Diving Physiology

Topics in this Chapter
- Respiration and Circulation
- Decompression Illness
- Narcosis
- Gas Toxicity
- Barotrauma
- Additional Concerns
- Preparing for Emergencies

Respiration and Circulation

Pulmonary System
- Its role is the exchange of gases
  - Oxygen
    - Critical ingredient in the metabolic process
    - Introduced into the body with each inhaled breath
  - Carbon Dioxide
    - By-product of metabolism, and potentially harmful to the body at elevated levels
    - Expelled from the body with each exhaled breath
Respiration and Circulation

Pulmonary System

Components

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

Alveoli

- Intricate series of tissue structures, forming the outer surface of the lungs
- 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

Respiratory rate

- At rest, the normal rate is about 10 to 18 breaths per minute
- May be consciously controlled, but it is largely an involuntary reflex
- Breathing reflex primarily is triggered by the level of carbon dioxide present in the blood (and the production of carbon dioxide is dependent upon the body’s workload)
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
    • The movement of any gas, at the capillaries, is dictated by the tension of that dissolved gas in the blood and the tension of that dissolved gas in the tissue
Respiration and Circulation

• Cardio-Vascular System
  – 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

Respiration and Circulation

• Cardio-Vascular System
  – Heart rate
    • For average adults, the resting heart rate is about 60 to 80 beats per minute
      – May be higher in elderly persons and children
      – May be lower in well-conditioned athletes
    • Heart rate is controlled by neuro sensors and chemical stimuli, and responds to physiological and psychological stressors
**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)
    - Will be covered in detail later

**Decompression Illness**

**DCI and Patent Foramen Ovale**
- Foramen Ovale is a 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
  - It is estimated to occur in 10% to 20% of the population
  - It may partially or completely re-open under some circumstances
    - Often it is insignificant in other daily activities
    - For divers, it might increase the risk of DCI
    - Not necessarily a contraindication for diving
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
- 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

- Nitrogen Narcosis
  - Can intensify with physical or psychological stress
    - Swimming against a strong current
    - Poor-fitting or ill-performing equipment
    - Peer pressure
    - Engaging in unfamiliar activities
    - Excessive task loading
  - More likely to occur in cold, dark and murky water, than at the same depth in a warm, bright and clear tropical environment

- Nitrogen Narcosis
  - If narcosis occurs
    - Ascend, with buddy, to a shallower depth
    - No lingering concern after surfacing
Narcosis

Inert Gas Narcosis
- Other gases also can create a similar effect
  - Helium
    - Relatively light gas, less narcotic than nitrogen; used in trimix for deep diving
  - Argon
    - Relatively heavy gas, significantly more narcotic than nitrogen; used for dry suit inflation because of thermal properties

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

• 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
  – Signs and symptoms
    • Increased heart rate and blood pressure
    • Diminished hearing and vision
    • Headaches
    • Dizziness and confusion
    • Shortness of breath and breathing difficulty
    • Profuse sweating
    • Tremors
    • Unconsciousness

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
  EXTREME CONCERN WHEN USING REBREATHERS!
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
  - Signs and symptoms
    - Dangerously elevated heart rate and blood pressure
    - Headache
    - Dizziness, confusion and dementia
    - Hearing and vision dysfunction
    - Convulsions
    - Unconsciousness
    - Respiratory and cardiac arrest
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
    - Filters begin to fail
    - Lubricants begin to breakdown
  - Improper handling of 100% oxygen during gas blending, which results in internal flashing

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
  - Abort the dive, if headache, nausea, or other symptoms occur at depth
  - Have cylinders filled by a qualified technician at a reputable dive facility

Gas 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
- May be caused by
  - 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
Barotrauma

- Lung Injuries
  - Pneumothorax
    - Escaping air is trapped within pleural sac surrounding the lungs
      - Pressure is exerted upon the adjacent surface of the lung, and may cause the lung to collapse, resulting in respiratory distress
      - Pressure also may extend to the heart, resulting in cardiac distress (known as tension pneumothorax)
  - Mediastinal emphysema (or pneumomediastinum)
    - Escaping air gathers within the center of the chest, under the sternum
      - Pressure is exerted upon the heart and central portion of the lungs, which may cause cardiac and respiratory distress
  - Subcutaneous emphysema
    - Escaping air rises within the chest and gathers around the base of the neck (often just under the skin)
      - Pressure may be exerted upon the larynx (voice box), causing difficulty speaking and swallowing
      - Pressure may be exerted upon the trachea (windpipe), causing respiratory distress
Barotrauma

Lung Injuries
- 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

Barotrauma

Lung Injuries
- First aid
  - Ensure the ABC's
  - Activate EMS or seek medical attention
  - Administer oxygen
  - Monitor the patient
  - Treat for shock
  - Perform CPR when appropriate

Barotrauma

Ear Injuries
- Components of the ear
  - Outer ear
  - Middle ear
  - Inner ear
    - The ear drum is a membrane between the outer ear and middle ear
    - The round window and oval window are membranes between the middle ear and inner ear
Barotrauma

Ear Injuries
- Middle ear must be equalized to changing ambient pressure
  - Eustachian tube connects middle ear to throat
    - Descent: Valsalva maneuver (pinch nostrils while gently blowing through nose)
    - Ascent: air normally escapes on its own
    - Descent and ascent: swallow, wiggle jaw, look up, and/or tilt head from side-to-side to help open Eustachian tube

Barotrauma

Ear Injuries
- Delayed or ineffective equalization
  - Most often caused by diver inattention
  - Also can be caused by congestion due to illness or allergy

Barotrauma

Ear Injuries
- Improper equalization of middle ear will cause pressure to be exerted upon the ear drum
  - Pressure results in discomfort and pain
  - Excessive pressure can rupture the ear drum, allowing water to enter into middle ear
    - Immediately alleviates the pressure
    - Vertigo
    - Risk of infection
Barotrauma

Ear Injuries
- Improper equalization may cause damage to the tissues of the middle ear
  - Tissues become inflamed and swollen
  - Blood and fluids are squeezed from tissues, into the air space of the middle ear
    - Tinnitus / partial loss of hearing
    - Vertigo
    - Sensation of water within the ear
    - Pain in ear, perhaps radiating to jaw
    - Risk of infection

Barotrauma

Ear Injuries
- Improper equalization may result in alternobaric vertigo
  - Caused by a sudden pressure differential between middle ear and inner ear
    - Extreme dizziness
    - Disorientation
    - Nausea

Barotrauma

Ear Injuries
- Improper equalization may cause damage to round window and oval window
  - Excessive pressure can rupture the membrane, with leakage of fluids from the inner ear into the middle ear
    - Hearing impairment (immediate / long-term)
    - Vertigo (immediate / long-term)
Barotrauma

• Ear Injuries
  – Improper equalization also may cause damage to tissues of the outer ear
    • May be caused by tight-fitting hood, build up of wax in the ear canal, or non-vented ear plugs
    • Tissues become inflamed and swollen
    • Blood and fluids are squeezed from the tissues, into the air space of the outer ear canal
      – Hearing disturbance
      – Sensation of water in the ear

• Ear Injuries
  – When any of these injuries are suspected
    • Suspend further diving activities
    • Seek medical attention

• Ear Injuries
  – DCS-related bubbles can form in the fluids of the inner ear
    • Similar signs and symptoms
      – Hearing impairment
      – Vertigo
    • May or may not be accompanied by additional signs and symptoms of DCI
    • First aid is the same as in all other cases of DCI
Barotrauma

• Ear Injuries
  - Swimmers ear is an infection of the outer ear, and not a pressure-related injury
    • It can mimic barotrauma
      - Often starts with itching, and sensation of water in the ear
      - Hearing disturbance
      - Pain in and around ear, perhaps radiating to jaw

• Prevention and treatment of swimmers ear
  - Over-the-counter remedies
  - 50% alcohol / 50% vinegar mixture
  - More severe infections may require antibiotics or other prescription medications
  - When swimmers ear is suspected
    - Suspend further diving activities
    - Seek medical attention if pain is present

• Nasal Sinus Injuries
  - Nasal sinuses consist of four pairs of air-filled sacs
    • Maxillary: largest, located below each eye
    • Frontal: next largest, located above each eye
    • Ethmoid: located on either side of the nose
    • Sphenoid: located above the throat
**Barotrauma**

- **Nasal Sinus Injuries**
  - These air spaces must be equalized to changing ambient pressure
    - Equalization normally occurs spontaneously during respiration
    - Valsalva maneuver will aid equalization
    - Equalization can be precluded by
      - Congestion of nasal sinuses or nasal passageways, due to illness or allergy

- **Nasal Sinus Injuries**
  - Improper equalization may cause damage to tissues
    - Tissues become inflamed and swollen
    - Blood and fluids are squeezed from tissues, into the air space of the nasal sinuses
      - Inhibits subsequent equalization
      - Headache
      - Pressure, numbness or pain
      - Blood or bloody mucus in nostrils
      - Risk of infection

- **Nasal Sinus Injuries**
  - Preventative measures
    - Postpone diving activities while congested
    - Avoid attempts at forceful equalization
    - Abort the dive when the nasal sinuses do not readily equalize
Barotrauma

Nasal Sinus Injuries
- Decongestant medications
  - May help to clear the nasal sinuses
  - Risk of medication wearing off during the dive, resulting in a significant reverse block
  - Possible rebound effect
  - Adverse side effects, such as drowsiness, might be magnified at depth
  - Consult a dive medicine physician

Barotrauma

Face and Eye Injuries
- Dive mask creates an artificial air space, which must be equalized to ambient pressure during descent and ascent

Barotrauma

Face and Eye Injuries
- During descent
  - Equalization is achieved by exhaling a small amount of air through the nose, into the mask
  - An unequalized mask can cause
    - Bruising across the face
    - Petechial hemorrhaging of capillaries in the face and eyes
    - Blood-shot appearance to the eyes
Barotrauma

Face and Eye Injuries

- During ascent
  - Expanding air must be vented from mask
    - Some air may be gently forced into the nostrils
  - Excess air escapes around mask skirt
  - An overly-tight mask strap
    - Can prevent effective equalization during ascent
    - May cause peripheral bruising along outline of mask skirt

Barotrauma

Face and Eye Injuries

- First aid
  - These injuries normally heal on their own
  - In severe cases, ice may be applied to help relieve inflammation and discomfort
  - Any disturbance in vision should be medically evaluated prior to further diving

Barotrauma

Face and Eye Injuries

- Bubbles may form under a contact lens during ascent
  - Often it is a temporary condition
    - Soreness
    - Decreased visual acuity
    - Halo-like aberrations surrounding bright sources of light
Barotrauma

Face and Eye Injuries
- DAN recommends that only soft contact lenses be used for diving
  • Otherwise a diver should consider having corrective lenses installed in the mask

Barotrauma

Face and Eye Injuries
- Additional sources of irritation
  • Over-pressurization within mask may force contact lens to too-tightly adhere to eye
  • Mask defogging agents
  • Excessive ultraviolet light (bright sunlight)
  • Saltwater or chlorinated water

Barotrauma

Face and Eye Injuries
- In any case of persistent or lingering discomfort or visual disturbance
  • Seek medical attention
Barotrauma

- **Face and Eye Injuries**
  - DCS-related bubbles can form in the interior of the eye or its related structures
  - Possible signs and symptoms
    - Blurred or double vision, or loss of vision
    - Pain around the eye
  - May or may not be accompanied by additional signs and symptoms of DCI
  - First aid is the same as in all other cases of DCI

Barotrauma

- **Jaw and Tooth Pain**
  - As previously cited
  - Certain types of ear and sinus barotrauma, as well as infection, can create pain that radiates into the jaw and teeth

Barotrauma

- **Jaw and Tooth Pain**
  - Barodontalgia
  - At depth, air may enter into an enclosed space
    - Below an ill-fitting dental filling, crown or cap
    - Within the periodontal pocket of a loose or abscessed tooth
Barotrauma

Jaw and Tooth Pain
- Barodontalgia
  - Upon ascent, air cannot quickly escape from this enclosed space
    - Pain during ascent and after surfacing
    - Might displace the filling, crown or cap
  - Can be avoided with appropriate dental care

Jaw and Tooth Pain
- Additional causes
  - Biting down forcibly on regulator mouthpiece
  - Poor-fitting regulator mouthpiece

Gastro-Intestinal Pain
- Gas, within stomach and intestines, usually compresses upon descent and expands upon ascent
  - An increase of gas at depth can cause discomfort or pain upon ascent
    - Inadvertently swallowing air
  - Production of gas can be stimulated by certain foods
Barotrauma

- **Gastro-Intestinal Pain**
  - If it occurs during ascent
    - The diver should slow or stop, and wait for the discomfort to pass
    - Rarely causes any significant harm
      - Except if excess gas accumulates within a herniated segment of the intestines

Additional Concerns

**Drowning and Near-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
    - Precludes the on-gassing of oxygen

- 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
  - Death can occur hours or days later, due to accumulation of fluids (secondary drowning)
**Additional Concerns**

- **Drowning and Near-Drowning**
  - In any case of near-drowning
  - The diver should seek prompt medical attention

**Additional Concerns**

- **Hypothermia and Hyperthermia**
  - Hypothermia is caused by the loss of body heat
    - Water whisks away heat 25 times faster than air of the same temperature
      - Uncontrollable shivering can appear with a drop of 1°C or 2°F in core temperature
    - Cold numbs both the mind and the body
      - Affects motor skills and thought processes
      - Magnifies the impact of narcosis
      - Can be a factor in the onset of DCS

**Additional Concerns**

- **Hypothermia and Hyperthermia**
  - Hyperthermia occurs when the body produces or absorbs more heat than can be readily dissipated
    - Symptoms include
      - Profuse perspiration
      - Headache
      - Nausea
      - Dizziness
      - Fainting
Additional Concerns

- Hypothermia and Hyperthermia
  - Proper exposure protection
    - It is more than just a matter of personal comfort
    - It is also a matter of diver safety!

- If either is suspected during a dive
  - Terminate the dive
    - A hypothermic individual requires warming
    - A hyperthermic individual requires cooling, and hydration
  - Less severe symptoms often alleviate within a reasonable time
  - More significant symptoms will require prompt medical attention

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

• Dehydration
  – It can be caused by
    • Breathing air from a scuba cylinder, which is
drier than atmospheric air
    • Fluids lost through perspiration
    • Urge to urinate when immersed in cool water
    • Caffeinated and alcoholic beverages, which
can have a lingering diuretic effect

Additional Concerns

• Dehydration
  – It can “sneak up” on a diver
    • Drink sufficient quantities of water, or other
non-caffeinated and non-alcoholic beverages
    • Monitor the color of urine
      – It should be clear to light yellow

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
    • Psychological reaction
      – Confusion, uneasiness, apprehension
    • Physical reaction
      – Dizziness, nausea
Additional Concerns

- Mid-Water Disorientation
  - Effects might be overwhelming, leading to panic

  - Effects can be minimized by
    - Focusing on ascent / descent line
    - Focusing upon one's instruments
    - Focusing upon a dive buddy

Additional Concerns

- Seasickness
  - May occur when the brain receives sensory information from the eyes, which conflicts with sensory information from the inner ears
    - Can produce nausea and vomiting
Additional Concerns

Seasickness

- Possible contributing factors
  - Fatigue
  - Dehydration
  - Certain acidic foods, or foods which stimulate the production of stomach gases
  - Natural acids present in an empty stomach

Seasickness

- Preventative measures
  - Over-the-counter medications can be effective
    - But some have side effects that might be problematic at depth
    - Consult a dive medicine physician before taking this type of medication
  - Remain above deck in fresh air, near middle of the boat, and focus upon a fixed distant object near the horizon

Seasickness

- If it occurs
  - Head for the railing on the leeward side of boat
  - Avoid confined areas below deck
  - Symptoms may relieve once diver descends below the surface of the water
  - Symptoms quickly subside once back on dry land, but may need replenishing fluids
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

- It can be "fooled" by external pressure
  - Such as
    - Under-sized dry suit neck seal
    - Overly-tight collar of a wet suit
    - Improperly fitted hood
  - Incorrect signals can be transmitted to the heart, to slow and reduce blood pressure
    - Unconsciousness can occur

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
  - Possible, though rare, in scuba diving
    - Usually involves an out-of-air emergency
  - Principally arises in free diving
    - Associated with excessive hyperventilation prior to descent
Additional Concerns

Other Injuries
- Diving is a physical activity
  - At times it may be strenuous
  - It involves relatively heavy equipment
  - Sometimes it is conducted from the slippery deck of a rolling dive boat

Additional Concerns

Other Injuries
- Significant demands can be placed upon the participant's respiratory and cardio-vascular systems
  - In the water
  - Out of the water

Additional Concerns

Other Injuries
- Participants also can be exposed to other injuries common to any active endeavor
  - Sprains or fractures
  - Bruises or burns
  - Lacerations or abrasions
Additional Concerns

Other Injuries

- Most injuries can be prevented, or at least mitigated
  - Use common sense precautions related to equipment handling and environmental conditions
  - Ensure an appropriate level of health and fitness for diving

Additional Concerns

Other Injuries

- The response to any injury starts with the ABC’s
  - Airway (open)
  - Breathing (present)
  - Circulation (present)

Additional Concerns

Other Injuries

- Once the ABC’s are confirmed, the focus can turn to any specific injury
  - A suspected fracture should be immobilized
  - A burn may be cooled with freshwater
  - Serious bleeding should be controlled with direct pressure
  - A wound should be covered with an appropriate dressing
Any Questions?