The Spectrum of Environmental Heat Illness

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Historical Perspectives and Introduction

Heatstroke, the most serious heat illness injury, was first described more than 2,500 years ago in the Old Testament.(1) Later in 24 B.C., a Roman army was virtually destroyed by heat illness in Arabia(2) and the armor-clad crusaders of King Edward were defeated by "heat and fever" as they engaged well-acclimatized Arab horsemen in the final battle for the Holy Land.(3) In 1756, 123 of the British captives died during one hot night while imprisoned in the "Black Hole of Calcutta."(4) In World War I, the British attack against the Turks in Mesopotamia was stalled by heat-related casualties which were so heavy that it almost cost the entire Middle East campaign.(5)

In military history, it is the invasion or occupation forces that usually suffer the ill effects of an adversely hot climate, but literally thousands of Egyptians soldiers "died without wounds" (from heatstroke) in the Six-Day War. An invasion of sorts recurs each year as religious pilgrims flock to Mecca where 1,025 deaths from heatstroke occurred in a two year period 1959-1961.(6,7) Despite aggressive interventions by the Saudi government to provide treatment stations along the pilgrimage route, hundreds of fatalities are expected each year for the next decade since the holy days will again fall during the hottest portion of the year.(8)

The toll exacted by an adversely hot climate during military campaigns lead the United States during World War II to prepare military recruits for rapid deployment to tropical climates by exposing them to vigorous conditioning and training in hot and humid environments such as Paris Island, SC. At least 125 fatal cases of heatstroke and a myriad of other morbid events including renal failure occurred during World War II "boot camp" training.(9) Similar conditions exist during training for various athletic endeavors, particularly football, and heatstroke remains a leading cause of death among American athletes, second only to head and spinal injuries.(10,11) Even in more temperate climates, strenuous physical exertion such as marathon running may precipitate serious heat-related injuries.(12)

Historically, civilian populations have also suffered the ravages of sustained heat waves. In Peking during a severe heat wave in July 1743, 11,000 deaths were attributed to heatstroke.(13) During heat wave years, this scenario is repeated to a more modest degree in the United States. The General Mortality Tables of the Vital Statistics Reports of the United States reveals an average of 820 heatstroke or heat exhaustion deaths during five heat wave years (1952-1955 and 1966) compared to 179 deaths per year in non-heat wave years over a 15 year review period.(14) This data source estimated 10 or more heat-precipitated deaths, predominantly from underlying cardiovascular disease, for every heatstroke death. The July heat wave of 1980 in St. Louis and Kansas City, Missouri increased deaths from all causes 57% and 64% respectively compared to the previous year.(15)

The intent of this Grand Rounds is to review:

1) The basic aspects of thermoregulation and acclimatization;
2) The clinical spectrum of heat illness:
   a) epidemiology
   b) recognition and differential diagnosis
   c) pathophysiology and complications
   d) treatment
3) Recommendations to prevent heat-related injuries.

Thermoregulation and Acclimatization

Mechanisms of Heat Gain --

A series of homeostatic mechanisms balance heat production, environmental heat gain and heat loss to control the body's temperature within fairly narrow limits. These homeostatic mechanisms can be overwhelmed by intense physical exertion in an excessively hot and humid environment or they can be impaired by illness and various drug therapies resulting in serious heat illness injury.

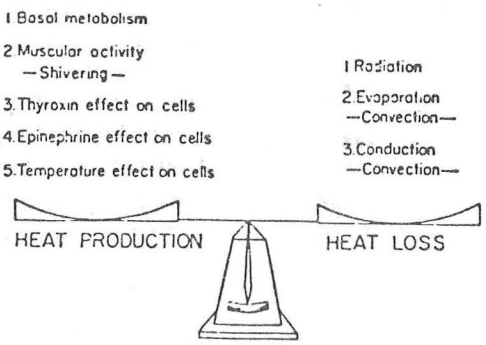


Figure 1: Excess heat produced as a by-product of metabolism and muscular activity must be balanced by heat dissipation. (from Guyton [19])

Basal metabolism, modulated by thyroid hormone and catecholamines, produces heat as a by-product at a rate of 60-70 kcal/hour in the resting adult.(Figure 1) If the adult happens to be resting in the sun, heat gained by irradiation may account for an additional 150 kcal/hour.(16) With intense physical exercise, 900-1,000 kcal/hour can be produced, but only for brief periods of time.(17) At this maximum rate of heat production, homeostatic mechanisms must also be maximally effective in order to dissipate heat, otherwise the body's core temperature would abruptly increase to temperatures incompatible with life.(18) The homeostatic mechanisms of heat dissipation are affected importantly by the environment, but a paradoxical increase in the rate of metabolic heat production occurs above temperatures of 106°F (41.1°C).(19)

Mechanisms of Heat Loss --

Radiation to air, convection-conduction to streaming air or fluid currents and evaporation of sweat produce heat loss.(20) (Figure 2) The most important of these processes under basal conditions, radiation to air, accounts for roughly 60% of the body's heat loss, however during the usual Texas summer when ambient temperature exceeds normal body temperature, heat gain occurs. Even under ordinary conditions, heat loss from convection-conduction to streaming air is limited, reaching a peak at only 16 to 18 m.p.h.(19)(Figure 3) Very little heat can be lost by this process under still conditions. Kamon and Avellini(21) have demonstrated that the limits of exposure for clothed men (insulation factor of 0.6 c/o - cotton t-shirt, underpants, long-sleeved shirt and trousers of 65% polyester-35% cotton, socks and gym shoes) working at levels requiring about 200 $W \cdot M^{-2}$ (27% VO_2 max.) do not change much as wind speed is increased above 2 $M \cdot S^{-1}$, to even an impractical speed of 15.8 $M \cdot S^{-1}$.

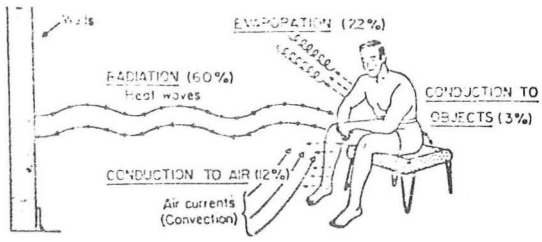


Figure 2: The mechanisms of heat loss are limited by the temperature, humidity and velocity of ambient air. (from Guyton[19])

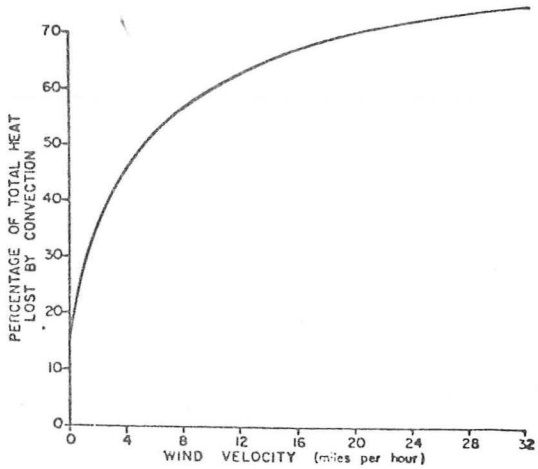


Figure 3: The percentage of heat loss occurring by convection is affected by wind velocity and while maximal at 16 m.p.h., only 12% of heat is lost by this route. (from Guyton[19])

The evaporation of sweat is an important cooling mechanism and may account for roughly 20% of the body's heat losses. Each 1.7 ml. of sweat should dissipate 1 kcal of heat. The unacclimatized, untrained individual can produce a maximum of 1.5 liter/hr. of sweat, but because some sweat is lost by dripping, and the maximal rate of sweating cannot be maintained, evaporation of sweat routinely dissipates only 650 kcal/hr.(18)

Blood volume reduction with diuretics (8.7% reduction) significantly reduced the sweating rate to esophageal temperature (T_{es}) relationship in five relatively fit men performing cycle ergometer exercise (65-70% $\dot{V}O_2$ max) for 30 minutes at 86 F° (30°C), 40% rh independent of changes in plasma osmolality.(22) During a control exercise period prior to diuretic therapy, blood volume decreased an average of 370 $\pm$ 64 ml. at 20 minutes compared to 270 $\pm$ 29 ml. during the study. On the other hand, hypervolemia, induced by intravenous isotonic serum albumin (7.9% plasma volume increase) resulted in a larger decrease in blood volume than control (421 $\pm$ 50 ml.), but no effect on the sweating rate.(Figure 4) It seemed that hypovolemia acted to conserve circulatory blood volume by decreasing sweating rates during exercise.(Figure 5) As a result, esophageal core temperature rose more rapidly in the hypovolemic subjects.(Figure 6)

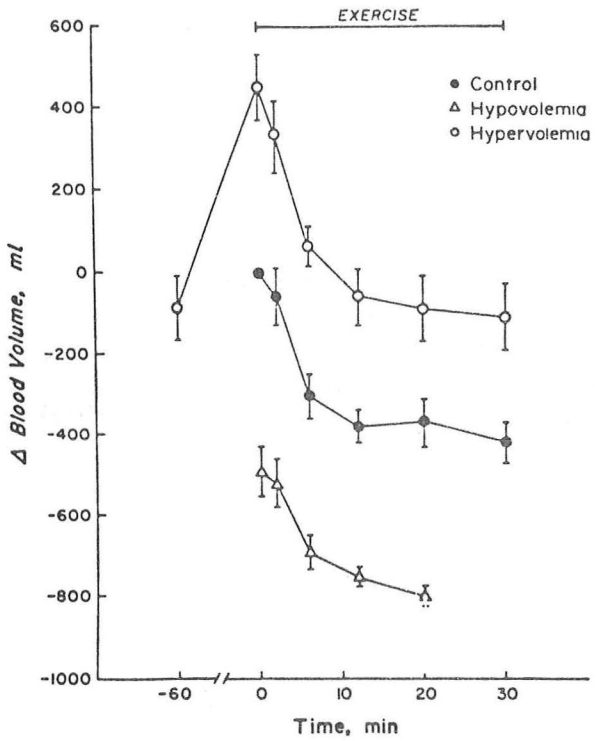


Figure 4: The absolute change from resting control value in blood volume at rest and during exercise in three blood volume states. The twenty-minute hypovolemic value is not shown since only 4 of 5 subjects finished this portion of the experiment. (from Fortney, et al[22])

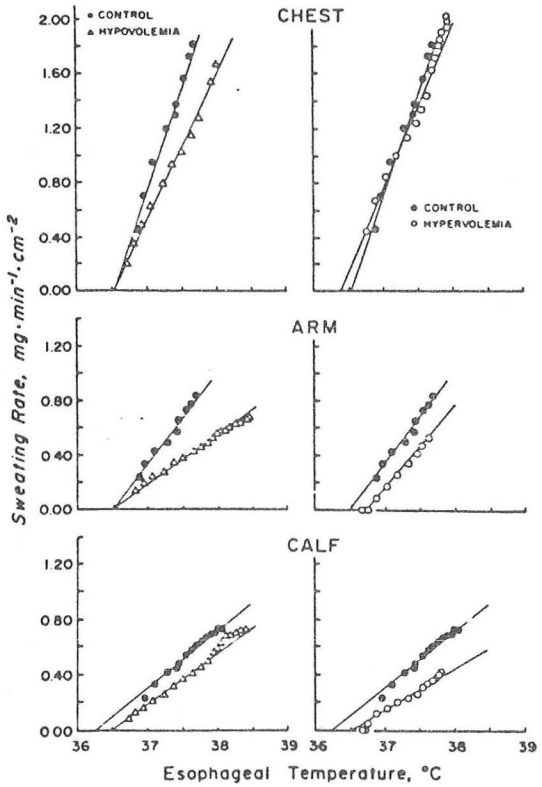


Figure 5: Local sweating characteristics of a representative subject. The slope of the sweating rate-to-esophageal temperature relationship (SR/T_{es}) was significantly reduced from the mean control values of 1.07 ± .16 mg. $min.^{-1}$ · CM^{-2} · $°C^{-1}$ (chest), and 1.09 ± .18 mg. $min.^{-1}$·CM^{-2} $C°^{-1}$ (arm) to 0.64 ± .11 and 0.63 ± .11 mg. $min.^{-1}$ · CM^{-2} · $°C^{-1}$ during hypovolemia. Interestingly, the SR/T_{es} slope was unchanged during hypovolemia over the active tissues of the calf.

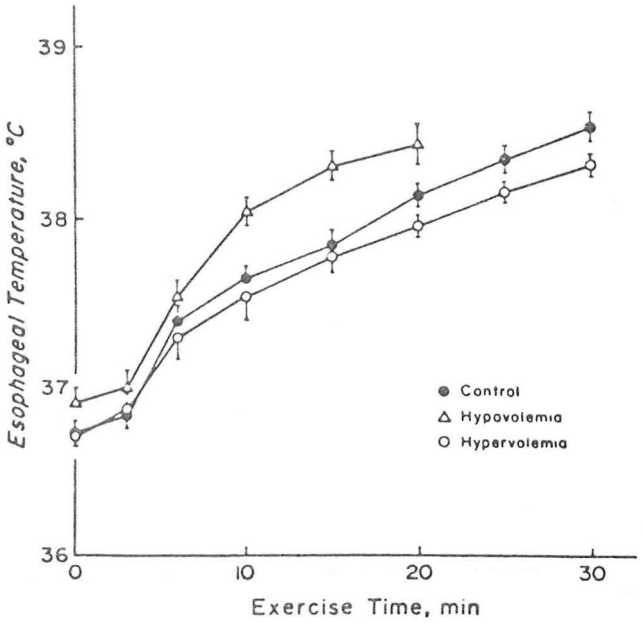


Figure 6: Esophageal temperature at rest and during exercise in 3 plasma volume states. (from Fortney, et al[22])

Evaporation of sweat is further impeded by high humidity. Holding ambient temperature steady, a step-wise increase in vapor pressure impairs heat dissipation.(21)(Figure 7)

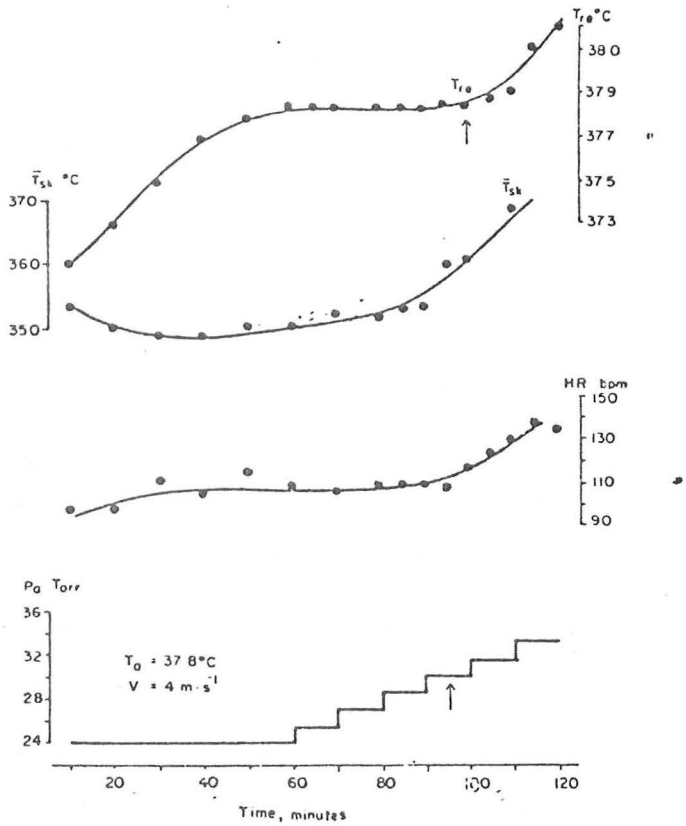


Figure 7: A typical time course in one subject of rectal temperature (T_{re}), mean skin temperature ($\bar{T}_{sk}$), and heart rate (HR) with a constant ambient air temperature (Ta) and velocity (V) with a step increase in vapor pressure (Pa). (from Kamon and Avellini[21])

In a hot and humid environment that favors neither loss nor gain of heat at rest, moderate exercise (300 kcal/hr.) can raise the core temperature 9 F° (5°C) within one hour.(20)(Figure 8) Addition of moderate to strenuous exercise to an otherwise tolerable environment can result in heat illness injury rather rapidly.

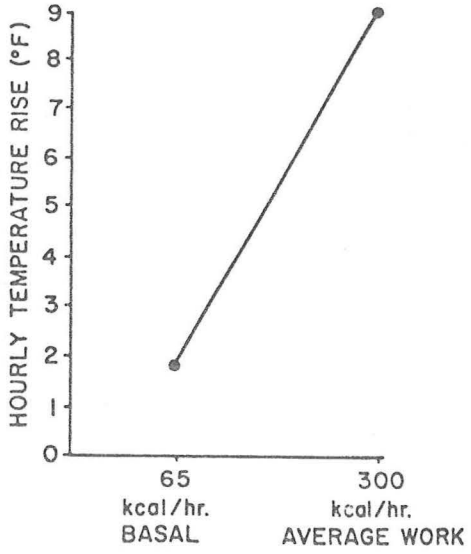


Figure 8: Relationship between rectal temperature compared to heat production in a warm humid environment that favors neither heat loss nor heat gain during rest. (from Knochel[20])

Acute Adaptations to Heat Exposure --

The ability of the body to dissipate heat depends ultimately on the integrity of the heart and circulatory system, i.e., the body's "radiator." Heated blood traversing the hypothalamus initiates the so-called Benziger reflex which results in a dilation of skin blood vessels and a stimulation of sweat production.(23) This reflex is operative even during passive warming and seems to be independent of plasma volume changes. During exercise in the heat, profound reductions in plasma volume occur for several reasons besides sweat losses. Smaller intermediate metabolic products of muscle glycogen accumulate intracellularly and act as a powerful osmotic force shifting water from plasma volume into muscle cells. In addition to increases in cutaneous blood flow, the vascular capacitance of the skeletal muscle bed increases ("exercise hyperemia") and further depletes effective arterial volume.(24) In an attempt to compensate, splanchnic vascular resistance may increase 100% and markedly decrease splanchnic blood flow despite a two-fold increase in cardiac output. Radigan and Robinson(25) demonstrated that passive exposure to a temperature of 123.8 F° (51°C) caused a 39% fall in renal plasma flow and a 21% reduction of glomerular filtration rate. This effect would be expected to intensify with exercise. If vigorous hydration is not maintained, urinary sodium excretion drops and oliguria intervenes. If not for the redistribution of splanchnic blood flow, however, serious hypotension would occur.

In baboon experiments, much of the renal vasoconstriction in response to heat stress can be prevented by either blockade of renin release with propranolol or by competitive inhibition of angiotensin II by [Sar^{-1} Ala^{8}] angiotensin II (Saralasin).(26) Heat stress is known to cause marked increments in plasma renin activity (PRA) in humans.(27) This occurs via increased release rather than a reduction in renin catabolism by the liver,(28) or an increase in renin substrate.(29) As in other species, renin release in humans appears to be triggered by increased sympathetic nervous outflow mediated by a beta-adrenergic mechanism in the kidneys.(30) PRA is also related to sodium intake but the neural release of renin is relatively insensitive to the state of sodium balance.(31) According to Zanchetti,(30) beta-blockade with propranolol does not interfere with non-neural mechanisms of renin release.

Escourrou, et al(32) conducted a two-part study to better define the role of the renin-angiotensin system in splanchnic vasoconstriction in heat-stressed male volunteers. The experimental conditions resulted in only a 1°C rise in rectal temperature by directly heating the subjects in water-perfused suits for 40-50 minutes. All subjects were on a normal salt diet. During Experiment 1 (control) arterial pressure was unchanged (85 Torr); PRA rose from 102 to 239 a angiotensin I· 100 ml^{-1}· 3 h^{-1}; and splanchnic vascular resistance (SVR) increased 73% (from 63 to 109 units). Experiment 2 was a repetition except each subject received 10 mg. of propranolol intravenously at the onset of heating to block renin release. Beta-blockade resulted in a blunting of cardioacceleration, a drop in blood pressure from 82 to 72 Torr, a block in the rise of PRA in two subjects, a reduced rise in three, and an actual increase in two. In both experiments, plasma noreprinephrine concentration rose indicative of an increased sympathetic nervous activity. Importantly, SVR still rose 60% in Experiment 2 (from 58 to 99 units).(Figure 9)

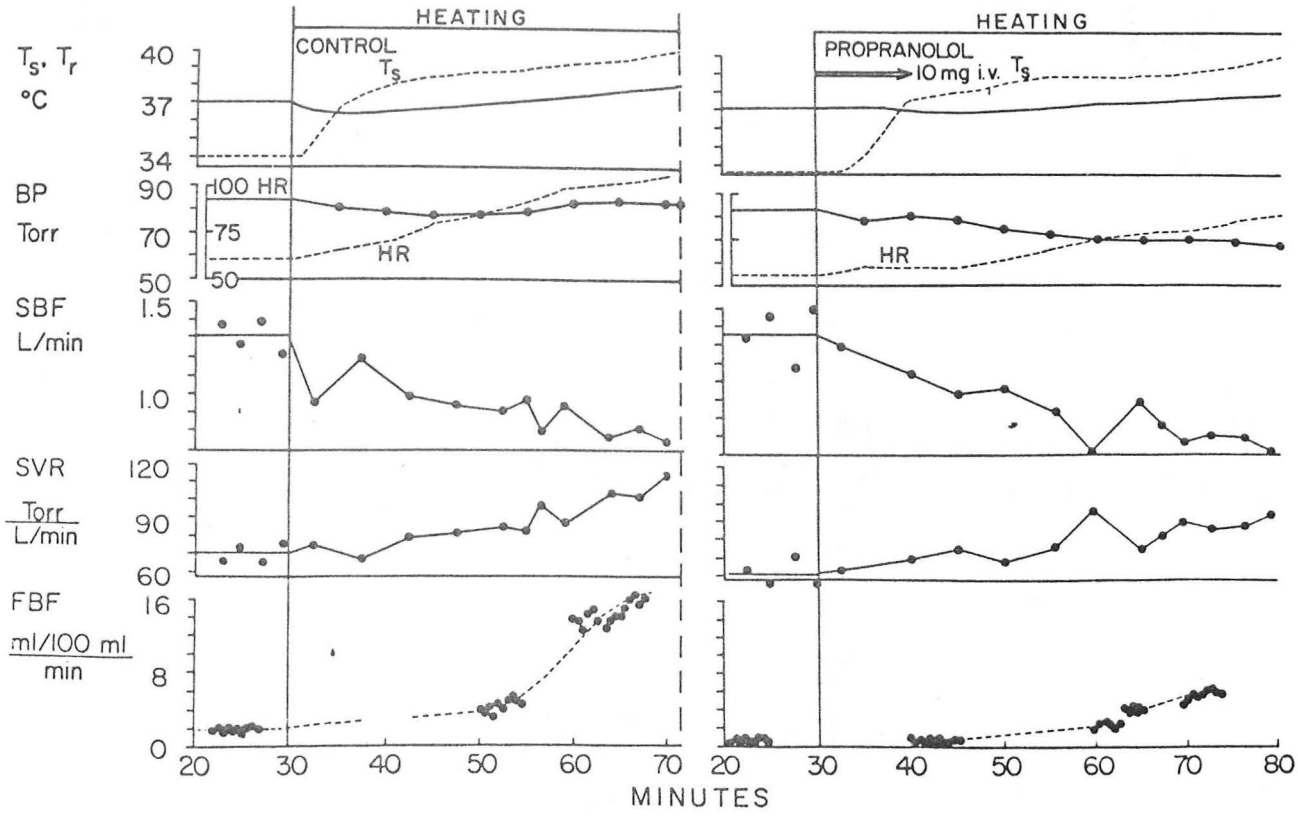


Figure 9: The response of a representative subject to heating before and after propranolol infusion. T_s=skin temperature; T_r=rectal temperature; HR=heart rate; BP=mean systemic blood pressure; SBF=splanchnic blood flow; SVR=splanchnic vascular resistance; FBF=forearm blood flow. (from Escourrou, et al [32])

Perhaps the increase in plasma norephinephrine is contributory to the increased SVR, particularly during moderate heat stress. Proppe(33) concluded that most of the superior mesenteric vasoconstriction was neural in origin, while Eisman and Rowell(26) attribute renal vasoconstriction primarily to the renin-angiotensin system. The Escourrou, et al(34) study, repeated with a potent anti-catecholamine agent such as clonidine, might further help dissect the role of catecholamines in the control of splanchnic blood flow. Antidiuretic hormone is released during heating perhaps in response to a fall in central venous pressure, (34) but it is probably not released in sufficient quantity to cause regional splanchnic vasoconstriction.

The reduced plasma volume and increased metabolic demands of skeletal muscle induced by exercise in the heat are partially compensated by increased SVR, however, it is critical that core heat be transferred to the skin before transfer of heat from skin to air can occur.

Roberts and Wenger(35) studied the control of skin circulation during exercise and heat stress by measuring forearm blood flow (ABF) during leg exercise in the heat. Forearm blood flow (ABF) measured by plethsmography is commonly used as an index of whole-body skin blood flow. At an ambient temperature of 77 F° (25°C), internal temperature (esophageal-T_{es}) starts to rise shortly after bicycle ergometry exercise begins.(Figure 10) The chest sweat rate and ABF also rise after a short lag period and continue to rise in proportion to the rise in T_{es}. A reasonably linear relationship exists between ABF and T_{es} and between T_{es} and the sweat rate rise once the threshold for vasodilation and sweating are achieved. The relationship between T_{es}, sweating and skin blood flow underscores the importance of these mechanisms of heat dissipation.

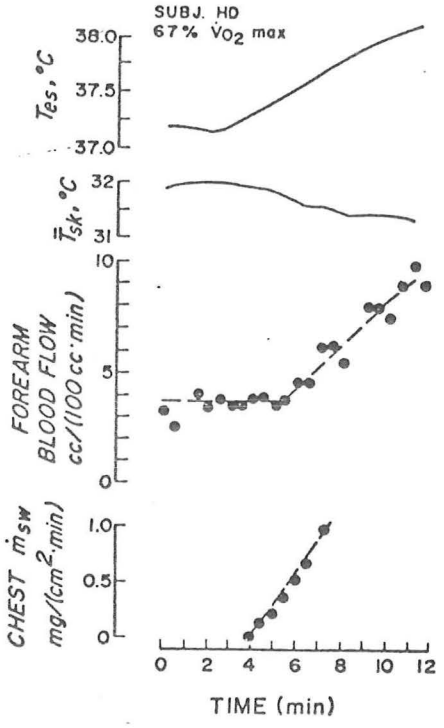


Figure 10: Time course of esophageal temperature (T_{es}), mean skin temperature ($\bar{T}_{sk}$), arm blood flow and chest sweating during a 12 minute exercise period at 67% $\dot{V}o_2$ max. Air temperature 25°C. (from Roberts and Wenger[35])

While the temperature of skin ($\bar{T}_{sk}$) remains relatively constant during exercise at an air temperature of 77 F° (25°C), higher air temperature results in an increase in $\bar{T}_{sk}$. At an air temperature of 95 F° (35°C) the $\bar{T}_{sk}$ is also 95 F° (35°C) providing an additional reflex stimulus for increased skin blood flow. Higher $\bar{T}_{sk}$ does not affect the slope of ABF:T_{es}, but it does shift the relationship toward a lower T_{es} (Figure 11). At any given T_{es}, ABF is greater at a higher $\bar{T}_{sk}$.

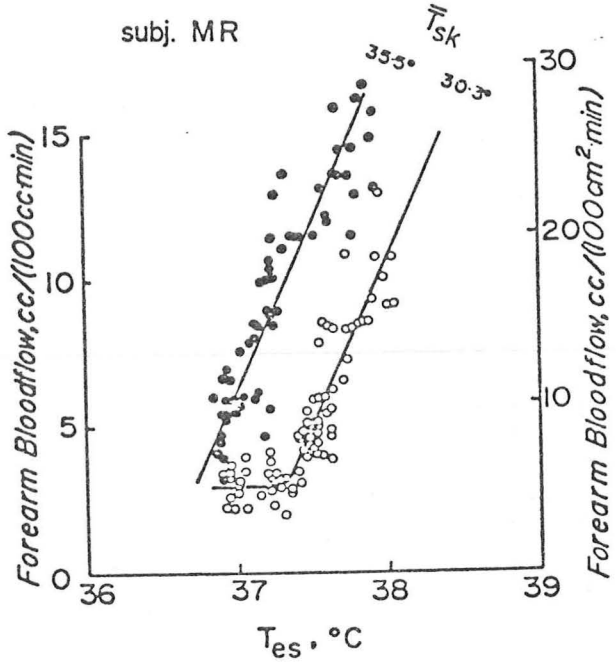


Figure 11: Forearm blood flow plotted against esophageal temperature (T_{es}) for exercise at two different air temperatures (hence 2 different skin temperatures ($\bar{T}_{sk}$)). (from Roberts and Wenger[35])

The ambient temperature also affects the capacitance of cutaneous veins. At a cool air temperature of 59 F° (15°C), sympathetic nervous activity causes vasoconstriction. In a hot environment, sympathetic venomotor tone is reflexly inhibited as skin temperature rises.(36,37) Any given distending pressure produces a larger increase in venous volume than at cooler temperatures.(Figure 12) Cutaneous venodilation improves the efficiency of heat loss since widening of the venous channels at a given volume flow rate slows the velocity of flow and allows more time for heat transfer to skin.(38)

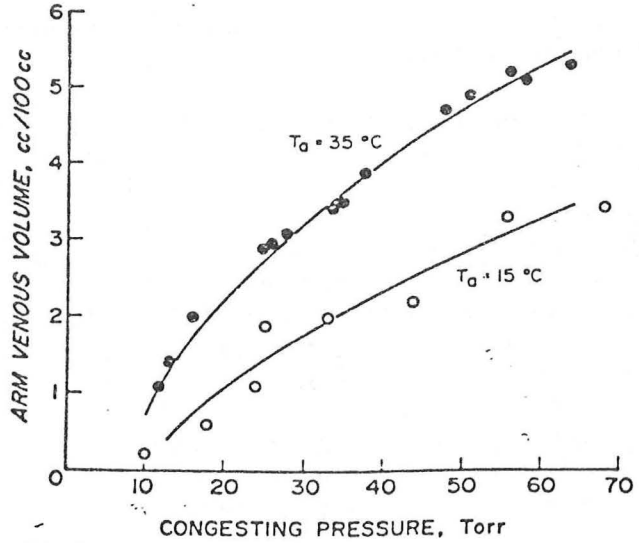


Figure 12: Arm venous volumes are plotted against congesting pressure during exposure to two different air temperatures. (from Roberts and Wenger[35])

Like the cardiovascular consequence of increased SVR, extensive peripheral venodilation is not altogether beneficial since the cardiac filling pressure and cardiac stroke volume are also reduced. Cardioacceleration must occur to deliver the necessary cardiac output to sustain the metabolic demands of exercise and dissipate heat gains.

In both supine and upright exercise, as exercise continues and T_{es} and ABF increase, cardiac stroke volume gradually declines.(Figure 13) Loss of volume from the vascular space serves to exaggerate the progressive reduction in cardiac stroke volume. Severe heat stress and moderate exercise act in concert to produce a reduction in splanchnic and renal blood flow,(39) widespread peripheral vasodilation and venodilation, and a reduction of blood flow to non-exercising muscle.(40) The rapidity of these changes suggest that they are mediated by the sympathetic nervous system.

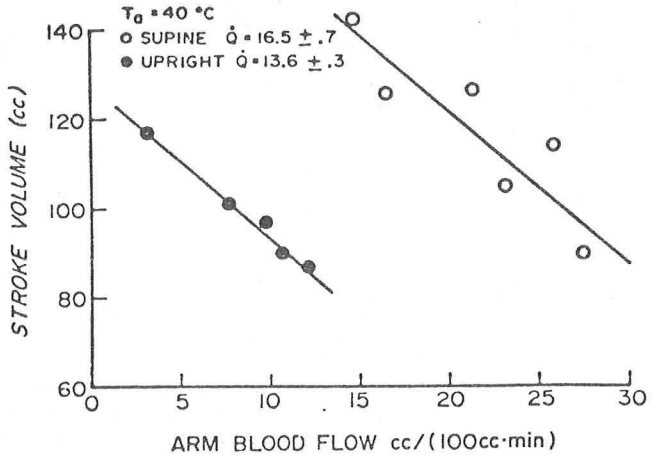


Figure 13: Cardiac stroke volumes vs. arm blood flow during upright and supine exercise at an air temperature of 40°C. (from Roberts and Wenger[35])

If these compensatory mechanisms fail because the heat stress is severe or the exercise extreme, arterial hypotension may ensue. When this occurs, low pressure arterial baroreceptors stimulate cutaneous vasoconstrictors and partially override the vasodilator reflexes to decrease skin blood flow and conserve central vascular volume. Higher core body temperature results as heat transfer from core-to-skin is impaired.

The hemodynamic changes occurring in ten unacclimatized, untrained men performing graded exercise (50 to 80% maximum) at temperatures of 78 F° (26.5°C) and 110 F° (43.3°C) has been described by Rowell et al.(41) As expected, exercising in the hotter environment resulted in cardioacceleration (174 to 195 beats/min.) and decreased stroke volume, cardiac output and central venous pressure. In a somewhat more dangerous setting, Gold(42) studied normal volunteers exposed to either dry heat at 130 F° (54.5°C) for two hours or 160 F° (71.1°C) for one hour. As heat gain occurred, a hyperkinetic circulatory state developed characterized by tachycardia, and markedly increased mean venous pressure (from 40 to 200 mm. water). As collapse seemed imminent, cardiac output actually fell, sweating ceased and the subjects became ashen, lightheaded or confused. Closed parked cars, attics, boiler rooms and South African gold mines represent the clinical counterpart of this study's milieu.

The responses to acute heat stress are summarized in Table 1.

TABLE 1.

Acute Adaptations to Exercise and Heat Stress

I. Initial cardiovascular responses

A. Peripheral circulatory changes

1) Hypothalamic (Benzinger) reflex

a) Cutaneous vasodilation
b) Increased sweating

2) Activation of the renin-angiotensin-aldosterone axis and sympathetic nervous system

3) Splanchnic vasoconstriction

4) Reduction in renal plasma blood flow

a) ↓ GFR
b) Sodium conservation, early potassium loss
c) Oliguria

5) Shunt of blood flow to exercising muscle (exercise hyperemia)

6) Osmotic movement of plasma water to skeletal muscle cells

NET EFFECT: Decreased effective arterial volume

B. Central circulatory changes

1) Venous return falls
2) Cardiac stroke volume falls
3) Cardioacceleration occurs

NET EFFECT: Cardiac output may be maintained, rise or fall depending upon the length and severity of exposure, activity level, and presence or absence of underlying disease states.

Adaptation to Chronic Heat Exposure --

Acclimatization is the physiologic process by which an individual develops tolerance to a hot environment. This term is insufficient when used to describe an individual unless it is qualified by activity levels i.e., sedentary, untrained or trained for hard muscular work. The process of acclimatization requires at least several weeks and the most important adaptations involve the cardiovascular, exocrine and endocrine systems.

In the physically trained and acclimatized person there is a substantial increase in muscle glycogen and myoglobin content along with an increase in mitochondrial density.(43,44) These changes make an important contribution to the acclimatization process by substantially increasing aerobic metabolism and decreasing endogenous heat production per unit of work performed.

Cardiovascular Adaptations --

An increased maximal cardiac output, a decreased peak heart rate, and an increased cardiac stroke volume in acclimatized subjects facilitate efficient delivery of heated blood from muscle and visceral to the body surface where heat can be dissipated.(45) The decline in glomerular filtration rates (GFR) during acute exposure to heat are reversed and GFR can increase approximately 20%.(46)

In human experiments, exercise performed in cool temperatures by unacclimatized subjects results in transient hemodilution and protein addition to the vascular volume.(47,48) As exercise begins, lymph flow from contracting muscles increase and this lymph has a high protein concentration. Return of protein to the vascular volume forms an osmotic base for the retention of salt and water within the vascular volume. The rate of return of protein early in exercise exceeds the rate at which protein is lost, thereby expanding plasma volume.

Senay(49) demonstrated this phenomenon in four unacclimatized male subjects exercising at 68 F° (20°C) for 45 minutes. However, he found just the opposite result when the same subjects were exercised at ambient temperatures of 86 F° (30°C) and 104 F° (40°C), that is, hemoconcentration with loss of protein from the vascular space.(Figure 14) The basic difference between mild exercise at a cool vs. a warm or hot ambient temperature was the patency of the cutaneous vascular bed. At the cooler temperature, the bed was constricted, whereas it was vasodilated by the warmer temperature.

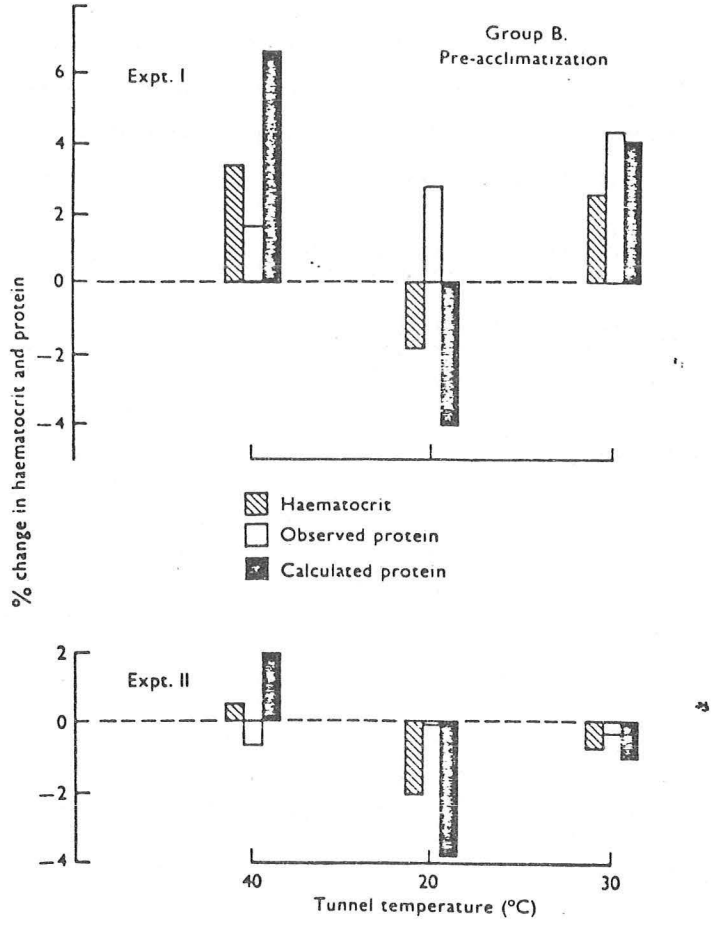


Figure 14: The mean results for 4 unacclimatized subjects blockstepping at a $\dot{V}O_2$ of 0.91 min. for 45 min. at each of the indicated temperatures. Between exposures the subjects resting for 1 hour in a normal environment and duplicate experiments were run 1 week apart. Protein and water were lost from the vascular volume during exposure to 40° and 30°C, but added during exposure to 20°C. (from Senay[50])

After acclimatization to heat, the vascular volume dynamics in these same four subjects dramatically changed during 45 minutes' exercise at 86 F° (30°C) and 104 F° (40°C).(Figure 15) When exposed to the warmer environments, the acclimatized subjects became hemodiluted and added protein to the vascular volume as they had previously during exercise at the cooler temperature. In fact, acclimatization did not significantly alter the hemodynamic response to exercise at 68 F° (20°C), but it did clearly change the cutaneous vascular bed from an area of fluid and protein loss to one of fluid and protein gain at 86 F° (30°C) and 104 F° (40°C).

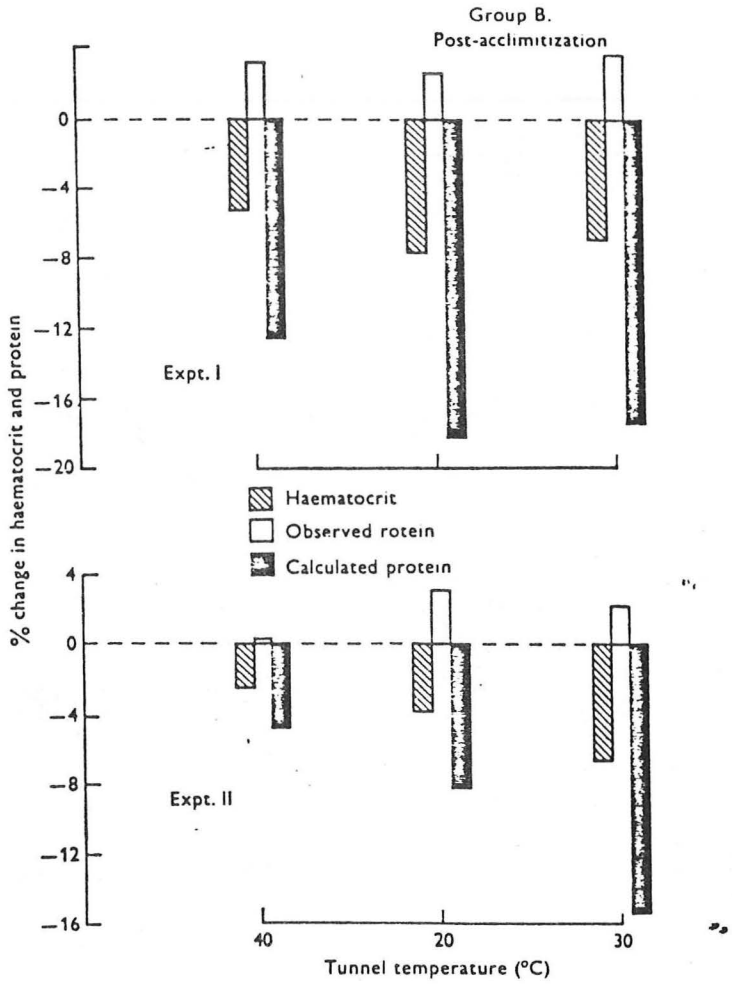


Figure 15: Response of same subjects in Figure 14 after heat acclimatization. Except for exposure to 20°C, the post-acclimatization results are opposite those seen prior to acclimatization. (from Senay[50])

The distribution of body fluids during exercise in heat was changed by training and acclimatization to heat in another experiment by Senay.(50) After eight days of four hour/day exercise periods in heat, a standard exercise test done in a hot room 93 F° (33.8°C DB, 32.4°C WB) was accompanied by remarkable hemodilution. The mean hematacrit decreased 8% as the plasma volume expanded between 15 to 20%.(Figure 16)

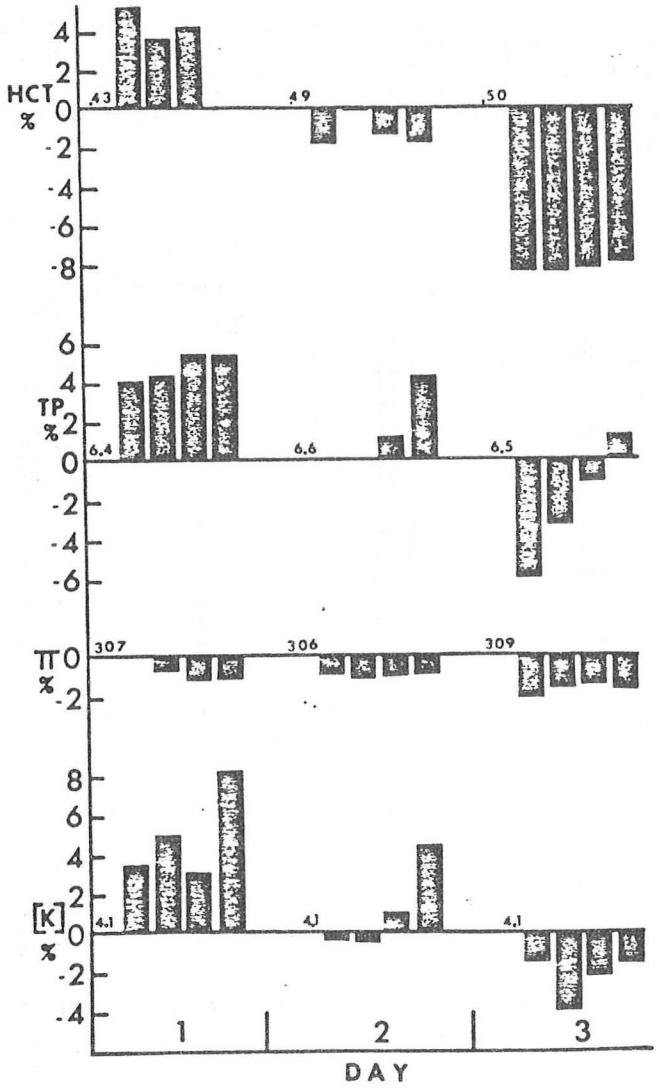


Figure 16: Mean % changes from control volumes for hematocrit (HCT), total protein (TP), potassium (K) and osmotic pressure as m osmol $\cdot$ l^{-1} of plasma water (TT) during standard exercise tests in a hot room. Day 1 is before training; Day 2 is after 42 days of training; Day 3 is after acclimatization. (from Senay[50])

Trained individuals respond to heat exposure in the short term by increasing plasma volume apparently by moving protein from the interstitial space into the vascular volume. After acclimatization, the resting plasma volume may return to the pre-acclimatization level in trained subjects, however they seem to gain the ability to rapidly increase plasma volume at the beginning of exercise in the heat. This phenomenon was found to be one of the differences between "heat tolerant" and "heat intolerant" individuals.(51) Nineteen heat tolerant and 15 heat intolerant miners were exercised to the same relative oxygen consumption in a hot environment. The heat intolerant subjects did not expand their plasma volume as well as the heat tolerant subjects. The plasma volume expansion of

the heat intolerant subjects was only 1/3 to 1/2 of that in the heat tolerant subjects. In the heat intolerant subjects the fault seemed to be in either delivery of proteins to, or their retention within, the vascular volume. The heat tolerant subjects moved fluid and protein into the vascular volume in response to exercise in the heat with a shift back out of the vascular compartment overnight.

Endocrine and Exocrine Responses to Heat --

With training, stability of vascular volume is attained during heat exposure, but a maximum protective response to exercise in heat is gained only upon acclimatization which is characterized by an aldosterone mediated expansion of plasma volume, extracellular blood volume and total body water.

Both acute heat exposure and physical training activate the renin-angiotensin system, thereby increasing the production of aldosterone. Despite diets high in sodium (300 m. Eq/day), plasma renin activity may be ten times normal.(46) The onset of aldosterone's effect on the kidney lags up to two hours following the onset of heat/exercise stress and its role in acute adaptation to heat is likely minimal. After several days, urinary sodium concentration falls and plasma volume, extracellular fluid volume and total body water expand. Once this new "steady state" is achieved, sodium reappears in the urine, so called "renal escape." Acclimatized subjects have a demonstrably higher exchangeable sodium (^{24}Na) and sodium space compared to subjects trained in a temperate climate.(52) Despite this, aldosterone levels remain significantly elevated in relation to sodium intake in the acclimatized individual.(53,54,55)(Figure 17) Exogenous mineralocorticoid administration results in expansion of body fluid compartments, but it does not acclimatize subjects to heat.(56)

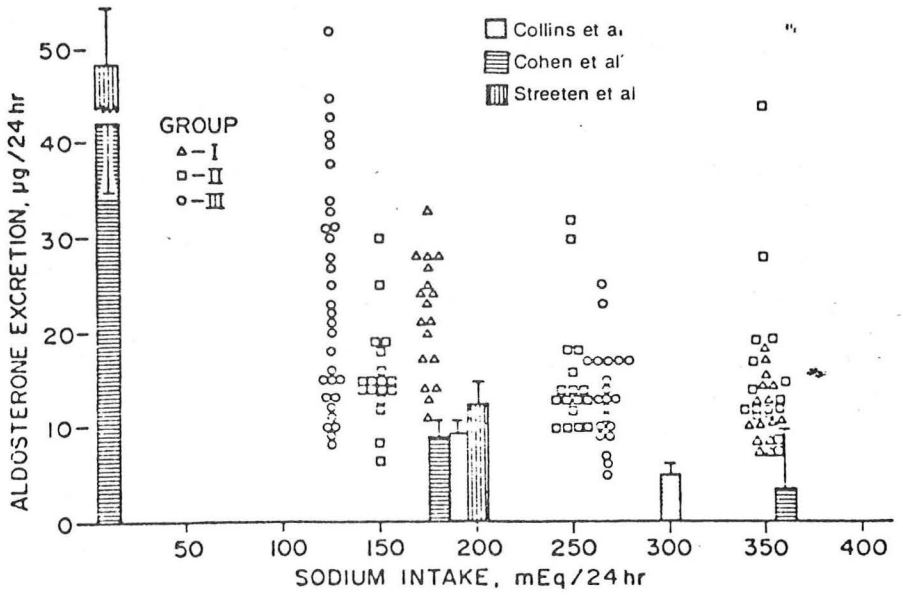


Figure 17: A comparison of aldosterone excretion and intake of sodium. Group I represents subjects undergoing basic military training in hot weather; Group II and Group III represent those training in cooler climates. The bars represent values reported by other investigators using identical analytical methods for normal subjects not performing strenuous physical work. Collins, et al(53), Cohen, et al(54), Streeten, et al(55) (from Knochel[20])

One week into the acclimatization process, the increased aldosterone production results in a diminished sweat sodium.(57,58) By the end of the second week, maximal sweat production increases and subjects can produce larger volumes of sweat with a lower sodium concentration for any given workload in the heat.(20)(Figure 18)

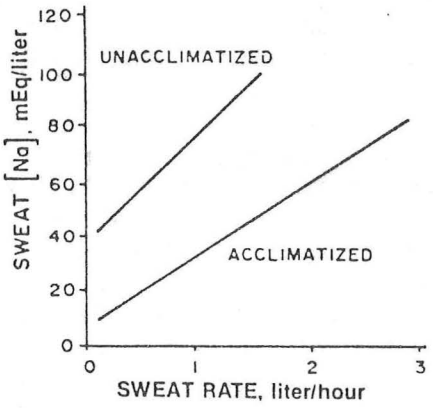


Figure 18: Relationship of sweat sodium concentration to sweat rate in acclimatized or unacclimatized subjects. (from Knochel [20])

Shvartz, et al(59) studied five young men undergoing eight days of heat acclimatization and training (bicycle ergometer; 50% $\dot{V}O_2$ max., 2 hrs/day) at 104F° (39.8°C[db]). A control group was studied while exercising the same amount at 75 F° (24°C). Total body sweat rates and water intake increased in the acclimatization group.(Figure 19) Local sweat rates (SR) for chest, thigh and arm increased with acclimatization/training (Figure 20) while the rectal temperature (T_{re}) at the onset of sweating decreased 0.9F° (0.49°C) from day 1 to day 8.(Figure 21) The T_{re} at the onset of sweating for controls decreased modestly 0.34F° (0.19°C) during conditioning. Thus both acclimatization and conditioning result in increased sweating sensitivity with acclimatization resulting in a greater change compared to conditioning. The sustained rise in aldosterone production, which leads to an expansion of body fluid compartments seemingly provides a "camel's hump effect" allowing for the increased sweating rates and increased sweating sensitivity. It would appear that escape from sweat gland sodium reclamation does not occur as with the kidney.

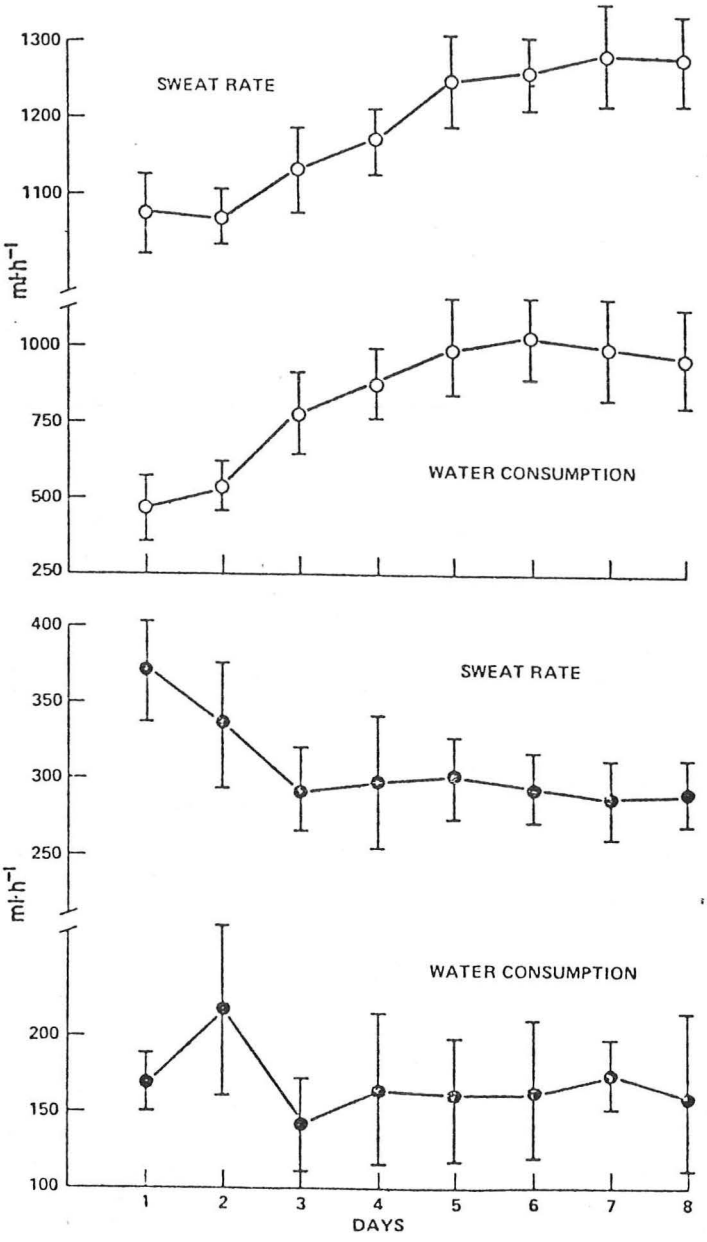


Figure 19: The total body sweat rate and water intake of acclimated (O) and control (●) groups. The difference between days 1 and 8 were significant ($p < 0.05$) for sweat rate in both groups and for water intake ($P < 0.01$) in the acclimated group. (from Shvartz, et al[59])

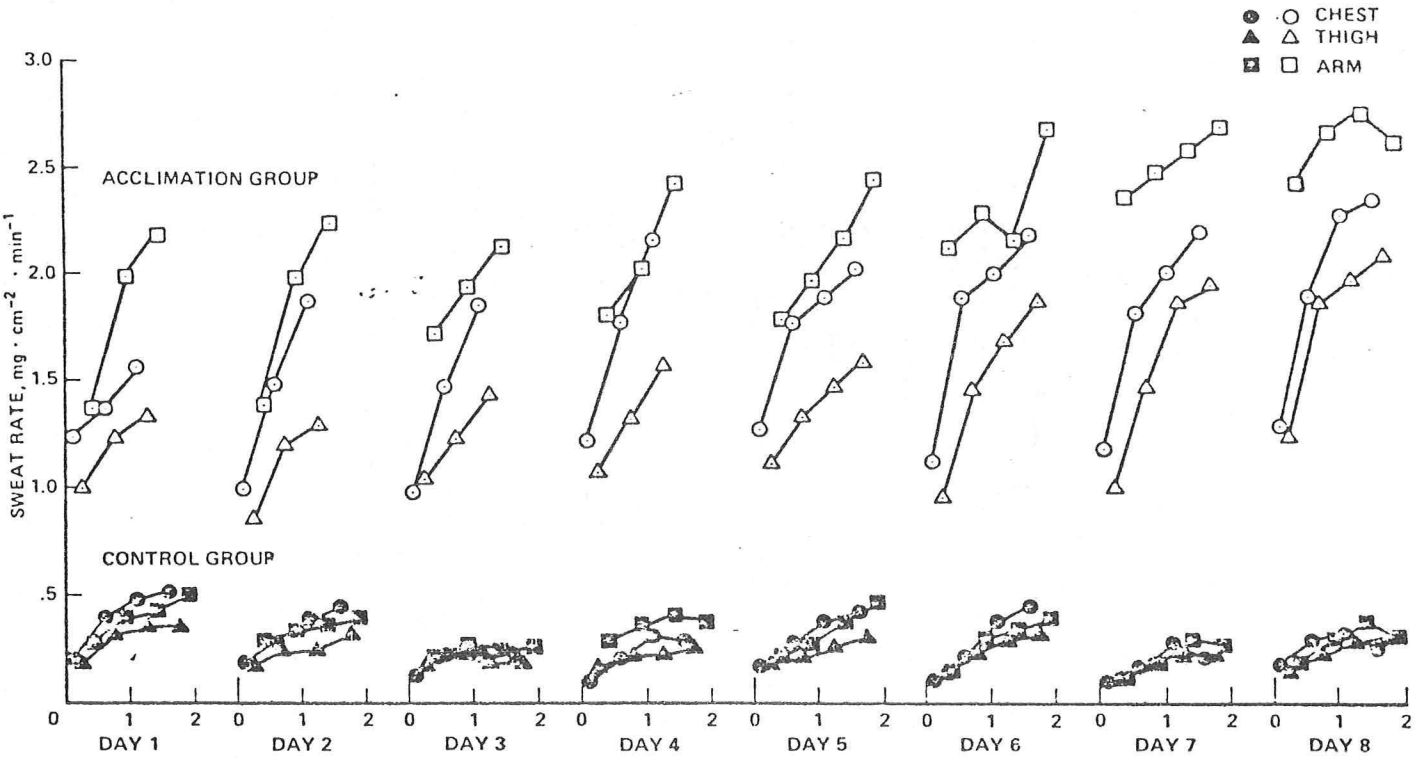


Figure 20: The regional sweat rates of acclimation and control groups during 8 days of the experiment. Measurements were taken every 10 minutes, but the final measurement for the acclimation group could not be obtained for the first 4 days because subjects did not complete the exposures. (from Shvartz, et al[59])

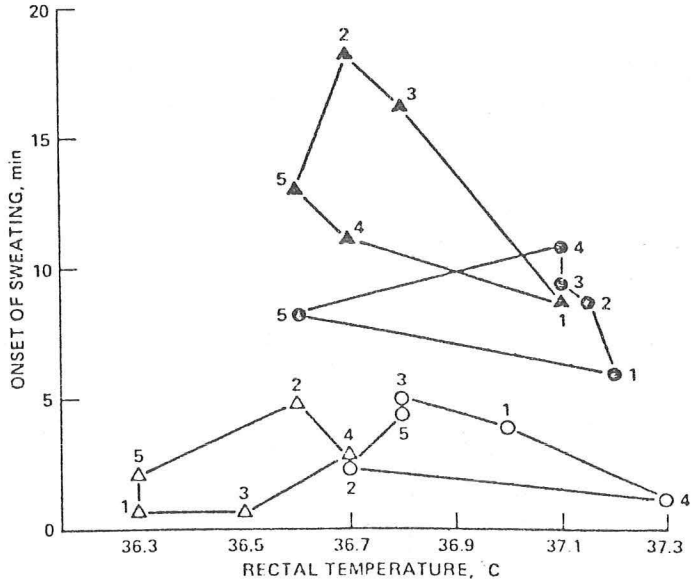


Figure 21: The time of onset of sweating in relation to rectal temperature (T_{re}) of acclimation group on day 1 (O) and day 8 (△) of exposure, with corresponding responses (●, ▲) for control group; 1-5 are subject numbers. (from Shvartz, et al[59])

In the later phase of acclimatization, sweat volume for any given workload may actually decrease. There are several possible explanations for this phenomenon. The increased metabolic efficiency and reduction of endogenous heat production associated with acclimatization may be responsible.(60) It is also possible that acclimatization results in the development of an improved sweating efficiency in a humid environment. Candas, et al(61) suggested that skin wettedness influences the evaporative efficiency of sweating (η_{sw}). They noted a decline in sweating rates, or hidromeiosis, (measured by a decline in the amount of sweat dripping from various parts of the body's surface) as the difference between $\bar{T}_{sk}$ and ambient air temperature narrowed in resting male subjects exposed to humid heat sufficient to cause skin wettedness ranging between 50% to 100%. The decline in sweating rate, however, did not result in a noticeable change in the evaporative rate of sweat or the core temperature (T_{es}). Their data also indicated that the local sweating rate per area of skin surface (M^2) was strongly increased by acclimatization, but there were marked variations from body site to body site and from subject to subject. Even under extreme experimental conditions, only acclimatized subjects could achieve full skin wettedness. The increased responsiveness of sweating resulted in more efficient evaporative adjustments by shifting sweat production to the extremities which provided a larger evaporative cooling surface and relatively little dripping. Increasing the overall intensity of sweating prior to achieving proper skin wettedness in the more evaporative zones resulted in an inefficient water loss from sweat dripping which limits heat exchange to air.(Figure 22)

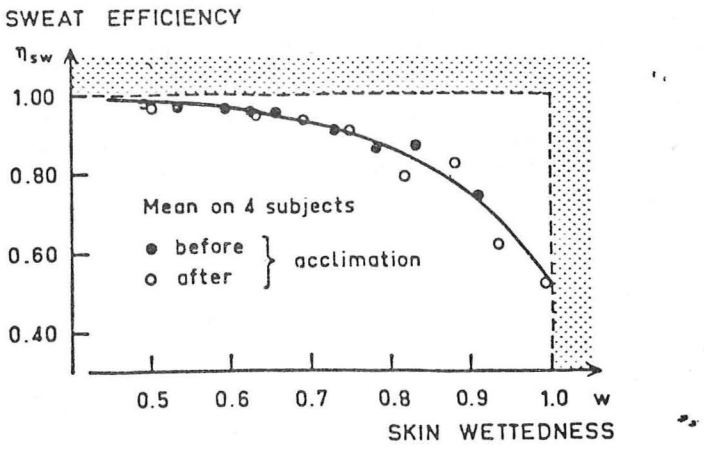


Figure 22: The relationship between sweating efficiency and skin wettedness. (from Candas, et al[61])

Evaporative efficiency of sweating was also affected by air velocity. At 0.2 $M \cdot S^{-1}$ and a skin wettedness of 70%, sweating efficiency approached unity. Higher air velocities of 0.6 or 0.9 $M \cdot S^{-1}$ decreased sweating efficiency by 10%. When the skin was fully wet, a 0.2 $M \cdot S^{-1}$ air velocity resulted in a 34% loss of sweat by dripping, whereas 44% and 51% of sweat was lost by dripping at air velocities of 0.6 and 0.9 $M \cdot S^{-1}$ respectively.(Figure 23)

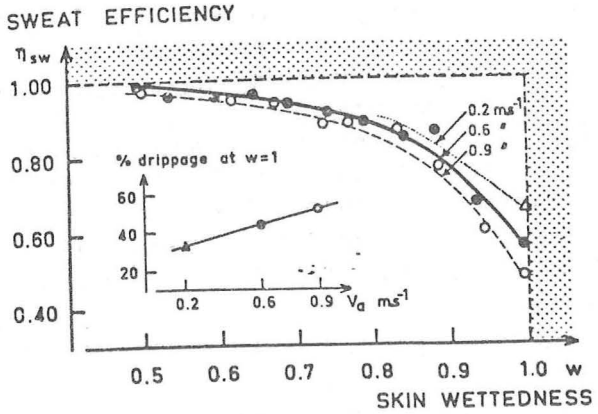


Figure 23: The effect of air velocity on relation between evaporative sweating efficiency and skin wettedness. (from Candas, et al[61])

The effect of physical training on the sensitivity and time course of sweating in women has been examined by Araki, et al.(62) Physically untrained and trained young female subjects pedaled a bicycle ergometer at work rates of 483 and 981 kgm. $min.^{-1}$ for two hours in summer and winter in an ambient environment of 86 F° (30°C) and 60% rh. Sweating was initiated more rapidly in the trained group than in the untrained group. The trained group working at a load of 981 kgm. $min.^{-1}$ exhibited a progressive decrease in sweat rate.(Figure 24) This effect was not observed at 483 kgm. $min.^{-1}$. Hidromeiosis was rarely seen in untrained subjects, however, after 60 days of physical training, initiation of sweating occurred more quickly and hidromeiosis was observed. Hidromeiosis could be overcome by increasing the workload to 1,070 kgm. $min.^{-1}$.(Figure 25) Previous physical training seems to improve subjects capacity for useful sweating during exercise in a hot environment.

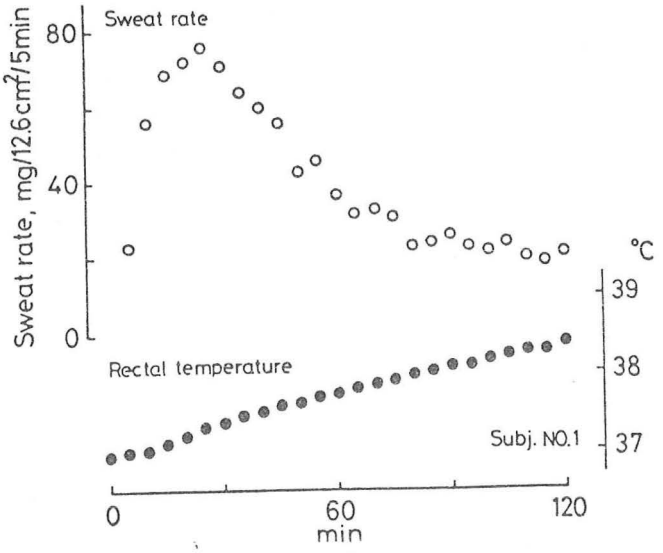


Figure 24: Time course of dorsal sweat rate and rectal temperature of a trained female subject working at 981 Kgm. $min.^{-1}$ (ambient temperature 30°C db, 60% rh). (from Araki, et al[62])

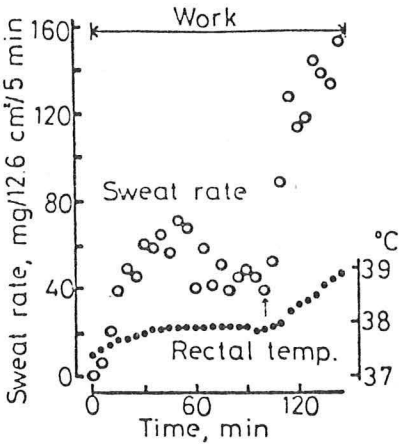


Figure 25: Change in dorsal sweating time course with increase in workload for an acclimatized female subject. ↓ indicates time of workload increase to 1,070 Kgm. min.$^{-1}$. (from Araki, et al[62])

Under conditions of sustained hard work in the heat, sweat volumes as high as 10 to 12 liter/day can be produced in subjects with access to unlimited fluid intake. The potassium concentration of sweat ranges between 5 and 10 mEq/liter. Urinary losses may also be inappropriately high in persons who are potassium deficient presumably due to the marked overproduction of aldosterone coupled to high dietary sodium chloride. As "renal escape" occurs, sodium wasted at proximal tubule is partially reclaimed by the distal tubule but at the sacrifice of body potassium stores.(46) Such persons may develop potassium deficits exceeding 500 mEq.(Figure 26) Normal persons undergoing acclimatization and performing moderate exercise in the heat would not be expected to develop a significant potassium deficiency if consuming a normal potassium diet. While potassium supplements are not necessary and may be dangerous, a normal potassium diet may be a prerequisite to proper conditioning and acclimatization.

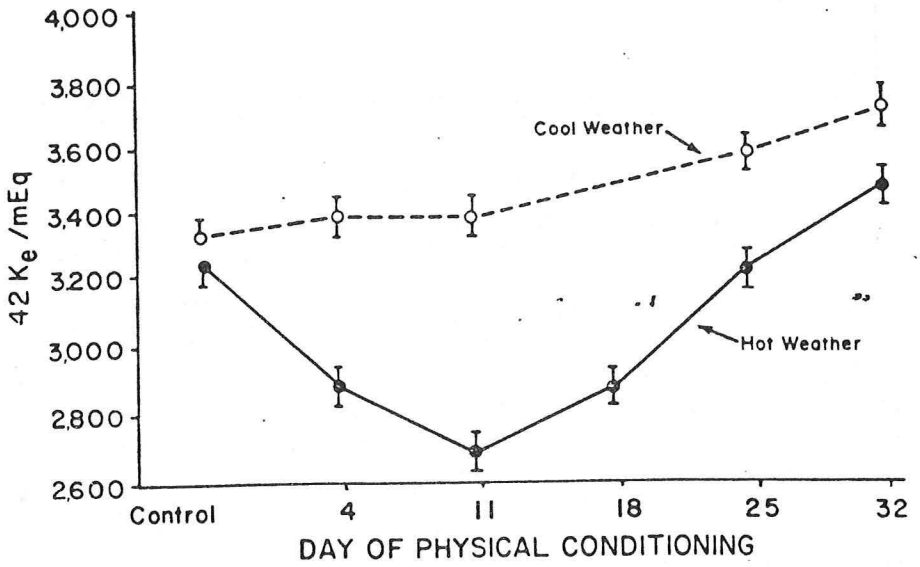


Figure 26: The average total exchangeable radioactive potassium (^{42}Ke) was compared in six military recruits training in hot weather with average values for men training in cool weather. The interval between the control study and training day 4 was seven days. Potassium deficits exceeded 500 mEq between the second and third week of training. (from Knochel [20])

Hubbard, et al(63) studied 182 male Sprague-Dawley rats weighing 250-300 gm. on either a diet containing 125 mEq or 8 mEq potassium/kg. Rats fed the low K^+ diet gained weight at only 1/3 the rate of rats on the normal (control) K^+ diet (1.7 vs. 5.2 Gm/day), and their skeletal muscle and plasma potassium levels fell by 28% and 47% respectively. When run to exhaustion at either 59 F° (15°C) or 68 F° (20°C), the low K^+ rats accomplished less than 1/2 the work of controls (26 vs. 53 kg.m)(Figure 27) but exhibited a much greater rate of heat gain per kilogram-meter work than controls, 0.22 F° vs. 0.09 F° (0.12 vs. 0.05°C). At an ambient temperature of 68 F° (20°C), the low K^+ rats, despite 25% lower body weights, 37% shorter run times, and 49% less work performed, had identical post-run core temperature and twice (33% vs. 17%) the mortality rate of controls. The heat injured rats on a low K^+ diet raised their plasma levels of K^+ to normal concealing the true deficiency state. The role of potassium deficiency as a risk factor for heat injury needs further elucidation, but potassium wasting diuretics were commonly used by victims of classical heatstroke during the 1978 (and 1980) Dallas heat wave.(64)

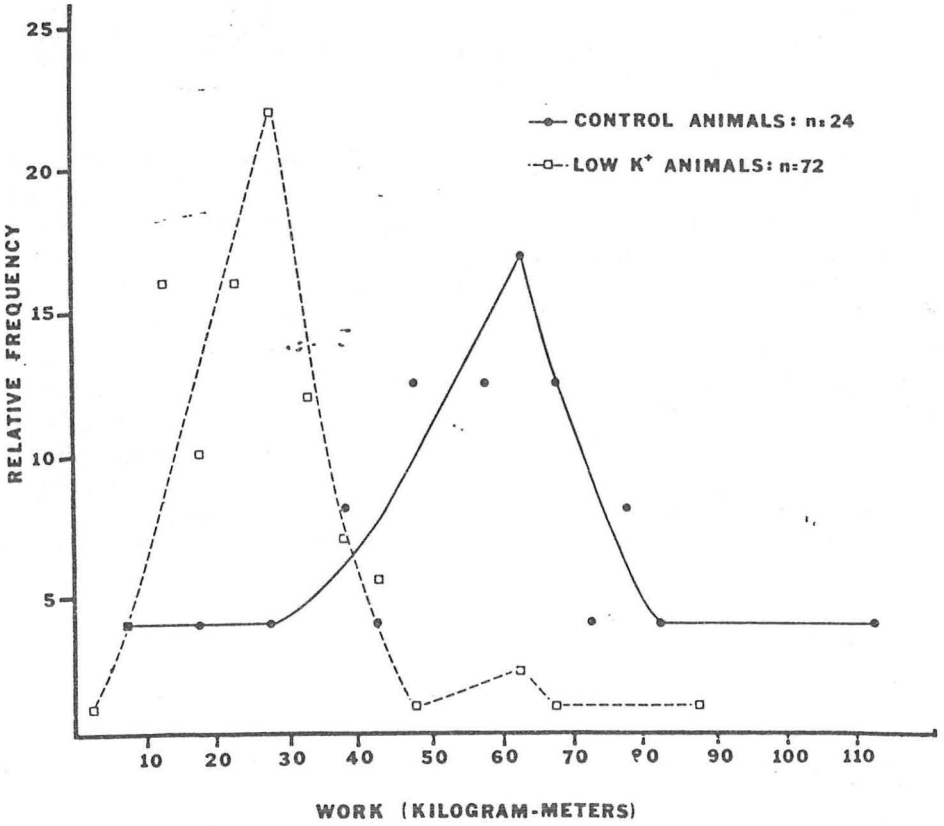


Figure 27: Untrained rats fed a control or a low potassium (Low K^+) diet for 32 days were made to run on a treadmill to exhaustion. Work performance was markedly reduced in Low K^+ animals but the increase in core temperature was comparable to animals working much harder. A two-fold increase in mortality occurred in the Low K^+ animals. (from Hubbard, et al[63])

Both physical work and heat exposure behave as potent stimuli for growth hormone release.(65,66) Although growth hormone can cause salt and water retention, it is likely not involved in the acclimatization process.(67) No association clearly exists between changes in plasma catecholamines and chronic adaptation to heat.(68) Adrenocorticotrophic hormone concentrations during heat stress and the subsequent achievement of acclimatization do not correlate.(69) On the other hand, strenuous physical activity such as marathon running may increase serum cortisol 2-3 fold.(70) Both cortisol and ACTH are known stimulators of renin substrate (RS) production by the liver. This increase in RS would tend to counterbalance increased RS consumption by the renin-angiotensin-aldosterone axis and result in the preservation of sodium and water balance during prolonged heavy physical work.

The chronic adaptations to heat exposure are summarized in Table 2.

TABLE 2.

Chronic Adaptations to Heat Exposure
(Acclimatization)

I. Circulatory adaptations

A. Cardiac performance improves

1) Increased cardiac stroke volume
2) Decreased peak heart rate
3) Increased maximal cardiac output

B. Renal - increased GFR (approximately 20%)

C. Cutaneous blood flow increases

D. Body fluid compartments expand and shift to protect plasma volume

II. Metabolic adaptation

A. Myoglobin content of skeletal muscle increases

B. Mitochondrial density of skeletal muscle increases

C. Muscle glycogen increases

III. Endocrine and Exocrine Adaptation

A. Sustained increase in aldosterone production

B. Increased evaporation efficiency of sweating

NET EFFECT: Increased work capacity in heat with a lower core temperature for any given workload. A more efficient delivery of blood from muscle and viscera to skin for heat exchange develops. The increased aerobic metabolism of skeletal muscle results in less heat production per unit of work. An increased sweat volume of a lower sodium concentration allows better dissipation of heat. Sweating efficiency improves (less wasteful dripping).

The Spectrum of Environmental Heat Illness

Heat Syncope --

Classically, heat syncope occurs in recruits-at-attention, post-calisthenics. In the majority of cases, repair of salt and water deficits and movement to a cooler environment rapidly reverses the clinical features. Postural pooling of blood has been blamed for this relatively mild malady, but there may be more to it than that. The potassium wastage associated with training/heat stress may result in some degree of autonomic insufficiency.(71) Hypokalemia can cause impairment of vascular responsivitity to catecholamines and blunted cardioacceleration leading to a magnification of fluid loss and orthostatic hypotension. In rare cases, potassium supplements may be necessary prior to resumption of training.

Heat Edema --

The physiologic adaptation of sodium and water retention, along with the direct effect of ambient air temperature on venomotor tone, occasionally result in ankle and leg edema. This fluid represents no threat to the patient and should not be treated with diuretics since expansion of body fluid compartments is desirable and necessary for heat acclimatization.

Heat Cramps --

Persons subjected to intense work in a hot environment who replace salt and water sweat losses with large volumes of water only are prone to heat cramps.(72) These cramps are intermittent, intense, excruciatingly painful, and usually involve the muscle groups of work, or on occasion, the abdominal muscles. The onset of painful cramping usually occurs sometime after the individual leaves the hot environment, hence the rectal temperature of victims is ordinarily normal.

Heat cramps commonly occur in acclimatized individuals with increased exercise tolerance. Such individuals are capable of copious sweating at higher performance levels. Although such persons have a more dilute sweat, the total sodium loss may exceed that of unacclimatized subjects. (Table 3) Sodium depletion enhances and prolongs calcium contractile properties in skeletal muscle, producing muscle cramps. Serum sodium tends to be low, but may be normal. One or two liters of intravenous normal saline or oral saline rapidly reverses the muscle cramping. The presence of systemic symptoms, particularly CNS manifestations, precludes the diagnosis of simple heat cramps and suggests the diagnosis of heat exhaustion.

TABLE 3.

Relationship of Sweat (Na^+) to Sweat Rate in Humans

	Maximum Sweating Rate	(NA^+) Concentration	Maximum (NA^+) loss/hr
Unacclimatized	1.5 liter/hr	100 mEq/liter	150 mEq/hr
Acclimatized	2.5 liter/hr	75 mEq/liter	175 mEq/hr

Heat cramps can be easily prevented by providing adequate water replacement and a parallel replacement of sweat sodium by increased dietary sodium chloride or one of the several oral electrolyte solutions. Salt tablets are not recommended because they can cause gastric irritations and fluid shifts into the bowel. Salt tablets also do not guarantee adequate free water replacement and can contribute to hypernatremia.

Heat Exhaustion --

Heat exhaustion is a disorder caused by sodium deficiency, water deficiency, or both. (Table 4) The sodium depletion type commonly is associated with muscle cramps and it tends to occur for the same reason, but unlike muscle cramps, it is more common in unacclimatized individuals. Clinically, victims are often afebrile, clammy, tachycardic, hypotensive and hyperventilatory. Urine output is normal, sweating may be present, and patients do not display intense thirst.(73) They do have systemic signs besides muscle cramps including headache, altered sensorium, weakness, fatigue, nausea, vomiting, diarrhea and diffuse myalgias. These patients have a contracted interstitial space, an expanded intracellular space, and mild hyponatremia which can easily be corrected by intravenous normal saline.

TABLE 4.

"Classic" Types of Heat Exhaustion

Water Depletion Type	vs	Sodium Depletion Type
1. Intracellular dehydration		1. Intracellular space expands
2. Hypernatremia		2. Hyponatremia
3. Body sodium stores are normal or elevated		3. Body sodium stores are deficient
4. Body temperature invariably elevated		4. Body temperature usually normal
5. Symptoms		5. Symptoms
a. Intense thirst		a. Not thirsty per se
b. Fatigue		b. Fatigue
c. Weakness		c. Profound weakness
d. Discomfort		d. Nausea, vomiting, diarrhea, anorexia
e. Anxiety		e. Headache
f. Confusion or impaired judgment		f. Giddiness
g. Paresthesias		g. Muscle cramps
6. Signs		6. Signs
a. Skin may tent		a. Skin is inelastic
b. Oliguria (low Na content in urine)		b. Clammy, pale appearance
c. Psychosis, hysteria, agitation		c. Hypotension
d. Tetany		d. Tachycardia
e. Seizures		
f. Muscular incoordination		
g. Coma		
7. May rapidly progress to heatstroke if not treated		7. Not as likely to progress to heatstroke

To replace fluids, first estimate the magnitude of the sodium deficit by multiplying the difference between 140 mEq/liter and the observed serum sodium concentration by the normal total body water (TBW) in liters.

Example: a 70 Kg. man with an observed serum sodium of 120:

1. TBW = 60% of body weight: 70 x .6 = 42 liters TBW

2. 140 mEq/L - 120 mEq/L x 42 = 840 mEq sodium

3. Recommended replacement: approximately 5 liters of intravenous normal saline, understanding that actually only half this amount is generally required before switching to oral administration. In severe hyponatremia, one half of the serum sodium deficit can be replaced by the correct volume of hypertonic (3%) saline administration, intravenously over two hours. The remainder of the sodium deficit should be replaced as IV normal saline over eight hours.

The water depletion variety of heat exhaustion presents with a more severe clinical picture of intense thirst, agitation, confusion or marked anxiety, headache, and often either psychotic or hysterical behavior. A combination of generalized muscle weakness, fatigue, discomfort and muscular incoordination is usually present. Victims tend to be febrile, up to 103 F° (39°C), and heat-induced hyperventilation may be prominent. Unlike sodium depletion heat exhaustion, victims tend to have decreased amounts of sweat, urine volumes are low and characterized by a low sodium concentration.(73) Victims tend to be hypernatremic. This type of heat exhaustion occurs in individuals exposed to a hot environment without adequate access to water or in individuals who cannot appreciate thirst normally. Heat exhaustion usually requires several days of heat exposure to develop, it tends to occur in epidemics, and like classical heatstroke, the victims are often very young, very old, or debilitated. Most patients with water depletion heat exhaustion, particularly in heat wave years, require admission to the hospital. A return to the climatic conditions that precipitated the episode would place the patient at extreme risk for classical heatstroke.

The following equation can be used to determine a patient's free water deficit by assuming that total body water (TBW) in liters is reduced in inverse proportion to the elevation of serum sodium.

Example: 70 Kg man, serum sodium (Na^+) 160 mEq/L

1) TBW = 60% of body weight: 70 x .6 = 42 L or normal TBW

2) $$\frac{\text{Normal TBW x Normal serum sodium } (Na^+)}{\text{Observed serum sodium}} = \text{Prevailing TBW}$$

or

$$\frac{42 \times 140}{160} = 36.7 \text{ L}$$

3) Normal TBW - Prevailing TBW = Free Water Deficit

or

$$42 - 36.7 = 5.3 \text{ L}$$

It is critical to avoid excessively rapid correction of hypernatremia. Presumably, all forms of body fluid hypertonicity result in the accummulation of "idiogenic" osmoles in brain cells in order to maintain brain volume. Since water moves across cell membranes more rapidly than solute particles, a sudden depression of plasma osmolality by excessive free water administration could result in acute cerebral edema. Ideally, serum sodium concentrations should not be lowered more rapidly than 4 mEq/L/hr. Therefore, as in the case above:

4) Replace 1/2 of the free water deficit intravenously with D_5W over 2-4 hours; replace the remainder more slowly, over 8-24 hours with D_5W intravenously or by oral administration of water.

Heat Stroke --

As in the discussion of heat exhaustion, it is convenient to subdivide heatstroke into two forms, classical and exertional. (Table 5) Classical heatstroke is characterized by three prominent findings: hyperthermia as defined by a rectal temperature above 105 F° (40.6°C), anhidrosis, and profound CNS dysfunction. Exertional heatstroke is a hyperthermic state in which the body's capacity to dissipate heat produced by muscular work in a hot environment is exceeded. Transient hyperthermia can occur with strenuous exercise, especially during competitive sporting events, without apparent symptoms, therefore, the diagnosis of exertional heatstroke should not be made on the basis of hyperthermia alone. Patients with exertional heatstroke may retain the ability to sweat and present with a cool skin, masking a frankly hyperthermic core. Rhabdomyolysis and disseminated intravascular coagulation are often prominent and severe features of this form of heatstroke. Lactic acidosis may be an early finding, but unlike classical heatstroke, it does not carry as grave a prognosis.(64) Whether classical or exertional, almost every organ system is in jeopardy of functional and/or structural damage. Generalized and often profound cellular injury (cytolysis) is more likely in exertional heatstroke.

TABLE 5.

Heatstroke—Definition and Clinical Characteristics

Classic	Exertional
1. Rectal temperature >105F (40.6C)	1. Rectal temperature 105F (40.6C)
2. Marked CNS disturbances disorientation confusion coma seizures	2. Marked CNS disturbances disorientation confusion coma seizures
3. Hot, dry skin with cessation of sweating	3. Skin may be moist when first seen
4. Occurs in epidemics during sustained heat waves. (High humidity and heat, day and night for several days.)	4. Occurs sporadically
5. More likely in the elderly, the very young, the infirm, and the poor	5. More likely in previously normal and healthy persons (e.g., military recruits, football players, laborers, marathon runners), performing intense muscle work. (Heat dissipation is exceeded by heat production or heat gain or both.)
6. Lower serum lactate levels with respiratory alkalosis Less profound alterations in hematologic, muscular, renal, and electrolyte systems	6. Elevated serum lactate levels More commonly associated with DIC, rhabdomyolysis, acute renal failure, electrolyte disturbances, and hyperuricemia

A variety of factors may precipitate either syndrome. In young, otherwise healthy individuals, lack of acclimatization is the most common predisposing factor, whereas the presence of cardiovascular disease would be more likely responsible in the elderly victim. Table 6 lists common predisposing factors for heatstroke.

TABLE 6.

Predisposing Factors for Heatstroke

I. In normal, healthy humans:

- A. Lack of acclimatization
- B. Salt and water depletion
- C. Heat intolerance
- D. Acute infection or fever
- E. Mild to moderate obesity

II. Commonly associated disease states:

- A. Cardiovascular
  1. Congestive heart failure
  2. Coronary artery disease
- B. Endocrine disturbances
  1. Diabetes
  2. Thyrotoxicosis
  3. Addison's
- C. Acute or chronic alcoholism (particularly delerium tremens)
- D. Malnutrition
- E. Impaired sweat production
  1. Miliaria
  2. Scleroderma
  3. Sweat gland injury
     a) Post-thermal burn
     b) Post-barbiturate poisoning
     c) Post-heatstroke
  4. Sweat gland ductal obstruction
  5. Ectodermal dysplasia
- F. Autonomic dysfunction (Shy-Drager syndrome)
- G. Schizophrenia
- H. Parkinsonism
- I. Potassium deficiency

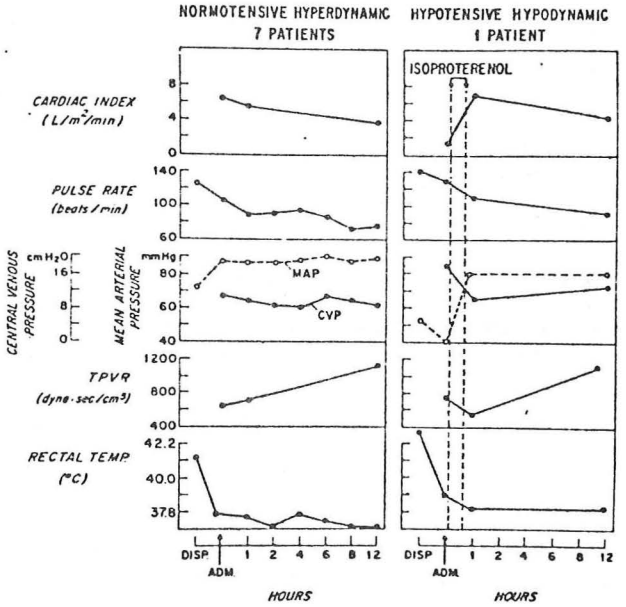
III. Drugs increasing the risk for heatstroke:

- A. Diuretics
- B. Anticholinergics
- C. Anti-parkinsonism
- D. Phenothiazine
- E. Tricyclic antidepressants
- F. Butyrophenones
- G. Antihistamines
- H. Sympathomimetics (amphetimine overdose)
- I. Thyroid hormones
- J. Hallucinogens (e.g., LSD, PCP)
- K. Beta-blockers
- L. Barbiturate or meprobamate withdrawal
- M. Methyldopa
- N. Propylthiouracil
- O. Severe salicylate poisoning
- P. MAO inhibitors
- Q. Succinylcholine
- R. Glutethimide

Pathophysiology and Clinical Complications of Heatstroke

Cardiovascular System --

Functional hemodynamic changes occur in victims of both exertional and classic heatstrokes. O'Donnell studying exertional heatstroke in eight Marine recruits (77) identified two hemodynamic patterns: hyperdynamic and hypodynamic. The seven hyperdynamic patients had a high cardiac index, a moderately decreased blood pressure, a low peripheral vascular resistance, but a moderately elevated venous pressure. (Figure 28) Cooling resulted in a return of the cardiac index to normal, a rise in blood pressure, and a progressive rise in peripheral vascular resistance. The one patient with a hypodynamic presentation displayed cyanosis, marked hypotension, a low cardiac index, and a markedly elevated central venous pressure. An infusion of isoproterenol promptly corrected the hypodynamic state.



Comparative Values for Type I (Left) and Type II (Right) Hemodynamic Patterns.
Isoproterenol corrects myocardial failure of the hypodynamic patient.

Figure 28: (from O'Donnell [78])

O'Donnell(78) found that the responses of conditioned atheletes to heat stress differed in many respects from those of less well conditioned Marine recruits. He studied eight marathon runners treated for heat stress injury during the 1976 Boston Marathon which was run during 90 F° plus (32-38°C[db]) temperatures and 60% rh. The data on these marathon runners were compared to similar observations on 15 non-conditioned Marine recruits. The cardiovascular reponse of the marathoners to heat stress was unique. (Figure 29) Mean arterial pressure and urine output were maintained at or near normal levels. In view of the low heart rate in marathoners and the clinical evidence of vasodilatation, stroke volume index was apparently increased to maintain cardiac output. These findings are consistent with earlier studies in conditioned athletes where an increased stroke volume index was one of the main circulatory adaptation to repetitive exercise.(79) These marathoners also had first degree heart blocks (increased P-R intervals) suggesting increased parasympathetic activity as a mediator of the relative bradycardia. This was in sharp contrast to the tachycardia experienced by non-conditioned Marines.

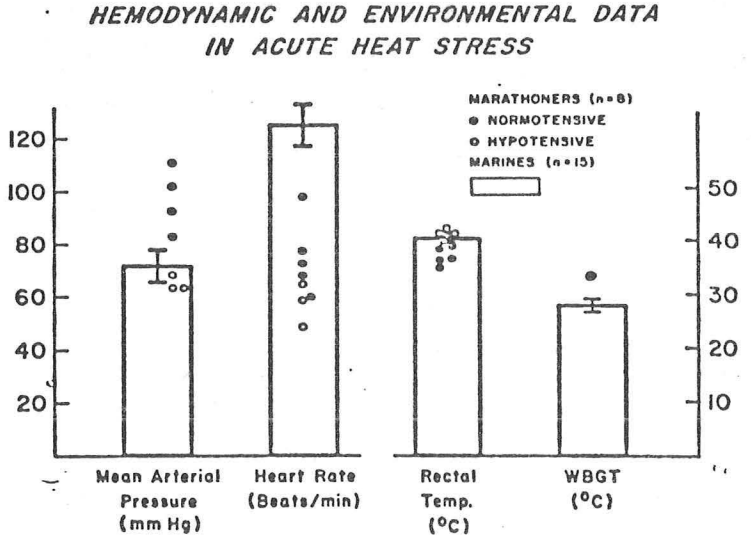


FIGURE This figure compares hemodynamic and environmental data from 15 Marine recruits to the 8 marathoners. Although mean arterial pressure and rectal temperature are comparable in the two groups, heart rate is markedly decreased in the marathoners. The environmental conditions, indicated by the wet bulb globe temperature (WBGT), were more severe for the marathoners than for the group of Marines.

Figure 29: (from O'Donnell and Clower [77])

Elderly victims of classical heatstroke also display two hemodynamic patterns. Serial hemodynamic studies were performed in seven elderly heatstroke victims (mean age 72 $\pm$ 6 years) by Sprung.(80) Two patients had an increased cardiac index (4.3 and 4.4 L/Min/M^2), increased right atrial pressure (10 and 12 mmHg), normal pulmonary capillary wedge pressure (10 and 12 mmHg), and decreased systemic vascular resistance (542 and 738 dyne. sec. CM^{-5}). The remaining five patients had a decreased cardiac index (mean 2.3 $\pm$ 0.2 L/Min/M^2), decreased right atrial pressure (mean 2 $\pm$ 1 mmHg), normal pulmonary capillary wedge pressure (mean 6 $\pm$ 3 mmHg), and increased systemic vascular resistance (mean 2020 $\pm$ 204 dyne. sec. CM^{-5}). Supraventricular tachycardia was observed in 5 of 7 patients. The inability to compensate hemodynamically when stressed by heat predisposes elderly individuals to heatstroke. Interestingly, 4 of 7 patients were taking psychotropic drugs (major phenothiazine tranquilizers, tricyclic antidepressants, anti-Parkinsonian agents) which may have altered their ability to sweat and contributed to their cardioacceleration.

Short of heat exhaustion or heatstroke, exposure to a progressively hot and humid environment can precipitate symptoms of congestive heart failure or angina in otherwise compensated elderly cardiac patients.(81) These experimental observations are supported by epidemiological data from a 3 year "Cardiac Failure Study" in Zaria, Nigeria. (80) A pronounced increase in hospital admissions for congestive heart failure occurred particularly for individuals with post-partum cardiomyopathy during the "hot and humid" months following the "hot-dry" season. (Figure 30) Increased cardiac demands for cooling, coupled with plasma volume expansion in the early phase of acclimization may be responsible for this phenomenon.

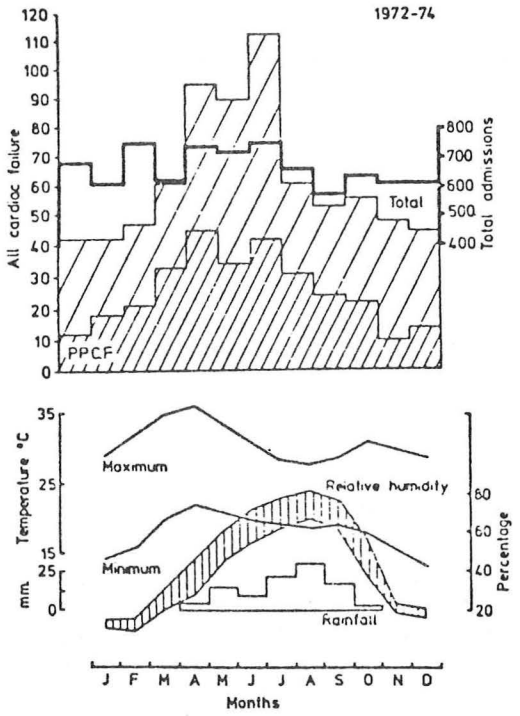
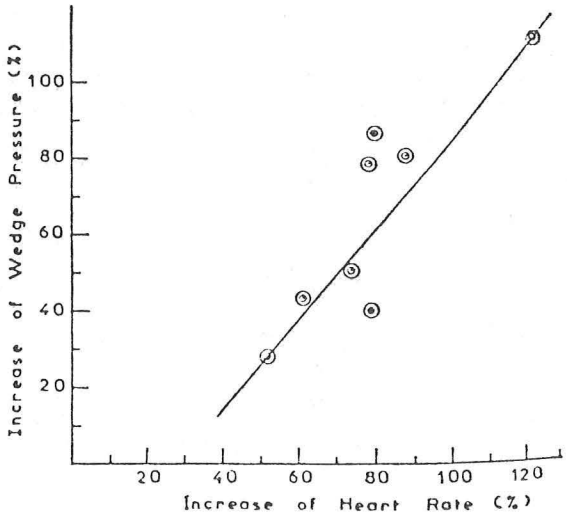


Figure 30: The seasonal variation of temperature and humidity in Zaria, Nigeria compared to the admission for all cardiac failure, post-partum cardiomyopathy failure (P.P.C.F.) and all hospital admissions. (Bold line - righthand scale) (from Parra, et al[82])

Patients with ischemic heart disease and cardiomyopathy are obviously at increased risk during acute thermal stress. Importantly, patients with mitral stenosis are liable to acute pulmonary edema or right-sided cardiac decompensation as cardioacceleration occurs and pulmonary wedge pressures rise during acute thermal stress.(83)(Figure 31) Patients with emphysema and cor pulmonale also may experience right-sided cardiac decompensation with thermal stress for similar reasons.



The relation between the degree of increase of heart rate and the rate of rise of wedge pressure after acute thermal stress in patients with mitral stenosis.

Figure 31: (from El-Sherif, et al[83])

Autopsy examinations on patients who died after heatstroke have shown various lesions including myofibrillar degeneration, interstitial edema, inflammatory cell infiltration, extensive subendocardial hemorrhages and localized areas of myocardial necrosis.(9,45) Transmural infarction in a Marine recruit (84) and papillary muscle infarction in a high school football player (85) have been reported as complications of heatstroke. These two victims had normal coronary arteries. Despite these serious examples, clinical myocardial injury is rare. Costrini, et al (86) prospectively obtained cardiac enzymes and electrocardiograms on 13 patients with exertional heatstroke and 14 patients with severe heat exhaustion. Despite initial presentations of tachycardia, hypotension and severe hyperthermia, creatine phosphokinase isoenzymes (CPK-MB) were not indicative of myocardial damage in any patient. This data is at variance with that of Kew (87) who demonstrated increases in myocardial specific lactic dehydrogenase (LDH) and electrocardiographic (EKG) changes in 17 of 26 Bantu men developing heatstroke while working underground in South African gold mines. These patients may have been more severely ill and somewhat older than those in the Costrini, et al(86) study. Clearly they did not receive definitive therapy for 1 to 3 hours in most cases and 12 of 26 men were still hypotensive after cooling. Nonetheless, none of these patients developed pathologic Q waves and most EKG changes were non-specific in nature. Hemolysis could be partially responsible for the elevations of LDH isoenzymes in this study.

While elevated CPK-MB isoenzyme levels are regarded as sensitive and specific markers of myocardial injury, borderline elevations can occur during physical training. Siegel, et al(88) measured mean CPK-MB isoenzymes from 64 samples obtained from 35 marathon runners after competition and found 130 IU/L or 8.3% of total CPK activity. The CPK-MB isoenzymes also peaked 24 hours

Myocardial scintography with technetium Tc 99m pyrophosphate was therefore performed at the appropriate time in 12 randomly selected marathon runners with a mean post-race serum CPK-MB level of 160 IU/L or 13% of total CPK activity. In all subjects the infarct avid "hot-spot" scan was negative. These findings strongly suggest that CPK-MB isoenzymes arise from a non-cardiac muscle source during vigorous physical training making the clinical diagnosis of myocardial injury during heatstroke even more elusive.

Arrhythmias may occur during heatstroke or during the cooling period of treatment. Sinus tachycardia or supraventricular tachycardia are more common but ventricular ectopy, conduction defects, and diffuse T-wave and ST segment abnormalities may occur.

Rhabdomyolysis and Renal Injury --

Myoglobinuria in healthy well-conditioned subjects can occur after performing an excessive number of repetitive exercises such as push-ups or squat jumps. Acute exertional rhabdomyolysis was studied in 40 Marine recruits from Paris Island, SC, hospitalized at the Naval Station, Beaufort, SC,(89). A one year follow up period was provided for the majority of the patients. A random group of 40 Marine recruits were chosen as a control group for comparisons of muscle enzyme levels and muscle strength after recovery. The mean serum CPK, LDH, and SGOT levels during hospitalization are depicted in Figure 32. On admission, patients had mean serum CPK and SGOT levels of 1,072 mIU/ml and 70 Karmen units respectively. The control group of asymptomatic Marine recruits had mean serum CPK and SGOT levels of 919 mIU/ml and 64 Karmen units respectively, on the third day of severe exertional stress. The differences were not statistically signficiant ($p > 0.05$).

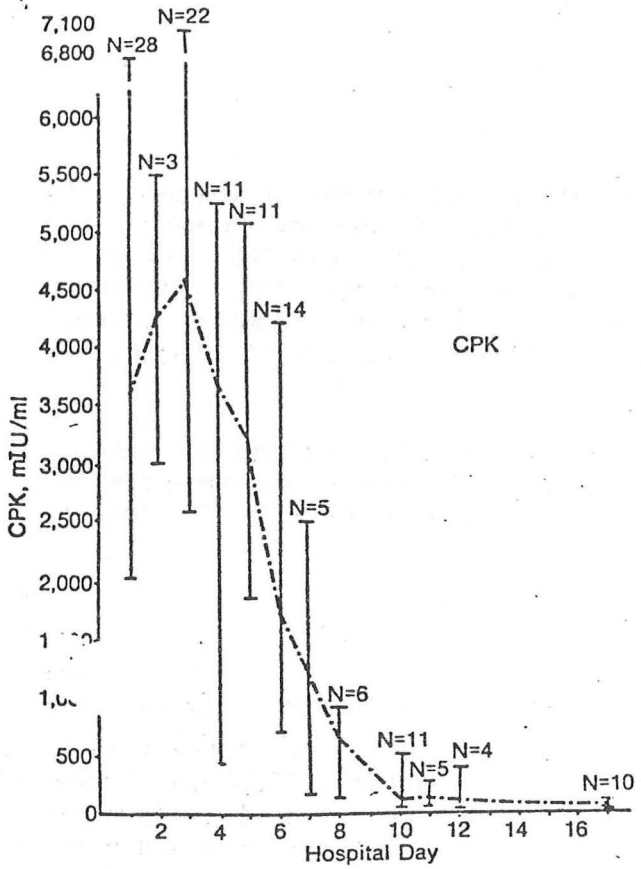
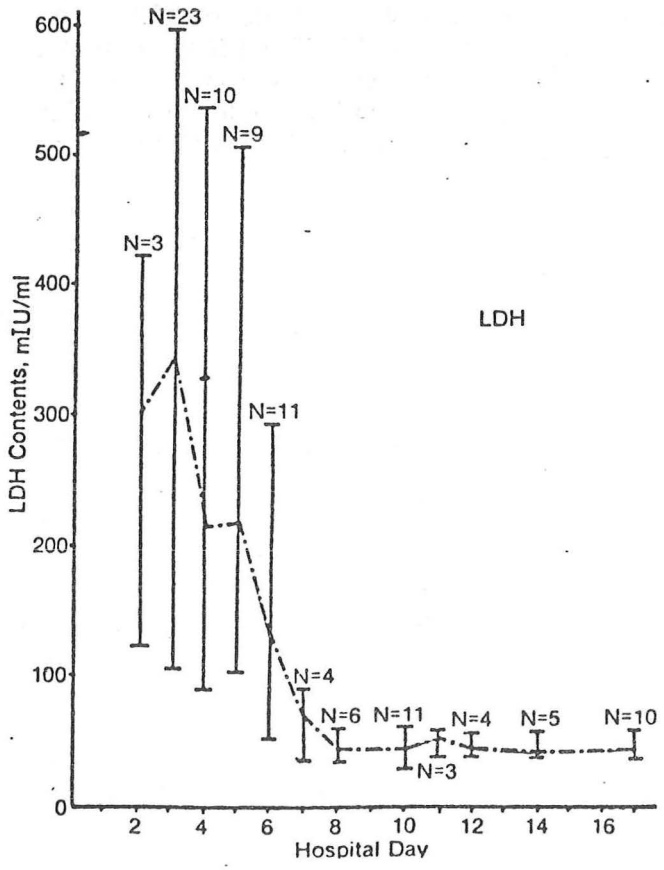
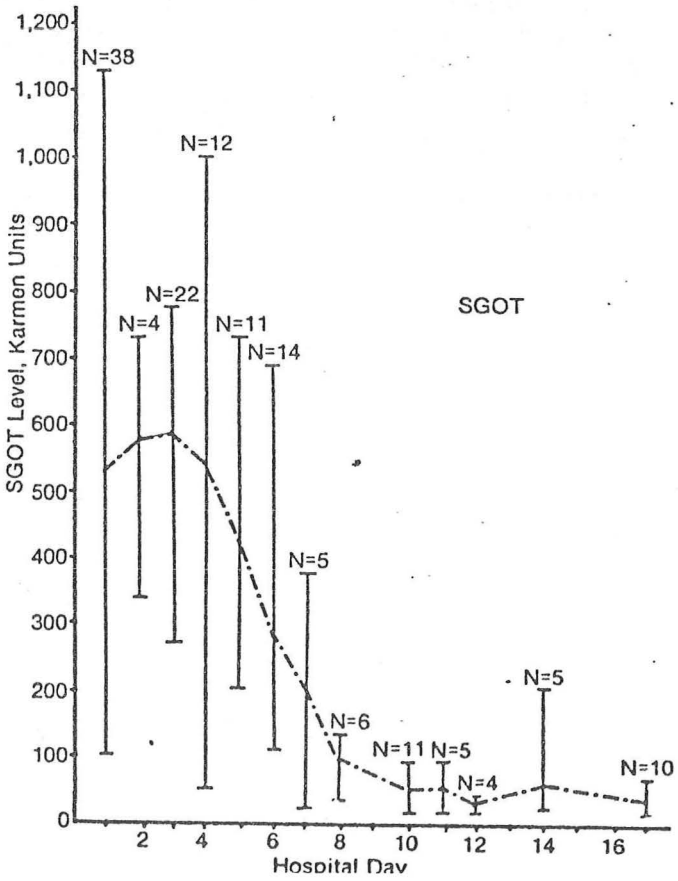


Fig 32-Mean serum CPK, LDH, and SGOT levels during hospitalization. N is the number of enzyme determinations used in computing the mean while the range is indicated by the vertical lines.





Mild elevations of BUN and creatinine were initially present, but returned to normal within 24 to 48 hours in all subjects. Uric acid levels were elevated in four of 23 measurements and heme pigment was demonstrated in all urine specimens by the O-tolidine reaction in the absence of gross or microscopic hematuria. Transient albuminuria (100 mg%), without accompanying glycosuria also occurred in all specimens during the first 24 hours. Urinary sediment abnormalities disappeared by the third hospital day. At the time of discharge, six men had an abnormal creatinine clearance, but repeat collections showed normal clearances in three of the six; the remaining three recruits were discharged from the service before they could be retested.

On re-exposure to regular training, the mean serum CPK and SGOT levels rose again, corresponding roughly to the severity of physical stress placed on the men.(Figure 33) A recurrence of clinically apparent muscle injury or renal impairment did not manifest upon the resumption of training.

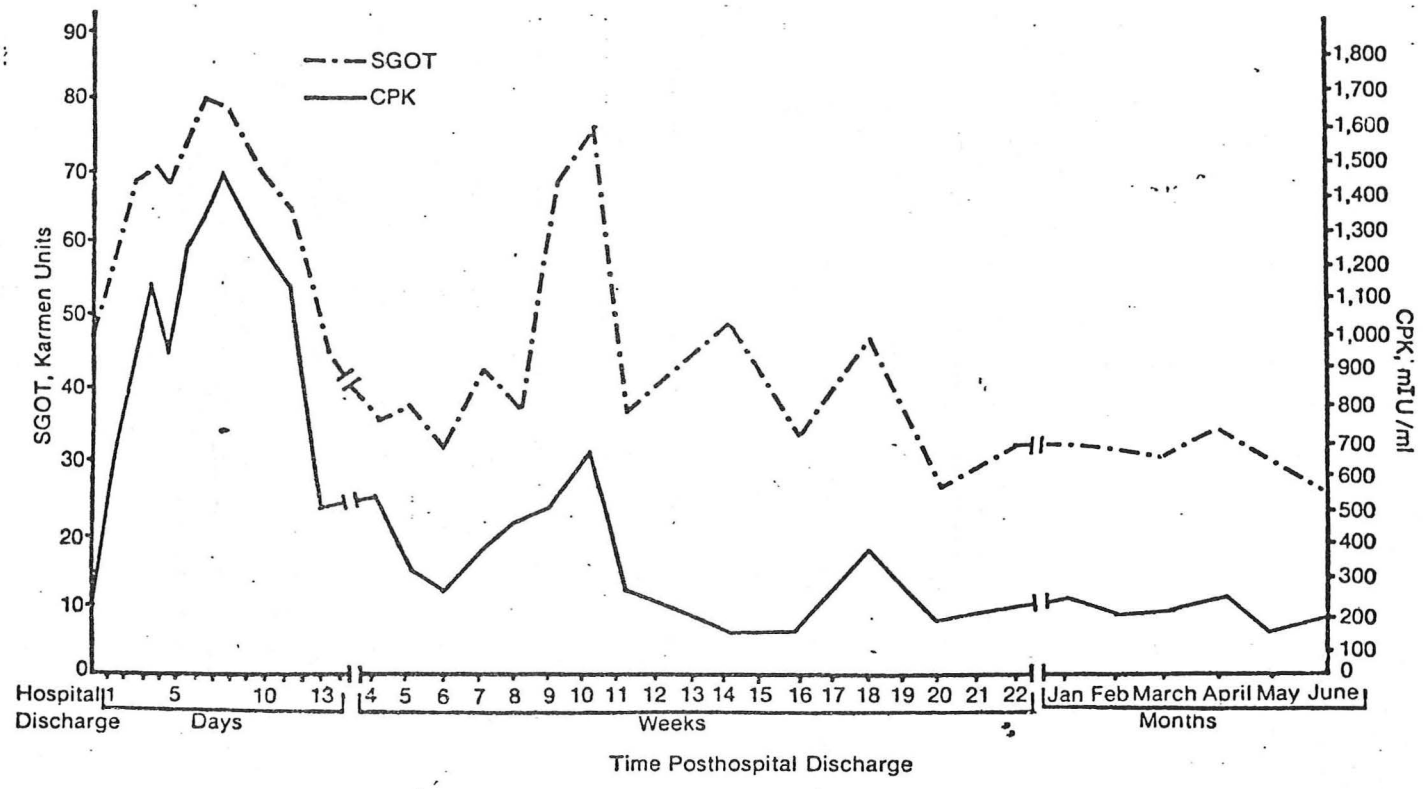


Fig 33-Mean serum CPK and SGOT levels on return to the regular training program and for the duration of one year.

Serum BUN and creatinine levels remained normal in all individuals "except during periods of strenuous exercise" when mild increases in both were observed. The authors attributed these observations to the findings of Schrier, et al (90) who studied the renal response to heat and exercise in military recruits and concluded that serum creatinine content increases and clearance of creatinine decreases during periods of severe exertional stress.

Muscle strength during hospitalization was impaired but by 100 days post-injury, and despite a return to physical training, muscle strength had improved and was identical to the Marine control group.(Figure 34)

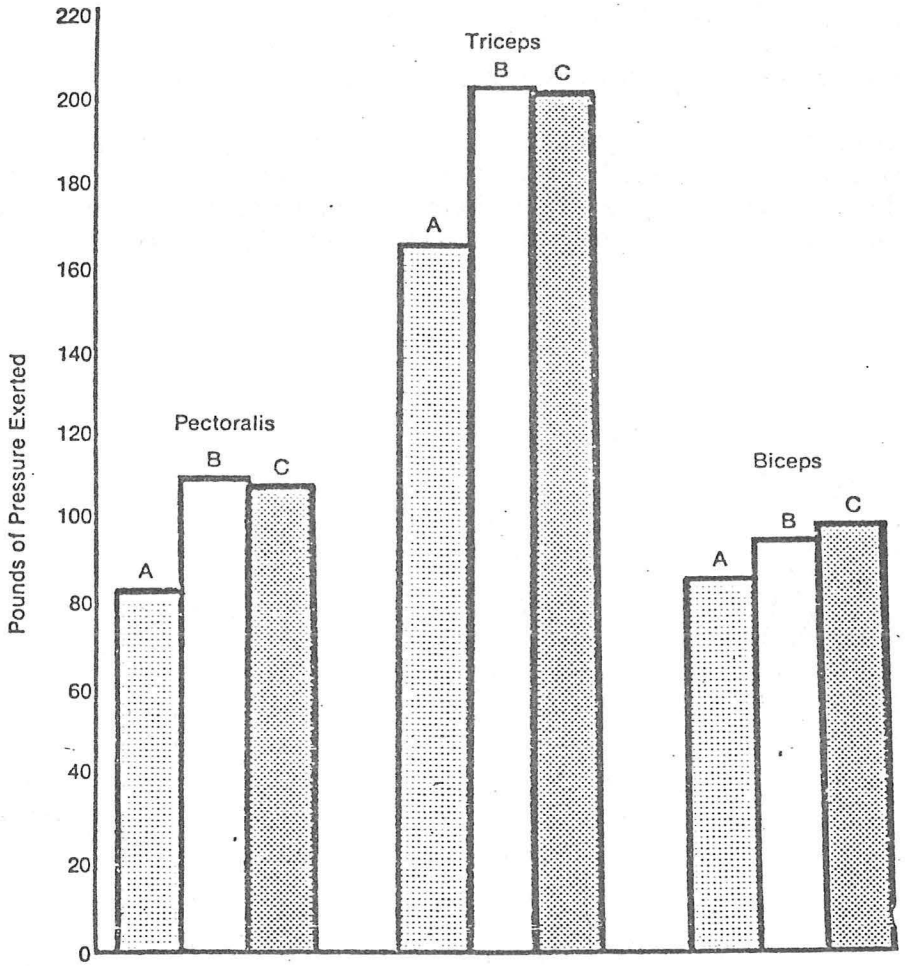


Fig34–Comparison of muscle strength in pectoralis, triceps, and biceps immediately after discharge from the Beaufort Naval Hospital (A) and again after 100 days (B). C represents a control group 100 days into recruit training.

This study suggests that no permanent renal dysfunction resulted from acute exertional rhabdomyolysis without heatstroke and that resumption of training did not result in an exacerbation. This conclusion was supported by earlier work from Howenstein (91) who reported on 18 cases of acute exertional rhadomyolysis occurring in Marine recruits after an excessive number of squat jumps. Fifteen of 18 renal biopsy specimens in these patients exhibited clear evidence of tubular necrosis. Each recruit made an uneventful recovery and returned to physical training without further renal complications.

Less reassuring is a recent study from the Israel Defense Forces.(92) Twenty non-obese army recruits (average age 18.0 ± 0.4 years) volunteered to participate in a prospective study measuring serum muscle enzyme levels, myoglobin levels, and renal function during eight weeks of "primary, specially designed, gradual military training" performed according to the protocol summarized in Figure 35. Before and after the specific exercises, blood samples were drawn for muscle enzymes and myoglobin and creatinine clearances were performed. Special attention ("forced") was given to adequate fluid intake during the training periods.

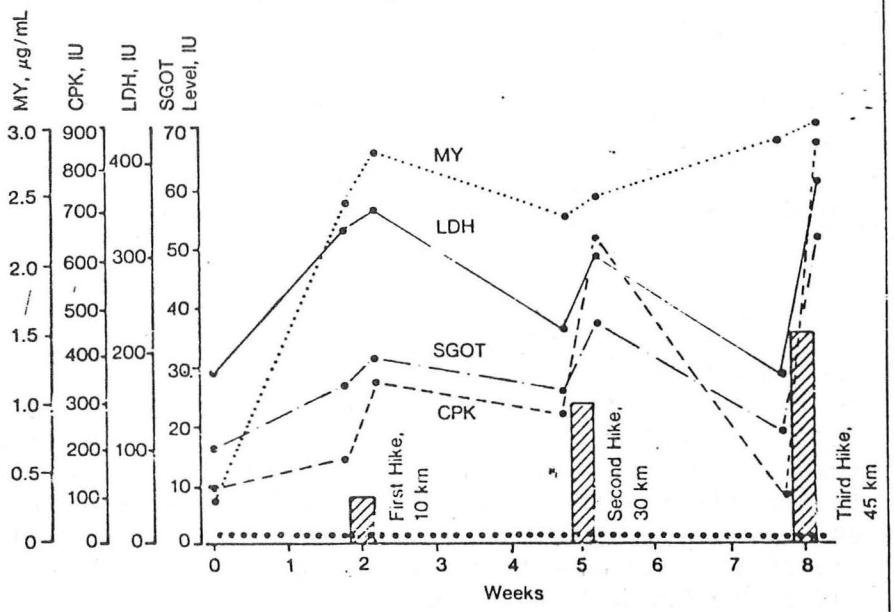


Fig 35—Training protocol during eight weeks. Dots indicate one hour of daily training, including 4 km of jogging under supervision of drill instructor. Average values are given of muscle enzymes, including myoglobin levels, as were measured during training program. MY indicates myoglobin level; CPK, creatinine phosphokinase level; and LDH, lactic dehydrogenase level.

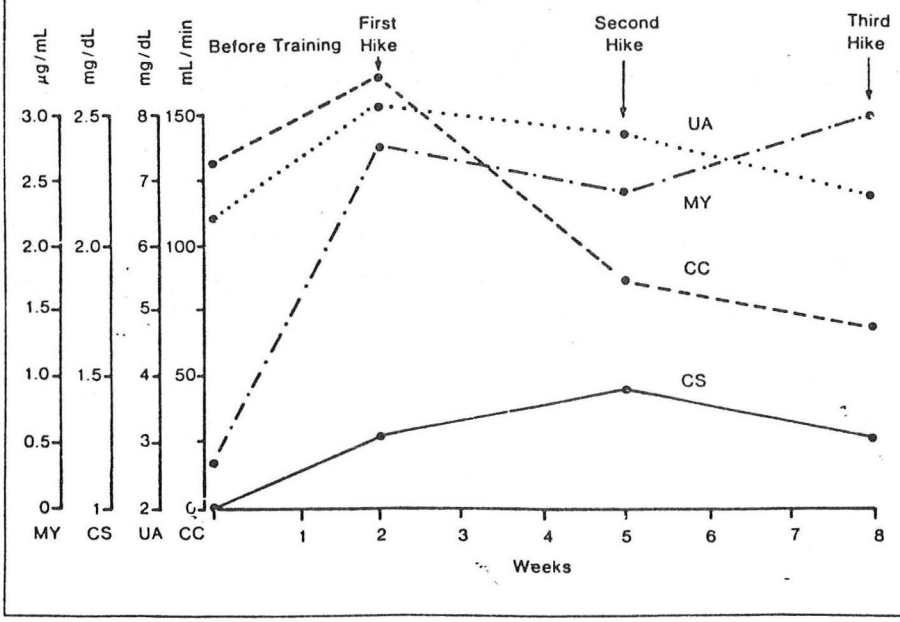


Fig 36-Average values of renal function tests and serum myoglobin levels after hikes. MY indicates myoglobin level; CS, creatinine serum level; UA, uric acid level; and CC, creatinine clearance.

Basal SGOT and LDH levels were found to be normal, whereas CPK and myoglobin levels were slightly elevated. After every hike, a significant increase was observed in the concentration of all three muscle enzymes ($p. < .05$). Before the second and third hike, the SGOT and LDH levels returned to normal ranges and CPK levels decreased significantly. Myoglobin levels remained elevated after the first hike ($p. < .005$), and only slightly increased after the second and third hike.

TABLE 7.

—Serum Muscle Enzyme and Myoglobin Levels Before and After Hikes (Mean ± SD)

Values	Before Training (N = 20)	1st Hike, 10 km (n = 18)		2nd Hike, 30 km (n = 17)		3rd Hike, 45 km (n = 15)		Normal Values
		Before	After	Before	After	Before	After	
SGOT, IU	16.06 ± 3.02	27.13 ± 5.16	31.0 ± 4.03	26.6 ± 6.21	38.2 ± 4.5	19.0 ± 4.5	52.3 ± 8.1	8-45
Lactic dehydrogenase, IU	186.33 ± 30.2	339.8 ± 13.0	395.63 ± 27.13	228.0 ± 24.8	301.9 ± 29.4	171.0 ± 16.7	382.0 ± 12.2	80-220
Creatinine phosphokinase, IU	111.00 ± 26.71	179.5 ± 49.6	359.0 ± 59.6	280.0 ± 69.45	652.3 ± 111.0	112.0 ± 24.6	858.0 ± 56.1	20-70
Myoglobin, μg/mL	0.39 ± 0.21	2.42 ± 0.89	2.77 ± 0.6	2.28 ± 0.69	2.40 ± 0.75	2.84 ± 0.55	2.97 ± 2.61	<0.1

A signficant increase in uric acid, urea, and creatinine concentration in the blood was observed during the first two weeks ($p. < .05$). During that period, creatinine clearance rose from 130 ± 30.4 to 165 ± 32.5 mL/Min. During the following weeks of training, no significant changes in serum uric acid or urea were monitored. Creatinine serum concentrations (5) rose from the second to the fifth week (between the first and second hike) from 1.28 to 1.45 mg/dL, and came down again to 1.25 mg/dL just before the third hike. A highly signficant decrease in creatinine clearance (CC) was observed between the first and second, and between the second and third hikes ($p. < .005$)(Table 8)

TABLE 8.

—Renal Function Test Results After Hikes (Mean ± SD)

Time	Uric Acid Level, mg/dl.	Urea Level, mg/dl.	Creatinine Plasma Level, mg/dL	Creatinine Clearance, mL/min
Before training	6.36 ± 1.18	29.31 ± 5.17	1.01 ± 0.18	130.0 ± 30.4
1st hike	8.10 ± 1.30	43.50 ± 9.30	1.28 ± 0.32	165.0 ± 32.5
2nd hike	7.65 ± 1.18	46.50 ± 4.50	1.45 ± 0.31	86.27 ± 22.5
3rd hike	6.80 ± 1.34	45.40 ± 10.07	1.24 ± 0.13	70.4 ± 20.9
Normal values	5-8	20-40	0-1.45	

Myoglobinemia was observed in all 20 recruits in this study. Despite gradual physical demands, myoglobinemia and elevation of muscle enzyme levels were observed within the first two days of training. The authors concluded that the persistent myoglobinemia resulted from continuous muscle fiber injury concurrent with prolonged training and physical activity so that no complete clearance of myoglobin from the blood could be achieved. They further concluded that the main muscle injury occurred in the first two weeks of training, and from then on, continuous muscle fiber disruption, as evidenced by myoglobinemia, caused a deterioration in renal function. Myoglobinuria and hyperuricemia are well known causes of renal function deterioration and may have accounted for the reduction in creatinine clearance.(93) Since this was a field trial, certain measurements were not made which would have been of interest. For example, Knochel, et al(94) suggests that exercise-induced rhabdomyolysis is more likely in potassium deficient subjects and it could have been enlightening to know total body potassium stores in these subjects. Since water was given in abundance and the study was performed during winter months, dehydration and/or heat stress cannot be blamed for these findings.

Exertional heatstroke victims are dehydrated, hyperuricemia, and excrete an acid urine with large quantities of uric acid, and uric acid nephropathy can occur.(95,96) Rhabdomyolysis and generalized cytolysis associated with heatstroke present large loads of myoglobin to the renal tubule during a period of time when the urine is concentrated and acidic. The myoglobin is less soluble in this circumstance and acute tubular necrosis can result.(95) Glomerular injury can be seen consequent to disseminated intravascular coagulopathy, but it is usually rapidly reversible. Interstitial nephritis has been seen in renal biopsies of patients surviving heatstroke only to experience progressive renal impairment.(97) The exact pathogenesis of acute renal failure in this setting is not known, but a combination of the four postulated mechanisms of tubular obstruction, toxic reactions from heme pigments, renal ischemia, and decreased glomerular permeability are likely at work.(98-100) The work of Melamed, et al(92) suggests that prolonged exercise, even without excessive dehydration, heat, or clinical symptoms of rhabdomyolysis may lead to significant renal impairment in a less dramatic setting. At Parkland, a number of patients with heat cramps or heat exhaustion (usually construction workers or hard laborers) have had significant renal injury that persisted with elevated serum creatinines and decreased GFR's for several weeks. A return to the work environment too soon has resulted in acute tubular necrosis in several such patients.

Occasionally, patients present with hyperkinetic agitation and fever associated with delerium tremens,(102) massive amphetamine overdose,(103,104) phencyclidine (105,106) or LSD intoxication(107) severe enough to cause frank rhabdomyolysis and renal injury. Crush injury secondary to drug sedative overdose is another well known cause of rhabdomyolysis severe enough to precipitate acute renal failure.

Early intervention with intravenous fluids and osmotic agents (e.g. mannitol) can prevent acute renal failure in exertional heatstroke victims.(101) An initial dose of 25 Gm of 20% mannitol in crystaloid is recommended. Early examination of the urine for specific gravity, osmolality, myoglobin (benzidine reaction), sodium concentration, and the urine/plasma concentration ratio for urea nitrogen aids in the identification of patients with acute renal failure from tubular necrosis. If the urine is isotonic to plasma, the urine/plasma concentration ratio for urea nitrogen is less than 5:1, and the urine sodium is high, acute tubular necrosis is likely. When these parameters are present, intravenous furosemide (40 to 120 mg) can be given in conjunction with mannitol and crystaloid to initiate a diuresis. Hopefully, this manuever will prevent oliguric renal failure and avoid the need for hemodialysis.

Central Nervous System Injury --

Neurological manifestations of heatstroke can be divided into three groups according to the time they occur, namely the acute stage, during convalescence, or the period of late permanent deficits. Heatstroke victims are usually in coma or have profound disorientation when first seen on arrival to an emergency department. Pupillary findings can be misleading; even wide dilated, "fixed" pupils occur in victims who recover. Cooling often results in a return of pupillary light reflexes. It is not uncommon to see nuchal rigidity, particularly in the elderly classical heatstroke victim, but the diagnosis of meningitis must then be considered in the differential. Coma generally reverses with cooling(108). Prolonged coma after achievement of a normal core temperature is a poor prognostic sign. During the cooling period, grand mal seizures often occur. Care must be taken to protect the patient's airway to prevent aspiration or injury during tonic-clonic activity.

Transient neurological signs are not uncommon during the convalescent period. Irritability and lack of concentration are common. Some patients remain disoriented for a time while a few actually have delusions and hallucinations (distinct from "ICU psychosis"). Several reports describe transient disturbances of gait, speech, cerebellar and mental function.(108-112)

Permanent neurological sequalae of heatstroke include profound cerebellar dysfunction (e.g., ataxia, nystagmus, dysmetria, dysarthria), dementias, diminished cortical function on intelligence testing, and peripheral neuropathies and hemiparesis.(113) In fatal cases, CNS damage is virtually universal, classically represented by combinations of cerebral edema, petechial hemorrhage, and marked deterioration or disappearance of Purkinje cells in the cerebellum.(9)

Gastrointestinal Manifestations --

Diarrhea and vomiting often occur during or just preceding the acute presentation of heatstroke.(108) Clinically, the act of cooling often initiates reflex vomiting and/or defecation. Upper gastrointestinal bleeding should suggest a Mallory-Weiss tear or erosive gastritis. Massive U.G.I. bleeds, characterized by hematemesis and melana, can occur anytime during the acute or convalescent phase of heatstroke.(114).

Hepatocellular injury with marked elevations in SGOT and bilirubin may accompany heatstroke.(115) A parallel reduction occurs in the hepatic synthesis of clotting factors. Kew, et al (116) suggests that SGOT levels greater than 1000 I.U. in the first 24 hours after cooling connote a poor prognosis. Hepatic enzyme elevations usually peak by 48 to 72 hours post-insult and fall rapidly over the following week or so, eventually returning to normal.

Gluconeogenesis and glycogenolysis represent major sources of metabolic heat production in the liver. The heat production by the metabolic activity of the liver may be partly responsible for the increased vulnerability of this organ to heat injury. It is also possible that the injury is more direct, a result of hepatic venous temperatures higher than previously appreciated. Rowell and associates(39) studied young, healthy, but unacclimatized men working for one hour in a temperate heat at 50% M $\dot{V}O_2$. Hepatic venous temperatures of 107 F° (41.6°C) were measured as simultaneous rectal thermister readings (inserted 6-8 cm.) of 104 F° (40.0°C) were obtained.

Post-mortem liver findings in addition to those of DIC, include degenerative changes or desquamation of sinusoidal lining cells, ballooning or flattening of microvilli, breaks in hepatocyte outer membranes, and electron-lucent vacuoles along the sinusoidal border.(116a)

Shibolet and associates (108) have pointed out the rarity of acute pancreatitis as a complication of heatstroke. Knochel, et al (84) reported the first case of pancreatitis associated with exertional heatstroke in 1961. This case was severe enough to cause common bile duct obstruction. Anoxia and severe acidosis are known to be inciting factors for the development of acute pancreatitis(117), therefore a higher incidence of this complication would be expected in heatstroke victims. Hyperamylasemia may reflect generalized cytolysis in addition to pancreatitis. During the heatstroke epidemic of 1978 in Dallas,(64) roughly one-third of the victims had a greater than two-fold increase in serum amylase without evidence of clinical pancreatitis. An elevated serum amylase was both clinically and statistically ($p. < .05$) indicative of a poor outcome defined by either death or irreversible brain damage.

Pulmonary Injury --

Hyperthermia reflexly stimulates respiratory drive and heatstroke victims typically display hyperventilation. Gastric content aspiration is an all too common complication of any type of coma, and heatstroke is no exception. Cooling also results in cutaneous vasoconstriction when an ice-bath is employed. Overzealous fluid administration and shifting of fluid from the previously vasodilated cutaneous bed to the core circulation can precipitate pulmonary edema. Non-cardiogenic pulmonary edema may be precipitated by severe shock, disseminated intravascular coagulation (DIC) or by gastric aspiration. DIC may result in hemoptysis and pathological evidence of pulmonary infarction.(118) Pneumonia has been reported as early as eight hours after the onset of heatstroke in otherwise healthy young patients.(9) This sort of pneumonia is often restricted to areas of hemorrhage and may be resistent to appropriate antibiotic coverage for that reason. "Prophylactic antibiotics" have been recommended for use in patients with prolonged coma(76), however, the results are uniformly disappointing and such practices cause more problems than they solve.

Hematologic Abnormalities --

Fibrinolytic activity is markedly accelerated by exercise.(119) Prolonged and strenuous exercise in 20 healthy young men, performing treadmill exercise for 20 to 30 minutes to a heartrate of 195 ± 9, resulted in an acceleraton of the mean euglobulin lysis time to 36% of the control values, but only elevated fibrinogen-fibrin degradation products to 109% of control values.(120) Physiologically significant fibrogenolysis apparently does not occur with strenuous exercise even though fibrinolytic activity is markedly accelerated.

In heatstroke, DIC, as defined by thrombocytopenia, elevated fibrin-split products, and hypofibrinogenemia, constitutes a major cause of severe hemorrhage and death during the convalescent phase.(101,121,122) This abnormality usually manifests 24 to 72 hours after presentation and ordinarily does not require specific therapy. If life-threatening bleeding is present, heparin therapy may be beneficial.(122) The usual course is one of recovery in five to seven days. Megakaryocyte depletion may be present on bone marrow examinations and even where platelets are not consumed, they may be qualitatively impaired.

The peripheral smear in heatstroke victims is routinely abnormal. Navari, et al(123) evaluated the initial peripheral smear of 25 heatstroke victims and found abnormal neutrophils in 23, showing hypersegmentation, nuclear budding and chromatin condensation. Similar changes were observed in the lymphycytes of seven patients. The predominant erythrocytic change was spherocytosis (8 to 28% of circulating erythrocytes), but schistocytes, ovalocytes and stomatocytes were also seen (seldom in excess of 5% of circulating erythrocytes). These investigators could not produce similar findings in vitro at 106 F° (41.4°C) in blood collected in heparin and sodium citrate. The effects of these changes on cellular function (phagocytosis and chemotaxis in neutrophils and oxygen carrying capacity in red cells) is unknown. Spherocytosis may account for the shortened red cell life span noted in patients with heatstroke.(124) Red blood cell viscosity increases along with osmotic and mechanical fragility, while erythrocyte deformability decreases during in vitro heating of human red cells for 15 minutes at 122 F° (50.0°C).(125) In vivo, these changes would lead to increased hepatic and splenic sequestration of heated erythrocytes.

Dermatologic and Sweat Gland Injury --

Petechial hemorrhages and ecchymosis accompany DIC. Sweat gland necrosis may follow heatstroke and cause impaired sweating.(126) Such patients are at increased risk for subsequent heatstroke events.

Electrolyte Disorders --

Potassium:

Profound and life-threatening electrolyte disorders are more likely in exertional forms of heatstroke. Despite total body potassium deficits and respiratory alkalosis, severe muscle injury can result in hyperkalemia particularly when concommitant renal failure is present. Close monitoring of serum electrolytes and EKG monitoring is wise. Rarely, emergency treatment with intravenous bicarbonate, calcium, and glucose/insulin infusion is necessary to rapidly treat life-threatening hyperkalemia. Kayexelate enemas may be helpful, but because too much time is required, they should not be used as the only corrective measure. Emergency hemodialysis should be considered early in the face of acute renal failure. In classical heatstroke, hypokalemia is more common, in fact 70% of the patients treated at Parkland from the 1978 Dallas heatstroke epidemic were hypokalemic.(64) Many of these patients had respiratory alkalosis and/or were taking thiazide diuretics as contributing factors.

Sodium:

The preponderance of patients with exertional heatstroke have high or normal serum sodiums.(86,108,127) On the other hand, patients with classical heatstroke may be hyponatremic. Fifty percent of the patients treated at Parkland from the 1978 Dallas heatstroke epidemic were hyponatremic(64) compared to 33% in another large series.(118) The replacement of intravenous fluids as previously described for heat exhaustion is appropriate and can be accomplished easily without undue hazard.

Phosphate:

Respiratory alkalosis is common in patients with heat exhaustion (128) and classical heatstroke(64) and may contribute to clinically significant hypophosphatemia(129,130) despite normal skeletal muscle phosphorus content.(131) Experimental hyperventilation in normal subjects may depress serum phosphorus concentration to values as low as 0.3 mg/dl.(132,133) The fall in serum phosphorus probably occurs because of accelerated cellular uptake of phosphorus resulting from increased activity of phosphofructokinase. This enzyme is exquisitively sensitive to changes in pH or pCO_2. By increasing its activity as pH rises during hyperventilation, cellular trapping of phosphorus occurs in the formation of phosphorylated glycolytic intermediates. Prolonged hypophosphatemia in a range less than 1.0 mg/dl, can result in widespread tissue destruction.(133) Recently, 21 cases of heatstroke were reviewed by Sprung, et al (134), and five patients were hypophosphatemic (2.0 ± 0.2 mg/dl), but only one patient had profound hypophosphatemia (< 1.5 mg/dl).

After rhabdomyolysis occurs, hyperphosphatemia may result as phosphorus is released from skeletal muscle stores. Hyperphosphatemia may mask phosphorus deficiency; in fact, an inverse relationship between serum phosphorus and muscle phosphorus content is usually seen after rhabdomyolysis.(106) The degree of hyperphosphatemia is also inversely related to the severity of hypocalcemia.

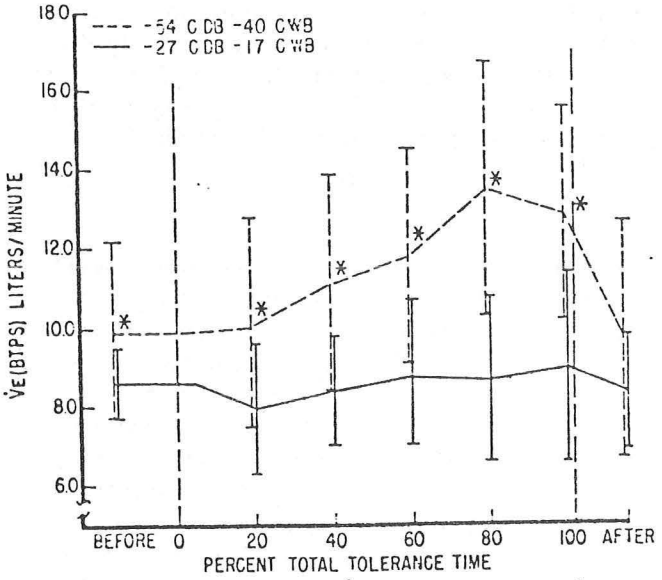
Calcium:

Hypocalcemia occurs in exertional heatstroke in association with precipitation of calcium in injured skeletal muscle.(135) Extremely low levels of serum calcium may ensue (<4.0 mg/dl), nevertheless, tetany and/or hypocalcemic seizures are unusual unless respiratory alkalosis is prolonged and severe or bicarbonate therapy is employed to rapidly correct a metabolic acidosis. Calcium administration should be avoided unless tetany or seizures are present, since it will be deposited in injured skeletal muscle as calcium carbonate and calcium phosphate.(135) Excessive intracellular calcium adversely affects mitochondrial function and can behave as a cellular poison making muscle injury more severe.(102) In the review of Sprung, et al(134), nine of 21 heatstroke victims were hypocalcemic (7.8 ± 0.3 mg/dl) on admission, the lowest being 5.7 mg/dl.

During the second week of recovery after heatsroke, hypercalcemia may occur in association with phosphaturia. This may be due to a transient hyperparathyroidism that occurs in response to the initial hypocalcemia and calcium deposition in injured skeletal muscle.(16) This "complication" is best observed and not treated.

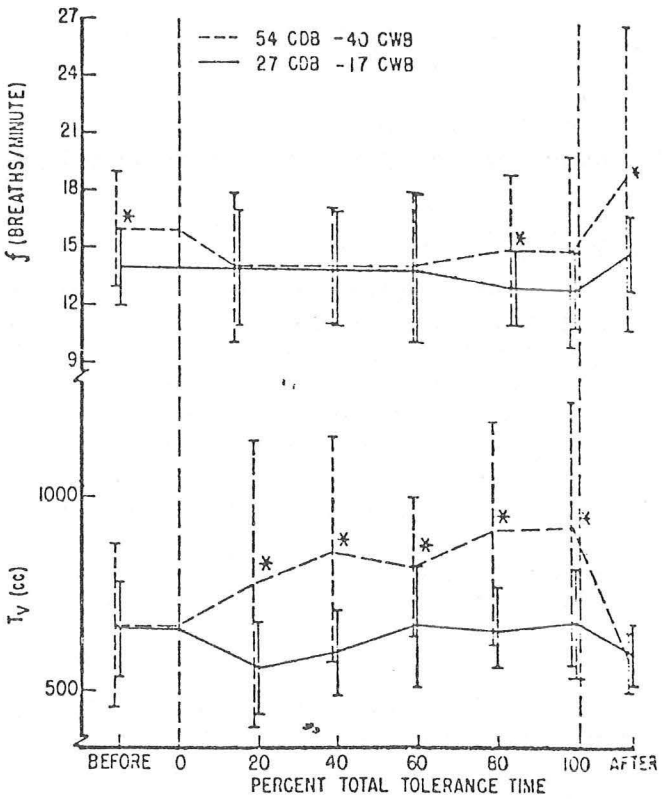
Acid Base Disturbances --

Haldane (136) in 1905 was the first to describe a heat-induced hyperventilatory state in men at rest. Several other early investigators also noted hyperventilation in response to heat stress.(137-139) Gaudio and Abramson (140) studied ten healthy male subjects, seated at rest during heat exposure to their individual limit of endurance (129.2 F° db - 104 F° wb or 54°C db - 40°C wb for a mean of 37 ± 8 minutes). Mean minute volume of ventilation (V_E) increased shortly after 20% of the total tolerance time had elapsed. At a control temperature of 80.6 F° (27°C db - 17°C wb), V_E did not increase.(Figure 37) The increase in V_E was primarily a function of increased tidal volume (T_V) and not increased respiratory rate.(Figure 38)



Mean minute volume ($\dot{V}_E$) before exposure to heat, at 20, 40, 60, 80, and 100% of each individual s tolerance time and 5 min after removal from the heat. The abscissas within the dotted lines represent the exposure period. The asterisk (*) indicates significance ($P < .01$) between means at corresponding points. The brackets (I) represent ± 1 SD.

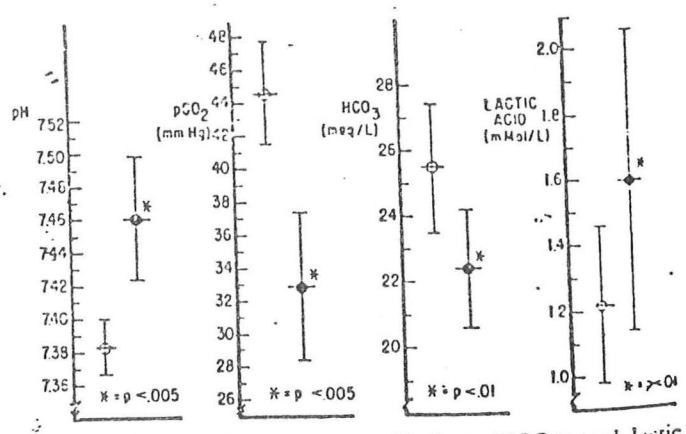
Figure 37



Mean respiratory rate ($\bar{f}$) and mean tidal volume ($\bar{V}_T$) before exposure to heat at 20, 40, 60, 80, and 100% of each individual's tolerance time and 5 min after removal from the heat. The abscissas within the dotted lines represent the exposure period The asterisk (*) represents significance ($P < .05$) between means at corresponding points. The brackets (I) represent ± 1 standard deviation.

Figure 38

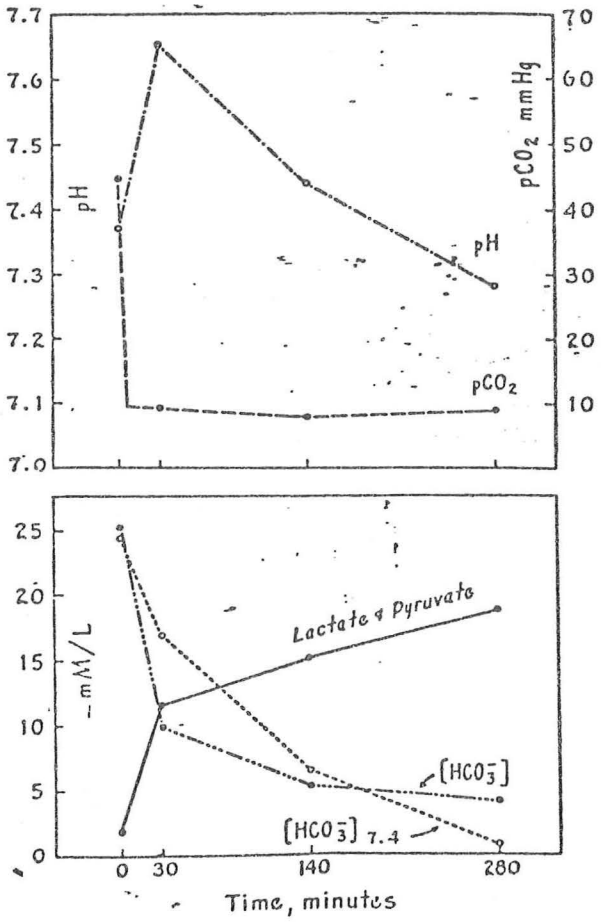
In the heat, as mean pCO_2 fell and mean pH rose ($p. < .005$), lactic acid rose significantly ($p. < .01$) in response to the hypocapnia.(Figure 39)



Mean values for venous pH, P_{CO_2}, HCO_3^-, and lactic acid immediately following the cool (-⊖-) session and the heat session (-●-). The brackets represent ± 1 standard deviation.

Figure 39

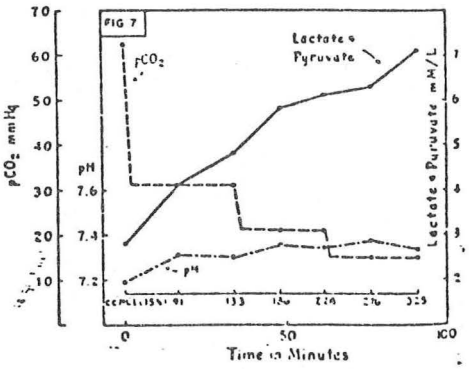
Eichenholz et al(141) had previously demonstrated the production of metabolic acidosis by inducing severe, sustained respiratory alkalosis and hypocapnia in dogs on mechanical ventilation. These authors noted a simultaneous rise in lactic and pyruvic acids with the development of a progressively increasing bicarbonate deficit.(Figure 40)



Progression of respiratory alkalosis to metabolic acidosis. Linear graph of values obtained in experiment shown in Fig. 2. Note that most of the true bicarbonate deficit is accounted for by the rise in lactate and pyruvate.

Figure 40

In a series of these dog experiments, pH and pCO_2 were independently controlled and the rise in lactic and pyruvic acids was found to be associated only with reduced pCO_2.(Figure 41)



Steady pH and variable pCO_2. (Mean values for two dogs.) The rise in lactate and pyruvate occurs in association with reduction in pCO_2 in presence of steady pH.

Figure 41

In a similar study,(142) the physiological parameters of forced room air hyperventilation in dogs, i.e., a decreased blood pressure, cardiac output, and liver blood flow were partially reversed by the addition of 5% CO_2.(Figure 42)

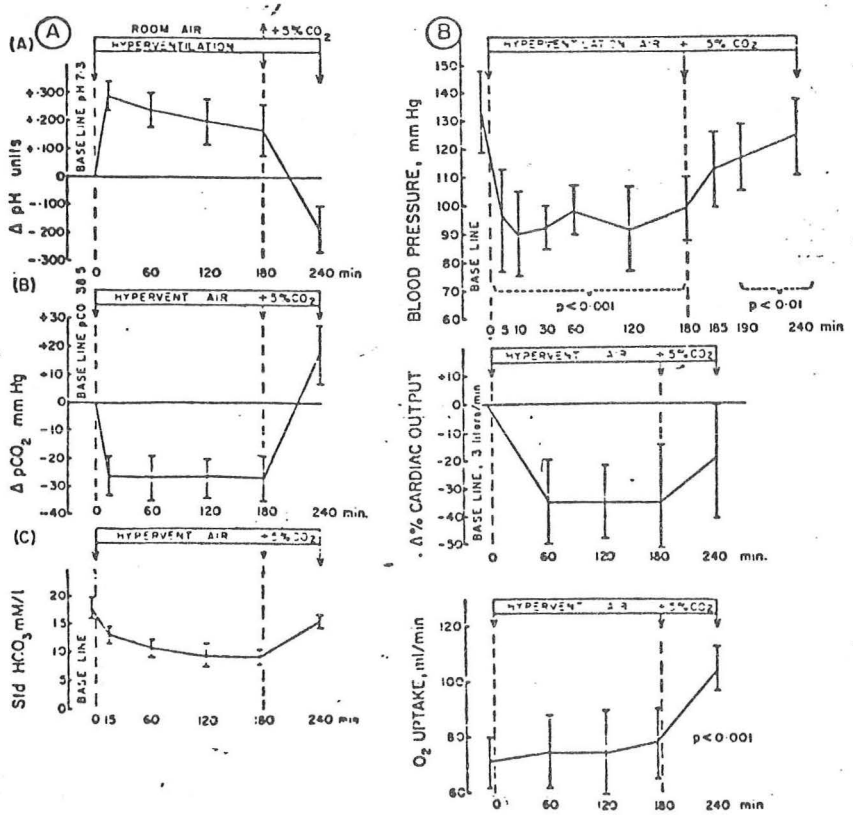
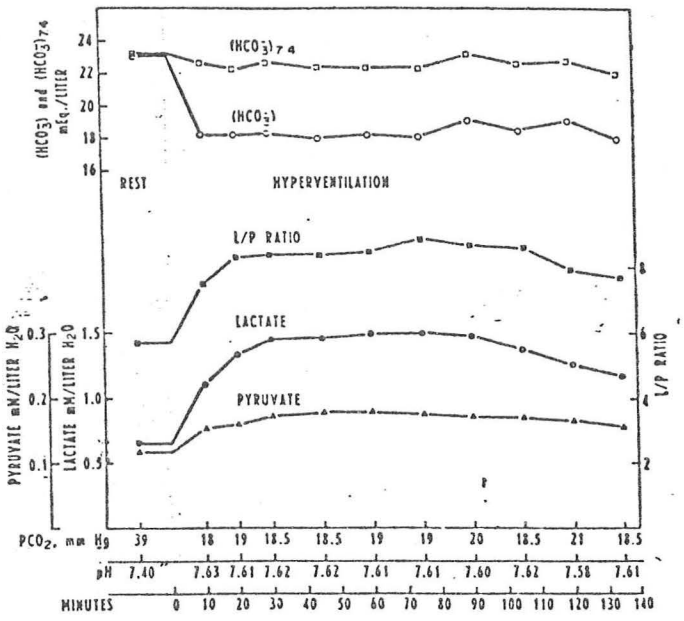


Figure 42

Physiological parameters. *A:* arterial blood pH, Δ P_{CO_2}, and standard bicarbonate. *B:* mean arterial blood pressure, cardiac output, and oxygen uptake. The vertical bars represent ±1 SD.

Eldridge and Salzer(143) concluded that respiratory alkalosis in humans leads neither to large increases in lactate and pyruvate nor to progressive shifts in the buffer curve of the blood. Using normal male adult volunteers, they measured arterial lactate and pyruvate at various levels of hypocapnia and alkalemia during active hyperventilation. Lactate and pyruvate levels increased in all subjects, and the increases showed an inverse relationship to the decrease in pCO_2 and H^+ concentration.(Figure 43) However, even the maximum changes were relatively small, the mean lactate increasing less than 1 mmol/L at pCO_2 = 20 mmHg, pH 7.61.

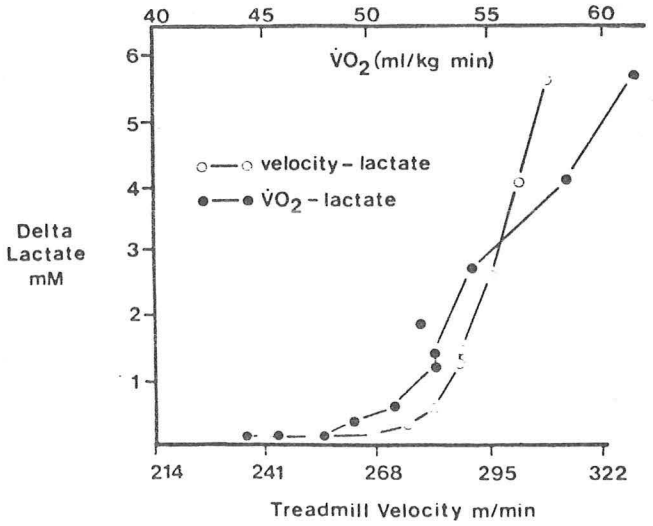


Mean changes in corrected bicarbonate [HCO_3^-] 7.4, bicarbonate [HCO_3^-], L/P ratio, lactate, and pyruvate during 135 min of hyperventilation at P_{CO_2} of less than 20 mm Hg.

Figure 43

Exhaustive exercise of a prolonged duration in marathon runners suprisingly revealed relatively low plasma lactate levels.(144) It seems that individuals can exercise up to a certain critical intensity with little or no accumulation of lactate in the plasma(145-148). However, when this critical intensity is surpassed, lactate accumulates exponentially.(147-149) Costill et al(150) demonstrated that experienced runners can utilize approximately 70% of their $\dot{V}O_2$ max before lactate begins to accumulate in the plasma. During "best marathon" runs, experienced marathoners utilize approxiamtely 75% of their $\dot{V}O_2$ max(151).

Several investigations have shown that plasma lactate concentrations are the sum of (1)production of lactate in the muscle, (2)the diffusion of lactate from muscle to blood, and (3)the uptake of lactate by various tissues.(152-154) The onset of plasma lactate accumulation (OPLA) cannot be used as the onset of an anaerbiosis but a point where the lactate concentration in muscle has increased, overcoming the gradient between muscle and blood.(155) It is true, however, that a pronounced ventilatory response often coincides with the OPLA.(145,148) Independent of the competitive level of the runner, setting a pace which allows the utilization of the largest possible $\dot{V}O_2$ just avoids the exponential rise in plasma lactate.(156)(Figure 44)

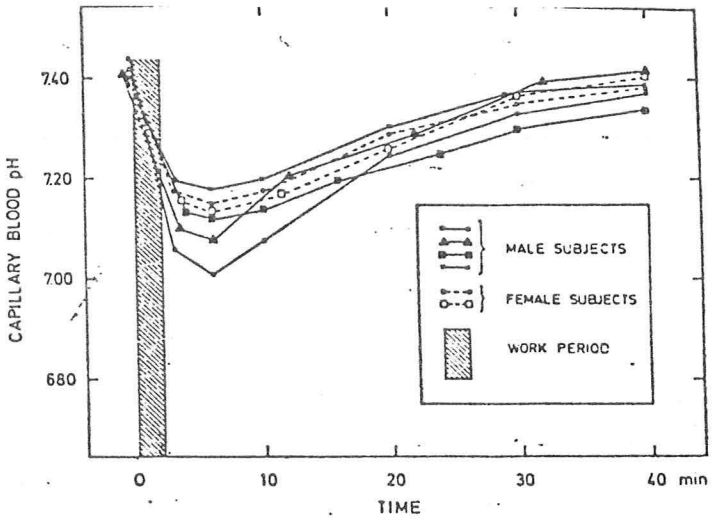


Relationship between treadmill velocity and delta lactate or oxygen consumption (ml/kg min) and delta lactate for a representative subject.

Figure 44

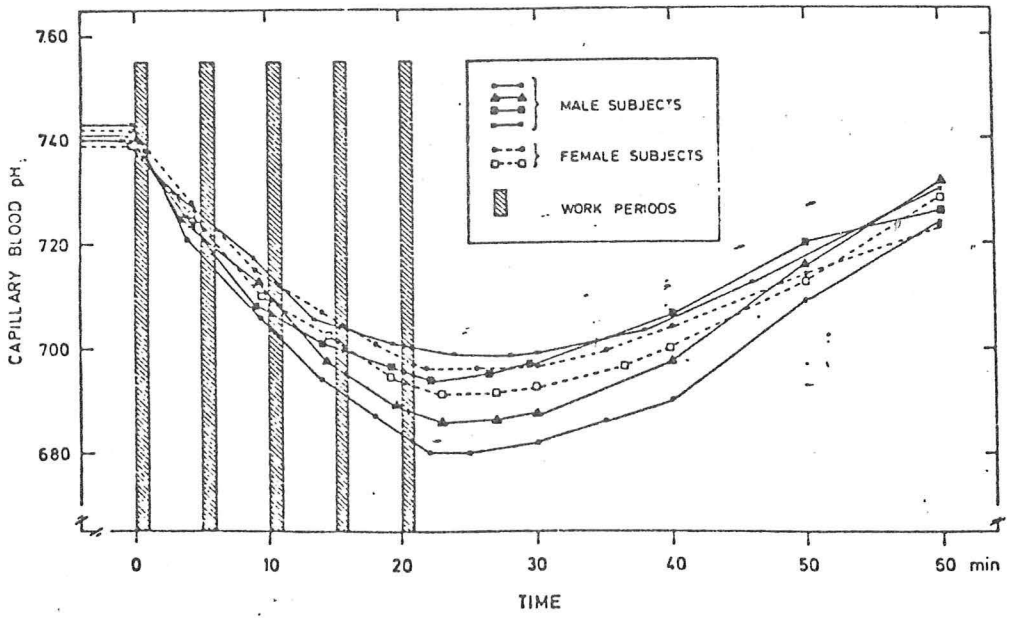
Energy-rich phosphate availability is an important limiting factor in heavy muscular work.(157) High skeletal muscle lactate levels appear about the same time as the onset of muscle fatigue. Accumulation of lactate inside skeletal muscle cells tends to lower the intracellular pH. Minor changes in intracellular pH alter the rates of chemical reactions in the cells, some being depressed, others accelerated. Hill(158) pointed out that the formation of lactic acid by skeletal muscle in response to stimulation stopped when the internal pH dropped to about 6.3 which could effect the rate of skeletal muscle glycolysis, in a fashion similar to what has been reported for brain tissue(159) and retina(160).

Intracellular accumulation of hydrogen ion has been suggested by Katz(161) as a possible cause of reduced cardiac contractility during metabolic acidosis. Increased hydrogen ion concentration does reduce the binding capacity for Ca^{++} through inactivation of the fibrillar protein, troponin.(162) The changes in capillary pH and intracellular muscle pH during maximal exercise of short duration in 13 young volunteers can be seen for continuous or intermittent types of exercise in Figures 45 and 46 respectively.(163) The inability for the skeletal muscle to contract in connection with maximal work to exhaustion in this study may in part be explained by inactivation of Ca^{++} binding processes in muscle cells. (Fatigue may be actually protective when commonsense fails.)



Capillary blood pH before and at different time intervals during recovery period after maximal exercise to exhaustion, i.e., treadmill running (n = 6).

Figure 45



Capillary blood pH measured at rest and at different time intervals during an intermittent exercise program (5 exercise bouts of approx 1-min duration with 4-min rest in between) and in the final recovery period (n = 6).

Figure 46

Patients with exertional heatstroke present with a relatively pure lactic acidosis.(15,86,164) In such patients, elevations of blood lactate in the range of 10-20 mmol/L are not unusual. In high trained cross country skiers subjected to repetitive, exhaustive exercise, hyperlactatemia was common, and one subject tolerated a blood lactate level of 32 mmol/L without apparent ill effect.(165) Though blood lactates have been mentioned in some studies of exertional heatstroke,(4,86,164) few papers have studied the subject systematically. Costrini, et al(86) described 13 Marine recruits with exertional heatstroke, most of whom had arterial pH and lactate measured on arrival to the hospital. Mean lactate for these patients was 14.7 mmol/L, and all patients survived without long-term sequalae. Two groups, subjects with either heat exhaustion or strenuous exercise had comparable blood lactates. This clinical study and the clinical observations cited are in sharp contrast to animal studies that suggest an inverse relationship between survival time in rats and the initial post-exercise blood lactate concentration.(166)

Whereas, there is no clear evidence that blood lactate correlates with prognosis in men with exertional heatstroke, significant (but mild by comparison) elevations of lactate appear to be harbingers of poor outcome in classical heatstroke victims.(64) The most frequent acid-base disturbance in classical heatstroke is respiratory alkalosis, but mixed disorders are common. A component of metabolic acidosis was present in nine of the 28 Dallas classical heatstroke victims in 1978 and in each instance, lactic acidosis was responsible for this component.

We divided the 28 patients into Group I (20 patients, surviving without sequalae), Group II (four patients surviving with permanent neurological deficits) and Group III (four patients who expired). The mortality rate was 14% for those victims living to arrive at the Parkland ER and an additional 14% of this group had new fixed neurological deficits.

The mean lactate level for our Group I patients was less than twice the upper limits of normal (Figure 47) and some of this modest elevation can probably be explained by the effect of hyperventilation.(142,143) All patients with an initial blood lactate greater than 3.3 mmol/L suffered a poor outcome, whereas all of those with an initial lactate less than 3 mmol/L did well. The mean lactate for Group II was 5.4 mmol/L and for Group III, 9.65 mmol/L. Observations during the 1980 Dallas heatstroke epidemic which extended our experience to 48 patients continued to support the blood lactate as a sensitive prognostic indicator at a level greater than 4 mmol/L. (Unpublished data)

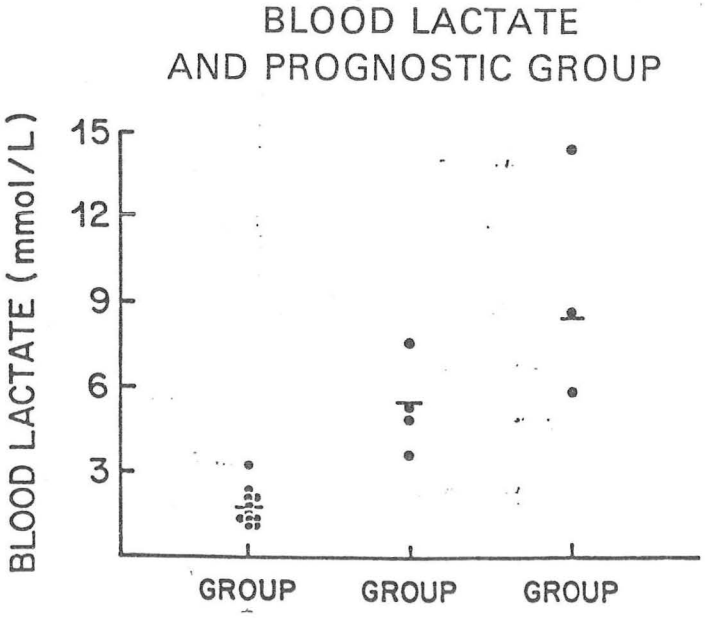
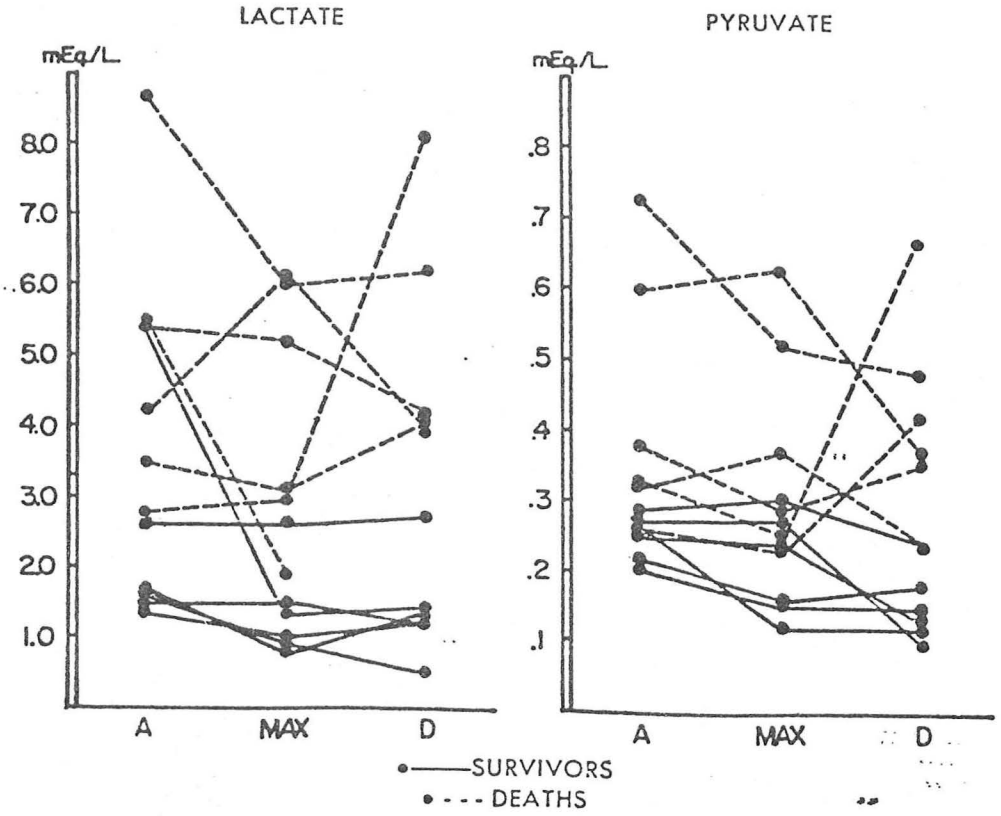


Figure 47

Blair, et al(167,168) demonstrated that patients with septic shock and a blood lactate greater than 3 mmol/L died regardless of therapy or initial pH.(Figure 48) Peretz(169) has shown that patients with shock syndromes from various causes had a mortality of 70% when arterial lactate was 4.5 mmol/L or higher.



A = admission level; MAX = highest interval level; D = level on discharge or death. Patients with admission lactate levels over 3.0 mEq./L. with one exception had a grave prognosis. A similar, though not as consistent a trend, is demonstrated with pyruvate concentrations.

Figure 48

Treatment of the Heatstroke Victim --

Prompt recognition of hyperthermia and appropriate pre-hospital care are key components to a successful outcome in the therapy of heatstroke. The initial core temperature does not correlate well with clinical outcome whereas duration of hyperthermia does. The following treatment protocol resulted in an 81% survival rate (although 10% of survivors had permanent neurological sequalae) in the last 48 patients treated at Parkland Memorial Hospital for heatstroke, 28 in the 1978 heat wave(64) and 20 in the longer 1980 heat wave.(18)

TABLE 9.

Treatment of Heatstroke in the Emergency Room(18)

1) Establish airway - endotracheal intubation should be accomplished in comatose patients if possible; prevent pulmonary aspiration.

2) Secure access to the circulation with an intravenous line that will withstand cardiopulmonary resusitation. (Use large bore needle or intracath.)

3) Insert a high rectal thermister probe with scale to 115 F° (46°C). Oral, axillary and anal temperatures are not sufficient.

4) Immediately cool the patient! This is the most important aspect of therapy. Efforts to cool the patient should begin in the field or in the ambulance while in transit to the hospital.

   a) Remove restrictive clothing prior to tranporting the patient.
   b) Wet the patient down in the field or use large fans to enhance evaporative cooling; or
   c) Cover the patient with wet sheets on a rubber mat and pack in ice or use an endothermic applicance. The body must be massaged to accomplish maximal cooling since these methods result in vasoconstriction, thereby inhibiting heat transfer from the core to the skin.
   d) Immersion in an ice water tub is preferrable to the above field techniques because conduction losses of heat to ice water occur rapidly. Goals for cooling are to drop the core temperature to approximately 102 F° (38.9°C) in 30 minutes to one hour. ER personnel should briskly massage the immersed victim to stimulate the exchange of heat. Rubber gloves and frequent rotation of ER personnel is mandatory to prevent severe cold-induced hand pain or mild frostbite injury. The disadvantages of this method include difficulty getting patients in and out of the tub, and difficulty protecting the endotracheal tube from slippage. Ice water immersion causes a counterproductive cutaneous vasoconstriction and impedes core heat dissipation. Whether or not this is clinically important has yet to be determined experimentally.
   e) If a tub is not available, put the patient on a rubber mat or covering on a metal stretcher. Place a wetted sheet on the patient, rub the skin briskly with ice or an endothermic device under direct air currents from a large fan. This procedure is much slower than ice water immersion.
   f) Iced saline lavage of the stomach through an Ewald tube can be done; antacids should be left in the stomach to prevent lung injury from pulmonary aspiration and to decrease the liklihood of erosive gastritis.

5) Continually monitor the rectal temperature even after the patient is cooled. If cooling is excessive and even sometimes when it is not, the core temperature can drift down to 92 F° (36°C) and require passive rewarming. In addition, hyperthermia can recur several hours later despite an air-conditioned milieu.

6) Use continuous EKG monitoring - atrial arrhythmias are common but serious ventricular arrythmias can occur.

7) Avoid excessive fluid administration during "hypotension." Cooling alone may restore blood pressure to normal by causing a translocation of cutaneous blood flow to the core circulation. Ignoring the degree of peripheral pooling may result in an overestimation of crystaloid needs. If cooling does not restore the blood pressure, 500 cc of normal saline should be rapidly infused. If this is not effective, estimate and administer crystaloid and free water deficits as previously described. Seventeen of 48 heatstroke patients presented with hypotension (systolic < 100 mmHg) at Parkland during 1978 and 1980, eight responded favorably to cooling, judicious fluid replacement, and in three cases to brief pressor support. The remaining nine hypotensive patients required prolonged pressor support and had poor clinical outcomes.

8) Use pressors only if the hypotension is refractory. Aramine or dopamine should be used, whereas norepinephrine should be avoided since it causes intense vasoconstriction of the cutaneous vessels. Generally patients with exertional heatstroke require substantially more IV fluid administration early in the treatment protocol. Pressors may be ineffective in the face of severe metabolic acidosis. If bicarbonate administration is necessary, monitor closely for signs of hypocalcemia.

9) Suppress seizure activity promptly. Convulsions commonly occur during the cooling period of therapy. Seizure activity generates an additional, and significant, heat load because of the associated intense muscular activity. Short acting drugs such as intravenous diazepam is recommended since recurrent seizures are unlikely. If seizures recur, phenytoin loading should be considered.

10) Anticipate underlying diseases, tissue injury and complications. Establish data base:

Obtain baseline laboratory evaluation including: BUN, creatinine, electrolytes, arterial blood gases, CBC, platelets, CPK, SGOT, bilirubin, protime, amylase and serum lactate. Check the serum for evidence of intravascular hemolysis. Measure urinary sodium concentration, specific gravity and/or osmolality, benzidine reactivity, protein by dipstick, and the urine/plasma concentration ratio of urea nitrogen and creatinine.

In the past, 50 mg to 350 mg of intravenous chlorpromazine has been recommended prior to the cooling phase to "paralyze the shivering mechanism" which generates a considerable amount of heat, and to act through its "muscle relaxant and cutaneous vasodilatory effects" to lower temperature(170-172). Chlorpromazine was used at Parkland virtually without question "as protocol" handed down from senior to junior house staff in much the same fashion as the original articles on chlorpromozine were handed down through review after review on heatstroke management. During the 1978 and 1980 heatstroke epidemics in Dallas, chlorpromazine was given to 19 of 48 patients. Of the 19 patients who received this potent alpha blocker, 14 were Group I, two were Group II and four were Group III patients using the previously described categorization. Eight of the 19 patients (42%) experienced a temporally related worsening of hypotension during cooling, or 3/14 (21%) Group I, 2/2 (100%) Group II, and 3/4 (75%) Group III patients respectively. In the 29 patients not receiving chlorpromazine, only three (10%) developed hypotension during the cooling phase ($p. < .016$). The classification system used in this study correlated closely with serum lactate levels without regard to chlorpromazine therapy, which was not administered until serum lactate levels had been obtained. The more seriously ill patients in Groups II and III were more likely to suffer further serious drops in blood pressure after chlorpromazine was given. Although these observations are retrospective, they suggest that chlorporomazine is contraindicated in the setting of classical heatstroke.

Despite occasional reports to the contrary(173,174), the use of steriods has not been helpful in the treatment of heatstroke.(118)

Dantrolene sodium is a drug that acts distal to the neuromuscular junction directly on skeletal muscle fibers by inhibiting the release of calcium ions from the sarcoplasmic reticulum.(188,189) The drug has been used successfully in controlling clinical spasticity caused by a variety of disorders(190) and in the prophylaxis and treatment of malignant hyperthermia.(191,192) Recently, a case report of the use of dantrolene sodium to treat heatstroke patients has appeared(193) and an article in Runner's World suggested that "heatstroke is a manifestation of malignant hyperthermia."(194) Malignant hyperthermia crises have traditionally been associated with a genetic muscle membrane disorder and general anesthesia. Several authors now suggest that emotional or physiological stress may trigger the syndrome.(195-198)

The anecdotal reports that suggest a beneficial effect of dantrolene sodium on heatstroke patients are not controlled. Careful review of the cases make any conclusions regarding this therapy highly questionable since standard cooling techniques were usually employed prior to administration of the drug. Currently, the manufacturer (Norwich-Eaton) is embarking upon a randomized, unblinded, parallel study to determine the efficacy and safety of dantrolene sodium in heatstroke therapy. The drug will be given simultaneously with standard cooling procedures so again, it will be difficult to separate the contribution of the drug to outcome, but ethically it would be impossible to perform a clinical study any other way at this point. One can only hope that the errors of "therapeutic incorporation" made with chlorpromazine therapy based on a few case reports are not repeated with dantrolene sodium until more information is available from animal studies or well designed clinical trials.

Recently, a new physiological treatment for heatstroke, utilizing the Makkah body cooling unit has been described.(8,175-177) Cooling is achieved through heat dissipation from all body surfaces by evaporating an atomised, intermittently applied water spray at 59 F° (15°C) from a warm skin at 87.8 - 91.4 F° (31 - 33°C). Evaporation is attained by blowing warm air at 113 F° (45°C) continuously over the patient. The atomised water is sprayed through small pores from evenly distributed nozzles placed equidistantly at 50 cm above and below a position adjustable meshed net upon which the nude patient lies. Warm air is blown over the entire body, from the same distance. An analysis of the cooling curve reveals that a drop of .54 F° (0.3°C) is attained every five minutes.(Figure 49) With a maximum cooling rate achieved by 30 minutes.(Figure 50)

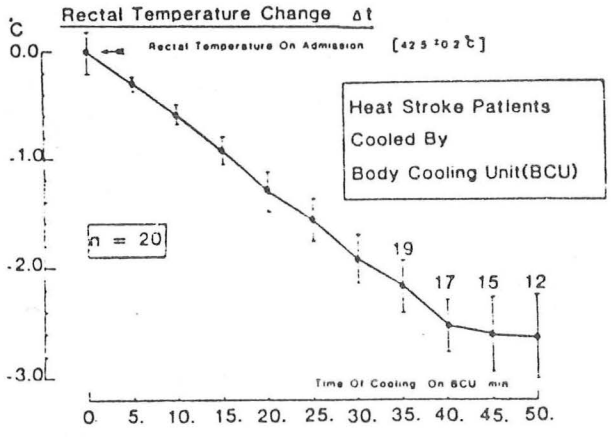


Figure 49

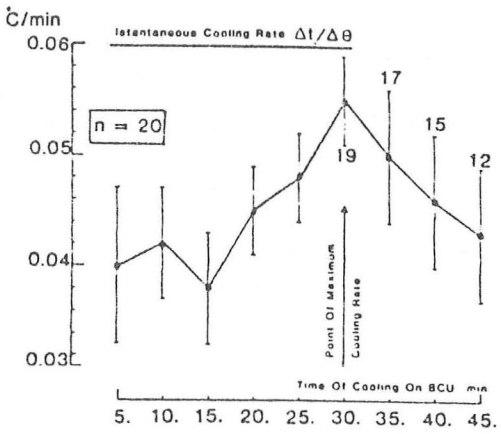
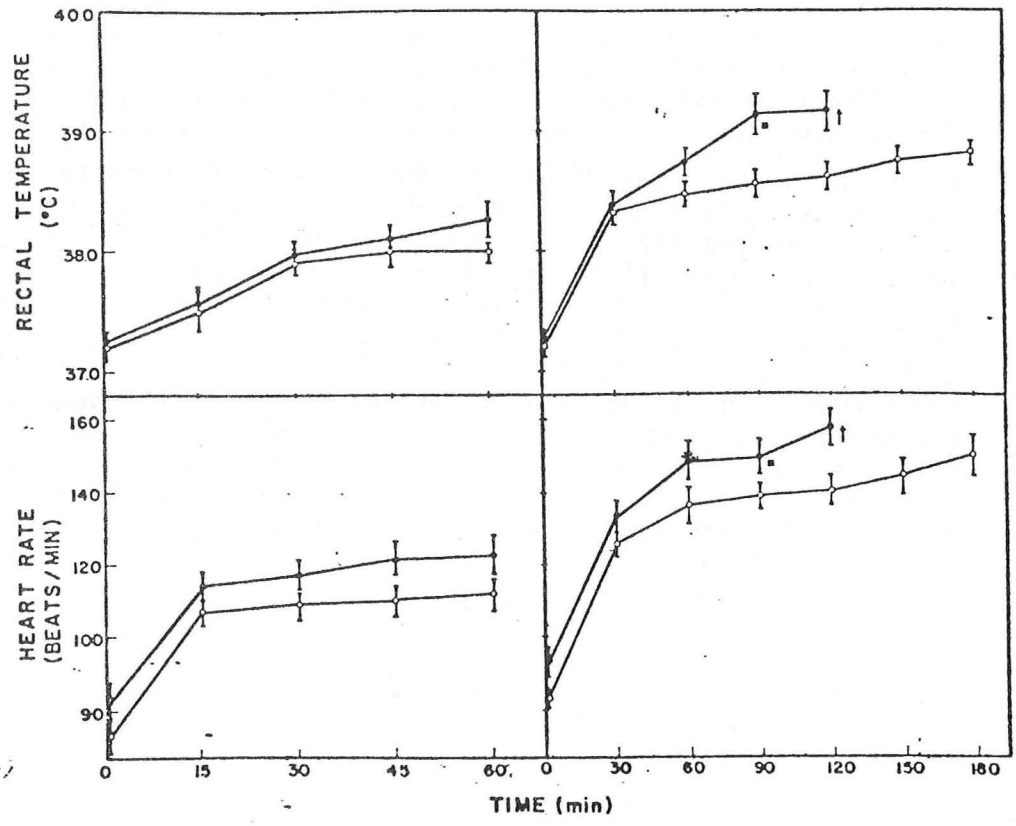


Figure 50

The design of this unit allows for more convenient monitoring of the patient's airway, EKG, fluid administration, etc. This approach to cooling is also more esthetically acceptable (and less painful) to ER personnel. Cooling with the MBCU is physiologically sound and the method may be superior to ice bath immersion, however, the unit is expensive and the only one currently available in the United States is on loan to Parkland (from the Western Group) for clinical research. Hopefully, such units will one day be portable enough to be utilized in the field for situations where potentially large numbers of heatstrokes may occur.

Prevention of Heatstroke: Exertional --

Physicians must recognize, in fact anticipate, the adverse climatic conditions known to increase risk for exertional heatstroke. The military has taken the lead in using climatic forecasting to reduce heat injuries from training. Training programs of all types should emphasize gradual, stepped physical exertion. Restrictive clothing, such as football pads, should not be used until acclimatization is achieved. Free access to fluids, either water or hypotonic electrolyte solutions should be encouraged, or better yet, forced at appropriate intervals. Rubber sweat suits should never be employed in order to "reduce" the obese athelete-to-be. A history of heatstroke in young, otherwise healthy subjects should alert trainers that heat intolerance may be present.(178)(Figure 51) Such heat intolerant individuals have not been found to have genetic malfunctions affecting muscle membranes and their normal resting CPK levels tend to exclude malignant hyperthermia.(179) Under the same heat load, heat-intolerant subjects have been shown to sweat similarly up to a point of sweat dripping documenting adequate sweat gland function. Heat-intolerant subjects have not been shown to have a higher metabolic rate than controls, but they do develop significantly higher core temperatures with heat stress/exercise because they retain more heat than their heat-tolerant peers. These findings indicate an impaired transport of heat from the core to the periphery. The question remains: Did these subjects already have heat-intolerance or was it acquired as a sequalae of heatstroke? The answer is not yet available. Individuals suffering from previous heatstroke should be evaluated carefully during the resumption of physical training in a hot environment.



Heart rate and rectal temperature of heat intolerant subjects (●) and control subjects (○) during exercise at 40 W at 23 °C (*left*) and 40 °C (*right*). Each point represents the mean value ± SEM for each measurement. * = five subjects, † = four subjects.

Figure 51

The increasing number of exertional heatstrokes occuring in marathon runners require special comment. These episodes are usually characterized by adverse climatic conditions, attempts to perform beyond previous limits, insufficient replacements of fluids, and failure to recognize early warning signs and symptoms of heat illness injury. The results of studies based on the 1979 Peachtree Road Race Experience (Atlanta, Georgia) are revealing and dispell some commonly held beliefs.(180) This study looked at the 29 heatstroke victims of an estimated 17,632 participants.

It had been suggested that race sponsors provide hypotonic fluids containing small amounts of glucose, sodium and potassium (less than 2.5 Gms%, 10 mEq/L, and 5 mEq/L respectively) at "water stations" located every 3 to 4 kilometers (2 to 2.5 miles) for all races of 16 kilometers (10 miles) or more and that runners should consume 400 to 500 ml of this solution 15 minutes before competition(181). The Georgia study revealed no difference in the amounts of fluids consumed between participants that faired well and those who experienced heat exhaustion or heatstroke.

It had been suggested that runners be taught the early warning signs of heat injury.(181) The Georgia results do not indicate that such a recommendation would be effective because there was no difference between the number of warning symptoms experienced by runners who suffered heatstroke and control runners; 91% of runners with heat injury experienced no symptoms or only one symptom, most often weakness, tiredness, or dizziness. The major difference between control runners and runners experiencing heatstroke was that the latter group more likely became caught up in the excitement of the race and tried to "run harder than ever before." This observation supports the earlier observation of Hamon and Zimmerman(15) who correlated attempts by novice runners to increase a running pace by approximately 1 min/kilometer during the last five kilometers of a race with the onset of heatstroke symptoms five to ten minutes thereafter. A greater emphasis should be placed on pre-race information, including specific instructions and advice for inexperienced runners who may attempt a distance or performance time well beyond their training levels or physical work capacities. It is still prudent to follow the admonition against conducting distance races (> 16 kilometers or 10 miles) when the wet bulb-globe temperature (WBGT) exceeds 82.4 F° (28°C). The WBGT = 0.7 (wet bulb temperature) + 0.2 (globe temperature) + 0.1 (dry bulb temperature). During periods of the year when daylight dry bulb temperature exceeds 80 F° (27°C), distance races should be conducted before 9:00 a.m. or after 4:00 p.m. Race sponsors should have responsible and informed personnel supervising each water station and they should have medical personnel available for emergency care and patient transport.

Prevention of Heatstroke: Classical --

Prevention of classic heatstroke, even more so than exertional heatstroke, requires appreciation for the epidemic nature of this injury which occurs primarily in heat wave years.(64) The majority of cases occur after approximately one week of sustained heat (greater than normal body temperature).(Figure 52)

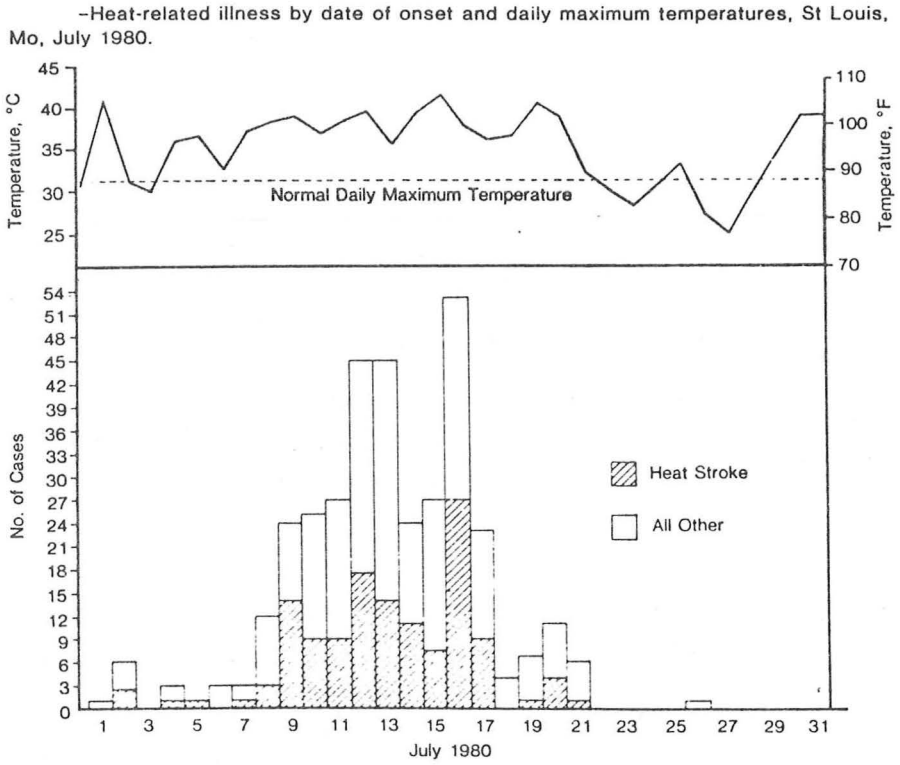


Figure 52

Even though the heat wave continued in 1980 for an extended period, most cases of heatstroke (and heat related deaths) occurred during the second through the fourth week of the heat wave similar to 1978.(Figure 53) High density, low income areas characterized by substandard housing with a low percentage of air conditioned residences provided over 90% of the cases seen in the 1978-1980 Dallas epidemics.(Figure 54) The frail, often fixed income, elderly with underlying medical problems were seemingly at highest risk. Home nursing visits or church group visitations might allow early detection of elderly victims before serious injury, however, the St. Louis experience(14) found that two-thirds of their heatstroke victims were reported as "ill less than one day" before hospitalization or being found dead. Therefore, even frequent observation in the high risk elderly may yield little opportunity for therapeutic intervention.

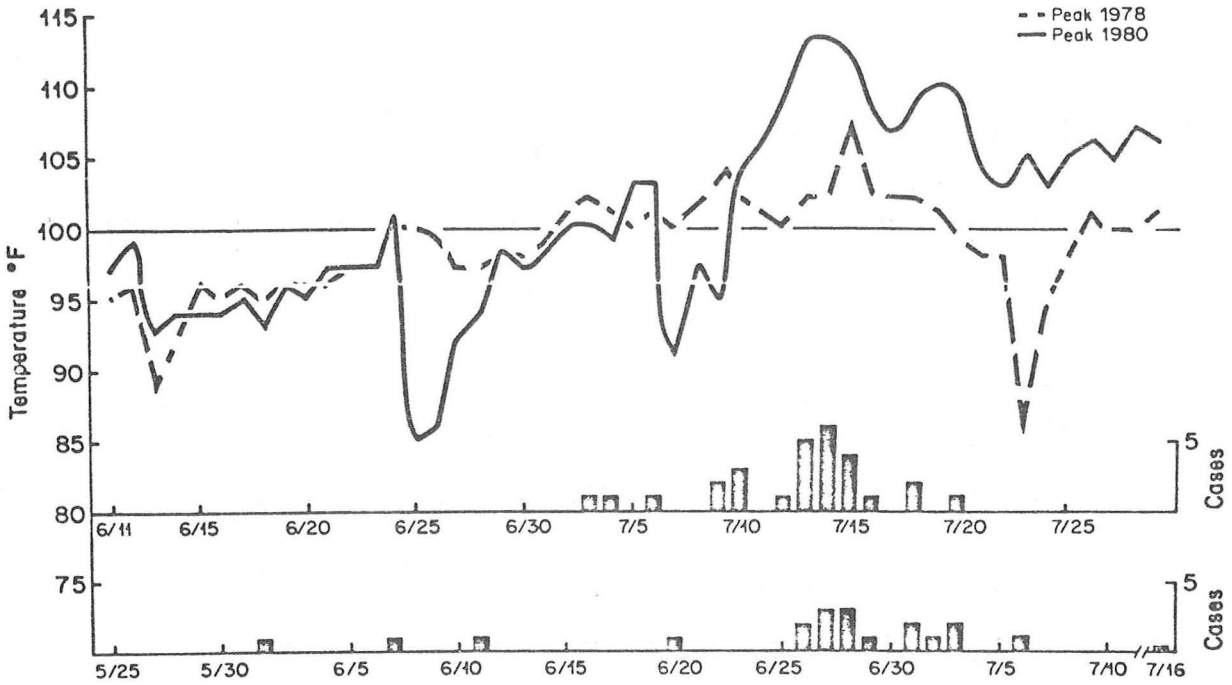
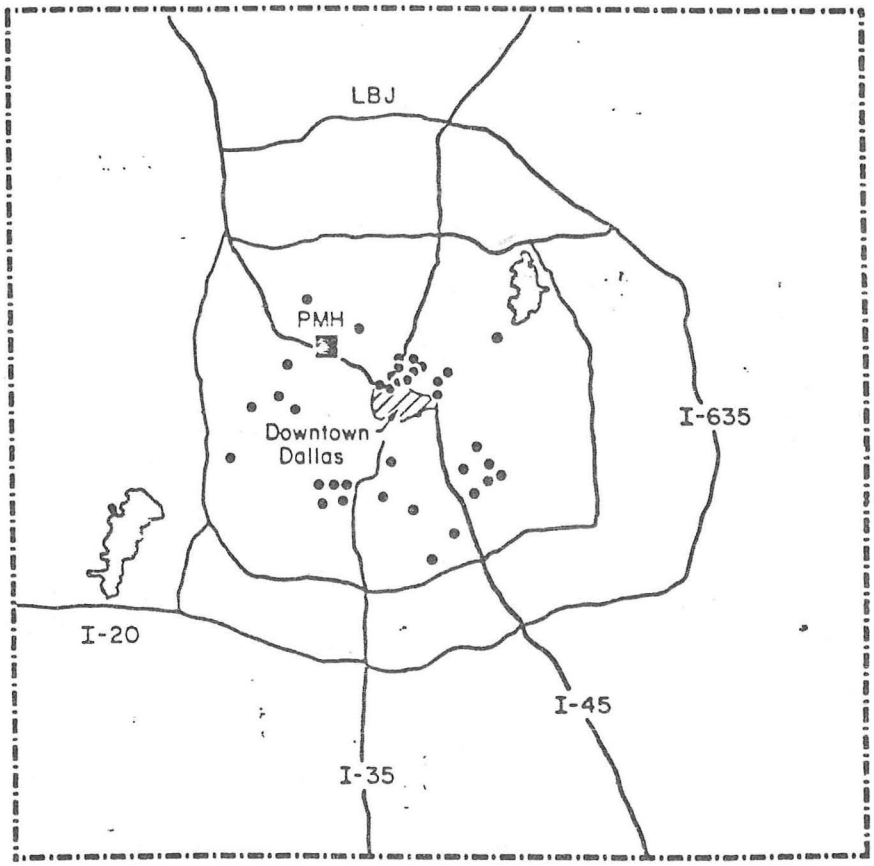


Figure 53: Heatstroke incidence treated at Parkland by date of onset and daily maximum temperatures. (Dallas, July, 1978)



Location in Dallas County of heatstroke victims. I-20 = Interstate highway west to Ft. Worth, Texas; I-35 = Interstate highway southwest to San Antonio; I-45 = Interstate highway southeast to Houston; I-635 and LBJ = Parts of a connecting loop that encircles Dallas; PMH = Parkland Memorial Hospital located just north and west of downtown Dallas. The highest heatstroke incidence occurred in Fair Park (southeast Dallas), South Oak Cliff (southwest Dallas), and West Dallas, areas of low income, high density housing.

Figure 54: A comparison of heatstroke incidence (Dallas 1978 vs. 1980) treated at Parkland.

The St. Louis study(14) paralleled the Dallas experience in several other ways. Heatstroke rates were 10-12 times higher for persons aged 65 or older and the age adjusted heatstroke rates were approximately 3:1 for non-white vs. white and low income vs. high socioeconomic status. The rural elderly and poor faired better than their city cousins(182,183) probably because of the "heat-island" effect of the inner city.

Educational campaigns, provision of temporary alternative housing, energy grants to the poor, and emergency donations of fans and water coolers can help to reduce the population at highest risk. Attempts to provide alternative housing in air conditioned geriatric "day care" centers was largely unsuccessful in 1980 in Dallas. The elderly potential victims were afraid to leave their homes unattended.

The common practice of leaving infants, toddlers, elderly people and pets in cars parked in the direct sun (even when partially ventiliated) is extremely dangerous. Tremendous heat stress can result after just a few minutes.(184)(Figures 55 and 56) This hazard must be emphasized in the lay media to educate the public and hopefully reduce the yearly report of fatalities occurring from this practice in this portion of the United States.(185-187)

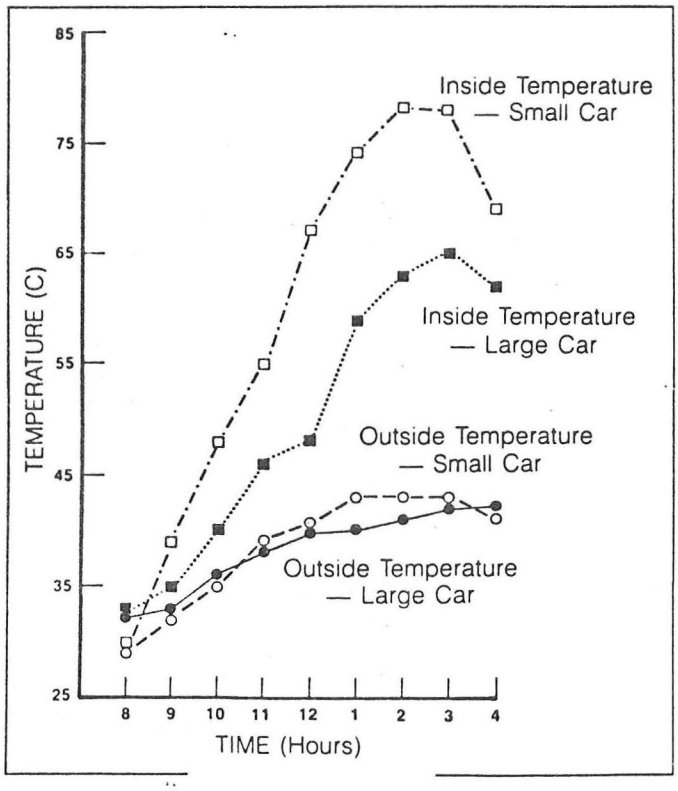


Figure 55

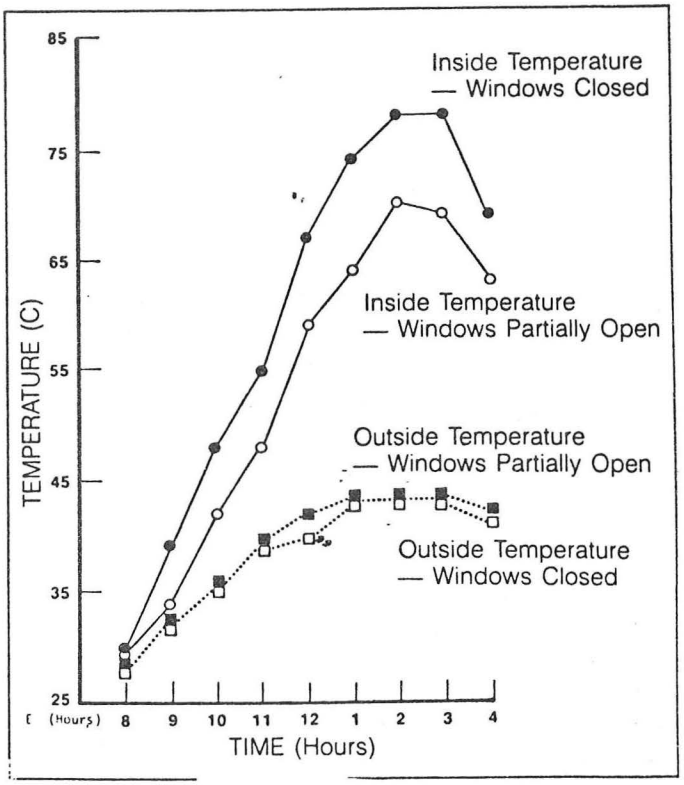


Figure 56

Finally, the Emergency Medical System (EMS) must be prepared. During heat waves, EMS mobile intensive care units (MICU) should carry ice or endothermic devices at all times or arrange for convenience store vendors to accept tokens for large quantities of emergency ice supplies. The EMS-MICU should be equipped with a portable inflatable raft to serve as a tub suited for packing a patient in a make-shift ice bath. All major emergency departments in the risk area must stock ice in sufficient quantities (Parkland keeps approximately 800 lbs. on hand during heat waves) and provide a room which can be quickly converted into a "heatstroke room" complete with bath tub, floor drains, rectal thermistor and other accessories to support CPR activities. Emergency department personnel require appropriate in-service instruction on the management of heat-related illness. During heat wave years, patients at risk for heat illness injury presenting with any serious decompensation of a chronic illness (congestive heart failure, chronic obstructive pulmonary disease, diabetes, etc.) or heat exhaustion should be admitted and taken out of an adverse environment to prevent an excalation of the illness to heatstroke.

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