



Chapter Seven

Diving Physiology



Topics in this Chapter

- ✓ Introduction
- ✓ Respiration and Circulation
- ✓ Decompression Illness
- ✓ Narcosis
- ✓ Gas Toxicity
- ✓ Barotraumas
- ✓ Additional Concerns
- ✓ General First Aid for Marine Related Injuries
- ✓ Review Questions

Introduction

Physiology was covered in detail in the SDI Divemaster course. Here the information is covered briefly.

For more detailed information refer to the SDI Divemaster materials.

Introduction

- **Caution – share this information judiciously!**
 - Keep it in a positive context
 - Emphasize safe diving practices
 - Don't focus only on the consequences, but instead point out how they can be avoided

Respiration and Circulation

- **Pulmonary System**

- Primary role is the exchange of gases

- Oxygen

- Critical ingredient in the metabolic process
- Introduced into the body with each inhaled breath

- Carbon Dioxide

- Expelled from the body with each exhaled breath
- Triggers breathing

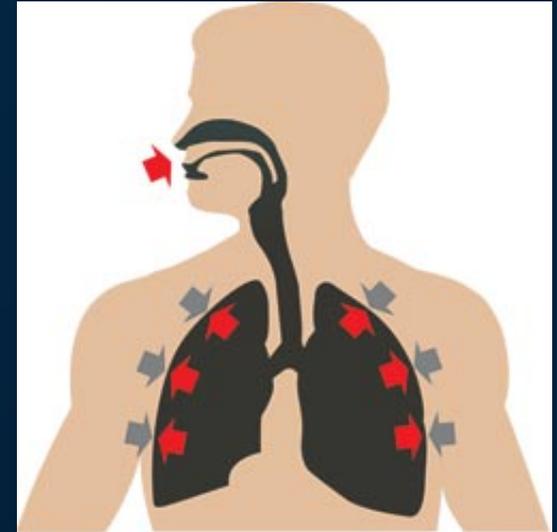


Respiration and Circulation

- **Pulmonary System**

- Components

- Lungs
- Pulmonary airway (leading to lungs, from mouth and nose)



Respiration and Circulation

- **Pulmonary System**

- Alveoli

- It is here that the actual gas exchange occurs, between the lungs and the bloodstream
 - The movement of any gas, through the alveoli, is dictated by the *partial pressure* of that gas in the lungs and the *tension* of that dissolved gas in the blood

Respiration and Circulation

- **Cardio-Vascular System**

- Its role is the movement of gases

- Oxygen

- Carried by the blood, from the lungs to the tissues, where it is then used in metabolism at a cellular level

- Carbon Dioxide

- By-product of metabolism, which is carried by the blood, from the tissues to the lungs

Respiration and Circulation

- **Cardio-Vascular System**

- Components

- Heart

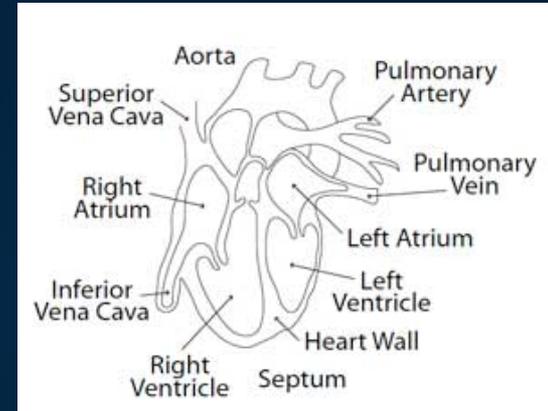
- Four-chambered pump

- Arteries

- Network of vessels which carry blood from the heart to the tissues

- Veins

- Network of vessels which carry blood from the tissues to the heart



Respiration and Circulation

- **Cardio-Vascular System**

- Capillaries

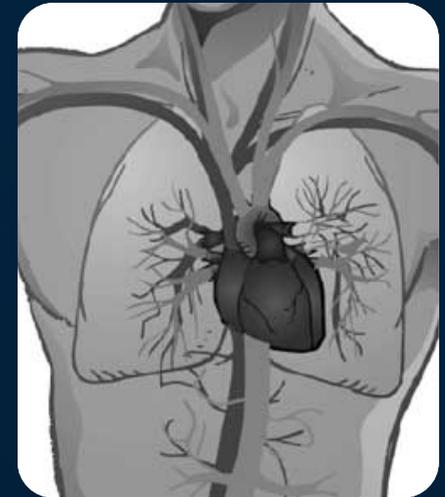
- Smallest of the blood vessels
- It is here that gases move between the blood and the tissues

- Hemoglobin

- Protein component in the blood, to which both oxygen and carbon dioxide attach

Respiration and Circulation

- **Cardio-Vascular System**
 - Two separate circuits of blood vessels
 - Pulmonary circulation
 - Flow of blood between the heart and the lungs
 - Systemic circulation
 - Flow of blood between the heart and the tissues



Decompression Illness

- **What is DCI?**

- Diagnostic classification for disease-like conditions that might befall a diver upon ascent to the surface, following any time at depth, as the direct result of decreasing ambient pressure
- Includes
 - Decompression Sickness (DCS)
 - Arterial Gas Embolism (AGE)

Decompression Illness

- **Decompression Sickness**

- Caused by formation of nitrogen bubbles within the tissues of a diver's body
 - Additional nitrogen is on-gassed at depth, and excess nitrogen is off-gassed upon ascent
 - When tolerance limits are exceeded, DCS can occur

Decompression Illness

- **Decompression Sickness**
 - Primary factors
 - Remaining too long at a given depth
 - Making a rapid ascent



Decompression Illness

- **Decompression Sickness**
 - Additional factors
 - Older age
 - Obesity
 - Poor fitness
 - Recent injury or illness
 - Cold conditions
 - Excessive workload
 - Fatigue
 - Dehydration
 - Prior occurrence of DCS

Decompression Illness

- **Decompression Sickness**
 - To minimize the risk
 - Ensure proper fitness and health
 - Stay properly hydrated
 - Use appropriate thermal protection
 - Avoid over-exertion

Decompression Illness

- **Decompression Sickness**

- Sport divers may further minimize the risk

- Dive conservatively
- Avoid diving up to the limits specified by dive tables or dive computer
- Adhere to maximum ascent rate indicated by dive tables or dive computer (slower is better)
- Perform a safety stop – 3 to 5 minutes, at 3 to 6 metres or 10 to 20 feet

Decompression Illness

- **Decompression Sickness**

- DAN recommendations: Minimum surface intervals for flying after diving
 - 12 hours after a single dive
 - 18 hours after multiple dives or multiple days of diving
 - 24 hours after any dive required staged or emergency decompression

Decompression Illness

- **Decompression Sickness**

- Severity depends upon the extent to which bubbles form, and the location in which they form

- Type I DCS

- Involves skin rash, itching, and/or localized pain

- Type II DCS

- Involves the central nervous system, the respiratory system, and/or the circulatory system

Decompression Illness

- **Decompression Sickness**

- Onset

- Usually within 15 minutes to 2 hours after surfacing
- But may be delayed up to 24 hours

- Once symptoms appear

- They may worsen over time
- They normally do not subside on their own

Decompression Illness

- **Decompression Sickness**
 - Unattended, it can result in long-term neurological complications
 - Early intervention greatly increases the chances for a full recovery
 - First aid at the scene
 - Professional medical care

Decompression Illness

- **Arterial Gas Embolism**

- Occurs when a gas bubble blocks the arterial flow of blood to a vital organ

- It might arise in decompression sickness
- More often, it occurs when the lungs become over-pressurized and air, still in its gaseous state, passes through the alveoli and enters the blood stream as an air bubble

Decompression Illness

- **Arterial Gas Embolism**

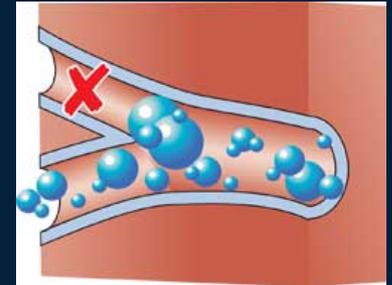
- Causes of lung over-pressurization

- Holding one's breath during an ascent
- Chest congestion, due to illness or allergy
- Asthma-like restriction of pulmonary airway
- Excessively rapid ascent, which surpasses the equalization process of normal respiration

Decompression Illness

- **Arterial Gas Embolism**

- Once a bubble enters the blood and passes into systemic circulation
 - It will travel through the progressively narrowing network of arteries
 - At the same time, decreasing ambient pressure (due to ascent) will cause that bubble to expand in size
 - Sooner or later, an arterial blockage likely will occur



Decompression Illness

- **Arterial Gas Embolism**

- Blockage can occur anywhere along the arterial network, and severity depends upon location of the arterial blockage

- Brain

- Sudden stroke (weakness, paralysis, respiratory distress, cardiac arrest)

- Heart

- Cardiac arrest

Decompression Illness

- **Arterial Gas Embolism**

- To minimize the risk

- Never hold one's breath
- Seek medical advise for any question regarding the overall health of the respiratory system
- Postpone diving while temporarily congested
- Always ascend slowly

Decompression Illness

- **Arterial Gas Embolism**

- Onset

- Unconsciousness may occur immediately upon surfacing, or even during the ascent
- Other signs and symptoms may be similar to DCS, but the onset is often more dramatic

Decompression Illness

- **DCI and Patent Foramen Ovale**

- Foramen Ovale is an flap-like valve in the heart, between the right atrium and left atrium

- It is open during fetal development (when there is no fetal respiration, and the fetus requires only systemic circulation)
 - It closes after birth, and usually seals (in order to establish pulmonary circulation, and segregate it from systemic respiration)

Decompression Illness

- **DCI and Patent Foramen Ovale**
 - Patent Foramen Ovale (PFO) refers to the situation where this valve does not seal
 - Not part of routine medical screening
 - For divers, it might increase the risk of DCI
 - Not necessarily a contraindication for diving

Decompression Illness

• Signs and Symptoms of DCI

- Skin rash or itching
- Tingling or numbness
- Joint or limb pain
- Back, abdominal, or chest pain or discomfort
- Unusual headache
- Extreme fatigue
- Weakness or paralysis
- Dizziness, loss of balance, or loss of coordination
- Confusion or disorientation
- Unresponsiveness or unconsciousness
- Convulsions
- Difficulty swallowing
- Slurred speech
- Hearing disturbance
- Visual disturbance
- Loss of bladder or bowel control
- Difficulty urinating with a full bladder
- Unusual coughing
- Rapid, shallow, or distressed breathing
- Blood or froth in mouth
- Rapid, erratic, or weak pulse
- Cardiac arrest

Decompression Illness

- **First Aid for DCI**

- As with any medical emergency, the primary and immediate care always focuses on the ABC's

- Airway (open)
- Breathing (present)
- Circulation (present)



Decompression Illness

- **First Aid for DCI**
 - After the ABC's have been confirmed
 - Activate EMS or seek medical care
 - Administer oxygen
 - Have patient lay down, in supine or recovery position
 - Monitor the patient
 - Treat for shock
 - Administer CPR when appropriate

Decompression Illness

- **First Aid for DCI**

- Possible benefits of emergency oxygen

- More quickly off-gas excess nitrogen
- Reduce blood sludging (thickening, due to excess nitrogen)
- Reduce nitrogen bubble size
- Increase oxygenated blood flow to tissues
- Reduce tissue swelling
- Ease breathing
- Improve the chances of making a full recovery

Decompression Illness

- **First Aid for DCI**

- There is no need to await the actual onset of signs and symptoms, before administering oxygen
 - When exposed to a distinct risk (such as a rapid ascent, or an omitted deco stop), the diver may start oxygen immediately
 - May prevent the onset of DCI
 - May reduce the severity of DCI

Decompression Illness

- **Five-Minute Field Neurological Evaluation**
 - Perform immediately whenever DCI is suspected, then repeat periodically if medical attention is delayed
 - Look for deviations from the expected norm
 - Look for differences, one side versus the other
 - Look for changes over time

DCS Field Evaluation

Diver (and/or Buddy) Interview

Details of all dive profiles

Check One: Air Nitrox Trimix O₂%

Any unusual events ?	Entanglement
Out-of-Air Emergency	Significant Over-Exertion
Equipment Malfunction	Loss of Buoyancy Control
Buddy Separation	Rapid Ascent
Other:	

Any Prior History of DCS ? No Yes (if yes, enter Date)

Any Other Medical Issues ? No Yes (if yes, explain)

Signs and Symptoms of DCS

Skin Rash	Hearing Disturbances
Tingling or Numbness	Visual Disturbances
Joint or Limb Pain	Slurred Speech
Back or Abdominal Pain	Distressed Breathing
Chest Pain or Discomfort	Severe Coughing
Extreme Fatigue	Blood or Froth in Mouth
Loss of Muscle Strength	Paralysis
Loss of Coordination	Convulsions
Dizziness	Unconsciousness
Disorientation	Cardiac Arrest
Neck Swelling	Rapid or Erratic Pulse
Abnormal Sounding Voice	Signs of Shock

First Aid for Suspected DCS

Administer Oxygen	
EMS / Medical Attention	Monitor Patient
Patient Laying Down (left side)	Treat for Shock
Provide fluids (if conscious)	CPB when appropriate

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Decompression Illness

- **Five-Minute Field Neurological Evaluation**

1. Orientation

2. Eyes

3. Forehead

4. Face

5. Ears

6. Gag Reflex

7. Tongue

8. Shoulders

9. Arms and Hands

10. Chest

11. Legs

12. Heel-to-Toe Walk

Decompression Illness

- **Recompression Therapy**

- Standard medical treatment for DCS and AGE

- Patient is placed inside hyperbaric chamber
- Pressure is increased, 3 to 6 bar / 3 to 6 atm
- Often combined with oxygen therapy
- After appropriate amount of time, pressure is slowly reduced

- Helps to reduce the size and extent of bubbles

Decompression Illness

- **Recompression Therapy**
 - Though it removes the bubble, tissue damage still remains
 - DAN recommendation: Refrain from diving for 2 to 4 weeks, following subsidence of neurological signs and symptoms



Narcosis

- **What is Narcosis?**

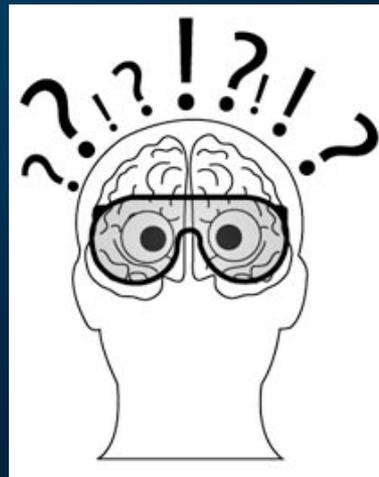
- State of intoxication, which can be caused by breathing a high concentration of inert gas, or a lower concentration of inert gas under elevated pressure

- Inert gas is absorbed into membrane of nerve cells, and begins to interfere with transmitted electrical signals
- Effect varies from one inert gas to another, and depends upon partial pressure of that inert gas

Narcosis

- **What is Narcosis?**

- Narcosis, by itself, is not physiologically harmful
 - It poses a risk because of its adverse impact upon overall alertness and performance



Narcosis

- **Nitrogen Narcosis**

- Nitrogen is most common inert gas encountered by recreational divers
 - Comprises 79% of each inhaled breath of air

Narcosis

- **Nitrogen Narcosis**

- Susceptibility can vary a bit from diver to diver, and from day to day, but nitrogen narcosis is primarily dependent upon depth
 - Shallower than 20 metres or 60 feet, usually there is little or no effect
 - 30 metres or 100 feet often is cited as threshold depth at which a diver will exhibit outward signs
 - More pronounced effects at deeper depths



Narcosis

- **Nitrogen Narcosis**

- Signs and symptoms

- Euphoria and lack of concern for own well-being, or conversely paranoia
- Diminished coordination
- Impaired thinking
- Foolish behavior
- Amplified sounds, including own heartbeat
- At extreme depths (beyond recreational limits) can cause hallucinations

Narcosis

- **Nitrogen Narcosis**

- Can intensify with physical or psychological stress
- Unlike DCI there are no lingering effects

Narcosis

- **Inert Gas Narcosis**

- Other gases also can create a similar effect

- Helium
- Argon



Gas Toxicity

- **What is toxicity?**

- Degree to which a gas is poisonous to the body as a whole, or to a specific tissue or process within the body
 - Time-dose concept
 - Time = duration of exposure to the gas
 - Dose = level (or intensity) of exposure, based upon partial pressure of the gas

Gas Toxicity

- **Central Nervous System Oxygen Toxicity**
 - Oxygen, at an elevated partial pressure, can short-circuit the central nervous system
 - Convulsions
 - Likely the diver will lose the regulator
 - Risk of drowning
 - Other symptoms may or may not appear, before convulsions occur

Gas Toxicity

- **Central Nervous System Oxygen Toxicity**

- Signs and symptoms

- ConVENTID

Con: Convulsions

V: Visual Disturbances

E: Euphoria

N: Nausea

T: Tinnitus / Tingling or Twitching

I: Irritability

D: Dizziness / Dyspnea

Gas Toxicity

- **Central Nervous System Oxygen Toxicity**
 - NOAA limits
 - Maximum PO_2 toxic dose is 1.6 bar / 1.6 atm
 - Minimum PO_2 toxic dose is 0.6 bar / 0.6 atm
 - Not a concern for divers when breathing air within recreational depths, but can be a concern when using nitrox

Gas Toxicity

- **Central Nervous System Oxygen Toxicity**
 - NOAA limits

Partial Pressure of Oxygen (bar / atm)	Single Dive Limit (minutes)	Daily Limit (minutes)
1.6	45	150
1.5	120	180
1.4	150	180
1.3	180	210
1.2	210	240
1.1	240	270
1.0	300	300
0.9	360	360
0.8	450	450
0.7	570	570
0.6	720	720

Gas Toxicity

- **Central Nervous System Oxygen Toxicity**
 - If convulsions occur underwater
 - Establish physical control of diver, and ascend
 - Hold regulator in place, but do not attempt to replace regulator if it was dropped

Gas Toxicity

- **Central Nervous System Oxygen Toxicity**
 - First aid
 - As convulsions subside, diver may enter a sleep-like state
 - Monitor the diver, and ensure the ABC's
 - Always seek medical attention, as diver may have inhaled water during convulsions

Gas Toxicity

- **Pulmonary Oxygen Toxicity**

- Caused by long-term exposure to elevated partial pressure of oxygen
- Usually not associated with sport diving activities

Gas Toxicity

- **Pulmonary Oxygen Toxicity**
 - Additional signs and symptoms (also known as whole-body oxygen toxicity)
 - Skin numbness or itching
 - Headache
 - Dizziness
 - Nausea
 - Visual disturbances

Gas Toxicity

- **Carbon Dioxide Toxicity**

- Carbon dioxide is a by-product of metabolism in animals, plants and other organisms, which is normally dispersed into the atmosphere
- Carbon dioxide also is a by-product of efficient (complete) combustion of carbon-based fuels

Gas Toxicity

• Carbon Dioxide Toxicity

- In diving, the greatest concern usually is the level of carbon dioxide produced within the diver's body
- Workload increases the production of carbon dioxide
 - Strenuous activity
 - Cold water
 - Older age, diminished health and fitness
 - Ill-performing regulator
 - Ineffective breathing pattern

Gas Toxicity

- **Carbon Dioxide Toxicity**

- First aid

- Lesser symptoms generally begin to alleviate on their own, after workload subsides
- If respiratory distress or unconsciousness
 - Monitor the diver, ensure the ABC's
 - Administer oxygen
 - Provide other first aid as appropriate



Gas Toxicity

- **Carbon Monoxide Toxicity**

- Carbon monoxide is a by-product of inefficient (incomplete) combustion

- It is not produced within the body
 - It enters the body as an inhaled contaminant
 - It attaches to the hemoglobin in the blood, where it quickly accumulates and prevents the transport of oxygen

Gas Toxicity

- **Carbon Monoxide Toxicity**

- Sources of contamination in the diver's air supply
 - Engine exhaust, from motor vehicle or similar source, introduced into compressor intake
 - Poor compressor maintenance
 - Improper handling of 100% oxygen during gas blending, which results in internal flashing

Gas Toxicity

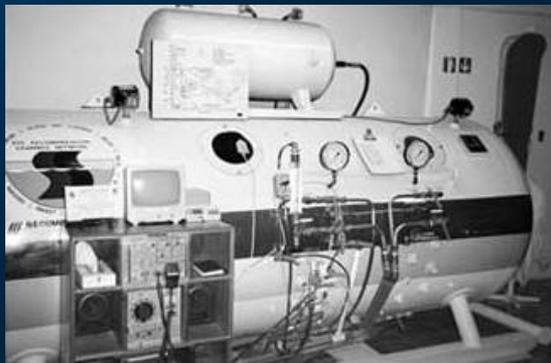
- **Carbon Monoxide Toxicity**

- Prevention

- Carbon monoxide is odorless and colorless, but often it is accompanied by additional contaminants
- Never use a breathing gas that has an odor or taste

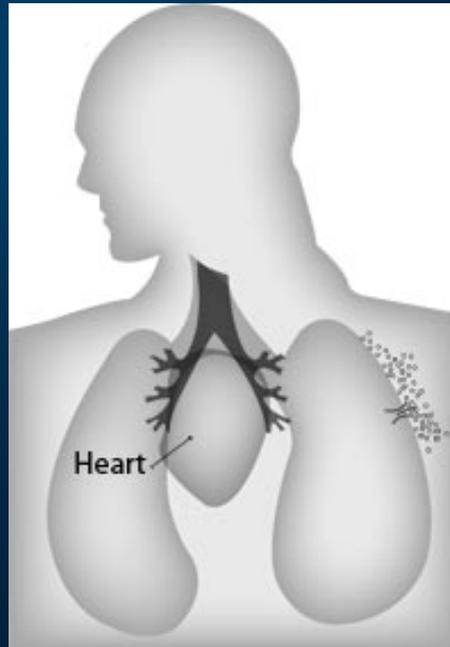
Gas Toxicity

- **Carbon Monoxide Toxicity**
 - First Aid
 - Monitor the diver, ensure ABC's
 - Administer oxygen
 - Seek medical attention
 - Medical care sometimes includes hyperbaric chamber therapy



Barotrauma

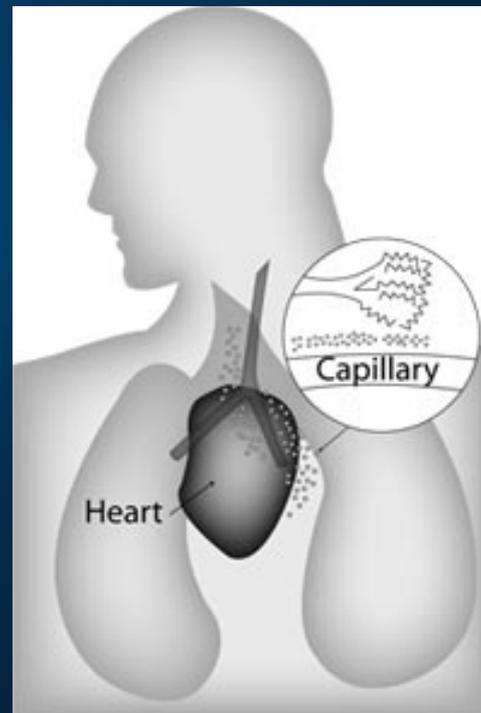
- **What is barotrauma?**
 - Pressure-related injury, usually accompanied by discomfort or pain



Barotrauma

- **Lung Injuries**

- During ascent, when expanding air is not vented from the lungs, the lung tissue may rupture



Barotrauma

- **Lung Injuries**

- Cause

- Increasing volume of air in lungs upon ascent not properly vented

- **Types**

- Pneumothorax

- Mediastinal emphysema (or pneumomediastinum)

- Subcutaneous emphysema

Barotrauma

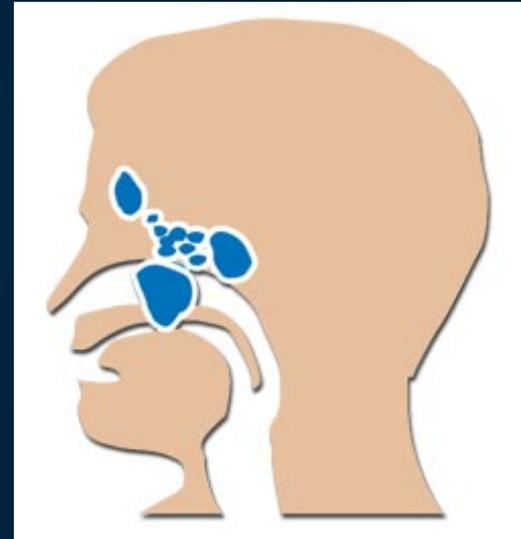
- **Ear Injuries**

- The ear drum is a membrane between the outer ear and middle ear
- Middle ear must be equalized to changing ambient pressure
- Swimmers ear is an infection of the outer ear, and not a pressure-related injury
 - It can mimic barotrauma

Barotrauma

- **Nasal Sinus Injuries**

- Nasal sinuses consist of four pairs of air-filled sacs
 - Maxillary
 - Frontal
 - Ethmoid
 - Sphenoid
- These air spaces must be equalized to changing ambient pressure



Additional Concerns

- **Drowning**

- Drowning is a form of asphyxiation (or oxygen starvation)
 - Caused when water or another fluid enters the airway and lungs
 - Interrupts the respiratory process

Additional Concerns

- **Near-Drowning**

- Near-drowning is a similar but initially non-fatal situation

- May occur when a volume of water is inhaled
 - Usually accompanied by unconsciousness
 - Lungs are injured, resulting in chemical and biological changes
 - Additional fluids begin to gather in lungs
- The diver should seek prompt medical attention
- Death can occur hours or days later, due to accumulation of fluids (secondary drowning)

Additional Concerns

- **Hypothermia and Hyperthermia**

- Hypothermia is caused by the loss of body heat
- Hyperthermia occurs when the body produces or absorbs more heat than can be readily dissipated

Additional Concerns

- **Dehydration**

- Reduced level of fluids in the blood and tissues
 - Adversely impacts various physiological processes
 - Can be a significant pre-disposing factor in DCS



Additional Concerns

- **Mid-Water Disorientation**

- The brain relies heavily upon visual references
 - Disorientation can occur in mid-water due to lack of reliable visual references
 - May occur in murky or clear conditions

Additional Concerns

- **Seasickness**

- Possible contributing factors

- Fatigue
- Dehydration

- Preventative Measures

- Remain above deck in fresh air, near middle of the boat, and focus upon a fixed distant object near the horizon

Additional Concerns

- **Carotid Sinus Reflex**

- Carotid sinus is located in the neck at the base of the carotid artery
 - It contains neuro sensors which monitor blood pressure for the brain
 - It transmits corresponding signals to the heart

Additional Concerns

- **Shallow Water Black-Out**

- Occurs during ascent, due to effect of decreasing ambient pressure upon a limited supply of oxygen held with the lungs
 - Principally arises in free diving
 - Associated with excessive hyperventilation prior to descent

Additional Concerns

- **Stings, Bites, and Envenomations**

- Most marine life injuries stem from

- Animal's natural defensive response to some perceived threat
- Inadvertently touching an animal or organism



Additional Concerns

- **Stings, Bites, and Envenomations**
 - In any case of suspected envenomation
 - Closely monitor the patient
 - Some individuals will have increased sensitivity, and pronounced allergic reactions are possible

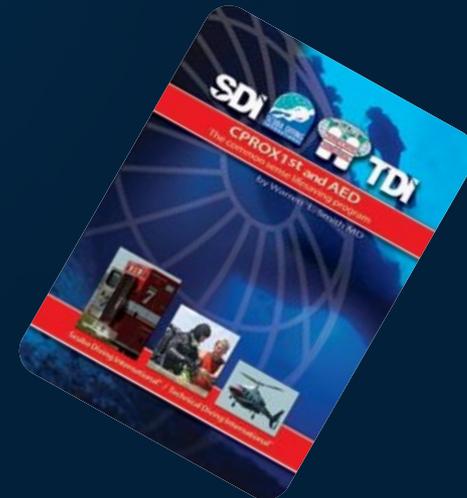


General First Aid for Marine Related Injuries

- **Appropriate Training**

- CPR and First Aid

- It is a prerequisite for this course
- It is the personal responsibility of the dive leader to remain current after this course
- SDI training options
 - CPR-1st
 - CPROX
 - CPROX-1st-AED



General First Aid for Marine Related Injuries

- **Other Injuries**

- Most injuries can be prevented, or at least mitigated
- The response to any injury starts with the ABC's
 - Airway (open)
 - Breathing (present)
 - Circulation (present)

Summary

- ✓ Introduction
- ✓ Respiration and Circulation
- ✓ Decompression Illness
- ✓ Narcosis
- ✓ Gas Toxicity
- ✓ Barotraumas
- ✓ Additional Concerns
- ✓ General First Aid for Marine Related Injuries



Review Questions

Review Questions

1. A build-up of _____ is the primary trigger for the breathing mechanism.

C. Carbon dioxide

2. Decompression Sickness is caused by the formation of nitrogen _____ within the tissues of a diver's body.

B. Bubbles

3. Bubbles can form in a diver's tissues as he ascends to the surface if he:

D. Both A and/or C

Review Questions

4. Factors that increase one's susceptibility to Decompression Sickness include:

D. All of the Above.

5. Type I Decompression Sickness may be characterized by which of the following?

B. Skin Rash, Localized Pain

6. The onset of symptoms of lung over-expansion injuries is usually delayed and subtle.

B. False

Review Questions

7. The signs and symptoms mnemonic “ConVENTID” is designed to help the diver recall are:

A. (ConVENTID – Convulsions /Visual Disturbance/ Euphoria/ Nausea/Tinnitus, Twitching, Tingling/ Irritability/ Dizziness, Dyspnea)

8. The most obvious cause of an AGE (Arterial Gas Embolism) is:

C. Holding one’s breath.

Review Questions

9. Which of the following are potential lung over-pressurization injuries?

D. All of the Above.

10. The first aid for lung over-expansion injuries is the same as that for _____.

A. DCS

11. Discomfort in an air space during descent is a _____ . Discomfort in an airspace during ascent is a _____ .

D. Squeeze, Reverse Block

Review Questions

12. The victim of a near-drowning who appears to be completely recovered should go home and rest.

B. False

13. The field neurological exam should be repeated every _____ to _____ minutes while the patient is awaiting professional medical attention.

C. 15, 30

Review Questions

14. The standard medical treatment for decompression illness (both DCS and AGE) is in-water recompression.

B. False

15. A Dive Leader should have available at the dive site a(an)

D. All of the Above.



Any Questions ?