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The University of Arizona M.S. 1985

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MEASUREMENT OF TOE TEMPERATURE AS AN EARLY INDICATOR OF ALTERATIONS IN PERIPHERAL PERFUSION

by

Gail Linnea Flodquist

A Thesis Submitted to the Faculty of the

COLLEGE OF NURSING

In Partial Fulfillment of the Requirements
For the Degree of

MASTER OF SCIENCE

In the Graduate College

THE UNIVERSITY OF ARIZONA

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This thesis has been approved on the date shown below:

Alice J. Longman

ALICE J. LONGMAN
Associate Professor Nursing

July 24, 1985
Date

This thesis is dedicated to my husband, Ron, and to my parents, Theodore and Linnea Flodquist. They have taught me to value questioning, to respect wisdom, to take pride in effort . . . . . and to temper success and disappointment with perspective and humor.

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ABSTRACT

Measurement of skin temperature of the great toe has been suggested as a means to assess peripheral perfusion. This descriptive study examined the changes in toe temperature and the relationship of toe temperature changes to current monitoring parameters.

Six critically ill subjects were studied. Toe temperatures were recorded every two hours along with other physiologic parameters. Descriptive statistics and case study analysis were used to examine the data.

Differences in mean toe temperature were seen between survivors and non-survivors and between those subjects with complicated and uncomplicated sepsis. Several factors which were associated with major changes in toe temperature were discussed. There were indications that toe temperature monitoring may be useful in patient assessment, especially if invasive monitoring techniques are not available. Further study is needed to establish the reliability of toe temperature monitoring as an addition to physiologic assessment.

CHAPTER I

INTRODUCTION

Shock, a state of "inadequate blood flow to vital organs or the inability of the body cell mass to metabolize nutrients normally" (MacLean, 1977, p. 65) is a serious complication that may develop as a result of severe illness or injury. In critically ill patients in surgical intensive care units, shock may occur following trauma with severe hemorrhage or tissue damage, after major surgery in patients with pre-existing health problems or risk factors and in patients with severe infection. Shock is a very serious complication, often progressive and life-threatening.

Shock is a complex physiologic process described as a cellular state of hypoperfusion rather than simply a blood pressure defect. Once thought to begin with the onset of hypotension, it is now known that shock begins with compensatory mechanisms to maintain adequate perfusion at the cellular level. The earliest clinical signs of shock reflect initial compensatory changes. Unless the precipitating or primary state is controlled or reversed, the shock state may progress beyond the individual's ability to compensate. Perfusion becomes inadequate to support cellular function and the late signs of shock indicating decompensation and organ dysfunction appear.

Shock is most effectively treated when identified early. The initial signs and symptoms of shock reflect changes in perfusion and the compensatory mechanisms that are activated to sustain circulation

and oxygenation. Neural and hormonal stimulation act on the heart to increase the rate and strength of contraction and, peripherally, to redistribute blood toward the central circulation to preserve cerebral and coronary perfusion (Thal, Brown, Hermeck & Bell, 1971). This early activity may be seen clinically as a slight increase in heart rate, slight change in alertness, change in skin temperature of the extremities and decreased urinary output.

Nurses caring for critically ill patients make frequent assessments of patients' status to evaluate response to therapy and to identify trends that may signify developing complications. Most aspects of patient assessment are done objectively and can be measured. Heart rate and urinary output are measurable. Neurological assessment, while partly subjective, is carried out through established guidelines that objectively trace trends and indicate changes. Evaluation of peripheral perfusion is often subjective. Touch is used to judge relative warmth of extremities and characteristics of pulses.

Measurement of skin temperature of the toe is a means of objective assessment of peripheral perfusion (Joly & Weil, 1969). Toe temperature has been shown to be a prognostic indicator of clinical status and response to treatment in patients in shock due to various etiologies (Facey, Weil & Rosoff, 1966; Henning, Weiner, Waldes & Weil, 1979; Joly & Weil, 1969). Matthews, Meade and Evans (1974b) described toe temperature changes as early indicators of complications following open-heart surgery. However, little information is available concerning the value of toe temperature monitoring as an early indicator of shock due to other causes.

Skin temperature is primarily dependent upon the degree of vasoconstriction or dilation of surface vessels. While normally a part of the thermoregulatory mechanism, skin temperature also reflects peripheral perfusion. The compensatory mechanisms that redistribute blood flow away from the skin may be indirectly evaluated by skin temperature as vasoconstriction produces a decrease in temperature. All these principles suggest that trends in toe temperature measurements, rather than touch, may be useful additions in monitoring critically ill patients.

Research Questions

What changes occur in the skin temperature of the great toe in critically ill patients in an intensive care unit?

What is the relationship of changes in the skin temperature of the great toe to other hemodynamic parameters (heart rate, blood pressure, urine output and core temperature) currently used to monitor critically ill patients in an intensive care unit?

Purpose of the Study

The purpose of the study was to describe changes in the skin temperature of the great toe in critically ill patients and to examine trends in toe temperature relative to other established monitoring parameters. The results of this study should be helpful in evaluating the reliability and usefulness of skin temperature measurements of the toe in hemodynamic monitoring.

Significance of the Study

Physical assessment of the critically ill patient is an important aspect of intensive care nursing. The assessment includes frequent or continuous monitoring of physiologic function. Such information is used to evaluate the patient's current status, response to therapy and to identify developing complications.

As with many complications, shock states are most effectively treated when detected in early phases. Each progressive stage requires more agressive and immediate therapy. Later shock states are difficult to treat successfully and may result in death. The importance of early detection of trends indicating a change in perfusion and cardiovascular status cannot be overemphasized.

Recognition of early signs of shock is clinically difficult as early signs may not be specific or measurable. Changes are subtle and may be attributed to other factors. For example, a change in the level of consciousness in the critically ill patient, an early sign of shock, may be interpreted as a response to hypoxia, fatigue or sleep deprivation. An increase in heart rate is also a nonspecific indicator. The most reliable information in the assessment of the critically ill is usually obtained by invasive monitoring techniques. Invasive monitoring does pose hazards and is not always available for the duration of time that a patient may be at risk for developing shock.

The significance of this study of skin temperature of the toe is to provide additional information about the reliability and usefulness of a non-invasive monitoring technique. This study may provide

nurses, who need objective and measurable information, with a new assessment technique.

Conceptual Framework

The conceptual framework for this study was based on two aspects of adaptive physiology: shock physiology and thermoregulation. The first section describes the anatomy and physiology of the cutaneous circulation, the process of thermoregulation and the relationship of skin circulation to the physiologic changes that occur during shock states. The second section is a general discussion of shock which includes the compensatory physiology of shock states, the stages of shock and a four-category classification of shock based on hemodynamic etiology.

Cutaneous Circulation and Thermoregulation

Anatomy of the Skin. As described by Jensen (1976), the skin is composed of three anatomical layers: the epidermis, dermis and hypodermis. The epidermis is the outermost layer and does not contain a vascular network. The second layer contains arterioles, venules and capillaries that serve a nutritive function. Similar to the microcirculation in other tissues, this network brings oxygen and substrates to skin tissues and removes metabolic waste.

The hypodermis contains larger arteries and veins in a more complex arrangement. This layer has venous plexuses with sympathetic nervous innervation throughout the body and special arteriovenous (A-V) anastomoses found in certain areas. The A-V anastomoses are

also supplied with sympathetic nerve fibers and are found in the palms of the hands, soles of the feet, fingers, toes, lips, nose and ears (Berne & Levy, 1981; Guyton, 1981; Jensen, 1976). Sympathetic stimulation with the release of norepinephrine causes vasoconstriction, an alpha-adrenergic response, in the venous plexuses and A-V anastomoses (Jensen, 1976).

Physiology of the Cutaneous Circulation. The primary functions of the cutaneous circulation are tissue nutrition and body temperature regulation. Because nutritional requirements of skin are low, only a small portion of the circulatory volume is needed for this function. Most of the cutaneous circulatory flow is related to mechanisms involved in maintaining body temperature. Blood flow through the skin is highly variable ranging from 1 ml to 150 ml/100 gms of skin/minute (Jensen, 1976). Normally, total blood flow to the skin tissues is approximately 300 ml/minute. The flow can increase to 2.1 liters per minute with maximal vasodilation constituting a much larger fraction of total cardiac output, far in excess of the metabolic needs of the skin tissue (Jensen, 1976).

Cutaneous circulation is regulated by both local and central mechanisms. Local regulation is a response to tissue metabolic needs. Central control is exerted by the sympathetic nervous system, primarily via the hypothalamus as a part of the thermoregulatory mechanism. In contrast to cerebral and coronary blood flow which are largely locally controlled, cutaneous circulation is primarily influenced by central mechanisms. Arteriovenous anastamoses are thought to be

centrally controlled and do not participate in local regulation (Berne & Levy, 1981).

Thermoregulation. The thermoregulation is defined by Jensen as the "homeostatic regulation of normal body temperature within narrow limits" (1976, p. 994). Heat is continually produced by the body as a result of cellular metabolism. Internal temperature must be maintained at a fairly constant level for optimal metabolic and biochemical function.

A core or rectal temperature of 37.6° C. or oral temperature of 37° C. is considered average normal body temperature (Guyton, 1981). The body tolerates slight variation, within 2° C., without major physiologic changes. Temperature variation is found among individuals and at different times of the day. Deviation from normal begins to impair central nervous system function. Hyperthermia of 44 to 45° C. may cause death (Jensen, 1976) as may body temperatures of 28° C. and lower (Dembert, 1982).

The primary mechanism for temperature regulation is to move heat from the body's core to its surface with the circulatory system providing bulk transport of heat. Cutaneous blood flow determines the potential for heat loss. Heat is released to the environment by four mechanisms: radiation, the loss of infrared heat rays; conduction, the direct transfer to another object; convection, movement of heat by air currents; and evaporation, the cooling effect of water leaving the skin surface (Jensen, 1976). The effectiveness of these mechanisms is influenced by the ambient temperature.

Skin temperature varies more than core temperature due to ambient exposure and changes in circulation. Usually a value between core and ambient temperatures, skin temperature will approach core temperature with vasodilation. Vasoconstriction of the cutaneous vessels decreases the temperature of the skin near to the ambient temperature range (Jensen, 1976).

The thermoregulatory center is located in the hypothalamus. Heat and cold sensitive neurons detect core temperature changes and also receive input from peripheral temperature receptors. Two separate structures of the hypothalamus are involved in temperature control: the preoptic area of the anterior hypothalamus and the posterior hypothalamus. The anterior portion is primarily concerned with heat loss while the posterior controls heat production and conservation (Jensen, 1976).

Hyperthermia, sensed by the anterior hypothalamus, causes cutaneous vessels to dilate allowing increased blood flow and heat transfer to the skin (Guyton, 1981). Both arterioles and the A-V anastamoses dilate as a result of sympathetic adrenergic inhibition (Berne & Levy, 1981).

In contrast, the posterior hypothalamus regulates heat production and conservation. Receptors sensitive to cold temperatures located in the skin and spinal cord stimulate the posterior hypothalamus to increase heat production and to decrease heat loss through the skin by causing peripheral vasoconstriction (Guyton, 1981).

Cutaneous Circulation During Stress. The cutaneous vessels respond to circulating catecholamines as well as to direct sympathetic

adrenergic stimulation. Changes may be seen in cutaneous blood flow in situations that cause a general activation of the stress response. Stressors, such as exercise, anxiety and hemorrhage, cause an increase in sympathetic activity and catecholamine release from the adrenal medulla (Guyton, 1981). Epinephrine and small amounts of norepinephrine cause vasoconstriction in the cutaneous vascular bed (Berne & Levy, 1981).

The A-V anastamoses are extremely sensitive to circulating catecholamines (Berne & Levy, 1981). Vasoconstriction of the A-V anastamoses markedly reduces blood flow into the venous plexuses lowering the skin temperature of those regions (Guyton, 1981). Increased sympathetic tone causes the venous capacitance vessels to constrict reducing the storage volume for blood in the skin and making additional blood available for circulatory support in other areas of the body (Berne & Levy, 1981). Maximal constriction of cutaneous vessels can add 5 to 10 percent to the circulating blood volume (Jensen, 1976).

Physiology of Shock States

Compensatory Physiology of Shock States. The ability of the circulatory system to maintain adequate perfusion under variable conditions is made possible by the system's mechanisms to detect change and respond appropriately. Aspects of the adaptive regulatory mechanisms are discussed in this section.

The heart is innervated by both sympathetic and parasympathetic fibers. Sympathetic stimulation of cardiac beta-receptors increases heart rate, speed of conduction and strength of contraction: positive

chronotropic and inotropic effects. The result of enhanced cardiac activity is an increase in cardiac output (Berne & Levy, 1981).

The peripheral vasculature is influenced by both local and external regulatory mechanisms. The small precapillary structures change diameter to regulate blood flow according to local tissue needs (Jensen, 1976). The stimulus for the change is thought to be a vasodilator substance released by tissue metabolic activity. Oxygen, carbon dioxide and hydrogen ion concentrations are known to affect vessel diameter but do not fully explain this process. Other metabolic factors are believed to participate in local regulation. Their effects may differ in various vascular beds (Berne & Levy, 1981).

External regulation of peripheral vessels is provided by neural and humoral sources. These vessels have both vasoconstrictor and vasodilator sympathetic innervation. Sympathetic stimulation with release of norepinephrine causes constriction of arterioles reducing flow and increasing peripheral resistance, an alpha-adrenergic effect (Jensen, 1976). Sympathetic stimulation also affects the venous system. The primary effect is reduction of capacitance and increased venous return to the heart (Guyton, 1981).

Peripheral vessels are also affected by humoral factors. Jensen (1976) described these effects as less important in normal physiology, but very important in acute stress such as shock.

The complex regulation of the cardiovascular system is integrated through nervous system reflexes and hormonal activity. The action of these reflexes and the role played by hormonal influences are discussed in the following section.

Baroreceptors provide an immediate adaptive response to decreased blood pressure in shock. The baroreceptors, stretch receptors located in the aortic arch and carotid sinus, send impulses to the vasomotor center in the medulla. The vasomotor center controls peripheral vessels in a state of partial constriction and affects heart rate by vagal activity. Hypotension reduces stimulation of the baroreceptors resulting in fewer impulses to the vasomotor center. The important effects of the baroreceptor response to hypotension are summarized by Guyton (1981) as arteriolar constriction which increases peripheral resistance, venous constriction which increases venous return and increased heart rate. These effects increase systemic arterial blood pressure by increasing cardiac output and peripheral resistance.

Chemoreceptors located in the aorta and carotid bodies perform a function similar to the baroreceptors but respond to changes in blood chemistry. When mean systemic blood pressure falls below 60 mmHg., these receptors respond to the decrease in oxygen supply caused by hypoperfusion (Berne & Levy, 1981). The chemoreceptors also respond to decreased pH or increased carbon dioxide levels (Guyton, 1981).

A third type of pressure reflex important in shock physiology is the central nervous system (CNS) ischemic response. Activated when mean systemic blood pressure falls below 40 mmHg., this response is the result of hypoperfusion of the vasomotor center itself. The CNS ischemic response is massive sympathetic discharge resulting in marked peripheral vasoconstriction and cardiac stimulation (Berne & Levy, 1981). Guyton (1981, p. 253) refers to this response as the "last

ditch stand" to raise systemic blood pressure and protect vital cerebral perfusion.

Hormonal activity plans an important role in cardiovascular support under stress. Guyton (1981) identified three hormonal systems that are activated in hypotensive states: norepinephrine-epinephrine, renin-angiotensin-aldosterone and vasopressin.

Sympathetic stimulation initiated by the vasomotor center affects the adrenal medulla causing a release of epinephrine and small amounts of norepinephrine into the general circulation. These circulating hormones have similar effects on cardiac and peripheral vascular function as seen with direct adrenergic stimulation of neural regulation. Specifically, both hormones cause vasoconstriction in the skin (Berne & Levy, 1981). Requiring several minutes to become active, these hormones augment the vasoconstrictive neural response to hypotension (Guyton, 1981).

Renin, an enzyme released by the kidney in response to hypotension, acts to form angiotension I which is converted to angiotensin II in the lung. Angiotensin, a powerful vasoconstrictor, acts on arterioles to raise blood pressure (Laragh, 1980) and veins to increase venous return (Guyton, 1981). Angiotensin increases fluid volume by a direct effect on the kidney to conserve sodium and water and stimulates the adrenal cortex to secrete aldosterone which also causes sodium retention in the kidney (Laragh, 1980).

The third hormonal system, vasopressin, is released from the posterior pituitary in response to hypovolemia and hypotension.

Vasopressin has a direct vascular effect of vasoconstriction and also increases water reabsorption in the kidney (Rothstein, 1979). Together, these hormones provide a sustained vasoactive effect on peripheral vessels and contribute to early signs of shock.

Another mechanism contributing to maintenance of intravascular fluid volume and restoration of normal blood pressure is the fluid shift which occurs in the microcirculation. Capillary fluid dynamics, which largely depend on hydraulic and oncotic pressures and capillary permeability, favor absorption of fluid from the interstitium in response to fluid loss or hypotension (Zweifach & Fronek, 1975). Such fluid movement is an important factor in restoring intravascular volume after mild to moderate fluid loss (Chaudry & Baue, 1982).

Stages of Shock. Guyton (1981) described three stages of shock that apply to the severity and progression of the shock state, nonspecific to etiology. The progression of the stages is largely based on feedback systems involved with the compensatory mechanisms.

The first stage, non-progressive or compensated shock, is severe enough to impair perfusion and activate the cardiovascular compensatory mechanisms. This first stage involves negative feedback. Regulatory mechanisms are able to compensate for the precipitating cause of the shock state and maintain perfusion at adequate levels (Guyton, 1981).

Positive feedback characterizes the second stage: progressive shock. Effects of the shock state overwhelm the compensatory mechanisms causing further deterioration. This creates a cycle in which "each increase in the degree of shock causes a further increase in the shock" (Guyton, 1981, p. 337).

Progressive shock involves cardiovascular deterioration. The structures which support compensatory mechanisms are themselves impaired by the inadequate perfusion. The heart muscle is hypoperfused and begins to fail. Similarly, the vasomotor center of the brain stem loses its ability to coordinate the supportive sympathetic nervous system activity. The slowed movement of blood allows small clots to form and obstructs flow through the small vessels. Walls of capillaries, damaged by hypoxia, show increased permeability allowing fluid to leak out of the vascular system into surrounding tissues (Guyton, 1981).

Important cellular changes are seen as the result of severe shock. The sodium/potassium "pumps" in the membrane deteriorate allowing sodium and water to enter the cell causing the cell to swell. Intracellular structures are damaged releasing toxic contents and vital cellular activity stops (Guyton, 1981).

A final factor in this second stage of shock is acidosis. Inadequate perfusion forces conversion to anaerobic metabolism with lactic acid production. Carbon dioxide accumulates as another result of the hypoperfusion further contributing to the acidosis (Guyton, 1981).

The point at which progressive shock becomes irreversible is debated and difficult to define. There seems to be a point at which therapy is no longer able to control and reverse the shock cycle. Individuals will die in spite of aggressive treatment. As explained by Guyton (1981), this situation occurs when tissue damage is irreversible. Guyton (1981) pointed to the energy depletion of prolonged anaerobic metabolism and cardiac failure as two primary causes of

irreversibility. Others have suggested evidence of cellular swelling and impairment of intracellular function as being the turning point (Chaudry & Baue, 1982).

Classification of Shock. Traditionally, classification of shock has been based on etiology: for example, neurogenic, septic, anaphylactic, hemorrhagic. Weil (1977) developed a four-category classification system for shock which links etiology to the hemodynamic changes involved. The categories are cardiogenic, obstructive, hypovolemic and distributive. Specific etiologies are listed with each category. While this classification identifies the primary defect, the progression of shock may involve characteristics of the other types of shock (Weil & Henning, 1979). This section outlines the physiology of shock involved in each category with emphasis on hypovolemic and distributive shock states.

Weil (1977, p. 182) defined cardiogenic shock as a "condition in which the cardiac pump is impaired to the extent that it cannot competently circulate available volume." Weil listed the underlying etiologies as myocardial infarction, cardiac failure and arrhythmias.

Hypotension from cardiac failure activates the compensatory mechanisms of vasoconstriction, tachycardia and fluid retention (Andreoli, Fowkes, Zipes & Wallace, 1975). While normally protective in early shock, these mechanisms may aggravate shock due to pump failure. Arterial vasoconstriction increases afterload increasing cardiac work. Fluid retention and venous constriction may increase preload beyond benefit (Cohn & Franciosa, 1977a). Compensatory tachycardia may increase

cardiac oxygen demand while impairing oxygen supply. These effects are poorly tolerated by the damaged heart and contribute to a cycle of ischemia and failure (Cohn & Franciosa, 1977b).

Weil (1977) defined obstructive shock as originating from a physical impediment to blood flow. He listed five anatomic sites where this may occur: vena cava, pericardium, cardiac chambers, pulmonary circuit and the aorta.

Hypovolemic shock is a state in which "the volume contained within the intravascular compartment is inadequate for purposes of perfusion" (Weil, 1977, p. 182). Hypovolemia may result from two types of fluid losses, exogenous and endogenous. Exogenous fluid loss may result from blood loss due to hemorrhage, plasma loss due to burns or fluid and electrolyte losses from dehydration. Endogenous fluid loss may be due to inflammation, trauma, or anaphylaxis. In either case, the losses are reflected in a decrease in available circulating volume relative to the vascular space (Weil, 1977).

The compensatory mechanisms are usually able to maintain blood pressure at normal levels in the face of acute blood loss up to 20% total volume (Rothstein, 1979). The early redistribution of blood flow away from skin, muscle, extremities and the mesenteric vascular bed is life-sustaining in support of the vital organs, but produces an abnormal distribution of blood flow in the microcirculation (Chaudry & Baue, 1982).

The pathologic effects of shock eventually reverse the direction of fluid movement in the capillary bed (Zweifach & Fronek, 1975). Arteriolar constriction promotes fluid loss into the interstitium

(Chaudry & Baue, 1982). Precapillary sphincters become unresponsive to sympathetic stimulation after a few minutes of anoxia. Venules are more resistant to hypoxic effects and maintain constrictive tone after the arterioles have lost sympathetic responsiveness. The increased venous tone coupled with arteriolar dilatation increases capillary pressure promoting the formation of tissue edema (Webb & Brunswick, 1982) and aggravates the hypovolemic state (Zweifach & Fronek, 1975). Histamine and other vasoactive substances increase capillary permeability adding to fluid loss. The resultant increase in blood viscosity promotes red blood cell and platelet aggregates which further obstructs flow through the microcirculation (Chaudry & Baue, 1982).

The continued redistribution of blood flow results in metabolic acidosis due to changes in oxygen transport. Vasoconstriction reduces oxygen availability forcing tissues to change to anaerobic metabolism with lactate accumulation (Shoemaker, 1982). Cells may not convert to normal metabolism even after blood volume has been restored (Chaudry & Baue, 1982).

Weil's category of distributive shock results from "impairment of perfusion not because of hypovolemia or cardiac failure but because of faulty distribution of blood within the peripheral blood vessels such that the capillary perfusion bed is inadequately perfused" (1981, p. 93). The location of the circulatory defect distinguishes this category from the others as it occurs peripherally in small arteries and veins.

Authors disagree as to the specific features of distributive/septic shock. Weil divided this category into high or normal resistance

with increased capacitance and low resistance with arteriovenous shunt. The first subcategory includes gram-negative sepsis, barbituate intoxication and neurogenic shock. Capacitance is increased and arterial resistance is increased or normal. Low resistance shock is most characteristic of gram-positive cocci infections, pneumonia and peritonitis (Weil & Henning, 1979).

Guyton (1981) summarized the common characteristics of septic shock as fever, vasodilation, high cardiac output, sludging of blood and coagulopathy. The high cardiac output is thought to result from local vasodilation due to local infection, the increased metabolic requirements of sepsis and generalized vasodilation due to fever and thermoregulatory mechanisms. Early septic shock may appear only as a febrile episode. Later, perfusion defects become more obvious and in the final stages, septic shock resembles the progressive failure seen in classic shock states.

Weil and Henning (1979) observed differences in the characteristics of septic shock depending on the causative organism. Shock due to gram-positive organisms involved increased vascular permeability with fluid loss into surrounding tissues and arterial vasodilation due to inflammation. Resistance was low with increased cardiac output, but there was early evidence of perfusion failure. Lactate increased and oxygen extraction decreased. These metabolic changes were attributed to arteriovenous shunting as blood is carried through non-nutritive channels depriving tissues of adequate oxygen.

In contrast, gram-negative sepsis often presented with high fever, chills and hypotension but not necessarily perfusion failure.

Fever and arterial dilatation caused warm extremities. This early "pyrogenic" phase did not show increased lactate indicating that perfusion was still adequate. The "warm shock" of gram-negative sepsis may progress to classical shock with peripheral constriction and cold, clammy skin, decreased urinary output and acidosis (Weil & Henning, 1979).

Wilson, Sarver and LeBlanc (1971) did not find differences in septic shock according to organism, but did observe high and low flow shock states. The differences were attributed to the presence of hypovolemia and cardiac insufficiency.

Schumer (1982) described the course of septic shock as beginning with a hyperdynamic phase. Systemic vascular resistance fell and cardiac output was increased. Eventually, hypovolemia developed from a gradual loss of fluid volume. Septic shock then entered a hypodynamic phase of increasing resistance and decreased cardiac output.

Whatever the mechanism, septic shock appears to progress to a low-flow state with increased arterial resistance, venous pooling and cardiac depression. Low-flow septic shock is associated with higher mortality rates (Hinshaw, 1982).

Summary: Conceptual Framework for the Study

The major components of the conceptual framework for this study are depicted in the following model (Figure 1). The right portion of Figure 1 describes the process of thermoregulation. Core and ambient temperature are major thermoregulatory influences. In normal adaptive physiology, a change in core or ambient temperature activates

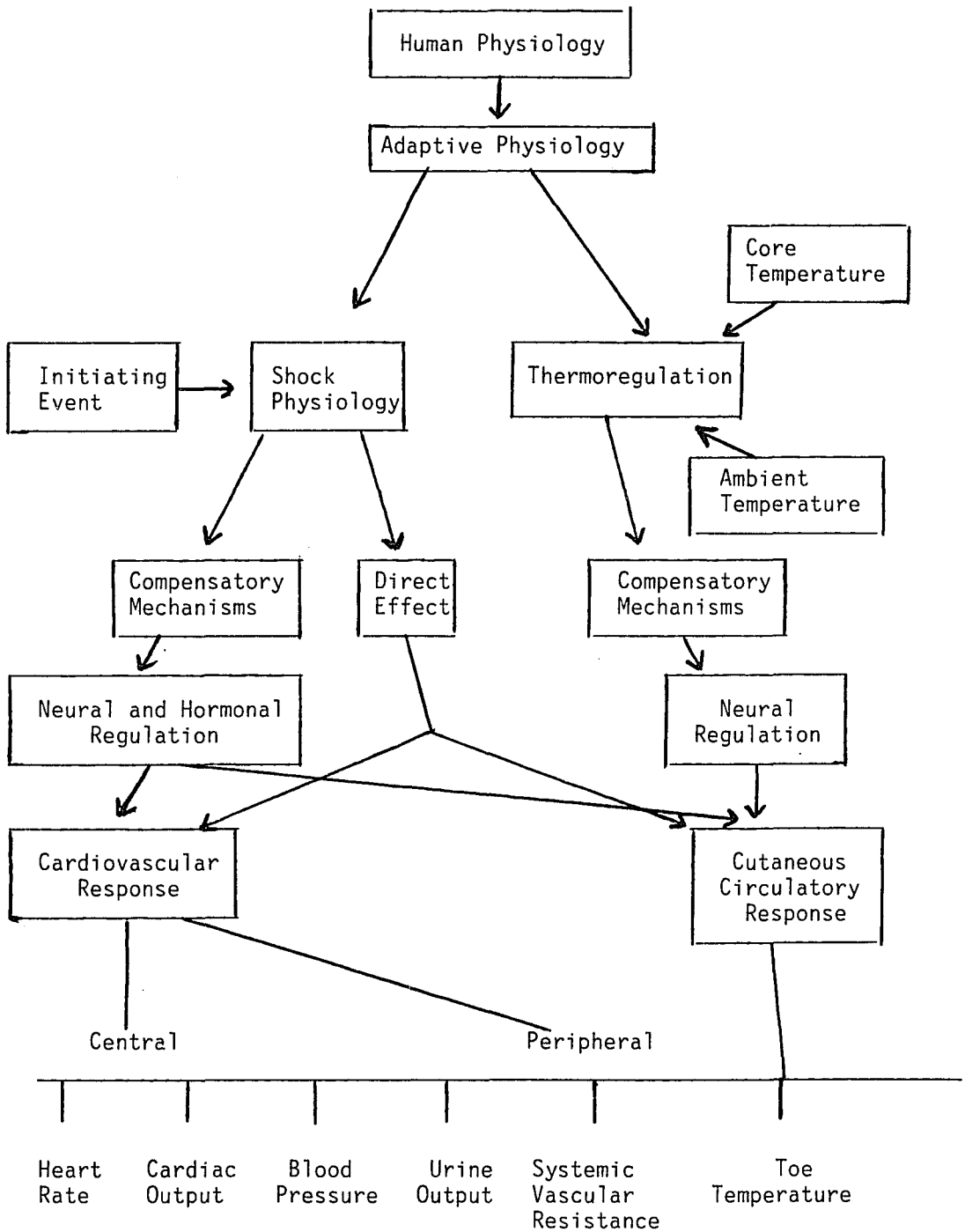

Figure 1. Model for Conceptual Framework

compensatory mechanisms mediated by the nervous system. Neural regulation controls heat loss by cutaneous vasoconstriction or dilation. The cutaneous blood flow can be indirectly measured by skin temperature.

The left portion of the model describes shock physiology. An initiating event, such as hemorrhage or severe infection, is the primary influence. In an effort to maintain adequate perfusion, compensatory mechanisms are activated via neural and hormonal pathways. Integrated neural and hormonal regulation affect the cardiovascular response. Heart rate, cardiac output, blood pressure, urine output and systemic vascular resistance are indicators of the cardiovascular state.

In a state of abnormal perfusion or shock, thermoregulation is no longer the sole influence on cutaneous circulation. Cutaneous vessels are also affected by the neural and hormonal mechanisms activated by the shock state. This provides the linkage between toe temperature and the other hemodynamic parameters.

The mid-portion of the model is a direct effect of the shock state which may be an additional factor. Independent of the compensatory mechanisms, direct influences may affect central and peripheral vascular function.

Summary

Shock is a serious and potentially life-threatening complication of severe illness or injury. Early detection is important in the successful treatment of shock. Nurses caring for critically ill patients use a variety of assessment tools; the most reliable of these methods

are objective. Measurement of toe temperature has been recommended as a method to objectively assess peripheral perfusion.

CHAPTER II

REVIEW OF THE LITERATURE

The association of cool extremities with critical illness is one that has long been observed. In a review of the historical appreciation of peripheral skin temperature, Ross, Brock and Aynesly-Green (1969, p. 880) cited a reference by Adams in The Genuine Works of Hippocrates (1849) in which Hippocrates advised that "it is a bad symptom when the head, hands, and feet are cold, while the belly and sides are hot, but it is a very good symptom when the whole body is equally hot." This chapter focuses on clinical studies and reports describing the relationship of skin temperature to blood flow, the relationship of toe temperature changes to other established monitoring parameters, toe temperature changes during shock and recommendations for early detection of shock and the use of toe temperatures.

Relationship of Skin Temperature to Blood Flow

The precise relationship of skin temperature to local blood flow has been difficult to establish. Matthews, Meade and Evans (1974a) identified four factors influencing skin temperature: environmental temperature, blood temperature, blood flow to the area and local heat production. Local heat production due to muscle or metabolic activity is minimal in the digits of the hands and feet and simplifies interpretation of temperature - flow relationships in these areas (Burton,

1939; Matthews et al., 1974a). Ambient and core temperatures remain important factors to be considered in the study of skin temperature of the toe.

Felder, Russ, Montgomery and Horwitz (1954) studied the relationship of blood flow to toe temperature using plethysmography and thermocouples under carefully controlled conditions with normal subjects. They found a correlation between blood flow and skin temperature ranging from 3 ml/100 ml/min at 24° C. skin temperature to greater than 30 ml/100 ml/min at 32° C. skin temperature. However, reviewing the results of similar flow/temperature studies, Woodcock (1975) concluded that influencing factors prevent precise correlation of skin temperature to blood flow. The validity of application of findings reported with normal subjects to patients in shock is also questioned (Joly & Weil, 1969).

Despite the difficulties of quantitative equation of flow and temperature, several researchers have proposed that toe temperatures do provide qualitative indication of trends in perfusion and support this view with the clinical studies which follow.

Relationship of Toe Temperatures to Other Parameters

Joly and Weil (1969) compared skin temperature at five sites with the cardiac output of patients in shock. Toe temperature showed the highest correlation ($r = 0.71$). Correction for room temperature, toe minus ambient temperature gradient, increased the correlation with cardiac output slightly ($r = 0.73$). They also reported a correlation between toe temperature and cardiac index. When the cardiac index

was less than 2 L/min/m^2, toe temperature was less than 27° C. Toe temperatures greater than 29.2° C. were associated with cardiac index in excess of 2 L/min/m^2.

Facey et al. (1966) reported an inverse relationship between toe temperature and systemic vascular resistance in patients with shock due to pancreatitis. On admission, these patients had decreased urine output, toe temperature, cardiac output, blood pressure and level of consciousness and an increased peripheral resistance. Improvement after fluid therapy was evidenced by improved mental status, normal urine output and a close relationship between increased toe temperature and decreased vascular resistance.

Henning et al. (1979) reported an inverse relationship between toe temperature and blood lactate levels. Lactate has been described as a reliable indicator of the state of peripheral perfusion (Weil & Afifi, 1970). Increases in the toe minus ambient temperature gradient were closely associated with decreases in lactate. Patients with shock who failed to show increases in the toe minus ambient gradient exhibited increases in lactate, decreases in cardiac index and decreased arterial blood pressure.

Toe temperature changes have been correlated to urine output (Facey et al., 1966). Urinary output is a strong indicator of renal perfusion but may be unreliable in cases of severe shock due to resultant renal insufficiency (Ross et al., 1969). Matthews et al. (1974b) concluded that toe temperatures can aid in the interpretation of renal function. In the presence of normal toe temperature, low urine output

reflects renal insufficiency while a pre-renal cause is likely when oliguria is seen with low toe temperature.

Several researchers have discussed the relationship of peripheral skin temperature to core temperature. Ibsen (1967) concluded that in shock patients with both low skin temperature and low core temperature, the shock state was so severe that metabolism was not sufficient to generate body heat. In contrast, patients in shock with high core temperature and low toe temperature have impaired perfusion due to vasoconstriction that prevents heat loss through the skin. He observed that the two temperatures may differ as much as 20° C. Brock, Skinner and Manders (1975) also described this relationship between core temperature and peripheral skin temperature. With normal thermoregulation, fever should result in vasodilatation with warm skin. Fever associated with low toe temperature is an indication of abnormal vasoconstriction. Rising core temperature may, in fact, be the result of impaired heat loss.

Toe temperature has been used as a predictive indicator of survival or mortality in patients with shock of various types. Joly and Weil (1969) reported significant differences in toe temperatures between survivors and non-survivors. Initial toe temperature on admission to the intensive care unit for survivors averaged 28.2 ± 0.3° C. Non-survivors were found to have toe temperature of 26.2 ± 0.2° C. These researchers found that increases in toe temperature after admission indicated an improved prognosis. Ruiz, Weil and Carlson (1979) concluded that toe temperature was valuable in predicting ultimate survival of patients in shock receiving dopamine therapy. While

there was no significant difference in toe temperature on admission between the ultimate survivors and non-survivors, there was a significant difference in toe minus ambient gradients after therapy was started. Toe temperature usually increased more than 2° C. above room temperature in those who survived. In patients who died, toe temperature often remained equal to or less than room temperature.

Matthews et al. (1974a) described a typical "warm-up" pattern for toe temperatures in patients after open heart surgery. This pattern consisted of three stages. The "cold stage" immediately after surgery had a lower normal limit of 23° C. An "intermediate zone" was evidenced by the onset of rapid warming of toe temperature. In non-ventilated patients this stage began 4.6 ± 2.5 hours post-operatively while ventilated patients showed a slightly delayed warming at 5.8 ± 2.6 hours. The reason for the difference in these two groups was not determined. Eventually, patients reached a "warm plateau" stage at 34° C. These researchers developed a nomogram for toe temperature changes defining time periods and temperatures of normal recovery.

In a second article, Matthews et al. (1974b) described 15 patients from a series of 131 post-open heart surgical patients who failed to show the normal warm-up pattern. The mortality rates of the two groups were significantly different. Eight of the 15 patients (53%) with an abnormal pattern died while the mortality of patients with normal temperature pattern was 7 of 116 (6%). Seven of the 15 patients with abnormal warm-up pattern showed no other signs of circulatory problems. The other eight patients also had low urine output

and five were hypotensive. The instances in which toe temperature was the only indication of problems were attributed to early cutaneous vasoconstriction that was sufficient to support more vital renal and cerebral function.

Toe Temperature Changes in Specific Shock States

Ibsen (1967) reported an experiment conducted with a normal subject in which a blood loss of 500 cc produced a skin temperature drop of 8° C. in the thumb without changes in blood pressure. Ibsen further observed that the thumb warms before the feet and that when the feet returned to normal temperature, the patient was recovered from shock.

Spitzer and Brock (1968) reported a case in which divergence of core and toe temperature indicated hypovolemia as the cause of shock in a post-operative patient with serious neurological complications. They stated that without the knowledge of the falling peripheral temperature, the rising core temperature would have been attributed to brain stem dysfunction.

Ross et al. (1969) reported cases in which prolonged vasoconstriction following open heart surgery indicated intravascular volume deficit. In one case, the patient developed fever of 41° C. following surgery with a decrease in skin temperature by 10° C. They concluded the cause of fever was not infection, but rather impaired heat loss due to compensatory vasoconstriction.

Henning et al. (1979) investigated toe temperatures as an indicator of perfusion in patients with shock due to various etiologies.

The hypovolemic group showed the lowest toe temperature and highest lactate levels on admission. Improvement with therapy was associated with increased toe temperature and decreased lactate. The toe minus ambient temperature gradient increased an average of 5.5° C. in survivors. Those patients who died showed an increased temperature gradient of 2.4° C. Patients who died showed improved cardiac index to normal levels, but toe temperatures remained low and lactic acidosis persisted indicating continued perfusion failure.

Analysis of bacteremic patients showed most to have a normal or high cardiac output. In patients who died, cardiac output remained high or normal, but toe temperature remained low (average toe minus ambient gradient increased only 0.3° C.) and lactic acidosis persisted. These results were attributed to arteriovenous shunting with abnormal distribution of blood flow. In contrast, patients who survived showed an average increase in toe minus ambient temperature gradient of 5.7° C. and decreased lactate levels. After therapy was initiated, toe temperature proved a better indication of survival than did blood pressure or cardiac index (Henning et al., 1979).

Wilson et al. (1971) found significant differences in cardiac index and peripheral resistance between pure septic shock and sepsis complicated by hypovolemia and cardiac insufficiency. Patients with pure sepsis had an increased cardiac index (4.2 ± 1.3 L/min/m^2) compared to those with complicated sepsis (2.2 ± 0.8 L/min/m^2). Total peripheral resistance was lower (700 ± 410) in pure sepsis than in complicated sepsis ($1,500 \pm 580$). While clinical evidence of perfusion usually

correlated well with calculated resistance, these researchers observed that some patients had cold, cyanotic fingers and toes despite increased cardiac output and vasodilation evidenced by low resistance.

Recommendations for Early Detection of Shock and Use of Toe Temperatures

Few descriptions of early shock, prior to hypotension, are available yet researchers stress the importance of early detection in the successful treatment of shock. Shoemaker, Montgomery, Kaplan and Elwyn (1973) reported greater differences in early and late periods between survivors and non-survivors of shock. They concluded that early assessment may identify those patients for whom more aggressive therapy is needed.

Berne (1962) distinguished compensated from decompensated shock, the latter marked by the onset of hypotension. He described increases in venous tone as being an early indication of compensated shock and recommended assessment of venous filling in the feet and peripheral skin temperature. In addition, Berne recommended using these same assessment parameters as a guide to fluid therapy. Ibsen (1967, p. 428) offered recommendations for using peripheral perfusion as a guide to the extent of therapy needed when using vasodilators to treat shock: "Open up and fill up - and stop when the feet get warm". Matthews et al. (1974, p. 348) also referred to the usefulness of toe temperatures as a guide to fluid therapy. An adequate volume "is simply that which will keep the toes warmer than 34°."

Summary

The literature provides support for toe temperature monitoring as a useful addition to currently employed assessment methods. Researchers have reported correlations between toe temperature and other hemodynamic parameters and the predictive value of toe temperatures related to ultimate survival of patients. The authors cited also suggest that toe temperature can be used as a guide to fluid therapy and aid in the interpretation of body temperature changes.

CHAPTER III

METHOD OF THE STUDY

This chapter includes the following aspects of the study: the design of the study, the methodology, the setting and sample selection, protection of human subjects, data instruments, data collection procedure and data analysis.

Design of the Study

A descriptive design was used to answer the research questions of the study: 1) what changes occur in the skin temperature of the great toe in critically ill patients in an intensive care unit; and 2) what is the relationship of changes in the skin temperature of the great toe to other hemodynamic parameters (heart rate, blood pressure, urine output and core temperature) currently used to monitor critically ill patients in an intensive care unit?

Setting and Sample

The study was conducted in a surgical intensive care unit of a medical center in the southwestern area of the United States. Permission to conduct the study was obtained from the Associate Director of Nursing for Research (Appendix A). Permission to contact subjects for participation in this study was obtained from the attending physicians (Appendix B).

A purposive convenience sample of six subjects was selected from the critically ill patients admitted to the surgical intensive care unit. Subject selection was based on the existence of, or potential for, impaired perfusion according to history and current status of the subject. All subjects, or the individual authorizing permission for inclusion in the study had to read and understand English.

Protection of Human Subjects

Approval to conduct the study was obtained from the Ethical Review Committee of the College of Nursing and from the University of Arizona Human Subjects Committee (Appendix C). A description of the study and a diagram of the temperature probe application procedure (Figure 2) was provided to each subject in the study. The risks and benefits of participation were explained and subjects were assured anonymity. Participation in the study was voluntary and subjects could withdraw at any time. Subjects who agreed to participate signed a written consent form (Appendix D). In the event the subject was unable to sign the consent form, authorization was obtained from the closest relative or guardian. The investigator had not cared for, nor was acquainted with the subject or family prior to obtaining consent.

Data Instruments

Four instruments were used for data collection: a demographic data sheet (Appendix E), a clinical data sheet (Appendix F), a skin probe for toe temperature measurement and a general purpose probe for ambient temperature.

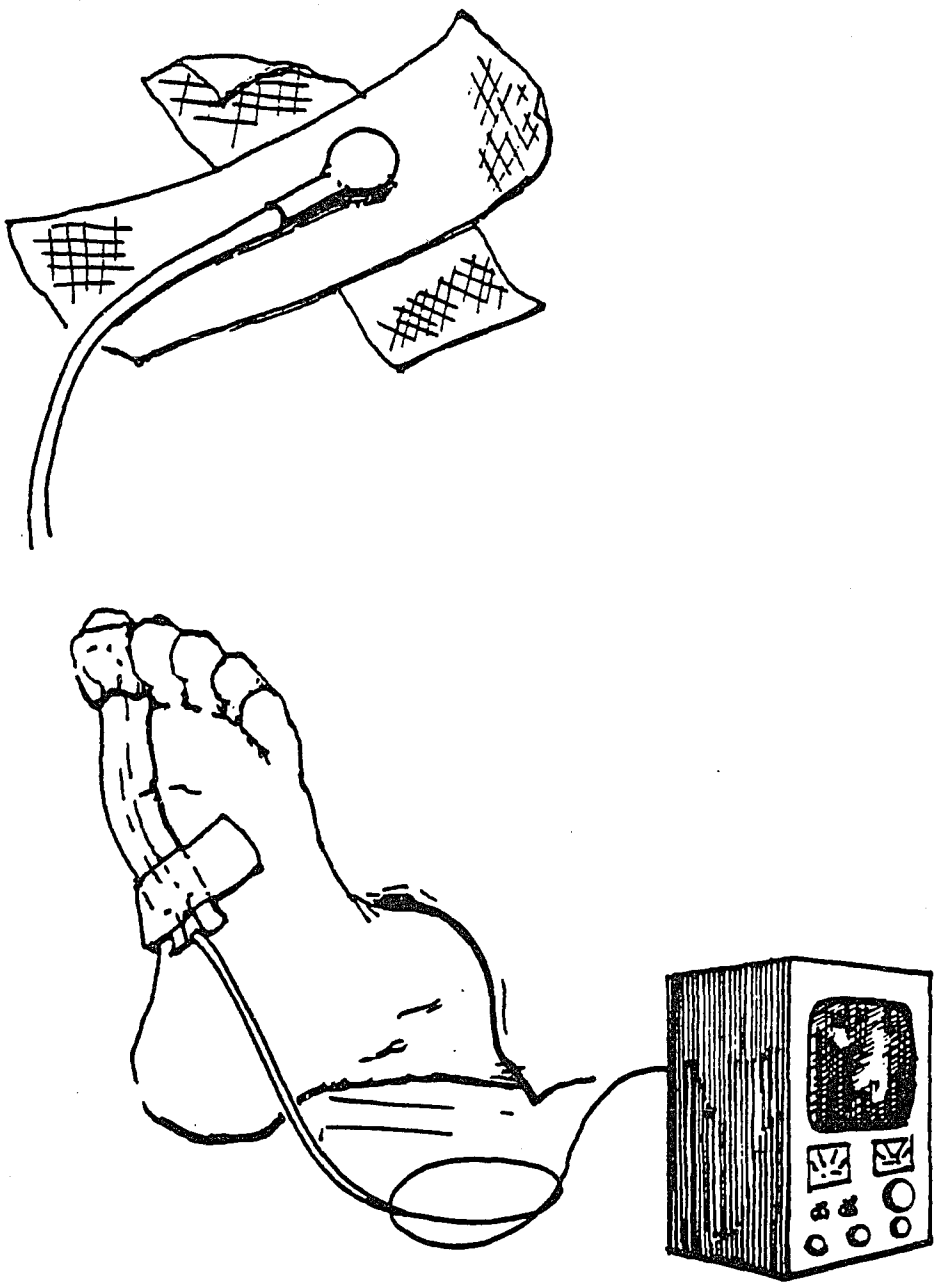

Figure 2. Temperature Probe Application Procedure

Demographic data included age, sex, diagnosis and other pertinent indicators of the subject's condition. The clinical data collected every two hours (heart rate, blood pressure, urinary output, toe temperature, ambient and core temperature) were recorded on the data sheet (Appendix F). Cardiac output, right atrial pressure and calculated systemic vascular resistance were recorded on the same sheet, as available, if the subject had a flow-directed pulmonary artery catheter in place.

Skin temperature measurements of the great toe were obtained using a Yellow Springs Instruments temperature monitor, Model 43, and a Yellow Springs Instruments thermistor probe, Model 409B. The monitor provides a Centigrade analog scale of 0.5° intervals producing a level of confidence of 0.25° C.

Ambient temperature measurements were obtained with the same temperature monitor and a Yellow Springs Instruments general purpose thermistor probe, Model 401. The probe was enclosed in a plastic syringe container and secured to the bed near the subject's foot.

The reliability of the temperature probes was determined prior to application to each subject and again following the data collection period by the investigator. Both the skin probe and ambient temperature probe were compared to two mercury thermometers in a water bath. Results were recorded for each subject on the data sheet (Appendix G) with a reliability level of 0.99 accepted. Electrical safety of the temperature monitor was determined by the biomedical engineering department according to department protocol.

Data Collection Procedure

Clinical Data

When subjects had been identified and consent for participation in the study obtained, the toe temperature and ambient temperature probes were checked by the investigator according to the procedure previously described.

The skin probe was secured to the plantar surface of the right great toe, or in subjects with indwelling femoral venous or arterial catheters, in the opposite, non-cannulated extremity. The probes were covered with standard one-inch cloth adhesive tape. The skin area beneath the tape and probe was inspected each day for irritation or pressure. The ambient temperature probe in the plastic container was secured to the foot of the bed at the level of the subject's foot but away from the subject.

Toe and ambient temperatures were recorded by the investigator and trained data collectors, registered nurses who worked in the intensive care unit. The data collectors were trained by the investigator through discussion and were given data collection guidelines (Appendix H). The reliability of each data collector was determined by trial readings with a level of 0.90 accepted. These results were recorded on the Data Collector Reliability sheet (Appendix I).

Toe and ambient temperatures were recorded every two hours for the duration of the study. The toe and ambient temperatures were recorded on the Clinical Data Sheet (Appendix F) in degrees Centigrade.

Additional clinical data, such as blood pressure, urine output, heart rate, and rectal or core temperature were taken from the charts as recorded by the nursing staff in the unit according to unit protocol. For the purpose of the study, rectal temperature and core temperature were considered equivalent. The parameters listed above were transcribed onto the clinical data sheet by the investigator. The toe and ambient temperatures were recorded on the clinical data sheet by the investigator or the data collectors.

Mean arterial blood pressure (MABP) was recorded from the digital readings of the direct intra-arterial monitors. When arterial monitoring was not available, the MABP was calculated by the investigator using the standard formula:

$$\bar{P}_a = P_d + 1/3\ (P_s - P_d)$$

where P_a represents MABP, P_d is diastolic pressure and P_s is the systolic pressure (Berne & Levy, 1981, p. 99).

Cardiac output determinations were recorded as available. When cardiac output determinations were made, the investigator recorded the parameters listed above and right atrial pressure. Systemic vascular resistance was calculated using the formula:

$$\text{SVR (dyne sec/cm}^5\text{)} = \frac{\text{MABP (mmHg.)} - \text{RAP (mmHg.)}}{\text{CO (liters/min.)}} \times 80$$

where RAP represents right atrial pressure, CO is cardiac output and 80 is the conversion factor (Wilson, Sarver and LeBlanc, 1971).

Demographic Data

The demographic data (Appendix E) were obtained by the investigator from the subject's chart. Items #5 (Significant Fluid Loss), #6 (Indication of Infection) and #7 (Major Hemodynamic Category) were completed based on medical chart data and with physician consultation.

Data Analysis

Data analysis was done using descriptive statistics. Demographic data, such as age, sex, diagnosis and surgical site or site of injury were described by range and frequency of occurrence. Hemodynamic category and aspects of infection were described.

Range, mean and standard deviation of the physiologic parameters were described for each subject, for the total sample and for clinical subcategories: survivors and non-survivors and complicated and uncomplicated sepsis. Conditions associated with major changes or trends in toe temperature were presented as case studies. The relationship of toe temperature to cardiac output and to systemic vascular resistance was described for the total group.

Summary

A convenience sample of six subjects from a medical center in the southwestern area of the United States was used for this study. Data collection instruments and the protocol were discussed. Descriptive statistics and case study analyses were used to present the results of the study.

CHAPTER IV

PRESENTATION AND ANALYSIS OF THE DATA

The results of the data analysis are presented in this chapter. First, the characteristics of the sample are described. Secondly, chart data pertaining to each subject's diagnoses, surgical procedures, hemodynamic categories and infections are presented. Finally, physiologic data for the subjects are described.

Characteristics of the Sample

A convenience sample of six subjects participated in the study. Four of the subjects were male, two female. Ages of the subjects ranged from 54 to 70 years. The mean age of the sample population was 63 years. The major diagnosis of the subjects varied. Two subjects were hospitalized for gastrointestinal bleeding. Three subjects had peritonitis; two resulting from intestinal performation, one associated with ascites. One subject was hospitalized for fever of unknown origin (Table 1).

Diagnoses and Surgical Procedures

In addition to the major diagnosis, each subject had other diagnoses or complications which significantly affected their status (Table 2). Five of the six subjects had undergone abdominal surgery during their hospitalization; four had surgery 24 hours prior to the study.

Table 1: Characteristics of Subjects: Age, Sex, Diagnosis and Outcome

SUBJECT	AGE	SEX	MAJOR DIAGNOSIS	OUTCOME
1	54	Male	Gastrointestinal Bleeding	Discharged
2	65	Female	Peritonitis: Perforated Appendix	Discharged
3	62	Male	Peritonitis: Pancreatic Cancer	Discharged
4	63	Male	Gastrointestinal Bleeding	Died
5	64	Male	Fever of Unknown Origin	Discharged
6	70	Female	Peritonitis: Small Bowel Perforation	Died

Table 2: Diagnoses of Subjects

SUBJECT	MAJOR DIAGNOSIS	OTHER DIAGNOSES
1	Gastrointestinal Bleeding	Pneumonia
2	Peritonitis: Perforated Appendix	Acute Renal Failure Cholelithiasis Urinary Tract Infection
3	Pancreatic Cancer	Hemorrhage, Ascites Peritonitis
4	Gastrointestinal Bleeding	Cirrhosis, Diabetes Ascites, Pneumonia Coagulopathy Urinary Tract Infection Peritonitis Chronic Pulmonary Disease
5	Fever of Unknown Origin	Esophagitis, Diabetes Rheumatoid Arthritis (Steroids) Pneumonia
6	Peritonitis: Small Bowel Perforation	Congestive Heart Failure Liver Dysfunction Diabetes Renal Cancer Urinary Tract Infection Ventricular Tachycardia Autoimmune Hemolytic Anemia (Steroids) Herpes Zoster

Subject one was hospitalized for gastrointestinal bleeding. Six days prior to the study, the subject underwent abdominal surgery, splenectomy, gastrotomy and oversew of varices for control of the bleeding. At the time of the study, Subject one also had pneumonia.

Subject two had an exploratory laparotomy within 24 hours prior to the study which showed peritonitis due to a perforated appendix. Additional diagnoses during the study included urinary tract infection, acute renal failure, cholelithiasis and diabetes.

Subject three had pancreatic cancer complicated by hemorrhage, ascites and peritonitis. An exploratory laparotomy 24 hours prior to the study showed extensive abdominal tumor.

Subject four was admitted for gastrointestinal bleeding and had surgery for a LeVeen shunt placement within 24 hours prior to the study. Complicating factors included cirrhosis, chronic obstructive pulmonary disease, ascites, diabetes, coagulopathy, urinary tract infection, pneumonia and hemorrhage.

Subject five was admitted with fever of unknown origin. Additional diagnoses included esophagitis, diabetes, rheumatoid arthritis with steroid use and pneumonia. Following the study, venous thrombosis was diagnosed.

Subject six underwent an exploratory laparatomy within 24 hours prior to the study which showed peritonitis due to small bowel perforation. In addition, this subject had complications of congestive heart failure, liver dysfunction, renal cancer, urinary tract infection, diabetes, ventricular tachycardia, autoimmune hemolytic anemia with steroid use and disseminated herpes zoster.

Major Hemodynamic Categories

Major hemodynamic category was determined by chart review of each subject's history, physiologic parameters, laboratory results and consultation with medical staff. All six subjects were classified under distributive-septic based on one or more factors: elevated white blood cell count, fever and positive culture. Subject two had mild congestive heart failure precipitated by acute renal failure and fluid overload. Subject four had evidence of significant hypovolemia from hemorrhage and fluid imbalance. Subject six was identified under three categories: hypovolemic, cardiogenic and distributive-septic (Table 3).

Sites of Infection and Infecting Organisms

All six subjects had positive cultures and clinical evidence of infection (Table 4). Subjects one and five had positive sputum cultures with gram-negative organisms and mixed flora, respectively. Subject three also had one site of documented infection: gram-negative organisms from abdominal fluid.

Three subjects had positive cultures from multiple sites. Subject two had urine cultures with fungal growth and abdominal cultures which showed both gram-positive and fungal infection. Subject four had three positive culture sites: gram-negative in urine and gram-positive in both sputum and abdominal fluid. Subject six was the only subject with documented positive blood cultures, a gram-positive organism. This subject also had urine cultures with fungal growth and gram-negative organisms from abdominal fluid.

Table 3. Major Hemodynamic Categories of Subjects

SUBJECT	HYPOVOLEMIC	CARDIOGENIC	DISTRIBUTIVE-SEPTIC	OBSTRUCTIVE
1			X	
2		X	X	
3			X	
4	X		X	
5			X	
6	X	X	X	

Table 4. Subjects' Sites of Infection/Organism

SUBJECT	BLOOD	URINE	SPUTUM	ABDOMEN
1			Gram +	
2		Fungal		Gram + Fungal
3				Gram -
4		Gram -	Gram +	Gram +
5			Mixed flora	
6	Gram +	Fungal		Gram -

Physiologic Data

Results of the physiologic data analysis are first presented in this section as case studies for each subject. Range, mean and standard deviation for the selected parameters are discussed as well as clinical trends and observations. Secondly, results for the total group and for subgroups (survivors and non-survivors and complicated and uncomplicated sepsis) are presented for comparison. Finally, the relationship of toe temperature to cardiac output and systemic vascular resistance for the total groups are presented. Ambient temperature was not used in the data analysis; mean ambient temperature was 24° C. ± 1° C. providing a controlled environment that did not significantly affect the toe temperature changes.

Case Studies

Subject one. Subject one was a 54 year old male admitted for gastrointestinal bleeding. Six days prior to the study, he underwent abdominal surgery for control of the bleeding. He developed gram-positive pneumonia post-operatively and was considered to be septic during the study period based on positive cultures, fever and leukocytosis.

Toe temperatures during the study ranged from 26.5 to 38° C. with a mean of 35.6° C. (S.D. 2.85) (Table 5). Core temperatures ranged from 36.8 to 40° C. with a mean temperature of 38.1° C. (S.D. 0.60).

Blood pressure during the study was stable; he had no episodes of hypotension, required no vasopressor support and received moderate amounts of intravenous fluids. Mean arterial blood pressure ranged

Table 5. Physiologic Data Summary - Subject One

	Toe Temps	Core Temps	Mean Blood Pressure	Heart Rate	Urine Output	Cardiac Output	Systemic Vascular Resistance
No Readings	24	23	24	24	24	6	6
Range:							
Minimum >	26.5	36.8	69.0	104.0	30.0	9.5	482.8
Maximum >	38.0	40.0	93.0	135.0	140.0	11.6	600.0
Mean >	35.6	38.1	79.5	123.3	69.2	10.6	533.2
Standard Deviation>	2.85	.60	5.70	9.23	24.22	.78	41.18

from 69 to 93 mmHg. With a mean of 79.5 mmHg. (S.D. 5.7). The subject was tachycardic with heart rate of 104 to 135 beats/minute, mean of 123.3 (S.D. 9.23).

Cardiac output for the study period was above normal ranging from 9.5 to 11.6 liters/minute with a mean cardiac output of 10.6 liters/minute (S.D. 0.78). Systemic vascular resistance (SVR) was low ranging from 482 to 600 dyne sec./cm^5 with a mean SVR of 533.2 (S.D. 41.18).

During the study period, Subject one showed one major decline in toe temperature (Figure 3) from 38 to 26.5° C. over a six hour period. Corresponding to the peak toe temperature, core temperature rose to 40° C. and heart rate increased to 135 beats per minute. A hypothermia blanket was started at the hour of peak temperature and continued for four hours resulting in the rapid decline of both toe and core temperatures and heart rate.

With the exception of the period of hypothermia, toe temperatures closely approximated core temperature. Mean difference between core and toe temperatures was 2.6° C. with a range from 0.7° C. to 10.7° C. following the hypothermia. Overall, the subject exhibited a stable hyperdynamic course demonstrated by high cardiac output, low SVR, high toe temperatures and normal blood pressure. Subject one survived and was discharged from the hospital.

Subject two. Subject two was a 65 year old female admitted with peritonitis from a perforated appendix. Associated complications included diabetes, acute renal failure, urinary tract infection and

LEGEND FOR HEMODYNAMIC TRENDS
(Key for Figures 3, 4, 5, 7, 9 and 10)

HR =	Heart rate (beats/minute)
MABP =	Mean arterial blood pressure (mmHg.)
SVR =	Systemic vascular resistance (dyne sec./cm^5)
Core =	Core temperature (° C.)
Toe =	Toe temperature (° C.)
CO =	Cardiac output (liters/minute)
Dopamine =	Dopamine hydrochloride (mcg/kg/min)
Nipride =	Nitroprusside (mcg/kg/min)
MS =	Morphine sulfate
Lasix =	Furosemide

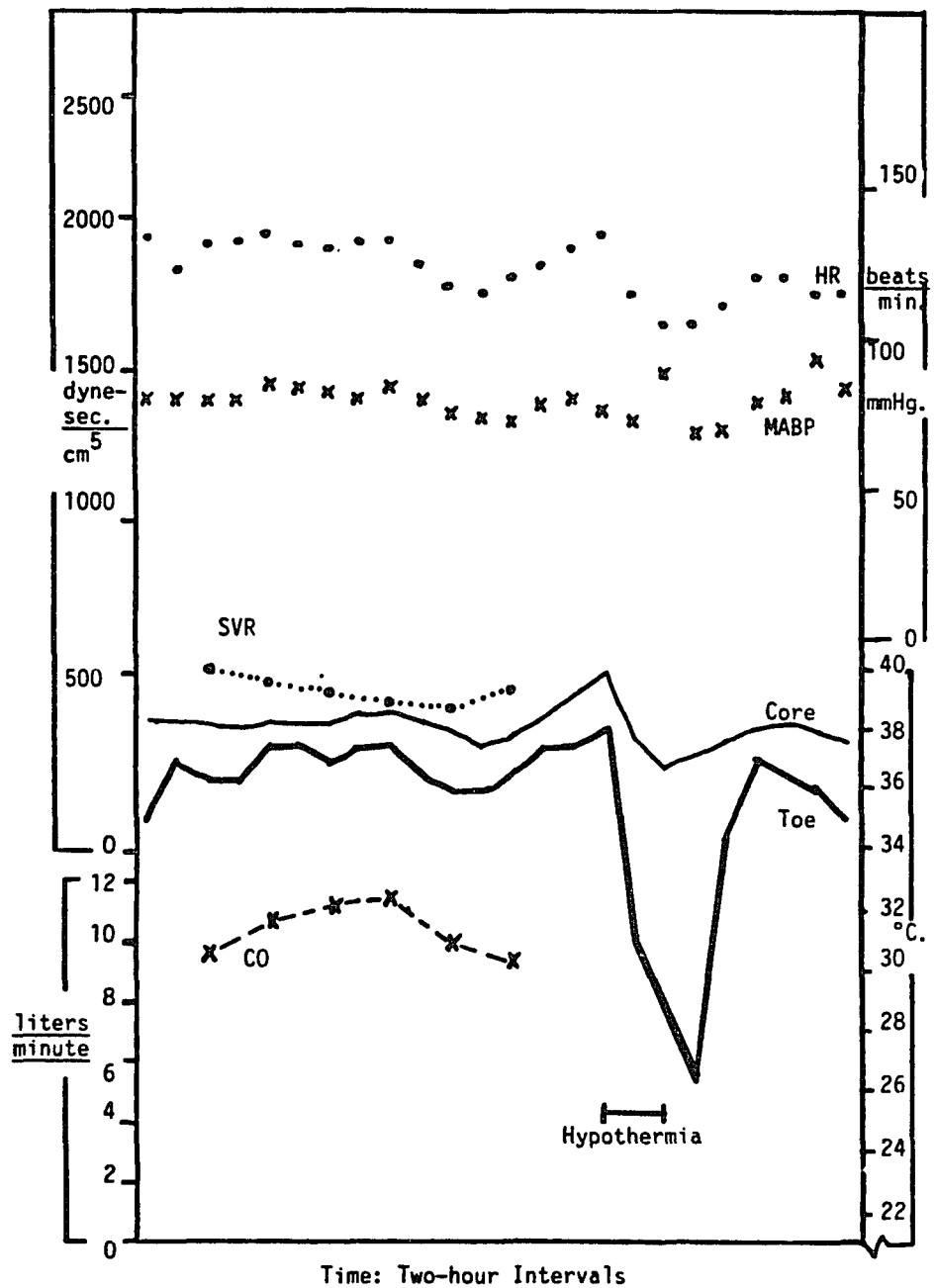

Figure 3. Hemodynamic Trends - Subject One

cholelithiasis. Subject two was admitted into the study eight hours following an exploratory laparotomy at which time she was considered to be septic. The subject was also placed in the cardiogenic category due to congestive heart failure resulting from fluid overload and acute renal failure.

Toe temperatures ranged from 24 to 35° C. with a mean of 30.5° C. (S.D. 3.6). Core temperature ranged from 36.7 to 37.5° C. with a mean temperature of 37.1° C. (S.D. 0.21) (Table 6).

Subject two was mildly hypotensive during the study and required dopamine hydrocholoride (dopamine) for blood pressure support. Mean arterial blood pressure ranged from 55 to 68 mmHg., mean equal to 61.9 (S.D. 3.6). The subject was not tachycardic; heart rate ranged from 72 to 94 beats/minute.

Cardiac output during this period ranged from 3.2 to 6.5 liters/minute with a mean of 5.1 (S.D. 1.07). Systemic vascular resistance ranged from 554.8 to 1150 dyne sec./cm^5 with a mean of 821.4 (S.D. 181.09).

Subject two showed wide fluctuations in toe temperature throughout the study period (Figure 4). Two large declines in toe temperature were noted. The first, in the beginning of the study, was not explained by the clinical situation. The second occurred during dialysis. Increased amounts of dopamine were required to maintain blood pressure. Cardiac output rose, SVR declined and toe temperature dropped, likely the combined effects of dialysis with the addition of its low-pressure system and increased vasopressor support. Other variations in toe

Table 6. Physiologic Data Summary - Subject Two

	Toe Temps	Core Temps	Mean Blood Pressure	Heart Rate	Urine Output	Cardiac Output	Systemic Vascular Resistance
No Readings	24.0	24.0	24.0	24.0	24.0	9.0	9.0
Range:							
Minimum >	24.0	36.7	55.0	72.0	.0	3.2	554.8
Maximum >	35.0	37.5	68.0	94.0	18.0	6.5	1,150.0
Mean >	30.5	37.1	61.9	83.7	9.1	5.1	821.4
Standard Deviation >	3.60	.21	3.61	5.51	4.80	1.07	181.09

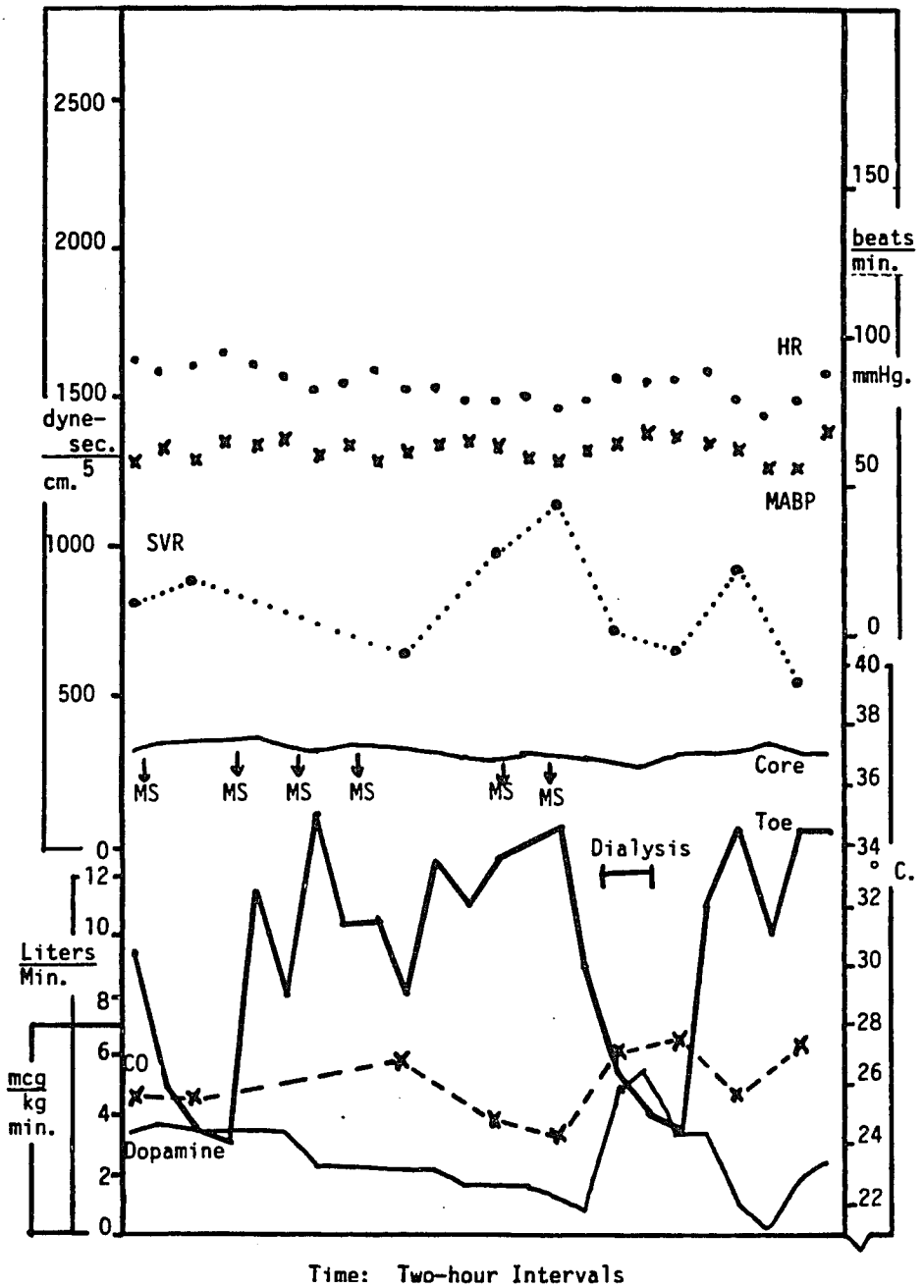

Figure 4. Hemodynamic Trends - Subject Two

temperature are not explained, however, the subject was hemodynamically unstable during this period and other variables, such as morphine sulfate (MS) were noted.

Despite sepsis, subject two was afebrile during the study period. Toe temperatures were in a moderate range. Mean difference between core and toe temperature was 6.6° C. with a range of 2.1 to 12.5° C. Cardiac output was low to normal, but lower than expected in sepsis. Systemic vascular resistance was low to normal, typical for sepsis. Subject two survived and was discharged from the hospital.

Subject three. Subject three was a 62 year old male admitted with pancreatic cancer, ascites and fever. Twenty four hours before the study, this subject underwent an exploratory laparotomy which showed peritonitis with widespread abdominal tumor. Subject three was considered to be septic during the study period.

Toe temperatures during the study ranged from 33 to 37° C. with a mean of 35.6° C. (S.D. 0.93). Core temperatures ranged from 37 to 38.2° C. with a mean of 37.6 (S.D. 0.30) (Table 7).

Subject three received low-dose dopamine for the first six hours of the study period. The subject was normotensive to slightly hypertensive during the study with systolic blood pressures of 120 to 160 mmHg. Mean arterial blood pressure ranged from 68 to 100 mmHg. with a mean of 85 (S.D. 7.7). Heart rate ranged from 70 to 102 beats/minute, mean equal to 85.8 (S.D. 8.9).

Cardiac output during this period varied from 4.8 to 10.5 liters/minute with a mean CO of 8 (S.D. 1.9). Systemic vascular

Table 7. Physiologic Data Summary - Subject Three

	Toe Temps	Core Temps	Mean Blood Pressure	Heart Rate	Urine Output	Cardiac Output	Systemic Vascular Resistance
No Readings	24.0	23.0	24.0	24.0	24.0	11.0	11.0
Range:							
Minimum >	33.0	37.0	68.0	70.0	45.0	4.8	524.4
Maximum >	37.0	38.2	100.0	102.0	380.0	10.5	1,387.8
Mean >	35.6	37.6	85.1	85.8	112.1	8.0	797.8
Standard Deviation >	.93	.30	7.72	8.91	91.65	1.92	280.84

resistance ranged from 524.4 to 1,387.8 dyne sec./cm^5 with a mean SVR of 797.8 (S.D. 280.8).

Toe temperature closely approximated core temperature. Core minus toe gradient ranged from 0.8 to 4.1° C. with a mean difference of 1.9° C. (Figure 5). Overall, the subject showed a stable, hyperdynamic course with normal to high cardiac output, low to normal SVR, normal to slightly hypertensive blood pressure and high toe temperatures.

Slight variations were noted in toe temperature during the study. These fluctuations are best explained by variation in intravenous fluids and furosemide (Lasix) effect on urine output (Figure 6). During the first hours of the study, toe temperature increased with increases in intravenous fluid. The first two doses of Lasix had small effects on urine output; toe temperature again increased with intravenous fluid. Toe temperature and cardiac output increased with the third dose of diuretic likely reflecting the beneficial effect of volume reduction at that time. Decreases in both toe temperature and cardiac output were seen following the fourth and fifth doses of Lasix. These responses may reflect overly vigorous volume reduction resulting in vasoconstriction and reduced cardiac output. Subject three survived and was discharged from the hospital.

Subject four. Subject four was a 63 year old male admitted with a gastrointestinal bleed from varices and cirrhosis. The subject underwent surgery for placement of a LeVeen shunt prior to the study. Associated factors included chronic obstructive pulmonary disease, ascites, adult onset diabetes, coagulopathy and hemorrhage.

LENGEND OF TOE TEMPERATURE AND FLUID BALANCE
(Key for Figures 6, 8, and 11)

IV =	Intravenous fluids (cc/hour)
UO =	Urine output (cc/hour)
PAW =	Pulmonary artery wedge pressure (mmHg.)
Toe =	Toe temperature (° C.)
CO =	Cardiac output (liters/minute
Dopamine =	Dopamine hydrochloride (mcg/kg/min)
Nipride =	Nitroprusside (mcg/kg/min)
Lasix =	Furosemide

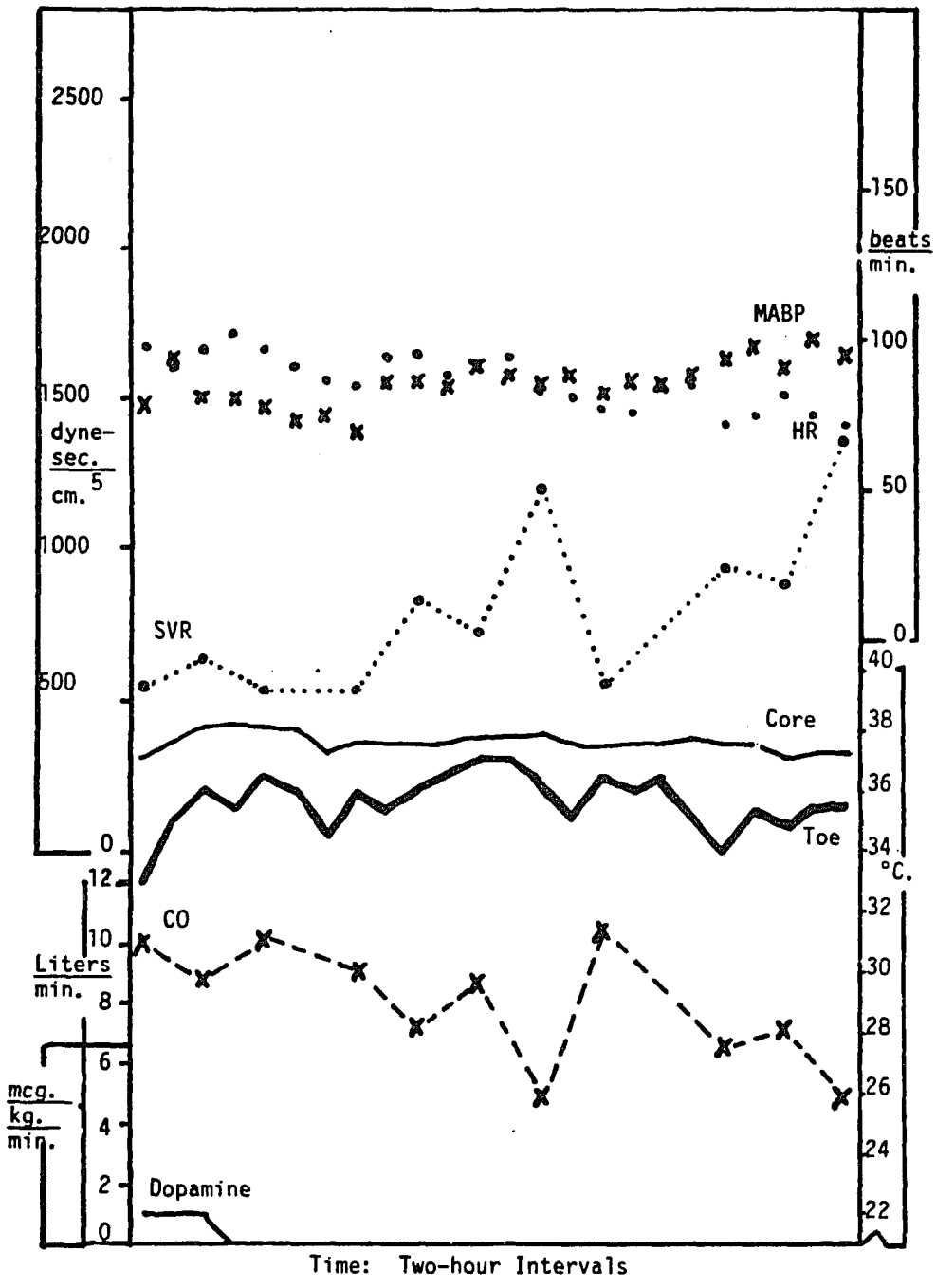

Figure 5. Hemodynamic Trends - Subject Three

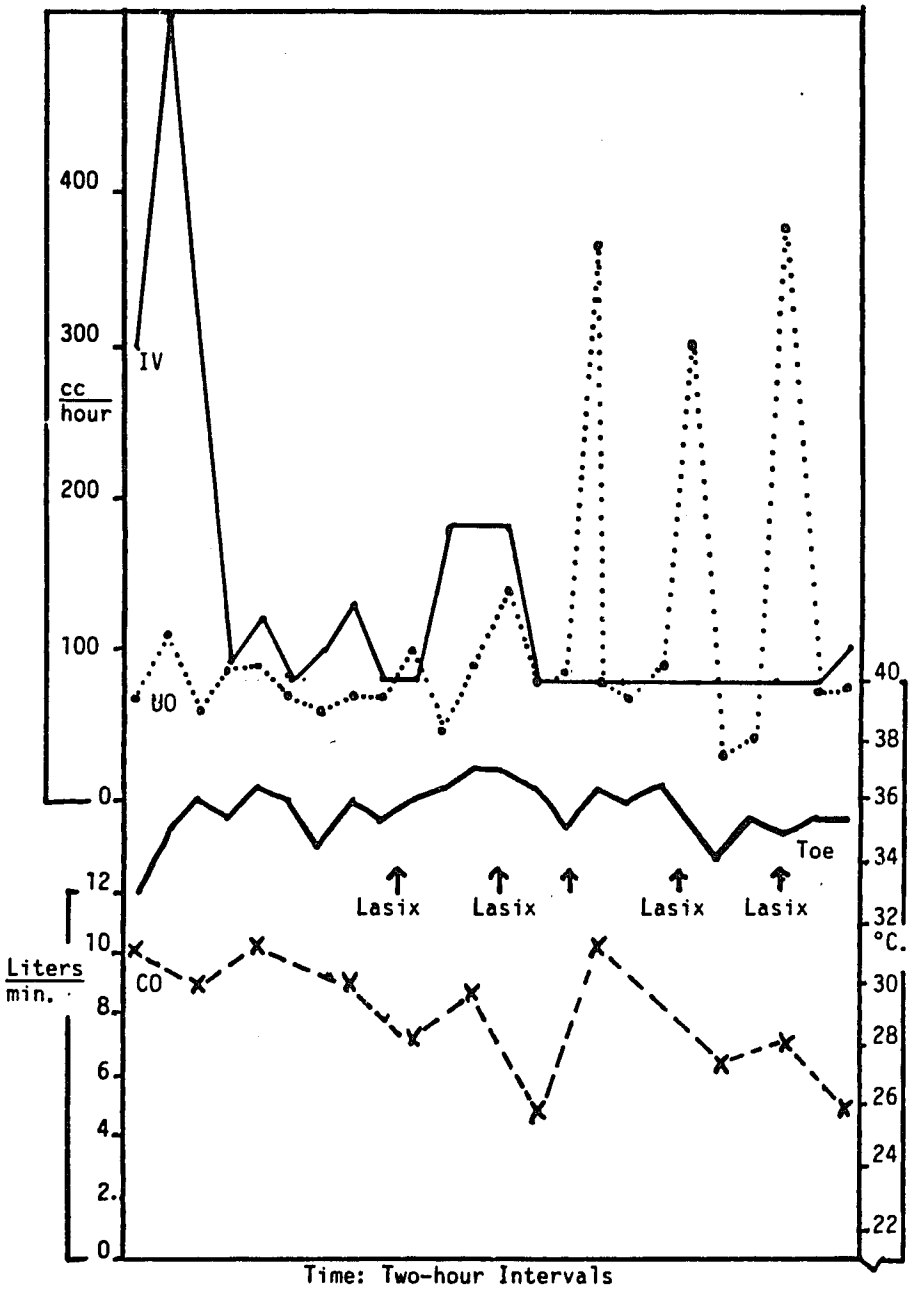

Figure 6. Toe Temperature and Fluid Balance - Subject Three

During the study, subject four was classified under two hemodynamic categories. He was considered septic based on positive urine, sputum and abdominal fluid cultures. Subject four was also hypovolemic from bleeding and required large amounts of blood and fluid replacement (100 to 535 cc/hour). The study was terminated after 26 hours due to the family's request.

Toe temperature during the study ranged from 27 to 34° C. with a mean of 31.4° C. (S.D. 2.25) (Table 8). Core temperature range was 36.7 to 37.5° C., mean equal to 37.4 (S.D. 0.21).

Subject four was hypotensive immediately prior to the study and at the end of the study period. Mean arterial blood pressure ranged from 60 to 87 mmHg. with a mean of 72.8 (S.D. 7.63). Heart rate ranged 94 to 136 beats/minute, mean equal to 109 (S.D. 10.9).

Cardiac output varied from normal to high: 6.4 to 12.1 liters/minute with a mean CO of 8.5 (S.D. 1.76). Systemic vascular resistance was low ranging from 469 to 733 dyne sec./cm.^{5}, mean equal to 623.8 (S.D. 81.7).

For the first 18 hours of the study, subject four showed a hyperdynamic pattern with high cardiac output, low SVR and moderately high toe temperature (Figure 7). Dopamine was used for two short periods for renal perfusion.

The final eight hours of the period show a decline in the subject's status. Heart rate increased. Mean arterial blood pressure declined, rose with dopamine, declined again. Systemic vascular resistance was low. Toe temperature and cardiac output showed a decreasing trend.

Table 8. Physiologic Data Summary - Subject Four

	Toe Temps	Core Temps	Mean Blood Pressure	Heart Rate	Urine Output	Cardiac Output	Systemic Vascular Resistance
No Readings	13.0	13.0	13.0	13.0	13.0	9.0	9.0
Range:							
Minimum >	27.0	36.7	60.0	94.0	6.0	6.4	469.4
Maximum >	34.0	37.5	87.0	136.0	240.0	12.1	733.3
Mean >	31.4	37.4	72.8	109.0	61.7	8.5	623.8
Standard Deviation >	2.25	.21	7.63	10.91	61.75	1.76	81.70

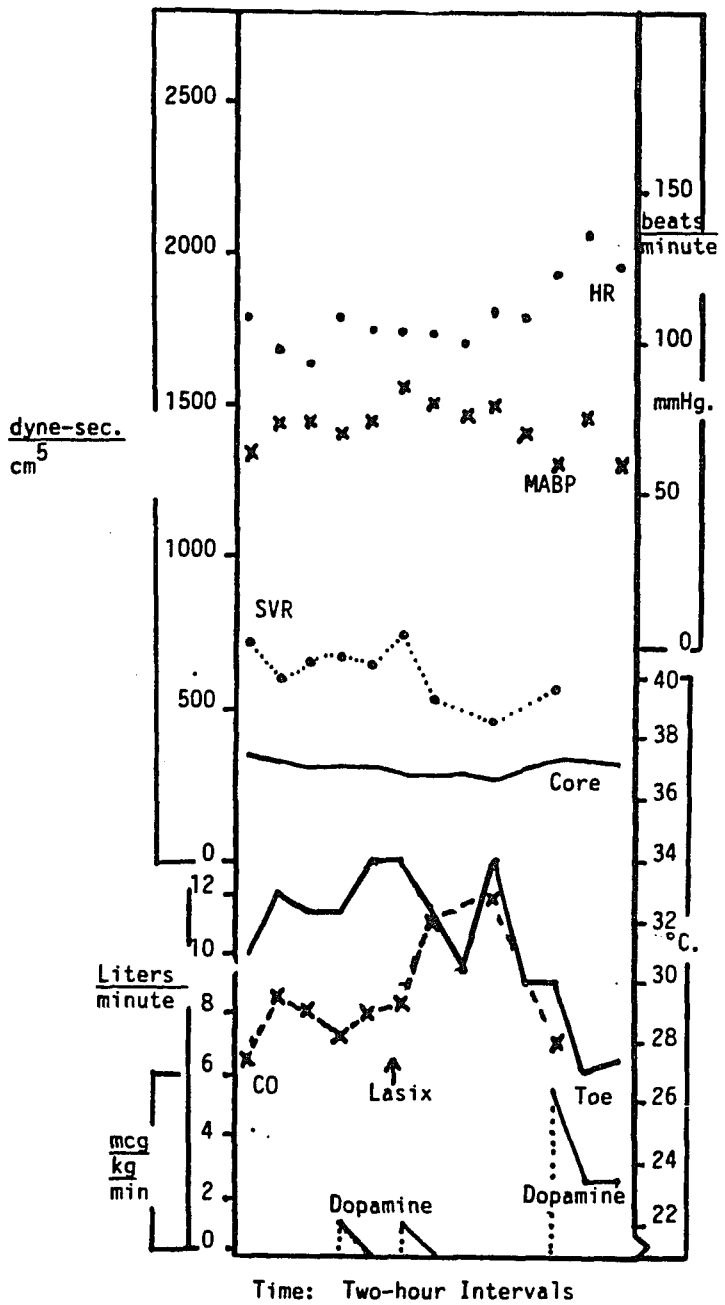

Figure 7. Hemodynamic Trends - Subject Four

Core temperature remained stable throughout the period. Core minus toe gradient ranged from 2.7 to 10.3° C. with a mean difference of 5.7° C.

Throughout the study, toe temperature and cardiac output follow general corresponding trends. Toe temperature and SVR show a general inverse relationship, but one that is less consistent.

Figure 8 shows the comparison of toe temperature with intravenous fluid, urine output and the effect of diuretic. Toe temperature increased with intravenous fluid, declined following Lasix and increased urine output, then increased with intravenous fluid. Cardiac output did not follow a similar trend. In the last eight hours, both toe temperature and cardiac output declined despite intravenous fluids.

In summary, subject four showed two distinct patterns: an early hyperdynamic phase requiring large fluid volumes to replace ongoing losses and a pre-terminal decline in all parameters despite vasopressor and fluids. Subject four died approximately 12 hours after the study period.

Subject five. Subject five was a 64 year old male admitted with fever of unknown origin. Associated problems included gastrointestinal distress with vomiting, dehydration, adult onset diabetes, rheumatoid arthritis with steroid use and pneumonia. Following the study, deep venous thrombosis was diagnosed. The subject was considered septic during the study based on elevated white blood cell count, fever and positive sputum culture.

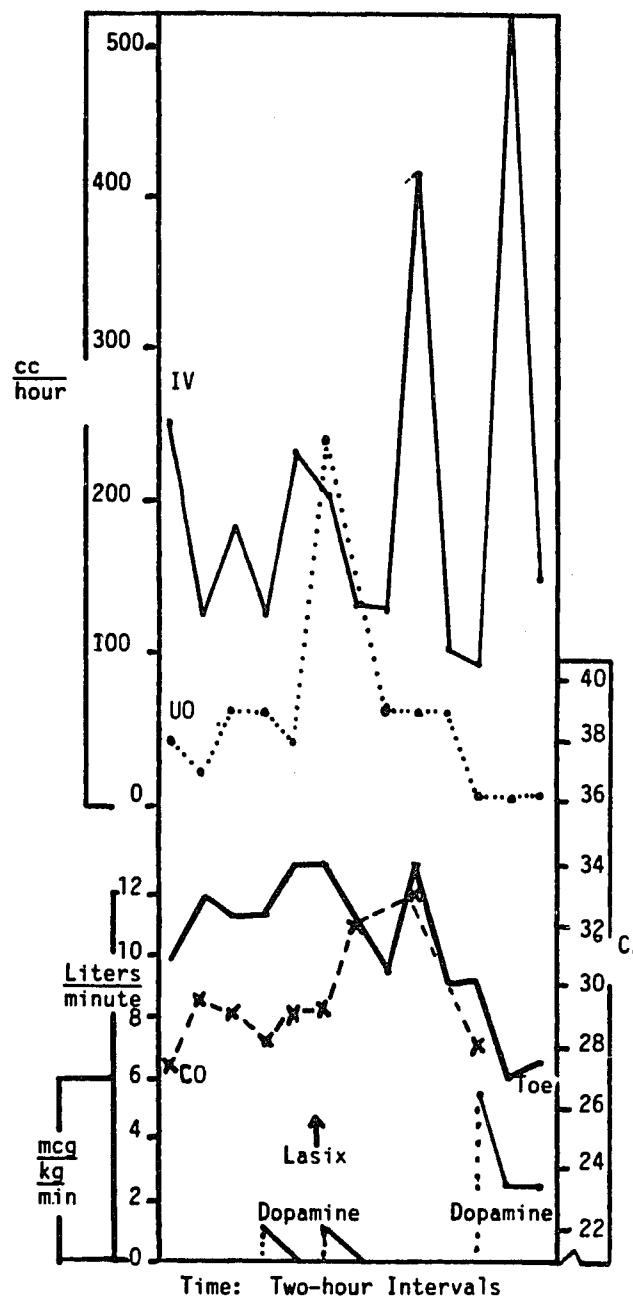

Figure 8. Toe Temperature and Fluid Balance - Subject Four

Toe temperature ranged from 25.5 to 36° C. with a mean of 33.9° C. (S.D. 2.62) (Table 9). The data on core temperature were incomplete.

Subject five was hypotensive during the first 12 hours of the study with systolic blood pressure as low as 80 mmHg. Mean arterial blood pressure ranged from 53 to 93 mmHg. with a mean of 78.5 (S.D. 8.62). Heart rate ranged 80 to 113 beats/minute, mean of 95.7 (S.D. 8.62). This subject did not have a pulmonary artery catheter, therefore no cardiac output or SVR determinations were available.

Two large declines in toe temperature were seen, both occurred at 10 A.M. on consecutive days (Figure 9). Prior to both episodes, the subject received a bath. The decrease in toe temperature was associated with a rise in core temperature. On the second occasion, the subject was cultured for a temperature greater than 38.5° C. Both episodes might be explained by a cool bath which caused toe temperature to decrease and caused core temperature to increase. Shivering or simply decreased heat loss through vasoconstricted skin tissue would cause core temperature to rise.

Subject five showed a general septic pattern: mild tachycardia, mild hypotension, adequate urine output and moderate to high toe temperature. Subject five survived and was discharged from the hospital.

Subject six. Subject six was a 70 year old female admitted with peritonitis due to small bowel perforation. An exploratory laparotomy was performed within 12 hours prior to the study. The subject had multiple associated conditions and complications: congestive heart

Table 9. Physiologic Data Summary - Subject Five

	Toe Temps	Core Temps	Mean Blood Pressure	Heart Rate	Urine Output	Cardiac Output	Systemic Vascular Resistance
No Readings	22.0	8.0	23.0	24.0	19.0		
Range:							
Minimum >	25.5	36.8	53.0	80.0	60.0		
Maximum >	36.0	38.6	93.0	113.0	425.0		
Mean >	33.9	37.5	78.5	95.7	167.9		
Standard Deviation >	2.62	.51	8.62	8.62	94.59		

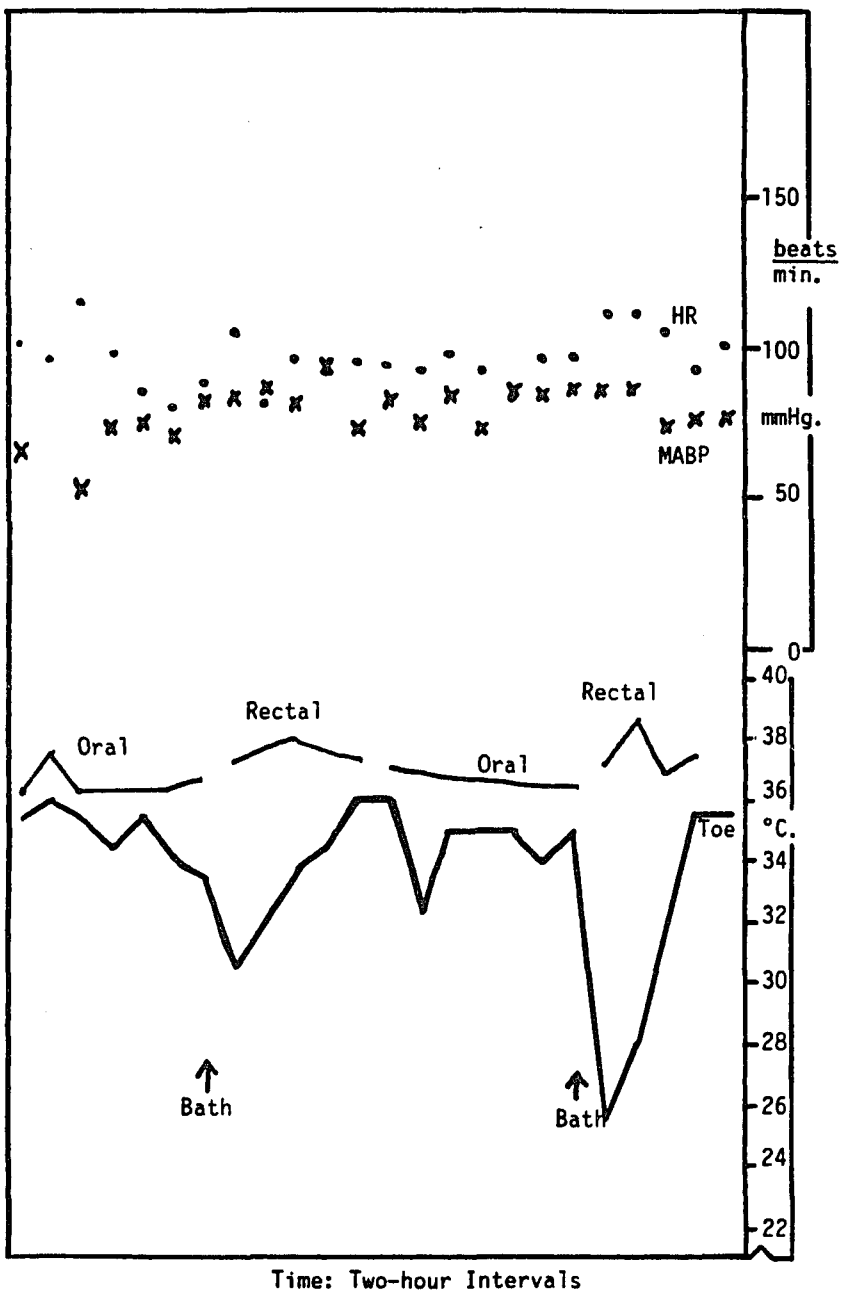

Figure 9. Hemodynamic Trends - Subject Five

failure, autoimmune hemolytic anemia with steroid use, liver dysfunction, renal cancer, cervical cancer, urinary tract infection, diabetes and herpes zoster.

Subject six was classified under three hemodynamic categories. Hypovolemia was attributed to post-operative fluid shift and peritonitis. The subject also had cardiogenic problems evidenced by congestive failure and pulmonary edema. The distributive-septic classification was made on the basis of fever, elevated white blood cell count and positive cultures.

Toe temperature ranged from 23.5 to 35° C. with a mean of 27 (S.D. 3.58). Core temperature ranged 36.5 to 37.6° C., mean equal to 37.2 (S.D. 0.29) (Table 10).

Post-operatively, the subject had severe peripheral vasoconstriction, low cardiac output and high SVR which improved with low-dose dopamine and nitroprusside (Nipride). Blood pressure was unstable in the first 24 hours of the study with brief episodes of hypotension. Mean arterial blood pressure ranged from 72 to 98 mmHg. with a mean of 85.1 (S.D. 8.35). The subject was tachycardic ranging 101 to 115 beats/minute, mean heart rate of 106.8 (S.D. 4.36). Urine output was adequate.

Cardiac output ranged 2.9 to 5.7 liters/minute with a mean output of 4.8 (S.D. 0.68). Systemic vascular resistance ranged 884.2 to 1,737.9 dyne sec./cm^5, mean of 1,181.2 (S.D. 201.2).

The greatest difference between core and toe temperature was seen in this subject. Core minus toe gradient ranged from 2.3 to 13.4° C. with a mean difference of 10.2° C.

Table 10. Physiologic Data Summary - Subject Six

	Toe Temps	Core Temps	Mean Blood Pressure	Heart Rate	Urine Output	Cardiac Output	Systemic Vascular Resistance
No Readings	24.0	24.0	24.0	24.0	24.00	18.0	18.0
Range:							
Minimum >	23.5	36.5	72.0	101.0	18.0	2.9	884.2
Maximum >	35.0	37.6	98.0	115.0	200.0	5.7	1,737.9
Mean >	27.0	37.2	85.1	106.8	63.5	4.8	1,181.2
Standard Deviation >	3.58	.29	8.35	4.36	40.63	.68	201.19

Two large increases in toe temperature were noted (Figure 10). The first occurred following a two hour period in which the dopamine was discontinued; only Nipride was infused. Cardiac output decreased during the same period and SVR increased. The increase in toe temperature and the simultaneous increase in SVR appears contradictory. Systemic vascular resistance at that time apparently reflected the state of vessels other than the periphery. Discontinuing the low-dose dopamine (2.7 mcg/kg/minute) likely allowed renal and mesenteric vasoconstriction. The decrease in cardiac output might then be explained by a sudden increase in SVR and, perhaps, loss of some inotropic support. The decrease in renal blood flow may have resulted in a redistribution of flow to the periphery with a warming of toe temperatures despite decreased cardiac output.

The second increase in toe temperature occurred in the last eight hours of the study. Cardiac output rose slightly, SVR decreased. This period followed several does of Lasix (Figure 11). Prior to this, pulmonary artery wedge pressure (PAW) had reached a high of 29 mmHg., decreased after the Lasix to 20 mmHg., then decreased further to 16 mmHg. The low toe temperature, low cardiac output and elevated wedge pressure reflect cardiac failure present when the first dose of Lasix was given. The increase in toe temperature and cardiac output likely represent an improvement in that state following a diuresis and decreased wedge pressure.

Despite the apparent sepsis, Subject six was not febrile. It was noted that two days after the study the Nipride was discontinued. Core temperature at that hour was 36° C. Over the next four hours,

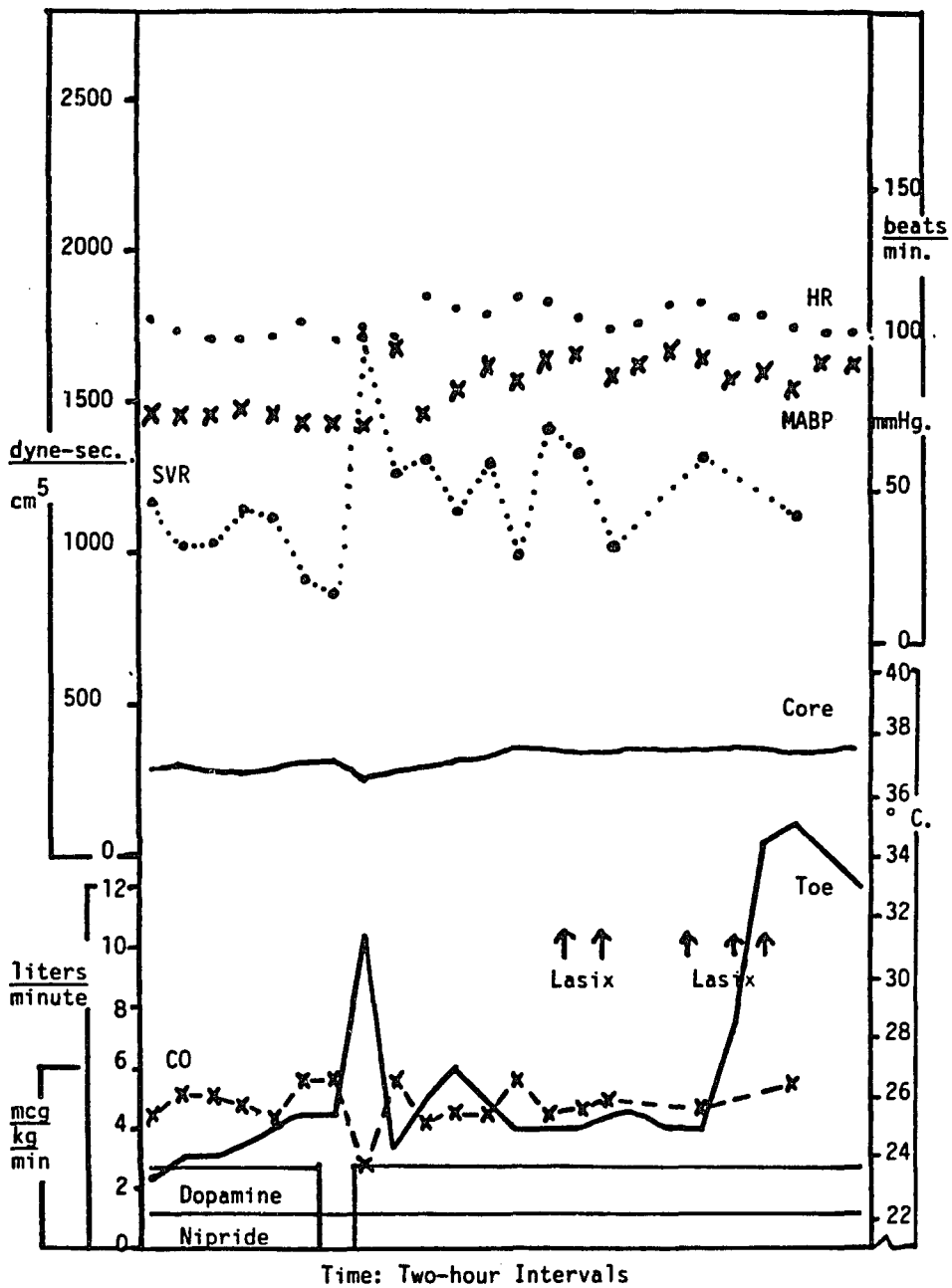

Figure 10. Hemodynamic Trends - Subject Six

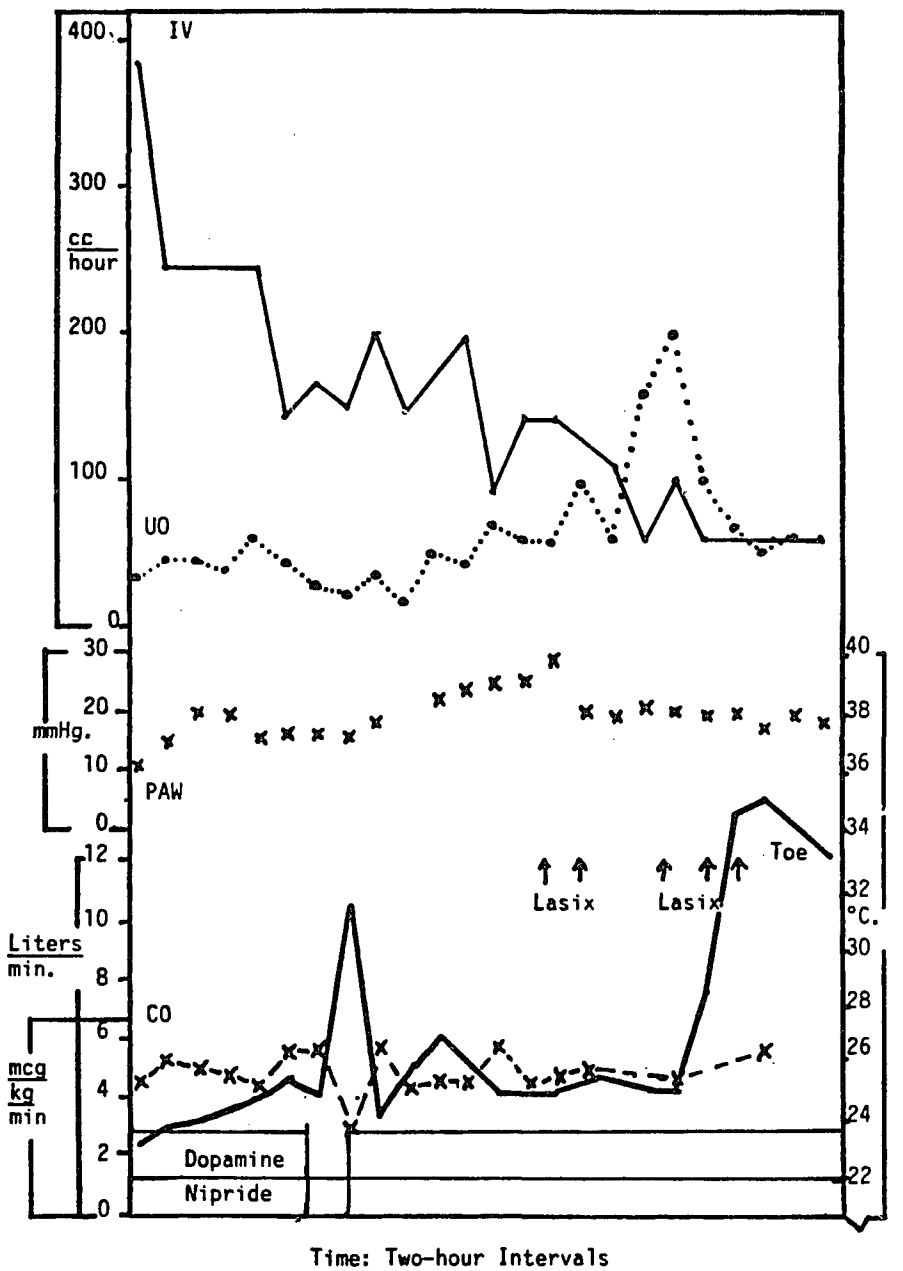

Figure 11. Toe Temperature and Fluid Balance - Subject Six

core temperature rose steadily to 37.2° C. Nipride-induced vasodilation apparently caused an obligatory heat loss and was, in part, the cause of subnormal core temperatures.

Overall, Subject six displayed a mixed hemodynamic picture. Cardiac output was low to normal but lower than expected for the septic state. Systemic vascular resistance was normal to high. Toe temperature was low to moderate. Subject six died approximately ten days after the study period.

Comparison of Toe Temperatures for Total Group and Subgroups

Table 11 shows the summary of toe temperature data for the subjects in this study. Range of toe temperature for the total group was 23.5 to 38° C. Mean toe temperature was 32.4° C.

Differences were seen between mean temperatures of the two subgroups; survivors (n = 4) and non-survivors (n = 2) and those with complicated (n = 3) and uncomplicated sepsis (n = 3). Mean toe temperature of survivors was higher than the mean for non-survivors. Mean toe temperature for survivors was 33.9° C. versus 28.5° C. for non-survivors. In the second subgroup, the mean toe temperature of those with uncomplicated sepsis was higher than those with complicated sepsis. The mean toe temperature for subjects with uncomplicated sepsis was 35.1° C. The mean for subjects with complicated sepsis was 29.3° C. It is noted that these subgroups contain the same subjects with the exception of Subject two. Subject two was a survivor with complicated sepsis. The remaining five subjects are found in corresponding

Table 11. Toe Temperature Summary: Total Group and Sub-groups in Degrees Centigrade

	Toe Temperature °C.		
	Minimum	Maximum	Mean
Total	23.5	38.0	32.4
Survivors	24	38	33.9
Non-survivors	23.5	35	28.5
Uncomplicated Sepsis	25.5	38	35.1
Complicated Sepsis	23.5	35	29.3

categories: survivor/uncomplicated sepsis and non-survivor/complicated sepsis.

Figure 12 shows the scatterplot of cardiac output in liters/minute and toe temperature in degrees Centigrade for all subjects. There is a positive relationship between these two parameters (r=0.63). Low toe temperature is associated with low cardiac output for this group, high toe temperature is generally associated with high cardiac output.

Figure 13 shows the scatterplot of systemic vascular resistance in dyne sec./cm^5 and toe temperature in degrees Centigrade for all subjects. There is no apparent relationship between these two parameters. Examination of some individual cases showed a general inverse relationship, that is, when toe temperature was high, SVR was low for that individual.

Summary

Analysis of data provided the range and mean toe temperatures for this group of subjects and information regarding the relationship of toe temperature to other physiologic indicators. Differences were noted between subgroups, survivors and non-survivors and complicated and uncomplicated sepsis. Subject data were presented as case studies using summary tables and graphs. Aspects of toe temperature changes were discussed in relationship to the subjects' clinical status.

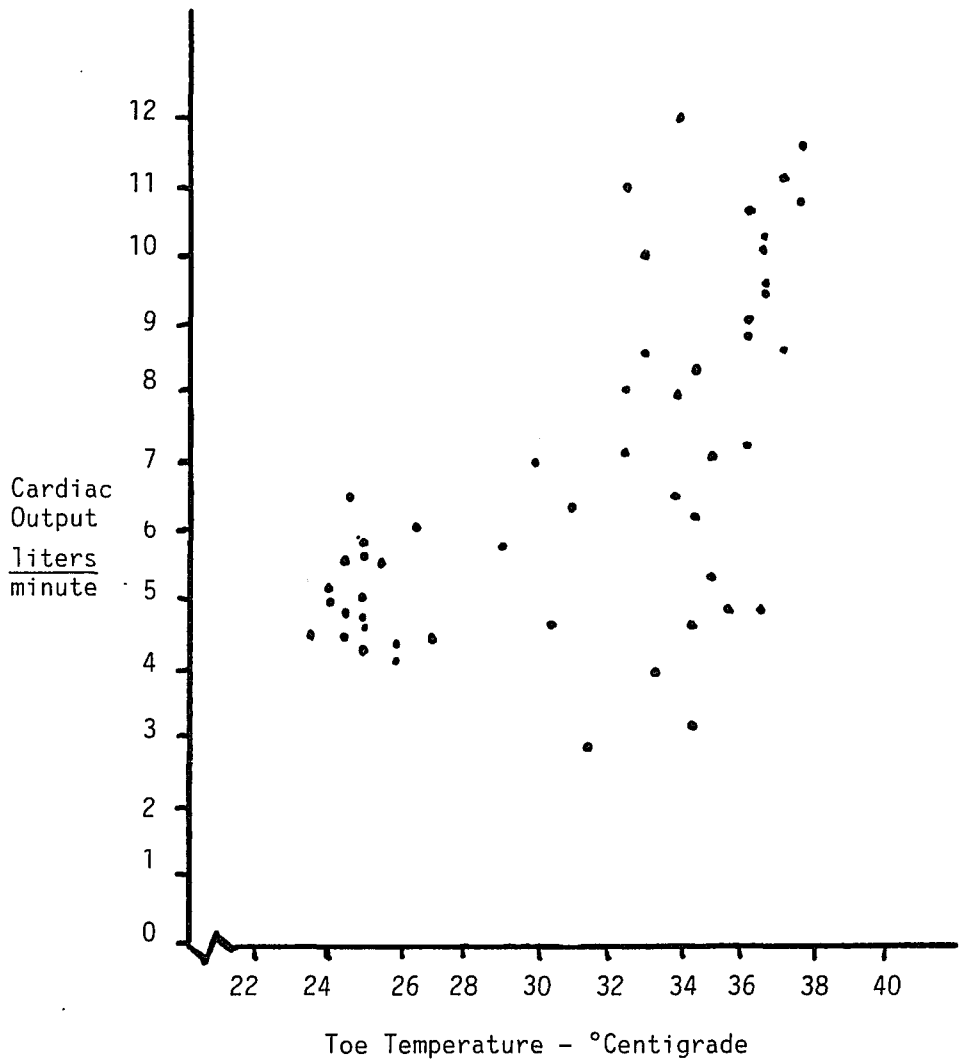

Figure 12. Scattergram of Cardiac Output and Toe Temperature - All Subjects

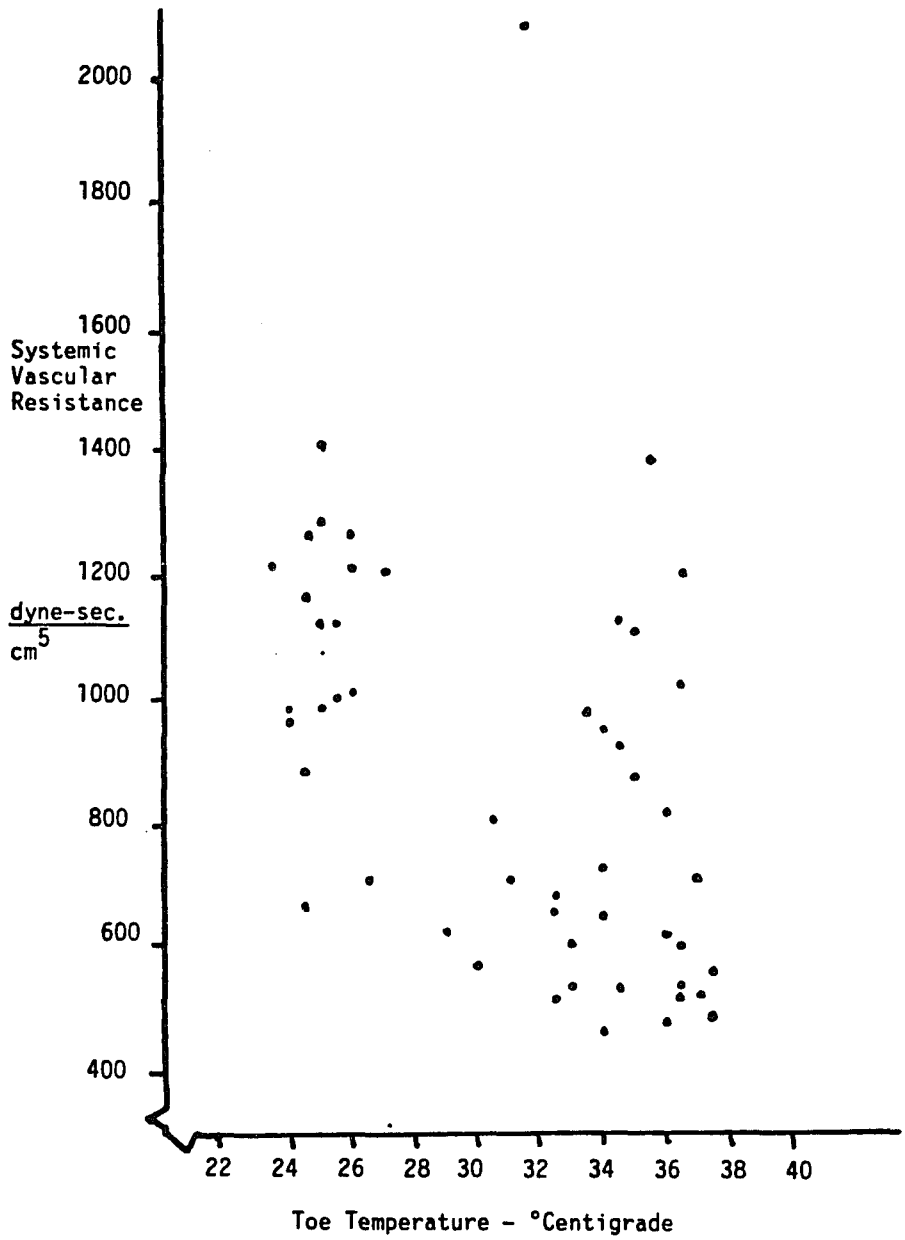

Figure 13. Scattergram of Systemic Vascular Resistance and Toe Temperature - All Subjects

CHAPTER V

DISCUSSION AND RECOMMENDATIONS

This chapter discusses the findings of the study. Limitations, implications for nursing and recommendations for further study are also presented.

Findings

The closest description of "normal" or desirable toe temperature found in the literature was that provided by Matthews et al. (1974a). These researchers described a "warm plateau" of 34° C. following open-heart surgery and recommended treatment to maintain toe temperature greater than 34° C.

The mean toe temperature for subjects in this study was 32.4° C. with a range of 23.5 to 38° C. Mean toe temperature was higher for survivors (33.9° C.) than non-survivors (28.5° C.) and higher for those subjects with uncomplicated sepsis (35.1° C.) than for subjects with complicated sepsis (29.3° C.).

Joly and Weil (1969) reported a correlation between toe temperature and cardiac output ($r = 0.71$). The present study also showed a positive relationship between toe temperature and cardiac output ($r = 0.63$).

Facey, Weil and Rosoff (1966) reported an inverse relationship between toe temperature and SVR in patients with shock due to pancreatitis. The present study did not show an inverse relationship between

these parameters for the total group. Failure in this study to show the previously reported results may be attributed to the small number of subjects, the limited readings available or that the readings were taken at two-hour intervals. Specific characteristics of the sample may also have been a factor; four of the six subjects had peritonitis. It may be that in sepsis due to peritonitis, with a large but localized area of inflammation/vasodilation, toe temperature is not an accurate indication of SVR.

Specific changes in toe temperature were presented as case studies. Possible explanations were offered based on available clinical information, however, cause and effect relationships cannot be established and results are not generalized to other patient situations.

Subject one showed a major decline in toe temperature associated with the use of hypothermia treatment for fever.

Subject two showed two major declines in toe temperature. The first was not explained. The second occurred during dialysis. Systemic vascular resistance decreased, likely a reflection of the low-pressure mechanics of dialysis. Cardiac output increased as dopamine support was increased. The decrease in toe temperature may have been a more accurate reflection of the physiologic stress during this period than the other parameters due to the "artifact" of dialysis.

Subject three showed no major changes in toe temperature but did show trends which closely paralleled those of cardiac output in response to intravenous fluid and diuretic therapy.

Subject four was the only subject that showed a major deterioration in status during the study period. The change took place in

the final eight hours. Mean arterial blood pressure declined initially with the toe temperature but responded to vasopressor; toe temperature did not increase. Toe temperature decreased two hours before urine output decreased. Data for cardiac output were not available for each two hour reading, therefore, the temporal relationship of the changes in toe temperature and cardiac output could not be examined. This early and sustained decline in toe temperature may have been an isolated event, or may offer support for the reliability of toe temperature monitoring reported by Henning et al. (1979) and Berne's (1962) assertion that peripheral perfusion is an early indicator of decompensated shock.

Subject five showed two major declines in toe temperature associated with increases in core temperature. The changes were not explained by the clinical situation, but both occurred in the morning following the subject's baths. Direct cause and effect cannot be established, but there are reports of fever due to abnormal vasoconstriction (Ross et al., 1969; Spitzer & Brock, 1968). The question remains whether the febrile episodes exhibited by this subject were due to infection or to decreased heat loss through vasoconstricted skin tissue. Knowledge of peripheral skin temperature may be useful in assessing core temperature changes and appropriate therapy.

Subject six showed the lowest trends for toe temperatures and the lowest individual reading (23.5° C.). These results are consistent with the clinical picture of sepsis complicated by severe cardiac insufficiency.

Subject six showed two major increases in toe temperature. The first was associated with a two hour period in which low-dose dopamine was discontinued. Simultaneous readings showed a decrease in cardiac output and increase in SVR. The changes may have been due to measurement error or unrelated events. A possible explanation of renal vasoconstriction and redistribution of blood flow was offered. The second increase in toe temperature may be explained, in part, by diuresis and cardiovascular improvement following an episode of fluid overload. The other parameters returned to prior, more optimal levels, therefore, resolution of the episode of overload does not fully explain the magnitude of the increase in toe temperature.

An observation of hypothermia in this subject with obvious sepsis and the increase in core temperature when Nipride was discontinued was reported. An explanation of obligatory heat loss due to vasodilator therapy was offered.

Limitations

1. The data were transcribed from the graphic record to the data sheet by the investigator. No interrater reliability was established.

2. Data were recorded onto the graphic record by several nurses caring for the subjects. As the investigator was not present for all readings, possible error in data recording could not be estimated. However, interrater reliability was established for toe temperature readings.

3. Toe temperatures were recorded every two hours. These intervals may not have been frequent enough to detect and/or explain changes. The unsolicited testimony of the nurses participating in the data collection indicated that toe temperature was valuable in alerting them to changes in the subjects' status, but that these changes were not always reflected in the parameters recorded two hours later.

4. Several setting limitations pertaining to consent were identified. Obtaining consent proved to be a major difficulty in the study, one that was not anticipated. Several potential subjects were non-English speaking or their family members did not speak English. In most cases, the subjects were themselves too ill to give consent; consent had to be obtained from family members. Two potential subjects did not have family members available. The most frequent difficulty was family refusal to give consent for the study due to the severity of illness and the crisis nature of the situation. Families seemed unable to understand explanations of the study or did not want anything unnecessary done to the subject. A final limitation was that the investigator could not have cared for the subject prior to obtaining consent. The investigator was employed on the study unit and had cared for a number of potential subjects. Permission for other staff to obtain consent was later obtained from the Assistant Director of Nursing for Research.

The difficulty in obtaining consent reduced the number of subjects and, at times, delayed the timing of the study. While all subjects had been critically ill, not all were unstable during the course of the study. One subject was actually hypertensive.

Implications for Nursing

Based on the literature review and observations made during this study, there appears to be support for the importance of including peripheral perfusion in the assessment of critically ill patients. Peripheral skin temperature assessment could aid in the interpretation of two physiologic areas: thermoregulation and hemodynamics. Skin temperature measurement may be valuable in assessment of fluid and diuretic therapy, particularly if invasive monitoring is not available. Further investigation is needed to establish the reliability of skin temperature measurement as a routine assessment tool.

Recommendations

If a similar study of toe temperature measurement were conducted, more frequent recording of all parameters or continuous trending which is now available, would be recommended.

The case study analyses revealed some unexpected changes that may have been isolated, idiosycratic events or that may warrent further investigation of the questions they raise.

1. To what extent are febrile episodes in critically ill patients due to therapeutic dehydration or environmental factors rather than infection or central thermoregulatory dysfunction? What factors should be considered in the selection of a method to treat fever?

2. What effect does routine use of hypothermia for control of fever have in patients with peripheral vascular disease? Does this routine method further impair peripheral circulation in this group of patients?

3. What is the effect of vasodilator therapy on core temperature? Can vasodilator therapy mask fever, a valuable indicator of infection?

4. Regarding the hemodynamic effects of low-dose dopamine: are certain patients at risk of significant hemodynamic alteration with the use of this generally considered low-risk therapy? Are there parameters which should be carefully monitored upon institution or withdrawal of this therapy?

Summary

This chapter discussed the findings of this study. Toe temperatures for this study group are described and compared to prior reports. Questions raised by case study analyses are also discussed.

APPENDIX A

AGENCY APPROVAL TO CONDUCT NURSING RESEARCH

THE UNIVERSITY OF ARIZONA
HEALTH SCIENCES CENTER
TUCSON, ARIZONA 85724

UNIVERSITY HOSPITAL

June 9, 1983

Gail Flodquist, R.N.
1002 N. Jerrie Avenue
Apt. 21
Tucson, Arizona 85711

Dear Ms. Flodquist:

It is a pleasure to approve the study, "Measurement of Toe Temperature as an Early Indicator of Alterations in Peripheral Perfusion." Ms. Shelley Zitman, the Head Nurse on 5 West, will be your contact person for the study (626-7487). Please contact her with any additional questions and concerns you may have.

Sincerely,

Ada Sue

Ada Sue Hinshaw, R.N., Ph.D., F.A.A.N.
Associate Director of Nursing for Research
Nursing Department
University Hospital
Professor, Director of Research
College of Nursing
University of Arizona

cc: Shelley Zitman, R.N.
Head Nurse, 5 West

ASH/kjm

APPENDIX B

PHYSICIAN'S CONSENT FORM

Date, 1983

Dr.

I am conducting a research study to investigate the value of toe temperature monitoring as an early indicator of alteration in peripheral perfusion in critically ill patients. The study will be conducted with 20 patients admitted to the surgical intensive care unit.

The research protocol is as follows. A skin probe will be secured to the ventral surface of the subject's great toe. Toe temperatures will be recorded every two hours for the duration of the study, not to exceed 48 hours. A second temperature probe will be used to record ambient temperature. Other parameters currently used to monitor these patients (heart rate, blood pressure, urine output and core temperature) will be recorded from the graphic record. When available, information from invasive monitoring techniques will be used; these include cardiac output and calculated systemic vascular resistance. Demographic data obtained from the patient's chart will include age, sex, diagnosis and other pertinent indicators of the patient's condition.

Subject selection will be based on history and current status indicating potential for impaired perfusion, or shock. All subjects, or the individual authorizing permission for inclusion in the study, must read and understand English. The nature of the study and the risks and benefits of participation will be explained and subjects will be assured anonymity. Subjects who agree to participate will sign a written consent form. I have enclosed a copy of the Subject's Consent Form. In the event the subject is unable to sign the consent form, authorization will be obtained from the closest relative or guardian.

I am seeking your permission to contact your patients for inclusion in my study. I am willing to answer any further questions you may have regarding my study and/or your patients' involvement. If you approve, please sign and return the enclosed Physician's Consent Form. Thank you.

Gail Flodquist, R.N.

PHYSICIAN CONSENT FORM

Permission has been given to Gail Flodquist, R.N., to contact my patients for inclusion in a research study conducted through the University of Arizona, College of Nursing, Graduate Division. The research project is titled: Measurement of Toe Temperature as an Early Indicator of Alterations in Peripheral Perfusion. This consent is given with the provision that consent is obtained from the individual patient. (This study has been approved by the Human Subjects Committee of the University of Arizona.)

I also understand that this consent form will be filed in an area designated by the Human Subjects Committee with access restricted to the investigator or authorized representative of the College of Nursing.

_____ _____

Physician's Signature Date

APPENDIX C

HUMAN SUBJECTS COMMITTEE APPROVAL

THE UNIVERSITY OF ARIZONA
TUCSON, ARIZONA 85724
HUMAN SUBJECTS COMMITTEE

17 May 1983

Gail Flodquist, B.S.N., R.N.
College of Nursing
Arizona Health Sciences Center

Dear Ms. Flodquist:

We are in receipt of your project, "Measurement of Toe Temperature as an Early Indicator of Alterations in Peripheral Perfusion",which was submitted to this Committee for review. The procedures to be followed in this study pose no more than minimal risk to the participating subjects. Regulations issued by the U.S. Department of Health and Human Services [45 CFR Part 46.110(b)] authorize approval of this type project through the expedited review procedures, with the condition that subjects' anonymity be maintained. Although full Committee review is not required, a brief summary of the project is submitted to the Committee for their information and comment, if any, after administrative approval is granted. This project is approved effective 17 May 1983.

Approval is granted with the understanding that no changes will be made in either the procedures followed or in the consent form to be used (copies of which we have on file) without the knowledge and approval of the Human Subjects Committee and the Departmental Review Committee. Any physical or psychological harm to any subject must also be reported to each committee.

A university policy requires that all signed subject consent forms be kept in a permanent file in an area designated for that purpose by the Department Head or comparable authority. This will assure their accessibility in the event that university officials require the information and the principal investigator is unavailable for some reason.

Sincerely yours,

Milan Novak

Milan Novak, M.D., Ph.D.
Chairman

MN/jm

cc: Ada Sue Hinshaw, R.N., Ph.D.
College Review Committee

APPENDIX D

SUBJECT'S CONSENT FORM

SUBJECT'S CONSENT

Project Title: Measurement of Toe Temperature as an Early Indicator of Alterations in Peripheral Perfusion

Investigator: Gail Flodquist, BSN, RN

You are invited to participate in a study designed to learn more about skin temperature monitoring to evaluate blood circulation in patients in intensive care units. Skin temperature reflects circulation in nearby blood vessels. Circulation, especially in the arms and legs, may change temporarily during illness or following surgery and such information is important to those caring for patients.

For this study, a temperature probe will be taped to the bottom of your great toe. The probe will be connected to a temperature monitor. The toe temperature will be recorded every two hours. Other readings normally taken by the nursing staff, such as heart rate, blood pressure, urine output and temperature will also be recorded. The study will last for 48 hours.

The possible risks involved in this study are skin irritation from the tape or from the probe. The investigator will check under the probe every day for signs of skin irritation. These risks are considered minimal. However, in the event of physical injury resulting from the research procedures, please be advised that financial compensation for wages or time lost and the costs of medical care and hospitalization are not available and must be borne by you.

There will be no additional cost to you, nor will you receive financial compensation for your participation. There is no direct benefit to you for participating, but the results of the study may be beneficial to other patients because of improved monitoring techniques.

All information used in this study is confidential. If you agree to participate, the investigator will use some information from your medical record such as your age, diagnosis and laboratory tests. Your name will not be used. All information will be coded by number and analyzed by computer. If the results of this study are published, your identity will not be revealed.

If you decide not to participate in the study, or to withdraw at any time, you may do so without incurring ill will or affecting your medical or nursing care. The investigator will be available to answer any questions you may have regarding the study. A copy of this consent form is available upon request.

If you understand what is involved and you consent to participate in this study, please read and sign the statement below.

"I have read the above 'Subject's Consent'. The nature, demands, risks and benefits of the project have been explained to me. I understand that I may ask questions and that I am free to withdraw from the project at any time without incurring ill will (or affecting my medical care). I also understand that this consent form will be filed in an area designated by the Human Subjects Committee with access restricted to the principal investigator or authorized representatives of the College of Nursing. A copy of this consent form is available to me upon request."

Subject's Signature _____ Date _____

Parent or Guardian _____ Date _____

I have carefully explained to the subject the nature of the above project. I hereby certify that to the best of my knowledge the subject signing this consent form understands clearly the nature, demands, benefits, and risks involved in participating in this study. A medical problem or language or educational barrier has not precluded a clear understanding of his/her involvement in this project.

Principal Investigator _____ Date _____

APPENDIX E

DEMOGRAPHIC DATA SHEET

DEMOGRAPHIC DATA

Subject Number ____

I.D. Number _____

1. Subject's Age: ____ 2. Subject's Dex: M _____ F _____

3. Diagnosis: _____

4. Surgical Site or Site of Injury:

Abdomen _____ Head _____ Multiple Sites ____

Chest _____ Genitourinary _____ None _____

5. Significant Fluid Loss/Imbalance: Yes ___ No ___

Hemorrhage _____ Third Space _____

Fluid and Electrolyte _____ Post-operative Warming _____

6. Indication of Significant Infection: Yes ____ No _____

Elevated WBC (> 10,000)

Fever (> 38.5° C.)

Positive Culture: Blood ____ Organism: Gram-positive _____

Urine ____ Gram-negative _____

Sputum ___ Fungal _____

Other ____ Mixed _____

7. Major Hemodynamic Category:

Hypovolemic ___ Distributive/Septic _____

Cardiogenic ___ Obstructive _____

Not Determined _____

8. Medications: Dopamine ___ Dosage: $\leq$ 5 mcg/kg/min $\geq$ 5 mcg/kg/min ___

Nitroprusside ___ Diuretic ___ Other _____

9. Elevated Creatinine Level: Yes ___ No ___

10. Hypotensive Episode During Study: Yes ___ No ___

APPENDIX F

CLINICAL DATA SHEET

LEGEND FOR CLINICAL DATA SHEET

1. Date

2. Time

3. T.T. °C: toe temperature in degrees Centigrade

4. A.T. °C: ambient temperature in degrees Centigrade

5. T - A: toe minus ambient temperature gradient in degrees Centigrade

6. Core °C: core or rectal temperature in degrees Centigrade

7. BP: systolic and diastolic blood pressure as recorded on graphic record

8. MABP: mean arterial blood pressure

9. HR: heart rate

10. UO: urine output

11. CO: cardiac output

12. RAP: right atrial pressure

13. SVR: systemic vascular resistance

14. IV rate: total intravenous fluids infused for current hour

CLINICAL DATA SHEET

Subject Number _____

ID Number _____

DATE	TIME	T.T°C	A.T.°C	T-A	CORE °C	BP	MABP	HR	UO	CO	RAP	SUR	IU RATE

APPENDIX G

TEMPERATURE PROBE RELIABILITY SHEET

TEMPERATURE PROBE RELIABILITY

Subject Number	Mercury Thermometer	Skin Probe Temperature	Reliability	Ambient Probe Temperature	Reliability

APPENDIX H

DATA COLLECTION GUIDELINES

DATA COLLECTION GUIDELINES

Project Title: Measurement of Toe Temperature as an Early Indicator of Alterations in Peripheral Perfusion

Investigator: Gail Flodquist, BSN, RN

You are being asked to assist in the data collection phase of a study I am conducting in this unit. The study involves monitoring toe temperatures of selected patients every two hours for a 48-hour period. Room temperature will also be recorded at these intervals. The data collection guidelines are as follows.

1. Prior to the time period when you will record the temperatures, I will ask you to record "trial" readings of the toe temperature and ambient/room temperature. I will record the temperature readings at the same time.

2. Every two hours, when you record standard monitoring values for the patient, record the toe temperature in Column #3 (T.T.°F) and record ambient temperature in Column #5 (A.T.°F) on the Clinical Data Sheet.

3. You will not be responsible for completing the remaining columns of the Clinical Data Sheet. I will complete those columns later from the patient's graphic record.

4. There may be times when the toe temperature probe must be removed and you will be asked to do this. Such times would be when the patient is transported off the unit (to O.R., diagnostic testing, etc.) or upon the patient's or family's request. Please notify me as soon as possible if you have to remove the temperature probe.

The estimated time required for recording these temperature readings is two minutes for each two-hour interval. If questions or problems arise during your data collection period, please contact me at the time listed below. Your assistance in this study is sincerely appreciated.

Gail Flodquist Phone: 326-4849

APPENDIX I

DATA COLLECTOR RELIABILITY SHEET

DATA COLLECTOR RELIABILITY

Rater Number/ Initials	___/__	___/__	___/__	___/__
Rater Skin Probe Reading	_____	_____	_____	_____
Investigator Skin Probe Reading	_____	_____	_____	_____
Reliability	_____	_____	_____	_____
Rater Ambient Probe Reading	_____	_____	_____	_____
Investigator Ambient Probe Reading	_____	_____	_____	_____
Reliability	_____	_____	_____	_____

LIST OF REFERENCES

Andreoli, K. G., V. H. Fowkes, D. P. Zipes, and A. B. Wallace (1975). Comprehensive cardiac care: A text for nurses, physicians and other health practitioners (3rd ed.). Saint Louis: C.V. Mosby Company.

Berne, C. J. (1962). Diagnosis of compensated hypovolemic shock. American Journal of Surgery, 103, 412-414.

Berne, R. M. and M. N. Levy (1981). Cardiovascular physiology (4th ed.). Saint Louis: C.V. Mosby Company.

Brock, L., J. M. Skinner, and J. T. Manders (1975). Observations on peripheral and central temperatures with particular reference to the occurrence of vasoconstriction. The British Journal of Surgery, 62, 589-595.

Burton, A. C. (1939). Range and variability of blood flow in human fingers and vasomotor regulation of body temperature. American Journal of Physiology, 127, 437-453.

Chaudry, I. H. and A. E. Baue (1982). Overview of hemorrhagic shock. In R. A. Cowley and B. F. Trump (Eds.), Pathophysiology of shock, anoxia and ischemia (pp. 203-219). Baltimore: Williams and Wilkins.

Cohn, J. N. and J. A. Franciosa (1977a). Vasodilator therapy of cardiac failure. The New England Journal of Medicine, 297, 27-31.

_____ (1977b). Vasodilator therapy of cardiac failure. The New England Journal of Medicine, 297, 254-258.

Dembert, M. L. (1982). Medical problems from cold exposure. American Family Physician, 25, 99-106.

Facey, F. L., M. H. Weil, and L. Rosoff (1966). Mechanism and treatment of shock associated with acute pancreatitis. American Journal of Surgery, 111, 374-381.

Felder, D., E. Russ, H. Montgomery, and O. Horwitz (1954). Relationship in the toe of skin surface temperature to mean blood flow measured with a plethysmorgraph. Clinical Science, 13, 251-257.

Guyton, A. (1981). Textbook of medical physiology (6th ed.). Philadelphia: W. B. Saunders Company.

Henning, R. J., F. Wiener, S. Valdes, and M. H. Weil (1979). Measurement of toe temperatue for assessing the severity of acute circulatory failure. Surgery, Gynecology and Obstetrics, 149, 1-6.

Hinshaw, L. (1982). Overview of endotoxin shock. In R. A. Cowley and B. F. Trump (Eds.), Pathophysiology of shock, anoxia and ischemia (pp. 219-235). Baltimore: Williams and Wilkins.

Ibsen, B. (1967). Treatment of shock with vasodilators measuring skin temperature on the big toe. Diseases of the chest, 52, 425-429.

Jensen, D. (1976). The principles of physiology. New York: Appleton-Century-Crofts.

Joly, H. R. and M.H. Weil (1969). Temperature of the great toe as an indication of the severity of shock. Circulation, 39, 131-138.

Laragh, J. H. (1980). Hyprtension. Drug Therapy, 10, 71-88.

MacLean, L. D. (1977). Shock: Causes and management of circulatory collapse. In D.C. Sabiston (Ed.), Davis-Christopher's Textbook of Surgery (pp. 65-80). Philadelphia: W. B. Saunders.

Matthews, H. R., J. B. Meade, and C. C. Evans (1974a). Significance of prolonged peripheral vasoconstriction after open-heart surgery. Thorax, 29, 338-342.

_____ (1974b). Significance of prolonged peripheral vasoconstriction after open-heart surgery. Thorax, 29, 343-348.

Ross, B. A., L. Brock, and A. Aynesly-Green (1969). Observations on central and peripheral temperatures in the understanding and management of shock. The British Journal of Surgery, 56, 877-882.

Rothstein, R. J. (1979). Hemorrhagic shock in multiple trauma. Topics in Emergency Medicine, 1, 29-40.

Ruiz, C. E., M.H. Weil, and R. W. Carlson (1979). Treatment of circulatory shock with dopamine. Journal of the American Medical Association, 242, 165-168.

Schumer, W. (1982). General treatment of septic shock. In R. A. Cowley and B. F. Trump (Eds.), Pathophysiology of shock, anoxia and ischemia (pp. 479-482). Baltimore: Williams and Wilkins.

Shoemaker, W. C. (1982). Pathophysiology and therapy of hemorrhage and trauma states. In R. A. Cowley and B. F. Trump (Eds.), Pathophysiology of shock, anoxia and ischemia (pp. 439-446). Baltimore: Williams and Wilkins.

Shoemaker, W. C., E. S. Montgomery, E. Kaplan, and D. H. Elwyn (1973). Physiologic patterns in surviving and nonsurviving shock patients: Use of sequential cardiorespiratory variables in defining criteria for therapeutic goals and early warning of death. Archives of Surgery, 106, 630-636.

Spitzer, A. G. and L. Brock (1968). The recognition of hypovolaemia after open-heart surgery. Guy's Hospital Report, 117, 131-138.

Thal, A. P., E. B. Brown, A. S. Hermeck, and H. H. Bell (1971). Shock: A physiologic basis for treatment. Chicago: Year Book Medical Publishers.

Webb, W. R. and R. A. Brunswick (1982). Microcirculation in shock - clinical review. In R. A. Cowley and B. F. Trump (Eds.), Pathophysiology of shock, anoxia and ischemia (pp. 181-185). Baltimore: Williams and Wilkins.

Weil, M. H. (1977). Current understanding of mechanisms and treatment of circulatory shock caused by bacterial infections. Annals of Clinical Research, 9, 181-191.

_____ (1981). Evaluation and treatment of the patient with cardiovascular collapse. Emergency Medicine, 13(9), 92-107.

Weil, M. H. and A. A. Afifi (1970). Experimental and clinical studies on lactate and pyruvate as indicators of the severity of acute circulatory failure. Circulation, 41, 989-1001.

Weil, M. H. and R. J. Henning (1979). New concepts in the diagnosis and fluid treatment of circulatory shock. Anesthesia and Analgesia, 58, 124-132.

Wilson, R. F., E. J. Sarver, and P. L. LeBlanc (1971). Factors affecting hemodynamics in clinical shock with sepsis. Annals of Surgery, 174, 939-943.

Woodcock, J. P. (1975). Theory and practice of blood flow measurement. London: Butterworth.

Zweifach, B. W. and A. Fronek (1975). The interplay of central and peripheral factors in irreversible hemorrhagic shock. Progress in Cardiovascular Diseases, 18, 147-179.