BASICS OF FIRST AID
Drowning

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World Health Organization

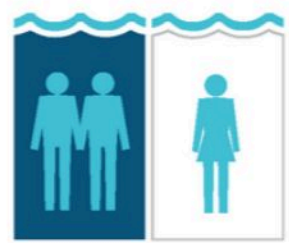
GLOBAL DROWNING PREVENTION

KEY FACTS

AT LEAST 236,000 people die **EVERY YEAR**

OVER HALF of all drowning deaths are among those aged **UNDER 30 YEARS**

MALES ARE TWICE AS LIKELY to drown as females

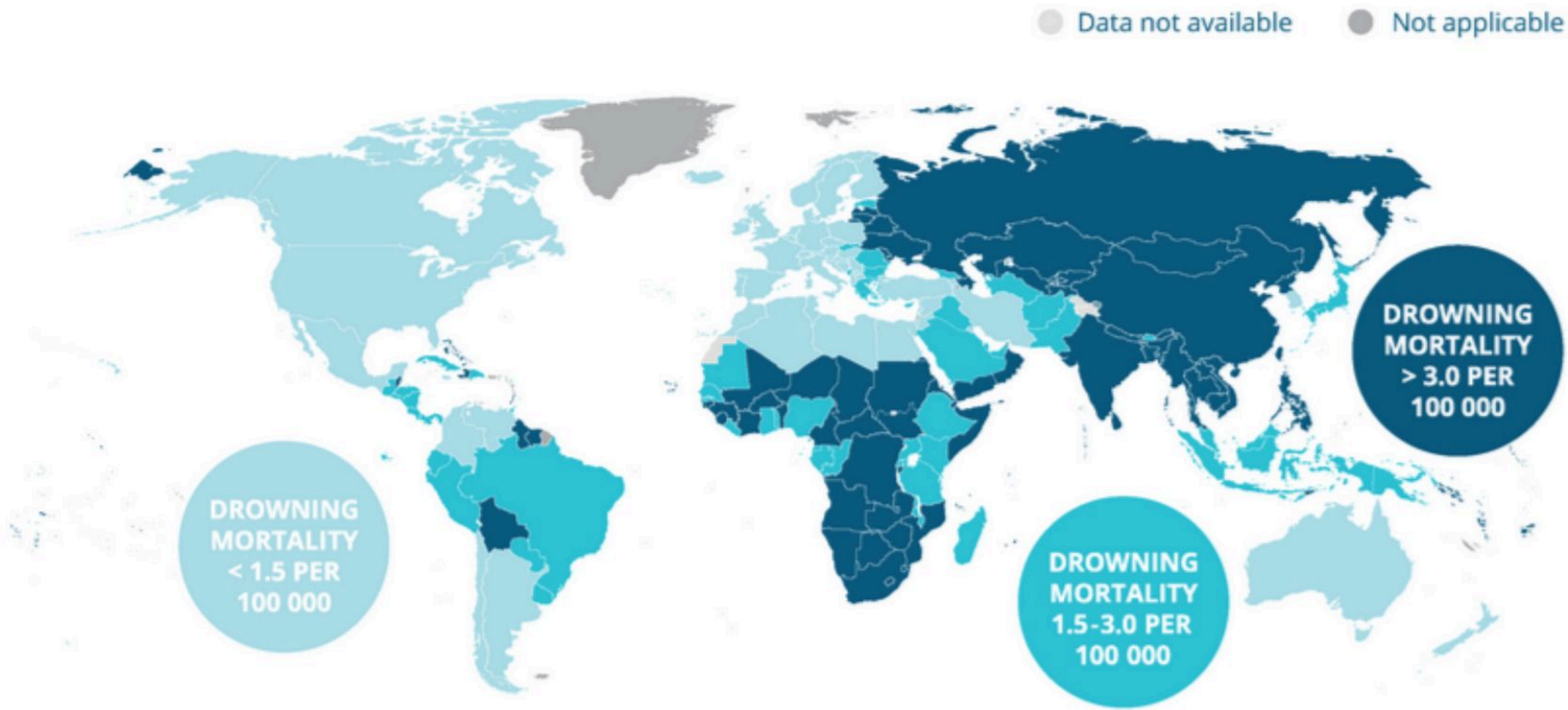


Drowning is one of the **10 LEADING CAUSES OF DEATH** for people aged 1-24 years

https://www.who.int/images/default-source/drowning/infographic-drowning-22-july-2021.png?sfvrsn=3c70d425_5

DROWNING RATES*

*Global Health Estimates 2019: Deaths by Cause, Age, Sex, by Country and by Region, 2019-2000. Geneva, World Health Organization; 2020.



https://www.who.int/images/default-source/drowning/infographic-drowning-22-july-2021.png?sfvrsn=3c70d425_5

Drowning is formally defined as the process of experiencing respiratory impairment from submersion/immersion in liquid

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‘Submersion’ ⇒ the airway going below the level of the surface of the liquid

‘Immersion’ ⇒ liquid being splashed across a person’s face.

https://www.rcemlearning.co.uk/reference/drowning/#1568890491084-3a97dd39-a049

Immersion

Hot-Water Immersion

"Thermoneutral" is the term for the water temperature at which heat loss equals heat production (53, 238). Most drowning events occur at water temperatures below the point of thermoneutrality, which is 35°C ± 0.5. Some drownings, however, occur in hot-water tubs, while pouring hot water over the head, or during diving or competitive swimming in warm water.

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↑ humidity of the ambient air ⇒
↓ limited evaporation of sweat above the water
Sweating also occurs **under water**⇒
This sweat **does not contribute to body cooling**
Skin temperature ↑⇒
cutaneous warm thermoreceptors (C-type fiber) interact with keratinocytes through TRPVc →spinal dorsal horn/trigeminal nerve → hypothalamic thermoregulatory centers (pre-optic area) ⇒cutaneous vasodilatation ⇒
↓ SVR ⇒
HR ⇒
↑ RR ventricular arrhythmias

Sweating⇒
dehydration⇒
thrombosis

Leaving the tub⇒
loss of the hydrostatic squeeze⇒
Hypotension

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Cold-Water Immersion

Most drownings occur in water colder than thermoneutral temperature, thus initiating physiological responses associated with cooling. In cold water, the responses that act as precursors to drowning are evoked by skin cooling (cold shock), then cooling of superficial nerves and muscles in the limbs, and finally cooling of deep body tissues (hypothermia).

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Cold Shock

After a fall into cold water, any intention to breath-hold can be overcome by cold shock (261, 263). The response starts in water ~25°C and peaks somewhere between 15 and 10°C; it peaks in the first 30 s of immersion and attenuates during the next 2–3 min (268). It is evoked by cold receptors located in the superficial sub-epidermal layer of the skin; below ~19°C, cold nociceptors contribute to the response with a sensation of intense cold pain being experienced in water below ~5°C (40, 163). The cold-shock response may be decreased but is still present in those with a high body temperature (159).

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Cold receptors respond to the sudden decrease in skin temperature resulting from immersion in cold water with a dynamic response that evokes gasping, hyperventilation, increased cardiac output, peripheral vasoconstriction, and hypertension. These responses, along with a generalized increase in muscle tension, can increase metabolic rate on initial immersion by a factor of four (98). This would, on its own, decrease breath-hold time during initial immersion because the hypoxic and hypercapnic thresholds for the breakpoint of breath-holding would be reached earlier (FIGURE 1). More important, thermo-afferents from the peripheral cold receptors dramatically increase respiratory drive via direct stimulation of the respiratory center (121), with a reflex stimulation at the spinal level of α-motoneurons innervating the intercostal muscles and diaphragm (166, 263). As a consequence, the gasp response and hyperventilation cause an inability to breath-hold. Maximum breath-hold time generally is 60–90 s at a comfortable air temperature and is reduced to just a few seconds in water colder than ~15°C. The inability to breath-hold represents the most hazardous response to cold-water immer-

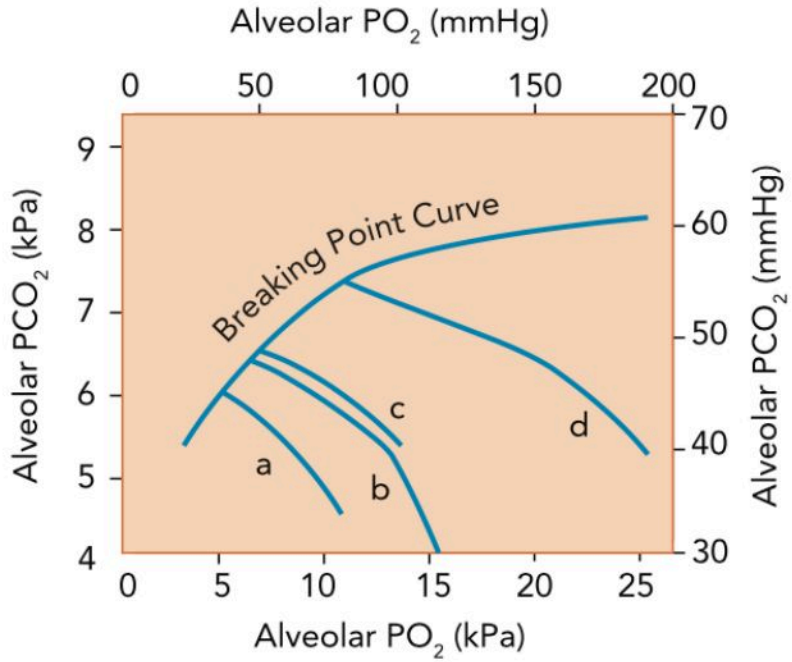

FIGURE 1. **The breaking points of breath-holding in different settings**
The "breaking point curve" defines the values of alveolar P_{O_2} and P_{CO_2} at the breath-hold break point when starting from different states. The normal alveolar starting point is shown. This point is displaced by different maneuvers, and the length of the arrows gives an indication of the changes of the breath-hold duration. See Refs. 73, 196. a, After breathing 15% oxygen; b, after hyperventilation; c, normal alveolar point; d, after breathing 30% oxygen.

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At the same time, upon initial immersion in cold water, the incidence of arrhythmias increases from 2% during cold water immersion with head-out-of-water free-breathing to 82% if the cold immersion is associated with face immersion and maximum breath-holding (see section *Diving Response* and *Autonomic Conflict* below).

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nective tissues (278). At muscle temperatures below 25°C, fatigue occurs because cooling impairs superficial muscle fibers leaving a smaller number of fibers to produce the same force (50). Maximum dynamic strength, power output, jumping, and sprinting performance have been related to muscle temperature with reductions ranging from 4 to 6% per degree fall in muscle temperature down to 30°C (27, 213).

At nerve temperatures below ~20°C, nerve conduction is slowed and action potential amplitude is decreased (62). Ulnar nerve conduction velocity falls by 15 m/s per 10°C decrease of local temperature. Nerve block may occur at a local temperature of between 5 and 15°C for 1–15 min and lead to a dysfunction that is equivalent to peripheral paralysis (22, 50).

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Deep-Tissue Cooling: Hypothermia

With regard to drowning, the most significant consequence of hypothermia is the loss of consciousness (LOC) with deep body cooling. This prevents individuals from undertaking physical activity to maintain a clear airway.

The progressive signs and symptoms are shivering (36°C), confusion, disorientation, introversion (35°C), amnesia (34°C), cardiac arrhythmias (33°C), clouding of consciousness (33-30°C), LOC (30°C), ventricular fibrillation (VF) (28°C), and death (25°C). Below a cardiac temperature of 28°C, the heart may suddenly and spontaneously arrest. VF may result from rough handling of the casualty at deep body temperature of ~28°C (88, 89). Hypothermia affects cellular metabolism, blood flow, and neural function. In severe hypothermia, the patient will be deeply unconscious. The decreased oxygen requirement of cold cells and organs causes decreased respiratory and heart rates. This makes it difficult to detect vital signs in the field. Tendon reflexes are absent and the pupils dilated: this may give the appearance of death (88).

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Table 2. ***Risk factors for immersion hypothermia (88, 119, 167, 213)***

- Water temperature: effects being most significant during cold water immersion
- Water movement: faster-moving liquids increase convective heat loss
- Surface area-to-mass area: the higher this ratio, the more cooling is facilitated
- Age: children cool faster than adults due to their lower levels of subcutaneous fat and higher surface area-to-mass ratio
- Body stature: tall, thin individuals cool faster than do those short and obese
- Body morphology: body fat and nonperfused muscle are good insulators
- Gender: females tend to have more subcutaneous fat than men but a weaker shivering response
- Fitness: high fitness level enables greater heat production
- Fatigue: exhaustion results in decreased heat production
- Nutritional state: hypoglycemia attenuates shivering and accentuates cooling
- Intoxication: alcohol and other drug depressants affect metabolism
- Lack of appropriate/specialized clothing

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Submersion

Sympathetic Activation, Fear of Drowning

Fear of drowning as a mechanism that results in drowning is most often reported in the gray literature and social media. Several triathletes

Breath-Holding

Under normal circumstances, typical alveolar P_{CO_2} at the breakpoint ranges between 43 and 53 Torr and occurs 60–90 s after breath-holding with ambient air (FIGURE 2). The breath-holding time can be influenced by several factors, including those listed in Table 3 (196).

In water, important additional physiological factors decrease breath-holding duration, including alcohol intoxication, water temperature below ~15°C, and the cold shock response that intensifies respiratory drive. Other factors that can influence breath-hold time include voluntary liquid aspiration such as occurs in suicides.

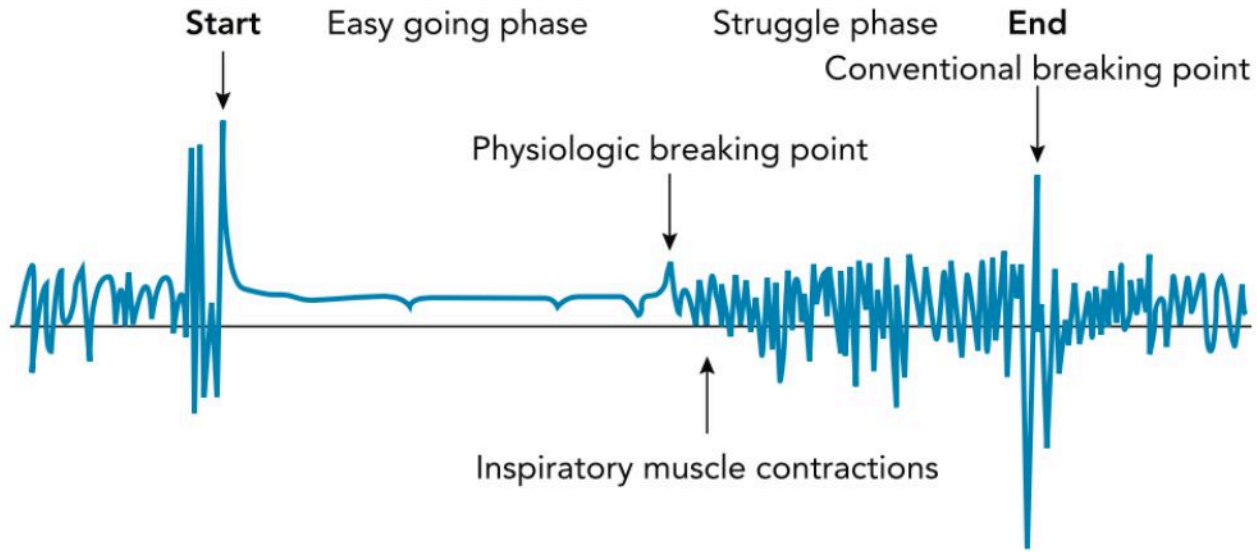

FIGURE 2. **Human thoracic movements measured by electromyography (EMG) during maximal breath-holding in an untrained, non-immersed subject**
"Easy going phase" and "struggle phase" are distinguished by the absence or presence of respiratory muscle activity that must be suppressed during breath-holding. Figure is from Ref. 72 and used with permission from Saunders.

Table 3. *Factors influencing breath-holding duration in air*

Metabolic rate during breath-holding
Prebreathing with hyperoxic or hypoxic gas mixtures
Carbon dioxide and oxygen storage capacity
Prior hyperventilation
Experience and psychological tolerance of unpleasant sensations arising during breath-holding

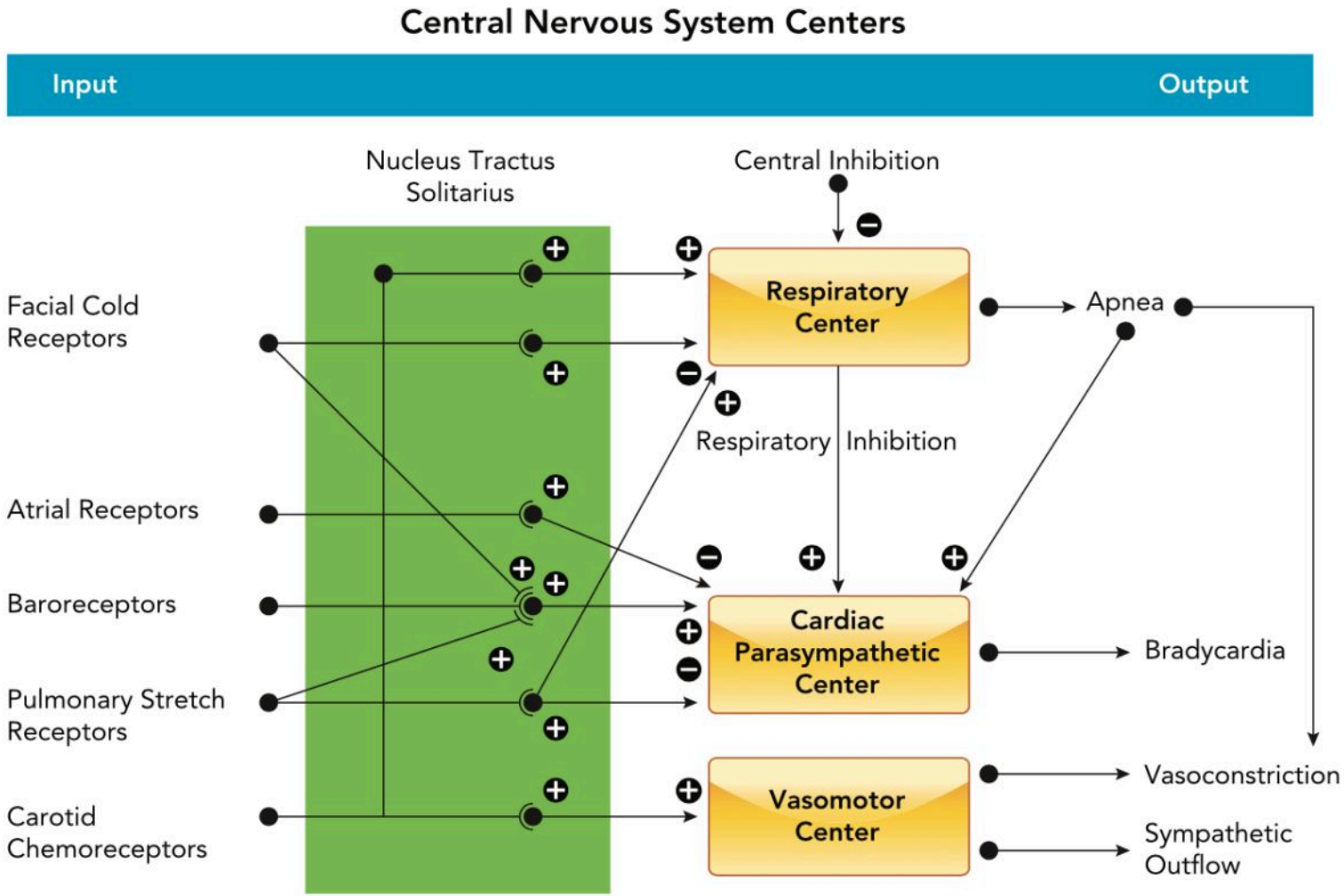

FIGURE 3. **Schematic figure of the diving response**
Input appears on the *left* and output at the *right*. In between are the neural connections located in the nucleus tractus solitarius and central nervous system control centers. The response is activated through the chemoreceptor sensitivity of the cold receptors of the skin and the unmyelinated C-fibers of the ophthalmic branch of the nervus trigeminus. For more details on the neurological pathways of the diving response, see also Refs. 162, 199, 226, 234. +, Excitatory neural connections, −, inhibitory neural connections. Figure is from Ref. 77 and used with permission from *Scandinavian Journal of Medicine and Science in Sports*.

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Table 4. ***Factors that increase effects of the diving response (10, 11, 17, 42, 77, 134, 231, 233)***

Precooling of the face
Contact of cold material with the face (water, air, cold packs)
Large air/water temperature gradient
Increased hypoxia
Prolonged or deeper submersion
Posture in the water
Smaller vital capacity lung volume
Previous breath-hold diving experiences
A series of repeated apnea dives or apnea exercises
Physical fitness

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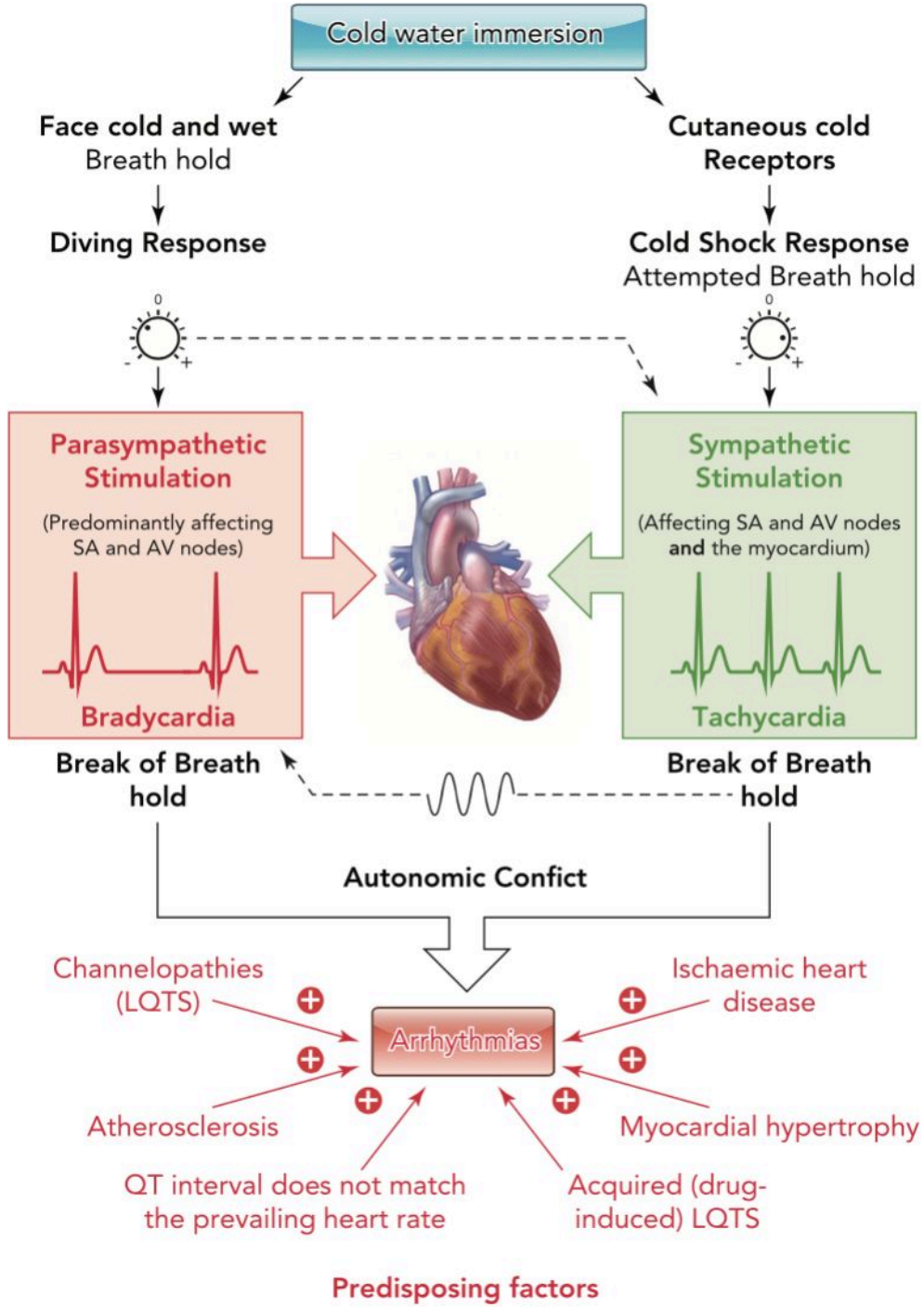
FIGURE 4. **Autonomic conflict**
Cold-water immersion activates two powerful responses: the diving response (on facial immersion) and the cold shock response (on the activation of cutaneous cold receptors). The magnitudes of these responses can vary with a range of factors including water temperature, clothing, and habituation. The diving response triggers a parasympathetically driven bradycardia, whereas cold shock activates a sympathetically driven tachycardia. It is hypothesized that together these conflicting inputs to the heart can lead to arrhythmias, particularly at the break of breath-hold, which increases parasympathetic tone that varies with respiration. The substrate for arrhythmias is enhanced by various predisposing factors. Figure is from Ref. 244 and used with permission from *The Journal of Physiology*.



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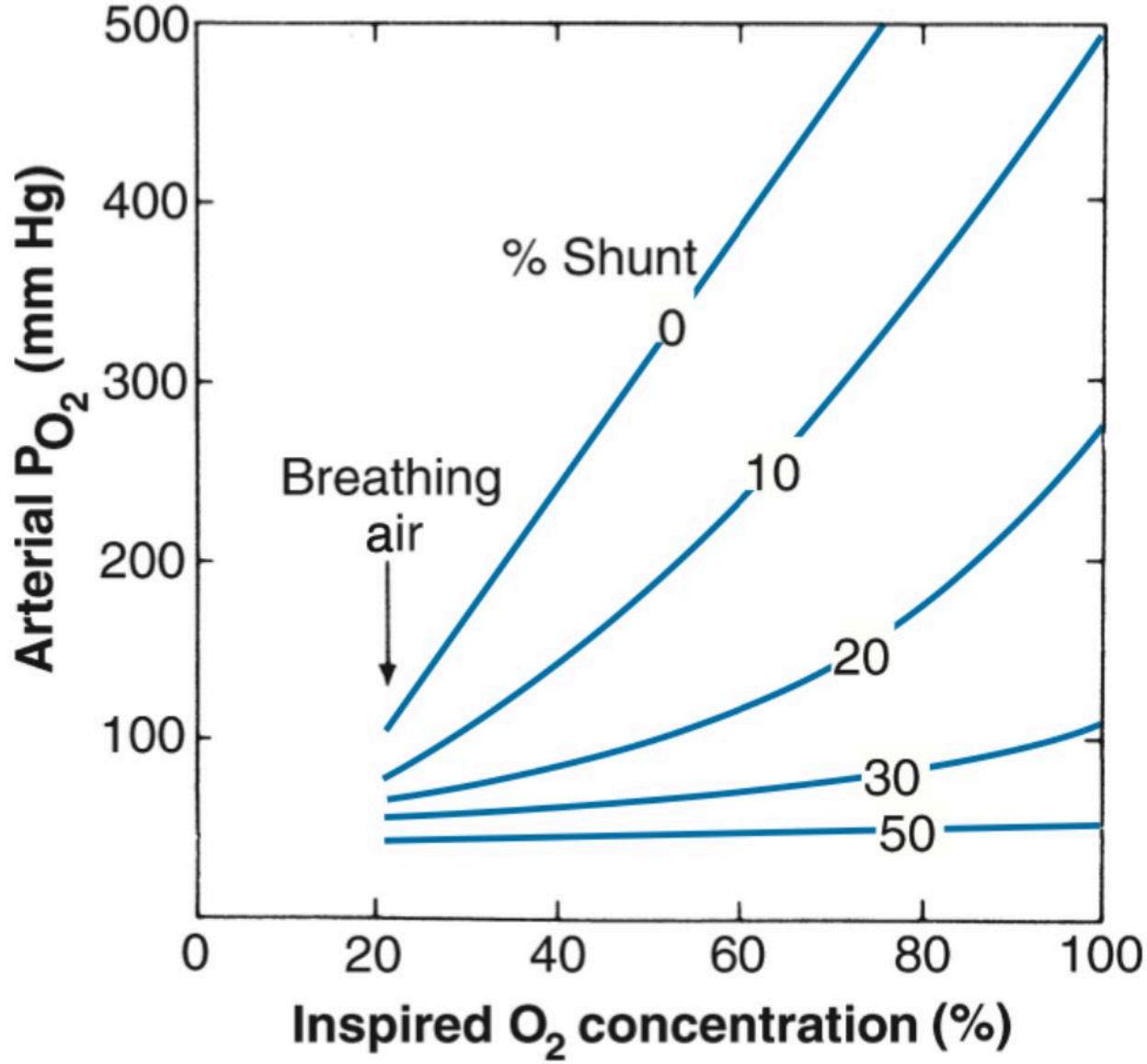
Hypotonic liquid, when reaching the alveoli, damages and dilutes pulmonary surfactant. The increase in the alveolar surface tension, along with diminution of pulmonary compliance, causes alveolar instability and atelectasis that alters the ventilation-to-perfusion ratio. Because a large part of the lung is not adequately ventilated, more venous blood bypasses the lungs, and the shunt fraction increases. Aspiration of 2.5 ml/kg of sea water causes the pulmonary shunt fraction to increase by 75% (206). Hypotonic fresh water tends to be absorbed into the pulmonary circulation and distributed throughout the body. Aspiration of



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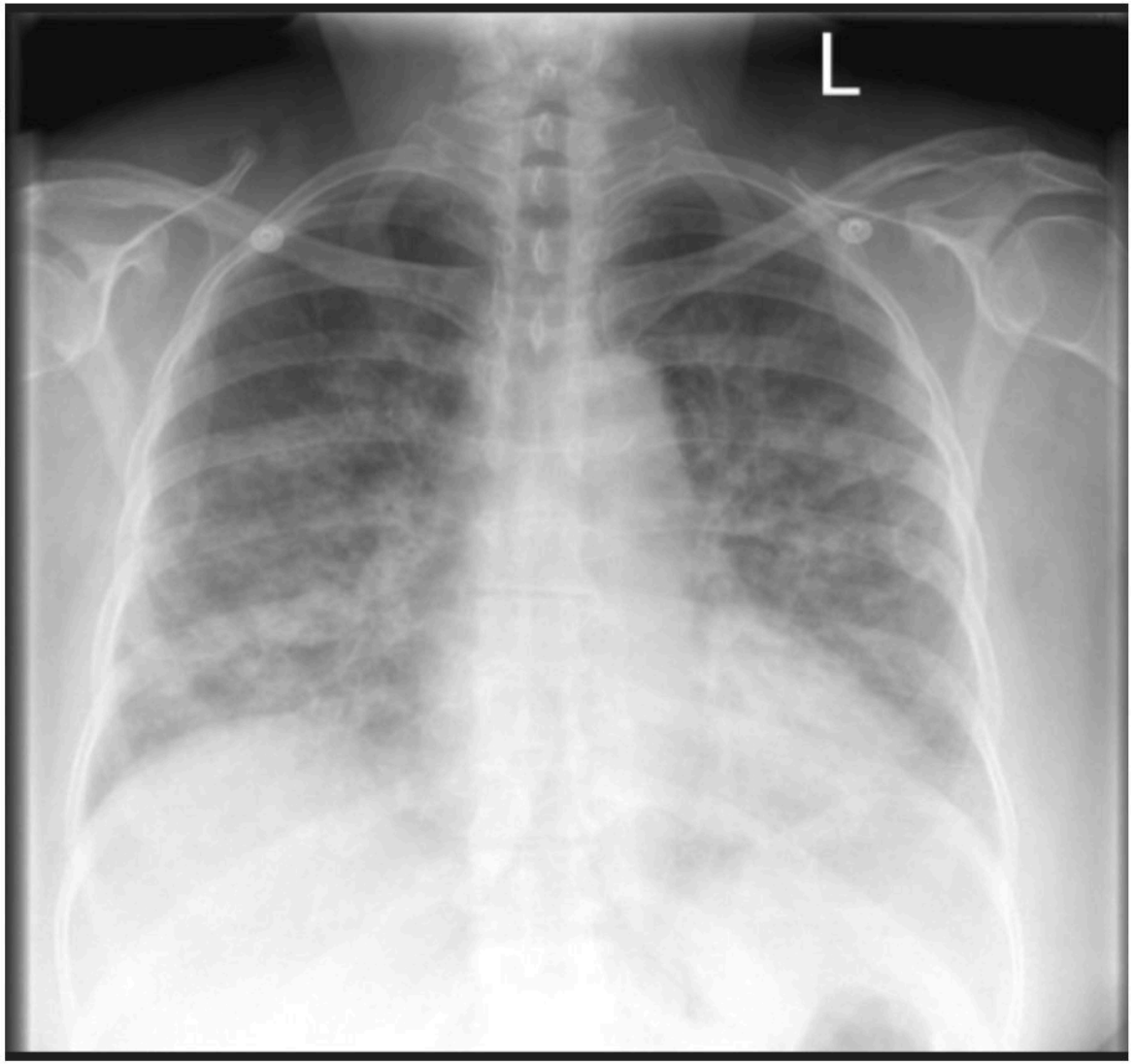
West JB, Luks A. West's Respiratory Physiology: The Essentials. Wolters Kluwer; 2016.

distributed throughout the body. Aspiration of hypertonic seawater draws liquid from the plasma into the alveoli and also causes damage to surfactant (215). In both situations, the supra-normal hydrostatic forces over the alveolar-capillary membrane will disrupt its integrity. Plasma enters the alveoli, incapacitating normal gas exchange. Plasma in the alveoli may also generate foam that further decreases pulmonary efficiency (147). This results in a local adult respiratory distress syndrome-like clinical picture (85, 92, 176, 274).



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https://www.eurorad.org/case/4650

Emesis

Detailed data on the occurrence of emesis in drowning are also lacking. One study, reported 25–60% of drowning victims vomited (151). Another study revealed that emesis occurred in 86% of drowning victims who required cardiopulmonary resuscitation and in 50% of those who required no intervention (154). Autopsy series have disclosed aspiration of gastric contents in 24% of drowning victims (80). In a large series on out-of-hospital cardiac arrest (CA) with a cardiac and non-cardiac etiology, emesis occurred in 30–35% of all patients (247). The trigger can be the condition underlying the arrest, CA itself, gastric distension caused by artificial ventilation, or improper chest compression that increases intra-abdominal pressure.

During drowning, gastric contents can be aspirated into the airways, resulting in pulmonary infection and chemical irritation (68, 274). Emesis can also interfere with pulmonary resuscitation. In drowning, both vomiting and cardiopulmonary resuscitation may cause gastric mucosal tears, the frequency of which varies widely among studies but has been detected in as many as 21% of patients (15, 33, 55, 145).

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Neurophysiology

The cerebral physiological response to drowning is poorly understood but is most likely an interaction between hypoxemia, submersion liquid temperature, aspiration, and cold shock. Most information pertaining to cerebral physiological responses to drowning is derived from experimental models simulating CA, which may not be directly relevant.

A critical event in drowning is loss of consciousness (LOC). This is often attributed to asphyxia following submersion, loss of pulmonary oxygen uptake, brain energy failure, and deterioration of brain function. Hypoxemia in normothermic healthy humans causes an initial cerebral vasodilatory response to preserve oxygen delivery (3). Progressive hypoxemia leads to a depletion of high-energy phosphates and loss of electrocortical activity consistent with LOC (171). The duration of this state defines the severity of injury and reversibility of neurological dysfunction.

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DROWNING

- Drowning victims need early rescue breaths
- Safety of rescuer is very important, but victim should be removed from water as soon as possible
- Rescue breaths can be given whilst in the water *if you are trained to do so*
- AED can be used (on dry land or in rescue boat) if victim's chest is dried

Approach safely

Check response

Shout for help

Open airway

Check breathing

Send someone to call 112

5 rescue breaths

30 chest compressions

2 rescue breaths

If alone, call 112 after 1 minute

EUROPEAN RESUSCITATION COUNCIL

Cardiac arrest

- Start resuscitation as soon as safe and practical to do so. If trained and able this might include initiating ventilations whilst still in the water or providing ventilations and chest compressions on a boat.

- Start resuscitation by giving 5 rescue breaths/ventilations using 100% inspired oxygen if available.
- If the person remains unconscious, without normal breathing, start chest compressions.
- Alternate 30 chest compressions to 2 ventilations.
- Apply an AED if available and follow instructions.
- Intubate the trachea if able to do so safely.
- Consider ECPR in accordance with local protocols if initial resuscitation efforts are unsuccessful.

Lott C, Truhlář A, Alfonzo A, et al. European Resuscitation Council Guidelines 2021: Cardiac arrest in special circumstances. Resuscitation. 2021;161:152-219. doi:10.1016/j.resuscitation.2021.02.011

Treatment Recommendations

We recommend that submersion duration be used as a prognostic indicator when making decisions surrounding search and rescue resource management/operations (strong recommendation, moderate-certainty evidence for prognostic significance).

We suggest against the use of age, EMS response time, water type (fresh or salt), water temperature, and witness status when making prognostic decisions (weak recommendation, very-low-certainty evidence for prognostic significance).

We acknowledge that this review excluded exceptional and rare case reports that identify good outcomes after prolonged submersion in icy cold water.

Perkins GD, Olasveengen TM, Mancini, MB , Chung S, Considine J, Kudenchuck P, Semeraro F, Smith C, Morley PT -on behalf of the International Liaison Committee on Resuscitation Basic Life Support Task Force.
Drowning Consensus on Science with Treatment Recommendations [Internet] Brussels, Belgium: International Liaison Committee on Resuscitation (ILCOR) Advanced Life Support Task Force, 2020 Jan 1. Available from: http://ilcor.org