCO_2 = 88 torr) until the pH reaches a value of

7.2. At this value a blood sample with a hemoglobin concentration of 20 gm% will have a $[HCO_3^-]$ of 33 mM/L. On the other hand, a blood sample with a low concentration of hemoglobin of 5 gm% would have a $[HCO_3^-]$ concentration of 27 mM/L (see Figure 4).

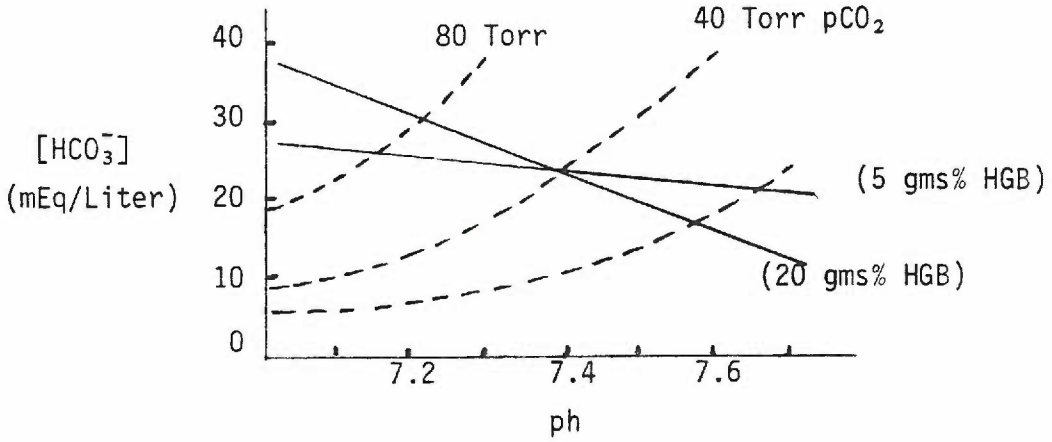


FIGURE 4.

The above pH/$[HCO_3^-]$ diagram illustrates the effect of high and low hemoglobin concentrations on the CO_2 titration curve.

3d) Example of a CO_2 Titration Curve Used in Acid-Base Assessment

Buffer curves are extremely useful tools in acid-base assessment. They provide a way of assessing the buffer capacity of blood at a particular point in time. Many diagrams have been constructed using buffer curves. The pH/$[HCO_3^-]$ diagram is probably one of the easiest to understand and one of the most widely used tools in acid-base assessment (see Figures 3, 4, 5). Three parameters are used (pH, pCO_2, and $[HCO_3^-]$) to assess metabolic or respiratory acid-base disturbances. The sector in which a patient's pH, pCO_2, and $[HCO_3^-]$ fall determines the specific type of acid-base disturbance. Points representing uncompensated

FIGURE 5.

Davenport Diagram

Each roman numeral indicates a different acid-base disorder: I indicates respiratory acidosis; II indicates mixed respiratory acidosis and metabolic alkalosis; III indicates metabolic alkalosis; IV indicates combined respiratory and metabolic alkalosis; V indicates respiratory alkalosis; VI indicates mixed respiratory alkalosis and metabolic acidosis; VII indicates metabolic acidosis; VIII indicates combined respiratory and metabolic acidosis.

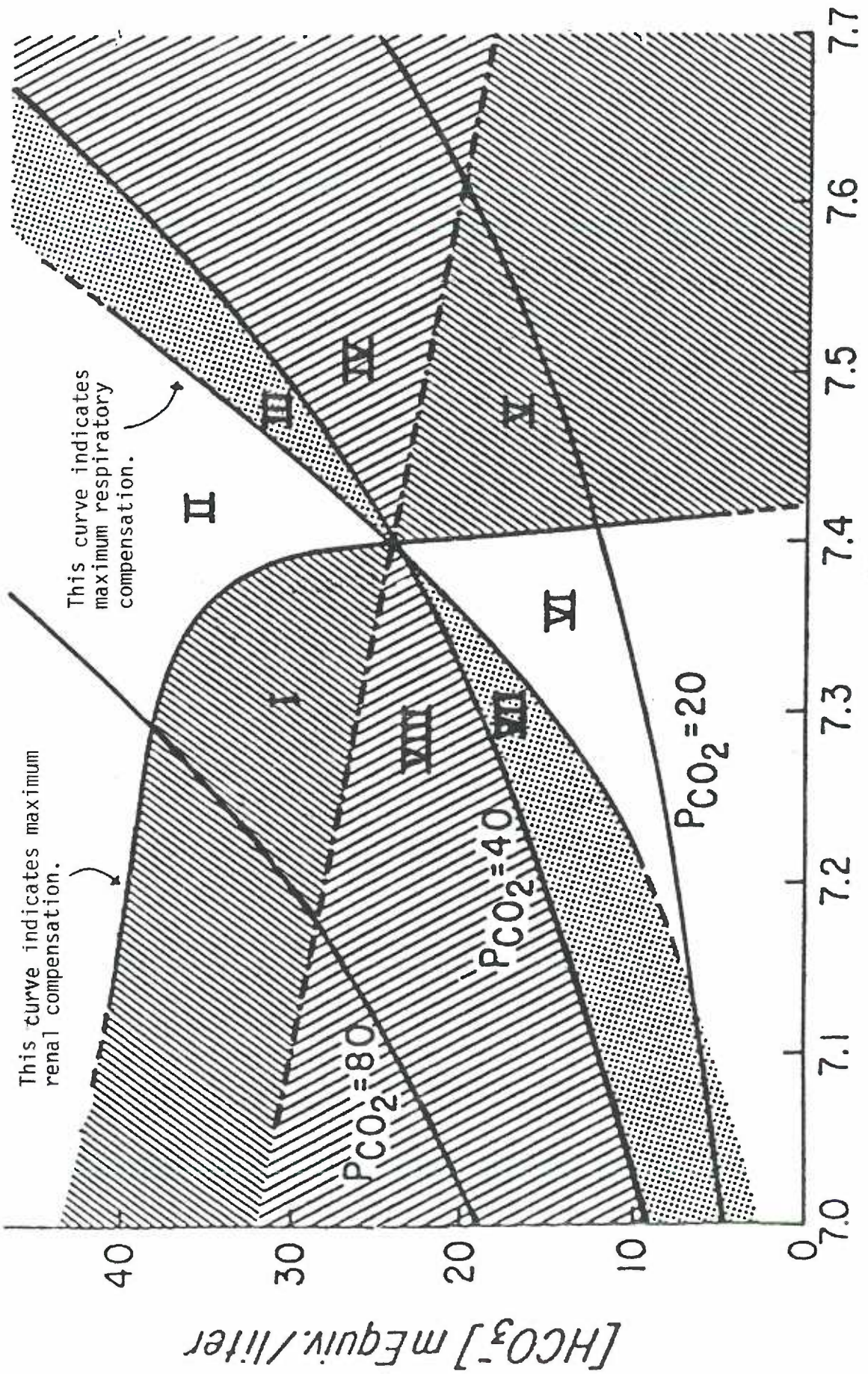


FIGURE 5. Davenport Diagram (modified from Keyes, 1982.)

respiratory acidosis or alkalosis lie on the CO_2 buffer line. Respiratory compensation for metabolic acid-base disturbances generally follow a path parallel to the buffer line. Any point on this graph below the buffer line indicates a base deficit. Any point above the buffer line indicates a base excess. The accuracy of this buffer line is, therefore, of great importance.

3c) The Difference Between In-Vivo and In-Vitro CO_2 Titration Curves

In-vitro CO_2 titration curves are derived by first removing a sample of blood from the body. The sample is then titrated with varying concentrations of CO_2. With each change in CO_2 concentration the pH and $[HCO_3^-]$ are determined and plotted on the pH/$[HCO_3^-]$ diagram. When CO_2 equilibrates with an in-vitro blood sample buffering occurs. This buffering, however, is confined to the plasma proteins and hemoglobin in blood only.

In-vivo buffer curves are determined by allowing CO_2 to equilibrate with blood before the sample is removed from the body. The key to this procedure is that it allows the blood to equilibrate with interstitial fluid before analyses are made. A change in CO_2 is accomplished by having the patient inhale high concentrations of CO_2 or by altering alveolar ventilation. At various concentrations of CO_2 the pH and $[HCO_3^-]$ of the sample are determined and the results plotted on a pH/$[HCO_3^-]$ diagram.

There are three major factors why the slope of the buffer line in-vivo differs from the in-vitro slope. These are: 1) the volume of interstitial fluid, 2) intracellular buffering, and 3) renal compensation over time.

Interstitial fluid volume is normally 2-3 times that of blood volume.

In addition, interstitial fluid has very few proteins and therefore is not as effective a buffer of CO_2 as is blood. When CO_2 is added to blood it quickly combines with H_2O forming H_2CO_3 which dissociates into hydrogen ions and bicarbonate ions. In-vivo the additional bicarbonate ions formed from the added CO_2 equilibrate with ISF. Therefore, because HCO_3^- diffuses out of blood into ISF, in-vivo, the change in $[HCO_3^-]$ of blood will be less than that found with blood equilibrated in-vitro. Consequently, the slope of the buffer line in-vitro is greater than the in-vivo slope (see Figure 6). The equilibration of HCO_3^- in-vivo between plasma and ISF has a dilutional-like effect on plasma $[HCO_3^-]$ (see Figure 8a & 8b). Therefore, patients with alterations in their ISF volume will have different slopes for CO_2 buffer curves. An increase in ISF as occurs in edema will cause a decrease in the slope of the in-vivo buffer line (see Figure 9).

Intracellular buffering is the second factor affecting buffer curves. When CO_2 is added to body fluids it can easily diffuse into the intracellular compartment. In the intracellular compartment CO_2 combines with H_2O to form H_2CO_3 (carbonic acid). Intracellular proteins can buffer this carbonic acid in the same way as hemoglobin buffers H_2CO_3 in the blood. In addition, H^+ diffuses from ISF into ICF in exchange for Na^+ and K^+ (Giebisch, Berger, & Pitts, 1955). As more hydrogen ions diffuse out of the ISF compartment more H_2CO_3 can dissociate into H^+ and HCO_3^-. The $[HCO_3^-]$ increases in ISF due to this shift (see Figure 7). The greater the number of body cells available in proportion to total body weight the more buffering that can take place. Intracellular buffering is, therefore, a function of lean body mass.

These first two factors, 1) intersititial fluid volume, and 2)

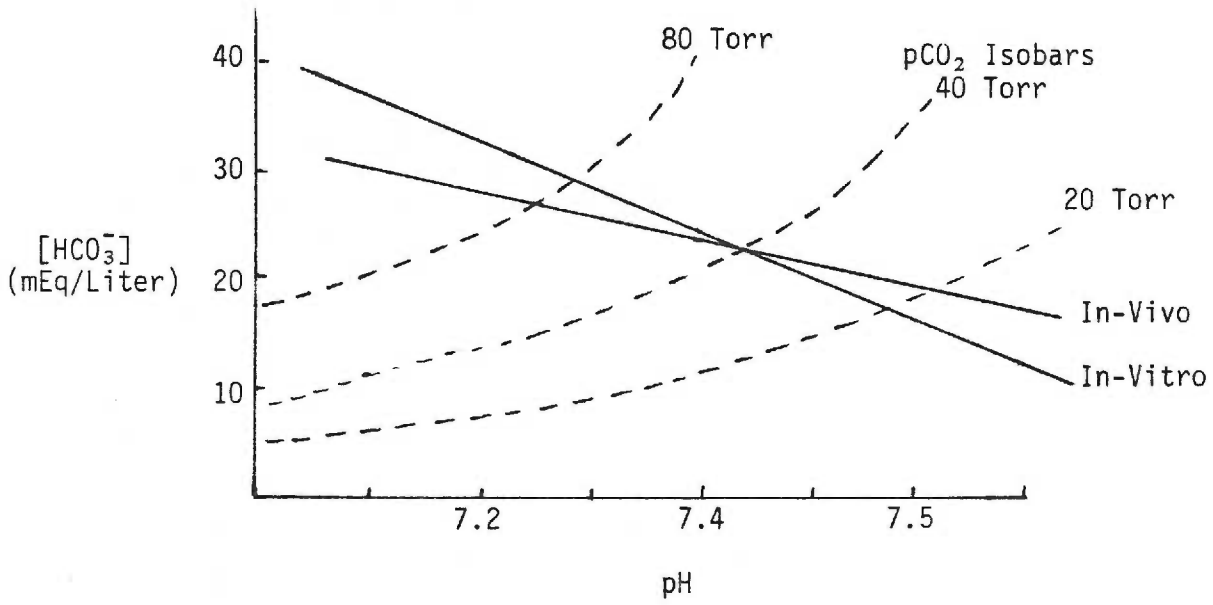


FIGURE 6.

The pH/$[HCO_3^-]$ plot above illustrates the difference between in-vitro CO_2 titration curves and an in-vivo CO_2 titration curve. The blood sample represented by the in-vivo curve was allowed to equilibrate with ISF at varying concentrations of CO_2. The above in-vivo curve, however, does not include the effect of intracellular buffering which would tend to decrease its slope.

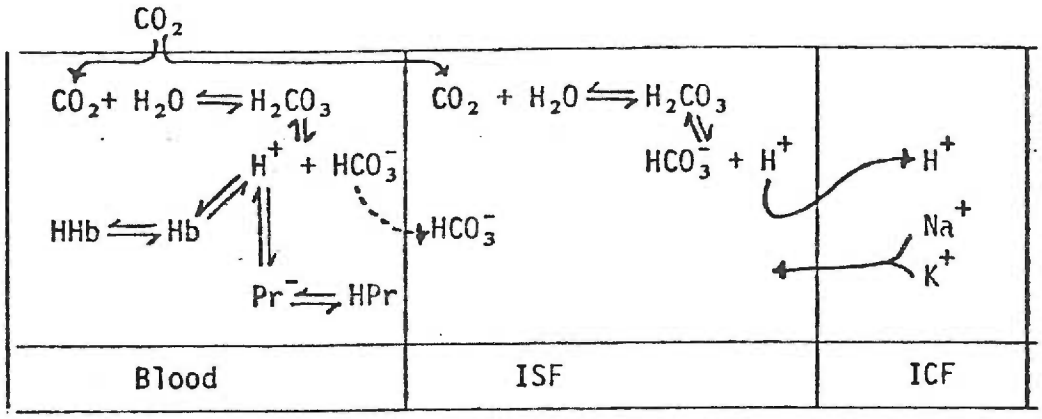


FIGURE 7.

The effects of adding CO_2 to the blood. With in-vitro titration, reaction is confined to the blood alone. With in-vivo titration, CO_2 and HCO_3^- diffuse into the ISF.

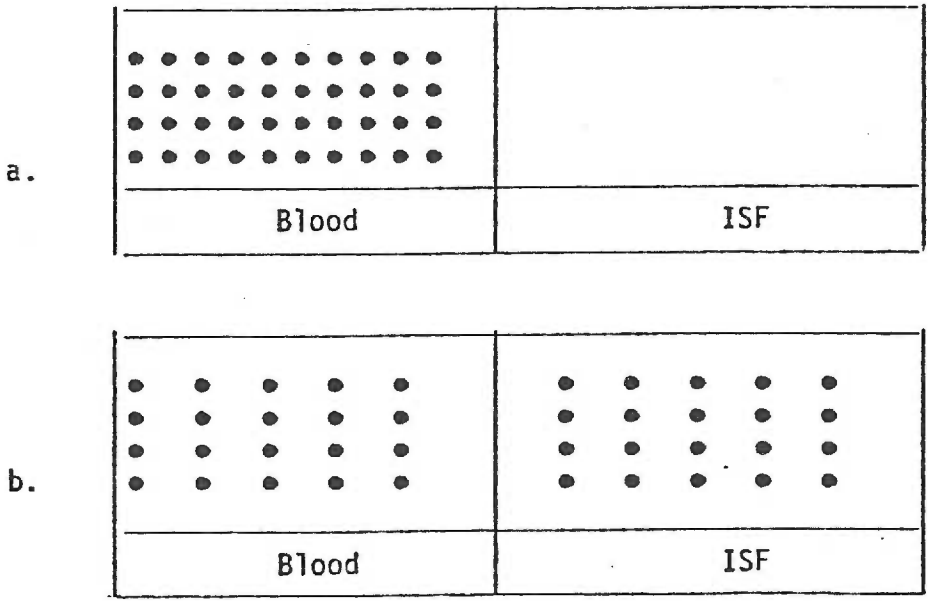


FIGURE 8.

The dots represent $[HCO_3^-]$ in the above illustrations. Figure a depicts HCO_3^- confined to the blood compartment which is similar to in-vitro blood samples. Figure b depicts HCO_3^- that has equilibrated with ISF. The dilutional-like effect is why in-vivo samples have a different slope than in-vitro blood samples.

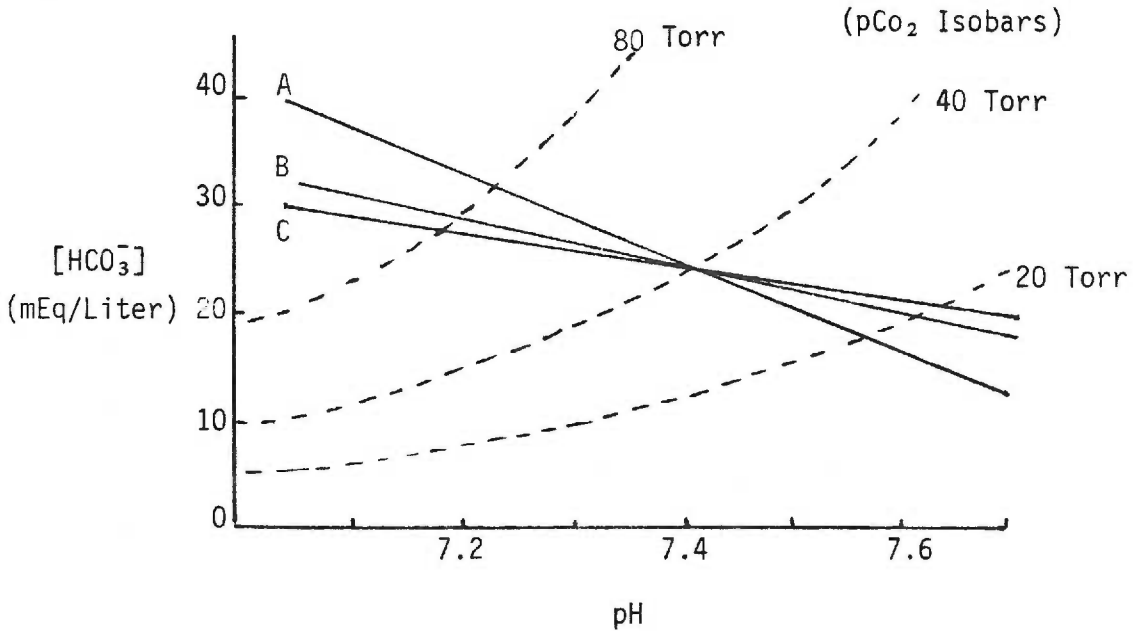


FIGURE 9.

The above pH/$[HCO_3^-]$ plot illustrates: A) In-vitro CO_2 titration curve, B) in-vivo CO_2 titration curve, and C) in-vivo CO_2 titration curve in an edematous state. The above in-vivo slopes do not include the effect of intracellular buffering.

intracellular buffering, affect the slope of the in-vivo buffer curve in opposite ways. Interstitial fluid volume, particularly when in excess, tends to decrease the slope of the in-vivo buffer curve. Intracellular buffering increases the slope of the in-vivo buffer curve. The net effect is the difference between these two opposing factors. In the normal person, interstitial fluid volume has the greater influence tending to dilute $[HCO_3^-]$ and decrease the slope of the in-vivo buffer curve.

The third factor affecting the in-vivo buffer curve is renal compensation over time. There is a significant difference in the body's ability to buffer acute hypercapnea as opposed to chronic hypercapnea. In chronic hypercapnea the renal tubule cells, over a few days time, generate additional bicarbonate to buffer extra H^+ formed (renal compensation). Because of renal compensation, the in-vivo buffer curve is steeper and $[HCO_3^-]$ is increased in chronic hypercapnea as opposed to acute hypercapnea.

To summarize, in-vivo buffer curves are a closer approximation of actual body buffering than in-vitro buffer curves. In-vitro buffer curves only take hemoglobin and plasma protein buffering into account. In-vivo buffer curves take into account the effect of 1) hemoglobin and protein in the blood, 2) interstitial fluid volume, 3) intracellular buffering, and 4) renal compensation over time. Arterial blood equilibrates with pulmonary interstitial fluid which under normal circumstances is a small volume. Therefore the slope of the CO_2 buffer curve determined from arterial blood will be steep. Venous blood, however, equilibrates with ISF of systemic tissues. Hence, there is more dilution of $[HCO_3^-]$ in venous blood. It is for these reasons venous blood has been associated with the true in-vivo buffer curve while arterial blood has been associated on in-vitro buffer curve.

REVIEW OF THE LITERATURE

There has been no reported research on the use of femoral venous blood-gas composition for assessment of acid-base status. There has been only one reported research study with reported value of femoral venous blood-gas composition during states of decreased cardiac output. The literature review is therefore organized in the following way:

1) Theoretical considerations regarding differences in mixed venous and arterial venous blood-gas compositions.
2) Predictability of mixed venous and peripheral venous blood-gas composition over a wide range of respiratory and metabolic acid-base disturbances.
3) The effects of decreased cardiac output on arterial, femoral venous, mixed venous, and peripheral venous blood-gas compositions.

1) Theoretical Considerations Regarding Differences in Mixed Venous and Arterial Blood-Gas Compositions

Roos and Thomas (1967) published a mathematical discussion on the theory of buffering of CO_2 in-vivo and in-vitro. They based their discussion on known facts already published. In their discussion they compared the slopes of arterial and mixed venous buffer (titration) curves under a variety of conditions, including alterations in cardiac output. They concluded from this discussion that buffer curves obtained from mixed venous blood provided true in-vivo CO_2 titration curves and those from arterial blood gave in-vitro CO_2 titration curves.

This conclusion is understandable when one refers to the model in Figure 1. As mentioned before, arterial blood equilibrates only with ISF of the pulmonary bed. The volume of ISF in the pulmonary bed is relatively insignificant compared to the volume of ISF in the rest of the body. Any dilutional effect pulmonary ISF has on arterial blood, therefore, follows a pattern similar to an in-vitro blood sample that has not been allowed to equilibrate with ISF. Mixed venous blood, however, has equilibrated with a much larger volume of ISF. Consequently, the CO_2 titration curve of mixed venous blood must follow an in-vivo equilibration pattern, i.e., equilibrated with ISF.

Roos and Thomas made three assumptions prior to their mathematical predictions. One, there is no net exchange of ions across the walls of tissue cells. As mentioned in the Theory Section of this paper, net exchange of ions across walls of tissue cells does occur (see Figure 7). The exchange effect opposes the influence of ISF by adding a small amount of HCO_3^- to ISF. In the acute situation the effect of cellular buffering, however, is relatively small, leaving the dilutional-like effect of ISF volume more predominant. The in-vivo slope from Roos and Thomas's calculations is, therefore, the combined effect of only two fluid compartments, blood and ISF.

The second assumption they made is that renal compensation did not have time to occur and therefore had no significant effect on ionic composition of ISF. Roos and Thomas allowed each alteration in CO_2 tension sufficient time to reach a new steady state, but not long enough for renal compensation to alter $[HCO_3^-]$. They reasoned that time for

steady state was largely dependent on blood flow through muscles. The two reasons for this are: 1) muscles form about 40 percent of the total body mass, and 2) under resting conditions their perfusion rate per unit mass is much less than remaining tissues. In a normal conscious man at rest an equilibration period of twenty minutes is assumed to be sufficient time to reach a steady state. Under conditions in which there may be drastic reduction in muscle flow, such as general anesthesia or decreased cardiac output, the time required for a new steady state to be reached might be prolonged.

The third assumption made was that there would be full oxygenation of mixed venous blood to avoid the influence of the Bohr and Haldane effects on the CO_2 titration curve. It was necessary to eliminate normal variances of the Bohr and Haldane effects in order to isolate the subtle differences between in-vivo and in-vitro CO_2 titration curves. Full oxygenation may be true for arterial blood, but not venous blood. Because of the Bohr and Haldane effects, the titration curve of mixed venous blood is parallel to and lies above that of fully saturated arterial blood (see Figure 10).

The Haldane effect reflects the change in CO_2 content of blood during oxygenation and deoxygenation of blood. Oxygenated hemoglobin is a stronger acid and gives off hydrogen ions. The hydrogen ions given up combine with bicarbonate ions to form carbonic acid. Carbonic acid then is dehydrated to CO_2 and H_2O. At a constant $paCO_2$ of 40 torr the additional CO_2 formed passes into a gas phase. The results of this process are a slight decrease in $[HCO_3^-]$ for a given pCO_2, thereby displaying the slope of the HbO_2 buffer line in Figure 10 parallel to but

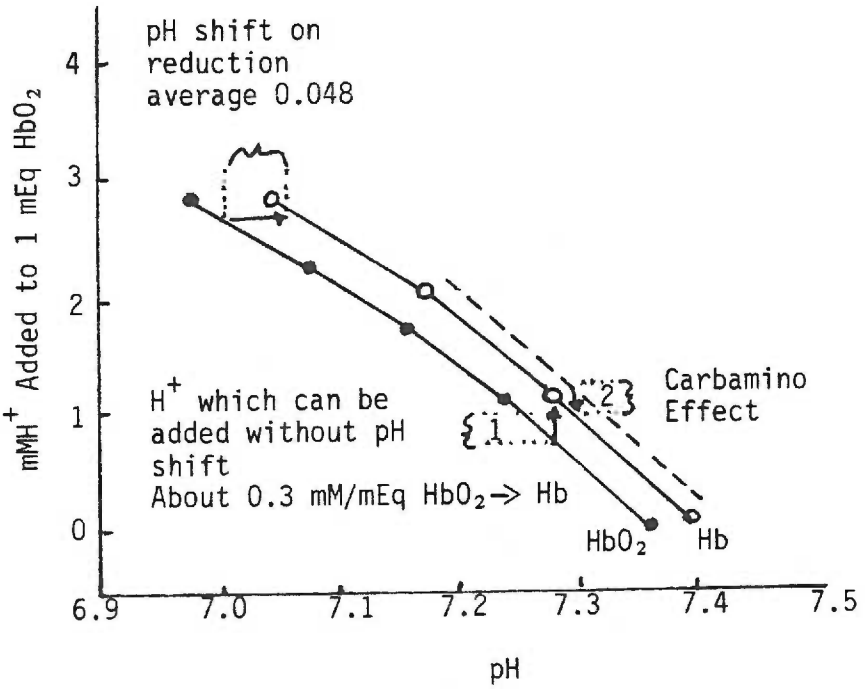


FIGURE 10

CO_2 titration curves of oxyhemoglobin (HbO_2) and reduced hemoglobin (Hb) at 37°C. The dashed line indicates the position of the titration curve of reduced hemoglobin in the complete absence of CO_2 (Davenport, H., The ABC of Acid-Base Chemistry, Chicago: University of Chicago Press, 1974, p. 30).

below the Hb buffer line.

When oxygenated hemoglobin is reduced or deoxygenated, it is a weaker acid and removes H^+ from the blood. The subsequent fall in H^+ causes carbonic acid to ionize into HCO_3^- and H^+, allowing more CO_2 to enter the blood from the gas phase. The result of this process is to increase the $[HCO_3^-]$ for a given pCO_2 displaying the slope of the Hb buffer line in Figure 10, which is parallel to and above the HBO_2 buffer line. The events described in the above two paragraphs is known as the Haldane effect.

It should be noted, however, that there is a greater displacement in-vitro by the Haldane effect than there is in-vivo. The maximum displacement of an in-vivo curve is less because the hemoglobin concentration in the in-vivo pool (blood + ISF) is less than the hemoglobin concentration in an in-vitro blood sample (Davenport, 1974).

The Bohr effect is the process by which an increase in pCO_2 decreases the amount of oxygen combined with hemoglobin at a given pO_2. It happens when CO_2 combines with the alpha-amino groups of the N-terminal valines of the four polypeptide chains of hemoglobin. As pCO_2 increases more CO_2 can react with these groups and produces an allosteric effect in the hemoglobin molecule, shifting the reaction between iron atoms and O_2 toward dissociation (Davenport, 1974). The Bohr effect would be more pronounced in a patient with advanced emphysema characterized by compensated respiratory acidosis with increased $paCO_2$ levels. The Bohr effect is also more pronounced on the venous side of circulation, particularly in the capillary beds of working muscles.

There, the Bohr effect helps facilitate release of O_2 from the hemoglobin molecule.

After explaining the above three assumptions, Roos and Thomas then examined the predicted relationships of arterial and mixed venous CO_2 titration curves under various conditions. Under steady state conditions of respiration, circulation, and metabolism arterial and mixed venous blood both fall on an in-vitro CO_2 titration line. During alterations in steady state conditions, mixed venous blood is titrated along the true in-vivo buffer line whereas arterial blood is titrated along an in-vitro CO_2 buffer line. Of particular interest is the difference in arterial and mixed venous blood buffer curves during alterations in cardiac outputs (see Figure 11).

Roos and Thomas predicted that by reducing cardiac output by one-half while maintaining a constant arterial pCO_2 the events illustrated in Figure 11 will transpire. Mixed venous blood will follow the in-vivo buffer line to a new steady state ($\bar{v}_1$ - $\bar{v}_2$) with a higher pCO_2 and $[HCO_3^-]$. The new mixed venous/arterial points ($\bar{v}_2$ - a_2) will be on an in-vitro buffer line parallel to and below the original in-vitro buffer line. Arterial blood-gas composition therefore changes as a result of decreased cardiac output even though arterial CO_2 tension is kept constant.

This picture is further complicated when CO_2 is altered in addition to cardiac output. There are normal alterations in cardiac output when pCO_2 is changed that follow a predictable pattern similar to that described for decreased cardiac output. However, when there are

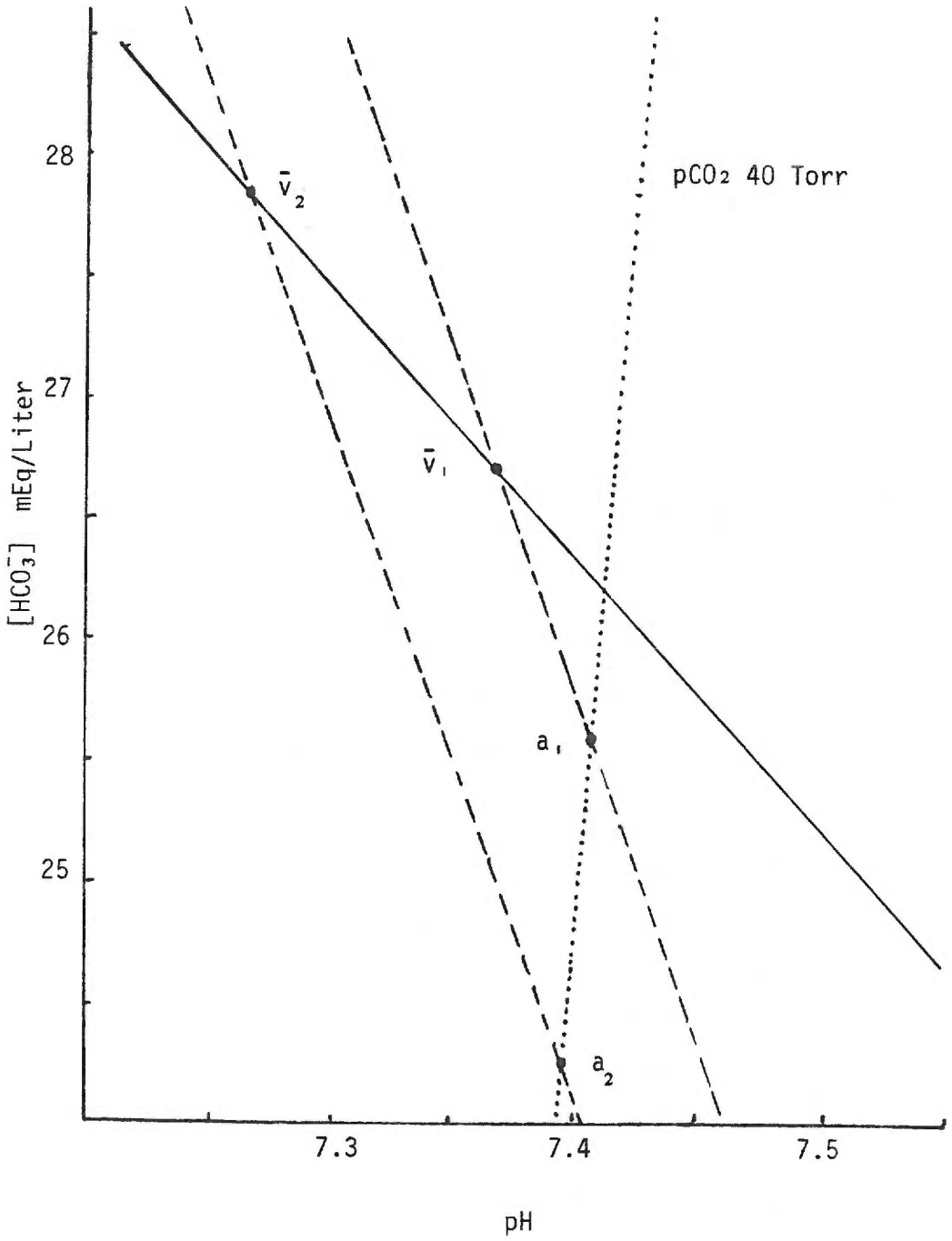


FIGURE 11

a_1 and $\bar{v}_1$ represent arterial and mixed venous blood-gas composition at control conditions. a_2 and $\bar{v}$ represent arterial and mixed venous blood-gas composition after cardiac output is reduced by 50%. $\bar{v}_2$ and $\bar{v}_1$ fall on the in-vivo buffer line. $\bar{v}_2 - a_2$ and $\bar{v}_1 - a_1$ follow an in-vitro slope but are parallel to one another (adapted from Roos & Thomas, 1967).

additional alterations in cardiac output such as occurs in hemorrhage, shock, or cardiac failure, then there is no longer a predictable relationship between the location of the two arterial points. Mixed venous blood-gas composition always follows in-vivo buffer curve regardless of a change in pCO_2, cardiac output, or a combination of the two. Arterial blood-gas composition, however, is not so predictable (see Figure 12).

In summary, the predictions of Roos and Thomas indicate that mixed venous blood follows an in-vivo CO_2 titration curve even in alterations of CO_2 and cardiac output. Arterial blood follows an in-vitro slope and is much less predictable during the same conditions. Their model and hypothesis was followed by numerous clinical and laboratory experiments which generally supported their conclusions (Garcia, Lai, Attebery & Brown, 1971; & Kappagoda, Stoker, Snow & Linden, 1972). The difference, however, between the in-vivo slopes was not as great as predicted from Roos and Thomas's original calculations. This is probably due to the fact that Roos and Thomas did not account for intracellular buffering in their model. Nevertheless, in states of low cardiac output mixed venous blood is still a better indicator of the true in-vivo CO_2 titration curve than arterial blood.

Michel (1968) published another mathematical model supporting the predictions of Roos and Thomas. Michel discusses how the Haldane effect alters mixed venous and arterial buffer curves during normal respiratory exchange, during hypoxemia, and during decreased cardiac output.

The Haldane effect refers to the change in carbon dioxide content

FIGURE 12

Oxygenated mixed venous plasma ($\bar{v}_1 - \bar{v}_2$) represents the normal in-vivo buffer curve. $a_1 - \bar{v}_1$ represents plasma compositions of arterial and mixed venous blood at control conditions. $a_2 - \bar{v}_2$ represents plasma compositions after an increase in arterial pCO_2 from 40-58 Torr, accompanied by an increase in cardiac output of 77%. Assuming instantaneous rise of arterial pCO_2 to 58 Torr, the course of arterial plasma composition is given by heavy line $a_1 - \bar{v}_1 - m - a_2$, that of mixed venous plasma by the heavy interrupted line $\bar{v}_1 - \bar{v}_2$. The interrupted line $a_1 - a_2$ represents the erroneous in-vivo curve from arterial sampling (adapted from Roos & Thomas, 1967).

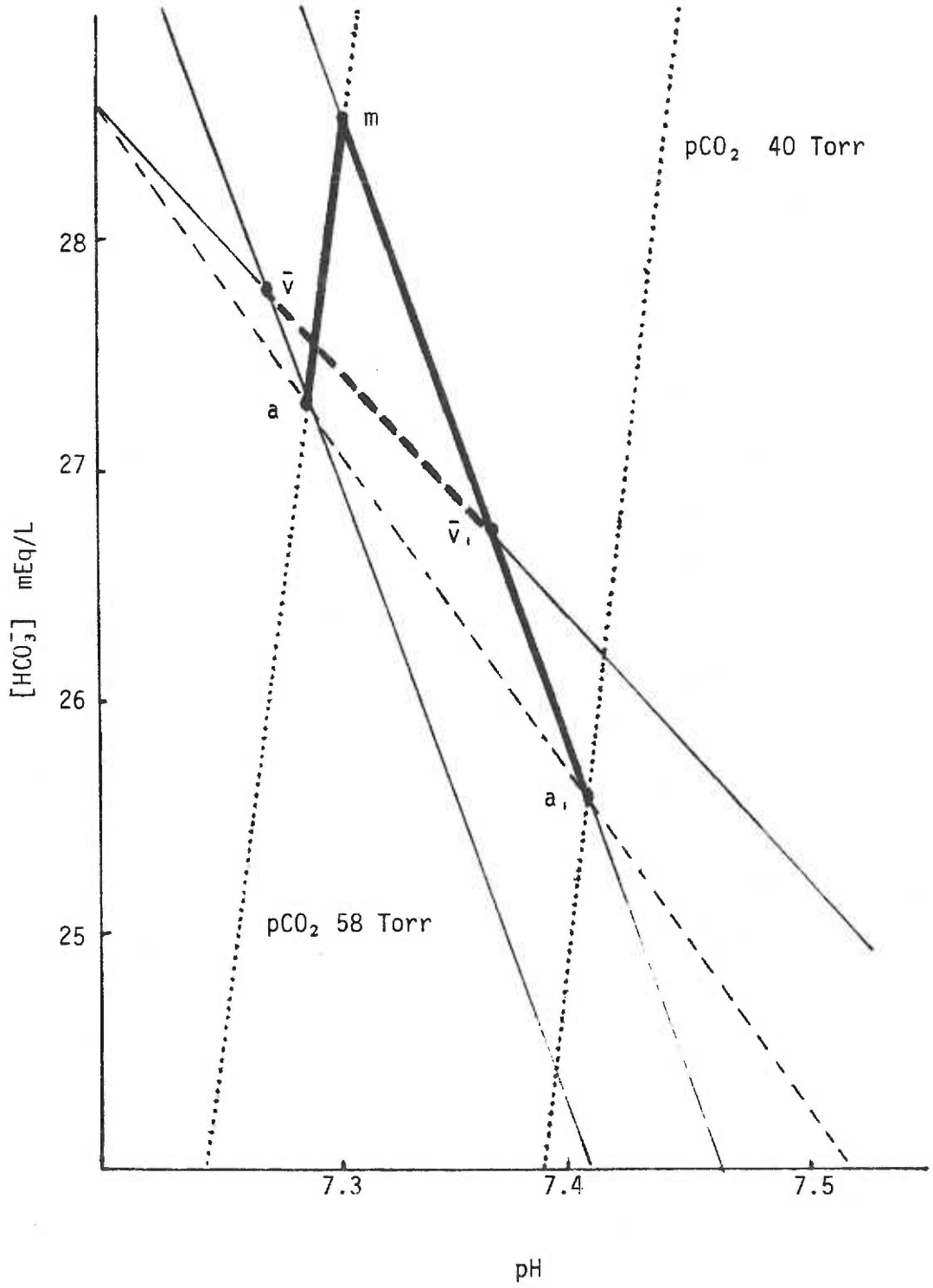

m
pCO2 40 Torr
28
v̄
a
27
v̄1
[HCO3−] mEq/L
26
a1
25
pCO2 58 Torr
7.3
7.4
7.5
pH

FIGURE 12

of blood accompanying oxygenation and deoxygenation of hemoglobin. When hemoglobin is oxygenated it becomes a stronger acid. Hemoglobin therefore gives up more hydrogen ions when it combines with oxygen. As a result the reaction in Equation 1 (page 11) shifts to the right. The additional H^+ combine with HCO_3^- to form H_2CO_3. Carbonic acid is then dehydrated to CO_2 and H_2O. At a constant arterial pCO_2 of 40 torr the additional carbon dioxide passes into a gas phase. Therefore, the $[HCO_3^-]$, pH, and total CO_2 of blood decrease when hemoglobin is reduced or deoxygenated. When hemoglobin is reduced or deoxygenated it becomes a weaker acid. Therefore it is able to take up H^+ from the blood. This causes a reversal of the reactions described above. As in Equation 1 (page 11) a fall in H^+ causes the reaction to shift to the left. Reduction of $[H^+]$ causes H_2CO_3 to dissociate into H^+ and HCO_3^-. The fall in $[H_2CO_3]$ allows more CO_2 to enter the blood from the gas phase. Therefore the $[HCO_3^-]$, pH, and total CO_2 increase slightly when hemoglobin is reduced (refer to Figure 10).

Michel analyzed the differential responses of the Haldane effect on in-vivo and in-vitro blood samples. In Figure 13 the in-vivo and in-vitro response for the Haldane effect is illustrated. Point A represents completely oxygenated hemoglobin (100% SO_2) of blood in-vivo and in-vitro at a constant $paCO_2$. Point C represents deoxygenated blood in-vitro at (70% SO_2) and a constant $paCO_2$. Point A is a common point for both in-vivo and in-vitro blood. Deoxygenated blood in-vitro falls on an in-vitro slope above and parallel to oxygenated blood in-vitro. Deoxygenated blood in-vivo falls on an in-vivo slope above and parallel

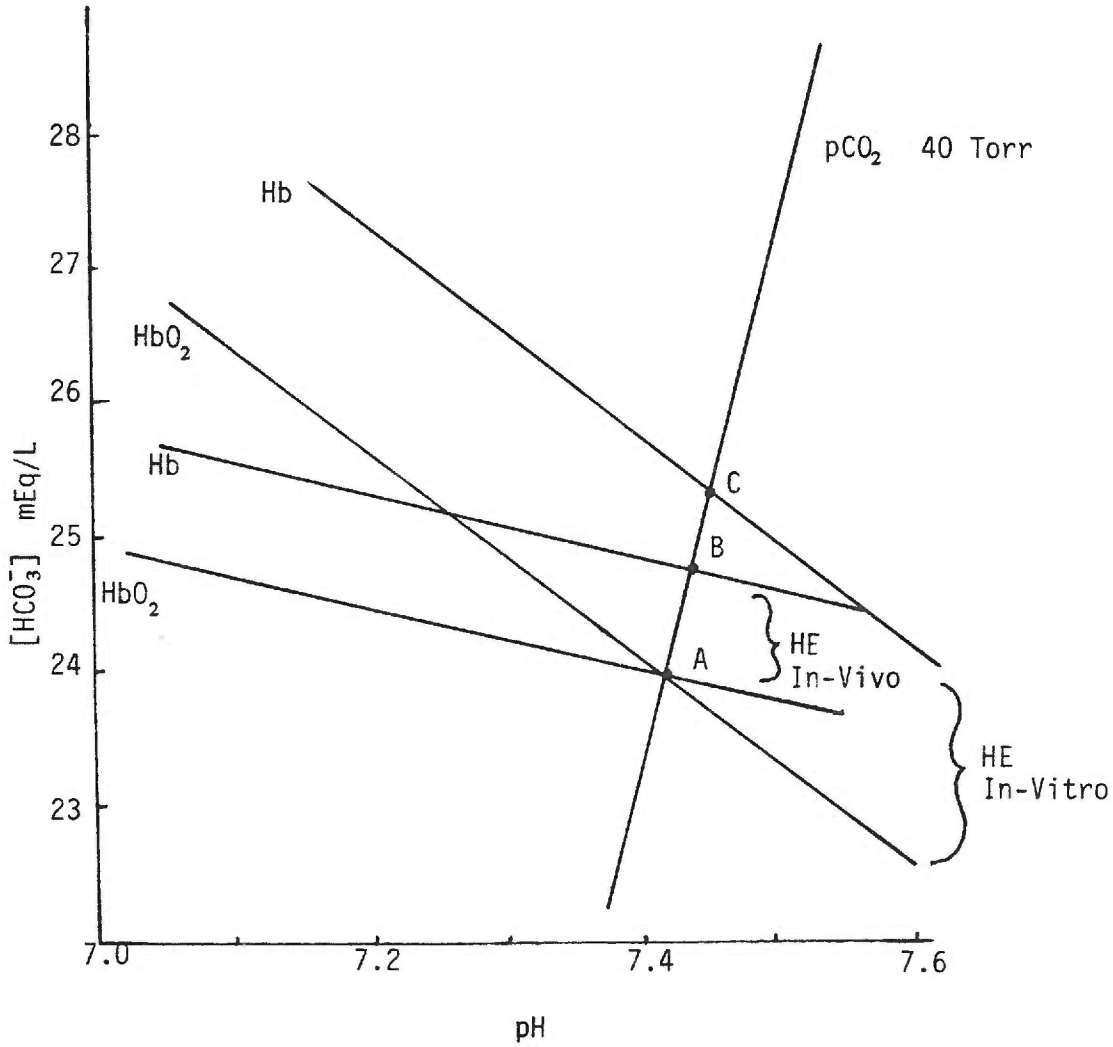


FIGURE 13

The Haldane effect (HE) of blood drawn in-vivo and in-vitro at a constant $paCO_2$ as mathematically calculated (modified from Michel, 1968).

to oxygenated blood in-vivo. The magnitude of the Haldane effect is greater in-vitro than in-vivo.

The first condition Michel analyzes is the normal respiratory cycle in a steady state. The term respiratory cycle as used by Michel involves changes occurring in the blood when it loses O_2 and takes up CO_2 in the tissues and loses CO_2 and gains O_2 in the lungs. Michel points out that in a steady state, i.e., constant VO_2 and VCO_2 as well as constant cardiac output, arterial and mixed venous buffer curves follow an in-vitro pattern. Arterial and mixed venous blood-gas compositions are related by gas exchange occurring in the lung. This exchange always follows an in-vitro buffer curve. Experimental evidence supporting this statement that under steady state conditions CO_2 and O_2 follow an in-vitro slope was shown by Chinard and Evans (1954).

This in-vitro relationship is illustrated in Figure 14. Point Vo represents mixed venous blood. Oxygenation of blood shifts the mixed venous point to V_1 and CO_2 dissociation causes the composition to change along an in-vitro slope to point Ao. Point Ao represents the original arterial composition during steady state conditions. Therefore, under steady state conditions mixed venous blood and arterial blood are related to one another through an in-vitro slope and the magnitude of the Haldane effect is shown a Δ HL. It is because of this relationship that analysis of in-vitro blood samples during steady state conditions has been useful.

Michel then looked at conditions when steady state was altered. The same Figure 14 illustrates what happens when there is a doubling of the A-V (arterial-venous) difference (or oxygen concentration) such as would occur if the cardiac output were reduced by one-half. The CO_2 and O_2

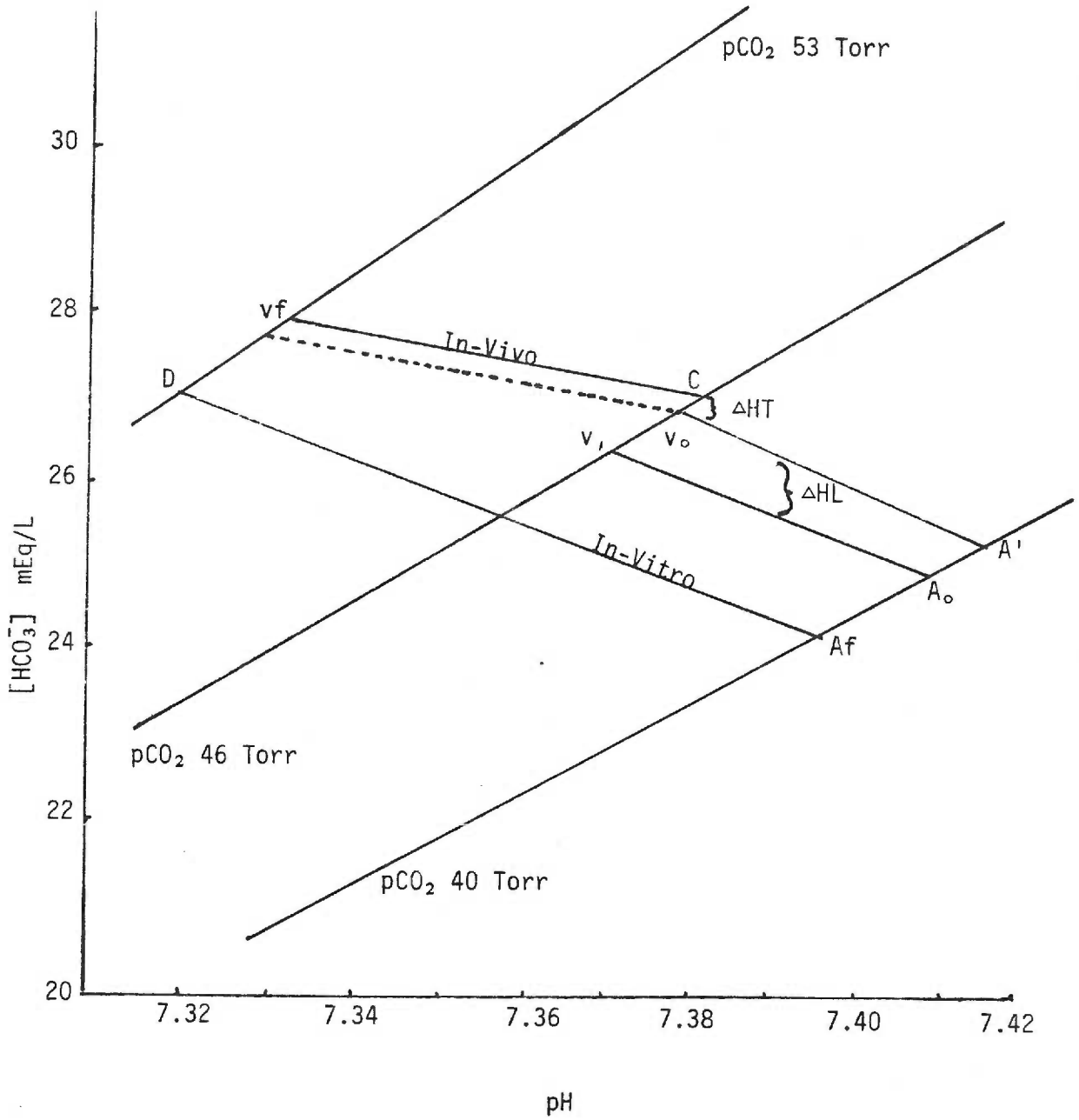


FIGURE 14.

The effects of doubling the A-V difference between arterial and mixed venous O_2 saturation at a constant $paCO_2$. A_o and V_o represent steady state conditions for arterial and mixed venous blood. Δ HL is the magnitude of the Haldane effect in the lungs and ΔHT is the magnitude of the Haldane effect in the tissues (revised Michel, 1968).

of arterial blood are kept constant. Ao represents the control point of arterial blood at a $paCO_2$ of 40 torr and oxygen saturation (SO_2) of 100%. The control point Vo represents mixed venous blood at a $pvCo_2$ of 46 torr and SO_2 of 70%. When the cardiac output is decreased by one-half two events occur in-vivo. One, the in-vivo Haldane effect displaces the venous point from Vo to point C. Second, the $pvCO_2$ and $[HCO_3^-]$ will also increase due to the decreased cardiac output to point Vf. In reality these events would occur simultaneously, but for the purpose of showing the separate effects are illustrated in two steps. The rise in pCO_2 as noted in Equation 1 (page 11) is accompanied by a rise in $[HCO_3^-]$ and $[H^+]$. Because these events all occur in systemic capillaries and follow an in-vivo buffer curve (C-Vf). The new venous point is Vf at a pCO_2 of 53.5 torr. In the lungs the venous blood is fully resaturated with oxygen. Blood from point D in the lungs then follows an in-vitro slope to point Af as CO_2 is removed. Point Af represents the new arterial value when cardiac output is decreased by one-half and at a constant arterial pCO_2. The new arterial point shows a decrease in pH and $[HCO_3^-]$ but not pCO_2. In comparison, the change in mixed venous blood was accompanied by a marked decrease in pH and increase in both $[HCO_3^-]$ and pCO_2.

Michel concluded that analysis of arterial blood-gas composition without reference to mixed venous blood might give an erroneous picture of the patient's acid-base status with particular emphasis in altered steady state conditions such as decreased cardiac output.

In summary, the theoretical considerations of Roos and Thomas (1967)

and Michel (1968) provided the impetus for looking at venous blood in assessing acid-base status of tissues. Several conclusions can be drawn from their work:

1) Mixed venous blood-gas composition is a better representation of ISF acid-base status than arterial blood-gas composition.
2) Mixed venous blood-gas composition represents a total body composite of ISF acid-base status.
3) Changes in the pCO_2 of mixed venous blood follow the true in-vivo CO_2 titration curve.
4) Changes in arterial pCO_2 follow an in-vitro CO_2 titration curve.
5) Mixed venous blood and arterial blood are related in the lungs via an in-vitro CO_2 titration curve during steady state conditions.
6) During alterations in steady state conditions such as decreased cardiac output or increase in pCO_2 mixed venous blood gives the true picture of acid-base status of ISF.

2) Predictability of Mixed Venous and Peripheral Venous Blood-Gas Composition Over a Wide Range of Respiratory and Metabolic Acid-Base Disturbances

Samet, Linhart, Barold, and Hildner (1969) conducted a study on the reliability of mixed blood for the measurement of blood-gas parameters. They obtained simultaneous arterial and mixed venous blood samples from 50 patients with a variety of cardiac problems. None of the 50 patients had acute cardiac problems or shock at the time of

the study. The pH, CO_2, and O_2 tensions were measured by a blood-gas analyzer using the microelectrode technique. The base excess was determined by means of an appropriate nomogram. Each sample was run in duplicate and required to match within narrow limits or repeat samples were performed. Each analysis was completed 15 minutes after sampling.

Samet, et al., found a significant correlation (+ 0.77, $p = 0.01$) when blood-gas parameters from mixed venous blood (abscissa) were plotted against values obtained from arterial blood (ordinant). However, there was a very low correlation (+ 0.29, $p = 0.05$) when parameters from mixed venous blood (abscissa) were plotted against the difference between mixed venous and arterial blood-gas parameters (ordinate). They concluded that there was a general trend in the relationship between mixed venous and arterial blood-gas parameters. Unfortunately, because of the low correlation between the differences in values of parameters found in mixed venous and arterial blood plotted against those from mixed blood they concluded that mixed blood was an unreliable substitute for arterial blood-gas assessment of acutely ill patients.

Samet, et al., drew an erroneous conclusion based on their evaluation of differences in mixed venous and arterial blood-gas parameters plotted against mixed venous blood-gas parameters. Griffith (1980) and Murphy (1982) strongly criticize the conclusions of Samet, et al., in their rejection of mixed venous blood as a reliable substitute for arterial blood. They discuss the relationship between variables which

are linearly related (x plotted against y) and how those same variables relate when (y-x) is plotted against (y). The following example modified from Griffith (1980) will help clarify the relationships and offer a more appropriate interpretation of data from Samet et al..

Given two variables x and y that are linearly related, then plotting y as an ordinate and x as an abscissa will yield a straight line. The following equation describes this relationship:

$$y = a + bx$$

where a = y intercept

b = the slope

Let's take an example of linear relationships with a slope of 1.0, 0.8, 0.5, and 0.2, and then compare the corresponding slopes for (y-x) plotted against (y). To simplify the discussion, the value of (a) will be zero. The conclusions would hold, however, even if (a) had a value other than zero (see pages 39 and 40).

In each of the four cases plotting y(ordinant) against x(abscissa) yields four lines with perfect correlations and varying slopes. When plotted as (y-x) verses (y) the slopes range from zero to -4, however, the correlations are still perfect. The closer the slope of (y vs. x) to 1.0, the closer the slope of (y-x vs. y) approaches zero. Data analyzed from the experiments of Samet et al. were responding appropriately for linearly related data. The strong correlation coefficient of 0.77 (with a slope approximating 1.0) obtained for CO_2 is not weakened by plotting its results as (y-x vs. y). Instead, the relationship for CO_2 responded exactly as predicted for two very positively correlated

CASE I

If: b=1 a=o y=x

y	x	y-x
1	1	0
2	2	0
3	3	0
4	4	0

Slope y-x vs. y=0

CASE II

If: b-0.8 a-o y=0.8x

y	x	y-x
1	1.25	-0.25
2	2.5	-0.50
3	3.75	-0.75
4	5	-1.0

Slope y-x vs. y=-.25

CASE III

If: b=0.5 a=o y=0.5x

y	x	y-x
1	2	-1.0
2	4	-2.0
3	6	-3.0
4	8	-4.0

Slope y-x vs. y = -1.0

CASE IV

If: b=0.2 a=o y=0.2x

y	x	y-x
1	5	-4
2	10	-8
3	15	-12
4	20	-16

Slope y-x vs. y = -4.0

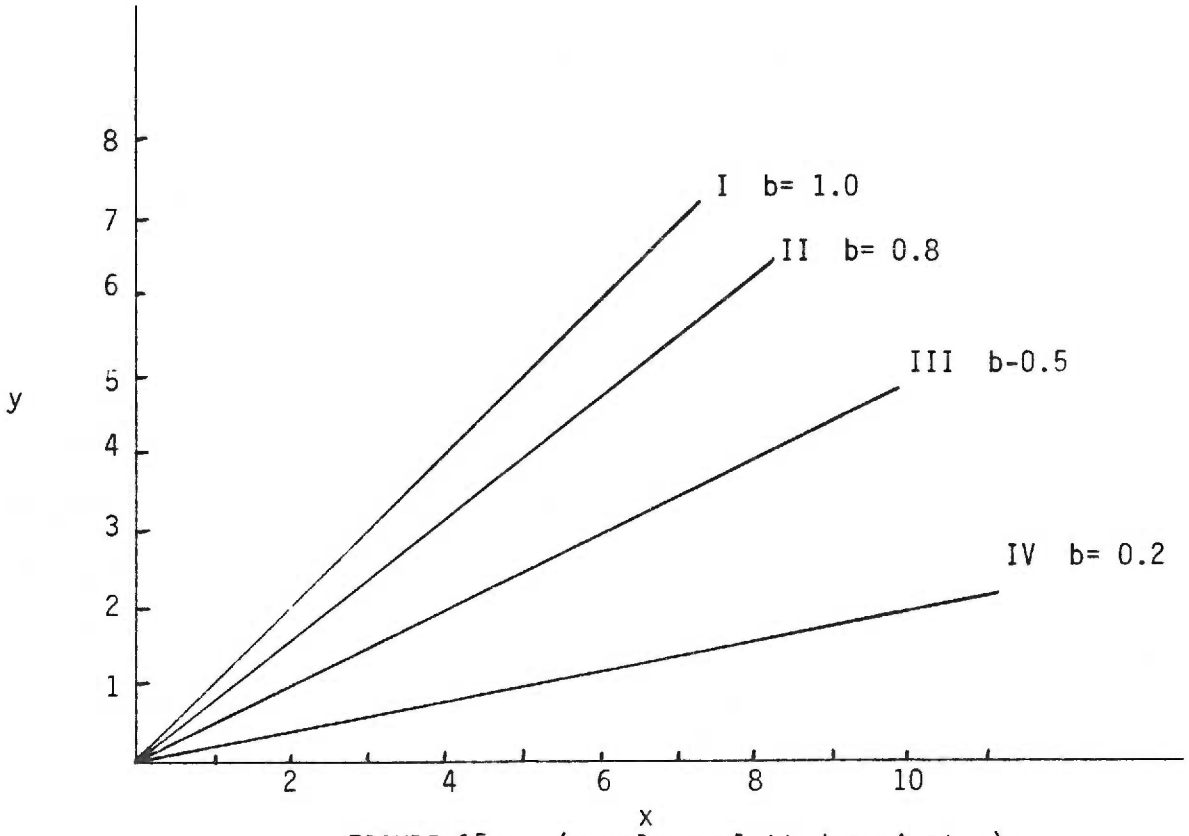


FIGURE 15a. (y values plotted against x)

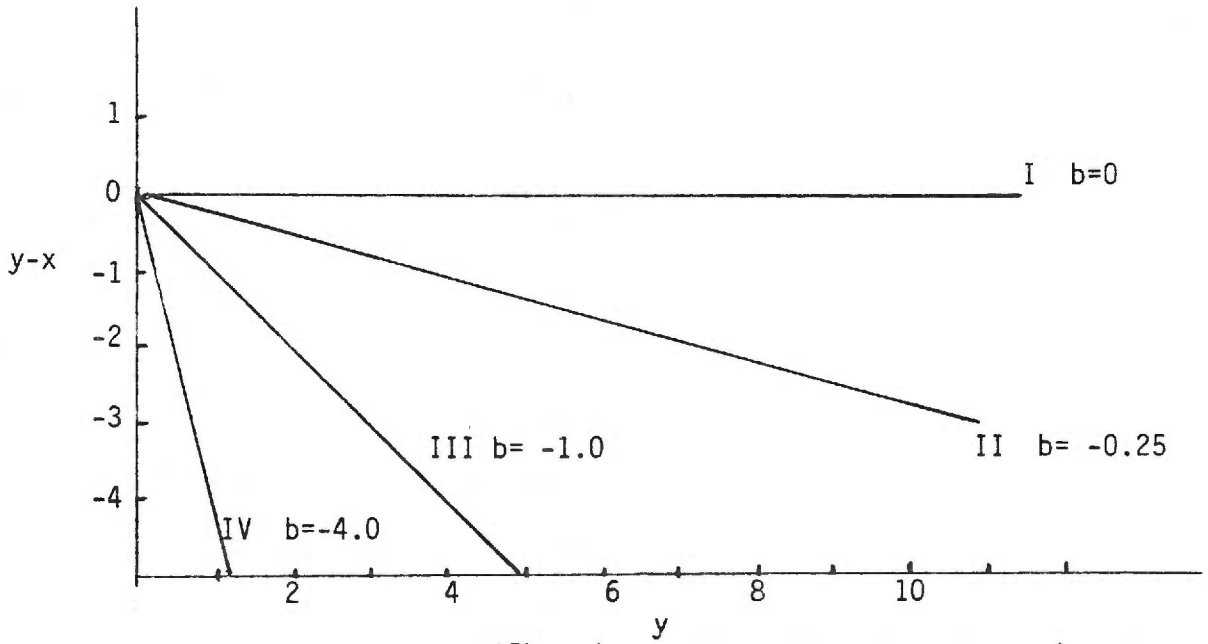


FIGURE 15b. (y-x values plotted against y)

parameters with a slope approaching 1.0. Consequently, the original interpretation of their data analysis is not only erroneous, but in fact actually supports the conclusion that mixed venous blood is a reliable substitute for arterial blood-gas analysis.

Bieber (1979) compared mixed venous blood-gas composition over a wide range of metabolic acid-base disturbances. Nine mongrel dogs were anesthetized and intubated. Catheters were inserted into the femoral artery and pulmonary artery for obtaining arterial and mixed venous blood-gas samples. Baseline blood-gas samples were drawn in addition to temperature, heart rate, and respiratory rate which were also monitored throughout the experiment. Metabolic acidosis was induced in five of the dogs by infusing 0.3M ammonium chloride (Bakers Analyzed Reagent) in 5% dextrose and water continuously at a rate of 5-7 mEq/Kgm over approximately two hours. Samples of mixed venous (PA) and arterial blood was then drawn at 30-minute intervals during the infusion. The infusion was continued until arterial pH was reduced to approximately 6.8. Metabolic alkalosis was induced in four dogs by infusing a 1M solution of sodium bicarbonate at a rate of 7-10 mEq/Kgm an hour. Again, samples were drawn at 30-minute intervals until a pH of approximately 7.6 was reached.

Results showed that mixed venous blood-gas composition followed a pattern similar to that of arterial blood over a wide range of metabolic acid-base disturbances. Mixed venous blood pH was consistently lower than arterial pH. Bicarbonate concentrations and pCO_2 values were consistently higher in mixed venous blood compared to arterial blood.

The relationship of pH to $[HCO_3^-]$ between mixed venous and arterial blood had a very high correlation.

Mixed venous pO_2 was consistently less than arterial pO_2. The pO_2 in metabolic acidosis increased for both arterial and mixed venous samples. Compensatory hyperventilation was considered to be the reason behind the increase in pO_2. During metabolic acidosis, hydrogen ions stimulate ventilation to decrease CO_2 and return pH toward normal. A concomitant effect, however, is an increase in pO_2.

In alkalotic states the pO_2 decreased for both arterial and mixed venous blood. Bieber explained this event as a consequence of hypoventilation. There is a depression of respiratory neurons and peripheral chemoreceptors during alkalosis causing hypoventilation and therefore a lower pO_2.

Bieber concluded that mixed venous blood does follow the same pattern of arterial blood during a wide range of metabolic acid-base disturbances. She also stated that mixed venous blood might be a better reflection of the acid-base status of tissues than arterial blood.

Carveth (1979) analyzed peripheral venous blood-gas composition during metabolic acid-base disturbances. She analyzed both arterialized and non-arterialized peripheral venous blood and compared them to arterial blood-gas composition. Arterialized blood involves warming the paw with a heat lamp to approximately 40°C prior to drawing a sample from a peripheral vein. Heating the paw dilates superficial blood vessels thereby increasing flow to the area. Arterialized peripheral venous blood (PVB) is theoretically more similar in blood-gas composition to arterial than mixed venous blood. Non-arterialized blood is theoretically more similar

to mixed venous blood-gas composition than arterial blood.

Eight healthy mongrel dogs were anesthesized and intubated. Catheters were inserted in the femoral artery and in a peripheral vein of each paw for blood samples. The catheters in the peripheral veins were inserted distally to insure free-flowing blood samples. A femoral vein was also catheterized for maintenance of anesthesia and to induce metabolic acidosis or alkalosis. After baseline blood work, metabolic acidosis was produced in four of the dogs by a continuous infusion of 0.3M NH_4Cl at 5-7 mEq/Kg over approximately two hours. Blood samples were taken approximately every 30 minutes during progressive acidosis until the pH was close to 6.8 pH units. Metabolic alkalosis was induced in the last four dogs by a continuous infusion of 1.0M $NaHCO_3$ at 5-7 mEq/Kg at approximately 7-10 mEq/Kg an hour. Blood samples were taken every 30 minutes during advancing alkalosis until the pH of arterial blood was approximately 7.6.

Carveth found that warmed or arterialized peripheral venous blood-gas composition was more strongly correlated with arterial blood than non-arterialized blood. The mean "r" values for pH, pCO_2, pO_2 were consistently higher for warmed PVB vs. arterial blood than unwarmed PVB vs. arterial blood. In regard to $[HCO_3^-]$, both warmed and unwarmed PVB had high correlations to arterial blood 0.991 and 0.992 respectively. The mean of mean differences and standard error of the mean were also consistently less for arterial minus arterialized PVB than arterial minus non-arterialized PVB. A smaller standard of error was therefore seen when blood-gas composition of arterialized PVB was used to estimate arterial blood compared to non-arterialized blood.

There were some subtle differences noted between results of blood-gas composition of dogs that underwent metabolic acidosis vs. alkalosis. When "t" tests were performed between the mean of mean differences of the arterial minus arterialized PVB and arterial minus non-arterialized PVB a significant difference was only found with the alkalotic group. Carveth offered a valid explanation of this finding. In metabolic alkalosis the increase in pH causes a shift of the oxyhemoglobin dissociation curve to the left. This causes hemoglobin to bind more tightly with O_2. Therefore, in metabolic alkalosis the pO_2 must be reduced to a lower value than in normal or acidotic states in order for hemoglobin to give up the same amount of O_2. If hemoglobin does not give up sufficient O_2 to the tissues anaerobic metabolism ensues leading to lactic acidosis. An increase in lactic acid production will cause a widening in the difference of pH between arterial and PVB.

During metabolic alkalosis this difference was not as great for arterialized PVB as it was for non-arterialized PVB, which would be expected. First, increased temperature of peripheral venous blood causes a decreased affinity between O_2 and hemoglobin (Slonim & Hamilton, 1976). Second, increasing flow of PVB by warming causes a washout of lactic acid that may have built up. Third, increased flow causes increased delivery of O_2 to the peripheral tissues. In arterialized PVB these three events are counterbalanced by the events that occur in alkalosis. This causes slightly less widening of A-V difference than occurs with non-arterialized PVB.

In metabolic acidosis there is a decrease in pH which causes the

oxyhemoglobin dissociation curve to shift to the right. This will decrease the affinity of hemoglobin to O_2, therefore hemoglobin will more readily give up O_2 to the tissues. It would seem that the three events described in the previous paragraph on warming PVB would have an additive effect during metabolic acidosis for arterialized PVB, thereby decreasing the A-V difference.

In summary, arterialized PVB is a reliable estimate of arterial blood-gas values during a wide range of metabolic acid-base disturbances.

Griffith (1980) compared mixed venous blood-gas composition with that of arterial blood during a wide range of respiratory acid-base disturbances. In her study she manipulated the respiratory status of nine mongrel dogs. Because of the use of animal models a more extreme range of acid-base disturbances could be studied than had been reported previously. The dogs were anesthetized, given curare and then the trachea was intubated. The dogs were then connected to a ventilator. A Swan-Ganz catheter was inserted into the pulmonary artery to monitor pressure and obtain mixed venous blood samples. A femoral arterial catheter was inserted to monitor blood pressure and obtain arterial blood samples. Another venous catheter was inserted in the jugular vein for maintenance of anesthesia. Respiratory acidosis was induced in five of the animals by varying concentrations of CO_2 in the inspired gas mixture. Concentrations included 3% CO_2 in 97% O_2, 5% CO_2 in 95% O_2, and 10% CO_2 in 90% O_2. Arterial and mixed venous blood-gas samples were drawn at 20 and 60 minute intervals as CO_2 concentration increased. After the final sample was drawn the $FiCO_2$ was then decreased by the same

decrements with blood samples drawn at 20 and 60 minute intervals between each decrease.

Respiratory alkalosis was accomplished by using a mechanical ventilator to hyperventilate the remaining four dogs. The inspired gas mixture was room air and their respiratory rate was kept constant. The tidal volume, however, was increased by 150 ml increments from an initial volume of 200-350 ml to a maximum of 650-750 ml, depending on the weight of the dog. Blood-gas samples were drawn at 20 and 60 minute intervals as tidal volumes were increased. After reaching peak volumes the tidal volumes were then reduced by the same decrements and blood-gas samples drawn between each reduction at 20 and 60 minute intervals.

Results showed that mixed venous blood-gas composition varied predictably and was closely correlated with arterial blood over a wide range of acid-base disturbances. In respiratory acidosis there was a high correlation coefficient ($\geqslant .83$) between mixed venous and arterial blood for pCO_2 and pH. The relationship to $[HCO_3^-]$ was highly correlated as well. The correlation of pO_2 for arterial and mixed venous blood-gas samples during respiratory acidosis was 0.69.

In respiratory alkalosis the correlation coefficients of mixed venous and arterial blood for pCO_2, pH, and $[HCO_3^-]$ was greater than 0.86. The pH/$[HCO_3^-]$ relationship was also greater than 0.86 during respiratory alkalosis. The correlation coefficient of the pO_2 of mixed venous and arterial blood was only 0.12 during respiratory alkalosis.

The pCO_2 of mixed venous blood was always slightly higher than that of arterial blood during respiratory acid-base disturbances. The

CO_2 titration curve of mixed venous blood did not have as steep a slope as arterial blood. This is in agreement with predictions of Roos and Thomas (1967), that the true in-vivo buffer curve for CO_2 is that of mixed venous blood. The fact that the mixed venous CO_2 buffer curve was steeper than predicted by Roos and Thomas is explained by the fact that intracellular buffering was not included in their model. It is most likely that intracellular buffering did have an effect on the pH/$[HCO_3^-]$ plot for mixed venous blood.

The pH of mixed venous blood was always less than arterial blood. This was explained as a result of metabolic waste products from metabolic activity added at the capillaries and flowing into venous blood.

The $[HCO_3^-]$ of mixed venous blood was always higher than arterial blood. This can be accounted for by Equation 1 (p. 11) where it was shown that an increase in $[CO_2]$ shifts the equation to the right and increases $[HCO_3^-]$.

During respiratory alkalosis the pO_2 of mixed venous blood decreased markedly, while that of arterial blood remained fairly constant. The explanation given for this difference was a decrease in cardiac output resulting from mechanical ventilation.

Griffith concluded that mixed venous blood-gas values (pH, pCO_2, $[HCO_3^-]$ closely mimicked arterial blood-gas values over a wide range of respiratory acid-base disturbances, when cardiac output was stable. Furthermore, since changes in the composition of mixed venous blood were predictable mixed venous blood can be used for acid-base assessment. In general, and particularly in respiratory alkalosis, the pO_2 of mixed

venous blood did not correlate well with that of arterial blood. However, Griffith points out that mixed venous pO_2 was a more accurate prediction of ISF pO_2 than was arterial pO_2.

Schriver (1981) compared peripheral venous blood-gas composition with that of simultaneously drawn arterial and mixed venous blood in respiratory acid-base disturbances. She studied changes in blood-gas composition of arterialized (warmed) peripheral venous blood and (unwarmed) or non-arterialized peripheral venous blood.

In her study she manipulated the respiratory status of 10 healthy mongrel dogs. Because of the use of animal models more extreme ranges of acid-base disturbances could be studied than had been reported previously. Schriver worked in conjunction with Griffith so the methods are the same with the exception of the preparation for drawing peripheral venous blood (PVB). A catheter was placed in the vein of each forepaw for obtaining PVB. To obtain arterialized venous blood (AVB), one paw was warmed under a heat lamp to a temperature of 38-42°C. A thermometer was placed in a skin pocket of the same paw.

Results showed that the pH, $[HCO_3^-]$, pCO_2 of both arterialized PVB and non-arterialized PVB were similar to arterial blood during acid-base disturbances. The correlation coefficients for pH and pCO_2 were greater than 0.92. The correlation coefficients for $[HCO_3^-]$ was greater than 0.84. Shriver found that the blood-gas composition of arterialized PVB and non-arterialized PVB did not differ significantly. She argued that arterialized PVB and non-arterialized PVB did not differ as expected because she used deeper veins in the forepaw than those used in Carveth's study (1979). Superficial veins may not have as great of a blood flow as deeper veins.

Also, flow in deeper veins may not be sufficiently increased by warming.

The partial pressure of oxygen (pO_2) for arterialized PVB and non-arterialized PVB did not correlate well with the pO_2 of arterial blood. However, no explanation for this poor correlation was offered. It is assumed that due to using deeper veins the pO_2 of both arterialized and non-arterialized samples would correlate more closely with mixed venous blood-gas values.

In Shriver's study the values for pH, pCO_2, and $[HCO_3^-]$ of arterialized and non-arterialized PVB were even more closely correlated with those of mixed venous blood than with those from arterial blood. The correlation coefficient for pH was 0.98 or greater, for pCO_2 the correlation coefficient was 0.97 or greater and for $[HCO_3^-]$ the correlation coefficient was 0.73 or greater. Values of pO_2 also correlated more strongly with mixed venous blood than arterial blood. The correlation coefficient for pO_2 varied from 0.07 - 0.94 during respiratory alkalosis and from -0.12 - 0.89 during respiratory acidosis.

Schriver concluded two main points, 1) that peripheral venous blood-gas composition may be a reliable indicator of that found in mixed venous blood, and 2) that arterializing or warming PVB may not be necessary for estimating arterial values of pH, pCO_2, and $[HCO_3^-]$ if a deeper peripheral vein is used.

3) <u>The Effects of Decreased Cardiac Output on Arterial, Mixed Venous, Femoral Venous, and Peripheral Venous Blood-Gas Compositions</u>.

Tung, Bettice, Wang, and Brown (1976) studied the effects of hemorrhagic shock on intracellular and extracellular acid-base changes

in dogs. Even though the purpose of this study is not directly related to my investigation some of his data are extremely beneficial. Tissue samples from hind limb skeletal muscles of each dog were analyzed to assess intracellular response. Extracellular response was determined by analyzing arterial, mixed venous, and femoral venous blood samples. Femoral venous blood was used as an aid in determining intracellular acid-base composition, the underlying assumption being that femoral venous blood has a "gas" composition the same as ISF of skeletal muscle.

Specifically, 22 mongrel dogs were anesthetized and intubated. A catheter was inserted into the left carotid artery to monitor mean carotid artery pressures. A pulmonary artery catheter was inserted to obtain mixed venous samples. A catheter was inserted into the femoral artery for hemorrhaging the dogs and another catheter was inserted into the femoral vein to draw femoral venous blood-gas samples. Bilateral nephrectomies were performed on the animals to eliminate the effect of renal compensation. An isotopic dye was also injected for determination of intracellular pH. After a stablization period of 2 hours control samples of arterial, mixed venous, femoral venous, and skeletal muscle were taken. The dogs were then bled until the mean arterial pressure reached 50 mm/Hg and the pressure was maintained at this level for approximately 2 hours. Arterial and mixed venous samples were taken at 30, 60, 90, and 120 minutes after establishing of steady state hypotension. A second skeletal muscle sample and femoral venous sample were obtained at 120 minutes.

Comparisons of pH, pCO_2, $[HCO_3^-]$ and O_2 saturation were made

between mixed venous and arterial blood. Lactate concentrations, pCO_2, pH, and $[HCO_3^-]$ of intracellular fluid were determined from tissue samples and femoral venous blood.

Although it was not the purpose of this study to compare femoral venous blood-gas values with mixed venous or arterial blood such a comparison yields significant information (Figure 16). In Figure 16, pH, pCO_2, and $[HCO_3^-]$ values are graphed during controlled hypotension. All values incurred the greatest change during the first 45 minutes after hemorrhage. Femoral venous blood seemed to closely correlate with mixed venous blood values. Unfortunately only two samples for femoral venous blood were taken. There were greater differences noted between arterial and mixed venous values than between mixed venous and femoral venous values.

The pH of arterial blood showed a gradual decrease from 7.36 to 7.21 during the 2-hour period of hypotension. The pH of mixed venous blood showed a precipitous drop during the first 45 minutes and then followed a pattern parallel to that of arterial blood. The pH of femoral venous blood followed a pattern similar to that of mixed venous blood but with a slightly greater decrease in pH. There was, therefore, an increased arteriovenous (A-V) difference for pH during hemorrhagic shock.

The pCO_2 of arterial blood decreased precipitously in the initial 45 minutes (from 38 to 25 torr) after hemorrhage and then leveled off. The pCO_2 of mixed venous blood increased the greatest amount during the first 45 minutes from 45 to 51 torr and then leveled off. The pCO_2 of femoral venous blood increased a greater amount from 47 to 60 torr. Again there was a marked increase in A-V difference in pCO_2 during controlled

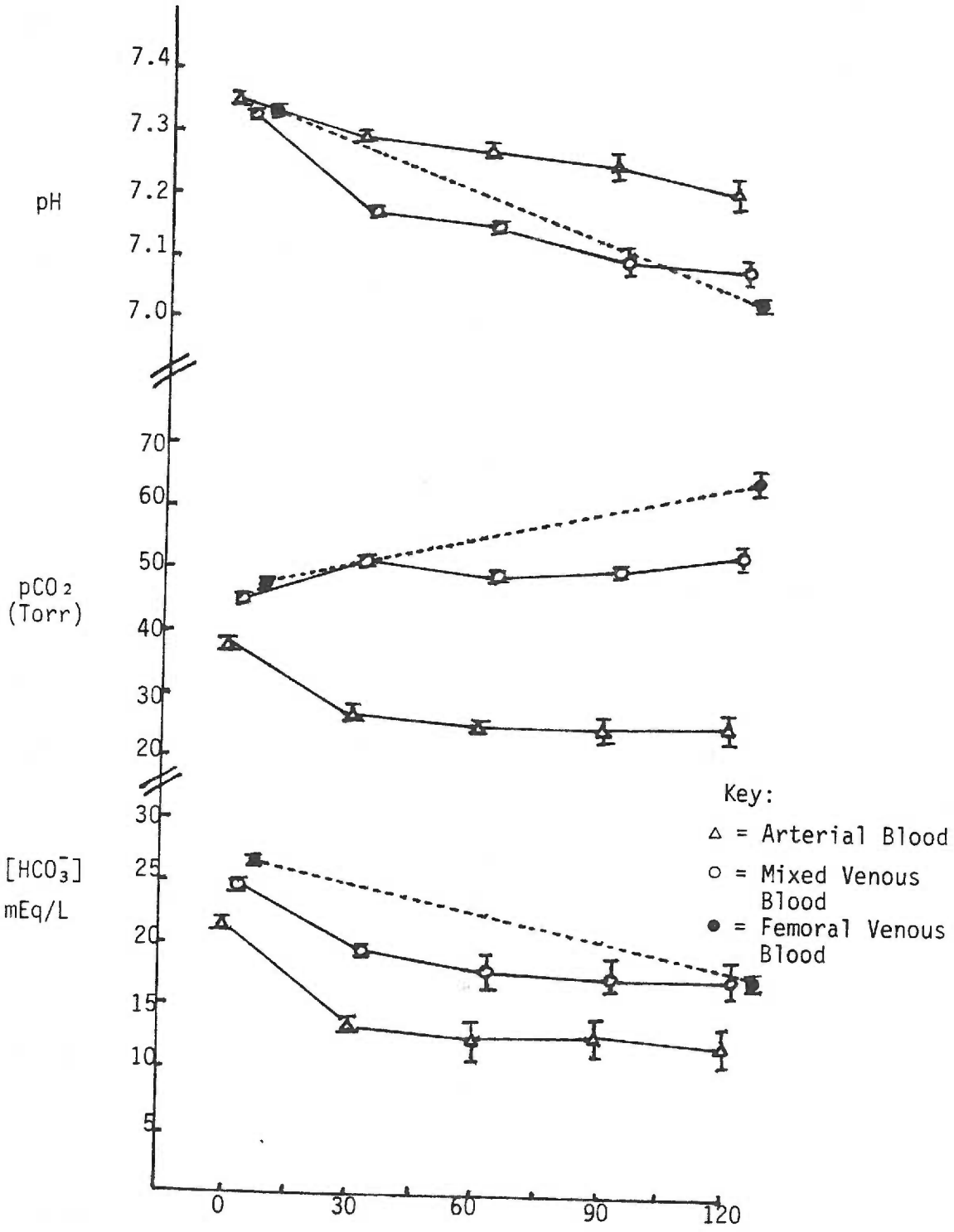


FIGURE 16

Acid-base parameters in arterial, mixed venous blood during hemorrhagic shock. Femoral venous values for control and at 120 minutes are plotted and connected by dashed lines (modified from Tung, et al., 1976).

hypotension. This can be accounted for by the fact that hemorrhage decreases cardiac output. Tissues suffer from decreased O_2 delivery and the resultant increased build up of metabolic waste products including CO_2 which cause a metabolic and respiratory acidosis in ISF. Respiratory compensation is stimulated from the decreased arterial pH and blood pressure. Due to this increased ventilation arterial blood has a lower pCO_2 during controlled hypotension. Arterial blood-gas parameters therefore indicate a partially compensated metabolic acidosis. The reason femoral venous blood has a higher pCO_2 than mixed venous blood reflects the fact that different organs and tissues have different metabolic rates and blood flow, especially in states of decreased cardiac output.

Bicarbonate concentration decreased in all three blood samples. The $[HCO_3^-]$ in mixed venous and femoral venous blood were almost identical after 2 hours. Arterial blood bicarbonate levels decreased to a greater degree in the first 45 minutes and then paralleled mixed venous blood. Again there was an increased A-V difference during steady state hypotension.

Extreme differences were noted between arterial and mixed venous pO_2 and O_2 saturation. Due to respiratory compensation arterial pO_2 increased an average of 14 torr. The increase in O_2 saturation is minimal at high pO_2's on the oxyhemoglobin saturation curve. The pO_2 of mixed venous blood, however, decreased precipitously from mean values of 36 to 16 torr. There is a profound effect in O_2 saturation due to the steepness of the oxyhemoglobin dissociation curve at pO_2 values this low. The low mixed venous pO_2 represent reduced O_2 delivery to the tissues due to

decreased cardiac output. The systemic tissues are acutely hypoxic despite normal or even increased arterial pO_2.

In summary, during states of decreased cardiac output there was a marked increase in A-V difference in all parameters studied. Arterial blood-gas composition represented a classic picture of partially compensated metabolic acidosis (low pCO_2, low pH, low $[HCO_3^-]$). Oxygenation of arterial blood, i.e., % saturation was adequate as indicated by the high paO_2 values. Venous blood-gas composition, however, reflected a combined metabolic and respiratory acidosis (high pCO_2, low $[HCO_3^-]$, and low pH). Mixed venous blood also indicated profound tissue hypoxia was present based on low pvO_2 and saturation values. It is obvious that arterial blood-gas composition reflected mainly pulmonary gas exchange and was not an adequate indicator of tissue acid-base status or oxygenation especially during states of decreased cardiac output.

Murphy (1982) investigated the use of mixed venous blood for assessment of acid-base status in states of decreased cardiac output. Ten mongrel dogs were anesthetized and intubated, but allowed to breathe room air. A Swan-Ganz flow-directed catheter was inserted into the right external jugular and advanced to the pulmonary artery (PA). The Swan-Ganz catheter served three functions: 1) to obtain cardiac outputs, 2) monitor PA pressures, and 3) to obtain mixed venous blood samples. A catheter was placed in the left jugular for administration of maintenance doses of anesthetic. A catheter was placed in the femoral artery to 1) monitor arterial blood pressure, 2) to bleed the dog, and 3) to obtain arterial blood samples.

A polygraph recorder (Grass Model 7C) was used to record arterial, PA pressures and heart rate. An Edwards Laboratories Cardiac Output Computer (Model 9520A) was used for determining cardiac outputs via

thermodilation. Baseline data were obtained 45 minutes after surgical procedures were complete to allow for stablelization. Baseline data included heart rate, respiratory rate, core temperature, hematocrit, plasma protein concentration, cardiac output, pO_2, pCO_2, pH, and $[HCO_3^-]$. Cardiac output was decreased in stages by bleeding appropriate amounts from the femoral artery. Approximately 40 minutes after each successive hemorrhage parameters listed under baseline data were repeated with successive hemorrhage.

Results showed a widened A-V difference for all blood-gas parameters due to decreased cardiac output. The pH decreased in both arterial and mixed venous blood, but there was a more marked pH decrement in mixed venous blood. Mean $[HCO_3^-]$ also decreased in both arterial and mixed venous blood, but there was greater decrease in arterial blood.

Changes in arterial and mixed venous pO_2 were similar to those reported by Tung, et al. (1976). Mean arterial pO_2 increased by 17 torr and hemoglobin was nearly saturated ($\geqslant$99%).

The mean pO_2 of mixed venous blood decreased by 23 torr and the O_2 saturation decreased by 30%. Therefore, mixed venous blood reflected evidence of tissue hypoxia whereas the pO_2 of arterial blood actually increased during hemorrhagic shock.

The mean arterial pCO_2 decreased while contrary to the results of Tung, et al., the mean mixed venous pCO_2 remained unchanged. In the study of Tung, et al., mean pCO_2 of mixed venous blood O_2 actually increased after hemorrhage. Murphy explains this discrepancy by the following equation (p. 26):

$$\dot{Q}\,[CO_2]\,mv = \dot{Q}\,[CO_2]\,a + \dot{V}CO_2 \cdot f \quad \text{(No.2)}$$

where:

$\dot{Q}$ = Cardiac output

$[CO_2]mv$ = Concentration of physically dissolved carbon dioxide in mixed venous blood

$[CO_2]a$ = Concentration of physically dissolved carbon dioxide in arterial blood

$\dot{V}CO_2$ = Metabolic CO_2 production.

f = That fraction of the CO_2 produced is transported as physcially dissolved CO_2.

From the above equation (No. 2), it can be seen that mixed venous pCO_2 is dependent on cardiac output, arterial $[CO_2]$ and increases from cellular metabolic activity. Since the dogs were anesthetized there would be no reason for a change in metabolic production of CO_2. Mixed venous pCO_2 therefore reflects two processes: 1) systemic delivery to capillary beds ($\dot{Q}\,[CO_2]a$), and 2) reduced cardiac output. Because both cardiac output and arterial pCO_2 decreased there was, therefore, decreased delivery of CO_2 to capillary beds. This decreased delivery counterbalanced any increased accumulation in venous blood so that there was no net change in mixed venous pCO_2.

Murphy's study showed that changes in mixed venous blood-gas composition follows a predictable pattern during states of decreased cardiac output. It also demonstrates two different acid-base pictures. Mixed venous blood reflects tissue status and arterial blood reflects output from the lungs. One unfortunate result of Murphy's study, however, was that about one-half of the dogs were in respiratory acidosis

during the control period. This was accounted for by the effects of general anesthesia on medullary centers. If the animals had been mechanically ventilated there may not have been such a variance.

Feldon (1982) investigated the use of peripheral venous blood to assess acid-base status when cardiac output was reduced. Feldon compared blood-gas parameters of (arterialized and non-arterialized) peripheral venous blood to those of arterial and mixed venous blood.

Ten healthy mongrel dogs were anesthetized and intubated, but allowed to breathe room air. A Swan-Ganz flow directed catheter was inserted into the pulmonary artery to 1) obtain cardiac outputs, 2) monitor PA pressures, and 3) obtain mixed venous samples. A femoral artery catheter was inserted to 1) monitor arterial pressure, 2) hemorrhage the dogs, and 3) obtain arterial samples. Another jugular vein was correlated for maintenance of anesthesia. A catheter was inserted into a vein in each front paw for peripheral venous samples. A subcutaneous pocket was made in one paw in order to monitor paw temperature.

A polygraph recorder (Grass Model 7C) was used to record arterial, PA pressures, and heart rate. An Edwards Laboratories Cardiac Output Computer (Model 9520A) was used for determining cardiac outputs via thermodilution. Forty-five minutes after all surgical procedures were complete baseline data was obtained. Baseline data included heart rate, respiratory rate, hematocrit, protein concentration, cardiac output, pO_2, pCO_2, pH, $[HCO_3^-]$. Cardiac output was decreased in stages by controlled hemorrhage from the femoral artery. Approximately 40 minutes after each hemorrhage the above data collection was then repeated.

Blood-gas values from both arterialized and non-arterialized PVB

were compared to blood-gas values obtained from arterial and mixed venous blood. When cardiac output was 50% of control or more, mean Arterial-Venous (A-V) differences for all blood-gas parameters were relatively constant. When cardiac output was reduced below 50% of control values neither arterialized or non-arterialized peripheral venous blood (APV, NAPV) correlated with arterial samples. The correlation appeared to be slightly better with arterialized peripheral samples than with non-arterialized samples when cardiac outputs were reduced more than 50% of control. Feldon explains these findings by the greatly reduced blood flow of peripheral veins during hemorrhage. When cardiac output was less than 50% of control increasing blood flow by heating the paw counteracted some of the compensatory vasoconstriction. When cardiac output was greater than 50% of control, then heating the paw did not increase peripheral circulation significantly.

The specific direction of change in blood-gas parameters of peripheral venous compared to arterial blood was similar to the results reported in the study of Tung, et al., (1976). Both pH and $[HCO_3^-]$ in arterial and peripheral venous blood decreased when cardiac output was reduced. The pCO_2 progressively increased and pO_2 decreased in peripheral venous blood when cardiac output was reduced. Conversely the pCO_2 progressively decreased and pO_2 increased in arterial blood when cardiac output was reduced. The pCO_2 and pO_2 of peripheral venous blood simply reflect decreased flow through systemic tissues. The pCO_2 and pO_2 of arterial blood reflects increased alveolar ventilation. The A-V differences were markedly enhanced when cardiac output was decreased more than 50% of control. Also, peripheral venous blood indicates a combined

metabolic and respiratory acidosis, whereas arterial blood indicates a compensated metabolic acidosis. Again, arterial blood reflected pulmonary function and peripheral venous blood-gas parameters reflected tissue acid-base status.

Blood-gas parameters of mixed venous blood (MVB) compared to arterialized and non-arterialized peripheral venous blood (APV & NAPV) were somewhat more closely correlated than parameters of APV and NAPV to arterial blood. It should be noted, however, that these correlations were not high. In general, mean MV-PV differences were markedly less than mean A-V differences. When cardiac output was greater than 50% of control mean MV-PV differences were slightly more constant for APV blood. Blood-gas values from increased flow in APV samples more closely approximated blood-gas values in flow weighted venous blood from the mixed venous site.

The blood-gas values of APV and NAPV blood changed in the same direction as mixed venous blood. Values of pH, $[HCO_3^-]$, and pCO_2 of peripheral venous blood were more closely approximated to mixed venous samples than comparisons of pO_2. The fact that pO_2 values did not correlate as well as other blood-gas parameters is similar to findings reported by Shriver (1981). In most of the dogs, pO_2 values decreased more markedly in mixed venous blood than PV blood. Even though there was reduced flow to peripheral tissues these tissues at rest must have had a lower O_2 consumption relative to flow than vital organs. Therefore, peripheral blood may not show dramatic decreases in pO_2 until flow is severely restricted. Mixed venous blood, however, contains venous blood from tissues with both high and low O_2 consumption. The higher O_2 consumption from vital organs

seems to outweigh lower O_2 consumption from peripheral tissues during decreases in cardiac output. Mixed venous blood, therefore, showed a more dramatic decrease in pO_2 than PVB. There were some inconsistent findings, however, when the pO_2 of PVB decreased below MVB values. In some cases this could be explained by the fact that cardiac output was reduced greater than 50% of control. In other cases, transient sympathetic stimulation may have caused marked vasoconstriction of peripheral arterioles. Further analysis revealed NAPVB was a slightly better indicator of mixed venous blood.

Summary of Review of Literature

1) Arterial blood represents output of the lungs while mixed venous blood represents output from systemic tissues.
2) There are close correlations between the values of pH, pCO_2, $[HCO_3^-]$ in PVB and those of both mixed venous and arterial blood over wide ranges of metabolic and respiratory acid-base disturbances.
3) Blood-gas composition of PVB is subject to a certain amount of variability depending on whether the samples are obtained during decreased cardiac output.
4) Decreasing cardiac output increases A-V differences in all blood-gas parameters.

Statement of the Problem

The validity of using mixed venous blood for acid-base assessment is well documented, particularly with regard to tissue acid-base status. Due to hazards and difficulties encountered in obtaining mixed venous blood, peripheral venous blood has been evaluated as an alternative to

obtaining mixed venous blood. Problems, however, have been encountered in reliability as well as difficulty in obtaining peripheral venous samples when a greater than 50% decrease in cardiac output exists. It is, therefore, necessary to explore a second alternative to using mixed venous blood. That second alternative is femoral venous blood. In the present investigation the following questions will be addressed:

1) How does femoral venous blood-gas composition compare to mixed venous and arterial blood-gas composition during states of decreased cardiac output?
2) Does femoral venous blood-gas composition change in a predictable pattern when cardiac output is reduced?
3) Can samples of femoral venous blood be obtained when cardiac output is reduced to values less than 50% of control?

Nursing Implications

Regardless of the setting, nursing's primary goal has always been the biological, psychological, and social well being of people. Even with the onset of many divergent theories of nursing practice this has remained a recurrent theme. Nursing is concerned with the total person which includes how that unique individual interacts with his environment as well as his belief system. Likewise, nursing is just as concerned with preventive health care as it is with illness.

In order to improve or maintain the biopsychosocial well being of people, nursing utilizes the "nursing process." Nursing process involves the problem solving steps of data collection, interpretation, decision-making, intervention, and evaluation. The difference between simple

problem solving and nursing process is that nursing process has a nursing focus. That nursing focus is the biopsychosocial well being of people interacting with their environment, regardless of where they are at on the health-illness continuum. This broad focus is necessary in order to give comprehensive and effective care.

For example, a patient may have blood-gas values and other clinical parameters indicative of impending death. The intervention chosen may depend upon whether this patient or his family has decided not to be resuscitated. Although this seems contrary to promoting or maintaining health, a patient has a right to make decisions about the care he receives. Likewise, death is an inevitable part of the life process, therefore death with dignity is not an unworthy nursing goal.

In light of the above example, the nurse-patient relationship needs some clarification. The preferred relationship is that the patient will make appropriate health care decisions and carry them out with minimal assistance from the nurse. There are times, however, when a patient is too ill, such as in a critical care setting, to make decisions or to care for himself. In such a setting the weight of decision-making and care giving is in the hands of the nurse. This places a heavy moral responsibility on the nurse to make decisions in conjunction with that patient's belief system. In addition, the nurse must give extra consideration to issues of safety, comfort, patient expense, and quality care since the patient may be unable to communicate or care for himself.

Unfortunately, priority may need to be given to only one aspect of a patient's biopsychosocial being at certain times in his health management. This is particularly true of critical care where a patient's

biological well being often takes precedence over psychosocial needs. This is not to disclaim the importance of the patient's psychosocial well being, but due to the critical status of their biological being it is sometimes a necessity.

Critical care is the most common setting in which blood-gas analysis is used to assess patients that are critically ill. Blood-gas analysis is a tool used in conjunction with other clinical indicators, i.e., skin coloring, mentation, vital signs, chest X-ray, etc., that determines a patient's health status. Critical care nurses are in a unique position to provide continuous assessment of the patient's condition. Because of this, critical care nurses are often given the responsibility to draw arterial blood-gas samples whenever they feel it is indicated based on their assessment of the patient. Nurses must then interpret the blood-gas values, decide upon the appropriate intervention, implement it, and evaluate the results. Although the responsibility for deciding upon the appropriate action may ultimately rest with the physician a nurse's assessment and suggested interventions are still invaluable. The nurse may know that the family doesn't want any more resuscitative efforts continued. In a different circumstance, the nurse may suggest that the patient not be weaned from the respiratory until morning so he can make up for needed sleep during the night.

With so much recent research on the value of venous blood-gas analysis a critical care nurse may soon have to make decisions regarding their use and interpretation. In order to deliver quality care, critical care nurses will have to 1) be knowledgeable about venous blood-gas interpretation, 2) be knowledgeable about the advantages and disadvantages of a particular

site, i.e., pain involved, accuracy, risks or complications, type of acid-base disturbance, and patient expense, 3) safely and correctly perform the procedure, and 4) impart that knowledge to other health team members.

If it can be shown that femoral venous blood provides an adequate substitute for mixed venous blood-gas composition, nurses will need to understand and discuss the precise rationale for choosing one site over another. Disadvantages of various sites are summarized in the following studies. Sise, et al. (1981) did a prospective study of 219 critically ill patients with pulmonary artery catheters. All catheters were inserted with the same careful and sterile technique. Results of their study showed a 3% (N=10) occurrence of major complications. Nine of the complications occurred during insertion and one complication occurred afterwards. Severe complications included subclavian vein thrombosis, pneumothorax, and arrythmias requiring treatment. Less severe complications included arterial puncture, venous bleeding, and infection. Infection rate greatly increased after a 3-day period. Cellulitis occurred in 16% of the patients and catheter-related sepsis in 8% of patients.

Puri, et al. (1980) also did a prospective study on the complications of catherizations, i.e., arterial, central venous, and pulmonary artery catheters. All of the patients were critically ill and careful technique was maintained to insert the catheters. Results showed that pulmonary artery catheters had complications of 10%. Bleeding, transient ectopic heart beats, ventricular tachycardia, and catheter related sepsis were among major complications listed. They also concluded the frequent breaks in the closed catheter system for obtaining cardiac output measurements would increase the risk of infection. It can be assumed that repeated

sampling for obtaining mixed venous samples might also increase the risk of sepsis.

Arterial catheters in Puri's, et al., study had the highest incidence of complications as would be expected from a higher flow system. Those complications included bleeding, hematoma, emboli, critically reduced arterial flow and hemorrhage necessitating transfusion.

Numerous types of nerve damage have also been reported following arterial puncture as opposed to catheterization. According to Pape (1978) brachial artery puncture in both children and adults may cause median nerve damage.

Feldon (1982) studied arterialized and non-arterialized peripheral venous blood (PVB) during states of decreased cardiac output. Peripheral venous samples, however, proved difficult to obtain below values of 50% control cardiac output. Schriver (1981) also found a lack of correlation between arterialized PVB and arterial blood. These results were contrary to high correlations of arterialized PVB and arterial blood found in Carveth's study (1979). This discrepancy was accounted for by the depth of peripheral vein chosen for sampling.

There is no literature available on the complications of drawing femoral venous blood. It can be assumed, however, that there would be less chance of bleeding complications due to low flow of venous circulation compared to arterial circulation. It could also be assumed that it is easier to obtain due to the size and location of the femoral vein during decreased states of cardiac output. There would also be less chance of infection compared to indwelling catheters. Due to the close anatomical position of the femoral artery, however, complications listed

under arterial punctures could occur if the artery was inadvertently punctured. Due to the larger size of the femoral vein a 5-minute time period for applying pressure after drawing a sample may be indicated. If the femoral artery is accidently punctured, then a 10-minute time period may be indicated. In any patient that is anticoagulated, this time period may need to be increased. Another consideration of whether to draw a femoral venous sample would be the presence of arteriosclerotic vascular disease or thrombophlebitis.

Advantages for using a particular site depends upon whether the purpose for drawing the blood outweighs the risk involved in obtaining the sample. For example, if it is necessary to know cardiopulmonary status, then mixed venous blood is preferred. If a patient already has a pulmonary artery catheter inserted, then obtaining mixed venous blood for total tissue acid-base assessment would be appropriate. If the catheter has been in longer than 3 days, however, the risk of infection may contraindicate the continuance of the catheter. In this instance, drawing peripheral venous or femoral venous blood may be more appropriate. If the cardiac output is reduced, or choice of peripheral veins limited, then the use of femoral venous blood would be indicated. If the patient is anticoagulated or arteriosclerotic vascular disease is present, then PVB may be used. Inserting a pulmonary artery catheter for the sole purpose of obtaining mixed venous samples would be an unnecessary risk if femoral venous blood proves to be an accurate substitute.

Research on venous blood-gas analysis has implications not just for critical care nurses. Any nurse involved in supervision, education, or consultation regarding acid-base status of patients will need to be aware

of the essential facts about venous blood-gas analysis. All nurses must continually upgrade their knowledge base and skills in their particular area of specialty.

Nursing is striving to build a solid nursing research foundation to guide nursing theory and practice. This is a slow process. Nursing, however, does not exist in a vacuum, but interacts with other health care disciplines and sciences. One way to speed up the process is through collaborative and interdisciplinary research.

CHAPTER II

METHODS

Statement of Variables

The independent variable is the percent change in cardiac output produced after each stage of hemorrhage. The dependent variables are the pH, pCO_2, $[HCO_3^-]$, and pO_2 of arterial, mixed venous, and femoral venous blood. Each dog served as its own control. Initial baseline measurements of the dependent and independent variables were made prior to hemorrhaging the animal. Measurements of dependent and independent variables were made after each successive decrease in cardiac output.

Procedures

Ten healthy mongrel dogs were anesthetized with sodium pentobarbital (30 mg/Kg body weight). Maintenance doses (30-45 mg) were given thereafter as needed. Each dog was intubated and allowed to breathe room air.

The femoral artery was catheterized for withdrawal of arterial samples. This catheter was also attached to an arterial pressure transducer for monitoring arterial pressure and heart rate on a Grass polygraph (Model 7C).

The femoral vein was also catheterized for withdrawal of femoral venous samples. The catheter was flushed at frequent intervals with heparinized saline (100 USP units of heparin/100 ml saline) between

samples in order to maintain catheter patency.

A Swan-Ganz flow-directed catheter was inserted into the pulmonary artery for withdrawal of pulmonary artery samples and measurement of cardiac output. The catheter was attached to a pressure transducer for monitoring the progression and position of the catheter as seen on the polygraph record. Position of the catheter was confirmed by direct visualization and palpation on post-mortem exam. Patency of the catheter was maintained via a continuous "to-keep-open" flush system of heparinized 5% glucose in water at a rate of 15 mgtt/min.. Glucose in water was used to minimize expansion of plasma volume. Another venous site was cannulated for administering maintenance doses of sodium pentabarbitol intravenously.

A baseline measurement of cardiac output was obtained using the thermodilution technique approximately 1 hour after all surgical procedures were completed. An Edwards Laboratories cardiac computer (Model 9520A) was used to determine cardiac outputs. (See Appendix A for reliability and calibration procedures.) Exactly 3 ml of iced 5% glucose solution was infused into the Swan-Ganz catheter for each determination. Again, glucose solution was used to minimize expansion of plasma volume. Approximately 4-5 determinations were made each time cardiac output was measured. The average of the best and three closest values were used as the value for cardiac output. The decision as to the best three determinations was based upon the characteristics of the cardiac output curve registered by the graphic recording from the cardiac output computer. To ensure that the animal was stable, cardiac outputs were measured approximately 1 hour after each successive bleeding.

Following measurement of cardiac output free-flowing blood-gas samples were then obtained simultaneously. Hematocrit and total protein concentration were also measured at this time (Hitachi Refractometer). After the samples were drawn, the dogs were bled via a femoral artery catheter. Approximately 200 ml of blood was removed during each bleeding. The actual volume of blood removed during each stage depended on each dog's calculated total blood volume and its ability to tolerate the loss.

All blood-gas samples were drawn anaerobically into 1 ml heparinized glass syringes. Unlike plastic syringes, glass syringes reduce the potential for O_2 and CO_2 diffusing through the body of the syringe itself. To further prevent leaking of gases along the barrel of the syringe, the plunger and barrel were well lubricated with silicone stopcock grease. A small amount of elemental mercury was also drawn up into the syringe to facilitate mixing the blood in the syringe prior to analysis.

Before drawing a sample a volume slightly greater than the dead-space of the catheter was withdrawn and discarded. Each venous sample was drawn very slowly to assure that the blood obtained was not contaminated with blood from upstream sources. Contamination of pulmonary artery blood with pulmonary capillary blood during states of low cardiac output is of particular concern. Any samples that were contaminated with air bubbles were discarded and redrawn. Before disconnecting the syringes from the catheter the mouth of the syringe was pointed downward. This allowed the mercury to seal the port and keep the blood sample from

equilibrating with air. The syringes were then immediately sealed, placed in a plastic bag, and the plastic bag placed in an ice bath. The ice bath reduced the metabolic rate of the blood cells.

After the blood samples were obtained the pH, pCO_2, and pO_2 were measured using a Radiometer blood-gas analyzer (Model BGA3 Mark 2). Bicarbonate concentration was calculated using the Henderson-Hasselbach equation (pKa = 6.1) calibration of the pH, pCO_2, and pO_2 electrodes was checked prior to analysis of each group of samples and periodically between samples as needed.

Reliability of Measurements

The Radiometer BGA-3 Mk II blood-gas analyzer was used to determine pCO_2, pH, and pO_2 of each blood sample. This analyzer has been proven to have reproducibility of ± 0.001 pH units, 1 0.1 mm/Hg pCO_2 and ± 1.0 mm/Hg p). Calibration of the pH, pCO_2, and pO electrodes followed the precise protocol outlined in the BGA3 Instrument Manual.

The Edwards Laboratories Model 9520A cardiac output computer was used to determine cardiac outputs. It has a range of 0.1 to 20L/min.. Its computer accuracy is 1-3% + 0.02L/min.. Computer repeatability has been shown to be better than ± 2%. Procedure for set up and determination of cardiac outputs was as outlined in the Edwards Laboratories Procedure Manual.

CHAPTER III

RESULTS

General Description

Ten mongrel dogs ranging in weight from 12.7-22.7 Kg were used for this study. The blood-gas composition of arterial, mixed venous, and femoral venous blood were determined when cardiac output was reduced. Since cardiac output is a function of body mass and each dog varied in size, changes in cardiac output were reported in terms of percent of control. Control cardiac output ranged from 1.53 to 3.73 L/min. in these dogs. Final cardiac output values ranged from 0.63 to 1.36 L/min. (25%-51% of control cardiac output).

Hematocrit and protein concentrations were measured with each set of blood samples (Tables I & II). Protein concentration decreased with hemorrhage and ranged in values from 4.1 to 5.2. In general, hematocrit concentration decreased slightly from control values to final hemorrhage values. In dogs 2 and 3, however, hematocrit actually increased even though sufficient blood had been removed to reduce cardiac output to less than 50% of control cardiac output. Additionally, values of hematocrit never decreased below 0.36 despite blood loss of greater than 50% of total blood volume. This can be explained by the fact that dogs are known to have profound splenic contraction following hemorrhage. Splenic contraction releases stored red blood cells from splenic sites into general circulation. At autopsy, the animals' spleens were noted to be greatly decreased in size.

Heart rate, respiratory rate, and core blood temperature from the pulmonary artery were continuously monitored throughout the experiment.

Summary values for these parameters during control and final cardiac output measurements are shown in Tables I and II. It should be noted that dogs 2, 5, 7, 8, and 9 were in respiratory acidosis according to arterial blood-gas composition during control periods, which was probably an effect of the anesthetic.

Mean values and standard deviations for pH, pCO_2, pO_2, and $[HCO_3^-]$ in arterial, mixed venous, and femoral venous blood are shown in Table III. Data from dog 1 are not included in the graphic and statistical analyses because the pulmonary artery catheter was not properly placed. Several samples from dog 1 had inappropriately high mixed venous pO_2 values suggesting blood had been withdrawn from the pulmonary capillary beds. For example, the fourth sample of arterial blood had a pO_2 of 92 while the simultaneously drawn sample of mixed venous blood had a pO_2 of 102. Repositioning of the pulmonary artery catheter proved difficult and uncertain due to the low cardiac output. Autopsy showed that the pulmonary artery catheter on dog 1 was incorrectly placed. In addition, a mixed venous blood sample could not be obtained for the final reduction in cardiac output (36% of control) due to severe reduction in blood volume.

In order to facilitate comparisons and presentations of results, specific blood-gas parameters are discussed under the following headings:

1) Comparison of femoral venous blood-gas composition with mixed venous and arterial blood-gas composition.
2) Mixed venous-femoral venous differences.
3) Predictability of mixed venous pCO_2 and pH based upon femoral venous and arterial values.
4) Physiological comparisons of pH, pCO_2, and $[HCO_3^-]$ of arterial,

mixed venous, and femoral venous blood using the pH/[HCO_3^-] diagram to assess acid-base status.

Comparison of Femoral Venous Blood-Gas Composition to Mixed Venous and Arterial Blood-Gas Composition

pH

The mean pH during control periods for arterial, mixed venous, and femoral venous blood was 7.32, 7.31, and 7.31 respectively (Table III). The final pH values of arterial blood increased in dogs 3, 5, 7, 8, and 9 and decreased in dogs 2, 4, 6, and 10 (Appendix A). The final pH values of mixed venous blood decreased in dogs 2, 4, 5, 6, 8, 9, and 10 and increased $\leq$ .01 pH unit in dogs 3 and 7 (Appendix A). All of the final pH values of femoral venous blood in dogs 2-10 decreased from control pH values. The pattern of change in pH for femoral venous blood paralleled the pattern of change in mixed venous blood (Figure 17). The final mean values for pH of arterial, mixed venous, and femoral venous blood were 7.32, 7.22, and 7.12 respectively (Table III). There was a widened mixed venous, femoral venous difference from control to final values in regard to pH.

pCO_2

The mean pCO_2 values during control periods for arterial, mixed venous, and femoral venous blood were 47.8, 52.1, and 54.0 torr respectively (Table III). Arterial pCO_2 decreased in dogs 2-10 after the final hemorrhage to a mean value of 26.2 torr (Table III).

Mixed venous pCO_2 increased in dogs 2, 4, 6, and 10, decreased in dogs 3, 5, and 7, and remained essentially unchanged in dog 9 (Appendix A).

The final mean value for mixed venous pCO_2 was 47.7 torr.

Femoral venous pCO_2 increased in all dogs except dog 7 where it remained approximately the same (Appendix A). The final mean pCO_2 for femoral venous blood was 62.9 torr. The pattern of change in the pCO_2 of femoral venous blood was similar to that found in mixed venous blood for all dogs except 1 and 3. The last four values in dog 1 and the final value in dog 3 were suspected of being contaminated by pulmonary capillary blood due to increasing MV pO_2 values.

$[HCO_3^-]$

The mean control values for $[HCO_3^-]$ in arterial, mixed venous, and femoral venous blood was 25.3, 25.3, and 26.1 mEq/L respectively (Table III). Final mean $[HCO_3^-]$ values were 13.2, 19.0, and 20.2 in arterial, mixed venous, and femoral venous blood, respectively. The pattern of change in $[HCO_3^-]$ of femoral venous blood closely paralleled the pattern of change in mixed venous $[HCO_3^-]$ (Figure 17).

pO_2

The mean control pO_2 values for arterial, mixed venous, and femoral venous blood were 76.2, 50.6, and 47.3 torr respectively. The mean pO_2 of arterial blood progressively increased during hemorrhage to a final mean value of 96.6 torr. The mean pO_2 of mixed venous and femoral venous blood progressively decreased to values of 22.6 and 19.0, respectively. The pattern of change in mean pO_2 of femoral venous blood closely paralleled the pattern of change in mixed venous blood (Figure 19). The mean pO_2 values of mixed venous blood were slightly higher than femoral venous mean pO_2 values (Table III). Regression analysis, however, showed only a moderate correlation between paired MV-FV samples, i.e., $r = 0.67$ (Table VI).

Mixed Venous - Femoral Venous Differences

Paired t-tests were performed on mixed venous-femoral venous differences in blood-gas parameters (Table IV). Mixed venous-femoral venous differences from 70% to 100% of control cardiac output were compared to those obtained from less than 50% of control cardiac output.

There was no significant difference between MV-FV pH values in the 70% - 100% of control range of cardiac output ($p > 0.1$). However, pH difference from the less than 50% of control range were significant $p < 0.001$ (Table IV). Thus for pH, MV-FV differences increased significantly when cardiac output was reduced below 50% control cardiac output.

Differences in pCO_2 were statistically significant for both high and low ranges of cardiac output (Table IV). However, for pCO_2, the MV-FV differences increased markedly at low values of cardiac output compared to high values from -2.7 torr to -13.9 torr (Table IV).

The MV-FV pO_2 differences were not statistically significant in either the high or low cardiac output ranges via paried t-tests (Table IV). This apparent unique similarity between MV-FV pO_2 values is illustrated in the bar graph (Figure 8). Visual examination of an identity plot for MV-FV pO_2 values, however, does not portray the same degree of similarity as mean values for MV and FV pO_2 (Figure 19). Regression analysis shows only a moderate correlation of 0.67 for pO_2 values of MV and FV blood-gas samples (Table VI).

Bicarbonate values, however, showed a statistically significant widening between MV-FV differences as cardiac output decreased below 50% of control (Table IV). Paired MV-FV samples from the greater than 70% range of control cardiac output showed no significant difference in $[HCO_3^-]$.

Paired MV-FV samples from the less than 50% range of control cardiac output showed a statistically significant difference in $[HCO_3^-]$ ($p < 0.001$).

Predictability of Mixed Venous pH and pCO_2 Based Upon Femoral Venous and Arterial Values.

Upon visual examination of Figure 17, a consistent pattern is evident. Mixed venous points appear to fall equidistant between arterial and femoral venous points. If the MV points are equidistant, then the MV values may be predicted from the mean of the respective arterial and femoral venous values. The results of this type of calculation are shown in Table V. Because of the apparent close correlation between actual and predicted values for MV pH and pCO_2, regression analysis was performed and the results reported in Table VI. The results of regression analysis show that MV pH and pCO^2 may be predicted from the mean of arterial and femoral venous pH and pCO_2 respectively (Figure 20).

pH/$[HCO_3^-]$ Relationship

The pH/$[HCO_3^-]$ diagram in Figure 21 illustrates the pH, pCO_2, and $[HCO_3^-]$ data points of the last three successive decrements of cardiac output in dogs 2-10. The pH/$[HCO_3^-]$ diagram can be used to assess acid-base disturbances. Before reporting the results, however, it should be mentioned that maximum renal and respiratory compensation curves are only approximate. Nevertheless, these curves are included for purposes of assessment.

Approximately 11 of 27 arterial points (40%) fall within the category of mixed metabolic acidosis and respiratory alkalosis. Six arterial points (27%) fall within the category of compensated metabolic acidosis. Ten

arterial points (37%) fall within the category of combined respiratory and metabolic acidosis. The two points in this category with the highest pCO_2 values occurred at cardiac outputs greater than 60% of control. The single arterial point that falls in the category of compensated respiratory alkalosis indicates that the dog was hyperventilating.

Twenty-four out of 26 mixed venous points (92%) fall within the category of combined respiratory and metabolic acidosis. Seven of the mixed venous points in the above category fell between pCO_2 values of 40 and 46 torr.

Twenty-five out of 27 femoral venous points (93%) fall within the category of combined respiratory and metabolic acidosis. Two of the 27 femoral venous values lie within partial compensated respiratory acidosis range. These two values were from dog 9. Even at a cardiac output of 90% of control this dog had femoral venous pCO_2 values in the 70 torr range and femoral venous $[HCO_3^-]$ in the 29-30 mEq/L range. The dogs' respiratory rate remained 10-15/minute throughout the experiment although its respiratory effort could have been more shallow as cardiac output decreased. Arterial blood-gas parameters for the same dog indicate that a high degree of respiratory acidosis was present. It could be, however, that these two apparently anomalous points simply represent a normal variation from the standard buffer line and should be included with the combined respiratory and metabolic acidosis group of points.

TABLE I

Control Values for Heart Rate, Respiratory Rate, Hematocrit, Protein, Cardiac Output and Temperatures for Dogs 1-10.

	Heart Rate (per min)	Respiratory Rate (per min)	Hematocrit	Plasma Protein (Concentration) (gm%)	Cardiac Output (L/min)	Temperature (Centigrade)	Estimated Blood Volume ml
Dog 1	192	18	0.50	6	2.61	38.1	1300
2	128	20	0.28	6.8	1.53	37.2	890
3	128	11	0.43	5.2	1.85	37.0	920
4	168	7	0.44	5.7	3.25	38.4	1340
5	96	5	0.44	6.7	1.86	35.3	1110
6	168	5	0.46	6.2	3.10	38.0	1340
7	180	7	0.44	6.0	3.12	37.6	1430
8	144	11	0.37	5.1	2.00	35.6	1080
9	144	15	-	-	2.95	37.4	1110
10	192	14	0.51	6.6	3.73	-	1590
$\bar{X}$	154	11	0.43	6.0	2.60	37.2	
S.D.	31	5	0.07	0.6	0.74	1.1	
Range	96-192	5-20	0.28-0.51	5.1-6.8	1.53-3.73	35.3-38.4	

TABLE II

Final Values for Heart Rate, Respiratory Rate, Hematocrit, Protein Concentration, Cardiac Output, Temperature and Blood Volume Removed for Dogs 1-10.

	Heart Rate	Respiratory Rate	Hematocrit	Plasma Protein (Concentration) (gm%)	Cardiac Output (4 min)	Temperature	Volume Blood Removed (ml)
Dog 1	180	24	0.45	4.9	1.31	38.8	950
2	150	30	0.43	4.2	0.51	-	570
3	120	46	0.47	4.0	0.67	37.2	600
4	210	13	0.42	4.8	0.67	38.8	740
5	142	16	0.42	4.5	0.87	36.1	765
6	156	40	0.39	5.0	0.76	39.7	725
7	150	12	0.41	5.0	0.87	98.6 (R)	775
8	138	36	0.36	4.1	0.73	35.4	610
9	172	32	0.41	4.6	1.36	38.2	740
10	180	36	0.43	5.2	1.22	-	1195
$\overline{X}$	160	28.5	0.42	4.63	0.90	37.74	
S.D.	26	11.8	0.03	0.41	0.30	1.57	
Range	120-210	12-46	0.36-0.47	4.1-5.0	0.51-1.36	35.4-39.7	

TABLE III

MEAN VALUES AND STANDARD DEVIATIONS
FOR BLOOD-GAS PARAMETERS OF DOGS 2-10

Site	% Control Cardiac Output		*pH	pCO_2	pO_2	$[HCO_3^-]$
Art	100%	$\bar{X}$	7.32	47.8	76.2	25.3
		SD	-.06	6.91	11.86	4.64
			+.05			
MV	100%	$\bar{X}$	7.31	52.1	50.6	25.3
		SD	-.05	7.65	5.91	1.72
			+.05			
FV	100%	$\bar{X}$	7.31	54.0	47.3	26.1
		SD	-.05	7.49	8.20	1.72
			+.05			
Art	>70%	$\bar{X}$	7.32	45.8	82.4	22.8
		SD	-.04	7.25	12.4	2.45
			+.03			
MV	>70%	$\bar{X}$	7.28	55.1	45.3	25.4
		SD	-.03	7.76	4.25	2.44
			+.02			
FV	>70%	$\bar{X}$	7.27	58.9	43.0	25.7
		SD	-.03	8.70	10.55	2.50
			+.04			
Art	60%	$\bar{X}$	7.30	45.0	88.6	21.0
		SD	-.07	14.85	4.53	3.82
			+.07			

NOTE: S.D. = Standard Deviation

*pH was converted to [H+] for averaging and then back to pH to avoid error in S.D. secondary to exponential nature of pH.

TABLE III (Continued)

Site	% Control Cardiac Output		pH	pCO_2	pO_2	$[HCO_3^-]$
MV	60%	$\bar{X}$	7.28	52.5	41.4	23.8
		SD	-.05	14.57	4.45	4.03
			+.04			
FV	60%	$\bar{X}$	7.23	60.7	37.7	24.4
		SD	-.08	21.99	12.94	5.09
			+.06			
Art	50%	$\bar{X}$	7.33	40.2	81.1	20.2
		SD	-.04	7.54	15.14	2.65
			+.04			
MV	50%	$\bar{X}$	7.28	51.0	39.5	23.1
		SD	-.03	7.54	4.06	2.71
			+.03			
FV	50%	$\bar{X}$	7.23	62.8	30.1	25.4
		SD	-.04	6.97	3.75	2.35
			+.04			
Art	40%	$\bar{X}$	7.31	39.8	92.3	19.6
		SD	-.07	4.99	6.92	1.67
			+.05			
MV	40%	$\bar{X}$	7.24	57.1	34.6	23.5
		SD	-.06	6.66	6.72	1.18
			+.06			
FV	40%	$\bar{X}$	7.18	68.7	28.3	24.7
		SD	-.08	13.18	8.69	1.94
			+.07			
Art	30%	$\bar{X}$	7.33	34.2	92.2	17.5
		SD	-.07	5.62	11.50	2.97
			+.06			

TABLE III (Continued)

Site	% Control Cardiac Output		pH	pCO_2	pO_2	$[HCO_3^-]$
MV	30%	$\bar{X}$	7.24	50.6	33.2	21.1
		SD	-.09 +.08	9.28	8.52	3.05
FV	30%	$\bar{X}$	7.16	64.5	25.9	22.7
		SD	-.08 +.10	9.76	8.25	2.56
Art	20%	$\bar{X}$	7.32	26.2	96.6	13.2
		SD	-.06 +.05	3.17	2.12	2.0
MV	20%	$\bar{X}$	7.22	47.7	22.6	19.0
		SD	-.09 .07	5.92	5.30	1.17
FV	20%	$\bar{X}$	7.12	62.9	19.0	20.2
		SD	-.07 +.05	3.70	7.07	1.82

TABLE IV

Results of Paired t-tests (MV-FV)

Parameter	% Control Cardiac Output	Mean Difference	T-Statistic	Probability
pH	>70%	0.009	1.4841	$p > 0.1$
	<50%	0.073	5.3610	$p < 0.001$
pCO_2	>70%	-2.7	2.6841	$p < 0.02$
	<50%	-13.9	6.7202	$p < 0.001$
pO_2	>70%	2.4	0.9009	$p > 0.3$
	<50%	4.9	2.0542	$p > 0.05$
$[HCO_3^-]$	>70%	-0.5	2.0392	$p > 0.05$
	<50%	-1.5	5.1041	$p < 0.001$

P is the probability that these values were from the same population

df for > 70% = 17

df for < 50% = 16

TABLE V

ACTUAL AND PREDICTED VALUES FOR INDIVIDUAL DOGS 1-10 FOR pH AND pCO_2

Dog	% Control Cardiac Output	Actual MV pH	Predicted MV pH	Actual MV pCO_2	Predicted MV pCO_2	Comments
#1	100%	7.37	7.37	44.1	42.9	
	85%	7.37	7.38	43.6	42.0	
	63%	7.40	7.38	36.6	40.5	
	58%	7.44	7.27	23.6	47.9*)	*Suspected
	50%	7.49	7.28	19.2	48.8*)	contaminated
	37%	-	7.21	-	50.3*)	pulmonary
#2	100%	7.32	7.35	50.8	47.3	capillary blood
	78%	7.28	7.31	54.2	48.0	based on rising
	71%	7.25	7.28	54.9	47.6	MV pO_2 and
	41%	7.18	7.21	59.4	52.0	misplacement of
	33%	7.09	7.11	61.9	56.0	PA catheter.
#3	100%	7.30	7.32	49.2	47.9	
	79%	7.29	7.31	51.4	48.5	
	54%	7.27	7.27	50.1	52.3	
	53%	7.29	7.28	44.8	49.4	
	59%	7.28	7.26	43.2	46.1	
	36%	7.31	7.25	34.0	45.0*)	*Suspected
#4	100%	7.36	7.37	43.8	40.8	contaminated
	57%	7.25	7.26	55.5	55.2	pulmonary
	38%	7.31	7.35	47.2	41.6	capillary blood
	29%	7.27	7.26	44.4	43.5	based on rising
	21%	7.12	7.16	55.5	44.1	MV pO_2 values.
#5	100%	7.24	7.24	62.7	60.3	
	93.5%	7.31	7.30	51.1	51.2	
	52.5%	7.26	7.27	55.6	52.2	
	48%	7.12	7.18	65.9	62.6	
	47%	7.20	7.20	60.6	56.3	
#6	100%	7.38	7.37	43.8	46.1	
	73%	7.33	7.34	48.3	47.1	
	56.5%	7.34	7.34	44.4	46.1	
	24%	7.24	7.21	48.7	49.1	
#7	100%	7.26	7.26	53.8	54.1	
	79%	7.29	7.27	45.8	47.9	
	60%	7.32	7.32	42.2	39.8	
	32%	7.27	7.26	45.2	48.4	
	28%	7.28	7.28	42.0	41.8	
#8	100%	7.25	7.27	65.4	62.7	
	72%	7.26	7.28	62.9	59.5	
	61%	7.25	7.22	62.8	65.7	
	45%	7.23	7.22	61.6	62.9	
	36%	7.22	7.22	57.4	57.6	

TABLE V (Continued)

Dog	% Control Cardiac Output	Actual MV pH	Predicted MV pH	Actual MV pCO_2	Predicted MV pCO_2	Comments
#9	100%	7.34	7.36	55.2	51.8	
	89%	7.25	7.27	66.9	64.1	
	78%	7.26	7.26	68.7	63.3	
	55%	7.25	7.27	63.4	60.7	
	46%	7.27	7.27	55.4	57.3	
#10	100%	7.33	7.34	46.8	46.95	
	69%	7.32	7.34	48.7	45.9	
	54%	7.32	7.34	48.6	45.6	
	43%	7.31	7.33	48.3	46.5	
	33%	7.25	7.31	53.7	45.0	
	33%	7.25	7.27	53.7	48.5	

TABLE VI

Regression Analysis MV-FV Differences

	pO_2
MV $\bar{X}$	39.01
S.D.	10.44
FV $\bar{X}$	35.09
S.D.	12.25
Intercept	4.33
Slope	0.79
Standard Error of the Estimate	9.18
*r	.67

* r = correlation coefficient

TABLE VII

Regression Analysis Values for Actual and Predicted MV pH and pCO_2

	ph	pCO_2
Actual $\overline{X}$	7.27	53.2
S.D.	0.06	7.5
Predicted $\overline{X}$	7.28	51.3
S.D.	0.06	7.0
Intercept	0.67	6.9
Slope	0.9	0.83
r	0.94	0.89
Standard Error of Estimate	0.02	3.2

* N = 45
* df = $\frac{44}{44}$

TABLE VIII

MV-FV pO_2 Differences

Dog	% C.O.	Site	pO_2	*Difference MV-FV pO_2
#2	100%	MV	41.70	-12.6
		FV	54.30	
	78%	MV	40.4	-27.6
		FV	68.0	
	71%	MV	37.4	-10.1
		FV	47.5	
	41%	MV	29.1	+ 0.4
		FV	28.7	
	33.5%	MV	24.0	+ 5.7
		FV	18.3	
#3	100%	MV	53.7	+19.5
		FV	34.2	
	79%	MV	49.5	+16.9
		FV	32.6	
	54%	MV	45.7	+16.5
		FV	29.2	
	53%	MV	41.4	+14.9
		FV	26.5	
	59%	MV	37.2	+ 9.6
		FV	27.6	
	36%	MV	44.4	+27.3 **
		FV	17.1	
#4	100%	MV	47.3	+ 0.1
		FV	47.2	
	57%	MV	34.1	+ 1.0
		FV	33.1	
	38%	MV	24.8	-12.7
		FV	37.5	
	29%	MV	22.6	- 1.8
		FV	24.4	
	21%	MV	18.3	- 3.9
		FV	22.2	
#5	100%	MV	54.3	- 1.6
		FV	55.9	
	93.5%	MV	48.9	+ 2.8
		FV	46.1	
	52.5%	MV	43.2	+ 6.4
		FV	36.8	
	47.8%	MV	37.8	+14.3
		FV	23.5	
	46.8%	MV	27.3	+ 4.9
		FV	22.4	
#6	100%	MV	44.9	+ 1.4
		FV	43.5	
	73%	MV	41.8	+ 9.7
		FV	32.1	
	56.5%	MV	36.8	+ 6.5
		FV	30.3	
	24%	MV	19.4	+10.8
		FV	8.6	

Key: MV = Mixed Venous Blood
FV = Femoral Venous Blood

*Negative values for differences indicate FV values were >MV values. Positive values for differences indicate MV values were >FV values.

**MV sample was contaminated with pulmonary capillary blood and so not included in statistical analysis.

TABLE VIII (Continued)

Dog	% C.O.	Site	pO_2	*Difference MV-FV pO_2	Dog	% C.O	Site	pO_2	Difference MV-FV pO_2
#7	100%	MV	48.8	+13.2	#9	100%	MV	50.5	-0.70
		FV	35.6				FV	51.2	
	79%	MV	47.7	+10.6		89%	MV	45.7	+ 7.4
		FV	37.1				FV	38.3	
	59.6%	MV	44.5	- 2.3		78%	MV	42.8	+ 4.3
		FV	46.8				FV	38.5	
	32%	MV	38.7	+10.6		55%	MV	38.4	+11.5
		FV	28.1				FV	26.9	
	28%	MV	30.1	+ 9.6		46%	MV	32	+ 9.9
		FV	20.6				FV	22.1	
#8	100%	MV	49.8	-14.0	#10	100%	MV	61.8	+12.2
		FV	55.8				FV	49.6	
	72%	MV	45.0	+ 4.5		69%	MV	50.8	+ 3.2
		FV	40.5				FV	47.6	
	61%	MV	30.2	+ 1.7		54%	MV	47.5	+ 4.70
		FV	28.5				FV	42.8	
	45%	MV	32.8	+12.10		43%	MV	35.5	+ 0.7
		FV	20.7				FV	34.8	
	36%	MV	24.6	+ 6.5		33%	MV	26.5	-11.20
		FV	18.1				FV	37.7	
						33%	MV	26.5	- 0.6
							FV	27.10	

TABLE IX

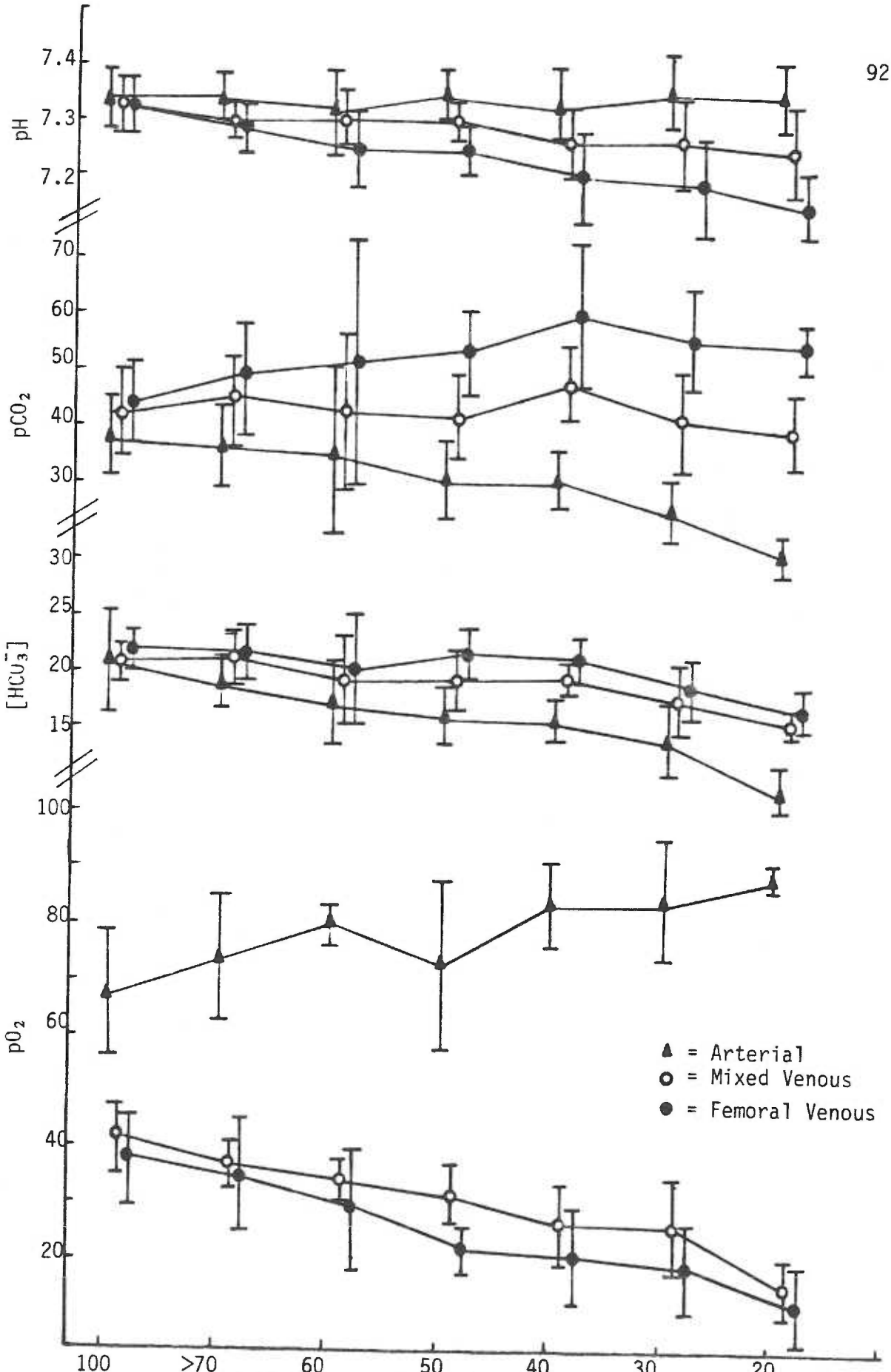
pO_2 MV-FV Differences
(Dogs 2-10)

% C.O.	Dog 2	Dog 3	Dog 4	Dog 5	Dog 6	Dog 7	Dog 8	Dog 9	Dog 10	$\bar{X}$ / S.D.
100%	-12.6	+19.5	+0.1	-1.6	+1.4	+13.2	-14.0	-0.70	+12.2	1.9 / 11.34
>70%	-27.6 -10.1	+16.9		+2.8	+9.7	+10.6	+ 4.5	+7.4 +4.3	+ 3.2	1.76 / 11.44
60%						- 2.3	+ 1.7			
50%		+16.5 +14.9 + 9.6	+1.0	+6.4	+6.5			+11.5		8.36 / 5.5
40%	+ 0.4			+14.3 + 4.9			+12.1	+ 9.9	+0.7	
30%	+ 5.7	+27.3	-12.7			+10.6	+6.5		+11.2 - 0.6	3.66 / 11.40
20%			-1.8 -3.9		+10.8	+ 9.6				

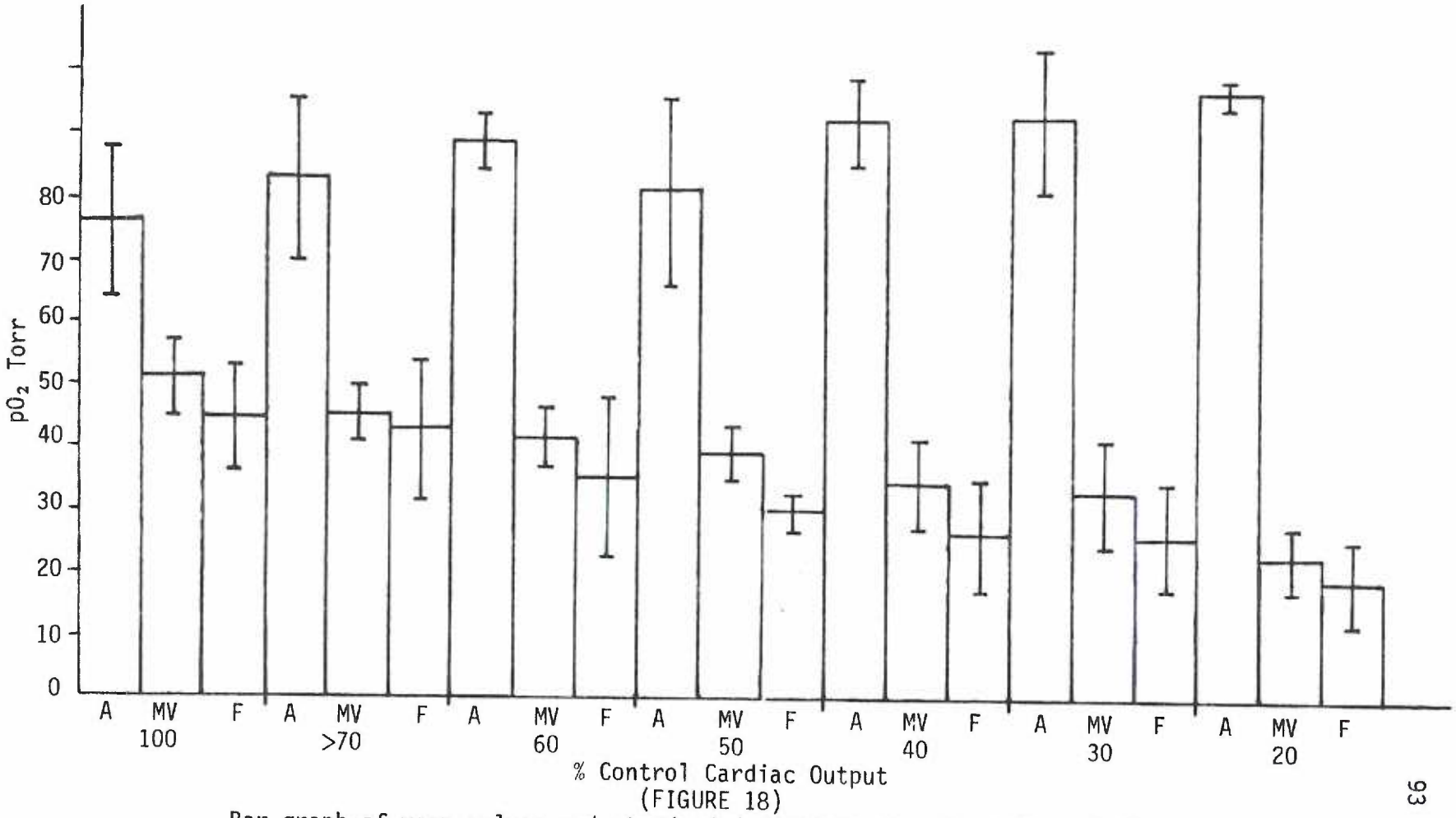
Negative values indicate FV values were > MV values.
Positive values indicate MV values were > FV values

FIGURE 17

Mean values and standard deviations for blood-gas parameters of Dogs 2-10.

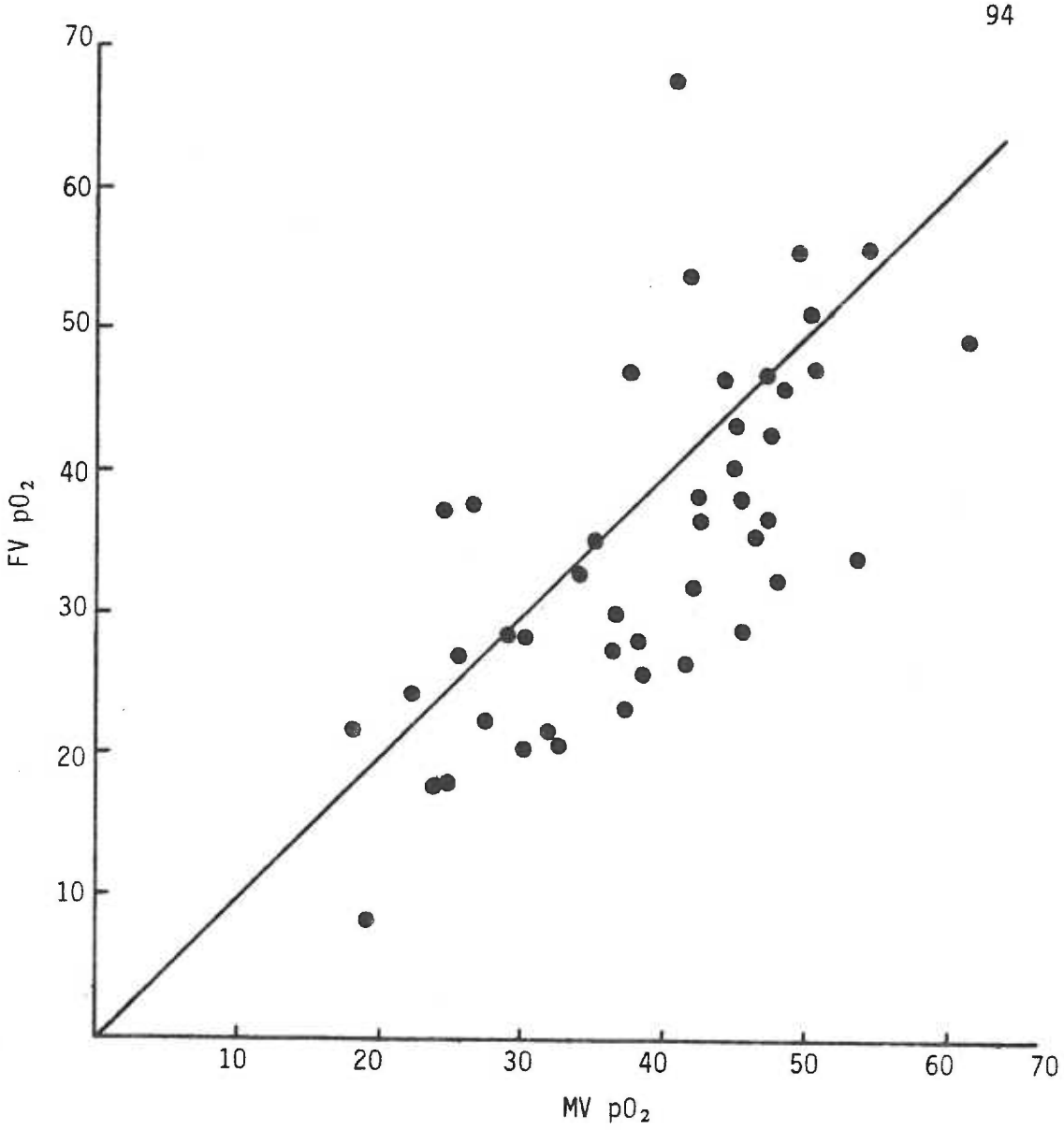

pH
7.4
7.3
7.2
pCO_2
70
60
50
40
30
$[HCO_3^-]$
30
25
20
15
pO_2
100
80
60
40
20
▲ = Arterial
○ = Mixed Venous
● = Femoral Venous
100
>70
60
50
40
30
20
% Control Cardiac Output

(FIGURE 17).



(FIGURE 18)

Bar graph of mean values and standard deviations for pO_2 of Dogs 2-10.

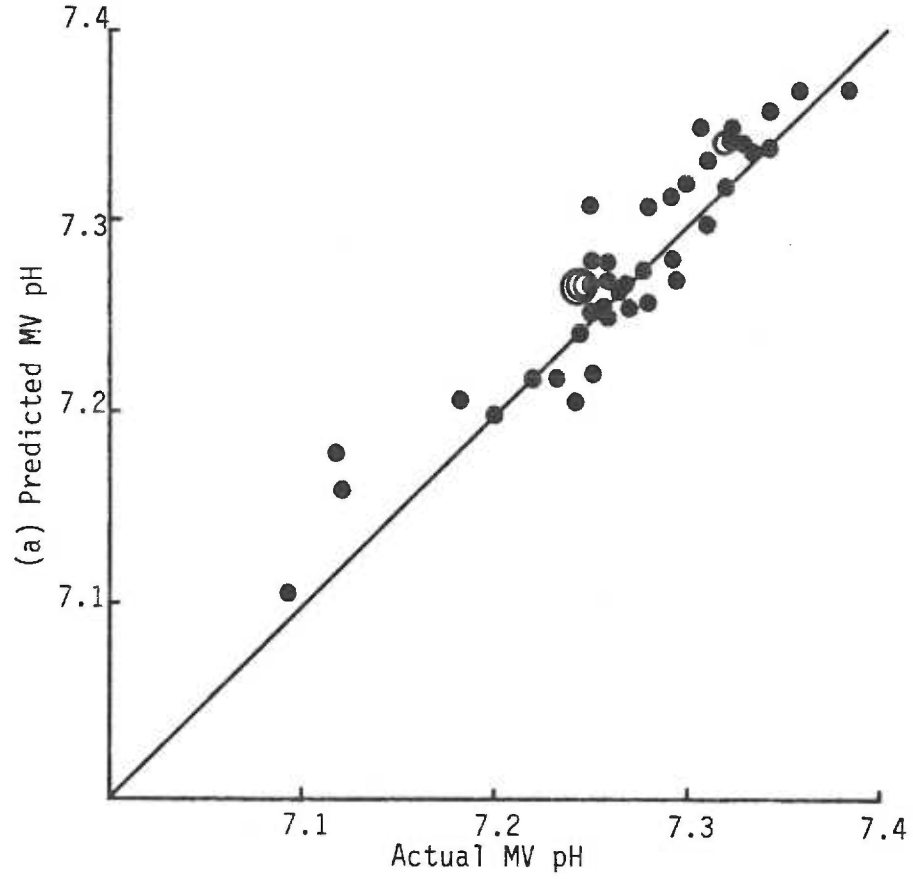


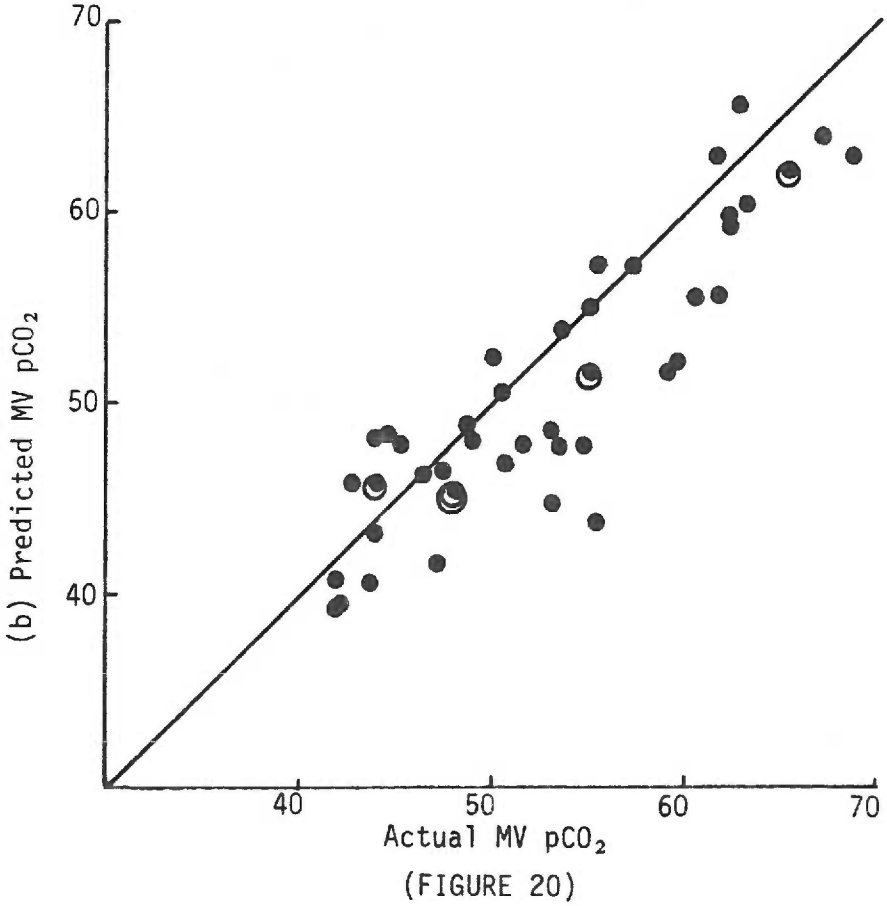
(FIGURE 19)

Identity plot of mixed venous pO_2 values versus femoral venous pO_2 values. The correlation coefficient for this relationship is r = 0.67. The diagonal line is the identity line.

FIGURE 20.

Identity plots of actual versus predicted values of mixed venous blood-gas parameters for pH and pCO_2 is illustrated in Figures (a) and (b) respectively. Predicted values are computed by taking the mean of simultaneously drawn arterial and femoral venous values for pH and pCO_2. The diagonal line is the identity line for both figures.


7.4
7.3
7.2
7.1
(a) Predicted MV pH
7.1
7.2
7.3
7.4
Actual MV pH


70
60
50
40
(b) Predicted MV pCO_2
40
50
60
70
Actual MV pCO_2

(FIGURE 20)

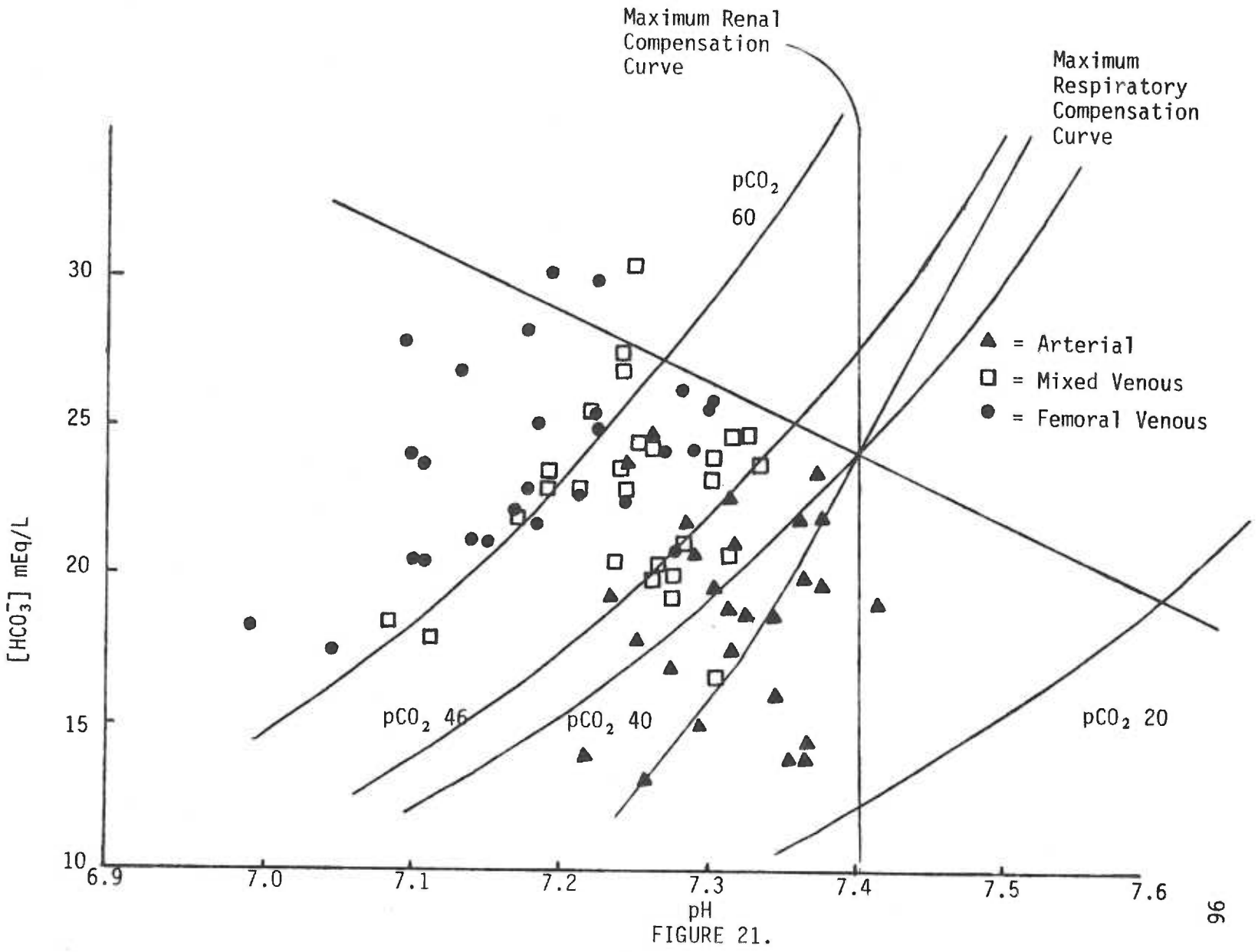

Maximum Renal Compensation Curve
Maximum Respiratory Compensation Curve
pCO_2 60
pCO_2 46
pCO_2 40
pCO_2 20
▲ = Arterial
□ = Mixed Venous
● = Femoral Venous
[HCO_3^-] mEq/L
30
25
20
15
10
6.9
7.0
7.1
7.2
7.3
7.4
7.5
7.6
pH

FIGURE 21.

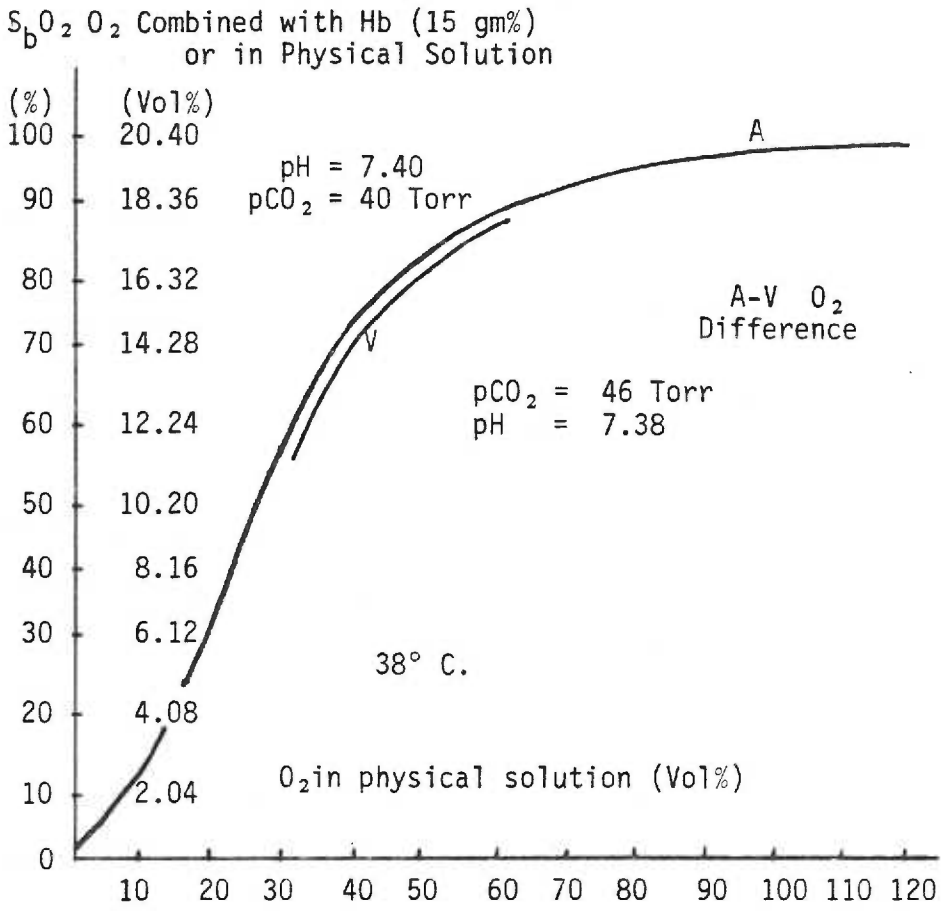


FIGURE 22.

"The oxyhemoglobin dissociation curve, showing the basic relationship of blood O_2 transport. Its shape has great physiologic importance. The full curve above applies to the arterial blood of healthy man at rest, whereas the small section to its right applies to venous blood. Point A represents normal values for arterial blood and point V for venous blood. Changes in CO_2 tension, pH, or temperature displace the oxyhemoglobin dissociation curve to the right or left. A physiologic shift from the venous to the arterial curve takes place as blood flows through the pulmonary capillaries, losing CO_2 and increasing in pH. The reverse shift occurs as blood flows through the systemic capillaries. Note that this effect, termed the Bohr shift, facilitates O_2 dumping in the tissues. Note also the relatively small amount of O_2 carried by the the blood in physical solution in the physiologic range of O_2 tension."

Source: Slonim and Hamilton, 1976 (p. 82).

CHAPTER IV

DISCUSSION

The discussion is organized in the following way:

1) How does femoral venous blood-gas composition compare to mixed venous and arterial blood-gas composition during states of decreased cardiac output?
2) Does femoral venous blood-gas composition change in a predictable pattern when cardiac output is reduced?
3) Can samples of femoral venous blood be obtained when cardiac output is reduced to values less than 50% of control?

How Does Femoral Venous Blood-Gas Composition Compare to Mixed Venous and Arterial Blood-Gas Composition During Decreased State of Cardiac Output?

pH

The mean values for initial pH in both mixed venous and femoral venous blood were less than that for arterial blood. This difference was expected according to the physiological model (p. 5) which illustrates differences in arterial versus venous circulation. Details of the specific rationale for this difference was carefully explained by Murphy (1982). In brief, addition of acids from metabolic activity of tissue cell diffuse into capillary blood which then flows into veins causing a slightly lower pH in venous blood compared to arterial blood.

Final mean values for pH decreased in arterial, mixed venous, and femoral venous blood. The greatest difference was seen in femoral venous

blood and the second greatest difference was seen in mixed venous blood. As is apparent from the theoretical framework, decreased O_2 delivery secondary to reduced cardiac output as well as continued CO_2 production would reduce the pH of mixed venous blood. Decreased O_2 supply to tissue beds leads to tissue hypoxia and anaerobic metabolism. Anaerobic metabolism in turn leads to increased lactic acid production. Lactic acid, therefore, contributes to the decreased pH in mixed venous blood. Furthermore, decreased cardiac output causes an accumulation of CO_2 produced by cellular metabolism. The accumulation of CO_2 shifts the reaction in Equation 1 to the right, thereby increasing [H+].

Arterial pH decreased for the same reasons described above, but respiratory compensation minimized the decrease in pH. Both increased [H+] and decreased pressure sensed by chemoreptors and baroreptors in arterial circulation act as stimuli to ventilation. If the dogs had not been anesthetized, respiratory compensation may have been more marked resulting in an even smaller decrease in arterial pH.

Initial mean pH in mixed venous and femoral venous blood were the same, 7.31. Final mean pH values, however, were markedly different. There was close to 0.1 pH unit difference between mixed venous and femoral venous blood, approximately the same degree of difference noted between arterial and mixed venous blood. Paired t-tests between mixed venous and femoral venous values showed there was no significant difference in control values. A significant difference was found when cardiac output was reduced to values less than 50% of control (Table IV). The reason for this wide degree of difference in values below 50% of control cardiac output can be attributed to different metabolic rates and blood flow from the particular site from which the

venous sample was drawn. Mixed venous blood represents a flow weighted average of all tissue beds of the body. Mixed venous blood is a mixture from well perfused regions that add very little extra H+ to blood and from regions of the body, such as the extremities, that may add large amounts of H+ to venous blood secondary to decreased cardiac output. There would, therefore, be less reduction in the pH of mixed venous blood because of mixing with blood from tissue beds with higher flow and lower metabolic rates.

Femoral venous blood, however, represents blood from a predominantly muscular bed, although bone, skin, and connective tissue contribute to its acid-base composition. These particular tissues are noted for high resistance to flow compared to organs like the heart. During reduced cardiac output compensatory vasoconstriction further decreases blood supply and oxygen to femoral tissue beds. There should be an increase in lactic acid concentration from decreased flow and ensuing anaerobic metabolism. The marked increase in lactic acid production would significantly increase [H+] in the extremities and, therefore, lower femoral venous pH below mixed venous values.

pCO_2

Mean arterial pCO_2 decreased (as expected) from a control value of 47.8 to a final mean value of 26.2 torr. Respiratory compensation in response to metabolic acidosis can account for the decrease in arterial pCO_2. The final mean value differs from that reported by others because the categories of cardiac output are different (Murphy, 1982). The final mean values of this study are based on data that falls in the range of 20%

control cardiac output. Murphy's data was explained on values that fell below 55% control cardiac output. From either perspective, however, the rationale is still valid.

Mean values for mixed venous pCO_2 changed very little from control to final values (52.1 to 47.7 torr). If all values of 50% control cardiac output for dogs 2-10 were computed as final mean values a score of 51.2 torr would result. This is contradictory to the report of Tung, et al. (1976) in which mixed venous pCO_2 increased after hemorrhagic shock was induced. Murphy (1982) explains this discrepancy by separating the processes that are involved in determining mixed venous pCO_2. She argued that mixed venous pCO_2 is a function of cardiac output, arterial $[CO_2]$, metabolic CO_2 production and the fraction of CO_2 that is transported as physically dissolved CO_2. Since the dogs were anesthetized it is assumed that there would be no increase in metabolic production of CO_2 due to activity. Therefore, mixed venous pCO_2 is a reflection of two processes. One process is the systemic delivery of CO_2 in arterial blood to the capillary bed, and the second is increased accumulation of CO_2 in capillary blood because of reduced blood flow due to decreased cardiac output. Because both cardiac output and arterial pCO_2 decreased, there was decreased delivery of CO_2 to tissue capillary beds. The decreased delivery counterbalanced any increased accumulation on the venous side due to decreased flow.

Mean control values for femoral venous pCO_2 increased from a value of 54.0 to a final value of 62.9 torr. Paired t-tests for mixed venous and femoral venous values showed a statistically significant difference at control values The difference increased greatly by final hemorrhagic values (Table IV). Increases in pCO_2 values for femoral venous blood over mixed

venous blood are consistent with decreases seen in pH for FV and MV blood. There are three reasons why femoral venous blood would have higher pCO_2 values than mixed venous blood. These are: 1) normal high resistance of femoral vascular beds, 2) compensatory vasoconstriction in response to decreased blood pressure, and 3) increased accumulation of CO_2 in femoral venous blood due to decreased flow.

Mixed venous blood, as mentioned previously, represents the flow weighted average from all systemic tissue beds. Organs such as the kidney have low vascular resistance and high blood flow per unit weight until a critical decrease in cardiac output is reached. Any increases in pCO_2 of mixed venous blood coming from femoral tissue beds are counterbalanced by low pCO_2 values from other tissue beds. Thus, the increase in mixed venous pCO_2 following hemorrhage will generally be of less magnitude than femoral venous pCO_2.

pO_2

Mean arterial pO_2 increased from initial value of 76.2 torr (>95% saturation) to a final mean value of 96.6 torr (>99% saturation). The change in oxygen saturation is minimal at these values of pO_2 (Figure 22). The fact that the dogs increased their pO_2 in response to hemorrhage is accounted for by compensatory hyperventilation. This respiratory compensation is secondary to increased [H+] from ensuing metabolic acidosis and decreased blood pressure as sensed by chemoreceptors and barareptors in arterial circulation.

Mean venous pO_2 values decreased from an initial value of 50.6 torr (approximately 80% saturation) to a final value of 22.7 torr (approximately

45% saturation). At low pO_2 values around 60 torr with normal hemoglobin values and temperature the oxyhemoglobin dissociation curve is more linear. Because of the linear nature of this curve at low pO_2 values each unit decrement in pO_2 has a more pronounced effect on oxygen saturation. This is consistent with the findings of Tung, et al. (1976). Acute tissue hypoxia exists during reduced cardiac output as reflected in mixed venous pO_2 values. Arterial pO_2, however, does not reflect this tissue hypoxia and in fact the pO_2 even increased above control values in this study.

Mean pO_2 of femoral venous blood decreased from an initial value of 47.3 torr (~ 77% saturation) to a final value of 19 torr (~ 22% saturation). Final values are based on 20% control cardiac output. A mean value of all dogs (2-10) at 50% of control cardiac output or less yields a final mean pO_2 of 25.8 torr or (~ 45% saturation). In addition, paired t-tests on mixed venous pO_2 versus femoral venous pO_2 values showed that FV pO_2 was not statistically different from MV pO_2 in control or final hemorrhage periods.

Regression analysis on MV-FV pO_2 differences, however, showed only a moderate correlation ($r = 0.67$) despite similarities noted in mean values. Despite the lack of strong correlation between FV and MV pO_2 values, both MV and FV pO_2 decrease with decreasing cardiac output. It is, therefore, reasonable to follow trends in femoral pO_2 as an indicator of the degree of tissue hypoxia.

The reason for the lack of strong correlation between MV and FV pO_2 values is speculative. According to the theoretical model (pg. 5) FV blood would be expected to have a lower pO_2 than simultaneously drawn mixed venous blood. Since there was no net increase in muscular activity due to

anesthesia, the MV-FV pO_2 differences were expected to be relatively constant.

Extraction rates for O_2 normally vary from one organ to the next (p. 7). Under hemorrhagic conditions, however, vasoconstriction and anatomical shunting can occur in various tissue beds. Extremities are generally the first to have flow compromised by vasoconstriction during shock, thereby shunting blood to more vital organs as well as maintaining blood pressure. Other vital organs do not usually undergo compensatory vasoconstriction until a more severe reduction in cardiac output is reached (Smith & Kampine, 1980). Variances could occur for at least two reasons: 1) Shunting may occur at different cardiac outputs in different animals, and 2) individual organ responses to shock may vary.

Individual responses to shock can vary in terms of what critical values must be reached before compensatory vasoconstriction affects vital organs. For example, one dog may undergo renal vasoconstriction at 50% control cardiac output whereas another dog may not vasoconstrict renal arterioles until 30% control cardiac output is reached.

Individual organs or tissue beds may also respond differently. For example, the heart is unable to increase its blood flow to coronary arteries and, therefore, extracts more O_2 from the blood received in the coronary circulation (Smith & Kampine, 1980). In fact, pO_2 values from coronary sinus circulation during hemorrhagic shock theoretically could be very close to low values seen in femoral venous pO_2. Furthermore, mesenteric circulation may exhibit vasoconstriction during hemorrhagic shock similar to femoral tissue beds. Inconsistent differences noted between MV and FV pO_2 values may, therefore, be attributed to variances of individual organs

or tissues during shock.

Clinical versus statistical significance needs to be discussed in regard to MV and FV pO_2 values if results are to be generalized to human situations. Standards for clinically significant variances in pO_2 are based upon the oxyhemoglobin dissociation curve (Figure 22). Due to the shape of the curve, decrements below 60 torr, given a normal hematocrit, temperature, and pH, can markedly decrease oxygen saturation. Even a 5 torr decrease in pO_2 could be significant in a severely compromised patient. Because of the lack of strong correlation between FV and MV pO_2 values, femoral venous blood may appear to be an unrealiable substitute for specific MV pO_2 values. It should be noted, however, that in healthy adults normal arterial pO_2 values may vary from 80-100 torr. Therefore, a precise predictable tool for specific pO_2 values may not be a realistic expectation due to normal biological variances. Nevertheless, since both MV and FV pO_2 decrease in response to hemorrhage, following trends in FV pO_2 can be a good indicator of systemic tissue hypoxia.

$[HCO_3^-]$

Mean control $[HCO_3^-]$ for arterial, mixed venous, and femoral venous blood was basically the same. Final mean values showed mixed venous and femoral venous $[HCO_3^-]$ to be approximately the same. Paired t-tests for MV-FV differences showed no statistical differences at control values. Paired samples below 50% of control cardiac output, however, showed statistically significant difference between MV-FV $[HCO_3^-]$. Final mean arterial $[HCO_3^-]$ were less than either mixed venous or femoral venous values. This low $[HCO_3^-]$ may be accounted for by examining Equation 1. During

hyperventilation stimulated by increased [H+], CO_2 is expired and the entire reaction shifts to the left. Because of this shift [HCO_3^-] is reduced in arterial blood. In venous circulation decreased flow allows accumulation of CO_2 which tends to increase [HCO_3^-] and minimizes the decrease in [HCO_3^-] from buffering lactic acid. Femoral venous [HCO_3^-] was slightly higher than mixed venous values, because there was a greater build-up of CO_2 in femoral venous blood than in mixed venous blood.

Does Femoral Venous Blood-Gas Composition Change in a Predictable Pattern When Cardiac Output is Reduced?

The ability to predict mixed venous pCO_2 and pH values based on simultaneously drawn samples of femoral venous and arterial blood certainly constitutes a predictable pattern (Table V, Figure 20). Visual examination of pH and pCO_2 values of femoral venous blood in Figure 17 graphically illustrates this pattern. Femoral venous pH and pCO_2 change in the same direction as do pH and pCO_2 of mixed venous blood, but the MV-FV differences increase as cardiac output is reduced. It also appears that mixed venous data points lie approximately midway between arterial and femoral venous data points for pH and pCO_2. Therefore, an average was calculated from each paired arterial and femoral venous pH and pCO_2 values (Table V). The mean obtained was then plotted as a function of the actual mixed venous parameter (Figure 20). Regression analysis of these data showed a strong correlation between predicted and actual values (Table VII).

Physiological rationale can explain why femoral venous pH and pCO_2 may vary from mixed venous pH and pCO_2, but it cannot predict to what degree it it will vary. It may be that conditions for this research project were

such that physiological processes were balanced and the averages predicted actual values. Under a different set of conditions, however, such as mechanical ventilation where actual pCO_2 remains nearly constant, then the relationship might not hold. There may still be, however, a constant relationship present even under other conditions. For example, if the dogs were ventilated at a constant $paCO_2$, then perhaps a different formula could be adopted to predict mixed venous pH and pCO_2.

Regression analysis showed a correlation coefficient of only 0.67 for MV and FV pO_2 values. Despite this poor correlation MV and FV values still decrease in response to decreased cardiac output. This downward trend of pO_2 values in response to hemorrhage constitutes a pattern. Changes in FV pO_2 values can, therefore, be monitored as an indicator of tissue hypoxia.

Bicarbonate concentration of femoral venous blood likewise follows a predictable pattern. Visual examination of the $[HCO_3^-]$ changes on Figure 17 graphically illustrate this predictable pattern. There is a very close approximation of mixed venous and femoral venous changes in $[HCO_3^-]$. Paired t-tests showed there was a significant difference between MV and FV $[HCO_3^-]$ as cardiac output was reduced below 50% control values (Table IV). Clinically, however, this difference would be of no importance. The difference while significant, would not alter intervention for a particular acid-base disturbance. It is also important to note that $[HCO_3^-]$ is calculated according to the Hendersen-Hasselbach equation from values of pH and pCO_2. Since MV pH and pCO_2 can be predicted from FV values a MV $[HCO_3^-]$ can also be calculated from predicted values.

pH/[HCO_3^-] Relationship

The results of plotting femoral venous data on the pH/[HCO_3^-] diagram also shows a pattern predicted from the theoretical framework. Almost all of the femoral venous points plotted in Figure 21 fall within the category of combined respiratory and metabolic acidosis. Most of the mixed venous data points fall in the same category. Femoral venous data points, however, tended to range more widely within this category with lower pH, higher pCO_2, and slightly higher bicarbonate values.

Arterial points fall in a different acid-base category than mixed venous or femoral venous blood (Figure 21). Arterial blood represents cardiopulmonary acid-base status. Venous blood represents tissue acid-base status. During hemorrhagic shock, these dogs exhibited profound tissue hypoxia which was reflected in femoral and mixed venous blood-gas composition. Arterial blood-gas composition, however, gives an erroneous interpretation of tissue acid-base status in states of decreased cardiac output.

Can Samples of Femoral Venous Blood Be Obtained When Cardiac Output is Reduced to Values Less Than 50% of Control?

It is obvious from raw data on dogs 1-10 in Appendix A that femoral samples could be obtained even at 20% control cardiac output. There was some trouble in obtaining mixed venous blood, however, particularly with dogs 1 and 3. Dog 1 was eliminated from statistical tests due to suspicion of the last three values being contaminated with pulmonary capillary blood. These suspected MV O_2 values were at cardiac outputs of 58%, 50%, and 37%, respectively (Appendix A). Suspicion of contamination was based upon rising MV pO_2 values with each decrement in cardiac output. On autopsy it

was verified that the pulmonary artery catheter was indeed incorrectly positioned.

The last MV pO_2 value of dog 3 was also suspected of contamination from pulmonary capillary blood for the same reason as stated for dog 1. The pulmonary artery catheter was found to be in proper position on autopsy, however. Careful technique was used to withdraw pulmonary artery blood slowly over a 1-2 minute period of time. Despite these measures and the apparent correct position of the pulmonary artery catheter in dog 3, pulmonary capillary blood still contaminated the mixed venous blood in 4 out of 18 samples when cardiac output was less than 50% of control (22%). Two of the samples were contaminated even at values of 58% and 50% control cardiac output.

The errors in obtaining mixed venous blood, despite proper placement of the pulmonary artery catheter in dog 3 and careful technique has important implications for advocating the use of femoral venous blood. This is especially pertinent considering that femoral venous blood can be used in lieu of mixed venous blood. During decreased cardiac output femoral venous blood may be the site of choice for predicting mixed venous values.

In summary, the following conclusions can be drawn:

1) Femoral venous blood-gas composition represents systemic tissue acid-base status.
2) Femoral venous blood-gas composition can be used as a predictive tool for mixed venous pH, pCO_2 and $[HCO_3^-]$.
3) Changes in femoral venous pO_2 follows a consistent pattern that can indicate the degree of tissue hypoxia.
4) Femoral venous blood can be obtained in states of decreased cardiac output.

Limitations of the Study

The major limitation of the study is that it is with dogs involving small numbers. Also many of the dogs had an initial respiratory acidosis secondary to anesthesia. It was also difficult to collate widely differing cardiac outputs for comparative purposes. Nevertheless, implications and physiological explanations for the results found in this study are sound.

Clinical Implications

In light of the results of this experiment it appears that femoral venous blood-gas analysis will have profound implications for nursing practice. Considerations for nursing practice regarding FV blood are addressed below:

1) Nurses that utilize acid-base assessment will need to be knowledgeable about available methods for acid-base assessment, particularly venous blood-gas assessment. This knowledge must include advantages and disadvantages of using a particular site. Nurses will need to be able to weigh the purpose of blood-gas analysis and weigh them against risks, pain, expense, and accuracy.
2) In order to be an advocate for use of a new method of acid-base assessment the nurse will need to be well versed in specific rationale for its purpose, advantages, and disadvantages. In addition, she will also need to be properly trained in correct technique for drawing femoral venous blood.
3) Since there are no current standards or criteria for drawing femoral venous blood nurses will need to be involved in establishing proper protocol.
4) Since human studies have not been conducted regarding the value

of femoral venous blood, nursing reseach is necessary. Studies under a variety of conditions would be extremely valuable.

5) Nurses will need to educate and monitor not only other nurses but other health team members as well. This education should include proper judgement in selecting a site, proper interpretation, and correct technique.

CHAPTER V

SUMMARY, CONCLUSIONS, RECOMMENDATIONS

Summary and Conclusions

Arterial blood is still the most widely used modality for assessing acid-base status in critical care settings. Use of mixed venous blood has made considerable gains, based on current research, in providing valuable information regarding total systemic tissue acid-base status. Problems in obtaining mixed venous blood, however, has led to research for alternative sites for venous blood, particularly during states of decreased cardiac output. Femoral venous blood is proposed to be reliable substitute and can be used to predict mixed venous pH, pCO_2, and $[HCO_3^-]$. Changes in femoral venous pO_2 can be used to monitor tissue hypoxia.

Ten mongrel dogs were subjects for this research project. The dogs were anesthetized, intubated, and allowed to breathe room air. Cardiac output was progressively decreased in each dog by intermittent controlled hemorrhage. Arterial, mixed venous, and femoral venous blood-gas samples were drawn simultaneously with each decrement in cardiac output.

Results showed that femoral venous blood is a valuable substitute for predicting mixed venous pH, pCO_2, and $[HCO_3^-]$. Trends in femoral venous pO_2 can be followed as an indicator of tissue hypoxia. Femoral venous and mixed venous blood-gas parameters fall within the same category of combined metabolic and respiratory acidosis during decreased cardiac output. Femoral venous blood-gas composition varied more than mixed venous blood-gas composition within that acid-base category, however. Femoral venous blood generally has an increased pCO_2 and $[HCO_3^-]$ and decreased pH compared to mixed venous

parameters. Arterial blood showed a different acid-base disturbance during hemorrhage, i.e., compensated metabolic acidosis and mixed respiratory alkalosis and metabolic acidosis. Femoral and mixed venous pO_2 indicated acute tissue hypoxia whereas arterial pO_2 actually increased during hemorrhage.

Based on these results it can be concluded that femoral venous blood is a valid substitute for mixed venous blood pH, pCO_2, and $[HCO_3^-]$ especially during decreased cardiac output. Femoral venous pO_2 values can be followed as an indicator of tissue hypoxia. Furthermore, because venous blood represents output from tissues, it is a much better assessment tool for determining acid-base status of tissues whereas arterial blood cannot provide that information.

Recommendations for Further Study

Because the research was based on dog experiments in a laboratory situation and in light of the positive correlations regarding femoral venous and mixed blood the following recommendations are suggested:

1) Clinical research comparing arterial, mixed venous, and femoral venous blood-gas composition during decreased cardiac output.
2) Research on femoral venous blood-gas composition during decreased cardiac output when the dogs are ventilated.
3) Research on femoral venous, mixed venous, and arterial blood-gas composition during decreased cardiac output due to other shock states, e.g., cardiogenic or septic shock.
4) Research on correlations between femoral venous pO_2 and coronary sinus pO_2 values.

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APPENDIX A

Raw Data from 10 Experimental Animals Showing Blood-Gas Parameters Obtained During Induced States of Decreased Cardiac Output.

SUMMARY OF DATA FOR DOG 1 (41# - 18.6 Kg) 2/13/81

Cardiac Output			$\bar{X}$ pH	S.D.	$\bar{X}$ pCO_2	S.D.	$\bar{X}$ pO_2	S.D.	$\bar{X}$ $[HCO_3^-]$
Control									
$\bar{X}$	2.6133	A	7.38	.0010	40.3	0.00	77.3	.0577	23.0
% Control	(100%)	MV	7.37	.0010	44.1	0.00	50.2	.2082	24.5
S.D.	0.2483	F	7.37	.0020	45.5	0.1247	50.6	.0577	25.2
Sample 2									
$\bar{X}$	2.230	A	7.40	.0021	37.2	.0577	84.6	.1528	22.1
% Control	(85.3%)	MV	7.37	.0015	43.6	.0577	48.1	.1528	24.6
S.D.	.2352	F	7.3	.0010	46.7	0.00	42.3	.2645	25.4
Sample 3									
$\bar{X}$	1.6533	A	7.42	.0091	33.3	.0577	87.6	.5292	21.2
% Control	(63.3%)	MV	7.40	.0010	36.6	.1528	43.6	.2082	21.9
S.D.	.0493	F	7.34	.0015	47.8	.0577	34.4	.1732	25.3
Sample 4									
$\bar{X}$	1.51	A	7.30	.0010	39.4	0.00	84.6	.1000	18.8
% Control	(57.8%)	MV	7.44	.0023	23.6	0.00	77.2	.1155	15.4
S.D.	.1649	F	7.25	.0015	56.4	0.00	29.7	.2645	23.8
Sample 5									
$\bar{X}$	1.31	A	7.33	.0015	37.2	0.00	91.7	.2887	18.9
% Control	(50.1%)	MV	7.49	.0017	19.2	.1155	102.0	.1528	14.1
S.D.	.0513	F	7.23	.001	60.3	.1000	27.0	.1527	24.5
Sample 6									
$\bar{X}$	.9575	A	7.30	.0010	32.5	.1000	90.1	.1000	15.3
% Control	(36.6%)	MV	-	-	-	-	-	-	-
S.D.	.0435	F	7.12	.0005	68.1	.0577	24.3	.1527	21.6

Key: A = Arterial Blood
MV = Mixed Venous Blood
F = Femoral Venous Blood
S.D. = Standard Deviation

SUMMARY OF DATA FOR DOG 2 (28# - 12.7 Kg) 2/20/81

Cardiac Output			$\bar{X}$ pH	S.D.	$\bar{X}$ PCO_2	S.D.	$\bar{X}$ PO_2	S.D.	$\bar{X}$ $[HCO_3^-]$
Control									
$\bar{X}$	1.53	A	7.35	.0026	46.2	.0577	83.0	.6000	24.9
% Control	(100%)	MV	7.32	.0021	50.8	.2000	41.7	.4359	25.5
S.D.	.1234	F	7.34	.0012	48.4	.1732	54.3	.1528	25.5
Sample 2									
$\bar{X}$	1.20	A	7.31	.0025	47.6	.0577	85.3	.3055	23.4
% Control	(78.2%)	MV	7.28	.0029	54.2	.1000	40.4	.0577	24.8
S.D.	.0141	F	7.31	.0020	48.4	.1155	68.0	.4509	23.4
Sample 3									
$\bar{X}$	1.097	A	7.30	.0017	43.0	.0000	91.4	.4509	20.6
% Control	(71.5%)	MV	7.25	.0025	54.9	.0577	37.4	.1732	23.3
S.D.	.0252	F	7.26	.0006	52.2	.2517	47.5	.5000	22.7
Sample 4									
$\bar{X}$	.63	A	7.26	.0021	40.6	.1155	98.3	.3055	17.8
% Control	(41.1%)	MV	7.18	.0025	59.4	.0577	29.1	.5508	21.7
S.D.	.0100	F	7.15	.0023	63.6	.1732	28.7	.4726	21.5
Sample 5									
$\bar{X}$	.51	A	7.22	.0012	34.6	.1000	107.3	.6110	13.7
% Control	(33.5%)	MV	7.09	.0020	61.9	.1000	24.0	.3512	18.2
S.D.	.0153	F	7.00	.0020	77.4	.1528	18.3	.4041	18.4

Key: A = Arterial Blood
MV = Mixed Venous Blood
F = Femoral Venous Blood
S.D. = Standard Deviation

SUMMARY OF DATA FOR DOG 3 (29# - 13.2 Kg) 2/27/81

Cardiac Output			$\bar{X}$ pH	S.D.	$\bar{X}$ pCO_2	S.D.	$\bar{X}$ pO_2	S.D.	$\bar{X}$ $[HCO_3^-]$
Control									
$\bar{X}$	1.845	A	7.33	.0025	42.3	.0577	87.2	.5132	21.72
% Control	(100%)	MV	7.30	.0021	49.2	0.00	53.7	.7638	23.3
S.D.	.0212	F	7.31	.0012	53.4	0.00	34.2	.0577	26.1
Sample 2									
$\bar{X}$	1.4652	A	7.36	0.00	37.6	.0600	93.3	.1200	20.6
% Control	(79.4%)	MV	7.29	.0017	51.4	0.00	49.5	.4359	23.9
S.D.	.0071	F	7.25	.00058	59.4	.0577	32.6	.0577	25.0
Sample 3									
$\bar{X}$	1.0033	A	7.31	.0025	40.2	.0577	91.3	.0577	19.7
% Control	(54.4%)	MV	7.27	0.00	50.1	.1155	45.7	.3215	22.3
S.D.	.0379	F	7.22	.0010	64.3	0.00	29.2	.4583	25.6
Sample 4									
$\bar{X}$	.9740	A	7.33	.0020	35.1	.1000	92.1	.1155	18.1
% Control	(52.8%)	MV	7.29	.0006	44.8	.1528	41.4	.0577	20.7
S.D.	.1006	F	7.22	.0023	61.6	0.00	26.5	.0351	24.6
Sample 5									
$\bar{X}$	1.090	A	7.35	.0029	29.5	.0577	98.3	.1528	15.9
% Control	(59.1%)	MV	7.28	.0012	43.2	.1000	37.2	.2646	19.6
S.D.	.0975	F	7.17	0.00	62.6	.1528	27.6	.4041	22.3
Sample 6									
$\bar{X}$	.6667	A	7.37	.0023	24.4	.1000	94.3	.1732	13.6
% Control	(36.1%)	MV	7.31	.0025	34.0	0.00	44.4	.1732	16.4
S.D.	.0929	F	7.12	.0010	65.6	.1528	17.1	.4041	20.4

Key: A = Arterial Blood
MV = Mixed Venous Blood
F = Femoral Venous Blood
S.D. = Standard Deviation

SUMMARY OF DATA FOR DOG 4 (42# - 19.1 Kg) 3/6/81

Cardiac Output			$\bar{X}$ pH	S.D.	$\bar{X}$ pCO_2	S.D.	$\bar{X}$ pO_2	S.D.	$\bar{X}$ $[HCO_3^-]$
Control									
$\bar{X}$	3.25	A	7.37	.0021	38.9	.0577	73.2	.0577	21.8
% Control	(100%)	MV	7.36	.0021	43.8	0.00	47.3	.1000	23.9
S.D.	.1947	F	7.37	.0029	42.7	.0577	47.2	.1528	23.7
Sample 2									
$\bar{X}$	1.84	A	7.26	.0020	52.8	.0577	56.4	.2887	23.2
% Control	(57%)	MV	7.25	.0006	55.5	.1528	34.1	.5000	23.7
S.D.	.0427	F	7.25	.0006	57.6	0.00	33.1	.5000	24.7
Sample 3									
$\bar{X}$	1.25	A	7.42	.0017	29.4	.1155	85.6	.5568	18.5
% Control	(38%)	MV	7.31	0.00	47.2	.0577	24.8	.2646	22.9
S.D.	.1471	F	7.27	.0015	53.8	.0577	37.5	.3786	24.0
Sample 4									
$\bar{X}$	.93	A	7.36	.0010	24.8	0.00	93.6	.5100	13.5
% Control	(29%)	MV	7.27	0.00	44.4	.1200	22.6	.3000	19.7
S.D.	.0420	F	7.15	.0025	62.2	0.00	24.4	.0577	21.1
Sample 5									
$\bar{X}$	.667	A	7.26	.0010	23.83	.0600	96.9	.4700	12.9
% Control	(21%)	MV	7.12	0.00	55.5	.3100	18.3	.2000	17.5
S.D.	.0321	F	7.06	.0010	64.3	.4163	22.2	.5132	17.5

Key: A = Arterial Blood
MV = Mixed Venous Blood
F = Femoral Venous Blood
S.D. = Standard Deviation

SUMMARY OF DATA FOR DOG 5 (35# - 15.9 Kg) 3/13/81

Cardiac Output			$\bar{X}$ pH	S.D.	$\bar{X}$ pCO_2	S.D.	$\bar{X}$ pO_2	S.D.	$\bar{X}$ $[HCO_3^-]$
Control									
$\bar{X}$	1.86	A	7.24	.0012	57.7	.1000	86.4	.2887	24.1
% Control	(100%)	MV	7.24	.0020	62.7	.1732	54.3	.4163	26.3
S.D.	.1555	F	7.23	.0015	62.9	.1732	55.9	.3055	25.9
Sample 2									
$\bar{X}$	1.74	A	7.36	.0025	39.6	0.00	115.2	.2082	21.4
% Control	(93.5%)	MV	7.31	.0020	51.1	0.00	48.9	.4933	24.7
S.D.	.0971	F	7.23	.0025	62.7	.0957	46.1	.0577	25.5
Sample 3									
$\bar{X}$	.97	A	7.32	.0006	41.3	.0577	100.1	.1155	20.8
% Control	(52.5%)	MV	7.26	.0021	55.6	.0577	43.2	.4509	24.4
S.D.	.1466	F	7.22	.0025	63.1	0.00	36.8	.3055	25.3
Sample 4									
$\bar{X}$	.89	A	7.24	.0021	46.1	0.00	91.0	.4359	19.1
% Control	(47.8%)	MV	7.12	.0021	65.9	.1155	37.8	.3512	23.1
S.D.	.0361	F	7.12	.0010	79.0	.1000	23.5	.3606	24.8
Sample 5									
$\bar{X}$	.87	A	7.28	.0012	37.0	.0577	95.5	.3464	16.8
% Control	(46.8%)	MV	7.20	.0020	60.6	.0577	27.3	.0577	22.8
S.D.	.0238	F	7.11	.0012	75.6	0.00	22.4	.3606	23.5

Key: A = Arterial Blood
MV = Mixed Venous Blood
F = Femoral Venous Blood
S.D. = Standard Deviation

SUMMARY OF DATA FOR DOG 6 (42# - 19.1 Kg) 3/20/81

Cardiac Output			$\bar{X}$ pH	S.D.	$\bar{X}$ pCO_2	S.D.	$\bar{X}$ pO_2	S.D.	$\bar{X}$ $[HCO_3^-]$
Control									
$\bar{X}$	3.10	A	7.36	.0015	43.5	.0577	51.5	.2517	23.7
% Control	(100%)	MV	7.38	.0006	43.8	0.00	44.9	.2082	25.2
S.D.	.0058	F	7.37	.0015	48.7	.0577	43.5	.1155	27.0
Sample 2									
$\bar{X}$	2.26	A	7.38	.0017	41.0	0.00	58.1	.1155	23.2
% Control	(72.9%)	MV	7.33	.0017	48.3	.1155	41.8	.1000	24.5
S.D.	.0833	F	7.305	.0026	53.1	0.00	32.1	.2517	25.6
Sample 3									
$\bar{X}$	1.75	A	7.38	.0017	37.8	.0577	68.4	.3215	21.8
% Control	(56.5%)	MV	7.34	.0015	44.4	.0577	36.8	.1000	23.4
S.D.	.0538	F	7.29	.0012	54.1	.0577	30.3	.1528	25.5
Sample 4									
$\bar{X}$	.76	A	7.30	.0021	30.9	.0577	78.5	.1528	14.8
% Control	(24.4%)	MV	7.24	.0015	48.7	.1528	19.4	.4041	20.0
S.D.	.1150	F	7.11	.0015	67.0	.1000	8.6	.3055	20.6

Key: A = Arterial Blood
MV = Mixed Venous Blood
F = Femoral Venous Blood
S.D. = Standard Deviation

SUMMARY OF DATA FOR DOG 7 (45# - 20.5 Kg) 4/4/81

Cardiac Output			$\bar{X}$ pH	S.D.	$\bar{X}$ pCO_2	S.D.	$\bar{X}$ pO_2	S.D.	$\bar{X}$ $[HCO_3^-]$
Control									
$\bar{X}$	3.12	A	7.27	.0020	50.1	.2000	64.2	.1528	22.3
% Control	(100%)	MV	7.26	.0020	53.8	.2646	48.8	.0577	23.4
S.D.	.0556	F	7.25	.0027	58.1	.0577	35.6	.1732	24.4
Sample 2									
$\bar{X}$	2.47	A	7.285	.0015	43.4	.4509	71.9	.3512	20.0
% Control	(79.2%)	MV	7.29	.0015	45.8	.3786	47.7	.2646	21.3
S.D.	.0608	F	7.26	.0006	52.4	.4041	37.1	.4163	23.0
Sample 3									
$\bar{X}$	1.86	A	7.35	.0006	34.5	.1155	91.8	.1528	18.3
% Control	(59.6%)	MV	7.32	.0006	42.2	.2082	44.5	.2082	20.9
S.D.	.0451	F	7.29	.0017	45.1	.1732	46.8	.1155	20.8
Sample 4									
$\bar{X}$	.99	A	7.32	.0026	34.5	.3512	94.6	.1732	17.3
% Control	(31.7%)	MV	7.27	.0010	45.2	.2646	38.7	.4726	20.3
S.D.	.0681	F	7.19	.0006	62.2	.1732	28.1	.4000	23.0
Sample 5									
$\bar{X}$	.87	A	7.37	.0006	25.4	0.00	97.5	.1528	14.1
% Control	(27.9%)	MV	7.28	.0006	42.0	.2082	30.1	.4509	19.0
S.D.	.0400	F	7.19	.0015	58.2	.1155	20.6	.1528	21.5

Key: A = Arterial Blood
MV = Mixed Venous Blood
F = Femoral Venous Blood
S.D. = Standard Deviation

SUMMARY OF DATA FOR DOG 8 (34# - 15.5 Kg) 4/10/81

Cardiac Output			$\bar{X}$ pH	S.D.	$\bar{X}$ pCO_2	S.D.	$\bar{X}$ pO_2	S.D.	$\bar{X}$ $[HCO_3^-]$
Control									
$\bar{X}$	2.0	A	7.27	.0010	59.0	0.00	74.7	.0577	26.4
% Control	(100%)	MV	7.25	.0021	65.4	0.00	49.8	.1732	27.9
S.D.	.1086	F	7.26	.0012	66.3	.1732	55.8	.3215	28.5
Sample 2									
$\bar{X}$	1.45	A	7.31	.0021	50.3	0.00	98.8	.1155	24.8
% Control	(72.4%)	MV	7.26	.0025	62.9	.1155	45.0	.2881	27.7
S.D.	.0780	F	7.24	.0012	68.6	0.00	40.5	.1528	28.4
Sample 3									
$\bar{X}$	1.22	A	7.25	.0026	55.5	.1155	85.4	.1000	23.7
% Control	(61.1%)	MV	7.25	.0012	62.8	.2519	30.2	.1528	26.6
S.D.	.0877	F	7.19	.0017	75.9	.4042	28.5	.4509	28.0
Sample 4									
$\bar{X}$	.89	A	7.29	.0017	46.4	.2082	98.6	.4509	21.6
% Control	(44.7%)	MV	7.23	.0006	61.6	.0577	32.8	.5000	25.0
S.D.	.0321	F	7.14	.0015	79.3	.2517	20.7	.3055	26.4
Sample 5									
$\bar{X}$	.73	A	7.32	.0015	37.3	.0577	103.6	.0577	18.8
% Control	(36.3%)	MV	7.22	.0015	57.4	.2000	24.6	.3000	22.6
S.D.	.0115	F	7.11	.0015	77.9	.0577	18.1	.1528	24.1

Key: A = Arterial Blood
MV = Mixed Venous Blood
F = Femoral Venous Blood
S.D. = Standard Deviation

SUMMARY OF DATA FOR DOG 9 (35# - 15.9 Kg) 4/17/81

Cardiac Output			$\bar{X}$ pH	S.D.	$\bar{X}$ pCO_2	S.D.	$\bar{X}$ pO_2	S.D.	$\bar{X}$ $[HCO_3^-]$
Control									
$\bar{X}$	2.95	A	7.37	.0015	49.0	.1155	83.0	.3512	27.3
% Control	(100%)	MV	7.34	.0006	55.2	.1000	50.5	.3786	28.9
S.D.	.0451	F	7.35	.0010	54.5	.0528	51.2	.1000	28.8
Sample 2									
$\bar{X}$	2.63	A	7.29	.0015	57.4	.1000	78.3	.2082	26.6
% Control	(89.2%)	MV	7.25	.0017	66.9	0.00	45.7	.2000	28.6
S.D.	.0351	F	7.24	.0015	70.7	.1000	38.3	.3606	29.3
Sample 3									
$\bar{X}$	2.29	A	7.27	.0015	55.3	.2517	74.1	.1528	24.8
% Control	(77.6%)	MV	7.26	0.00	68.7	.1000	42.8	.1732	30.1
S.D.	.0351	F	7.24	.0006	71.3	.0577	38.5	.1732	29.4
Sample 4									
$\bar{X}$	1.63	A	7.32	.0015	45.0	.1732	86.5	.1528	22.4
% Control	(55.3%)	MV	7.25	.0021	63.4	.0577	38.4	.4509	27.2
S.D.	.1063	F	7.22	.0017	76.4	.1000	26.9	.3215	30.1
Sample 5									
$\bar{X}$	1.36	A	7.38	.0015	33.9	0.00	94.5	.1528	19.5
% Control	(46.1%)	MV	7.27	.0015	55.4	.1000	32.0	0.00	24.4
S.D.	.0322	F	7.16	0.00	80.6	.1732	22.1	.2517	27.5

Key: A = Arterial Blood
MV = Mixed Venous Blood
F = Femoral Venous Blood
S.D. = Standard Deviation

SUMMARY OF DATA FOR DOG 10 (50# - 22.7 Kg) 4/24/81

Cardiac Output			$\bar{X}$ pH	S.D.	$\bar{X}$ pCO_2	S.D.	$\bar{X}$ pO_2	S.D.	$\bar{X}$ $[HCO_3^-]$
Control									
$\bar{X}$	3.66	A	7.35	.0017	43.3	.2082	82.5	.4509	22.9
% Control	(100%)	MV	7.33	.0021	46.8	.0577	61.8	0.00	24.1
S.D.	.2601	F	7.32	.0021	50.6	.3000	49.6	.5033	25.1
Sample 2									
$\bar{X}$	2.54	A	7.36	.0021	40.8	.1000	86.1	.0577	22.3
% Control	(69%)	MV	7.32	.0026	48.7	.1528	50.8	.0577	24.3
S.D.	.0900	F	7.31	.0026	50.9	.3055	47.6	.2516	24.9
Sample 3									
$\bar{X}$	1.99	A	7.37	.0010	38.8	.0577	89.6	.4619	21.8
% Control	(54%)	MV	7.32	.0023	48.6	.0577	47.5	.5292	24.5
S.D.	.3414	F	7.30	.0010	52.4	.4041	42.8	.2645	25.1
Sample 4									
$\bar{X}$	1.57	A	7.37	.0006	35.7	.1155	78.6	.5508	19.9
% Control	(43%)	MV	7.31	.0023	48.3	.3215	35.5	.1732	23.6
S.D.	.4209	F	7.28	.0010	57.3	0.00	34.8	.3785	26.2
Sample 5									
$\bar{X}$	1.22	A	7.31	.0006	39.8	0.00	73.3	.2517	19.5
% Control	(33%)	MV	7.25	.0012	53.7	.0577	26.5	.1000	22.6
S.D.	.1808	F	7.30	.0023	50.1	.3055	37.7	.1527	24.0
Sample 6									
$\bar{X}$	1.22	A	7.31	.0005	39.8	0.00	73.3	.2516	19.5
% Control	(33%)	MV	7.25	.0011	53.7	.0577	26.5	.1000	22.6
S.D.	.1808	F	7.22	0.00	57.2	.4582	27.1	.1527	22.9

Key: A = Arterial Blood
MV = Mixed Venous Blood
F = Femoral Venous Blood
S.D. = Standard Deviation

AN ABSTRACT OF THE THESIS OF

JEANNIE JETT

For the MASTER OF NURSING

Title: THE USE OF FEMORAL VENOUS BLOOD IN ASSESSMENT OF ACID-BASE STATUS DURING STATES OF CARDIAC OUTPUT.

Approve: _____
Jack L. Keyes, Ph.D., Thesis Advisor

Arterial blood is widely used for acid-base assessment at the present time. Mixed venous blood has proved valuable in assessing tissue acid-base status. Problems and risks in obtaining mixed venous samples, however, have led to research for alternatives to mixed venous blood. Femoral venous blood has been proposed as a reliable substitute for mixed venous blood especially during decreased cardiac output. The following questions were asked in this study:

1) How does femoral venous blood-gas composition compare to mixed venous and arterial blood-gas composition during states of decreased cardiac output?
2) Does femoral venous blood-gas composition follow a predictable pattern during decreased states of cardiac output?
3) Can femoral venous blood be obtained consistently when cardiac output is reduced below 50% control cardiac output?

Ten mongrel dogs were subjects for this experiment. The dogs were anesthetized, intubated, and allowed to breathe room air. Cardiac output was progressively decreased in each dog by intermittent, controlled hemorrhage. Cardiac output was determined via the thermodilution technique.

Samples of arterial, mixed venous, and femoral venous blood were drawn simultaneously after each decrement of cardiac output. Blood-gas parameters of pH, pCO_2, and pO_2 were determined and $[HCO_3^-]$ was calculated from the Henderson-Hasselbalch equation.

Results showed that femoral venous blood is a reliable predictor for mixed venous pH, pCO_2, and $[HCO_3^-]$ during decreased cardiac output. Femoral venous pO_2 values can be followed as indicators of tissue hypoxia. Femoral venous blood-gas parameters also fall within the same category of acid-base disturbance as mixed venous blood during hemorrhage. Femoral venous blood had slightly higher pCO_2 and $[HCO_3^-]$ and slightly lower pH values than those of mixed venous blood. Arterial blood-gas parameters showed a pattern of compensated metabolic acidosis and mixed metabolic acidosis and respiratory alkalosis.

From the results it can be concluded that femoral venous blood does follow a predictable pattern during decreased cardiac output. Femoral venous blood can be used as a reliable predictor of mixed venous pH, pCO_2, and $[HCO_3^-]$. Venous blood provides a more accurate assessment of tissue acid-base status especially during decreased cardiac output. And last, femoral venous blood can be obtained consistently at low values of cardiac output.