ACCIDENTAL HYPOTHERMIA

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Accidental hypothermia is a major cause of morbidity and mortality in the United States. This is especially true among certain groups such as outdoor workers, the homeless, the elderly and very young, and trauma victims. Hypothermia is probably grossly underreported in this country because most cases are thought to be secondary to some other cause or situation.

Temperature Regulation

The regulation of body temperature allows homeothermic animals to have considerable independence from environmental temperature and a near constant internal environment despite exposure to a wide range of external conditions. This regulation is necessary for optimal metabolic function because of the temperature dependence of enzymatic reactions in the body. Man's temperature is regulated to an optimal level which is near the maximum temperature tolerated by most metabolically active cells. Consequently, a rise of only a few degrees will result in death after a short period of time. On the other hand, a comparable fall in temperature is tolerated easily, as illustrated in Figure 1.

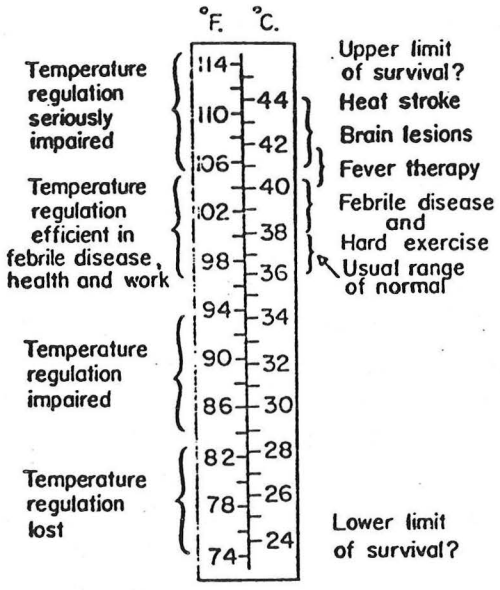

Figure 1. Body temperatures under different conditions illustrating upper and lower limits of survival.

The mechanisms of transfer of heat between man and the environment can be divided into evaporative and nonevaporative means as seen in Figure 2.

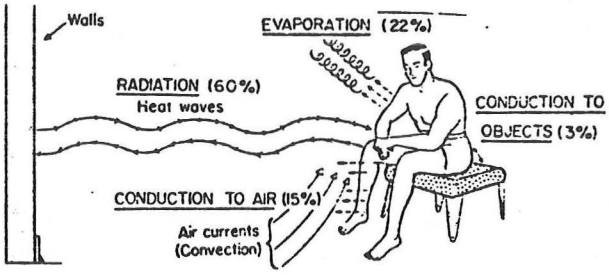

Figure 2. Mechanisms of heat loss from the body

Evaporation accounts for the loss of 0.6 kcal per gram of water evaporated. In a cool environment where heat loss from sweating is minimal, evaporation of insensible perspiration (respiratory tract, oral cavity, and small amounts diffusing through the skin) can account for 20-25% of basal heat production. As heat loss increases with cold exposure, this mechanism will account for only a small portion of total heat loss to the environment and is not regulated.

Nonevaporative heat transfer is very important in temperature regulation in a cold environment and consists of conduction, convection, and radiation. The amount of heat dissipated by any of these mechanisms is proportional to the temperature difference between a subject and the environment. Conduction, the transfer of heat in kinetic form between molecules or atoms of objects in contact, is usually of little consequence unless the subject is immersed in cold water, where the thermal conductivity is 32 times as great as air. Convection is heat transfer by movement of molecules between two locations of different temperatures. The loss of body heat by this mechanism is greatly increased by wind or water currents and large temperature gradients between the skin and environment. Radiation is the transfer of heat between objects by nonparticulate means or electromagnetic waves, i.e., the warmth felt from a warm object. The transfer of heat by this mechanism is greater when a large temperature differential exists between objects. At an ambient temperature of about 20°C, heat loss by radiation in man can account for up to 70% of heat produced. The uncovered head is an important source of radiant heat loss accounting for up to one half of the total body heat production at 4°C. The loss of heat by radiation is also proportional to the exposed surface area of the body. For example, more heat is lost to a cold environment in a spread eagle position than a curled position.

Some mechanism of temperature regulation is obviously necessary to maintain a metabolically optimal temperature. That the body can regulate temperature despite the above mechanisms of heat loss implies some sensor mechanism exists that compares actual body temperature to some reference point, and any deviation from this point results in effector mechanisms designed to return the temperature to normal. Normal rectal temperature in man is generally considered to be in the range of 36.5°C to 37.6°C with oral temperatures about 0.6°C lower. Rectal temperature, however, may vary even within the rectum because of the close proximity of parts of this organ to the veins draining the lower extremities. This problem must be considered in hypothermic patients who have extremities that are significantly cooler than their core temperature. The range of normal temperatures in a healthy population is broad as illustrated in Figure 3 representing the oral temperatures of 276 medical students sitting in class between 8 and 9 a.m.[1]

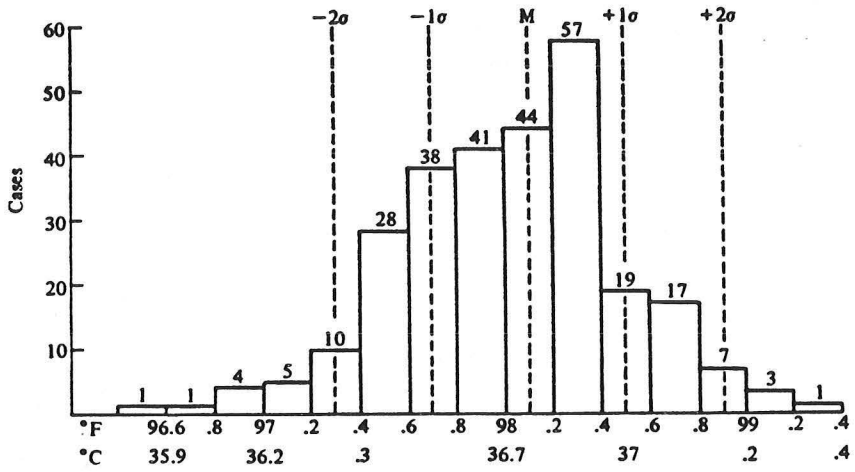

Figure 3. Histogram of oral temperatures of 276 medical students seated in class between 8 and 9 a.m. Mean, 98.1 ± 0.4°F.

Also a circadian pattern in body temperature has been reported with the lowest temperatures found in the morning and the warmest in the early afternoon. Although peak daily temperature is the same regardless of season, morning temperatures are lower in the winter than in the summer as shown in Figure 4.[2]

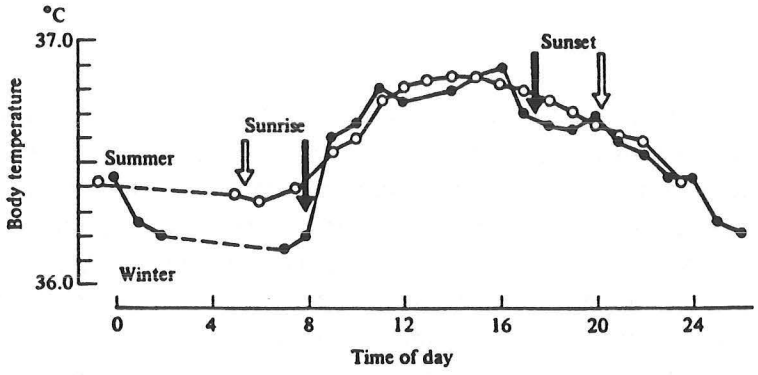

Figure 4. Circadian rhythm in body temperature.

A system for temperature control, as mentioned above, needs a sensor mechanism, controller, and effector mechanisms designed to maintain a constant body temperature. The accepted physiologic counterparts to these components are as follows:

Sensors	Controller	Effector Mechanisms
Skin Visceral Hypothalamus	Hypothalamus	Behavior Sweating Vasoconstriction Shivering Nonshivering thermogenesis

Cold and warm thermosensors are located throughout the skin. However, the density of these receptors varies considerably with a greater number present in the skin of the face and hands than the legs and chest. Other cold thermosensors have been identified in the upper gastrointestinal tract, tongue, respiratory system, muscles and spinal cord. Histologically, cold receptors are unmyelinated fibers that divide into a number of naked nerve endings that penetrate superficially into the cytoplasm of basal epithelial cells[3]. Physiologically, at least two types of receptors exist, warm and cold, with discharge frequencies increasing as temperature goes up and down respectively as shown in Figure 5[4].

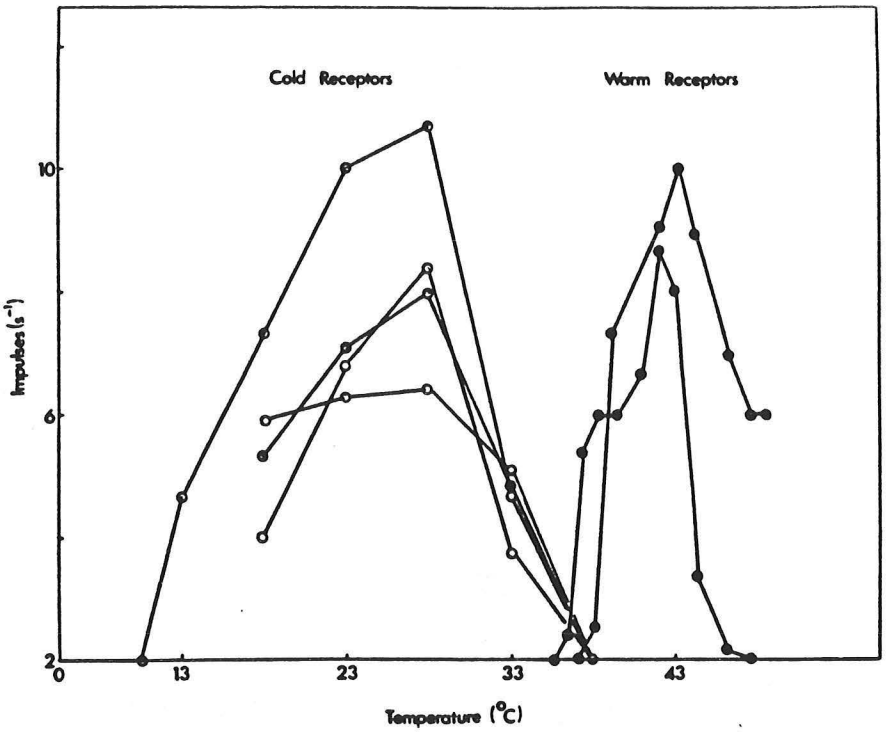

Figure 5. Static sensitivity curves for four cold receptors and two warm receptor preparations in rat skin.

Each cold thermoreceptor has a discharge or firing frequency that is related to both static temperature and the rate of change of temperature. This discharge frequency seems to be due to the properties of a transmembrane sodium pump[5] skin thermosensors begin to fire at about 33°C. As temperature falls, the static temperature discharge frequency increases with maximum discharge rates at about 20°C. Figure 6[6] illustrates this temperature dependence of discharge rate.

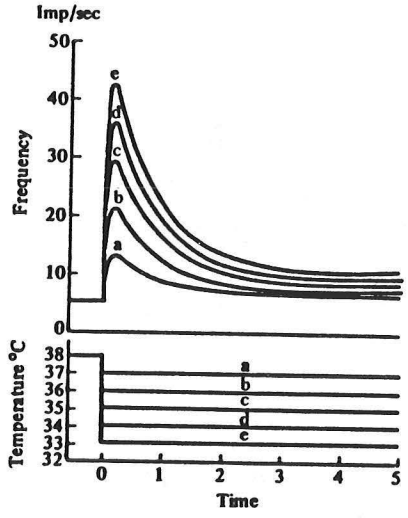

Figure 6. Impulse frequency of single units related to temperature change.

Each receptor has a characteristic firing rate for a given temperature with colder temperatures having a faster discharge frequency. The rate of change of temperature also influences discharge rate in that rapid changes in temperature influence the frequency of firing more than slower changes as seen in Figure 7[6].

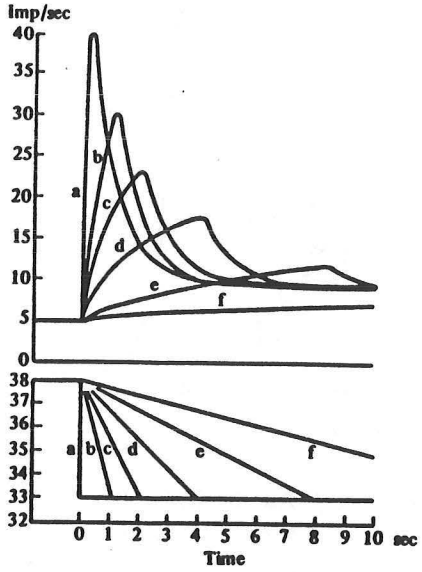

Figure 7. Impulse frequency of single units related to temperature change.

The net effect is complicated but can be appreciated in Figure 8[7] where a cold themosensor has a given firing rate at 26°C. A rapid increase to 30°C results in silence during the change of temperature with the resumption of a new slower firing rate when the new temperature is reached. On the other hand, a rapid drop in temperature results in a rapid discharge rate followed by a gradual decrease to a new frequency, faster than that of the higher temperature.

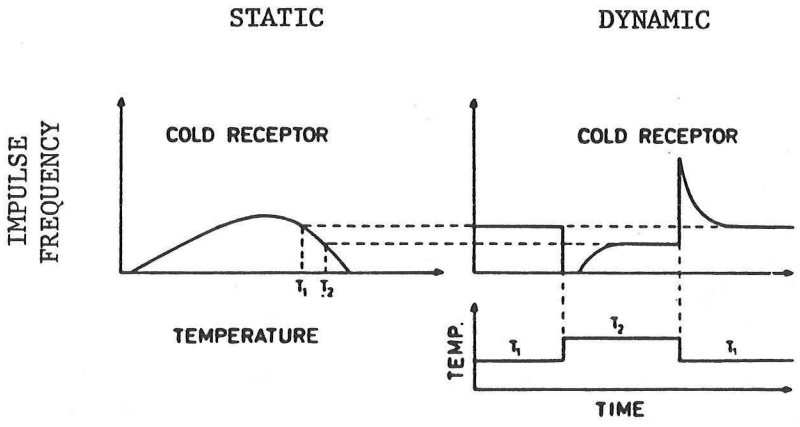

Figure 8. Generalized response of cutaneous cold receptors to constant temperatures (static response) and to rapid temperature changes (dynamic response).

The modification and transmission of the above information to the central nervous system occurs, along with pain sensation, through the dorsal nerve roots to the lateral spinothalamic tracts and eventually the hypothalamus and cortex via the thalamocortical system. Cortical stimulation by this system results in conscious temperature sensation and behavioral changes that reduce heat loss.

The role of the hypothalamus in the regulation of body temperature is well established. This area receives information regarding body temperature from the entire body, senses the temperature of arterial blood, and coordinates the effector systems designed to generate and maintain temperature. Multiple neuronal systems provide input from peripheral and cutaneous thermoreceptors, spinal thermoreceptors, midbrain reticular formation, brainstem monoaminergic pathways, and the limbic system. Anatomically, data suggest that at least two areas are involved in this complex process. A group of cells in the posterior hypothalamus, the "heat maintenance" center, receives impulses from peripheral cold thermoreceptors and when stimulated, controls and coordinates the mechanism for heat production and conservation, i.e. , shivering, vasoconstriction, and metabolic rate. When stimulated, this center also sends inhibitory impulses to the anterior hypothalamus. When this "heat maintenance" center is damaged experimentally or naturally, the ability to conserve heat or increase heat production in the cold is lost, while heat losing mechanisms remain relatively normal.

A second region in the preoptic/anterior hypothalamus seems to be more involved in heat loss mechanisms and possibly contains the "thermostat" postulated to be necessary for temperature control. Experimental damage to this "heat loss" center results in an inability to lose heat and maintain a normal temperature in a hot environment while the ability to conserve and generate heat in a cold environment is retained. This area also contains warm and cold thermosensors that monitor the temperature of arterial blood as it passes through this region of the brain[8,9,10]. If cold receptors are stimulated by a fall in arterial blood temperature, impulses are sent to the posterior hypothalamus that initiate mechanisms of heat production and conservation. Warm thermoreceptor stimulation, on the other hand, stimulates sweating, vasodilatation, and other means of heat loss. This can be appreciated in Figure 9[11] where hypothalamic warming results in an increase in the discharge frequency of a thermosensitive neuron in the preoptic area (curve A) and thereafter an increase in respiratory rate (curve B). The interaction between the effects of the peripheral and central thermosensors is complex. Heat production at any given central temperature can be modified significantly by changing skin temperature as illustrated in Figure 10[12].

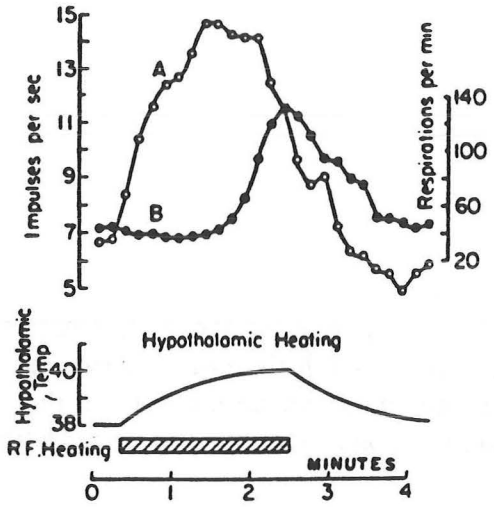

Figure 9. Discharge frequency of a neuron in the preoptic region (Curve A) and change respiratory rate (Curve B) in relation to hypothalamic temperature.

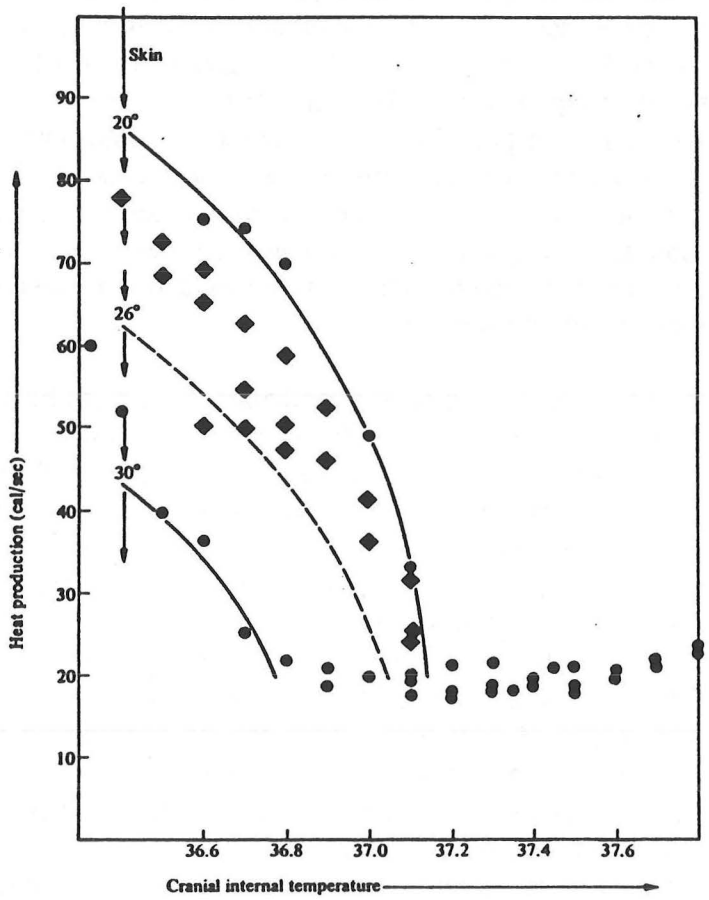

Figure 10. Results from experiments in the human calorimeter showing that the relationship between heat production and cranial internal temperature is modified by the skin temperature.

The concept of a "thermoneutral zone" is important in understanding the development of clinical hypothermia. This zone represents the range of ambient temperature within which metabolic rate is at a minimum and temperature regulation is achieved by nonevaporative physical processes alone. This zone, represented by CD in Figure 11, is a fairly narrow range in which autonomic (skin blood flow) and behavioral responses are the most important means of temperature regulation. At lower temperatures, evaporative heat loss remains minimal while nonevaporative heat loss is paralleled by an increase in heat production to maintain a normal core temperature. The zone of hypothermia (A) is reached when environmental temperature falls below a critical temperature (B) where metabolic rate is at a maximum.

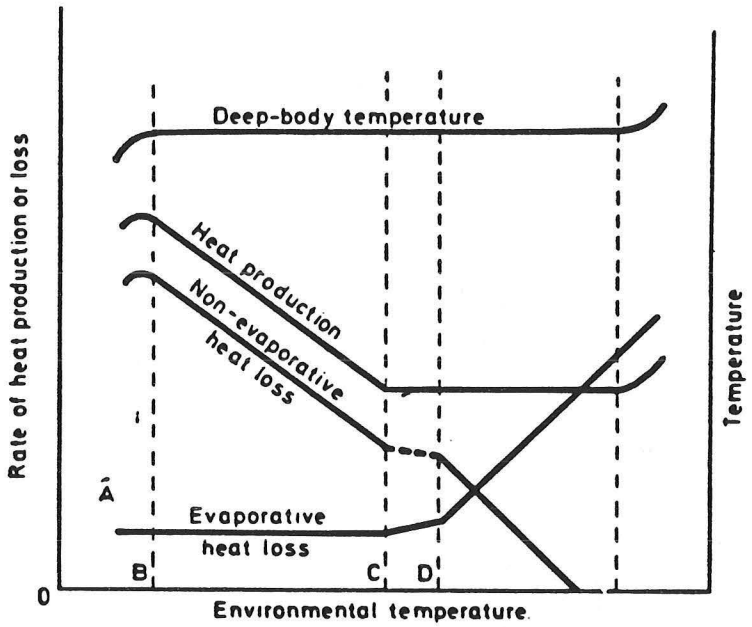

Figure 11.

The effector mechanisms set in action by the hypothalamus in response to peripheral or central cold receptor stimulation are complex but can easily be divided into means to decrease heat loss and means to increase heat production. When a subject is placed in a cold environment, the first mechanisms that comes into play to maintain temperature is a reduction in heat lost to the environment primarily through behavioral and circulatory adjustments. Behavioral adaptations to conscious perceptions of low skin temperature in man are obvious and include posturing, seeking of shelter, clothing, physical activity, and migration.

Circulatory responses to decrease heat loss fall primarily into two classes. One is to increase the insulating capability of the skin and subcutaneous tissues by shunting blood away from those tissues by vasoconstriction. This is accomplished primarily through activation of the sympathetic nervous system. This peripheral vasoconstriction increases the thickness and decreases the thermal conductivity of an outer "shell" to protect the temperature of the inner "core" consisting primarily of the skull, thoracic and abdominal viscera. This concept of a core with its protecting shell is illustrated in Figure 12.

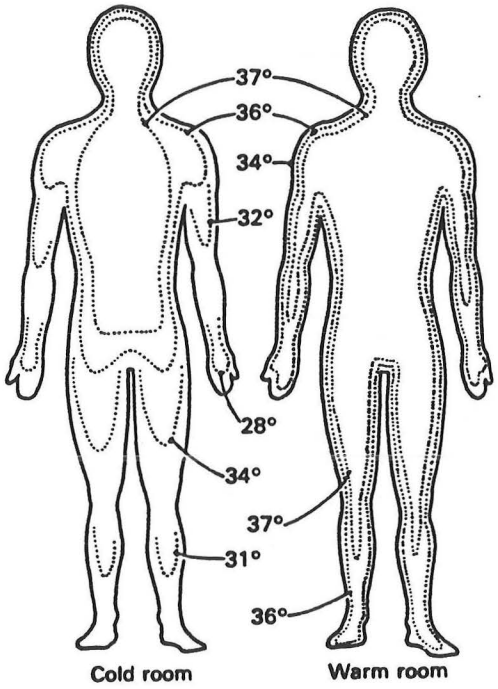

Figure 12. Schematic representation of temperature gradients forming a "core" and "shell" in a man in a cold and warm environment.

This insulating vasoconstriction can be intense and reaches a near maximum with only a small fall in core or environmental temperature. With further drops in temperatures, other mechanisms must be brought into play to maintain temperature (Figure 13).

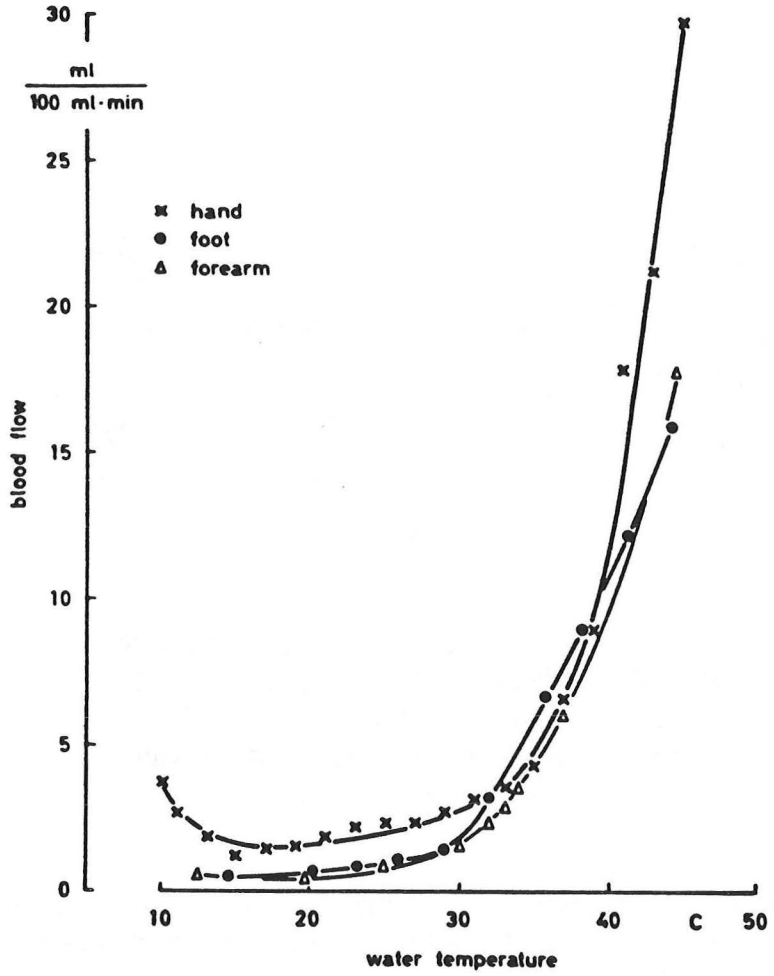

Figure 13. Relationship between blood flow in the human hand, foot, and forearm, and water temperature of the plethysmograph[13].

A second vascular mechanism which may be important in man is a counter-current heat exchange system in the extremities. Figure 14 illustrates this concept. In a warm environment, superficial veins dilate to facilitate heat transfer from the vascular system to the environment. With cold temperatures, however, veins in close proximity to the arteries may become more dilated with arterial heat transferred to them in the proximal extremities and returned to the central (core) circulation. This counter-current mechanism is highly developed in some homeotherms but its relative importance in man is unknown.

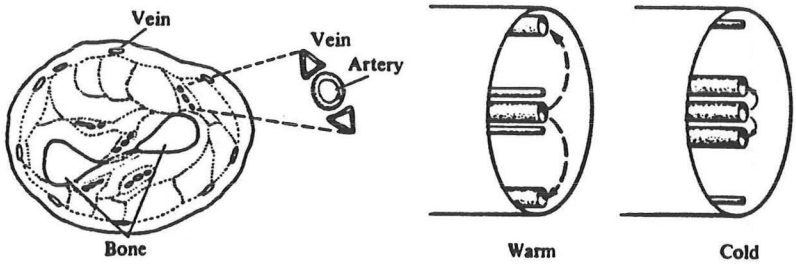

Figure 14. Heat exchange system in the forearm with a diagrammatic representation of the shift in venous blood flow from superficial vessels in warm surroundings to deep-lying vessels in the cold.

As environmental temperature falls below the thermoneutral zone and peripheral vasoconstriction is near maximum, the body begins to increase heat production by metabolic processes as seen in Figure 15.

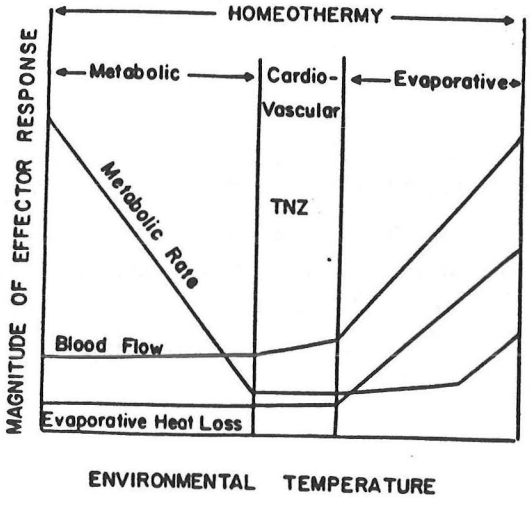

Figure 15. General thermoregulatory profile for a hypotheleal homeotherm indicating primary effector responses.

The acute response to a drop in environmental temperature is to shiver. This synchronous contraction and relaxation of antagonistic muscle groups can increase heat production by several fold. Shivering does not transform all of the heat produced into an increase in body temperature because of the loss of insulation and increased heat loss from convection. Shivering is the primary means of increasing heat production when homeotherms are acutely exposed to cold or cold acclimatized homeotherms are exposed to temperatures below the temperature of acclimatization. Shivering thermogenesis is mediated primarily through the neural pathways that enervate skeletal muscle with probable contribution from circulating catecholamines.

With prolonged exposure to cold, the relative importance of shivering thermogenesis gives way to a rise in heat production by nonshivering thermogenesis (Figure 16). The mechanisms by which heat production is increased are poorly understood but involve a synergistic action of thyroxine and catecholamines on the metabolism of many tissues (Figure 17) and substrates.

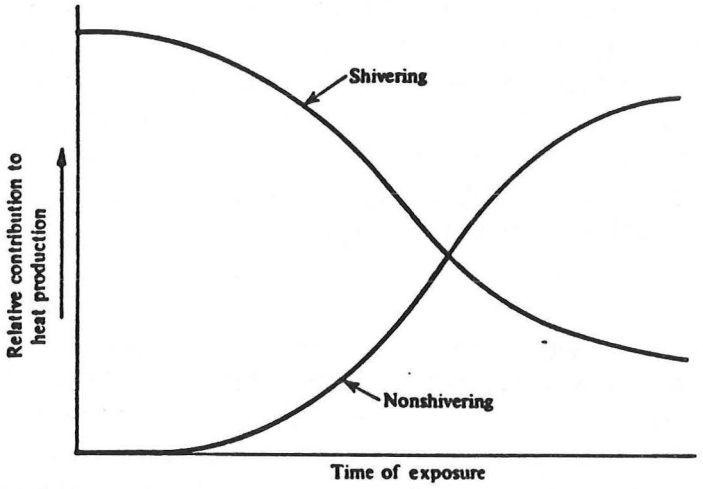

Figure 16. Schematic diagram of the relative contribution of shivering and nonshivering heat production with time of exposure to a cold environment.

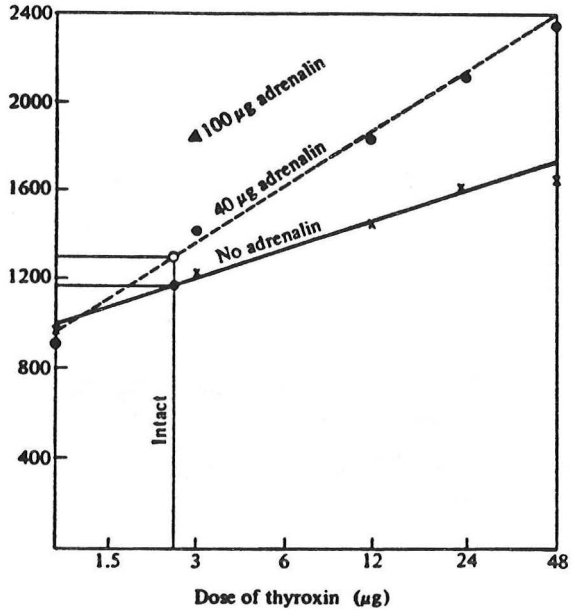

Figure 17. Regression of oxygen consumption of thyroidectomized rats treated with various doses of epinephrine plotted against the dose of thyroxin on a logarithmic scale.

The above mechanisms of temperature regulation require the coordination of several organ systems, primarily cardiovascular and neuroendocrine. The acute response to a hypothermic situation is mediated by neural mechanisms concerned with vasoconstriction, sweating, shivering and substrate provision. Neuroendocrine mechanisms that increase nonshivering thermogenesis become important after more prolonged exposure. Cold acclimatization involves circulatory adjustments to protect certain parts of the body, metabolic adaptations to increase heat production and behavioral changes to minimize cold stress and discomfort.

Pathophysiology of hypothermia

When heat loss is in excess of maximum heat production or when heat generation/regulation is inadequate in a cool environment, hypothermia develops. While clinically important hypothermia is probably not specifically lethal to individual cells, derangements of metabolic activity and organ function will result in the death of a patient when critical temperatures are reached. A thorough understanding of the pathophysiology of these changes is vital for any clinician treating or resuscitating hypothermic patients. A sophisticated study of these patients is obviously difficult given their critical condition. Consequently, much of the data presented below is the result of elaborate studies on patients undergoing induced hypothermia for therapeutic reasons. Obviously, controlled hypothermia in such a clinical setting is markedly different from that resulting from exposure. However, many generalizations can be made if such differences are appreciated.

Oxygen consumption and metabolic rate. Oxygen consumption and metabolic rate fall as temperatures decline, primarily because of the temperature dependence of metabolic processes. The decline in oxygen consumption with hypothermia is thought to be exponential as illustrated in Figure 18[14], although a linear relationship has been suggested[15]. This fall in metabolism and the fact that metabolic processes are depressed more than the diffusion of metabolites account for the successful resuscitation of many hypothermic patients after prolonged cardiorespiratory collapse.

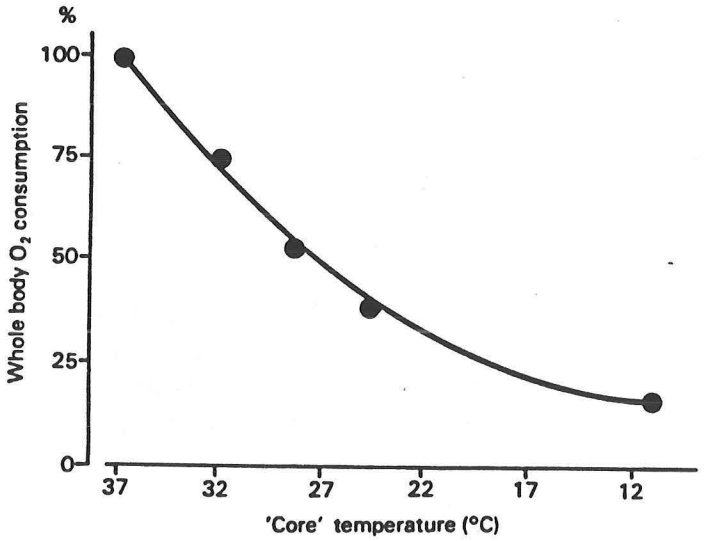

Figure 18. Curve showing the reduction in whole body 0_2 consumption during hypothermia in man.

The effects of hypothermia on oxygen availability are complex. As temperature falls, oxygen solubility in plasma and tissue binding increase favoring oxygen availability to tissues[16,17]. As blood is cooled, however, the oxyhemoglobin curve is shifted to the left creating an unfavorable relationship between oxygen supply and demand. In general, these influences offset each other and oxygen supply is adequate for the reduced metabolic demand. However, oxygen availability can be inadequate during rewarming when relatively warm tissues which are metabolically active are perfused by cold blood[18].

Cardiovascular System - When a person is exposed to a cold environment and body temperature falls slightly, the cardiovascular system responds with tachycardia and a moderate increase in central venous pressure, blood pressure, peripheral vascular resistance and cardiac output. These changes are due primarily to the increase in metabolic demand by shivering muscle and an increase in sympathoadrenal outflow elicited by fear, fighting responses and the drop in skin temperature. As hypothermia progresses, however, the primary changes in the cardiovascular system are depressive. These changes again are largely protective allowing the myocardium to better tolerate prolonged periods of anoxia and substrate deprivation.

Cardiac output falls progressively as hypothermia develops being about 70% of normal at 31°C. This reduction in cardiac output is due primarily to a fall in ventricular rate with stroke volume being normal[19,20] or perhaps slightly reduced[21]. With rewarming, cardiac output tends to rise progressively[20] although a return to normal may be delayed.

Heart rate falls progressively as temperature declines[22] and eventually results in cardiac standstill. This is due to a depression of atrial and ventricular pacemaker activity with a relative prolongation of systole over diastole[16,23]. The slow systolic time in many patients results in a flat pulse wave making the pulse difficult to palpate even when direct measurements of blood pressure are normal.

Despite the decline in cardiac output and heart rate, blood pressure usually remains remarkably normal[24] because of a marked rise in peripheral vascular resistance[19]. This increase in vascular tone is due to sympathetic stimulation, an increase in circulating catecholamines, a direct effect of the cold on peripheral vessels and an increase in blood viscosity with hemoconcentration. This vasoconstriction is generalized but not uniform in that blood is shunted from most tissues to support the heart and central circulation[25]. Circulatory reflexes supporting blood pressure are maintained to about 28°C although the response to hypotension is blunted below about 30°C. Hypotension is commonly seen during treatment in the form of "rewarming shock" when the intense vasoconstriction is lost and peripheral resistance falls dramatically. Hypothermic vasoconstriction results in increased work by the myocardium, but an increase in myocardial efficiency and the decrease in metabolic demand due to hypothermia make the lower cardiac output and rate more than adequate in most instances.

In summary, the cardiovascular response to cold stress has two phases. Acutely, exposure results in sympathetic stimulation with an increase in heart rate, cardiac output, peripheral

resistance, blood pressure and central venous pressure. As core temperature falls, cardiovascular depression is then seen with a fall in heart rate and cardiac output and a return to normal of blood pressure and central venous pressure.

Hypothermia causes a decrease in oxygen and metabolic demand of the myocardium as with other tissues. The effect on myocardial blood flow is, however, variable. Surface cooling to 25-28°C has been reported to decrease coronary blood flow with further cooling causing a rise[26,27]. Central cooling to the same degree, on the other hand, increases coronary blood flow down to 10°C because of a decrease in vascular resistance[27,28,29]. The clinical significance of changes in blood flow and substrate availability is difficult to establish. In 1978, Carlson reported an increase in creatine phosphokinase MB isoenzyme in patients with severe hypothermia without evidence of myocardial infarction, suggesting myocardial cellular damage[30]. However, the net effect is probably that despite changes in blood flow and substrate availability, the delivery of oxygen and nutrients to the myocardium is generally adequate for the reduced demand.

Cardiac arrhythmias, especially atrial fibrillation[22], are very common with temperatures less than 30°C. In general, the incidence of arrhythmias increases as core temperature falls. With declining temperature, the action potential of myocardial cells and conduction fibers lengthens with the appearance of a characteristic dip in the early part of the plateau phase. Maclean and Emslie-Smith have suggested these changes are due to ion flux changes across the sarcolemma[31] and unrelated to changes in blood pH or electrolytes.

The appearance of atrial arrhythmias does not necessarily indicate the presence of organic heart disease but only the metabolic and physiologic changes seen with hypothermia. These arrhythmias usually are benign and resolve without specific treatment as core temperature rises. Correction of metabolic derangements, digoxin, or quinidine may potentiate the conversion to sinus rhythm although drug treatment is usually unnecessary. Ventricular ectopic beats are less commonly seen and are usually isolated premature beats. The appearance of ventricular ectopy does not indicate intrinsic heart disease but may herald the appearance of more serious ventricular rhythms[32]. Ventricular fibrillation is considered the cause of death of many patients with hypothermia, but its actual contribution is obviously difficult to judge because most deaths are unmonitored. The incidence of serious ventricular arrhythmias increases as temperature decreases being very rare at temperatures greater than 32°C and an imminent danger if less than 28°C[33,34]. The exact cause of this arrhythmia is unknown but some postulate that differences in temperature between the endocardium and epicardium[35] may vary conduction rates enough to initiate a reentry circuit. The incidence of ventricular fibrillation is related also to the presence of hypoxia, acidosis, hypercapnia, and electrolyte disorders. External or internal body stimulation, such as urethral catheterization, movement, endotracheal intubation and vascular catheterization also predispose to the development of this arrhythmia. Like other tissues, the hypothermic environment allows the myocardium to tolerate cardiovascular collapse and anoxia longer than at room temperature, making vigorous resuscitative efforts important despite seemingly prolonged ventricular fibrillation or asystole[36,37].

Electrocardiographic changes are very common in hypothermia and many times may even suggest the diagnosis. Mechanical artifacts due to extracardiac muscle activity frequently obscure low voltage complexes and make the detection of EKG changes difficult unless an esophageal lead is used. Although sinus tachycardia may be seen with mild degrees of hypothermia, its presence should suggest complicating factors such as gastrointestinal bleeding, volume depletion, drug overdose, carbon monoxide poisoning or sepsis. As a general rule, the EKG changes associated with significant hypothermia reflect the depressing effect upon rhythmicity and conductivity. An almost linear fall in atrial and ventricular rate develops with progressive hypothermia. This effect on cardiac rhythm is probably a direct effect of cold temperatures since it is not influenced by vagotomy or atropine[38]. As core temperature falls, higher rhythmic centers are depressed earlier than lower centers. Myocardial conductivity is seriously depressed with any significant hypothermia and is manifest by prolonged PR, QRS, and QT intervals. QT interval prolongation is very common and may remain prolonged for several days after euthermia has been restored. This increase is unrelated to changes in serum pH or calcium. Nonspecific changes in the ST segment and T waves are also common and may persist days after rewarding The most consistent changes in the electrocardiogram are widening of the base of the QRS interval and J point deflection leading to so-called Osborn waves[39] as illustrated in Figure 19. This abnormality is best seen in leads reflecting the left ventricle and are probably due to alterations in ion flux in the myocardial sarcolemma. Contrary to previous belief, these deflections do not herald the onset of ventricular fibrillation and can be seen with hypothermia unrelated to exposure[40,41,42].

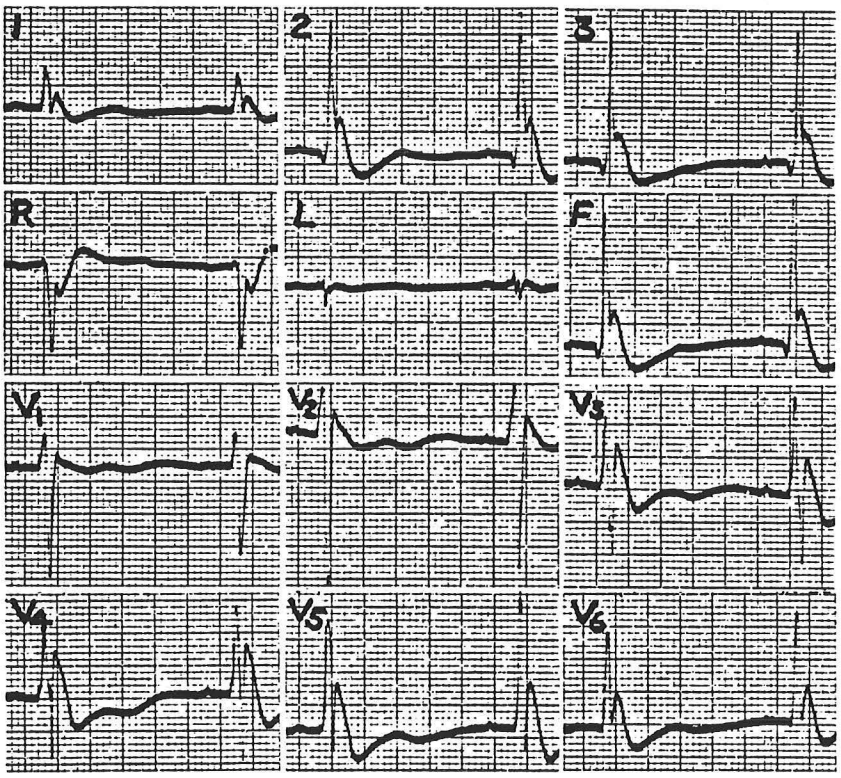

Figure 19. Osborn waves in hypothermic patient

Central Nervous System. The metabolic rate of the brain declines as hypothermia develops, although the fall may be blunted if shivering is present. This fall in metabolic demand allows for successful cerebral resuscitation even after prolonged periods of anoxia and circulatory arrest at very low temperatures[43]. Suzuki, et al., have reported several neurosurgical patients who tolerated clamping of the middle cerebral artery for up to 40 minutes at 30°C without neurological sequelae[44]. With hypothermia, cerebral blood flow declines due to a combination of factors including a fall in cardiac output and an increase in cerebrovascular resistance and blood viscosity. Cerebrospinal fluid volume, total brain volume and cerebral venous pressure all decrease due to shifts in fluid compartments. Cerebrospinal fluid pleocytosis is very uncommon[45].

As with other organs, hypothermia generally results in a depression of the central nervous system. Central nervous system signs and symptoms are extremely variable, but as core temperature falls to about 32°C, a progressive decline in mental status develops associated with gait ataxia, tremulous speech, normal to hyperactive deep tendon reflexes and appropriate pupillary responses. Below 32°C, deep tendon reflexes become less active as the patient develops dysarthria and stupor. Around 30°C, movements become delayed and pupillary responses become sluggish. At this point, the patient usually will be able to answer simple questions although response time will be delayed and perseveration may be present. Below 28°C, the patient may appear awake and respond to noxious stimulation but usually demonstrates little spontaneous movement and response to verbal stimulation. Below 26°C, most patients are unresponsive to any stimulation and pupils become very sluggish or fixed and deep tendon reflexes diminish. This depression of the deep tendon reflexes is characterized by a prolongation of the contraction and relaxation phases[46]. Babinski responses remain flexor to about 26°C with usually no response elicited at lower temperatures. An extensor response is very unusual and should suggest a complicating condition[45]. Hoffman's sign is positive to about 30°C and thereafter disappears.

With the development of hypothermia, shivering begins and reaches a maximum at 32-33°C. Below 30-32°C, however, shivering ceases and muscle rigidity becomes prominent sometimes causing opisthotonos.

A summary of the central nervous system responses to hypothermia is outlined in the following table[45]:

Table I: Central Nervous System Manifestations of Hypothermia

32 - 35°C	Confused, lethargic Normal deep tendon reflexes Corneal and pupillary responses normal
27 - 32°C	Responds verbally Normal or slightly depressed deep tendon reflexes Pupils normal or sluggish Muscle tone normal or slightly increased
20 - 27°C	No verbal responses Normal or diminished response to noxious stimuli Pupils sluggish or fixed Depressed deep tendon reflexes Increased muscle tone

Electroencephalographic changes have been described during induced hypothermia although their relevance to accidental exposure is unknown. As the core temperature drops to less than 28°C, there is a progressive slowing of the electroencephalographic pattern with theta activity and disorganized high voltage delta activity. Electrical activity usually ceases altogether at 15-20°C. A flat EEG is clearly not an indicator of cerebral death as a reversal of the above changes may be seen with rewarming[43].

Respiratory Function. As with other organ systems, the pulmonary response to the early phases of hypothermia or its causes is one of stimulation with an increase in respiratory rate and subsequent respiratory alkalosis. After this initial response, there is a fall in respiratory rate[47], vital capacity and minute ventilation that is proportional to the fall in metabolic rate associated with hypothermia. During this phase, respirations become shallow and slow. Although difficult to prove, the frequent association of hypothermia and carbon dioxide retention with respiratory acidosis implies some abnormality of respiratory control. Hypothermia has little direct effect on the mechanical properties of the lung other than mild bronchodilatation and a decrease in compliance[48]. Cooling also causes an alpha mediated increase in pulmonary vascular resistance and pressure[49]. Airway resistance usually remains normal unless complications develop.

If shivering does not occur, production of carbon dioxide falls by about 50% with a drop in core temperature to 29°C[50]. This combined with an increased solubility of carbon dioxide leads to a fall in the respiratory quotient from 0.82 to 0.65 at a core temperature of 30°C. As in other clinical conditions, the adequacy of ventilation is determined by the measurement of arterial PCO_2) and if artificial ventilation is necessary, appropriate adjustments to the rate and depth of respiration must be made to avoid hyperventilation, and respiratory alkalosis with

resulting adverse effects on oxyhemoglobin dissociation and cerebral blood flow. Many patients with accidental hypothermia have a significant respiratory acidosis because of hypoventilation and respiratory assistance may be necessary in these cases.

Hypoxia is also a significant problem encountered with many patients suffering from accidental hypothermia. This is especially important if the increased oxygen demand of shivering cannot be met and a significant oxygen debt develops. The determination of arterial pO_2 is difficult because of the considerable error encountered when determinations of pO_2 are made at a temperature different from that of the patient. The significance of this can be seen below indicating the appropriate correction factors for pO_2, pCO_2, and pH when these determinations are made assuming a normal body temperature. Despite these corrections, a significant number of hypothermic patients will have arterial pO_2 less than 70 mm Hg and many times less than 50 mm Hg.

Table II: Effect of body temperature on arterial blood gases

	↑ 1°C *†	↓ 1°C *†
pH	↓ .015	↑ .015
PCO_2 (mm Hg)	↑ 4.4%	↓ 4.4%
PO_2 (mm Hg)	↑ 7.2%	↓ 7.2%

* = change with reference to 37°C

†% = percent change of the value measured at standard 37°C

Although the only consistent pulmonary abnormality induced by cold exposure is mild bronchodilatation, other abnormalities may be seen when complicating factors such as a decreased cough reflex, a decrease in ventilation, atelectasis, infection, ventilation perfusion abnormalities and noncariogenic pulmonary edema[51] are present.

Renal Function. Hypothermia has a depressant effect on most indices of renal function although these are usually transient and return to normal within 24 hours of warming[52]. Despite the abnormalities described below, gross renal function remains adequate in most patients. When core temperature drops to about 28°C, renal blood flow is reduced up to 50 percent by a combination of hypotension, low cardiac output, high renovascular resistance, and a direct effect of cold. Glomerular filtration rate is usually significantly reduced during hypothermia but quickly returns to normal when rewarming is accomplished. The effects of hypothermia on the renal tubule are complex. Sodium, chloride and glucose transport are depressed resulting in natriuresis and glycosuria. Hydrogen ion excretion is also severely impaired contributing significantly to the observed metabolic acidosis. As temperature falls, the ability of the kidney

to conserve water is significantly impaired due to decreased sensitivity of the nephron to ADH and a depressed output of ADH from the posterior pituitary. As a result of these changes and the shift of plasma volume from the peripheral to the central circulation, the hypothermic patient frequently excretes a relatively large amount of dilute urine despite a low systemic blood pressure or cardiac output (cold diuresis). On the other hand, oliguria may develop at any time during the development or treatment of hypothermia. When it occurs, oliguria is frequently due to hypovolemia, acute tubular necrosis from rhabdomyolysis, shock, or drug overdose.

Electrolytes: Serum sodium and chloride concentrations are usually normal in uncomplicated accidental hypothermia. The presence of hyponatremia suggests a complicating disease process such as myxedema, hypoadrenalism, hypopituitarism, vomiting or diarrhea.

Serum potassium is frequently normal in uncomplicated hypothermia but may be slightly depressed especially if respiratory alkalosis is present[53]. Significant hypokalemia without respiratory alkalosis should suggest coexistent alcoholism or malnutrition. Iatrogenic hypokalemia may be seen after treatment if large amounts of potassium-free or glucose-containing solutions are used. Hyperkalemia is unusual unless associated with renal failure or rhabdomyolysis.

Serum calcium levels are usually normal in hypothermia although hypercalcemia and hypocalcemia have been reported. Abnormal levels should suggest rhabdomyolysis, alcoholism, renal failure, volume depletion or malnutrition. Hypophosphatemia has been noted during the recovery phase of hypothermia. Serum magnesium tends to be low.

Acid-base disturbances are very common in hypothermia. Acute exposure to a cold environment frequently results in hyperventilation with resultant respiratory alkalosis. As hypothermia becomes established, patients generally develop a significant acidosis from carbon dioxide retention and/or lactate accumulation. Carbon dioxide retention frequently occurs as respiratory rate and tidal volume fall. In the hypothermic patient, any increase in arterial pCO_2, produces a greater fall in pH than would be anticipated in a euthermic patient due to the temperature dependence of the protein buffering capacity of the blood. The metabolic acidosis produced during hypothermia is primarily due to lactic acid. Shivering during the initial phases of hypothermia or during rewarding can create a considerable lactate load especially if tissue hypoxia is present. The amount of oxygen available to hypothermic tissues can be adversely affected by blood viscosity, a leftward shift of the oxyhemoglobin dissociation curve by hypothermia, arterial hypoxia, and perfusion of warm metabolically active tissues by cool blood. The lactic acidosis of hypothermia is also worsened by a decreased ability of the liver to metabolize lactate[54]. During rewarding, the metabolic acidosis may worsen significantly presumably due to mobilization of lactic acid from poorly perfused peripheral tissues, increased production of lactate from shivering muscle, and uneven rewarding techniques.

As hypothermia develops, there appears to be a shift in the distribution of body fluids from the plasma volume to the interstitial and intracellular fluid spaces resulting in a tendency to generalized edema and slight intracellular edema.

Gastrointestinal Tract: As with other organ functions, hypothermia depresses the gastrointestinal tract. Acute dilatation of the stomach can be seen and should be anticipated especially in patients who are vomiting and have abdominal distention. Gastric erosions and hemorrhages are very common in hypothermia as is adynamic ileus, colonic dilatation and a generalized decrease in splanchnic blood flow. Although the liver itself may be better able to tolerate hypothermic temperatures, its ability to utilize glucose and metabolize lactic acid is seriously depressed[54]. The excretion and detoxification of some drugs are also depressed during hypothermia[55] so that appropriate judgements concerning blood levels must be made. Extreme abnormalities in liver function tests are unusual. The association of acute pancreatitis with hypothermia is confusing. Some patients develop severe pancreatitis possible due to ischemia, while others have increases in serum amylase with no clinical evidence of pancreatitis.

Endocrine System. As core temperature falls, the release of most pituitary hormones (including ACTH and ADH) is depressed with normal function being rapidly restored on rewarming[56]. However, an increase in peripheral levels of thyroid stimulating hormone has been reported in some species of animals, human infants acutely exposed to cold, and in adults with chronic hypothermia. Several investigators[57,58], however, have reported no rise in thyroid stimulating hormone levels in adults with acute exposure or hypothermia.

With acute exposure to cold temperatures, a rise in serum cortisol levels may occur; but as hypothermia becomes established, a fall in adrenal function proportional to the fall in temperature is seen. This depression in adrenocortical function is due to a direct effect of cold and a decreased sensitivity to ACTH as temperature drops below 30°C[59]. Frequently, however, serum cortisol levels are normal or near normal even with profound hypothermia, presumably due to a temperature sensitive decrease in metabolism and conjugation of this hormone by the liver. The depression of adrenal responsiveness to ACTH rapidly returns to normal after rewarding.

The response of the adrenal medulla to hypothermia is biphasic. Initially a rise in serum epinephrine and norepinephrine[60] occurs as a response to thermoregulatory and environmental stress. Elevated urinary catecholamines have also been reported in persons who die from hypothermia[61]. As temperature approaches 30°C, however, catecholamines begin to fall[62] with a significant depression occurring by 28°C[63]. At any temperature below normal, the serum levels of catecholamines may not accurately reflect adrenal release because of a decrease in activity of catechol o-methyl transferase and monoamine oxidase[64].

Acutely, no change is seen in serum thyroxine levels after up to three hours of exposure to cold[57] although a decrease in temperature of 2°C may decrease free T4 by 25%. Although

thyroid sensitivity to TSH is depressed, the long half-life of thyroxine prevents any significant change in the levels of this hormone during acute hypothermia, and the development of significant hypothyroidism is unlikely unless exposure is severe and prolonged.

Hypothermia results in a reversible depression of the pancreas with a fall in insulin release due most likely to a direct effect of cooling and not alpha adrenergic stimulation. This inadequate insulin response is illustrated in Figure 20.

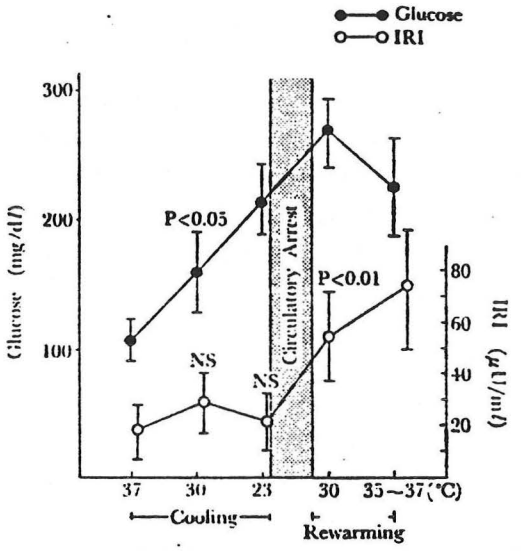

Figure 20. Changes of blood glucose and plasma IRI during hypothermic open-heart surgery[65]

Peripheral glucose utilization is also depressed and resistant to large amounts of insulin if hypothermia is severe. Hyperglycemia is commonly encountered in hypothermia and can be quite severe. The causes of this rise in glucose include: 1) inadequate insulin, 2) depressed peripheral utilization of glucose, 3) increased glycogenolysis and 4) increased catecholamines early with exposure.

An increase in free fatty acid levels is seen early with exposure and persists with the development of hypothermia. These compounds are an important energy source for shivering muscles and are produced probably in response to sympathetic stimulation[66]. It has been suggested that these compounds may contribute to myocardial toxicity in ischemic situations but their relevance to arrhythmias in hypothermia is unknown.

Hematologic System. The cold diuresis and fluid compartment shifts that occur with hypothermia create a variable amount of hemoconcentration and a fall in plasma volume. However, the extent of hemoconcentration is variable as shown in a study from Bellvue[67] where

the mean hematocrit was 33.6%. The white cell count, on the other hand, usually falls as temperature drops. The white cell differential count is usually normal as is the white cell response to infection with moderate degrees of hypothermia. Some degree of thrombocytopenia is common although severe depressions in platelet count are usually seen only with temperatures less than 30°C. Disseminated intravascular coagulation can be seen with rewarming[68].

Factors Associated or Predisposing to Hypothermia

Severe hypothermia is unusual in young healthy persons except in situations of severe cold stress. Most patients seen in metropolitan hospitals suffer from some underlying illness or disorder which predisposes them to the development of hypothermia[67]. Identification of these predisposing factors and conditions is necessary for treatment as well as prevention of hypothermia. While a detailed discussion of these disorders is not possible in this presentation, some of the more important predisposing conditions will be addressed.

Elderly. The elderly are particularly susceptible to the effects of low environmental temperature. Like classic heat stroke, hypothermia in the elderly occurs mostly indoors and in combination with significant medical illness. Fixed income, substandard housing, poor insulation and mechanical problems with heating sources combine to allow the nighttime bedroom temperatures of many old people to approach that of the outside environment. Studies have shown that elderly persons with cold homes tend to have lower oral as well as early morning urine temperatures[68]. Advancing age, receiving supplemental benefits, a perception of cold extremities and a preference for a warmer environment are all associated with a low morning temperature in elderly patients.

Thermoregulatory responses diminish progressively with age[69] due to a combination of factors including:

1) Decreased vasoconstrictor response when exposed to a cool environment decreasing the ability to conserve heat

2) Decreased ability to generate heat by metabolic processes and shivering

3) Malnutrition and a decrease in subcutaneous fat

4) Possible decreased sensitivity to the thermal discomforts of cold

The mortality rate for hypothermic elderly patients is high[70,71] primarily because of the high incidence of severe coexisting medical illness .

Metabolic. Several endocrinopathies can present as or have hypothermia as a complicating

factor. Probably the most widely recognized of these is hypothyroidism although the incidence of this disorder in hypothermic patients is probably less than 10 percent[45,67]. In severe hypothyroidism, metabolic heat production can be severely depressed because of low thyroxine levels, and most patients have low body temperatures. However, bradycardia, atrial fibrillation, cardiomegaly, edema, myxedematous facies, mental slowing and delayed relaxation of the deep tendon reflexes can be seen with uncomplicated hypothermia and mimic hypothyroidism. Patients with concomitant hypothermia and myxedema have a very high mortality. The development of hypothermia in a myxedematous person, especially in a warm environment should suggest infection, drug use (especially sedatives), or trauma. Hypoglycemia frequently presents with hypothermia probably due to a central nervous system deprivation of glucose. Hypopituitarism may also present with hypothermia and coma, especially in concert with infection or volume depletion. Other signs of hypopituitarism should suggest the diagnosis and treatment should include volume repletion, corticosteroids and glucose as well as rapid rewarming. Diabetes mellitus with ketoacidosis can present with hypothermia and may be a more frequent cause than hypothyroidism especially during warmer months.

Central Nervous System Disease. Many central nervous system disorders can present with hypothermia. Many of these involve the hypothalamus, although more generalized cerebral conditions and disruption of afferent and efferent thermoregulatory tracts can result in significant loss of temperature control. The list of central nervous system conditions associated with hypothermia is extensive and includes: cerebrovascular disease, subdural hematoma, tumors, head trauma, anorexia nervosa, Parkinson's disease, Wernicke's encephalopathy, spinal cord transection, sarcoidosis, Alzheimer's disease, and schizophrenia.

Drugs. Many drugs in therapeutic and supratherapeutic doses can influence the body's ability to regulate temperature. Alcohol is probably the most common drug encountered in this group. Patients are usually chronic alcoholics subject to chronic exposure to cold environments although alcohol can significantly impair thermoregulation in young, healthy persons[72]. Vasodilation, reduced shivering, decreased central thermoregulatory sensitivity, exposure, impaired judgement, hypoglycemia, and Wernicke's encephalopathy contribute to the hypothermic predisposition of alcohol. As with other causes of drug induced hypothermia, mortality increases with the presence of other underlying diseases.

In therapeutic doses, many drugs counteract thermoregulatory responses and predispose to hypothermia. These drugs are especially dangerous to patients with other medical illnesses which predispose to thermoregulatory failure and include phenothiazines, tricyclic antidepressants, benzodiazepines, morphine, reserpine, and general anesthetics.

Other drugs usually require supratherapeutic doses (overdose) to seriously impair thermoregulation and cause hypothermia. These include: barbiturates, glutethimide, meprobamate, methaqualone, ethchlorvynol, heroin, cannabis, and ethylene glycol. Interestingly, the prognosis for most of these overdoses with hypothermia is better than for other predisposing causes.

Malnutrition. Malnutrition can seriously impair the body's ability to cope with a cold environment. This is especially important in the elderly, the homeless, children with protein calorie malnutrition and those with anemia of nutritional origin.

Dermal Dysfunction. Generalized erythrodermal skin diseases are occasionally associated with hypothermia due to increased cutaneous blood flow and evaporative heat loss. For the same reasons, burn patients are predisposed to hypothermia.

Paget's Disease of Bone. Hypothermia can develop in patients with Paget's disease of bone because of the increased vascularity of bony areas near the skin surface resulting in increased heat loss.

Exposure. Obviously, severe cold stress can lead to hypothermia in any individual but certain conditions make its development more likely. For example, immersion in cold water results in a greater loss of heat than exposure to air of equal temperature because of the high thermal conductance of water. Immersion in water 10-15°C usually leads to uncontrollable gasping and swimming is possible for only a short distance. Heat loss in this situation is facilitated by movement and can be minimized by flexing the arms to the axilla and legs to the abdomen. Studies have suggested that men working underwater may develop significant hypothermia without symptoms[73,74]. This was most likely to occur in those with little subcutaneous fat. Marcus and Redman[75] have also demonstrated that cold discomfort is inversely proportional to work rate. Hypothermia can also develop in temperate climates, especially in elderly patients with concurrent medical illness[76].

In summary, numerous clinical situations impair thermoregulatory function and predispose to hypothermia. In general, those related to drug or toxin overdose and environmental exposure without underlying medical illness have a much better prognosis.

Management of Hypothermia

Hypothermia is defined as a core temperature of less than 35°C and should be considered a medical emergency. Many routine emergency room thermometers do not measure temperatures below about 34.5°C, so the diagnosis of hypothermia depends largely on a high index of suspicion. If the diagnosis is being entertained, an estimate of core temperature should be obtained by one of several means. A high rectal temperature obtained with a thermistor probe will give a reasonable measurement of core temperature in most patients. Esophageal temperature with the probe placed at the level of the right atrium will perhaps give a more accurate measurement of core temperature, but such measurements are uncomfortable to the patient, difficult to properly place, and may precipitate ventricular arrhythmias or fibrillation. The tympanic membrane is supplied by a branch of the carotid artery, as is the hypothalamus, and may be used to estimate core temperature if an appropriate instrument is available. However, the accuracy of these instruments has not been validated in appropriate studies of

hypothermia patients. All things considered, rectal temperature is probably the most frequently used.

Once the diagnosis has been made, any predisposing causes or complications of hypothermia should be sought with a thorough history and physical examination because mortality is directly related to their presence. If the patient is comatose, steps must obviously be taken to insure an adequate airway and prevent gastric aspiration. A large intravenous catheter should be inserted and thiamine given immediately. Stimulation of the patient, however, should be kept to a minimum to avoid precipitating ventricular fibrillation. A chest x-ray should be obtained to detect complicating factors such as pneumonia, aspiration, congestive heart failure or adult respiratory distress syndrome. Abdominal x-rays should be obtained if there is any evidence of gastric or colonic dilatation, peritonitis, ileus, pancreatitis or gastrointestinal hemorrhage. Hematologic evaluation should be directed towards identifying predisposing causes as well as complications of hypothermia. Suggested laboratory evaluation is outlined as follows.

Laboratory evaluation of hypothermia

All Patients	Selected Patients
Complete Blood Count	Serum Lactate
Platelets	Serum Ketones
Glucose	Toxicology Screen
BUN/Creatinine	Carboxyhemoglobin
Sodium	Calcium and Magnesium
Potassium	Inorganic Phosphate
Chloride	Cortisol
Bicarbonate	Thyroxine
Amylase	CK
Arterial pH, pCO_2 $P0_2$	
Urinalysis	
Prothrombin Time	
Partial Thromboplastin Time	

While a low or low normal white blood cell count is expected in significant hypothermia, one must not ignore the possible contribution of coexistent malnutrition or folate deficiency. An elevated white blood cell count, especially with a left shift should suggest an underlying infection. The platelet count is also depressed by hypothermia, but again complicating folate deficiency or disseminated intravascular coagulation should be considered. An elevated hemoglobin is common in hypothermia and suggests hemoconcentration due to volume depletion or fluid compartment shifts. A low hemoglobin may be seen if gastrointestinal bleeding, malnutrition, alcoholism or folate deficiency is present. Hyperglycemia due to increased glycogenolysis, poor peripheral utilization of glucose and inadequate insulin release is frequently

encountered. Hypoglycemia on presentation should suggest concurrent alcoholism or diabetes mellitus.

Serum amylase should be measured on all patients because of the association of hypothermia with pancreatitis. Arterial pH measurement is necessary because metabolic and respiratory acidosis may be life threatening. Hypoxia should suggest underlying pulmonary pathology such as pneumonia or adult respiratory distress syndrome. Hypercarbia is frequently seen in uncomplicated hypothermia, but its presence in the appropriate situation suggests hypothyroidism. A low arterial PCO_2 usually indicates a complication such as pneumonia, lactic acidosis, or diabetic ketoacidosis is present. Arterial blood gas measurements should be corrected for body temperature as previous discussed. Serum lactate and ketones should be measured in patients who have a serious metabolic acidosis. Toxicologic evaluation is indicated in any patient whose history is unknown or if the possibility of drug or poison ingestion exists. Calcium, magnesium, and inorganic phosphate measurements are important in alcoholic patients and in those with myoclonus or rhabdomyolysis. Serum cortisol and thyroxine levels are warranted if the clinical situation suggests hypothyroidism, adrenal insufficiency or hypopituitarism.

Constant electrocardiographic monitoring is mandatory for all patients during rewarming because of the significant incidence of arrhythmias and ventricular fibrillation. Late rewarming collapse due to severe bradycardia or heart block can occur up to 48-72 hours after rewarming and should be treated with a pacemaker if necessary. Blood pressure, pulse, temperature, neurologic status and urine output should be monitored frequently during rewarming. Central venous and arterial pressure monitoring, Swan-Ganz catheterization, and cardiac pacing may be necessary in selected patients; but should be avoided if possible because the irritation can precipitate ventricular fibrillation in the hypothermic myocardium.

Rewarming techniques. The proper technique for rewarming hypothermic patients has become a subject of considerably controversy. General recommendations regarding the treatment of hypothermia are difficult to establish because of the wide variety of predisposing factors and complicating diseases and a lack of randomized trials evaluating rewarming techniques. However, certain considerations should influence the method of rewarming chosen for a given patient. It has long been accepted that a warming rate of about 0.55°C per hour is acceptable in a stable patient although many shivering young persons may produce heat at a much faster rate. Consequently, many authorities believe that passive rewarming of hemodynamically stable hypothermic patients is best. With this technique, the patient is allowed to generate his/her own heat with insulating material such as blankets being the only external intervention. In general, this method will allow a slow rise of 0.5-1.0°C/hour most patients if the initial core temperature is greater than about 28-30°C. If the increase in temperature is less than 0.5° per hour, a complicating disease such as hypothyroidism should be suspected. This passive method of rewarming is especially effective in patients with acute hypothermia without significant underlying disease. Although this method has been used successfully by many authorities, mortality may still be high.

Active rewarming methods have been advocated by some as a means to rapidly return core temperature to near normal in patients with severe hypothermia and/or cardiorespiratory arrest. The fibrillating or asystolic hypothermic myocardium is resistant to mechanical or pharmacologic intervention until temperatures are above 28-30°C. For this reason, no hypothermic person should be pronounced dead until the core temperature is above 30°C. DaVee[37] has reported a patient with functional survival after a fall in core temperature to 16°C and prolonged cardiopulmonary resuscitation. Successful resuscitation after cardiac arrest with severe hypothermia generally depends on a previously healthy heart and the protective effects of hypothermia.

Several disadvantages of active external rewarming have been described. First, "rewarming shock" occurs when rewarming causes a decrease in the intense vasoconstriction resulting in a fall in peripheral vascular resistance and blood pressure if the cardiac output cannot be increased. This is especially a problem in elderly persons with significant preexisting cardiovascular disease. Second, a drop in core temperature is occasionally seen before rewarming begins. This fall in core temperature has been implicated in precipitating ventricular fibrillation during the early phases of treatment. This "after drop" in core temperature has been thought to be due to cold blood in peripheral tissues being returned to the central circulation by vasodilatation induced by rewarming, although it may be due in part to the delayed conduction of heat from the external to internal environment. Finally, the lactic acidosis associated with hypothermia may be worsened significantly with active rewarming because of uneven rewarming and renewed perfusion of ischemic tissues.

Active rewarming generally is divided into external and internal techniques. With active external rewarming, heat is applied to the surface of the body with hot water bottles, warm water, etc. This method of rewarming has been used most successfully in young patients with acute hypothermia[71]. External rewarming, however, is more likely to induce "rewarming shock", especially in older persons with chronic exposure[77]. The success of active rewarming has been varied. Duguid[77] and Weyman[78] have reported an increased mortality in patients rewarmed by active methods. However, Frank[79] reported ten patients, seven of which had underlying medical problems, who were successfully treated by immersion into a 4°C water bath despite the fact that some of the patients were elderly.

To avoid the above problems with active external rewarming, rapid rewarming of core blood has been attempted by several means. This active core rewarming minimizes rewarming shock and acidosis and avoids afterdrop of core temperature. Methods used to accomplish active core rewarming include the following:

Core rewarming techniques

Cardiopulmonary bypass[80,81,82,83,84]
Hemodialysis[85]
Heated oxygen[86,87,88]
Peritoneal lavage[89,90]
Mediastinal lavage[80]
Warm gastric lavage[91]
Colonic lavage
Warm IV solutions
Radiant heat cradle over torso[92]
Microwave

Core rewarming techniques have become popular in the recent past. Peritoneal lavage is easy and can be performed in most emergency departments. Aggressive core rewarming can be accomplished by cardiopulmonary bypass. This method has the advantage of very rapid rewarming with some assurance of adequate oxygenation.

In summary, the method of rewarming will depend in large part on the patient and the necessity for rapid rewarming. In general, young patients with acute immersion hypothermia will rewarm rapidly with passive techniques if hypothermia is not extreme. Active external rewarming should be avoided in older patients with relatively chronic hypothermia and significant underlying cardiovascular disease. Patients with cardiopulmonary arrest should be rapidly rewarmed by a core rewarming technique to at least 30°C while resuscitative measures are in progress. Mortality by any technique depends primarily on the presence or absence of underlying diseases. If the patient is healthy, any rewarming technique will be successful; and if serious underlying diseases are present, mortality will be high no matter how the patient is warmed. To date, there are no controlled, randomized studies comparing the above rewarming techniques.

Oxygen. Hypothermia decreases the metabolic requirements of the body, but the adverse effects temperature has on the oxygen dissociation curve may cause an inadequate amount of oxygen to be delivered to peripheral tissues. If the corrected arterial pOl, is normal, enough oxygen is probably available to meet the metabolic demand. However, if hypoxia develops, significant tissue injury and metabolic acidosis will result. Shivering during rewarming may greatly increase the oxygen requirement by muscle and worsen the metabolic acidosis if oxygen supply is inadequate. Because of these factors, hypothermic patients should be given supplemental oxygen with ventilatory assistance if necessary. Oxygen should be given with heated mist to assist in rewarming.

Fluid and Electrolytes. No general recommendation regarding the fluid and electrolyte requirements of hypothermic patients can be given because of their wide diversity. Any intravenous fluid that is given should be warmed to 40°C before administration. This can easily be accomplished with a blood warmer or other heat exchanger. Many patients will require

central venous pressure monitoring to accurately determine their volume requirements. Rewarming shock should be treated vigorously by expanding plasma volume if the central venous pressure is low.

Dehydration can be determined by measuring osmolality or estimated from the serum sodium and usually occurs in patients who have an inability to drink water or have an altered hypothalamic thirst mechanism. If significant dehydration is present, careful repletion with free water in the form of D_5W is indicated. However, one must keep in mind that fluid compartment shifts with rewarming will correct some of the elevated serum osmolality. Sodium depletion should be determined clinically and correction undertaken if indicated to improve tissue perfusion. Volume overload, however, should be carefully avoided.

Acid-base disturbances. The ideal pH and arterial PCO_2 in patients with hypothermia are not known, but values should probably be near normal to maximize ventricular function and vascular responsiveness, prevent respiratory depression, and allow catecholamines and drugs to function predictably. As noted above, these values should be corrected for body temperature if the measurements are made assuming a temperature of 37°C. Bicarbonate should be given for serious metabolic acidosis (pH less than 7.2), but care must be exercised to avoid subsequent metabolic alkalosis and its adverse effects on oxyhemoglobin dissociation, calcium, ventricular irritability, and cerebral blood flow. With rewarming, a transient worsening of the metabolic acidosis may occur as tissue hypoxia develops and lactate is washed out of previously vasoconstricted tissues. Recognition and treatment of this phenomenon is important to reduce the risk of ventricular fibrillation. A mild respiratory acidosis may favorably affect oxygen delivery and counteract intense peripheral vasoconstriction, but severe respiratory impairment with significant carbon dioxide retention should be treated with assisted ventilation. Again, alkalosis should be avoided by appropriate ventilatory adjustments realizing the reduced carbon dioxide generation in hypothermic patients.

Glucose. Hypoglycemia should obviously be suspected in any patient presenting with hypothermia. On the other hand, hyperglycemia should be treated only if severe and potentially life threatening. Insulin has little effect if the core temperature is below 30°C and if given, serious hypoglycemia and hypokalemia can result as rewarming takes place. Diabetic ketoacidosis with serious hypothermia (below 30°C) is probably an indication for rapid rewarming so that erogenous insulin can exert its metabolic effect.

Steroids. Convincing data supporting the routine use of corticosteroids in hypothermic patients does not exist. Some authorities advocate the use of high dose corticosteroids in these patients on the theoretical grounds that they increase coronary blood flow, decrease the oxygen consumption of the myocardium, shift the oxyhemoglobin dissociation curve to the right, stabilize lysosomal membranes, and preserve myocardial function in hyperkalemic hypothermic cardioplegia. Until convincing data are available, corticosteroids probably should not be used unless adrenal or pituitary insufficiency or hypothyroidism is suspected.

Vasopressors. In general, vasopressors should be avoided if possible because of their ability to induce ventricular arrhythmias in hypothermic patients. Hypotension should be first treated with volume and plasma expansion as indicated by measurements of central venous pressure or pulmonary capillary wedge pressure.

Antiarrhythmic drugs. Drugs with significant myocardial depressing effects such as quinidine and propranolol should be avoided in hypothermia because of their propensity to depress cardiac output and worsen hypotension. Serious ventricular arrhythmias can be treated with bretyllium.

Antibiotics. Data supporting the routine use of prophylactic antibiotics in hypothermia do not exist, and one should withhold these drugs until specific indications exist.

Thyroxine. Thyroxine should be given if significant hypothyroidism is suspected. Replacement doses of corticosteroids probably should also be given with this drug.

To conclude, accidental hypothermia is a medical emergency with mortality directly related to the presence of serious underlying disease. Supportive measures and rewarming techniques must be individualized. Treatment of concomitant underlying illnesses is important if significant survival is to be anticipated.

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