Submersion Injuries and Drowning

June 2021

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Objectives

- Define important terminology
- Discuss incidence and epidemiology
- Highlight risk factors
- Talk about prevention and survival interventions
- "Immerse" ourselves in some pathophysiology
- Work through pre-hospital management techniques
- Close on prognosticator and predicting outcomes

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DO NOT PROCEED!...

…Without first making two very important concessions:

First: There is a lot of water out there.

Second: Humans are not granted with the natural ability to breath underwater.

GOT IT? GOOD!

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Terminology

- What drowning is…
  - "The process of experiencing respiratory impairment from submersion/immersion in liquid"
  - Drowning outcomes are classified by: drowning death, drowning with morbidity, and drowning without morbidity
  - Now considered a process and not an outcome

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Terminology

Other water-related conditions that do not primarily involve the airway and respiratory system are submersion injuries, rather than drowning.

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Terminology

- Outdated terms:
  - Wet drowning, dry drowning, active drowning, passive drowning, silent drowning, near-drowning, and secondary drowning
  - Still widely used, so familiarize yourselves, but please, do not use
- Outdated classification systems:
  - Drowning vs. Near-drowning
    - Near-drowning = nonfatal drowning
  - Wet drowning vs. Dry drowning
    - Physiologic mechanism holds no prognostic or treatment significance

Incidence and Epidemiology

- 372,000 people drowned worldwide and 4,308 in the United States in 2012
- 7% of all injury-related deaths
- True incidence of drowning underestimated due to underreporting
- Drowning occurs overwhelmingly in low- and middle-income countries

Incidence and Epidemiology

- Boating-related incidents accounted for additional deaths (sound important?)
- Drowning is the leading cause of death by unintentional injury between the ages of 1 and 4 years, ranks second among children between the ages of 5 and 9, and is the sixth leading cause of injury death between the ages of 15 and 24
- 1 pediatric drowning:4 pediatric nonfatal drownings

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Risk Factors

- Age: toddlers, teenage boys
- Location: home swimming pools, bathtubs, buckets
- Gender: males > females; 3:1
- Race: black children are at highest risk
- Drugs: alcohol
- Trauma: secondary to diving, falls
- Personal: lack of ability to swim, lower level of physical fitness, pre-existing medical conditions

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Prevention

1-4 Years Old	4-15 Years Old	15-65 Years Old	Older than 65
Parents within arms reach	Direct parental supervision	Never swim alone	Never swim alone
Discuss swim lessons with Pediatrician	Swimming instruction	CPR certification	Regular doctor visits
Empty all water containers	Buddy system in pool	Boating safety courses	Medication awareness
Four-sided pool fencing	Comprehension of depth	Drug and alcohol avoidance	
CPR instruction for parents	Recognize drowning risks	Recognize dangerous ocean currents	
Flotation devices			

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Prevention: Pre-Immersion

- Children of all ages should wear PFDs (personal flotation devices)
- Four-sided pool fencing, self-locking gate (5 feet tall), water-level filled close to external ground level (in-ground pools)
- Supervision and lifeguards
- Special training for out-of-hospital personnel

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Prevention: Pre-Immersion

- Swimming lessons and Boating instruction
- All individuals involved in water sports should be familiar with PFDs and other sport-specific safety devices
- Additional equipment: wetsuits, drysuits, thermal protection, survival suits, whistles, locator beacons, etc.
- Education about and adherence to policies for alcohol and drug use

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Prevention: Post-Immersion

- Preparation is key!
- "Reach, throw, row, go."
- Never physically engage an actively drowning victim
  - Wear a PFD
  - Carry a PFD
  - Stop a safe distance from the victim
  - Throw or push the PFD to the victim
  - Engage victim after panic subsides
- HELP position/Huddle technique

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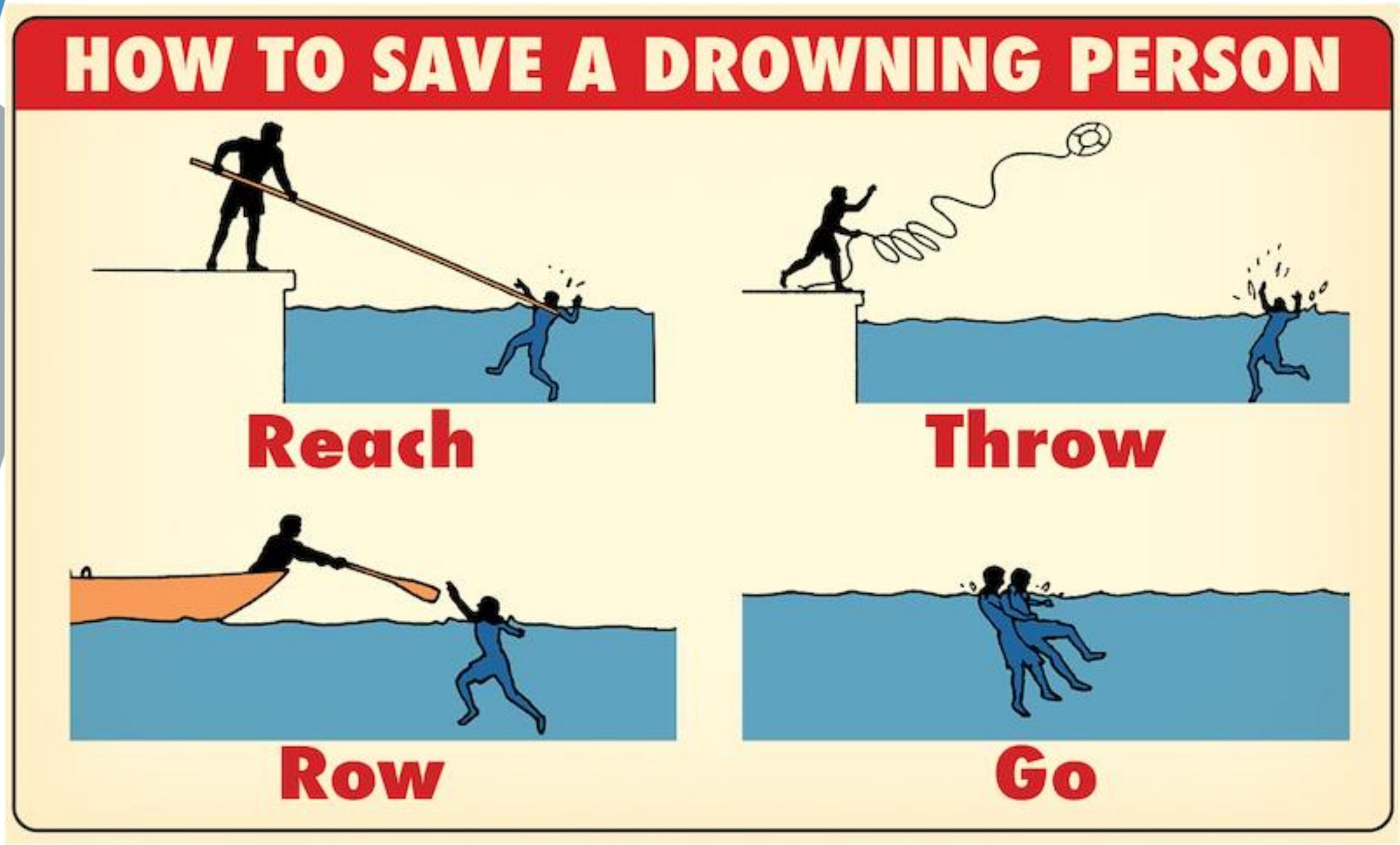
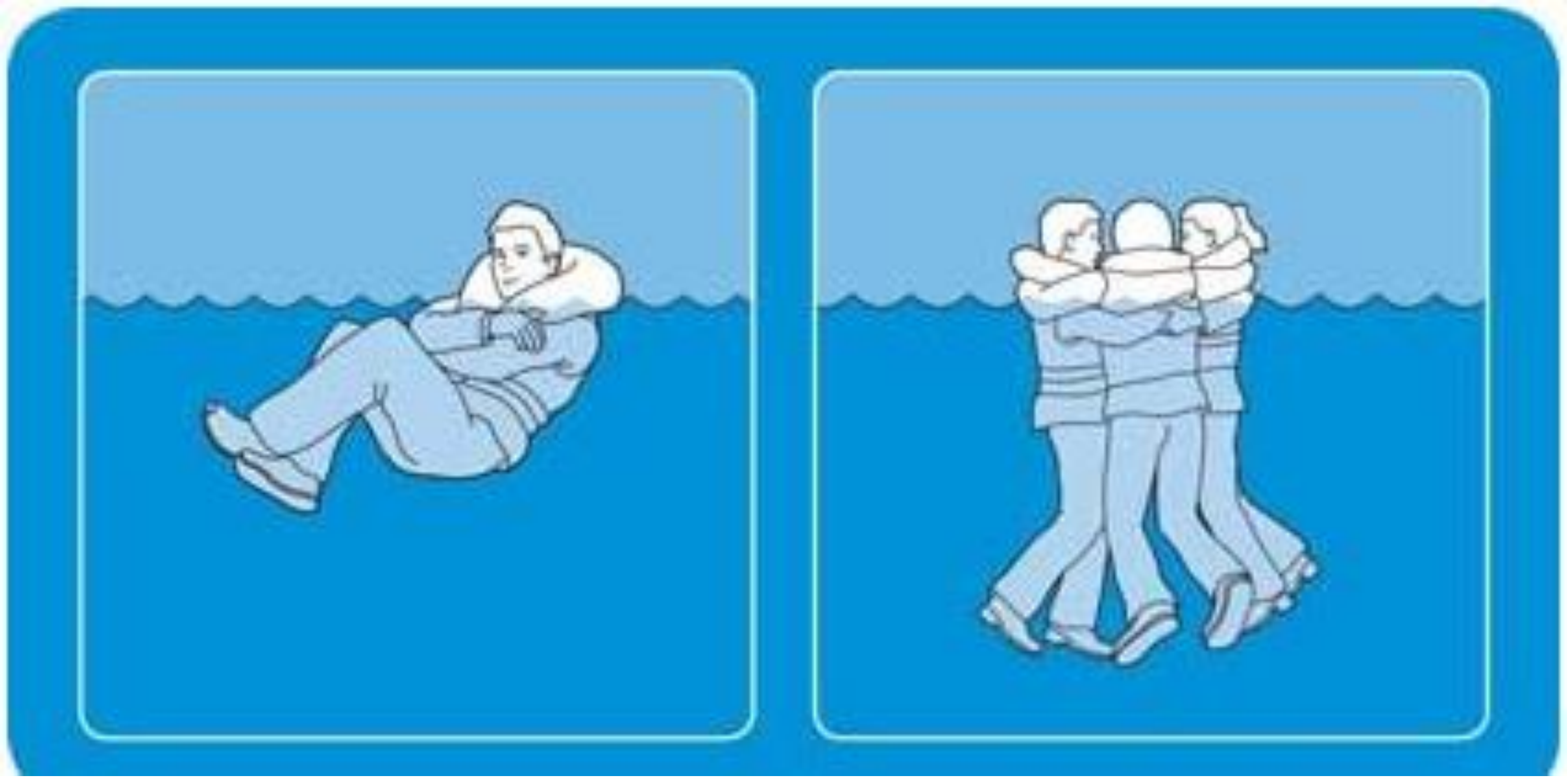
Prevention: Post-Immersion



Prevention: Post-Immersion



Pathophysiology

- Thermoneutrality
- Immersion vs. Submersion
- Immersion
  - Hot-water immersion
  - Cold-water immersion
    - Cold shock
    - Superficial tissue cooling
    - Deep tissue cooling: Hypothermia

Pathophysiology

- Submersion
  - Sympathetic activation, fear of drowning
  - Breath-holding
  - Diving response
  - Autonomic conflict
  - Upper airway reflexes
  - Aspiration of water
  - Swallowing of water
  - Emesis
  - Electrolyte disorders
  - Neurophysiology

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Pathophysiology - Thermoneutrality

- “Thermoneutral” is the term for the water temperature at which heat loss equals heat production

- Most drowning events occur at water temperatures below the point of thermoneutrality, which is 35C +/- 0.5 (86F to 95.9F)

Pathophysiology – Immersion vs. Submersion

Immersion = Airway is above the surface of the liquid

Submersion = Airway is below the surface of the liquid

Pathophysiology - Immersion

- Hot-Water Immersion (HWI)
  - Hot-water tubs, pouring hot water over the head, or during diving or competitive swimming in warm water
  - Thermoregulation during HWI vs. hot ambient air
    - Evaporation
    - Sweating

Pathophysiology - Immersion

- Hot-Water Immersion
  - Increased heart rate
  - Thrombosis
  - Orthostatic hypotension
  - Seizures
  - Hyperthermia

Pathophysiology - Immersion

- Cold-Water Immersion (CWI)
  - Cold Shock
    - Overcomes the intention to breath-hold
    - Starts in water approximately 25C (77F)
    - Peaks in the first 30 seconds and attenuates during the next 2-3 minutes
    - Maximum breath-hold time generally is 60-90 seconds at a comfortable air temperature and is reduced to just a few seconds in water colder than approximately 15C (59F)

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Pathophysiology - Immersion

- Cold-Water Immersion
  - Cold Shock
    - Gasping
    - Hyperventilation
    - Increased cardiac output
    - Peripheral vasoconstriction
    - Hypertension
    - Increased metabolic rate
    - Aspirations
    - Arrhythmias
    - Drowning

Pathophysiology - Immersion

- Cold-Water Immersion
  - Superficial Tissue Cooling
    - Skin, superficial nerves, then muscles
    - Muscle fatigue at temperatures below 25C (77F) due to impairment of superficial fibers, leaving a smaller number of fibers to produce the same force

Pathophysiology - Immersion

- Cold-Water Immersion
  - Superficial Tissue Cooling
    - 4-6% reduction in muscle performance for every 1C fall in muscle temperature down to 30C (86F)
    - Peripheral paralysis at nerve temperatures around 5-15C for 1-15 minutes

Pathophysiology - Immersion

- Cold-Water Immersion
  - Deep Tissue Cooling: Hypothermia
    - 36C (96.8F) – Shivering
    - 35C (95F) – Confusion, Disorientation
    - 34C (93.2) – Amnesia
    - 33C (91.4) – Cardiac arrhythmias
    - 30-33C (86-91.4F) – Clouding of consciousness
    - 30C (86F) – Loss of Consciousness
    - 28C (82.4F) – V-fib
    - 25C (77F) – Death

Pathophysiology - Immersion

- Cold-Water Immersion
  - Deep Tissue Cooling: Hypothermia
    - Risk factors include: water temperature, water movement, surface area-to-mass area, age, body stature, body morphology, gender, fitness, fatigue, nutritional state, intoxication, lack of appropriate/specialized clothing

Pathophysiology - Immersion

- Cold-Water Immersion
  - Deep Tissue Cooling: Hypothermia
    - The variation in rates at which people cool in water below thermoneutral temperatures, and the poor association between the signs and symptoms of hypothermia and actual deep body temperature, make the determination of time of useful consciousness and survival time “more of an art than a science.”
    - In the field, measurement of the degree of hypothermia in an immersion victim is difficult.

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Pathophysiology - Submersion

- Sympathetic Activation, Fear of Drowning
  - Reported in gray literature and social media
  - Paralysis and/or loss of muscle strength due to hyperarousal of the sympathetic activation during panic in the water
  - Leads to a combination of physical and psychological stressors that potentiate cold shock, disable swimming ability, or at least create the feeling that swimming ability is seriously decreased

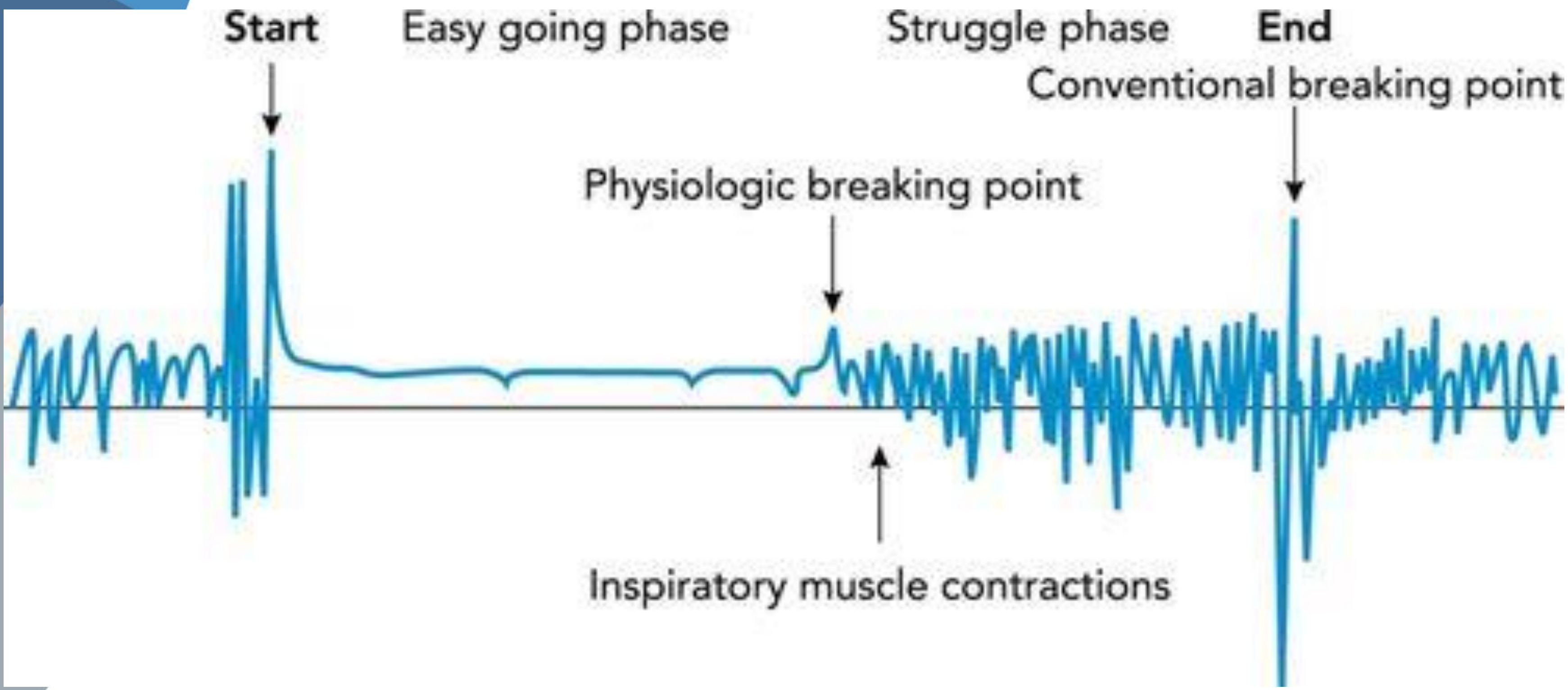
Pathophysiology - Submersion

- Sympathetic Activation, Fear of Drowning
  - Mass start of swimming
  - Change to open water
  - Cold water, rip currents, unexpected underwater objects, losing visual contact with the bottom, observation of marine life, entanglement, entrapment, or equipment malfunction
  - Concern about sudden onset of previously diagnosed and treated minor physical problems

Pathophysiology - Submersion

- Breath-Holding
  - “Easy going phase”
  - “Struggle phase”
  - Respiratory movement can extend breath-hold time
  - Swallowing can extend breath-hold time
  - The variation between individuals in maximum breath-hold time is large

Pathophysiology - Submersion



Pathophysiology - Submersion

- Breath-Holding
  - Factors influencing breath-holding in air
    - Metabolic rate
    - Pre-breathing with hyperoxic or hypoxic gas mixtures
    - Carbon dioxide and oxygen storage capacity
    - Prior hyperventilation
    - Experience and physiological tolerance of unpleasant sensations arising during breath-holding

Pathophysiology - Submersion

- Breath-Holding
  - Additional physiologic factors that decrease breath-holding duration in water
    - Alcohol intoxication
    - Water temperature below 15C (59F)
    - Cold shock response

Pathophysiology - Submersion

- Diving Response
  - Aides in overall conservation of oxygen during apneic diving or cold water exposure to the face
  - Autonomic = Automatic
  - Better developed and faster onset in children than adults
  - Can be activated by apnea alone or by facial immersion alone, but their combination enhances the response
  - Most important is the presence of cold water and a large ambient air-to-water temperature gradient

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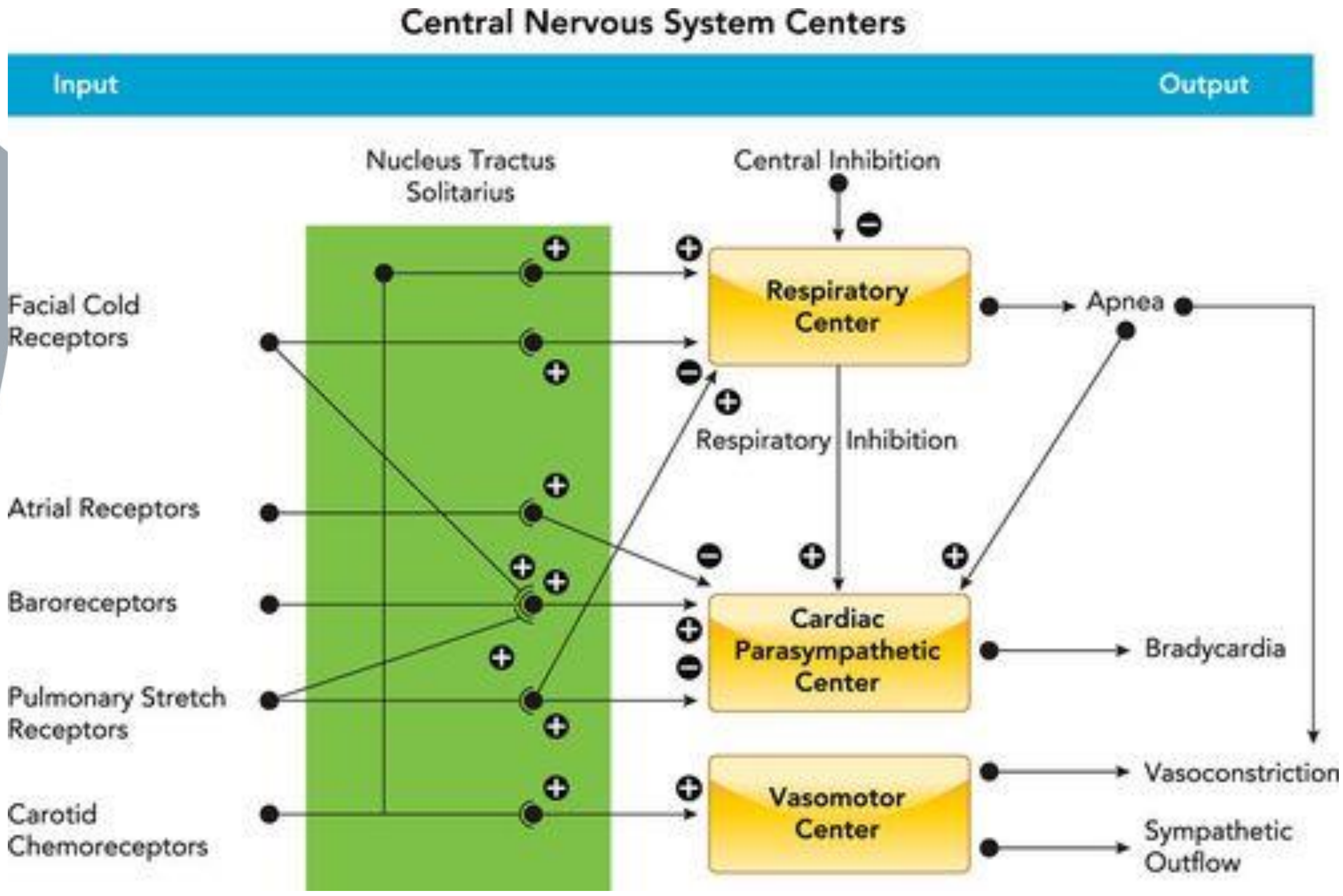
Pathophysiology - Submersion

- Diving Response
  - Simultaneous activation of sympathetic and parasympathetic responses, leading to apnea, peripheral vasoconstriction, hypertension, and bradycardia

Pathophysiology - Submersion

- Diving response
  - Decreases metabolism, which leads to a decrease in oxygen consumption and a slower desaturation during apnea
  - Vasoconstriction and hypertension lead to shunting of blood from the peripheral vasculature, increased carotid artery blood flow, and vasodilation of the brain leading to better cerebral perfusion
  - Bradycardia adds to the oxygen-saving effects through decreased myocardial oxygen consumption

Pathophysiology - Submersion



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Pathophysiology - Submersion

- Diving Response
  - Factors that increase the effects
    - Pre-cooling of the face
    - Contact of cold material with the face
    - Large air/water temperature gradient
    - Increased hypoxia
    - Prolonged or deeper submersion
    - Posture in the water
    - Smaller vital capacity lung volume
    - Previous breath-holding dive experience
    - A series of repeated apnea divers or apnea exercises
    - Physical fitness

Pathophysiology - Submersion

- Autonomic Conflict
  - Interplay between sympathetic (positive) and parasympathetic (negative) signals to the heart
  - Causes arrhythmias
  - Usually observed within 10 seconds of breath-holding
  - Incidence of arrhythmia increases if breath-holding is accompanied by cold water submersion
  - Arrhythmias are predominantly supraventricular and junctional, but can be fatal with pre-existing heart conditions

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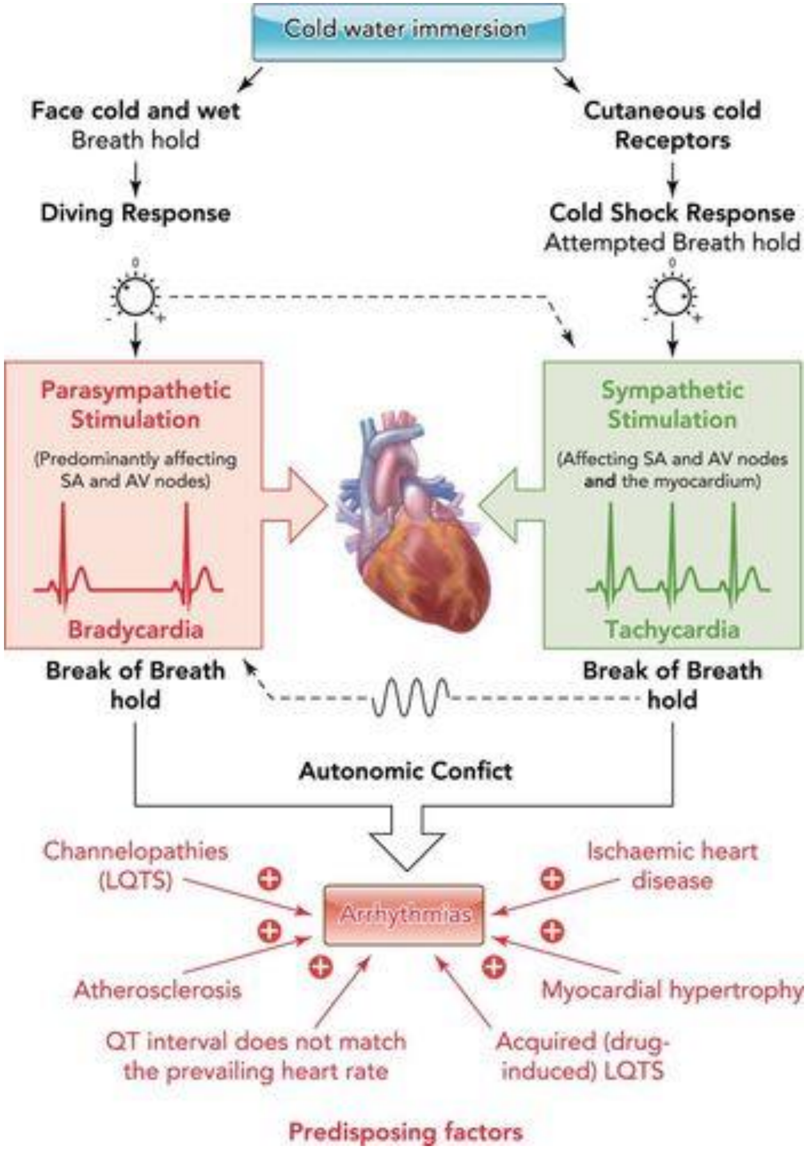
Pathophysiology - Submersion



Pathophysiology - Submersion

- Upper Airway Reflexes
  - Laryngospasm is an antiquated explanation for “dry-drowning”
  - If a laryngospasm initially occurred as a protective reflex, it will cease to operate as a result of progressive hypoxia of the laryngeal muscles while underwater breathing efforts are sustained
  - Penetration of liquid into the lungs occurs in almost all drowning deaths
  - Forceful ventilatory efforts against a closed glottis may cause damage

Pathophysiology - Submersion

- Upper airway reflexes
  - Mimicker of liquid aspiration
    - Pulmonary edema
      - Hyperbaric stress
      - Extreme negative intrathoracic pressure
  - Anatomic coordination exists between the larynx muscles, respiratory reflexes, and cough control through the same internal branches of the superior laryngeal nerve
  - Still poorly studied

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Pathophysiology - Submersion

- Aspiration of Water
  - Both hypertonic and hypotonic aspirated liquids cause changes to the pulmonary surfactant and to the alveolocapillary barrier that result in systemic hypoxemia
  - Hypertonic vs. Hypotonic liquid effects

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Pathophysiology - Submersion

- Aspiration of Water
  - Hypotonic liquid (Fresh water)
    - Damages and dilutes pulmonary surfactant
    - Increase in alveolar surface tension and decrease in pulmonary compliance
    - Alveolar atelectasis and instability
    - Alerted ventilation-to-perfusion ratio
    - Venous shunting
    - Damage to alveolar-capillary membrane
    - Adult Respiratory Distress Syndrome-like picture
    - Absorbed into the pulmonary circulation and distributed throughout the body

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Pathophysiology - Submersion

- Aspiration of Water
  - Hypertonic liquid (Seawater)
    - Draws liquid from the plasma into the alveoli and also causes damage to surfactant
    - Damage to alveolar capillary membrane
    - Adult Respiratory Distress Syndrome-like picture

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Pathophysiology - Submersion

- Swallowing of Water
  - Aspiration of gastric contents
  - Life-threatening electrolyte disorders
  - Usually occurs during partial head-out immersion or during breath-holding
  - Uncontrolled, premature entry of liquid leads to disruption of normal physiologic processes, which coordinate breathing and swallowing, and precipitate aspiration
  - Data is lacking

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Pathophysiology - Submersion

- Emesis
    - Data is lacking

Pathophysiology - Submersion

- Electrolyte Disorders
  - In most environments, drowning is not associated with clinically important electrolyte changes
  - Liquid redistribution within the body rapidly restores electrolyte balance
  - Hypo- and hypertonic liquid cause a ventilation/perfusion shift, hypoxemia, and metabolic acidosis, which, in turn, cause myocardial depression, pulmonary vasoconstriction, and changes in capillary permeability
  - The final common pathway is hypoxemia

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Pathophysiology - Submersion

- Neurophysiology
  - Poorly understood
  - Most likely an interaction between hypoxemia, submersion liquid temperature, aspiration, and cold shock
  - Progressive cerebral hypoxia (Asphyxial cardiac arrest) may be more detrimental than abrupt cessation of oxygenated cerebral blood flow (Cardiogenic VF arrest)
  - Conscious suppression of hyperventilation in cold water may be beneficial in prolonging duration to LOC so as to aid in brain cooling before submersion

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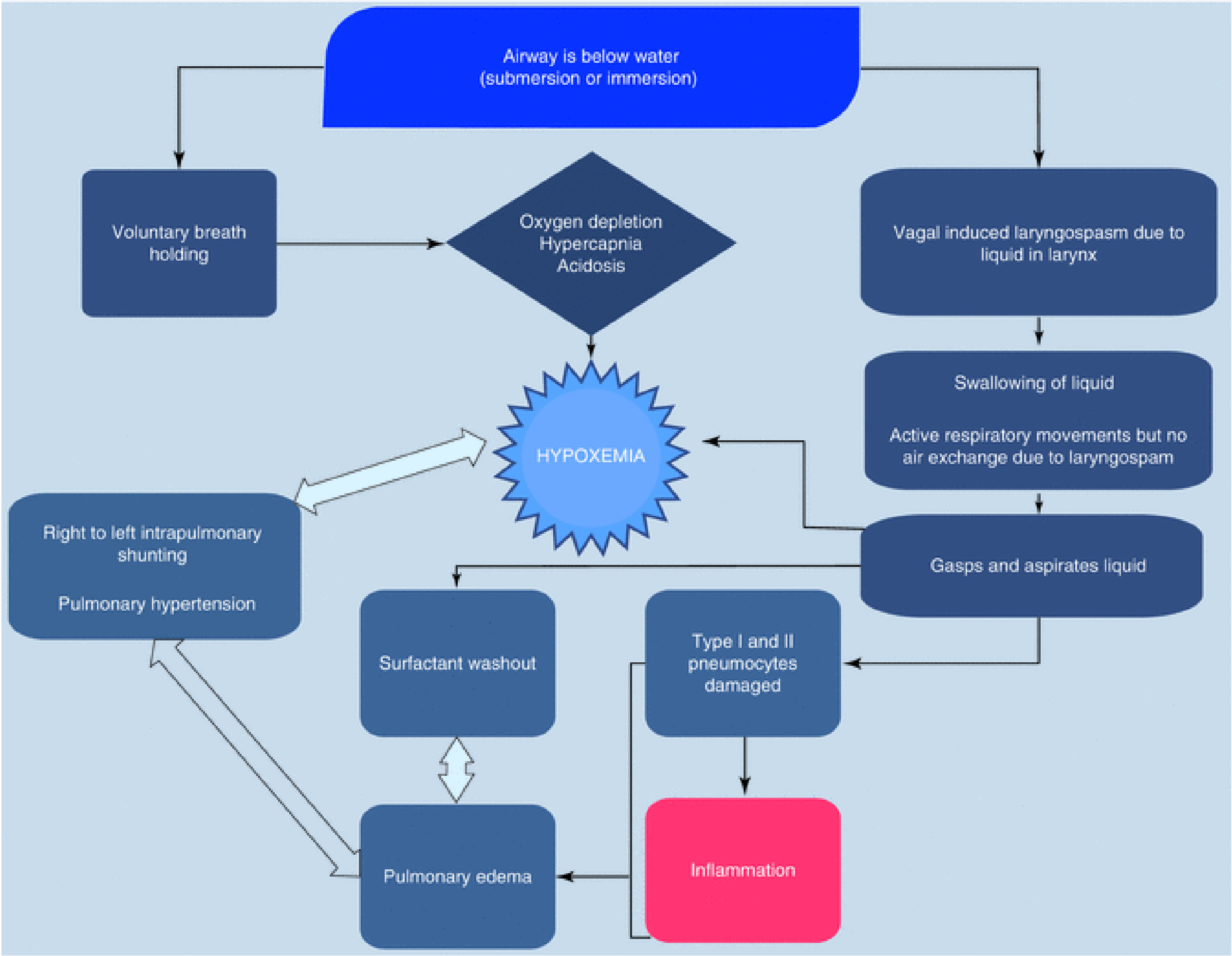
Pathophysiology - Submersion

- Neurophysiology
  - The brain's tolerance to energy deprivation is closely associated with brain temperature
  - Intact circulatory function is necessary to rapidly decrease brain temperature
  - Pulmonary aspiration may aid brain survival due to cooling of blood flowing past aspirated cold water
  - Overall, decreased oxygen delivery to the brain, leads to energy metabolism failure, and tissue death
  - Many drowning victims survive with permanent brain damage

If only there was a simple diagram to sum it all up…



*One proposed mechanism

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Pre-Hospital Management Techniques

- Time is of the essence
- Irreversible neurologic deficits are common after 4-5 minutes
- Hypothermia may offer a protective benefit (recall previous lecture)
- Risks vs. benefits of rescue effort

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Pre-Hospital Management Techniques

- Accurate timing and documentation of the course of events
  - Vital signs
  - Clinical state
  - Environmental conditions
  - Scene description
  - Estimated time of immersion/submersion
  - Type and temperature of the water and air
  - Events during transport to the hospital
- Evaluate for medical cause, trauma, and associated injuries

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Pre-Hospital Management Techniques

- Immediate attention to the airway and oxygenation
- Appropriate resuscitative measures
- Rescue breathing in the water is discouraged, but may be the only feasible option
- Rapid extrication from the water is the priority to ensure that CPR and rescue breathing are adequate
- Transport to an emergency facility with ongoing CPR should take place unless resuscitation is determined to be futile

Pre-Hospital Management Techniques

Re-appraisal of a 20-year-old Drowning Classification Tool

STUDY DESIGN

Retrospective study over 4 summers (2014-2017) of ICUs in France, French Polynesia and French Antilles

Examined outcomes in **312 adults** categorized into Szpilman drowning classification (from 1997)

- **GRADE 1** Normal pulmonary auscultation with coughing
- **GRADE 2** Abnormal pulmonary auscultation with rales in some pulmonary fields
- **GRADE 3** Acute pulmonary edema without arterial hypotension
- **GRADE 4** Acute pulmonary edema with arterial hypotension
- **GRADE 5** Isolated respiratory arrest
- **GRADE 6** Cardio-pulmonary arrest

RESULTS

80% of patients benefited from rapid extraction from water <10min and EMS in prehospital period

Mortality was low for Grades 2-5, and similar to previous reports for Grade 6 (54%)

Drowning-related cardiac arrest remains cornerstone of prognosis

Population	310 *n* (%)	Age (years)	Sex Ratio (F/M)	30-day Mortality, *n* (%)
Grade 2	20 (6)	52 +/- 18	8/12	0
Grade 3	134 (43)	57 +/- 20	55/79	3 (2.2)
Grade 4	8 (3)	49 +/- 24	5/3	0
Grade 5	49 (16)	52 +/- 22	16/33	1 (2)
Grade 6	99 (32)	53 +/- 19	29/70	53 (54.1)

Prognosis was better than previously reported for most classifications. Rapid recognition and intervention to interrupt the drowning process are important.

Markarian T, et al. *CHEST* 2020;157(8):596-602

CHEST

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Pre-Hospital Management Techniques

Table 1. Classification of drowning patients based on clinical findings on initial presentation and associated mortality

Grade	Respiratory findings	Cardiovascular findings	Mortality, %
0	Normal auscultation and no cough	Radial pulses present	0
1	Normal auscultation with mild cough	Radial pulses present	0
2	Rales, small amount of foam in mouth	Radial pulses present	0.6
3	Acute pulmonary oedema	Radial pulses present	5.2
4	Acute pulmonary oedema	Hypotension	19
5	Respiratory arrest	Hypotension	44
6	Cardiopulmonary arrest	Pulselessness	93

Adapted from Schmidt et al.[31]

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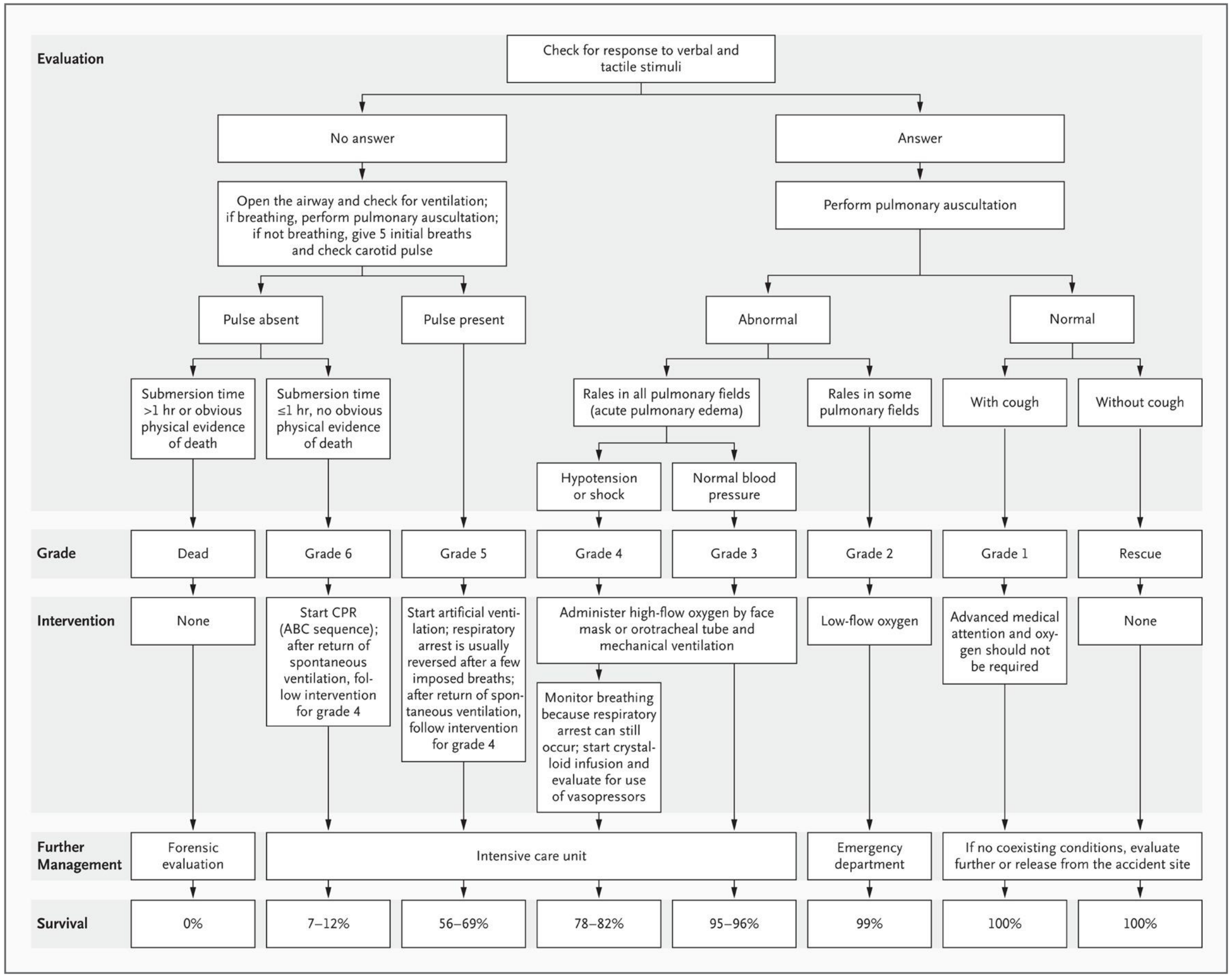
Pre-Hospital Management Techniques



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Pre-Hospital Management Techniques

- The Asymptomatic Patient: Grades 0 and 1
  - Patients with no other comorbid conditions who have been rescued from the water and who are alert, with a clear chest examination on auscultation, no respiratory distress, and with or without coughing
  - May not need further medical care
  - Patients may develop symptoms over the next 8 hours
  - Hypothermia is difficult to ascertain at the scene
  - Consider observation/monitoring period of 10-15 minutes
  - Protect from the elements

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Pre-Hospital Management Techniques

- The Symptomatic Patient: Grades 2, 3, and 4
  - All submersion patients requiring on-scene intervention or resuscitation, or showing signs of distress, should be transported to a hospital for evaluation
  - Protection of the airway to ensure oxygenation and ventilation is the first priority
  - Maintaining perfusion to reverse the metabolic consequences of acidosis comes next
  - Lateral recumbent positioning
  - Prevent/treat hypothermia
  - Monitor for and treat cardiac dysrythmias

Pre-Hospital Management Techniques

- The Patient in Respiratory or Cardiopulmonary Arrest: Grades 5 and 6
  - Initiation of immediate ventilatory support and early CPR results in better prognosis and outcomes
  - Supplemental oxygen +/- more definitive airway interventions +/- PEEP valve should be initiated as soon as possible
  - Nasogastric/orogastric tube placement as indicated for gastric decompression
  - Examination for oral/airway foreign bodies
  - Have suction available
  - Cervical collar as indicated
  - Perform a thorough medical assessment

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Pre-Hospital Management Techniques

- Cervical Spine Injury
  - Rare in drowning
  - High-speed boating accidents, surf-related injuries, diving accidents, etc
  - Routing spinal immobilization in unnecessary
  - If indicated by mechanism of injury or physical examination, USE IT!

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Pre-Hospital Management Techniques

- The Obviously Dead or Still-Submerged Patient
- Terminating Resuscitation Efforts
- Contact Medical Control

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Pre-Hospital Management Techniques

Evidence pertaining to survival following a submersion injury is limited to a large case-control study and other case series. The following factors at presentation have been associated with a poor prognosis:

- Duration of submersion >5 minutes (most critical factor)
- Time to effective basic life support >10 minutes
- Resuscitation duration >25 minutes
- Age >14 years
- Glasgow coma scale <5 (ie, comatose)
- Persistent apnea and requirement of cardiopulmonary resuscitation in the emergency department
- Arterial blood pH <7.1 upon presentation

THANK YOU!

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