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Environmental Hyperthermia

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Heat-Related Illnesses : History

- Death reported from field labor : (Old Testament, II Kings 4:18-20)
- Roman Army in Arabia decimated by heat : 24 B.C.
- King Edward & Crusaders lost battle against Arabs : 3rd Crusade
- Heat wave in Peking, China : 11,000 deaths : 1743
- 123 British troops died in Black Hole of Calcutta : 1856
- U.S. Army : 125 reported deaths in basic training : 1941-44
- 820 U.S. reported deaths / "heat wave year" (1952-55, 1966)
- Several thousand deaths in heat wave in Greece / Italy : 1987
- ? > 10,000 deaths in France in 2003

Heat-Related Illness : Incidence

- ? About 4000 deaths / year in U.S.A.
- Second leading cause of death in amateur athletes (head trauma is first)
- Can cause mass numbers of deaths during "heat wave"
- Some cases mistakenly attributed to heart disease

Controversies or Unclear Points

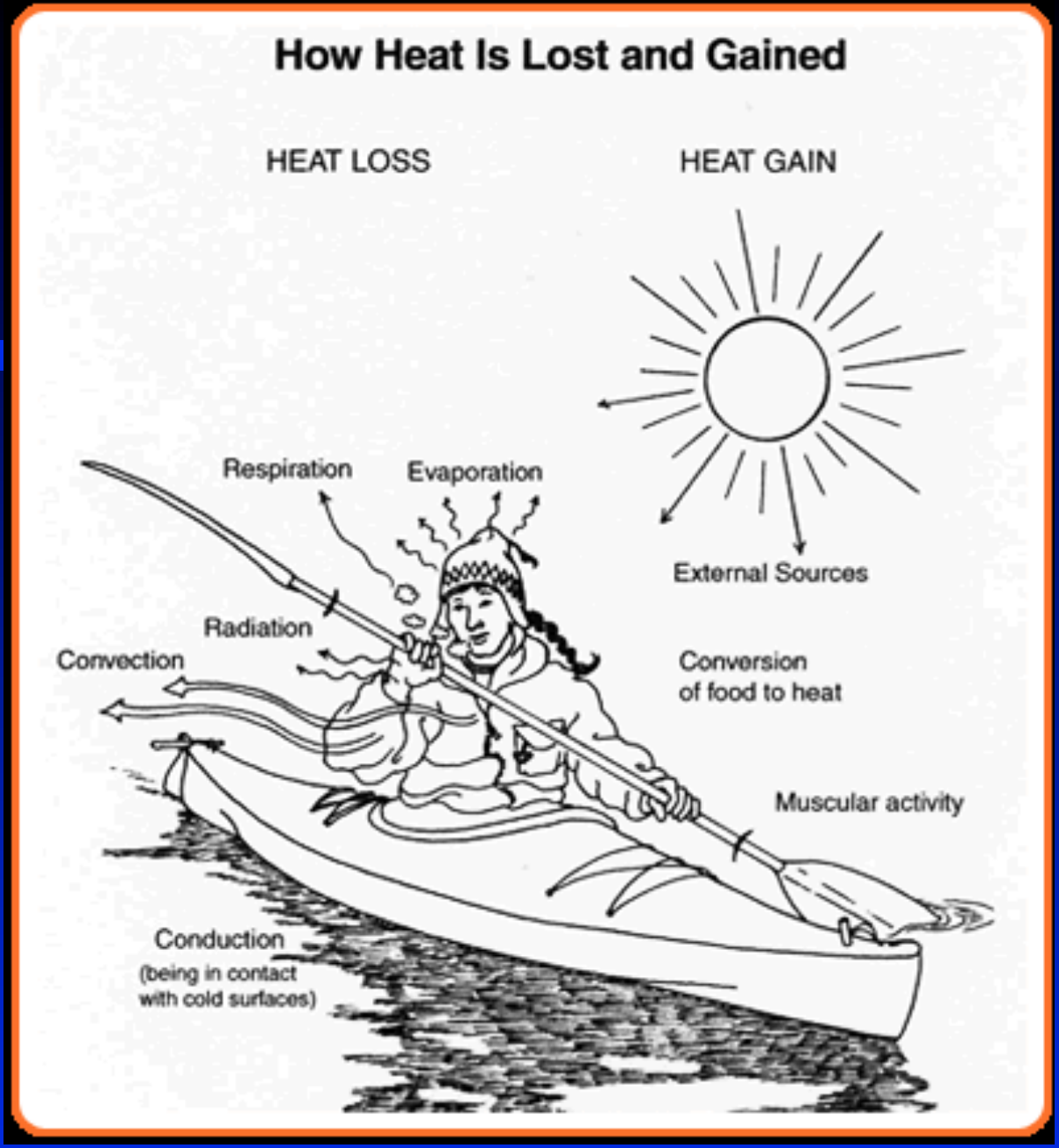
- Environmental Hyperthermia
  - What is the most effective central cooling method ?
  - What is the best method to limit shivering ?
  - Are any medications helpful as adjunct therapy ?

Hyperthermia : Causes

- Infections
- Drug reactions
- Neuroleptic malignant syndrome
- Malignant hyperthermia
- Environmental

Mechanisms of Heat Transfer

- Conduction (2 %)
  - Transfer of heat by direct physical contact
- Convection (1 to 40 %, depends on wind velocity)
  - Transfer of heat to air / water vapor circulating around body
- Radiation (30 to 65 %)
  - Heat transfer by infrared waves
- Evaporation (10 to 80 %)
  - Conversion of liquid sweat to vapor (0.58 Kcal / cc of H_2O evaporated)



Mechanisms of heat transfer from the skin

Predisposing Factors to Heat-Related Illness (Excluding Drugs)

- Exogenous heat gain
- Endogenous heat gain
- Impaired heat dissipation

Sources of Exogenous Heat Gain

- Closed spaces (locked cars, etc.)
- Bright sunshine (150 Kcal / hr)
- Hot tubs
- Lack of air conditioning
- Hot soil (can transmit heat thru shoes)

Sources of Endogenous Heat Gain

- Exercise (300 to 900 Kcal / hr)
- Agitation / restraint
- Fever / infection
- Hypermetabolism / hyperthyroidism

Baseline Energy Metabolism

- Basal metabolism (adult male)
  - 65 to 85 Kcal/hr or 50 to 60 Kcal/hr/m2 body surface area
- For every 100 calories produced :
  - O2 consumption is 20 liters
  - CO2 production is 20 liters
  - 100 ml water is needed (for sweat and respiratory loss)

Energy Expenditure During Different Activities

Activity	Kcal / hr
LABOR	
Shoveling	570
Hand sawing	450
Pushing wheelbarrow	300
Carrying bricks	216
Light assembly work	108
Typing	84

Energy Expenditure During Different Activities (cont.)

Activity	Kcal / hr
SPORTS & RECREATION*	
Football	102
Wrestling	114
Hockey	173
5-mile run	360
Walking (4 mph)	340
Basketball	344
Swimming	660

- *Calorie expenditure per event given as increment above basal requirement

Causes of Impaired Heat Dissipation

- High environmental temperature
- High environmental humidity
- Lack of acclimatization
- Excessive clothing
- Obesity
- Diabetes / autonomic neuropathy
- Sweat gland dysfunction (dehydration, cystic fibrosis, ectodermal dysplasia, scleroderma, extensive scars)
- Previous heatstroke

Hyperthermia : Types of Causative Drug Reactions or Effects

- Hypersensitivity
- Hypermetabolism
- Impaired thermoregulation
- Impaired heat dissipation
- Impaired cardiovascular compensation
- Direct pyrogens

Representative Drugs Causing Hyperthermia

- Hypersensitivity
  - Antibiotics
  - Antiarrhythmics
  - NSAID's
  - Phenytoin
- Pyrogens
  - Antibiotics
  - Cancer chemo Rx
- Hypermetabolism
  - Salicylates
  - Thyroid
- Impaired Heat Dissipation or Compensation
  - Phenothiazines
  - Ethanol
  - Diuretics
  - Laxatives
  - Beta blockers
- Muscle Hyperactivity
  - Cocaine
  - Amphetamines
  - Phencyclidine
  - MAO inhibitors

Children at Greater Risk of Heat Stress

- Obesity
- Febrile state
- Cystic fibrosis
- Diabetes mellitus
- Diabetes insipidus
- Ectodermal dysplasia
- GI infection
- Chronic heart failure
- Caloric malnutrition
- Anorexia nervosa
- Mental deficiency
- Peripheral vascular disease

Environmental Causes of Hyperthermia

- Mild forms of heat illness :
  - Heat edema
  - Heat cramps
  - Heat syncope
  - Prickly heat
- Heat Exhaustion :
  - Sodium depletion type
  - Water depletion type
- Heatstroke :
  - Classic
  - Exertional

Treatment of Mild Forms of Heat Illness

- Heat edema (usually only hands, feet, ankles)
  - Elevation, support hose (do not use diuretics)
- Heat cramps (due to Na depletion)
  - Cooling, PO fluids containing some salt
- Heat syncope (usually due to mild fluid depletion)
  - Rest, PO fluids
- Prickly heat
  - Skin cleansing, loose clothing, antibiotics if pustular

Acclimatization to Heat Exposure

- Improved metabolic efficiency (increased aerobic metabolism, decreased heat wasted in making ATP)
- Sweating promoted at lower core temperature
- Rate of sweating increases from 1.5 to 3 liters / hr
- Stroke volume increases, cardiac output increases, heart rate decreases
- Aldosterone secretion increases (Na in sweat decreases from 30 to 5 meq / liter)
- Potassium retention

Acclimatization to Heat Exposure

- Gradual : takes 10 to 20 days
- Full tolerance may take 2 months

Heat Exhaustion : Sodium Depletion Type

- Etiology
  - Usually in unacclimatized
  - Usually young age
  - Exercise in hot environment
  - Mildly inadequate fluid intake & moderate inadequate Na intake

Heat Exhaustion : Sodium Depletion Type

- Sx : ± febrile, headache, weakness, fatigue, nausea, diarrhea, cramps, ± hypotension / tachycardia
- Rx : Rest, cooling, fluids (PO or IV) with sodium

Heat Exhaustion : Water Depletion Type

- Etiology : Usually elderly with inadequate free water intake ; can lead to heatstroke
- Sx : Febrile, thirst, weakness, confusion
- Rx : Cooling, rest, hypotonic fluids ; if elderly, may need hospital admission

Heatstroke : Items Required for Diagnosis

- Exposure to heat stress : internal or external
- Elevated body temperature (usually > 40 ℃)
- Major CNS dysfunction (bizarre behavior, seizures, coma, etc.)
- Usually tachypneic, tachycardic, hypotensive
- Usually anhydrotic

Heatstroke

- A true emergency
- Rapid dx and Rx essential
- Two types :
  - Classic
  - Exertional

Classic Heatstroke

- Usually elderly
- Occurs after exposure to heat for ≥ 1 week
- Mortality 70 % untreated, 10 to 20 % treated

Exertional Heatstroke

- Usually younger age
- Usually after heavy exertion
- May still have sweating
- May have rhabdomyolysis / renal failure
- Mortality 30 % untreated, < 10 % treated

Table 3 : Comparison of Classic and Exertional Heatstroke

	Classic	Exertional
Age of patients	Elderly	Younger
Epidemiology	Epidemic (heat waves)	Sporadic
Predisposing diseases	Present	Absent
Sweating	Absent	Often present
Acid/base disturbance	Resp. alkalosis	Metabolic acidosis
Renal failure	Uncommon	Common
Rhabdomyolysis	Uncommon	Common
Disseminated intravas-cular coagulation	Uncommon	Common
Hyperuricemia	Mild	Marked

Heatstroke : Differential Diagnosis

- Meningitis / encephalitis : do LP if not sure
- Cerebral falciparum malaria
- CVA / traumatic intracranial bleed
- DKA with infection
- Thyroid storm
- Neuroleptic malignant syndrome*
- Malignant hyperthermia*

*These should show muscle rigidity

Heatstroke : Emergency Treatment Protocol

- Airway management : intubate if comatose ; High flow O2 for all
- Large bore IV and rapid bolus 500 to 1000 cc NS
- Draw blood (CBC, lytes, BUN, glucose, creatinine, PT, PTT, platelets, lactate, calcium, LFT's, CPK, ABG)
- Rapid external cooling : fully undress patient : ice bath with skin massage (Hubbard tank) or cool skin soaks and fans
- Foley and NG tube insertion : iced NG lavage

Heatstroke : Emergency Treatment Protocol (cont.)

- Monitor core temp. (high rectal probe or esophageal) ; stop external cooling when core temp. < 102º F
- Monitor for hypotension, hypocalcemia, arrhythmias, seizures, acidosis, ARF
- Admit to ICU
- Acetaminophen (do not use aspirin)
- Consider low dose phenothiazine (chlorpromazine 25 mg IV) or diazepam IV to promote heat loss and lessen shivering

Heatstroke : Early Complications & Treatment

- Shivering : generates heat so should be suppressed with chlorpromazine or thiopental
- Hypotension : usually Rx with increased IV fluids
- Rhabdomyolysis / renal failure : usually only need Rx with fluids but may need bicarb ± mannitol
- Acidosis
- Hypocalcemia
- Hypoglycemia : Rx with IV glucose
- Seizures : standard Rx with diazepam or lorazepam, phenytoin

Heatstroke : Late Complications

- DIC
- Hepatic necrosis / failure
- Renal failure with hyperkalemia
- Acute MI ; reported but uncommon
- Muscle compartment syndrome
- CNS damage
- Permanently impaired thermoregulatory control : susceptible to heatstroke again under even milder conditions

Heatstroke : Mortality Reports

Setting	Type	Treatment	Mortality
3 military series	exertional	ice bath	0 / 66
Heat wave (U.S.)	classic	ice bath	14%
Mecca pilgrimage (1979)	mixed	BCU	11%
Mecca pilgrimage (1986)	mixed	KSU bed	0 / 25
1986 U.S.A. series	classic	fan, ice packs	7%
1967 series, younger patients	exertional	ice packs only	24%
1977-1983 Louisville, KY	classic	ice packs, sheets	21%

Heatstroke : Rate of Cooling Effect on Mortality

Author	Mortality Reported
Vicario	33% if 1 hr. temp. > 38.9°
	15% if 1 hr. temp. < 38.9°
Yaqub	18% if > 1 hr. to 38.5 °
	5% if < 1 hr. to 38.5°

Heatstroke : Rapid Body Cooling Techniques

Technique	Reported Cooling Rate (C / min)
Ice water immersion	0.21 to 0.23
BCU (net / spray)	0.11 to 0.17
Iced gastric lavage	0.08 to 0.11
High freq. jet ventilation	0.06
Dantrolene treatment	0.04
Spontaneous (no treatment)	0.03 to 0.06

Khogali's Objections to Ice Water Immersion (Favoring Use of BCU)

- Peripheral vasoconstriction shunting blood from skin (? rise in core temp.)
- Induction of shivering : raises heat production
- Extreme discomfort to patient
- Difficulty performing CPR
- Difficulty monitoring VS
- "Unpleasant and unhygienic" conditions if emesis or diarrhea occur

Other Cooling Methods

- Groin, neck, axillae, or scalp ice packs
  - Limited effectiveness
- Iced peritoneal lavage
  - Only a few case reports
- Cold O2 / Cold IV fluids
  - Minimal heat exchange
- Iced enemas
  - Minimal heat exchange
- Cardiopulmonary bypass
  - Effective but time consuming to set up

Probably the best cooling method is water spray and fans with the patient on an open stretcher

Source undetermined

Heatstroke : Prognosis (Px)

- If coma < 3 to 4 hrs. : px good
- If coma > 10 hrs. : likely fatal
- SGOT < 1000 in first 24 hr. : px good
- SGOT > 1000 in first 24 hr. : likely fatal
- Temperature > 42.2 ℃ on admission : worse px but can have complete recovery

Heat Illness : Prevention

- Time exertion to avoid sunlight exposure and the hottest daytime hours (10:00 am to 3:00 pm)
- Light loose clothing permitting airflow over body surface
- Consume 400 to 500 cc fluid before exertion and 200 to 300 cc at 20 min. intervals during exertion
- Check body weight before practice : if wt. down 3 % , increase PO fluids ; if wt. down 5 %, cancel participation that day ; if wt. down 7 %, immediate fluids & consider medical attention
- Use only low osmolal fluids (< 2.5 g glucose and $\leq$ 0.2 g NaCl per 100 cc)
- Extra NaCl and potassium intake during acclimatization
- Cancel event if WBGT > 30^{o}C

Potential Problems with Salt Tablet Use

- Delayed gastric emptying
- Osmotic fluid shift into gut
- Gastric mucosal damage
- Hypernatremic dehydration
- May impair acclimatization
- May exacerbate potassium depletion

Hyperthermia : WBGT

- Wet bulb globe temperature = Heat Index
- WBGT = 0.7 X wet bulb temperature

+

0.2 X black globe temperature

+

0.1 X dry thermometer temperature

Wet-Bulb Globe Temperature (WBGT) and Recommended Activity Levels

C°	F°	Activity
15	60	No precautions
19-21	66-70	No precautions as long as H2O, salt & food easily available
22-24	71-75	Postpone sports practice, avoid hiking
24	76	Lighter practice, work only with rest breaks
27	80	No hiking or sports
28	82	Only necessary heavy exertion with caution
30	85	Cancel all exertion for unacclimatized; Avoid sun exposure even at rest
31.5	88	Limited brief activity for acclimatized, fit personnel only

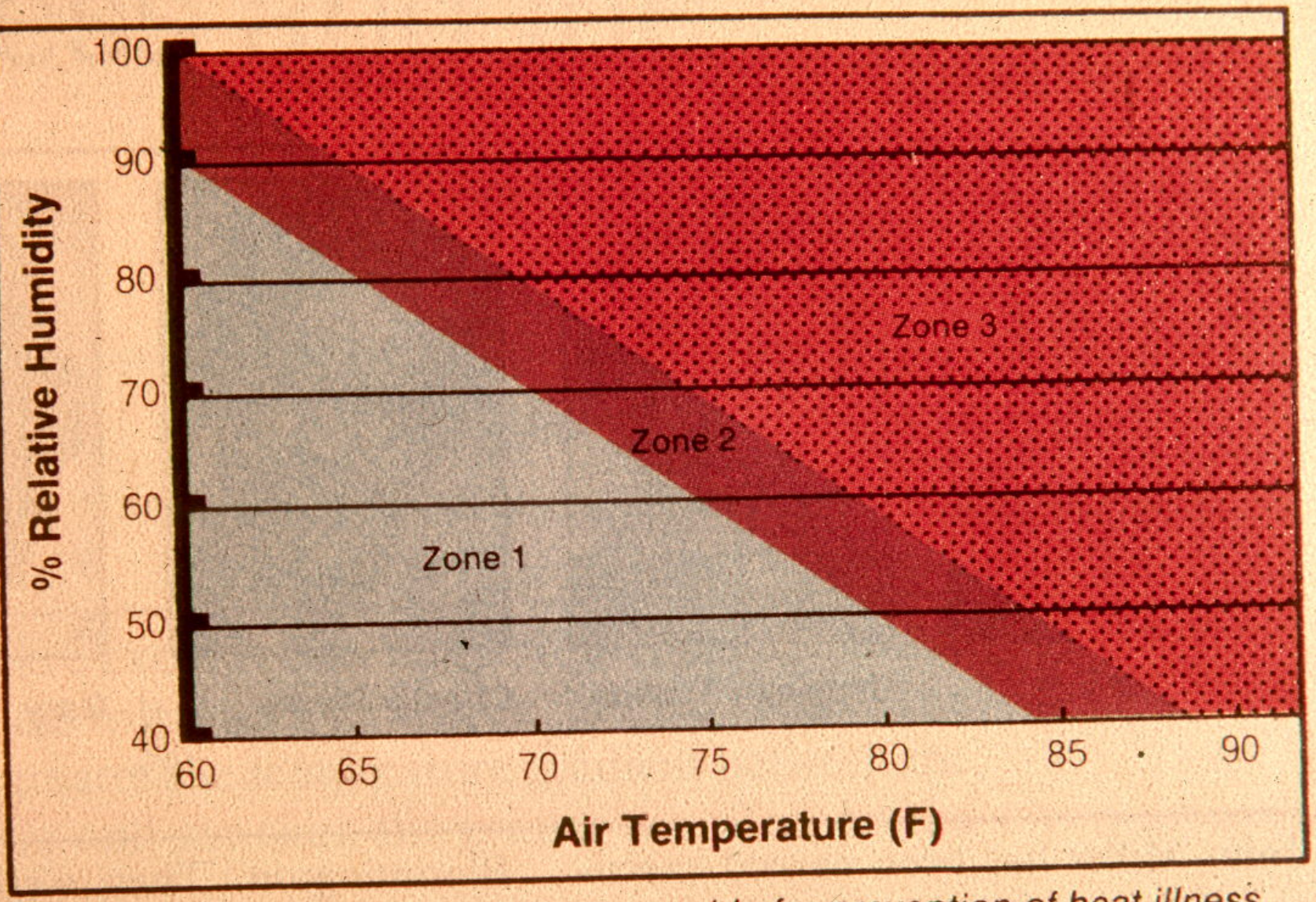


Figure 1. *Weather guide for prevention of heat illness during prolonged strenuous exercise. (Reproduced with permission from Mathews-DK, Fox EL: The Physiological Basis of Physical Education and Athletics, ed 3. New York City, CBC College Publishing, 1981.)*

Neuroleptic Malignant Syndrome (NMS)

- **Definition :**
  - –Idiosyncratic reaction to neuroleptic agents (phenothiazines, etc.) that consists of fever, mental status changes, muscle rigidity, autonomic dysfunction, respiratory distress and possible rhabdomyolysis; May cause as many as 4000 deaths / year
  - –Occurs with therapeutic doses of neuroleptics and is not related to duration of therapy
  - –Occurs with phenothiazines, butyrophenones, thioxanthines, metaclopromide (Reglan) and withdrawal from amantadine or levodopa

NMS : Symptoms / Signs

- Fever (in 100 %)
- Parkinsonism (98 %)
  - Muscle rigidity, tremor, bradykinesia, dystonia
- CNS symptoms (in 77 %)
  - Agitation, stupor, coma, seizures, ataxia, nystagmus
- Tachycardia / tachypnea
- Diaphoresis
- Increased WBC, LFT's, CPK, and catecholamines
- May have rhabdomyolysis / acute renal failure

NMS

- Occurs with therapeutic doses of neuroleptics
- Not related to duration of therapy
- Subsequent exposure does not always cause recurrence
- Most reported cases in young males

NMS : Incidence

- First described 1968
- Affects < 1 % of patients on neuroleptics
- 9 to 30 % mortality in reported cases
- ? 4000 deaths / year

NMS Symptom Complex

- I : Hyperpyrexia (may reach 41°C)
- II : Generalized Rigidity; Akinesia
- III : Altered Consciousness
  - Dazed mutism
  - Stupor
  - Coma
- IV : Autonomic Dysfunction
  - Diaphoresis
  - Dyspnea
  - Urinary incontinence
  - Labile blood pressure
  - Tachycardia

NMS : Causative Agents

- Haloperidol / fluphenazine : 1/2 of reported cases
- Chlorpromazine / other phenothiazines
- Thioxanthines
- Metaclopromide
- Withdrawal from amantadine or levodopa
- ? more severe if neuroleptic plus lithium

NMS Onset and Duration

- Usually gradual onset : over 1 to 3 days
- Lasts 1 to 2 weeks after stopping oral neuroleptics
- May last several weeks after stopping IM neuroleptic ("depot" preparations)

NMS : Treatment

- Basic Rx same as for heatstroke
  - O2, cooling, IV fluids, cardiac monitoring, ICU admission
- Stop the neuroleptic !
- Consider use of adjunctive drugs : (To restore CNS dopamine levels)
  - Bromocriptine 2.5 to 20 mg PO tid
  - or Amantadine 100 mg PO tid
  - or Levodopa 100 to 230 mg PO tid
  - or Dantrolene 1 to 10 mg / Kg / day IV or PO
- Consider ECT (for Rx of the original condition) if the neuroleptic cannot be restarted

Malignant Hyperthermia

- **Definition :**
  - **Inherited condition (autosomal dominant with variable penetrance) causing fever, acidosis and muscle ridigity in response to halogenated general anesthetics and depolarizing neuromuscular blockers (succinylcholine)**
  - **Probably due to excessive release of intracellular calcium in muscle ; Can rarely occur in predisposed patient from stress alone**

Malignant Hyperthermia : Incidence

- 1 per 200,000 patients exposed to general anesthesia
- Has occurred in response to stress with only local anesthesia
- Untreated mortality 70 %

Etiologic Drugs for Malignant Hyperthermia Syndrome

- Halogenated general anesthetics
- Succinylcholine

Malignant Hyperthermia

- Usually occurs early intraoperatively
- Can rarely present postoperatively
- Can rarely present from stress alone
- Can occur in patient who has had uneventful prior surgery & anesthesia

Malignant Hyperthermia : Patients at Risk

- Positive family history
- Family history of neuromuscular diseases
- Increased muscle bulk
- Frequent muscle cramps
- Excessive anxiety
- Twitches / fasciculations at rest
- Diagnostic muscle biopsy / contracture test available at some centers

Malignant Hyperthermia : Family History

- Always specifically ask about family history of problems with general anesthesia (and also pseudocholinesterase deficiency) prior to anesthetic administration
- If any question of malignant hyperthermia, use narcotic / benzodiazepine / N2O but not halogenated anesthetics or succinylcholine

Malignant Hyperthermia : Diagnosis

- Fever : sudden rise : often 41° C
- Tachycardia / tachypnea
- Muscle rigidity (may first note masseter spasm)
- DIC (may first note capillary bleeding in the surgical wound)
- Ventricular arrhythmias (may first note PVC's)
- Acidosis
- Hypotension
- Rhabdomyolysis / myoglobinuria

Malignant Hyperthermia : Treatment

- Discontinue the anesthetic immediately (use new tubing or new anesthesia machine)
- Ventilate with 100 % O2
- Discontinue the surgery and close the wound quickly
- Call for help
- Start external cooling : Ice packs to scalp, groin, axillae : hypothermic blanket : uncover patient
- Insert NG and foley : start iced NG lavage
- Draw blood (SMA6, CBC, LFT's, PT, PTT, CPK, Ca, ABG)
- IV fluid bolus ± bicarb ± mannitol
- Give dantrolene 1 mg / Kg IV every 3 to 5 min. (until symptoms subside or dose of 10 mg / Kg reached)

Malignant Hyperthermia : Complications

- Vascular collapse
- CNS deficits
- Renal failure
- Bleeding

Prevention of Malignant Hyperthermia

- Choose other anesthetics (local, regional, spinal, N2O + narcotics + pancuronium)
- Pretreat with 1 mg / Kg dantrolene PO q8h X 4 doses prior to surgery or 2.5 mg / Kg IV 30 min. before surgery
- Have cooling materials and adequate dantrolene in OR prior to inducing anesthesia
- 24 hour malignant hyperthermia hotline : (209) - 634-4917

The Only 2 Things of Important Relevance to Ask About in the Family History

- Malignant hyperthermia
- Pseudocholinesterase deficiency

Factors that Help Differentiate Neuroleptic Malignant Syndrome (NMS) from Malignant Hyperthermia (MH)

	NMS	MH
Precipitating factors	Neuroleptics	Inhaled anesthetics, depolarizing muscle blockers, stress of surgery
Onset	90% within 14 days; up to years	Minutes to hours
Cardinal signs	Temp. as high as 105.8°F(41°C), autonomic nervous system dysfunction	Temp. as high as 111.2°F (44°C), rigid jaw muscles
Genetic predisposition	No	Yes

Factors that Help Differentiate Neuroleptic Malignant Syndrome from Malignant Hyperthermia (cont.)

	NMS	MH
Elevated creatine kinase levels when asymptomatic	Rare	Often
Localization of thermoregulatory deficit	Hypothalamus	Muscle (sarco-plasmic reticulum)
Treatment	Supportive care, dopaminergics, dantrolene	Supportive care, dantrolene
Mortality	Up to 20 %	Up to 60 %