Review – Heat Stroke

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Definition

- Heat cramps
  - “Heat cramps" is a misnomer (not related to heat?)
  - Nearly all cases: high intensity or to exhaustion
  - Possible etiology: Dehydration, electrolytes imbalance, extreme environment, neurogenic fatigue…

- Heat syncope
  - Also, “heat syncope” is a misnomer (not direct related)
  - Also named as “exercise associated collapse”
  - Mechanism: completes endurance event → Abrupt decrease in venous return
  - Symptoms signs of light-headedness, tunnel vision, pale and sweaty skin, and decreased pulse rate

Heat exhaustion

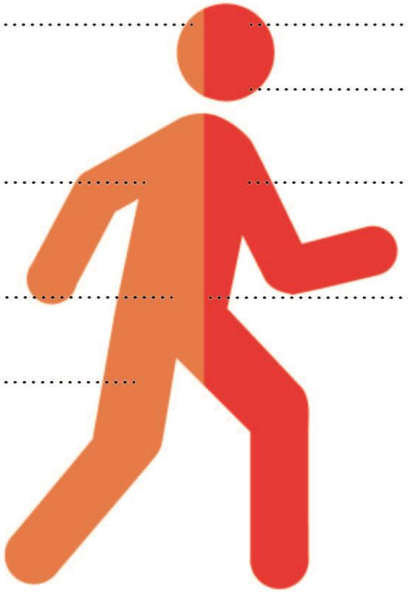
- Inability to maintain adequate cardiac output
- Clinical criteria: difficulty continuing with exercise; Core temperature 38.3-40.0 degrees; No neurological defect (or mild)

Heat stroke

- Characterized by encephalopathy and additional organs damage, association with high body temperatures
- Two main criteria: core temperature >40 degrees; CNS dysfunction
- Others including: tachycardic and hypotensive; profuse sweating, dehydration

SIGNS OF HEAT EXHAUSTION

- Mild headache, lightheadedness
- Cool, pale skin (heavy sweating)
- Nausea, vomiting
- Muscle cramps, fatigue, weakness



SIGNS OF HEAT STROKE

- Throbbing headache, confusion, seizure, irritability, or altered/loss of consciousness
- Oral body temperature of 104°F and above; dry mouth
- Hot skin
- Nausea, vomiting

Many signs of heat exhaustion can overlap with signs of heat stroke. When in doubt, call 9-1-1.

WHAT TO DO

MOVE to a cooler place
COOL with ice/cold water and lay down
DRINK cool water or sports drinks
CALL 9-1-1 if symptoms last longer than 1 hour

CALL 9-1-1 IMMEDIATELY
MOVE the affected person to the shade or cooler place
COOL the affected person with immersion in cool water or by placing ice packs on the neck and groin areas

www.health.mn.gov/heatplanning

MDH Minnesota Department *of* Health

www.health.mn.gov/heatdata

Classification

Classic heat stroke

- Elderly, comorbidities, ADL dependent patient
  - Diminished thermoregulatory capacity or difficult to response
  - Takes long disease course (1-3 days after onset of illness)
  - More likely occurred in summer or extreme weather event
- Prepubertal (esp infants)
  - High ratio of BSA, undeveloped thermal regulation system, relatively low blood volume, low sweating rate
  - Caution for a closed car!!

Exertional heat stroke

- Sporadic, direct to strenuous physical activity
- Commonly occurred on athletes, laborers, soldiers
- Over-motivation and peer-pressure (or from coaches) → driving to perform beyond physiological capacity
- May be triggered without high environment temperatures
  - Other factors plays the rules of thermal regulation

Social factors	Overmotivation, peer and coach pressure
Functional factors	Low physical fitness (physical effort unsuited to physical fitness; "killer workouts"), lack of acclimatization (habituation) to heat, low work efficiency, overweight (reduced ratio of skin area to mass and greater heat-storage capacity in fat layers), protective clothing (reduced sweating efficiency)
Acquired factors	Viral or bacterial infection (even if subclinical), dehydration, sleep deprivation, sweat-gland dysfunction (e.g., deep burns, scarred skin on >40% of total body-surface area)
Congenital factors	Chronic idiopathic or familial anhydrosis, ectodermal dysplasia
Drug abuse	Amphetamines and amphetamine-like agents (e.g., ephedra), MDMA, cocaine, PCP and LSD, synthetic stimulants of the cathinone class (e.g., α-PHP), alcohol

△ Risk factors of exertional heat stroke

Classic

- Source from external
- Induced by poor heat dissipation

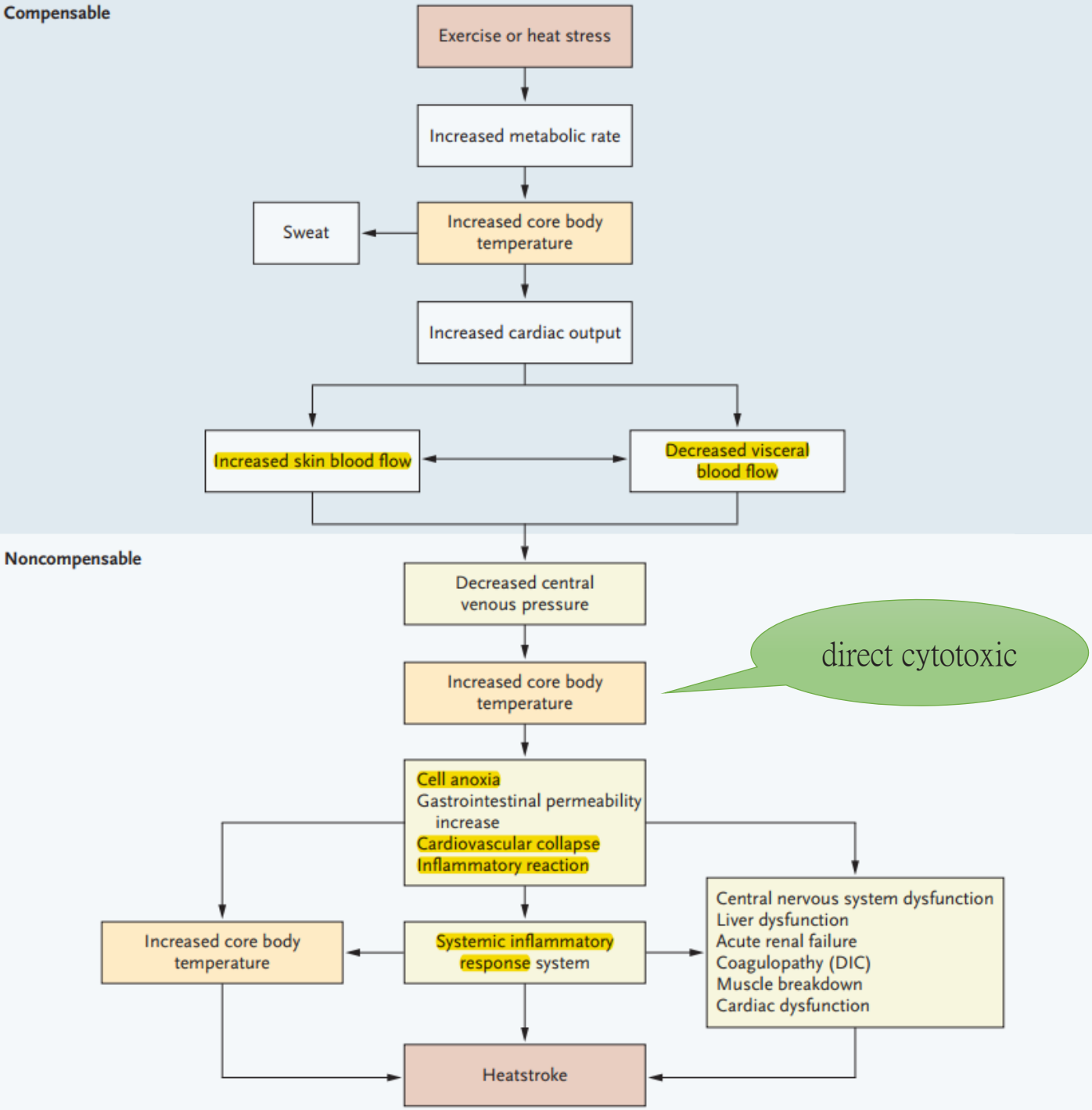
Exertional

- Source from internal
- More complications

Table 1. Epidemiologic and Clinical Features of Classic and Exertional Heatstroke.

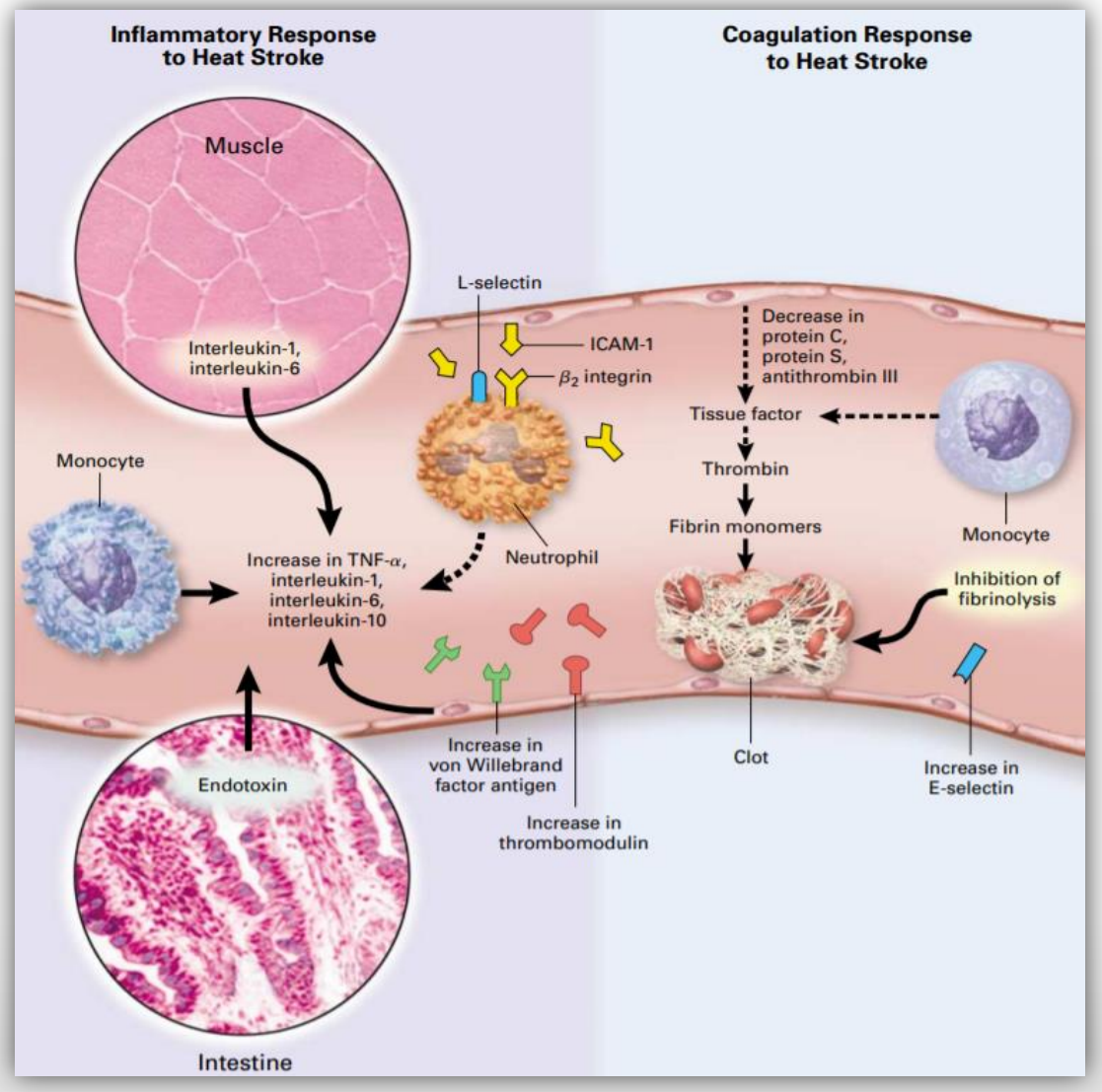
Feature*	Classic Heatstroke	Exertional Heatstroke
Age group	Prepubertal, elderly	Postpubertal and active
Occurrence	Epidemic (heat waves)	Sporadic (any time of year)
Concurrent activity	Sedentary	Strenuous
Health status	Chronically ill	Generally healthy
Medications	Often being used (prescribed medications)	Usually none being used (sometimes ergogenic aids, illicit drugs)
Mechanism	Absorption of environmental heat and poor heat dissipation	Excessive heat production, which overwhelms heat-loss mechanisms
Sweating	May be absent (dry skin)	Usually present (wet skin)
CNS dysfunction	Common	Common
Acid–base disturbance	Respiratory alkalosis	Metabolic acidosis
Rhabdomyolysis	Unusual	Frequent
Liver dysfunction	Mild	Marked to severe
Renal failure	Uncommon (<5%)	Common (25–30%)
DIC	Mild	Marked to severe
ARDS	Common	Common
Creatine kinase	Mildly elevated	Markedly elevated
Calcium	Normal	Low (hypocalcemia)
Potassium	Normal	Usually high (hyperkalemia)

Pathophysiology


Compensable
Exercise or heat stress
Increased metabolic rate
Sweat
Increased core body temperature
Increased cardiac output
Increased skin blood flow
Decreased visceral blood flow
Noncompensable
Decreased central venous pressure
Increased core body temperature
direct cytotoxic
Cell anoxia
Gastrointestinal permeability increase
Cardiovascular collapse
Inflammatory reaction
Increased core body temperature
Systemic inflammatory response system
Central nervous system dysfunction
Liver dysfunction
Acute renal failure
Coagulopathy (DIC)
Muscle breakdown
Cardiac dysfunction
Heatstroke

Inflammation and Coagulation

- Involving endothelial cells, leukocytes, and epithelial cells
- Dysregulation of inflammatory reaction (circulatory failure, hypoxemia, increased metabolic demands, direct thermal injury)
  → SIRS

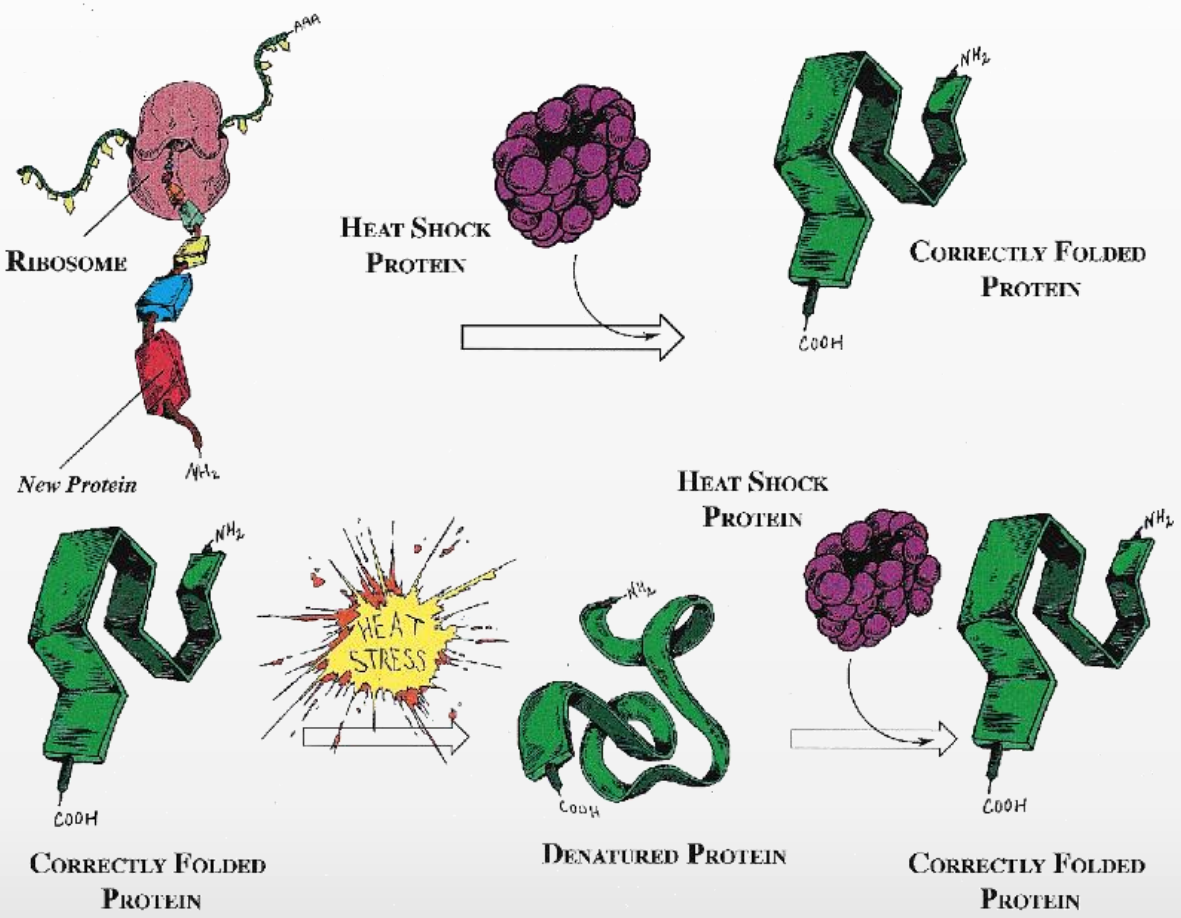


Ref: Abderrezak Bouchama, M.D., and James P. Knochel, M.D. "Heat Stroke". N Engl J Med 2002; 346:1978-1988 DOI: 10.1056/NEJMra011089

Intestine Endotoxins

- Heat stoke → decrease GI blood flow → damages cell-to-cell junctions → endotoxins and pathogens leak into systemic circulation

Direct thermal injury



Diagnosis

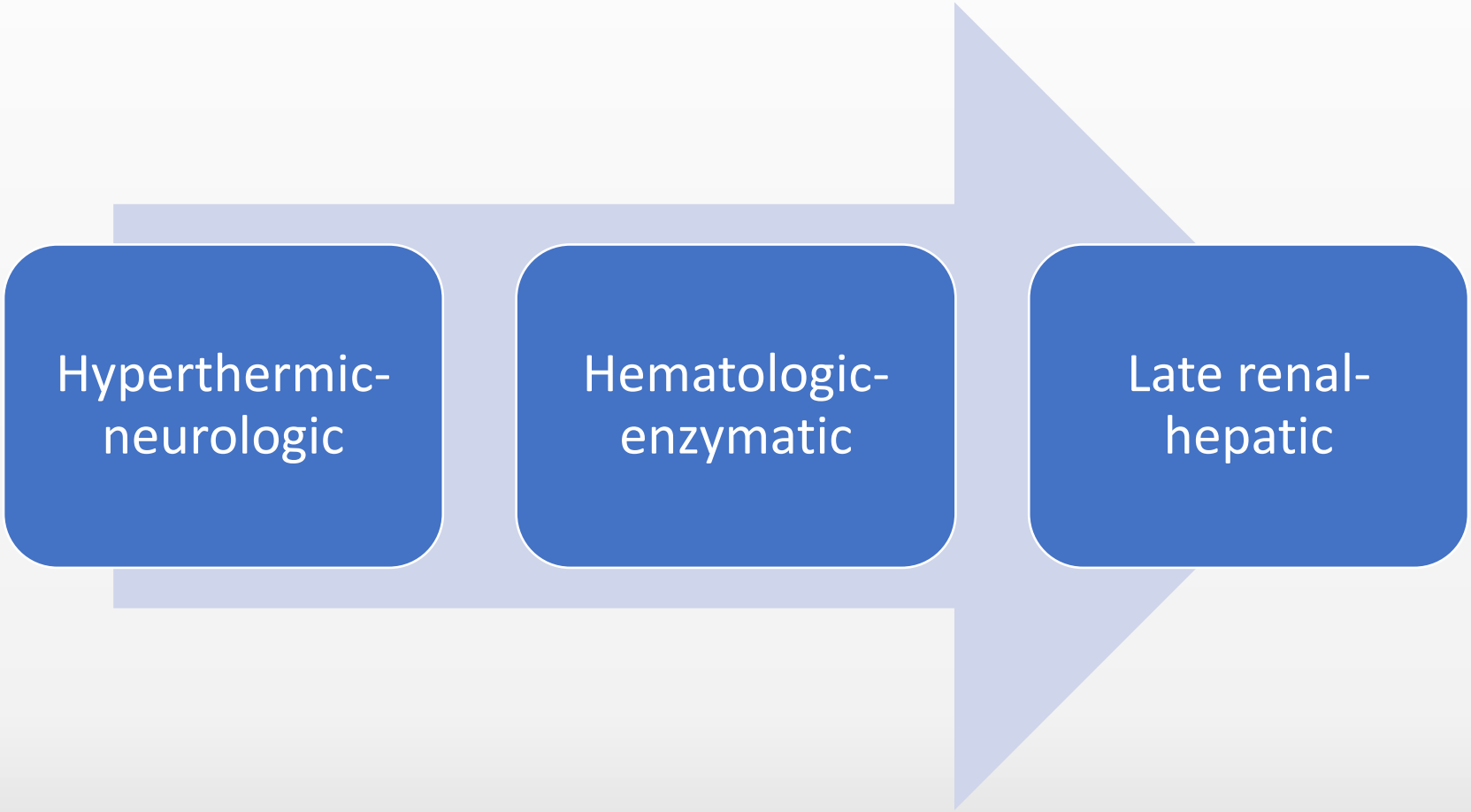
The triad

- Hyperthermia
- Neurologic abnormalities
- Exposure to hot weather (or physical exertion)

Other symptoms signs

- Profuse sweating, wet skin → exertional
- Dry skin, decrease sweating gland function → classic

Three phase


Hyperthermic-neurologic
Hematologic-enzymatic
Late renal-hepatic

Hyperthermic-Neurologic phase

- Behavioral changes, confusion, delirium, dizziness, weakness, agitation, combativeness, slurred speech, nausea, vomiting
- Seizures, brain edema, sphincter incontinence in severe cases
- Conscious regain once the BT<40.5°C

The hypothesis that damage to the preoptic anterior hypothalamus is responsible for the loss of thermoregulation has not been proved

Hematologic-enzymatic phase

- Multiorgan failure peak within 24-48hr
  - DIC
  - ARDS
  - Acute renal, cardiac, hepatic failure
  - Rhabdomyolysis (in exertional type)
- If prompt treated, may recovered without lasting effects
- Some neurologic sequelae may persisted weeks to months
- If kidney/liver failure sustained (>96hr, late renal-hepatic phase): poor prognosis

The Autopsy Findings

The end-organ damage is induced by:

- **Heat-induced** necrotic and apoptotic cell death
- Widespread micro-thrombosis, hemorrhage, and inflammatory injury

Biomarkers

(these biomarkers are experimental and have not been clinically tested or approved)

- HMGB1
- Neutrophil gelatinase–associated lipocalin
- Troponin I
- Ratio of urine heat shock protein 72 to urine Cr
- Histone
- Cryptdin 2 peptide

Treatment

Core temperature control

- Critical threshold: 40.5˚C
- Target core BT: 38-38.5 ˚C
- Need rapid and effective cooling method

	Exertional	Classic
Cooling method	• Immersion in cold water (0.2-0.35 ˚C/min) • Evaporating: Water on body and fanning (0.1 ˚C/min)	Recommend multi-type • Immersion • Infusion • Ice packs • Evaporating

Pharmacology treatment

- No pharmacologic agents accelerate cooling
- Antipyretics (Acetaminophen, aspirin, NSAIDs..) are not necessary, and may caused renal/kidney burden
- Dantrolene currently no evidence for heat stroke

Deal with organ damage

Table 3. Guidelines for the Treatment of Heatstroke.*

Treatment	Comments
Treatment on site	
CPR	Perform according to ACLS protocol; administer oxygen at 4 liters/min to increase oxygen saturation to >90%
Core body temperature	Monitor rectal temperature and perform cooling in cases of hyperthermia; for exertional heatstroke, cold-water immersion; for classic heatstroke, conductive or evaporative cooling
Fluids	Administer isotonic saline IV (1–2 liters/hr); dehydration is not a major issue
Seizure medication	Administer benzodiazepines IV (5 mg) until seizures cease (not more than 20 mg)
Evacuation	For classic heatstroke, transport immediately to ED; for exertional heatstroke, transport to ED after cooling to body temperature <39.0°C
Treatment in the ED	
Core body temperature	Monitor rectal or intravesical temperature and perform cooling until core temperature <38.0°C; use either a cooling suit or cold fluids (4°C, 1000 ml/30 min) infused through central catheter; antipyretics are toxic and should be avoided; dantrolene has not been proved to be effective
Seizure medication	Administer benzodiazepines IV (5 mg, repeated) or phenytoin IV (loading dose, 15–20 mg/kg in 15 min) until seizures cease
Laboratory testing	Perform CBC, urinalysis, blood cultures, kidney-function and liver-function tests (ALT, AST, ammonia, INR); test for glucose, electrolytes, arterial blood gases and acid–base balance, clotting function, CK, LDH, myoglobin, CRP
Monitoring of circulation	For circulatory failure, administer fluids (30 ml/kg), monitor CVP or perform invasive hemodynamic monitoring, maintain mean arterial pressure at >65 mm Hg (or >75 mm Hg if patient is elderly or has hypertension), all with a goal of normal lactate level and urine output >50 ml/kg/hr; vasopressors should be considered if fluid therapy fails

Treatment in the ICU	
General	Perform CPR according to ACLS protocol; ECMO may be used as needed Monitor rectal, intravesical, or blood temperature; continue cooling to maintain core temperature at <38.0°C by infusing cold fluids (4°C, 1000 ml/30 min) through central catheter or use extracorporeal blood cooling for resistant hyperthermia; antipyretics are toxic and should be avoided; dantrolene has not been proved to be effective Perform laboratory tests: CBC, glucose, arterial blood gases and acid–base balance, clotting function, CK, LDH, liver function (ALT, AST, ammonia, INR), myoglobin, kidney function, urinalysis, CRP, blood cultures; repeat every 12 hr during the first 48 hr, then every 24 hr
Heart failure	Perform CPR according to ACLS protocol; perform invasive hemodynamic monitoring and echocardiography; for mild multiorgan failure, administer dobutamine IV (1 μg/kg/min, then 2–20 μg/kg/min as needed) or milrinone IV (loading dose, 50 μg/kg in 10 min, then 0.2–0.75 μg/kg/min) or adrenaline IV (1 μg/min); for severe multiorgan failure, ECMO may be used as needed
Acute kidney injury	Administer crystalloid solution to maintain urine output >50 ml/kg/hr; administer furosemide IV (10–20 mg in patients without previous exposure to diuretics; follow-up dose depends on urine output); provide hemodialysis or CVVH in cases of volume overload, severe acidosis, hyperkalemia, or uremia; adjust fluid infusion rate according to blood pressure and urine output; monitor electrolytes and correct as needed
Encephalopathy and brain edema	For a score of <8 on the GCS,† intubate and ventilate; for mild hyperventilation (Pco_2, 34–36 mm Hg) administer hypertonic saline 3% IV (starting dose, 100 ml/30 min, then according to patient's total body water to reach sodium level increase of 12 mmol/day) or mannitol 20% IV (0.25–2 g/kg in 30 min); keep head at 45-degree angle, administer tranquilizers; patients with hyperammonemia require hemofiltration or MARS therapy; condition improves with cooling; consider monitoring ICP
Rhabdomyolysis	Administer IV fluid infusion, 1–2 liters/hr (aggressive fluid treatment in the first hour), then 300 ml/hr; furosemide IV (10–20 mg in patients without previous diuretic treatment; follow-up dose depends on urine output) in case of fluid overload; sodium bicarbonate, 30 mmol/hr (to achieve urine pH >6.5); myoglobinuria is expected; hypercalcemia and metabolic alkalosis (pH >7.5) should be avoided
DIC and other coagulation abnormalities	For bleeding and thrombosis, administer fresh-frozen plasma (bolus dose, 10–15 ml/kg, then 200–400 ml according to coagulation indexes); administer cryoprecipitate (5–10 U each time) for fibrinogen level of <180 mg/dl; administer platelet concentrates (infusion of one therapeutic dose) if platelet count <20 per mm^3 or if there is bleeding and platelet count <50 per mm^3; in patients with hepatic failure, consider PCC to achieve a target INR ≤1.5; inject PCC dose according to INR and patient's weight; avoid heparin; beware of hypothermia and metabolic acidosis
ARDS	Perform intubation and mechanical ventilation; avoid fluid overload
Liver failure	Monitor liver function and mental status for at least 4 days; provide supportive treatment: hemodynamic stability, *N*-acetylcysteine IV (bolus dose, 150 mg/kg in 200 ml of 5% glucose solution for 20 min, then 50 mg/kg in 500 ml of 5% glucose solution for 4 hr, then 100 mg/kg in 1000 ml of 5% glucose solution for 16 hr); administer hypertonic saline 3% IV or mannitol IV (0.25–2 g/kg in 30 min in 20% solution), hemofiltration, laxatives (e.g., oral lactulose, 30 ml every 2 hr until diarrhea occurs), oral rifaximin (400 mg 3 times a day) in case of fulminant liver failure; liver transplantation rarely needed, and there is no evidence that it is effective
ECG changes	Monitor continuously for possible arrhythmias; ECG changes are nonspecific

Novel way for MODS

(these medications are not been widely use clinically)

- Xanthine oxidase inhibitor (allopurinol)
  - reduce portal lipopolysaccharide levels by protecting cell-to-cell junctions
- Recombinant activated protein C
  - improve inflammation and the dysfunctional coagulation cascade
- Type III antithrombin concentrate
- Recombinant soluble thrombomodulin-α
  - treat DIC
- Serine proteases
  - suppress pancreatic enzyme activity, reducing systemic inflammatory markers

Prevention and Acclimatization

Prevention

Classic	Exertional
• Stay in A/C homes • Using fans • Take cool shower • Decrease exertion • **Increasing social contact**	• **Acclimatization** • Matching exertion with physical fitness • Avoiding hot times training schedule • Vapor barrier clothing • Hydration • Setting rest period • Caution for early signs

高溫停止體能鑑測挨批　國防部：國軍不是草莓兵

記者林銘翰／台北報導

國防部11日上午召開記者會，針對「國軍熱傷害防治作為」進行說明，不過日前陸軍總司令陳寶餘曾因氣溫過高下令停止體能鑑測，事後遭網友批評是「草莓司令」，國軍甚至遭酸是「草莓兵」，國防部發言人陳中吉11日表示「外界說國軍

HEAT ACCLIMATIZATION GUIDE 2003

RANGER & AIRBORNE SCHOOL STUDENTS

HEAT ACCLIMATIZATION GUIDE

- Should you be concerned about hot weather?
- What is heat acclimatization?
- How do you become heat acclimatized?
- How fast can you become heat acclimatized?
- What are the best heat acclimatization strategies?

Benefits of Acclimatization

Table 1. Benefits of Heat Acclimatization	
Thermal Comfort – Improved	Exercise Performance – Improved
Core Temperature – Reduced Sweating – Earlier & Greater Skin Blood Flow - Earlier Body Heat Production – Lower	Heart Rate - Lowered Thirst - Improved Salt Losses (sweat and urine) – Reduced Organ Protection - Improved

Duration and Schedule

- About 1-2 weeks

US CDC	US Army
• New worker, **add 20% exposure for each day** • Workers who have had previous experience, started with **50% exposure on D1** **60% on D2** **80% on D3** **100% on D4**	• 60% physiologic adaptations complete by the end of 1st week; **80% at the end of 2nd week** • **Minimum daily heat exposure >2hr** + cardiovascular endurance exercise (not strength training) • Gradually increase intensity or duration

Maintaining Acclimatization

US CDC	US Army
• Workers can maintain acclimatization even away from the job for a few days • Absent for **a week** may be a significant loss of acclimatization	• Acclimatization will be **retained for ~1 week**, then **75% lost within 3 weeks** • A day or two of intervening cool weather will not interfere with acclimatization

Table 2. Heat acclimatization suggestions for soldiers going to Ranger, Airborne and other Elite Schools.

Strategy	Suggestions for Implementation
Start early	1. Start at least 1 month prior to School 2. Be flexible and patient: performance benefits take longer than the physiological benefits
Mimic the training environment climate	1. In warm climates, acclimatize in the heat of day. 2. In temperate climates workout in a warm room wearing sweats.
Ensure adequate heat stress	1. Induce sweating. 2. Work up to 100 minutes of continuous physical exercise in the heat. Be patient. The first few days, you may not be able to go 100 minutes without resting. 3. Once you can comfortably exercise for 100 minutes in the heat, then continue for at least 7-14 days with added exercise intensity (loads, or training runs).

U.S.ARMY

Teach yourself to drink and eat	1. Your thirst mechanism will improve as you become heat acclimatized, but you will still under-drink if relying on thirst sensation. 2. Heat acclimatization will increase your water requirements. 3. Dehydration will negate most benefits of physical fitness and heat acclimatization. 4. You will sweat out more electrolytes when not acclimatized, so add salt to your food, or drink electrolyte solutions during the first week of heat acclimatization. 5. A convenient way to learn how much water your body needs to replace is to weigh yourself before and after the 100 minutes of exercise in the heat. For each pound lost, you should drink about one-half quart of fluid. 6. Do not skip meals, as this is when your body replaces most of its water and salt losses.

Thanks for listening

Yoram Epstein, Ran Yanovich (2019). Heatstroke. N Engl J Med 380;25: 2449-2459

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