Emergency Oxygen for Scuba Diving Injuries (EO2)

Student Handbook

DAN
DIVERS ALERT NETWORK

VERSION 3.1

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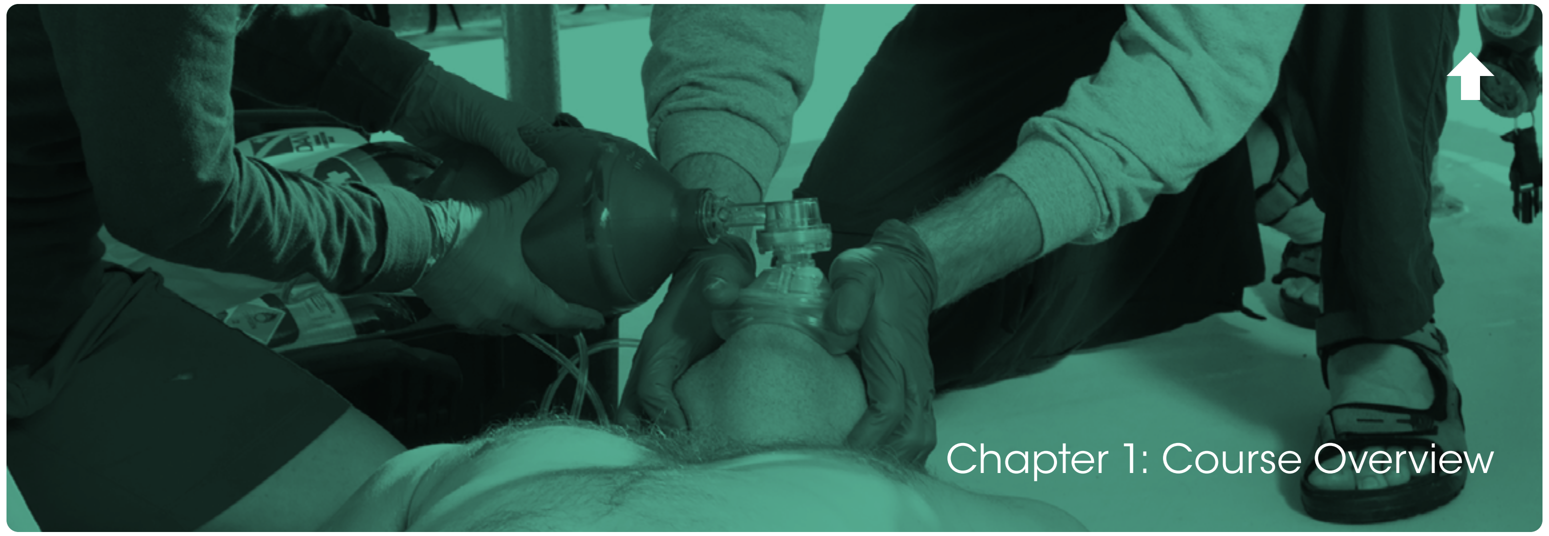
This program meets the current (as of December 2020) consensus on Guidelines for Resuscitation from the International Liaison Council on Resuscitation (ILCOR) and as issued by its member organizations including the American Heart Association (AHA), the European Council on Resuscitation (ERC), the Heart and Stroke Foundation of Canada (including the course requirements for CPR-C in Canada), Australia New Zealand Council on Resuscitation (ANZCOR), the Resuscitation Council of South Africa, the InterAmerican Heart Foundation, and the Resuscitation Council of Asia.
9th Edition, Rev 3.0, February 2023

Eighth edition published December 2017; Seventh edition published March 2012; sixth edition, May 2006; fifth edition, September 2002; fourth edition, February 1997; third edition, November 1994; second edition, April 1994; first edition, November 1993.

Table of Contents

EMERGENCY OXYGEN for SCUBA DIVING INJURIES



Chapter 1: Course Overview

Scuba diving injuries are rare and are often subtle when they occur. In the unlikely event of an injury, being able to recognize the problem and initiate appropriate action can speed the diver's recovery and minimize lasting effects. **Oxygen** first aid is one of the initial responses for diving injuries.

The Emergency Oxygen for Scuba Diving Injuries (EO2) course is an entry-level training program that teaches participants common presentations of dive injuries and how to provide emergency oxygen first aid.

During this course, participants will become familiar with the signs and symptoms associated with decompression illness and nonfatal drowning and the proper administration of supplemental oxygen. Proper assembly, disassembly and use of all component parts found in the DAN Oxygen Unit are included in the skills section of this course.

Successful completion of the Emergency Oxygen for Scuba Diving Injuries course includes demonstrating skill competency and passing a final knowledge assessment. Upon completion, you will receive a provider card indicating that you have been trained in administration of oxygen for scuba diving and drowning injuries.

First-Responder Roles and Responsibility

First aid is the provision of initial care for an injury or illness. The three key aims of first aid are to (1) preserve life, (2) prevent the condition from worsening and (3) promote recovery. All skills performed in an emergency should be within the scope of one's training. Maintain skills and knowledge proficiency by reading current literature and participating in supervised practice sessions. Talk to your Instructor for options.

Reading this handbook without instruction and practice will not make someone competent to use oxygen in a diving emergency.

Prerequisites

A current certification in full cardiopulmonary resuscitation (CPR) is a prerequisite for this program. Certification is accepted from any recognized organization. If you are not yet certified in CPR, please talk with your EO2 Instructor about becoming CPR certified before starting this course. There is no minimum age requirement to participate in this course. Some countries, states and local municipalities may have minimum age stipulations for the use of emergency oxygen.

Scuba Certification

Scuba diving certification is not a course prerequisite. This course teaches scuba divers and interested nondivers how to provide emergency oxygen first aid to injured divers. Familiarity with diving equipment and diving terminology will make understanding the material easier. However, interested and informed nondivers should be able to master the material.

Retraining

Emergency-response skills deteriorate with time. Retraining is required every two years to maintain Emergency Oxygen for Scuba Diving Injuries Provider certification, and regular practice is encouraged to retain proficiency. All skills performed in an emergency should be within the scope of one's training.

Continuing Education

Continuing education is encouraged in the form of additional training courses, supervised practice sessions, reading current literature and refresher training. Your EO2 Instructor can provide information about these programs.

How To Use this Handbook

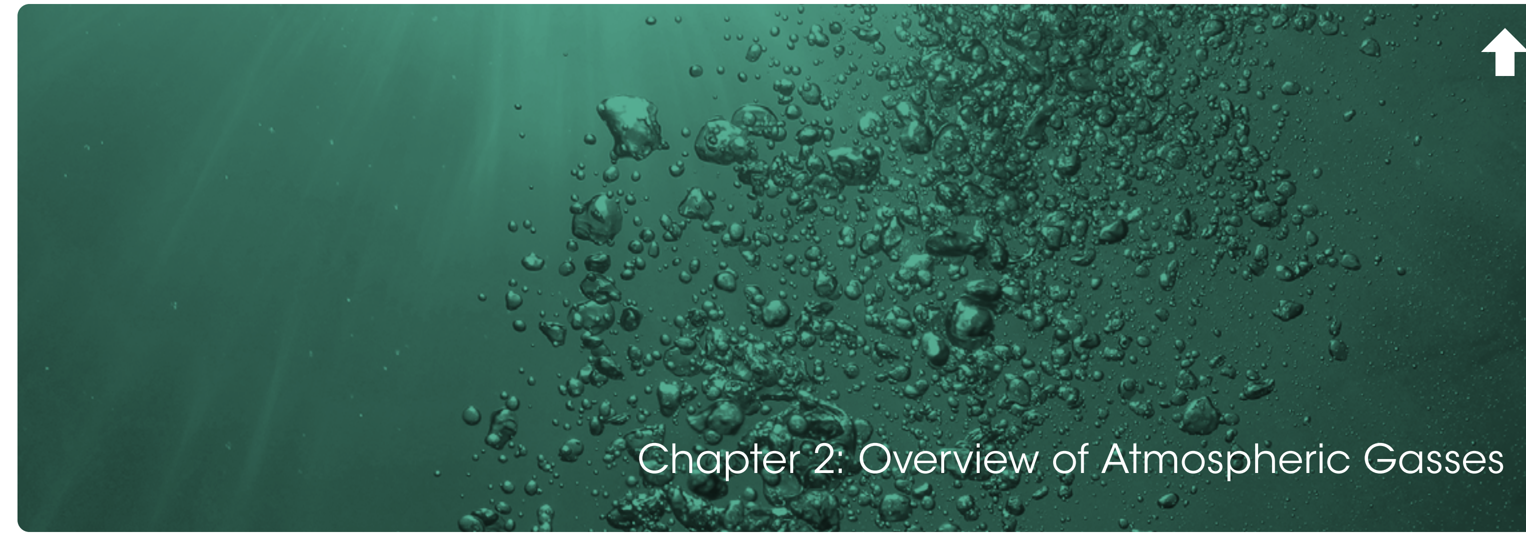
Each chapter in this student handbook contains three distinct features.

- The beginning of each chapter has a list of questions to assist with learning. This is the information you should look for as you read the material, complete the knowledge development sections, and participate in class discussions.
- Boxes labeled "Note" provide explanations that are important for understanding the material just presented.

- Boxes labeled “Advanced Concepts” contain additional information beyond what is required for this course. It is enrichment for students who want to know more.

Terminology

This student handbook introduces medical terms that may be unfamiliar to some readers. Familiarity with basic medical terminology will enhance the quality of communication with emergency and health care workers. A glossary of terms is provided in the back of this handbook.



Chapter 2: Overview of Atmospheric Gasses

Objectives

1. What is oxygen?
2. How much oxygen is in both inhaled and exhaled air as we breathe?
3. How is oxygen transported to body tissues?
4. What is carbon dioxide, and how is it eliminated from the body?
5. What is nitrogen?
6. What is **carbon monoxide**, and why is it dangerous?

The air we breathe is composed of many different gases. One is critical to our survival; others play a significant role when we breathe under pressure while scuba diving. This chapter provides a brief overview of some of these atmospheric gases and the role they may play under pressure.

Oxygen (O_2)

Oxygen is a colorless, odorless, tasteless gas that composes approximately 21 percent of the Earth’s atmosphere. It is a vital element for survival and is needed for cellular metabolism. We may experience discomfort, unconsciousness or death within minutes when oxygen supplies are inadequate (hypoxia) or absent (anoxia).

Inhaled oxygen is primarily transported from the alveolar capillaries throughout the body by red blood cells (erythrocytes). Hemoglobin is the oxygen-carrying molecule within erythrocytes responsible for binding both oxygen and carbon dioxide. At rest, humans consume approximately 5 percent of the available 21 percent of oxygen in the air. Exhaled air therefore contains about 16 percent oxygen. These percentages will vary somewhat by individual and level of activity, but they provide a tangible example of oxygen utilization.

This fact has practical importance for rescue breathing, because our exhaled breath contains less oxygen than normal air.

Note:
Although exhaled air has lower oxygen content than atmospheric air, this amount is still sufficient for effective rescue breaths.

Advanced Concepts

During aerobic metabolism, our cells require oxygen to convert biochemical energy in the form of nutrients (sugar, proteins and fatty acids) into the energy-storage molecule called adenosine triphosphate (ATP). The production of ATP generates water, heat energy and carbon dioxide.

In health care settings, blood oxygen levels are commonly measured with a pulse oximeter. This device, which is often placed over the end of a finger, measures hemoglobin saturation — the percent of hemoglobin binding sites occupied by oxygen — through a color shift between oxygenated and deoxygenated blood states. Normal values while breathing air are 95-100 percent at low to moderate altitudes. Values below this warrant medical attention. **Hypoxemia** (low levels of blood oxygenation) may necessitate prolonged supplemental oxygen therapy to maintain values within normal levels.

The role of oxygen for diving injuries is to promote **inert** gas washout and enhance oxygen delivery to compromised tissues. When providing supplemental oxygen to an injured diver, a pulse oximeter is not used as a measure of oxygen treatment effectiveness or as an assessment of inert gas washout.

Advanced Concepts

Carbon dioxide is heavily concentrated in blood as bicarbonate (HCO_3^-) and serves a critical role in acid-base buffering. The remaining carbon dioxide is found either dissolved in plasma or bound to hemoglobin.

Carbon Dioxide (CO_2)

Normal air contains only about 0.04 percent carbon dioxide, which is a waste product of cellular metabolism. Exhaled gas from respiration contains approximately 4-5 percent carbon dioxide. Elevated levels of carbon dioxide in a breathing-gas mixture can lead to drowsiness, dizziness and unconsciousness; this is especially true when diving or breathing under increased atmospheric pressure.

Note:
Although exhaled air contains higher levels of carbon dioxide than air, rescue breaths — if performed correctly — should not result in significant elevations in the individual's carbon dioxide levels. In all immersion-related cases in which rescue breaths or other respiratory devices are used (bag valve mask or positive pressure device), supplemental oxygen is recommended.

Advanced Concepts

An elevation in exhaled carbon dioxide levels, relative to inhaled air, is an indication of metabolic activity. In some medical settings, carbon dioxide levels in exhaled air are monitored (capnography) and indicate cellular respiration and adequacy of airway management.

Nitrogen (N_2)

Nitrogen exists in different chemical forms. As a gas, nitrogen composes about 78 percent of the Earth's atmosphere and in this form is physiologically inert, meaning it is not involved in cellular metabolism. In nondivers who remain at a constant ambient pressure, the concentration of nitrogen in the exhaled air is also about 78 percent. In the case of divers who have been breathing inert gas under pressure, the percentage of exhaled nitrogen would be expected to rise above this level while offgassing. Because nitrogen is an inert gas, however, it does not interfere with resuscitation efforts during rescue breathing.

Inert gas absorption (nitrogen and helium) is associated with **decompression sickness** (DCS). DCS and the role of oxygen are discussed in the next chapter.

Advanced Concepts

Ingested or organic nitrogen (taken in as a solid, liquid or supplement) is compounded with hydrogen and other ions to form amines — the foundation of amino acids, which make up proteins. These amine groups are broken down and absorbed by our digestive system but do not enter our tissues or bloodstream as absorbed gas (N_2). As a result, ingestion of amines does not pose a decompression risk or alter our propensity for DCS. The only form of nitrogen that plays a role in DCS is the inorganic gas molecule N_2.

Carbon Monoxide (CO)

Certain gases such as carbon monoxide interfere with tissue oxygen delivery. carbon monoxide binds more readily to hemoglobin and inhibits both the uptake of oxygen and the delivery to tissues. Carbon monoxide poisoning can lead to fatal tissue hypoxia. Even small amounts of carbon monoxide in a diver's breathing gas can be hazardous. Inspired gas partial pressures increase with depth, so even small fractions of carbon monoxide within a cylinder can become toxic when breathed under pressure. For this reason it is critical to regularly test compressor air purity and quality. The use of portable gasoline-powered air compressors require extra caution because combustion engines generate carbon monoxide in the exhaust. A diver exposed to elevated levels of carbon monoxide may exhibit severe headaches, altered levels of consciousness and other neurological **symptoms**.

Review Questions

1. Oxygen is a clear, odorless gas essential to life.
   a. True
   b. False

2. The atmospheric air we inhale contains ____ percent oxygen.
   a. 12
   b. 16
   c. 21
   d. 27

3. The air we exhale contains about ______ % oxygen.
   a. 12
   b. 16
   c. 21
   d. 27

4. Oxygen is carried throughout the body by
   a. white blood cells
   b. red blood cells
   c. bone marrow
   d. blood plasma

5. Carbon dioxide is
   a. a waste product of metabolism
   b. a toxic gas
   c. essential for life
   d. an inert gas

6. Nitrogen comprises ____ percent of atmospheric air.
   a. 21
   b. 27
   c. 67
   d. 78

7. Carbon monoxide is
   a. a waste product of metabolism
   b. a toxic gas
   c. essential for life
   d. an inert gas

Review answers are on Page 65.

Chapter 3: Respiration and Circulation

Objectives

1. What is hypoxia?
2. Why is oxygen necessary for life?
3. Where does gas exchange occur in the body?
4. What body structures comprise the respiratory system?
5. What body structures are included in the cardiovascular system?

Oxygen (O_2) is essential for life. Within minutes of experiencing severe oxygen deficiency (**hypoxia**) or the absence of oxygen (**anoxia**), severe discomfort, unconsciousness or or death may occur.

Under normal circumstances, breathing ensures an adequate oxygen supply to tissues. The respiratory system provides an effective interface between the bloodstream and the atmosphere and facilitates gas exchange. Most critical to normal life is the intake of oxygen and removal of **carbon dioxide** (CO_2).

Carbon dioxide results from cellular **metabolism** and is transported by blood to the lungs, where gas exchange across the alveolar-**capillary** membrane enables elimination in the exhaled breath. In normal respiration, elevated levels of carbon dioxide, not low levels of oxygen, provide the primary respiratory stimulus. The rapid elevation of dissolved carbon dioxide during short periods of breath-holding provides quick insight into the power of its influence.

The Respiratory System

The respiratory system is comprised of the upper airways (mouth, nose and **pharynx**), the **trachea** (windpipe) and the lungs. Key supporting structures include the chest wall (ribs and **intercostal muscles**) and diaphragm (a muscle critical to respiration that separates the **thorax** from the abdomen). Surrounding the lungs and lining the inside of the chest wall is a thin membrane called the **pleura**. Although this is one continuous membrane, its coverage of both the lungs and chest wall forms a double layer. Between these two pleural-membrane layers is a potential space (see Advanced Concepts box) that contains a thin layer of fluid that acts as a lubricant, allowing efficient movement of the lungs during breathing.

Air is drawn into the mouth and nose and passes into the pharynx. The pharynx divides into two distinct passages: the trachea and the esophagus. The opening to the trachea is protected from food (solids and liquids) during swallowing by a flexible flap of tissue called the **epiglottis**. The esophagus, located behind the trachea, is a conduit for food and fluids en route to the stomach.

In contrast to solids and fluids, air travels from the pharynx through the **larynx** (voice box) and into the trachea. The trachea consists of a series of semicircular **cartilaginous** rings that prevent collapse. The trachea passes down into the chest cavity and branches into the right and left **bronchi**, which enter the right and left lungs, respectively. The bronchi progressively divide into smaller and smaller tubes and finally into the **alveoli**. This branching pattern is commonly referred to as the bronchial tree.

The alveoli, located at the end of the smallest branches of the respiratory tree, have extremely thin walls and are surrounded by the pulmonary capillaries. The alveoli have been likened to tiny balloons or clusters of grapes.

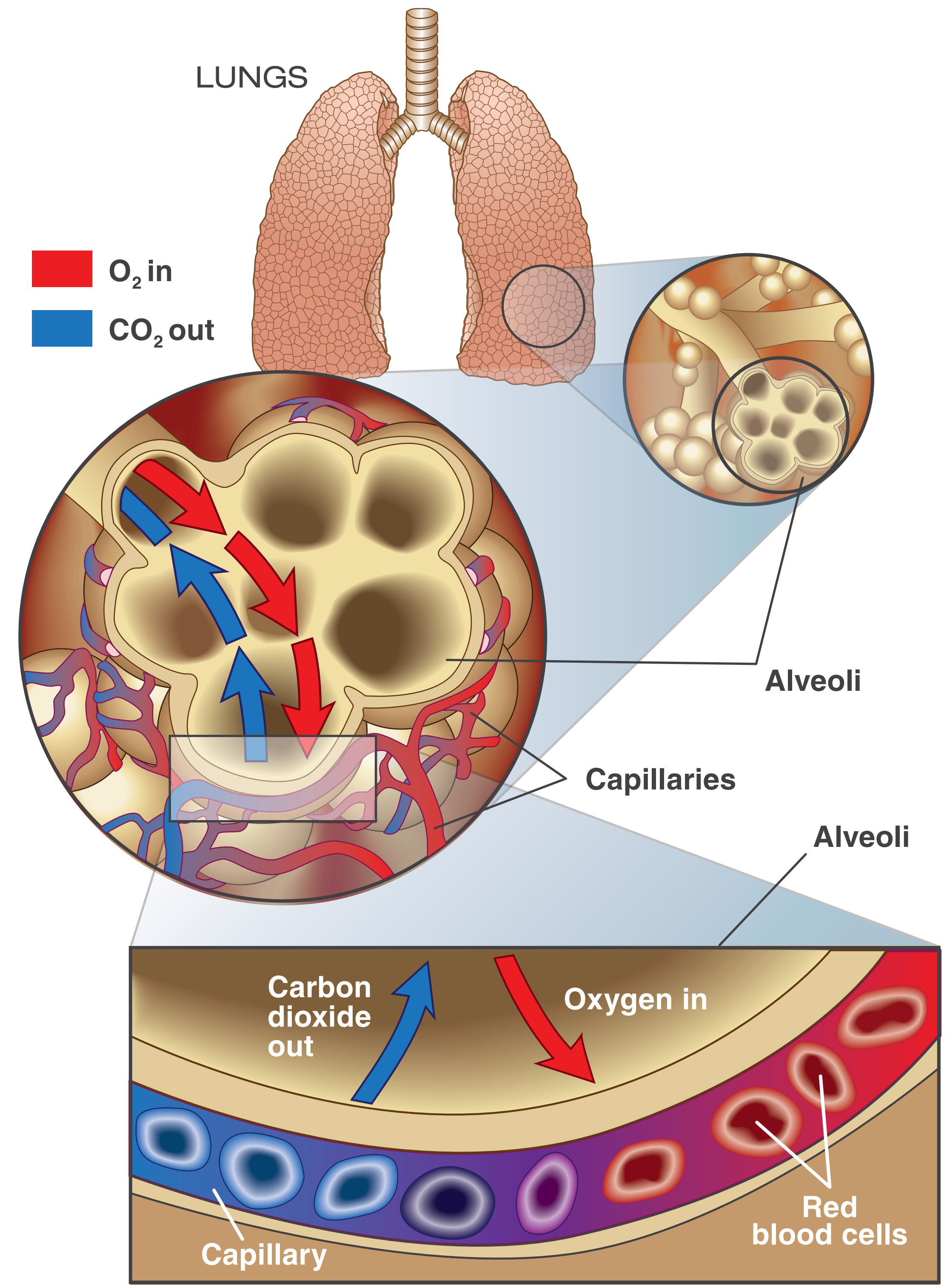
Advanced Concepts

Potential Space: The double-layered pleural membrane is made up of the parietal layer, which lines the thoracic cavity, and the visceral layer, which coats the organs.

These two layers normally remain closely adherent due to a slightly negative pressure that keeps them from separating. Because there isn't a separation between these membranes, this area is known as a potential space and becomes a true space only if the membranes are injured or rupture.

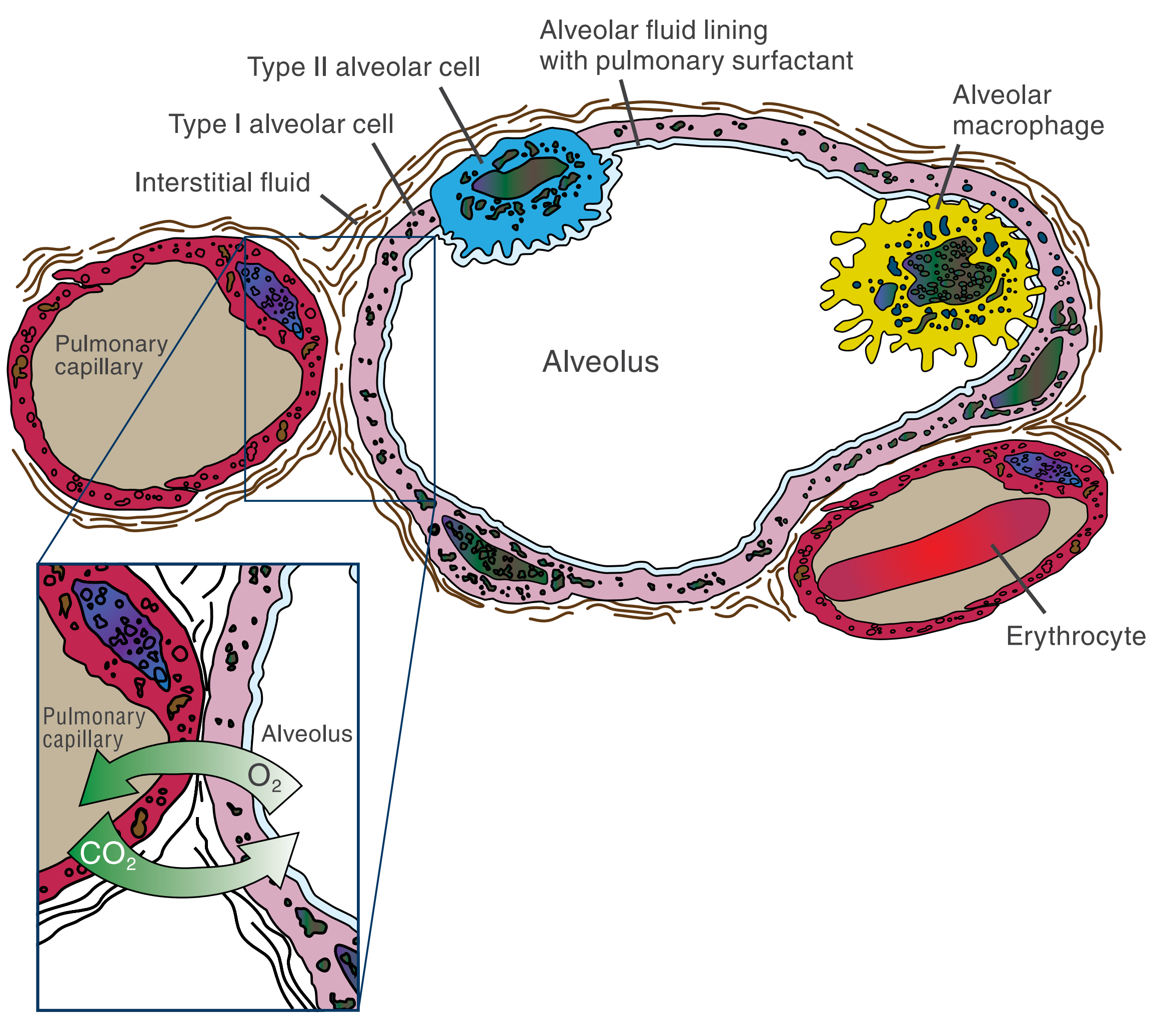
A pneumothorax forms from the entry of air between these layers (intrapleural space) and may form from escaped alveolar air subsequent to pulmonary barotrauma.

In both lungs, millions of alveoli cover a combined surface area of around (70 square meters/ 750 square feet) — or roughly the size of a tennis court.



A detergentlike substance known as lung or pulmonary **surfactant** coats the inner surface of the alveoli. Pulmonary surfactant decreases the surface tension of water within the alveoli and thus reduces its tendency to collapse at the end of expiration. If the surfactant is removed, as may occur in a submersion incident, the alveoli may collapse and remain collapsed after the inhaled water is removed (or reabsorbed), severely compromising gas exchange.

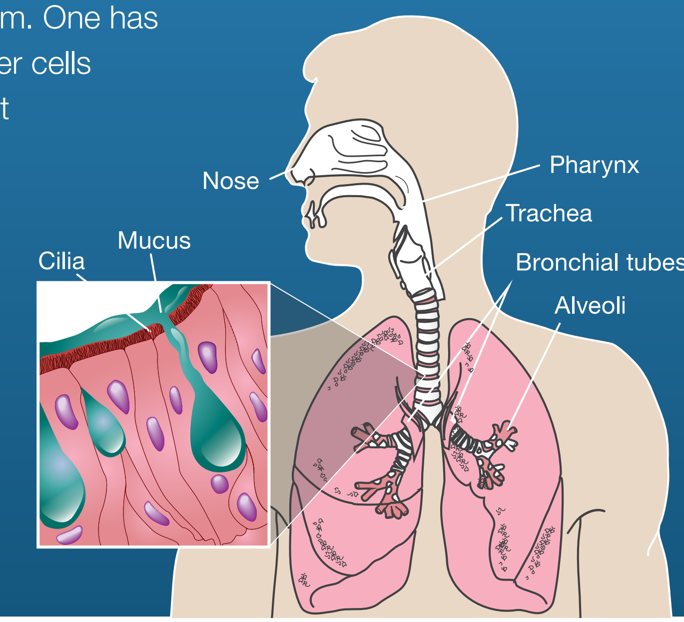
Large areas of collapsed alveoli are known as **atelectasis** and may evolve into a pneumonic focus (pneumonia) if they become infected. This is one reason why follow-up medical care is critical in nonfatal drowning. Appropriate intervention can reduce or prevent complications associated with drowning.



The average adult alveolus has an estimated diameter of 200-300 micrometers and is only a cell layer thick. Alveoli lie adjacent to capillaries that are also one cell layer thick, and this proximity enables the rapid exchange of carbon dioxide and oxygen. The thin alveolarcapillary membrane separates the content of the lung from the bloodstream. If this membrane tears or becomes compromised due to trauma from a lung-overexpansion injury (pulmonary barotrauma), it may enable gas to pass out of the alveoli and into the bloodstream. Gas entering the vascular system can travel throughout the body as an air embolism. This topic is discussed in more detail later in this chapter.

Advanced Concepts

Two types of cells line the respiratory system. One has small hairlike structures called cilia; the other cells produce a mucous substance that is swept by cilia. These two cells work in concert. The sticky mucous substance captures foreign particles, and the cilia move this mucus up into the pharynx, where it can be swallowed and digested together with any trapped foreign particles. In smokers, the mucus is thicker and the cilia are damaged, which hinders the lungs' natural self-cleaning mechanism.

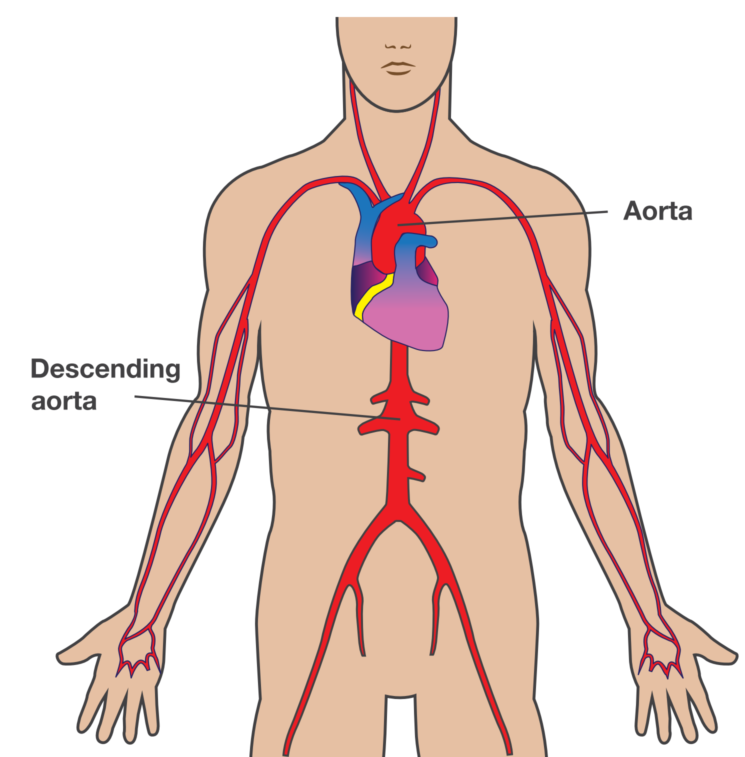


The Cardiovascular System

The cardiovascular system includes the heart and blood vessels. It is a closed-circuit system dedicated to pumping blood, transporting oxygen and nutrients to tissues via the arteries and removing waste products such as carbon dioxide via the veins.

The Heart

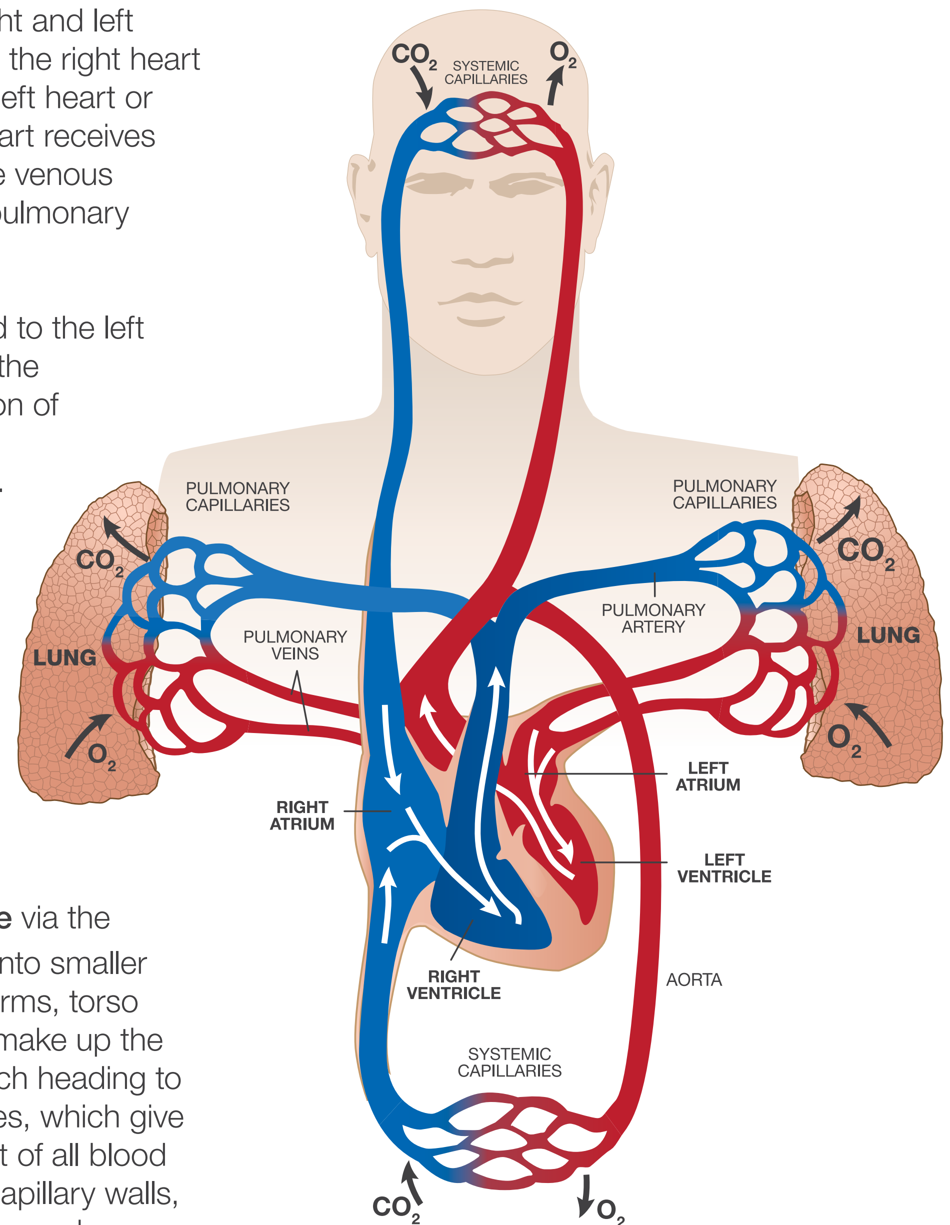
The heart is a hollow muscular organ situated in the thoracic cavity between the lungs in a space called the **mediastinum**. A thin connective tissue sac called the **pericardium** surrounds it. The pericardium — like the pleural linings of the lungs — reduces friction between the heart and surrounding structures.



The heart is a strong muscular pump that, in the average adult, has the capacity to beat spontaneously at a rate of about 70 times per minute. (The normal resting heart rate is 60-100 beats per minute and may be as low as 40 beats per minute in athletes.[2]) Approximately 6 liters (about 1.5 gallons) of blood is pumped throughout the body every minute. When exercising, this output may double or triple depending on exertion.

The heart is divided into a right and left pump system (also known as the right heart or pulmonary circuit and the left heart or systemic circuit). The right heart receives deoxygenated blood from the venous system and pumps it to the pulmonary circuit to exchange gases.

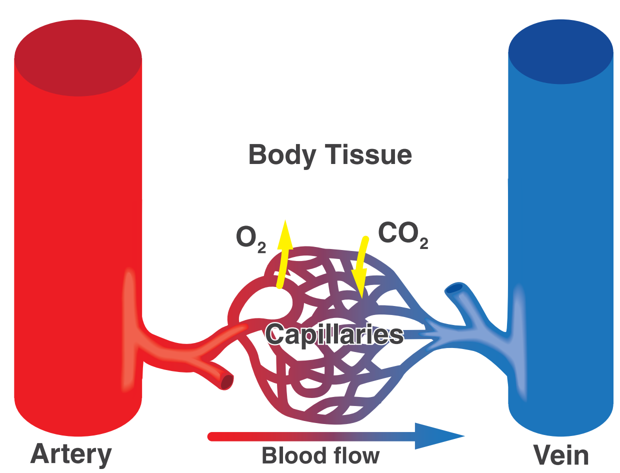
Oxygenated blood is returned to the left heart, where it is pumped to the systemic circuit. Transportation of blood through both circuits completes a circulatory cycle.



Blood Vessels

Blood leaves the left **ventricle** via the **aorta**, which then branches into smaller arteries to supply the head, arms, torso and legs. The blood vessels make up the vascular tree, with each branch heading to progressively smaller branches, which give rise to capillaries, the smallest of all blood vessels. Through these thin capillary walls, gases and nutrients are exchanged. Functionally, the heart and large blood vessels represent a pump-and-distribution system for the capillaries, responsible for supplying tissues with oxygen and nutrients and removing carbon dioxide and other metabolic waste products.

From the peripheral capillaries, the blood is gathered into small, thinwalled veins and returned via larger veins to the atria of the heart. Most veins direct blood flow by means of one-way valves that prevent blood from traveling in the wrong direction or pooling due to gravity.

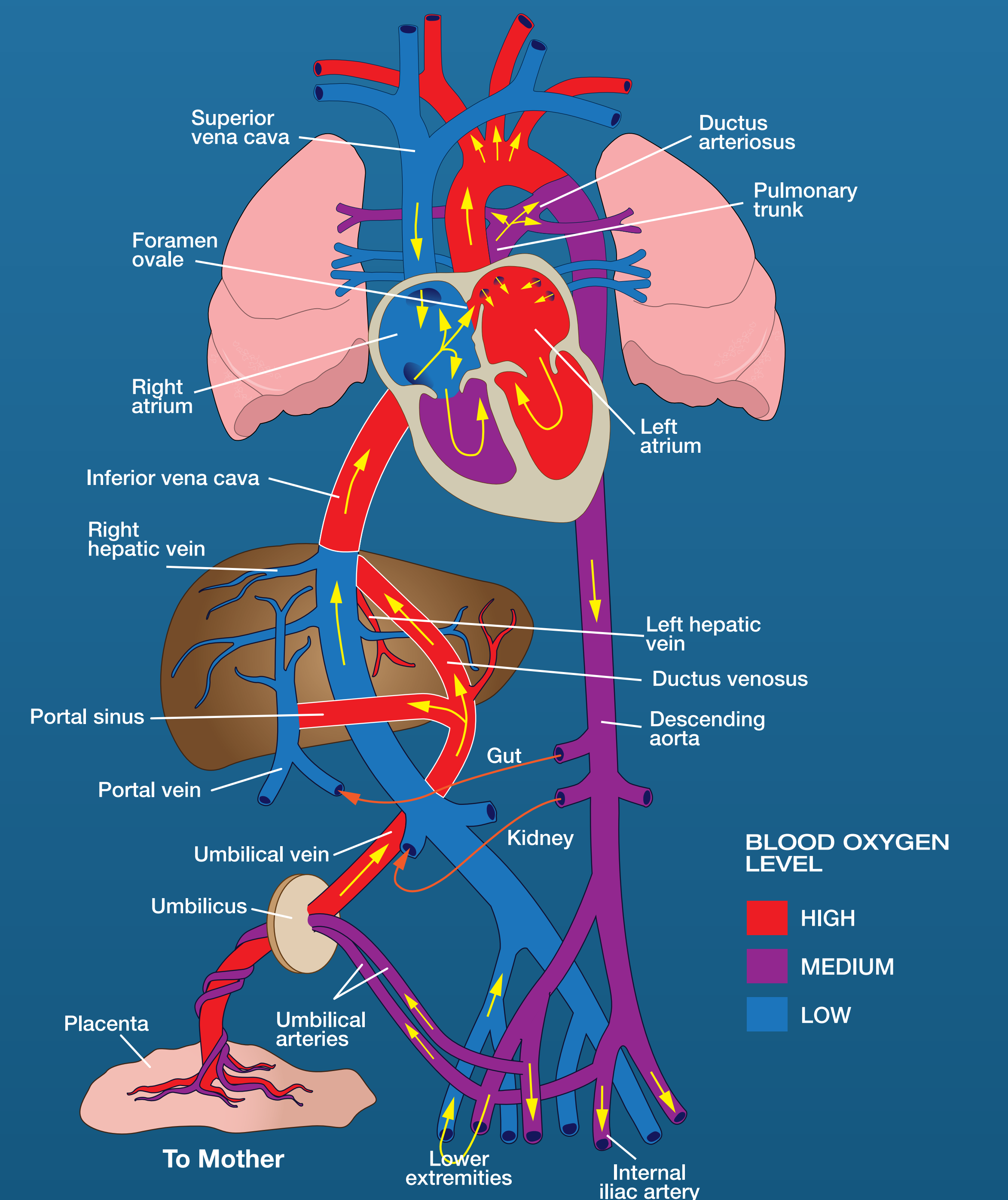


Advanced Concepts

Fetal Circulation

Within the uterus, the fetus lives in a fluid-filled environment. As such, the lungs are not used for gas exchange, and circulating blood is largely shunted away from pulmonary tissue. In the fetus, gas exchange takes place in the placenta, drawing available oxygen from the mother's blood.

(Continued on the next page.)



Fetal Circulation (Continued)

Two unique passages in the fetal circulation allow blood to bypass the lungs. These two portals, known as the ductus arteriosus and foramen ovale, usually close soon after birth with the baby's first breaths.

The ductus arteriosus (a duct between two arteries) enables blood coming from the right ventricle to directly enter the aorta and thus bypass the lungs. Once this passage closes, blood is transported to the lungs, which are now needed for blood oxygenation. A vestige (remnant) of the ductus will remain as a ligament bonding the aorta and the pulmonary artery (ligamentum arteriosum or arterial ligament).

The foramen ovale (an oval-shaped hole) is a passage between the atria that allows blood to shunt from the right **atrium** to the left, thus bypassing the nonfunctional lungs. At birth, when the pressures in the left atrium increase, this passage usually closes, leaving only a depression in the wall, known as the **fossa ovalis**. Closure of the foramen is incomplete in approximately 25-30 percent of the population, thus leaving a patent (open) foramen ovale (PFO). The PFO is not physiologically relevant in many persons, but it may predispose a small number of people to certain medical issues.

Advanced Concepts

Blood is a specialized fluid (actually a distinct organ system) that links the respiratory system to the rest of the body. Approximately 55 percent of our circulating blood volume is comprised of plasma, the visible fluid fraction of blood. While mostly water, plasma also contains proteins, glucose, minerals, nutrients, waste products and dissolved gases. The cellular constituents of blood include erythrocytes (red blood cells, or RBC), which transport oxygen and carbon dioxide, and leukocytes (white blood cells, or WBC), which play a critical role in infection control and inflammatory responses. The third constituent is **platelets**, which are cell fragments responsible for initiating the clotting process.

Review Questions

1. Hypoxia is a condition of low oxygen supply.
   a. True
   b. False

2. An absence of oxygen
   a. may cause cell death
   b. is known as anoxia
   c. may cause unconsciousness
   d. all of the above

3. Gas exchange takes place at the
   a. vein-artery interface
   b. long bone joints
   c. alveolar-capillary membrane
   d. muscle-nerve junctions

4. The respiratory system does not include which of the following:
   a. nose
   b. mouth
   c. trachea
   d. heart

5. The circulatory system does not include which of the following:
   a. mouth
   b. veins
   c. arteries
   d. heart

Review answers are on Page 65.

Chapter 4: Decompression Illness (DCI)

Objectives

1. What are the most important initial actions in responding to diving accidents?
2. What is decompression illness (DCI)?
3. What is the primary cause of decompression sickness (DCS)?
4. What are the primary symptoms of DCS?
5. What is arterial gas embolism (AGE)?
6. What is the primary risk factor for AGE?
7. Why is it important to seek medical evaluation when DCI is suspected?
8. What are the most prevalent symptoms of DCI?
9. What are the typical onset times of DCS and AGE symptoms?

The term **decompression illness** (DCI) describes **signs** and symptoms arising either during or subsequent to decompression, and it encompasses two different but potentially linked processes:

1. decompression sickness (DCS)
2. arterial gas embolism (AGE)

Note:
While the underlying cause of these two conditions may be different, the initial medical management (first aid) is the same. The most important initial actions performed in diving accidents are early recognition and the use of supplemental oxygen.

Decompression Sickness

DCS results from bubbles formed within tissues or blood from dissolved inert gas (nitrogen or helium). The size, quantity and location of these bubbles determine the location, severity and impact on normal physiological function. Besides the anticipated mechanical effects that can cause tissue distortion and blood-flow interruption, bubble formation may trigger a chain of biochemical effects. These include activation of clotting mechanisms, systemic inflammation, leakage of fluids out of the circulatory system and reactive vasoconstriction. These effects may persist long after bubbles are gone and may play a significant role in the duration and severity of clinical signs and symptoms.

While the effects of bubbles have an impact on us on a systemic level, specific signs and symptoms are thought to result from either bubble accumulation or its impact on specific areas. Examples include joint pain, motor or sensory dysfunctions and skin rash.

The mild or ambiguous nature of some DCS symptoms may result in denial on the part of some injured divers. The assessments and tools offered during this course may help with motivation for providers as well as injured divers to pursue first aid care and follow-up treatment.

DCS is generally only life-threatening with extreme exposures. Early treatment with high concentrations of oxygen (as close to 100 percent as possible) has been shown to speed symptom resolution and optimize the impact of recompression therapy.[4] Though symptom resolution is a desired effect of oxygen first aid, it is important to emphasize that it should not be considered a definitive treatment or arbitrarily stopped when symptoms resolve.

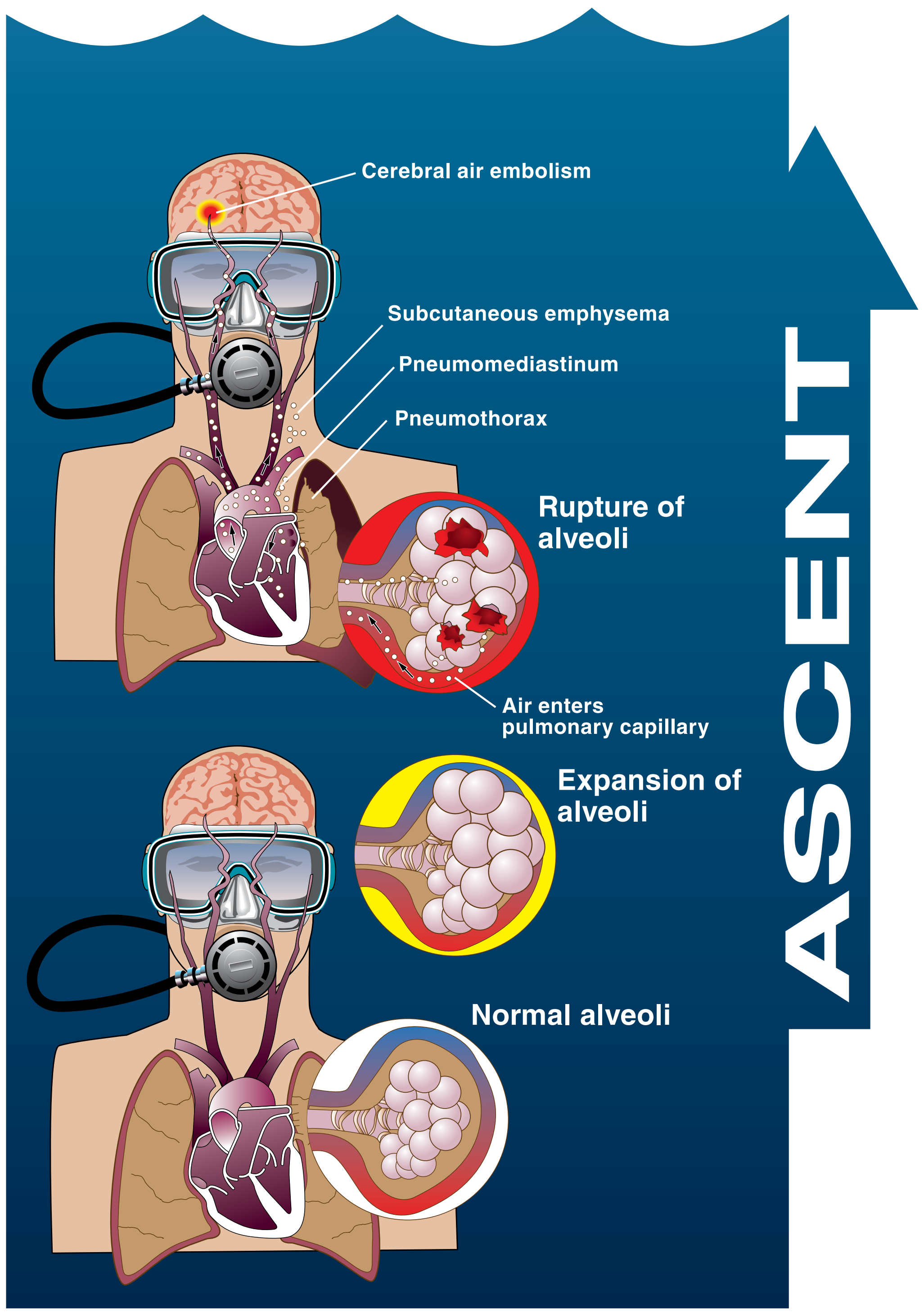
Important aspects to remember about DCS include:

- Symptom onset occurs after surfacing or, in some extreme exposures, well into ascent.
- Factors contributing to bubble formation include the degree of supersaturation (the amount of excess inert gas), rapid ascent and decreasing ambient pressure (such as when flying or driving to altitude after diving).
- The development of DCS symptoms may differ substantially among individuals; symptoms may be subtle or obvious.
- Multiple areas of the body may be involved.

Arterial Gas Embolism (AGE)

AGE in divers typically results from a lung-overexpansion injury. The greatest risk for this injury occurs in shallow water and may result from breath-holding in as little as 1.2 meters (4 feet) of seawater. Lung-tissue trauma can allow the entrance of breathing gas into the blood vessels returning to the heart (pulmonary veins). These bubbles, if transported to the brain, can cause rapid and dramatic effects.

AGE is the most severe result of pulmonary barotrauma and often presents suddenly either near or at the surface.



Pulmonary barotrauma with subsequent AGE and representation of brain (cerebral) injury. Recreated by Divers Alert Network from *Lancet* 2011; 377: 154.

Any suspicion of neurological symptoms should prompt immediate oxygen therapy and transportation to a medical facility.

The primary risk factor for AGE is breath-holding during ascent. Other potential risk factors include underlying conditions such as lung infections and preexisting diseases such as asthma that may increase the risk of air trapping.

Depending on the location of gas collection, signs and symptoms may include chest pain, changes in voice pitch, difficulty breathing or swallowing, gas bubbles felt under the skin (typically around upper thorax, neck and/or face) and cyanosis (bluish coloration of the lips).

Advanced Concepts

A separate but related concern is AGE that occurs secondary to venous bubbles bypassing the pulmonary filter and entering the arterial system directly. The process through which blood passes from the right side of the circulatory system to the left and bypasses the pulmonary filter is called shunting — in this case, right-to-left shunting. Shunting may occur through a physiologically relevant PFO or passage through the lungs (transpulmonary shunt). Regardless of the method, problems can occur when bubbles enter the arterial circulation. Bubbles may affect the central nervous system (CNS) and cause acute neurological symptoms. Symptom onset in this scenario could develop after a longer interval than the 10-15 minutes typically described in cases of AGE since the source of the arterialized bubbles is from the venous system and not pulmonary barotrauma. It is important to note that while bubbles in the systemic circulation are undesirable, their presence does not automatically cause symptoms. Bubbles have been visualized in the left heart following decompression in subjects who have not developed symptomatic DCI.

Common Signs and Symptoms of DCI

While providing emergency oxygen to an injured diver, you may see his or her condition change with time. In the case of complete symptom resolution, continue oxygen administration, and seek medical attention regardless of perceived improvement.

Injured divers may have one or more of the following signs and symptoms. This list is ranked in order of presentation frequency based on decompression illness of 2,346 recreational diving incidents reported to Divers Alert Network from 1998 to 2004.

- **Pain** (initial symptom in 41 percent of cases)

  Commonly associated with neurological symptoms, the pain has been characterized as a dull, sharp, boring or aching sensation in or around a joint or muscle. It may begin gradually and build in intensity or be so mild that it is disregarded.

  – Movement of the effected joint or limb may or may not make a difference in the severity of the pain. The pain may be out of proportion to the amount of work or exercise performed and may be referred to as unusual or just "different."

– DCI pain can be difficult to distinguish from normal aches and pains. Symptoms can mimic other illnesses such as viral infections, muscle or joint pain, fatigue from exertion and other nonspecific discomforts.

- **Paresthesia/Numbness** (initial symptoms in 27 percent of cases)

  Paresthesia/anesthesia/dysesthesia are terms that refer to altered sensations and may present as abnormal sensation (paresthesia), decreased or lost sensation (anesthesia) or hypersensitivity (dysesthesia). Paresthesia is commonly characterized as a pins-and-needles sensation. These altered sensations may affect only a small patch (or patches) of skin and may go unnoticed by the diver until they are revealed by a thorough medical evaluation. A diver may complain that an extremity has "fallen asleep" or a "funny bone" has been hit. Numbness and tingling most often occur in the limbs and may be associated with complaints such as a cold, heavy or swollen sensation.

- **Constitutional symptoms** (initial symptoms in 14 percent of cases)

  These are generalized symptoms that do not affect a particular part of the body. Examples include extreme fatigue, general malaise and nausea.

  – Extreme fatigue: It is not unusual to be fatigued after a scuba dive or other physical activity. The fatigue associated with DCI is typically more severe and out of proportion with the level of exertion required by the dive. The diver may want to lie down, sleep or ignore personal responsibilities such as stowing gear or cleaning equipment.

- **Vertigo/Dizziness** (initial symptoms in 6 percent of cases)

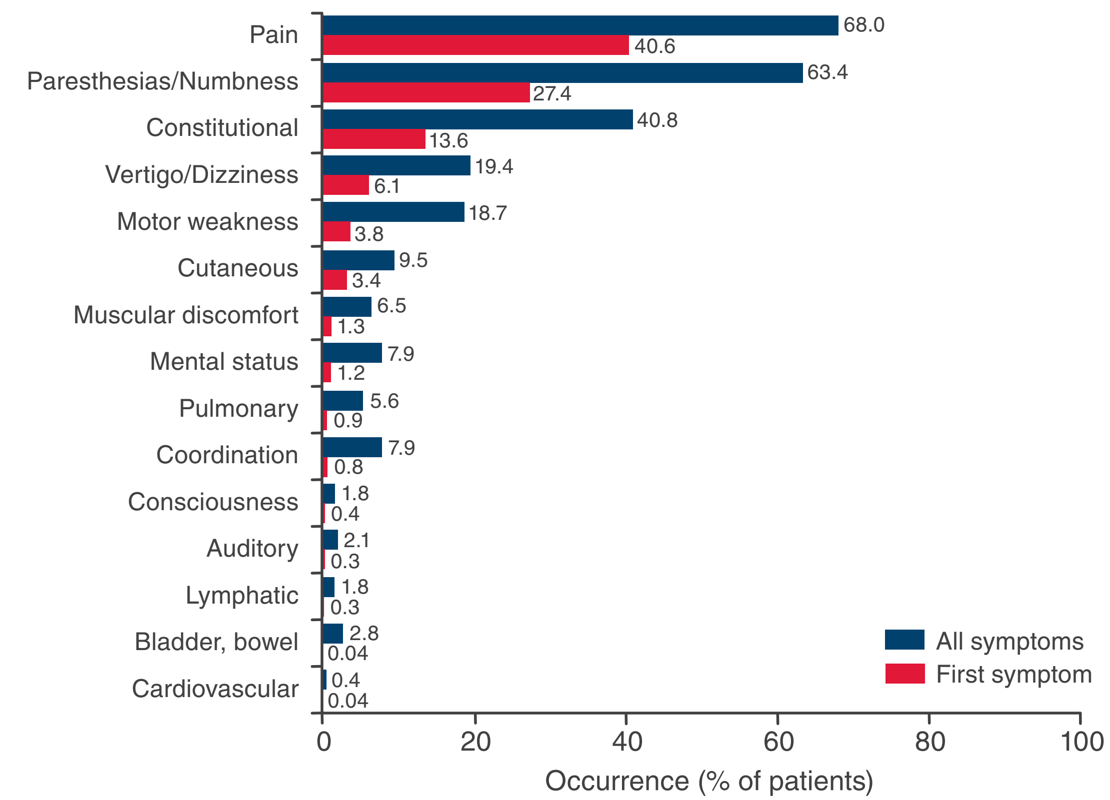
  Vertigo: Vertigo is generally described as an acute "sensation of spinning" (i.e.,the environment moves around the diver or the diver around the environment), merry-go-round, drunkenness, or being off-balance. Vertigo presenting during or after the dive should be considered a serious symptom suggesting inner-ear/vestibular involvement.

  – There are several causes for such symptoms that are not related to DCI. These include round- or oval-window rupture (associated with difficulty equalizing), alternobaric vertigo (each ear experiencing a different pressure exposure) and caloric vertigo (each ear experiencing a different temperature exposure).

  – Dizziness: Dizziness is a feeling of unsteadiness, which may also be characterized as lightheadedness, and is commonly associated with nausea.

- **Motor weakness** (initial symptom in 4 percent of cases)

  This symptom may present as difficulty walking due to decreased muscular strength or limb paralysis.



Classification and frequency distribution of initial and eventual manifestations of decompression illness in 2,346 recreational diving accidents reported to Divers Alert Network from 1998 to 2004

- **Cutaneous (skin) symptoms** (initial symptom in 3 percent of cases)

  Skin signs are often located on the chest, abdomen, back, buttocks or thighs. Rashes commonly migrate (move to different parts of the body). Effected areas may be tender or itch and are thus often confused with allergies or contact dermatitis.

- **Altered mental status** (initial symptom in 1.2 percent of cases)

  Symptoms may include confusion, personality changes or speech disturbances (slurring of words or nonsensical speech).

- **Pulmonary issues** (initial symptom in 0.9 percent of cases)

  Difficulty breathing may be the result of pulmonary barotrauma or a severe form of DCS known as the chokes (a rare but life-threatening condition caused by an overload of **venous gas emboli** that severely affects cardiorespiratory function). There are also many other causes of respiratory compromise not necessarily related to or associated with DCI — all of which should prompt medical evaluation.

- **Coordination/cerebellar function** (initial symptom in 0.8 percent of cases)

  Cerebellar function controls the coordination of the body's voluntary movements. Although lack of coordination rarely appears as an initial DCS symptom, it is a common clinical finding on exam and generally associated with a form of neurological DCS. It can be manifested as the inability to walk a straight line or decreased motor function and control.

Any suspicion of neurological symptoms should prompt immediate oxygen therapy and transportation to a medical facility.

Other Signs and Symptoms of DCI

- **Altered level of consciousness**: Identified as an initial symptom in 0.4 percent of cases
- **Lymphatic DCS**: Identified as an initial symptom in only 0.3 percent of cases, it deserves mention because this symptom does not immediately resolve with successful recompression treatment. It is often characterized by localized swelling affecting the trunk and shoulders.
- **Audiovestibular or inner-ear DCS**: This is an alteration of balance or hearing that can be associated with vertigo.
- **Visual disturbance**: Loss or blurring of vision or loss of visual fields
- **Bowel and bladder issues**: Spinal cord DCS may injure the nerves responsible for bladder and bowel control. Urinary catheterization is often indicated to relieve injury to the bladder.
- **Cardiovascular issues**: Hypotension and/or chest pain caused by bubbles within the chambers of the heart or extravascular bubbles around the heart can be the result of pulmonary barotrauma as well as a compression or tension pneumothorax.
- **Convulsions are rare**.

Epidemiology of DCI and DCS

DCI is an uncommon event that nonetheless warrants attention and concerted efforts to prevent. Based on 441 confirmed or possible incidents of DCI referenced in the *2008 DAN Annual Diving Report*, 3.9 percent were classified as possible AGE.[5]

The occurrence of DCS varies by population. Based on DAN data, the per-dive rate among recreational divers is 0.01-0.019 percent; among scientific divers it's 0.015 percent; for U.S. Navy divers it's 0.030 percent; and for commercial divers it's 0.095 percent.[5,6]

Previously published per-dive DCS rates based on 135,000 dives by 9,000 recreational divers were 0.03 percent. This rate was higher in those who performed deep cold-water wreck dives versus the group aboard warm-water liveaboards. The incidence of DCS from warm-water liveaboards was 2/10,000 (0.0002) and among cold-water wreck divers in the North Sea 28/10,000 (0.0028).[7]

DCI Symptom Onset

While the timing of symptom onset varies, the majority of people complain of DCS symptoms within six hours following a dive. Symptom onset may be delayed by as much as 24 hours, though beyond this time frame the diagnosis becomes increasingly questionable.

In contrast to DCS, AGE will typically show a more dramatic array of neurological symptoms, most of which will show up immediately upon surfacing or within 15 minutes of the time of injury. As one might expect, sudden neurological injury that leads to unconsciousness may result in drowning.

Oxygen and the Importance of Proper Medical Evaluation of DCI

The diagnosis of DCI is based on history and clinical findings — there is no diagnostic test. Symptoms can range from very mild to severe and, particularly in the former case, may be dismissed by divers or appear to resolve by the time medical care is sought.

In some cases the use of oxygen leads to symptom resolution, which may prompt the decision to forego medical assessment. DAN recommends seeking prompt medical evaluation in all cases of suspected DCI regardless of the response to oxygen first aid. For those tempted to avoid medical assessment, be advised that symptoms may recur, and the risk of recurrence may be reduced with hyperbaric treatment.

Recompression Therapy

An injured diver may feel better or experience reduced symptom severity after receiving emergency oxygen. Despite symptom improvement, and in some cases resolution, divers should still seek medical evaluation. The primary medical concern is that symptoms (especially neurological symptoms) may recur when supplemental oxygen therapy is stopped. This is one of the reasons DAN recommends transportation to the nearest medical facility for evaluation and not necessarily to the nearest hyperbaric chamber.

This is advised for several reasons.

- Only a small number of hospitals are equipped with hyperbaric chambers.
- Many hospitals with hyperbaric chambers are not equipped to treat diving injuries 24 hours a day. It takes time to assemble a chamber crew for treatment of a diving injury.
- Before accepting the transfer of an injured diver, many hospitals require a referral from DAN or a physician.
- Some chambers are open only when they have patients.
- Some chambers are not equipped to treat divers.

Every dive injury is unique, and crucial medical decisions must be made individually by a physician trained in dive medicine. The decision about where to treat an injured diver can be made only after a thorough medical evaluation and appropriate consultation. DAN is always available to provide information to emergency medical staff regarding diving injuries and the potential benefit of hyperbaric treatment. DAN also provides evacuation assistance and care coordination with treating facilities. Prolonged treatment delays, usually measured in days, may reduce the effectiveness of treatment and may extend the time needed to achieve optimal symptom resolution. It should be understood, however, that in the majority of less severe cases, minor delays of a few hours rarely affect the final treatment outcome.

Residual Symptoms

Residual symptoms following hyperbaric oxygen treatment are not uncommon, especially in severe cases or when considerable delays (sometimes measured in days) in treatment initiation have occurred.

Divers who experience persistent symptoms following hyperbaric oxygen therapy should remain under the care of a hyperbaric physician until symptoms have resolved or further therapy is deemed either unnecessary or unlikely to provide further benefit. A decision to return to diving should be made in consultation with a physician knowledgeable in dive medicine.

Review Questions

1. Decompression illness includes
   a. decompression sickness
   b. arterial gas embolism
   c. both of the above

2. The most important initial actions in responding to diving accidents are to recognize there is a problem and to administer 100 percent oxygen.
   a. True
   b. False

3. DCS is caused by
   a. breath-hold during descent
   b. breath-hold during ascent
   c. inert gas bubbles in the body

4. The primary risk factor for AGE is
   a. breath-hold during descent
   b. breath-hold during ascent
   c. inert gas bubbles in the body

5. It is important to seek medical evaluation when DCI is suspected because
   a. symptom resolution does not mean DCI is no longer present
   b. symptoms may recur
   c. risk of recurrence may be reduced by hyperbaric treatment
   d. all of the above

6. The single most common symptom of DCI is
   a. numbness
   b. constitutional (fatigue, nausea)
   c. muscle weakness
   d. pain
   e. balance/equilibrium

7. Initial DCS symptoms
   a. occur within 15 minutes of the time of injury
   b. typically occur within six hours of surfacing
   c. may be delayed up to 24 hours
   d. both b and c

8. AGE symptoms
   a. occur within 15 minutes of the time of injury
   b. typically occur within six hours of surfacing
   c. may be delayed up to 24 hours
   d. both b and c

9. People who received first aid for suspected DCI should always receive a follow-up evaluation by a dive medicine physician.
   a. True
   b. False

10. Returning to diving following DCI should be done in conjunction with a physician knowledgeable in dive medicine.
   a. True
   b. False

Review answers are on Page 65.

Chapter 5: Oxygen and Diving Injuries

Objectives

1. What are the benefits of providing a high concentration of oxygen to an injured diver?
2. How does establishing a gas **gradient** help the injured diver?
3. What is the primary goal of emergency oxygen for injured divers?
4. What critical factors affect the percentage of oxygen delivery when using a demand valve?
5. What is the initial flow rate for constant-flow oxygen-delivery systems?
6. What is the priority for oxygen delivery in remote areas?
7. What are the concerns for oxygen toxicity when delivering emergency oxygen first aid?
8. What are the symptoms of nonfatal drowning?
9. What is the first responder's role in a nonfatal drowning?

The most common diving injuries for which oxygen use is recommended are AGE and DCS. In the case of AGE, bubbles may enter the arterial system following lung overexpansion and lung-tissue rupture. In the case of DCS, problems arise when gas dissolved in body tissues during a dive comes out of solution in the form of bubbles during or after decompression. Bubbles may cause tissue disruption, compromise blood flow, trigger inflammatory responses and/or cause other problems.

Though most cases of DCS are mild and do not pose an immediate risk to life, impaired circulation or function in vital areas such as the brain and spinal cord can result in severe neurological symptoms. These can range from mild tingling and pain to weakness, paralysis, difficulty breathing, unconsciousness and even death.

Oxygen administration for a suspected diving injury creates a partial-pressure gradient that accelerates the rate of inert-gas elimination, and therefore bubble elimination, from the body. Effectively, when oxygen instead of inert gas is inhaled, the oxygen blood levels are so much higher, relatively speaking, that a more rapid outflow of inert gas into the lungs develops to restore equilibrium. This can slow and then reverse bubble formation. The high concentration of inhaled oxygen increases the inbound gradient for oxygen, increasing oxygen delivery to injured or ischemic tissues (areas with poor circulation). This may also reduce pain and swelling (edema) and limit or reverse hypoxic injury.

The Emergency Oxygen for Scuba Diving Injuries course emphasizes the use of oxygen for diving injuries and nonfatal drowning but does not address other indications for oxygen treatment.

Nonfatal Drowning

Nonfatal drowning refers to a situation in which someone almost died from being submerged underwater and was unable to breathe. In the case of prolonged asphyxia (not breathing) or reduced cardiac and lung function due to submersion, oxygen therapy may be crucial. While nonfatal-drowning victims may quickly revive, lung complications are common and require medical attention. In addition, fluid and electrolyte imbalances may develop with the potential for delayed symptom onset.[12]

Symptoms of nonfatal drowning may include difficulty breathing, bluish discoloration of the lips, abdominal distention, chest pain, confusion, coughing up pink frothy sputum, irritability and unconsciousness. Individuals may also be anxious or cold and would benefit from removal of wet clothes and possible treatment for hypothermia.[11]

As a first responder, your primary role is to monitor vital signs, provide supplemental oxygen and transport to the nearest medical facility as soon as possible.

Note:
Keep yourself safe. Avoid in-water rescue unless trained and properly equipped.

Oxygen Flow Rates

The primary goal of emergency oxygen for injured divers is to deliver the highest percentage of inspired oxygen possible. Remembering this goal is key to delivering optimal care.

There are two variables that affect delivered oxygen concentrations: mask fit and flow rate (measured in liters per minute or **lpm**). In the case of demand valves with oral resuscitation masks (discussed in Chapter 16: Oxygen Delivery Systems and Components), proper fit and seal are critical because the flow rate is not adjusted. When using constant-flow systems, mask fit is still crucial because leaks result in decreased inspired fractions of oxygen (FiO2). Enhanced flow rates are an inefficient way to compensate for a poor-fitting mask.

Delivery Device	Flow Rate	Inspired Fraction+
Oronasal mask (pocket mask)	10 lpm	≤ 0.5–0.6 (50%–60%)*
Nonrebreather mask	10-15 lpm	≤ 0.8 (80%)**
Bag valve mask	15 lpm	≤ 0.9–0.95 (90%–95%)
Demand valve (MTV)	N/A	≤ 0.9–0.95 (90%–95%)

** May vary with respiratory rate **Less variation with changes in respiratory rate*
+Delivery fractions vary with the equipment and techniques used. This table summarizes various oxygen-delivery systems and potential values of inspired oxygen with their use.

Nasal cannulae are generally operated at relatively low flow rates of 2-4 lpm. Nasal cannulae are the least-efficient method of oxygen delivery, typically delivering fractions no greater than 0.3 (30 percent). Simple face masks may deliver fractions of 0.5-0.6 at flow rates between 10-15 lpm.

Nonrebreather masks can deliver a higher fraction but probably still no greater than 0.8. Demand valves are appropriate for conscious and spontaneously breathing divers and with careful mask management may deliver fractions up to 0.9-0.95.

Accidents frequently occur in remote locations or far away from medical services, and oxygen supplies are generally limited. Rescuers face the dilemma between maximizing inspired fractions and limiting flow rates in an attempt to conserve oxygen supplies. The priority should always be to maintain the highest inspired fractions possible.

As shown in the above table, the best solution is the demand valve (or manually triggered ventilator used as a demand valve). If continuous-flow delivery is required or the only method available, start at 10-15 lpm and increase or decrease in increments based on the needs of the diver, ensuring that the reservoir bag remains full.

Flow rates above 10 lpm will not cause harm but will deplete oxygen supplies more quickly. If the next level of care is accessible before the supply is exhausted, higher flow rates can be used to maintain optimal oxygen fractions and enhance the injured diver's comfort. Any perceived or suspected worsening in a diver's condition should prompt reassessment.

Hazards of Breathing Oxygen

Oxygen toxicity can occur when one breathes high concentrations of oxygen for prolonged periods or while under pressure. Oxygen toxicity occurs in two forms: central nervous system (CNS) and pulmonary (lung) toxicity. In CNS oxygen toxicity, seizures may develop when someone breathes oxygen at greater than 1 atmosphere absolute (ATA) pressure. The risk of acute toxicity increases with elevations in partial pressure. For this reason, the accepted safe recreational limit for oxygen partial pressure while underwater is 1.4 ATA.

Breathing high concentrations of oxygen for prolonged periods at the surface can cause pulmonary oxygen toxicity, which is quite distinct from CNS toxicity. In this setting, lung tissue may become irritated when breathing elevated oxygen concentrations. The underlying mechanism for this is the production of oxygen free radicals in a quantity that overwhelms our cellular antioxidant defenses. Initial symptoms may include substernal (behind the sternum) irritation, burning sensation with inspiration, and coughing.

The most severe symptoms may occur after about 12 to 16 hours of exposure at 1 ATA.[13] The time to initial symptom onset is expected to decrease at higher partial pressures (greater than 1 ATA). Symptoms may be seen from 8 to 14 hours at 1.5 ATA[14] and from 3 to 6 hours at 2 ATA.[13,14] At higher pressures, symptoms may occur more quickly but are often less severe due to limited exposure times. The prevailing concern with oxygen partial pressure levels greater than 2.5 ATA is CNS toxicity.[12,14,15]

CNS toxicity is **not** a concern for the oxygen provider rendering first aid. Pulmonary oxygen toxicity is also not a significant concern for first responders delivering oxygen at maximal concentrations on land or at sea level for less than 12-24 hours.

Advanced Concepts

Chemical oxygen systems deliver neither sufficient flow rates nor sufficient oxygen volume to be effective. The average measured flow rates were 3 lpm (Pollock and Hobbs, 2002) and less than 2 lpm (Pollock and Natoli, 2010) with total flow durations of little more than 15 minutes for one reactant set.

Review Questions

1. The primary goal of delivering the highest concentration of oxygen possible to an injured diver is to facilitate inert gas washout and improve oxygen delivery to compromised tissues.
   a. True
   b. False

2. Providing a high concentration of oxygen to an injured diver may provide these benefits:
   a. accelerate inert gas elimination
   b. reduce bubble size
   c. enhance oxygen delivery to tissues
   d. reduce swelling
   e. all of the above

3. Symptoms of nonfatal drowning may include
   a. difficulty breathing
   b. abdominal distension
   c. chest pain
   d. hyperthermia
   e. all but d

4. In the event of an unresponsive drowning victim requiring **CPR**, begin with **ventilations** and follow the ABC protocols of CPR.
   a. True
   b. False

5. As a first responder to a nonfatal drowning, your role is to
   a. monitor vital signs
   b. provide supplemental oxygen
   c. transport to the nearest medical facility
   d. all of the above

6. The initial flow rate for constant-flow oxygen delivery is
   a. 2-4 lpm
   b. 10-15 lpm
   c. 20-25 lpm
   d. the rate the injured diver will tolerate

7. The percentage of oxygen delivered when using a demand valve is influenced by
   a. flow rate
   b. mask fit
   c. mask seal
   d. both b and c

8. In remote areas, the priority in oxygen delivery is
   a. to conserve oxygen supplies
   b. to maximize the highest inspired fraction of oxygen
   c. limit the flow of oxygen

9. Oxygen toxicity, whether CNS or pulmonary, is not a concern for oxygen first aid administered to an injured diver.
   a. True
   b. False

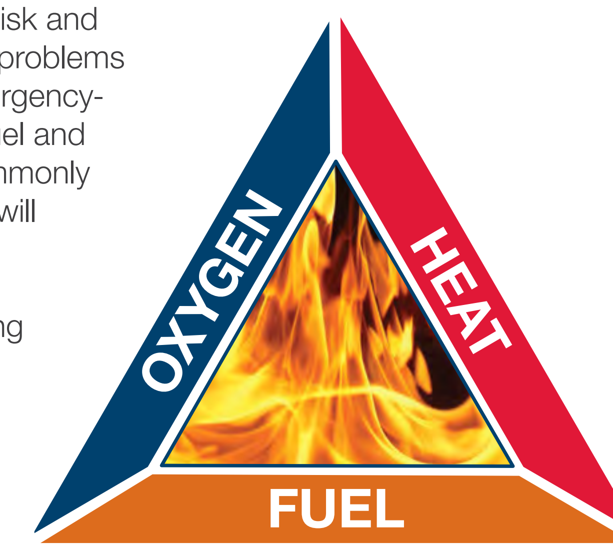
Review answers are on Page 65.

Chapter 6: Handling Oxygen Safely

Objectives

1. What is the fire triangle, and how is oxygen involved?
2. What safety precautions should be implemented when handling and using oxygen equipment?
3. What grade of oxygen should be used for diving first aid?
4. What documentation is required to receive an oxygen fill?
5. How should an oxygen unit be stored?
6. When should an oxygen unit's components and cylinder pressure be checked?
7. When and how should reusable oxygen masks and removable plastic oxygen system parts be cleaned?

Oxygen is not flammable, but all substances need oxygen to burn and may burn violently in an environment of pure oxygen. The higher the oxygen concentration, the greater the potential fire risk and acceleration (CGA P45 section 4.1 2018). However, problems associated with the use of properly maintained emergency-oxygen devices are rare. Three elements — heat, fuel and oxygen — are required for a fire to exist. This is commonly called the fire triangle. Emergency oxygen systems will always have at least one element: oxygen.



Oxygen providers should reduce the risks of handling oxygen. Be sure that the hazards from fuel (hydrocarbons are commonly used as lubricants in diving and are found on dive boats), heat from the sun and rapid opening of the oxygen cylinder valve are minimized.

Where Does Pure Oxygen Come From?

Fractional distillation of air yields pure oxygen. Air is first filtered to remove any debris and dirt. Compressed to very high pressures, it is dried to remove water vapor. To liquefy the gas, it is cooled to very low temperatures and allowed to slowly rewarm. As it is rewarming, various components of air (primarily oxygen and nitrogen) are captured and stored in separate containers as they reach their particular boiling points.

There are many grades of oxygen, but the three primary ones that oxygen providers need to consider are

- Aviator-grade oxygen
- Medical-grade oxygen
- Industrial-grade oxygen

Each grade must be 99.5 percent pure oxygen; however, differences exist in how the cylinders are filled, affecting the overall purity of the oxygen. For example, to prevent freezing at high altitudes, aviator-grade oxygen has a lower moisture content than medical-grade oxygen.

The filling procedures for medical-grade oxygen require that an odor test be conducted and the cylinder contents be evacuated before the fill. When odors are detected or damage to the valve or cylinder is observed, medical-grade oxygen cylinders are either retired or cleaned before being returned to use.

Industrial-grade oxygen is not recommended for use with dive injuries. Industrial-grade oxygen guidelines allow for a certain percentage of impurities and other gases to be contained within the cylinder. While both aviator- and medical-grade oxygen are suitable for breathing, industrial-grade oxygen may not be. The procedures for filling industrial oxygen cylinders do not ensure that the oxygen is free of contamination.

Safety Precautions When Using Oxygen

Oxygen cylinders require the same care as scuba cylinders with a few additional precautions.

- Do not allow the use of any oil or grease on any cylinder or device that comes in contact with oxygen. Hydrocarbons are an especially significant risk due to combustibility. The result may be a fire.
- Oxygen cylinders should not be exposed to temperatures higher than 52°C (125°F) in storage (e.g., in a car trunk).
- Do not allow smoking or an open flame around oxygen and oxygen equipment.
- When turning on an oxygen cylinder valve, always turn it slowly to allow the system to pressurize. This will reduce the possibility of an oxygen fire if combustible contaminants have been introduced into the system. Once the system is pressurized, open the valve one full turn.
- Remember to provide adequate ventilation when using oxygen. In a confined, poorly ventilated space (e.g., the cabin of a boat), the oxygen concentration may build up and create a fire hazard.
- Use only equipment (cylinders, regulators, valves and gauges) made to be used with oxygen. Avoid adapting scuba equipment for use with oxygen.
- Visually inspect the condition of valve seats and oxygen washers, and make sure the materials are compatible for oxygen use.
- Keep the valves closed with the system purged when the unit is not in use. Close valves on empty cylinders. Empty cylinders should be refilled immediately after use.
- An oxygen cylinder should always be secured so that it cannot fall. When carrying an oxygen cylinder by hand, carry it with both hands, and avoid holding it by the valve or regulator. When transporting an oxygen cylinder in a car, secure and block the cylinder so it does not roll.

Filling Oxygen Cylinders

In many areas, medical-grade oxygen is considered a prescription drug, which can make it difficult to refill your emergency oxygen cylinder. The most common method of documenting the need for oxygen is a prescription; however, prescriptions are for diagnosed medical conditions. The prescription allows for use only by the individual who was given the prescription.

The other method of obtaining an oxygen cylinder fill is by providing documentation of training in the use of emergency oxygen. Your DFA Pro Provider card is your documentation of appropriate training. Since retraining is to be completed every two years, you will need to maintain your skills by taking a refresher program. Ask your instructor about retraining opportunities.

Another less common method is use of a prospective prescription, which allows a trained individual to acquire oxygen for use in a diving injury. A physician trained in dive medicine may be willing to provide this prescription.

Some countries, states and local governments have regulations that require that oxygen supply companies document all medical-grade oxygen distillation, cylinder transfills and sales. These governmental agencies routinely inspect the facility's operations and documentation to verify compliance with these regulations. Other areas have few or no regulations regarding the distribution of oxygen.

Oxygen Unit Storage and Maintenance

A few simple things will keep the oxygen unit in excellent working condition for years

- Keep the oxygen unit in its storage case, fully assembled and turned off. This allows for rapid deployment. Storing the unit in its case also reduces the likelihood of damage to component parts and prevents exposure to the corrosive properties of sea water.

- Store the oxygen unit with the valve closed and the regulator depressurized. This prevents the oxygen from being accidentally drained if a leak goes undetected.
- Before every dive outing, check the oxygen unit's components and cylinder pressure. Keep the cylinder filled with oxygen at all times. Have extra cylinders, washers and masks on hand for extended delivery and/or to assist more than one injured diver.
- Clean thoroughly any removable plastic oxygen unit parts and reusable oxygen masks after use. Soak the masks in a mild bleach solution of one part bleach and nine parts water for at least 10 minutes. Rinse thoroughly with fresh water, and allow to air dry completely. Harsh detergents or other chemical cleaning agents may cause mask deterioration or irritate an injured diver's skin upon contact. Other cleaning options include the use of chlorhexidine or alcohol.

Review Questions

1. Oxygen is one element of the fire triangle.
   a. True
   b. False

2. Safety precautions to implement when using oxygen cylinders include
   a. not allowing any oil or grease to come in contact with oxygen cylinder
   b. not exposing oxygen cylinders to high temperatures or allow smoking/open flames around oxygen
   c. providing adequate ventilation when using oxygen
   d. using only equipment made for use with oxygen
   e. all of the above

3. With what grade of oxygen should an oxygen cylinder for diving first aid be filled?
   a. aviator or industrial grade
   b. medical grade only
   c. medical or industrial grade
   d. aviator or medical grade

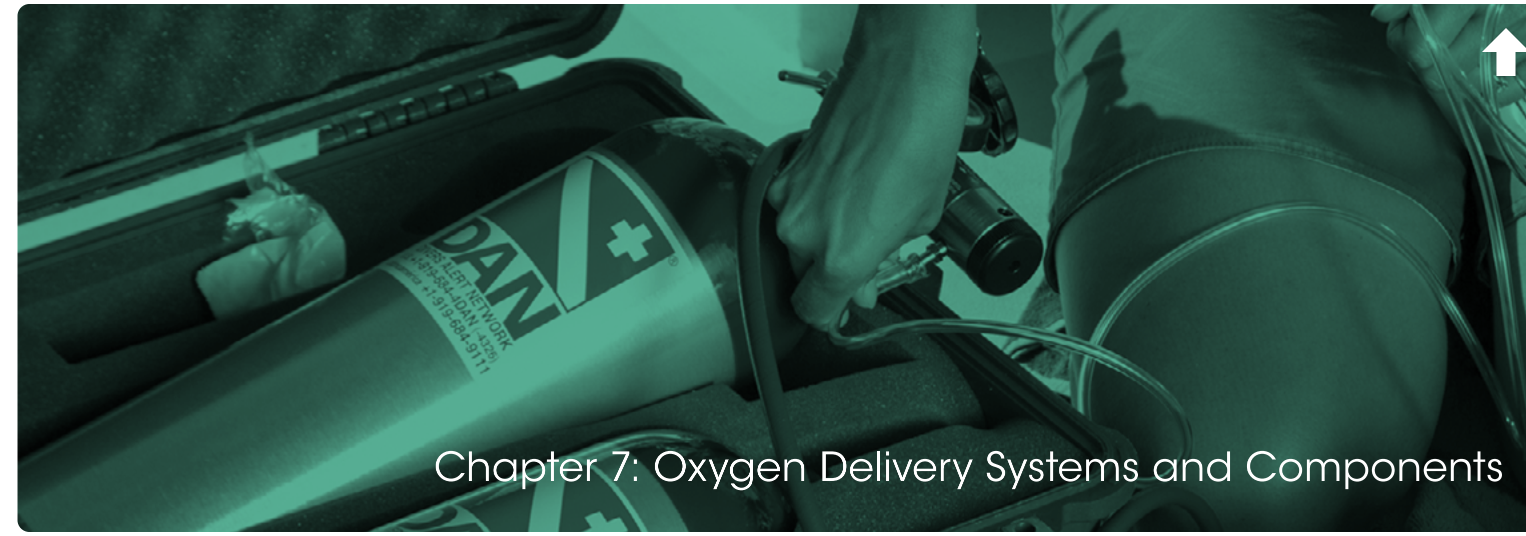
4. Methods for obtaining oxygen fills may include
   a. prescription
   b. documentation of training in oxygen delivery
   c. prospective prescription
   d. any of the above

5. When should an oxygen unit's components and cylinder pressure be checked?
   a. every two years
   b. before every outing
   c. every week
   d. annually

6. An oxygen unit should be stored
   a. with the valve closed
   b. in its protective case
   c. assembled
   d. all of the above

7. It is not necessary to clean oxygen parts and masks.
   a. True
   b. False

Review answers are on Page 65.



Chapter 7: Oxygen Delivery Systems and Components

Objectives
1. What are the components of an oxygen delivery system?
2. What are the hydrostatic testing requirements for an oxygen cylinder?
3 What two factors influence what cylinder size is appropriate?
4. When should the oxygen provider switch to a full cylinder?
5. Which oxygen regulator is preferred for diving first aid?
6. How often and by whom should an oxygen regulator be serviced?
7. Why is a demand valve the first choice for delivering oxygen to an injured diver?
8. What are the advantages and disadvantages of the following?
   a) Manually triggered ventilator b) Bag valve mask

Oxygen Delivery Systems
Oxygen delivery systems consist of an oxygen cylinder, a pressure-reducing regulator, a hose and a face mask. There are many oxygen equipment options. Descriptions for each system component as well as applicable guidelines are listed below.

Common Oxygen Cylinders
Oxygen cylinders, the principal component of the oxygen system, come in a variety of sizes and are made of either aluminum or steel. Oxygen cylinders are subject to the same hydrostatic testing as all compressed-gas cylinders. The testing cycle is established by law or regulation and may vary by location. Common hydrostatic testing intervals range from annually to every 10 years. For example, the hydrostatic testing period is one year in Australia, two years in some European countries, five years in the U.S., and 10 years according to ISO standards. Visual inspections of oxygen cylinders are typically completed with hydrostatic testing.

Any concerns by you or the fill station about the condition of the cylinder between hydrostatic testing dates should prompt additional testing or inspections before filling the cylinder.

Oxygen cylinders should be clearly labeled. For easy identification and to minimize the risk of using a cylinder and/or its contents for an unintended purpose, oxygen cylinders may be color coded. White is the international standard but is not universally used. Many areas, including the United States, use green. In the U.S. oxygen cylinders are required to be labeled as containing oxygen, with or without the green color designation.

Ask your Emergency Oxygen Instructor about the oxygen cylinder designation requirements in your area.

Capacity is the primary concern when choosing a cylinder. Enough oxygen should be available to allow for continuous delivery to an injured diver from the time of injury at the farthest possible dive site to the next level of emergency response (the nearest appropriate medical facility or point of contact with **EMS**).

Another consideration is having enough oxygen for a second injured diver.

The duration of common portable oxygen cylinders varies based on the size of the oxygen cylinder as well as oxygen flow, consumption rate and the type of delivery device. Common single portable oxygen cylinders can last from 15 minutes to 60 minutes. Nonportable oxygen cylinders can last up to eight hours or more. DAN Oxygen Units come with either an M9 (248 liters) or a Jumbo-D (636 liters) oxygen cylinder.

A 15-minute oxygen supply may be all that is needed if diving from shore where EMS is available and can respond quickly. A one- or two-hour supply may be required when diving from a boat offshore. When diving farther offshore and assistance is hours away, consider carrying a nonportable oxygen cylinder or multiple portable oxygen cylinders. Consult your Emergency Oxygen Instructor about which cylinder size is most appropriate for your use.

The delivery device affects the duration of the oxygen supply. When using a constantflow regulator (discussed later), the approximate duration of an oxygen cylinder can be determined using this formula:

Capacity in liters ÷ flow in liters per minute = approximate delivery time

For example, if a cylinder holds 640 liters and the oxygen flow rate is 15 liters per minute, the cylinder will last approximately 43 minutes. At 10 liters per minute, the same cylinder will last 64 minutes.

When a diver uses a demand inhalator valve (discussed later), it is more difficult to determine an exact time of supply. The rate at which the oxygen is used will depend on the injured diver's breathing rate and volume. Generally, the average oxygen use on a demand valve is equivalent to 8 to 10 liters per minute. Demand-style delivery is preferred because no oxygen is wasted, and usually the oxygen supply lasts longer.

A partially filled oxygen cylinder should be changed to a full one when the pressure drops below 200 **psi** (14 bar). If only one cylinder is available, however, it should be used until the oxygen supply is depleted.

Oxygen Pressure Regulators

The pressure regulator attaches to the oxygen cylinder valve and reduces the cylinder pressure to a safe working pressure compatible with demand valve or constantflow equipment. Various methods of attachment are available.

In some areas, pins engage matching holes on the cylinder valve. This pin-indexed valve is called a CGA (Compressed Gas Association) 870 medical oxygen valve. These pins are aligned to prevent an oxygen regulator from being used on a cylinder that may contain another gas. This system is important in locations where there are various gases in use, and each requires its own regulator and cylinder. Pin placement is specific for each gas.

In other areas, oxygen cylinders may have threaded gas-outlet valves (CGA 540 medical oxygen valve and bull-nose valve) that will accept regulators intended only for medical oxygen use.

Top: Multifunction regulator with CGA 870 connection
Bottom: Multifunction regulator with CGA 540 connection

Ask your Emergency Oxygen Instructor which connection systems for oxygen cylinders and regulators are used in your region.

Oxygen delivery occurs via three common types of regulators regardless of how the regulator is attached to the cylinder valve.

1. A constant-flow regulator can deliver a fixed or adjustable flow of oxygen.
2. A demand regulator functions like a scuba regulator and delivers oxygen when the demand valve is activated.
3. A multifunction regulator combines the features of both the demand and constantflow regulators.

A multifunction regulator is preferred over the other styles because it will allow a rescuer to provide as close to 100 percent oxygen as possible to two injured divers simultaneously and permits various mask options.

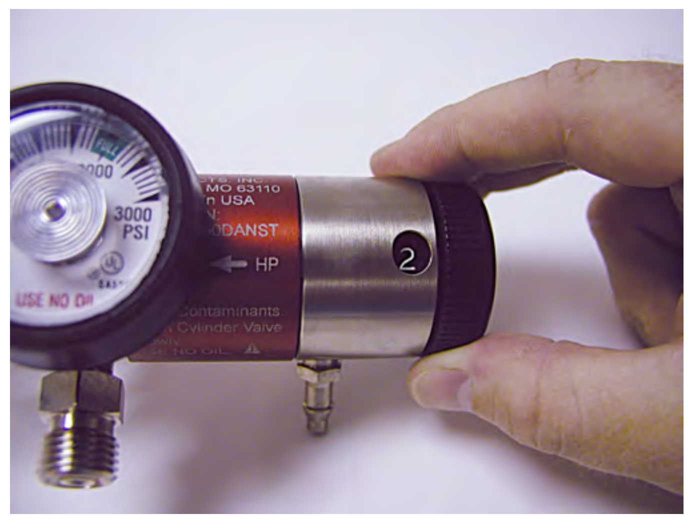
All DAN Oxygen Units come equipped with multifunction regulators.

Regardless of the type of oxygen regulator used, it should be serviced every two years by a factory-authorized service representative.

Oxygen regulator features

Several features on the oxygen regulator facilitate delivery of oxygen to an injured diver.

Pressure gauge. The oxygen regulator has a pressure gauge that provides visual monitoring of the oxygen level in a cylinder by indicating the volume of gas remaining in the cylinder. As noted previously, once the gas pressure reaches 200 psi, replace the cylinder with a full one. If another cylinder is not available, use the cylinder until it is completely empty, monitoring the injured diver so you can remove the mask when the oxygen supply is depleted.



Flow meter. The flow meter, an integral part of the pressure regulator, indicates the oxygen flow rate delivered through the barbed outlet to the constant-flow device (nonrebreather mask or oronasal resuscitation mask with supplemental oxygen inlet). Oxygen flow is measured in liters per minute (lpm). The control valve regulates the flow rate on the regulator. The flow-rate indicator window is on the front of the flow meter.

The DAN multifunction regulator is designed to deliver up to 25 lpm. DAN recommends an initial flow rate 10-15 lpm when used with either a nonrebreather mask or oronasal resuscitation mask. The flow rate can be increased as needed.

Adapters. In some regions, oxygen-compatible adapters accommodate various regulators with other oxygen cylinders. These adapters provide flexibility when one travels to other areas where different cylinders and valves are used. Adapters also let you use regulators designed for portable oxygen cylinders with large nonportable ones.

Oxygen system adapters are available commercially. To minimize the risk of fire and explosion, they should be oxygen cleaned. Avoid homemade adapters and the use of scuba regulators with high oxygen concentrations. It should be noted, however, that the CGA discourages use of adapters.

Hoses and Tubing

Since an oxygen demand valve requires approximately 50 psi (3.5 bar), an intermediate pressure hose attaches to the threaded outlets on both the oxygen regulator and demand valve. The threaded outlets are diameter indexed safety system (DISS) attachments that restrict use to only hoses that are oxygen compliant. This hose may be green, white or another color. Use only those hoses originally configured to connect to oxygen regulators or delivery valves. Modified hose connections should not be used.

Oxygen Masks and Delivery Devices

An oxygen mask secured firmly to the face permits the inhalation of higher concentrations of oxygen. Using a demand valve with an oronasal mask can deliver optimal oxygen concentrations with minimal waste, thereby preserving supplies for as long as possible. For diving injuries, it is recommended that oxygen be delivered by a demand valve and oronasal mask to provide as close to 100 percent inspired oxygen as possible. In contrast, common constant-flow masks provide from 35 to 75 percent oxygen.

Demand valve

DAN Oxygen Units contain a demand inhalator valve (similar to a scuba regulator second stage). When an injured diver begins breathing through the mask and a proper seal between the mask and the injured diver's face is maintained, the injured diver will receive the highest oxygen concentration possible. With the demand inhalator valve, oxygen flows only when the injured diver inhales, and the available oxygen supply will often last much longer than with a constant-flow system. You may use either an oronasal mask or an oronasal resuscitation mask to fit the demand valve to the injured diver's face.

Nonrebreather mask

The nonrebreather mask is a constant-flow mask that may be used to assist a breathing injured diver, allowing the diver to inhale oxygen from the reservoir bag positioned below the face mask.

The nonrebreather mask consists of a mask with three nonreturn valves — one on either side of the mask and one separating the mask from the reservoir bag. If any of theses valves is missing, consider not using the mask. Oxygen tubing, located at the bottom of the mask where the reservoir bag is attached, connects the mask to the regulator via the constant-flow barb.

During inhalation, oxygen flows from the reservoir bag into the mask, where the injured diver breathes in the oxygen. The nonreturn valves on the sides of the mask prevent air from being inhaled, which would dilute the oxygen being inspired. During exhalation, the same one-way valves prevent exhaled air from flowing back into the bag and instead release it to the outside. During exhalation, the reservoir bag refills with pure oxygen.

The nonrebreather mask is an effective way to deliver a high concentration of inspired oxygen using the constant-flow feature of the regulator. This mask, however, requires a large supply of oxygen because of the constant flow. Unless the mask completely seals around the face, air will leak past the mask and valves and dilute the oxygen. Thus, this method of oxygen delivery is the second choice, after the demand valve, for a breathing injured diver.

A nonrebreather mask is recommended for the breathing injured diver who does not tolerate the demand inhalator valve or when multiple diving injuries require oxygen. An initial flow rate of 10-15 lpm is suggested when using the nonrebreather mask. Adjust the flow rate to the nonrebreather mask so that the reservoir bag does not completely deflate during inhalations. If the reservoir bag is continually deflated, check the seal of the mask, and adjust the flow rate accordingly, or switch to a demand valve.

With a good fit and proper technique, the nonrebreather mask may deliver inspired oxygen concentrations up to 80 percent.

Note:
Caution: If the oxygen supply to the nonrebreather mask is interrupted and a good seal is in place, the injured diver faces some risk of suffocating. Therefore, one should never leave an injured diver unattended and should always monitor breathing while providing emergency oxygen first aid using a nonrebreather mask. Remove any mask before turning off the gas supply.

Several other oxygen delivery devices, such as the partial rebreather mask, (missing one or more one-way valves reducing percentage of oxygen delivery) the simple face mask and the nasal cannula, are available and used in other settings. These devices do not deliver sufficient percentages of oxygen and are not discussed in this course.

Bag valve mask (BVM)

The BVM is a versatile mask-reservoir combination that provides oxygen when available, via the constant-flow barb on the oxygen regulator, or regular air. It aids rescuers in providing ventilations to both a nonbreathing or inadequately breathing injured diver or in circumstances when physical contact may not be desired.

It has a self-inflating bag that is connected to a mask by means of a mechanism with several one-way valves. When the bag is compressed, oxygen or air is directed through the mask and into the injured diver's lungs. When BVMs are used to ventilate with air, they provide oxygen at concentrations of 21 percent, compared with the 16-17 percent delivered through rescue breathing. BVMs can provide much higher oxygen concentrations when connected to an oxygen cylinder. The concentrations of oxygen are substantially reduced, however, when the mask seal is poor.

Current BVMs incorporate a tube connection for oxygen and a reserve bag that is usually connected to the base of the resuscitation bag. Oxygen passes into both of them each time the bag is compressed.

The bag and the mask are available in sizes suitable for adults, children and infants. Most adult self-inflating bags have a volume of 1600 mL. A system for an adult should never be used on a child because the bag can over expand a child's lungs. Some systems include a mechanism for preventing lung overexpansion.

Note:
When providing emergency oxygen with a BVM, it is recommended that a tidal volume of 400-600 mL (roughly one-third of the ventilation bag volume) be given for one second until the chest rises. These smaller tidal volumes are effective for maintaining adequate arterial oxygen saturation, provided that supplemental oxygen is delivered to the device. These volumes will reduce the risk of gastric inflation.

The mechanics of the BVM make it a two-person skill. Many studies have clearly shown that, in general, the technique as applied by a single rescuer produces very poor ventilations, even though the rescuer may be well trained and conduct it perfectly. Therefore, it is recommended that the BVM be used by a minimum of two trained rescuers to guarantee the optimal ventilation. One rescuer manages the airway and keeps the mask sealed well, and the other compresses the bag. BVMs are a good choice when two rescuers are available because it is less fatiguing than providing ventilations.

Note:
Achieving a good seal while lifting the diver's jaw with one hand and using the other to compress the ventilation bag is very difficult for a single rescuer. The injured diver's mouth may remain closed beneath the mask or the tongue may create an obstruction due to poor airway management. Leaks are difficult to prevent when attempted by a single rescuer. Potential leaks are minimized with two rescuer delivery. On the other hand, if a good seal is obtained on the injured diver's face, the BVM can produce enough pressure to expand the stomach and/or damage the lungs — hence the earlier recommendation to limit tidal volume to 400-600 ml.

Some versions of the bag valve mask have a stop valve to help prevent overinflation. It restricts air flow from the bag to the injured diver if it meets resistance, such as if the lungs are overfilled, during ventilations. The stop valve also may be activated if too much pressure is being used to operate the system. Either way, the stop valve prohibits administration of further air volume.

Despite the potential problems, the BVM can be very effective if used by properly trained rescuers.

Description and function of a typical BVM device

Even though various BVM models have differing design details or characteristics, the operating principles are the same. You should become familiar with the model you use.

Ventilation bag

Ventilation bag. This bag is designed to reinflate after it is compressed. It refills with air or oxygen through a suction valve at the end of the bag. The suction valve also functions as a nonreturn valve, preventing the gas from escaping from the bottom of the bag and preventing strain around the neck of the bag.

Tolerance valve. Depending on the manufacturer, this assembly contains two one-way valves. The first is the "lip valve," which opens when the gas exits from the ventilation bag and closes when the gas goes in the opposite direction. This allows the gas contained in the ventilation bag to be directed toward the injured diver and prevents the expired gas from reentering the bag. The expired gas is directed from the assembly through a separate membrane or through the lip valve, which rises to allow the gas to be dispersed. This membrane also prevents the air from returning to the injured diver.

Oxygen reserve bag

Oxygen reserve bag. The majority of BVM devices have a reserve bag of some type. The reserve bag is designed to collect the oxygen during the expiration cycle so that it is available for the inspiration cycle. The BVM should include a mechanism for preventing excess pressure in the system and/or in the reserve bag caused by the introduction of unused gas. Some systems have slits in the reserve bag that open under pressure and allow excess gas to escape. Other devices use an outlet valve or a membrane. In addition, the BVM requires an inlet that allows a certain amount of air to reenter when the reserve bag is used if there is insufficient gas to allow the ventilation bag to refill.

Manually Triggered Ventilators (MTV)

The manually triggered ventilator, also known as a flow-restricted oxygen-powered resuscitator, is a dual-function regulator. It allows the rescuer to provide emergency oxygen to a nonbreathing or inadequately breathing injured diver with optimal oxygen levels. The user can start or stop the oxygen flow immediately by activating a button similar to the purge button of a scuba regulator.

It can also function as a demand valve that can deliver maximum oxygen concentrations to the breathing diver and minimize the gas waste.

Note:
Lower tidal volumes are recommended with MTVs. These smaller tidal volumes are effective for maintaining adequate arterial oxygen saturation and will reduce the risk of gastric inflation. Ventilations are given over one second until the chest rises. Two rescuers are recommended when using the MTV. One rescuer should maintain the airway and mask seal, while the second rescuer activates the ventilator.

Manually triggered ventilators offer several advantages. They deliver higher concentrations of oxygen than manual ventilations with supplemental oxygen and are less tiring for the rescuers delivering care. Manually triggered ventilators can deliver a flow greater than 40 lpm to a nonbreathing or inadequately breathing injured diver, an amount that is significantly more than what is required to satisfy the breathing requirements of an individual. Some older versions of oxygen-powered ventilators even exceeded 160 lpm (normal inspiratory flow is 60-120 lpm) in delivered oxygen. Previously it was thought that this amount was necessary to ventilate an injured diver. However, such a high flow rate can easily cause distension of the stomach, which can lead to regurgitation and the aspiration of stomach contents (which normally occurs when the **esophagus** pressure is greater than 15-20 cm H_2O). (normal esophageal pressure is 5-10 cm H_2O). In addition, a high flow rate can potentially damage the lungs, plus older models did not allow for pressure release, possibly impeding exhalation.

The MTV-100, the model of manually triggered ventilators DAN uses as an option in its oxygen units, is designed to terminate either the flow or the pressure if excessive pressure is detected in the airways. It automatically limits the flow rate to 40 lpm. This corresponds with American Heart Association recommendations to use a lower flow rate to reduce complications. It terminates the flow completely when it detects a mounting pressure of greater than approximately 60 cm H_2O. Additionally, a redundant valve was added for use in the event that the first one failed.

Finally, some devices can stop providing gas prematurely without alerting the operator. This can happen when the lungs of the injured diver present resistance or when there is a poor response from the lungs as can happen when ventilating an individual with asthma or an injured diver who has experienced a submersion incident. If the device does not have an alarm mechanism, the operator may not become aware of the resistance during resuscitation, leading to an airway obstruction or an undetected overexpansion of the lungs. The MTV-100 has an audible click that alerts the operator of excessive levels of pressure in the airways.

MTVs, as well as demand valves, require a supply of oxygen to function therefore they can no longer be used when the oxygen supply is exhausted.

DAN Oxygen Units

DAN Oxygen Units were specially designed with divers in mind. Each unit is capable of delivering high concentrations of inspired oxygen to injured divers.

Rescue Pak

The Rescue Pak is an affordable and compact oxygen system, ideal for areas where emergency medical services exist nearby or the distance to the nearest medical facility is short. It includes the following:

- Brass multifunction regulator
- Demand valve with hose
- M9 oxygen cylinder (248 liters)
- Nonrebreather mask with 6-foot tubing
- Oronasal resuscitation mask
- Waterproof case
- Optional MTV-100 with hose

Rescue Pak Extended Care

The Rescue Pak Extended Care, a popular choice among divers, is a self-contained kit that has all the necessary equipment to provide first aid for both breathing and nonbreathing injured divers. It includes the following:

- Brass multifunction regulator
- Demand valve with hose
- Jumbo-D oxygen cylinder (636 liters)
- Nonrebreather mask with 6-foot tubing
- Oronasal resuscitation mask
- Waterproof case
- Optional MTV-100 with hose

Dual Rescue Pak Extended Care

DAN's dual-cylinder unit is ideal for offshore diving or for divers who desire a greater oxygen supply. It includes the following:

- Brass multifunction regulator
- Demand valve with hose
- Two Jumbo-D oxygen cylinders (636 liters each)
- Nonrebreather mask with 6-foot tubing
- Oronasal resuscitation mask
- Waterproof case
- Optional MTV-100 with hose

DAN also offers cylinders with a white shoulder for those regions that require that color designation for oxygen. If sold in a kit that includes a hose and demand or MTV, the hose is also white.

Charter Boat Oxygen Unit

DAN's Charter Boat Oxygen Unit allows the use of larger oxygen cylinders, which allow for extended oxygen treatment. It includes the following:

- Brass multifunction regulator with CGA-540 connector
- Demand valve with hose
- Oronasal resuscitation mask
- Nonrebreather mask with tubing
- Wrench for CGA-540 connector
- Waterproof case

First Aid Backpack with Oxygen Option

Not only is this backpack fully stocked with first aid supplies, it also includes an adjustable padded pouch with Velcro backing, designed to fit a standard M9 oxygen cylinder. This is a portable, durable and practical unit with reflective strips and D-rings featured on the shoulder straps, and the waterproof cover is stored in the bottom compartment of the backpack. It includes the following items:

- Brass multifunction regulator
- M9 cylinder (248 liters)
- Demand valve with hose
- Oronasal resuscitation mask
- Nonrebreather mask with 6-foot tubing
- Dive safety slates
- Nitrile gloves
- Medications/Tools Pack
- Stop Bleeding/Shock Pack
- Wounds (Cuts) Care Pack
- Fractures/Sprain/Strain Pack

Other DAN Oxygen Unit options (as well as first aid kits) are available. Check the DAN store at danshop.co.za for additional configurations.

Review Questions

1. Which of the following is not part of an oxygen delivery system:
   a. oxygen cylinder
   b. pressure-reducing regulator
   c. lubricants to facilitate assembly
   d. oxygen hose
   e. face mask

2. What is the primary consideration when choosing an oxygen cylinder?
   a. capacity
   b. number of injured divers
   c. cylinder markings

3. A multifunction regulator is preferred in emergency oxygen for scuba diving injuries because it can provide emergency oxygen to two injured divers at the same time.
   a. True
   b. False

4. An oxygen cylinder should be switched during care when the pressure drops below 200 psi if another cylinder is available or, if another cylinder is not available, use the cylinder until it is empty.
   a. True
   b. False

5. Oxygen cylinders are subject to periodic hydrostatic testing.
   a. True
   b. False

6. Oxygen cylinder marking colors are standardized throughout the world to avoid confusion.
   a. True
   b. False

7. Oxygen regulators are fitted with a pin indexing system to prevent use on other cylinder valves that may not contain oxygen.
   a. True
   b. False

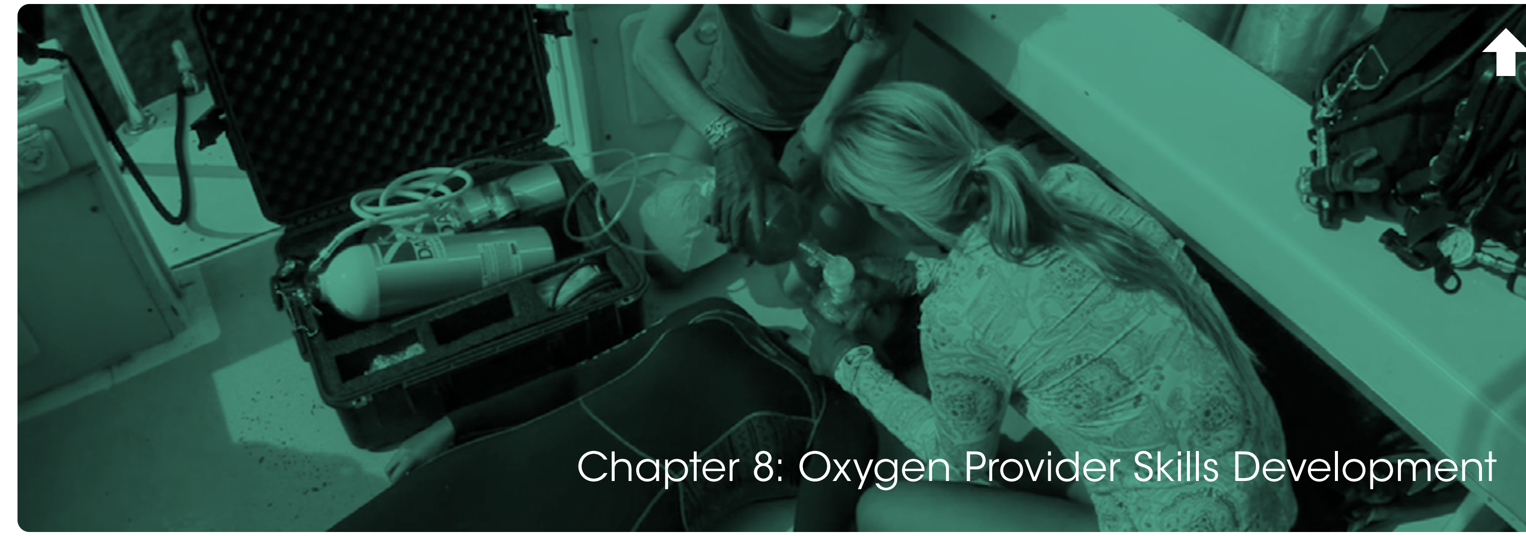
8. A demand valve flows only when the injured diver inhales, allowing the oxygen to last longer.
   a. True
   b. False

9. A bag valve mask
   a. is a self-inflating bag with a mask that aids in providing ventilations
   b. has a manual trigger that initiates oxygen flow
   c. is best used by two rescuers working together
   d. a and c

10. Manually triggered ventilators ____
    a. allow rescuers to deliver high concentrations of oxygen to nonbreathing or inadequately breathing divers
    b. can also function as a demand valve
    c. are best used by two rescuers
    d. all of the above

11. A constant flow mask that is recommended when a breathing injured diver cannot activate the demand inhalator valve or when there is more than one injured diver is a:
    a. nonrebreather mask
    b. oronasal resuscitation mask
    c. bag valve mask

Review answers are on Page 65.



Chapter 8: Oxygen Provider Skills Development

Objectives

For the skills included in this course, the oxygen provider will be able to:

1. Oxygen equipment identification, disassembly and assembly
   - Identify the component parts of the DAN Oxygen Unit
   - Disassemble and reassemble with minimal assistance the DAN Oxygen Unit or equivalent
2. **S-A-F-E**
   - List the steps in performing a scene safety assessment
   - Perform a scene safety assessment in a scenario
   - Use appropriate first aid barrier devices in a scenario
   - Demonstrate a caring attitude toward a simulated diver who has become ill or injured
3. Initial assessment with basic life support (review only)
   - Establish responsiveness of a simulated injured/ill diver
   - Demonstrate current sequence of providing care with proper ventilations and compression rates
4. Demand inhalator valve
   - Provide emergency oxygen to a responsive breathing injured diver using the demand inhalator valve and oronasal mask
5. Nonrebreather mask
   - Provide emergency oxygen to a simulated unresponsive, breathing injured diver using the nonrebreather mask
   - Discern when options for oxygen delivery are not working adequately, and switch to another as appropriate

6. Bag valve mask
   - Provide emergency oxygen to a simulated nonbreathing or inadequately breathing injured diver using the bag valve mask on a CPR mannequin
7. MTV
   - Provide emergency oxygen to a simulated nonbreathing or inadequately breathing injured diver using an MTV and oronasal mask on a CPR mannequin
8. Emergency assistance plan
   - List the components of an emergency assistance plan
   - Develop an emergency assistance plan for the local diving area

Being able to provide emergency oxygen to an injured diver is more than just knowing what to do, it is being able to do it. The following skills are essential elements to oxygen delivery. Your EO2 Instructor will guide you through this skill development section.

Oxygen Equipment Identification

DAN Oxygen Unit components (labels correspond with image)

A. oronasal resuscitation mask with oxygen inlet
B. T-handle
C. handwheel wrench
D. pressure gauge
E. multifunction regulator
F. constant-flow controller
G. barbed constant-flow outlet
H. DISS threaded outlet
I. demand inhalator valve
J. intermediate pressure hose
K. oxygen cylinder and valve
L. nonrebreather mask
M. MTV

SKILL: Oxygen Equipment Disassembly and Assembly

Objectives:
- Identify the component parts of the DAN Oxygen Unit.
- Disassemble and reassemble with minimal assistance the DAN Oxygen Unit or equivalent.

Follow these simple steps to assemble and disassemble the DAN Oxygen Unit.
- Ensure oxygen unit is depressurized.
- Open constant-flow control.
- Check pressure gauge.
- Remove multifunction regulator from the oxygen cylinder valve.
- Secure oxygen cylinder.
- Remove oxygen washer from multifunction regulator.
  – Note: Washer is different from standard scuba O-ring.
- Remove oxygen hose from multifunction regulator.
- If the fitting is too tight, use handwheel/wrench to unscrew the hose.
- Remove oxygen hose from demand inhalator valve.
  – Note: Both ends of the oxygen hose are identical.
- Unscrew the plastic mask adapter from the demand inhalator valve.
- Remove inhalation/exhalation assembly.
- To assemble, repeat steps in reverse.
  – Note: Check valves; ensure oxygen does not flow from threaded ports.

Objectives:

- List the steps in performing a scene safety assessment.
- Perform a scene safety assessment in a scenario.
- Use appropriate first aid barrier devices in a scenario.
- Demonstrate a caring attitude toward a simulated diver who has become ill or injured.

Follow these simple steps to perform a scene safety assessment.

Remember S-A-F-E

S	**Stop**	• Stop • Think • Act
A	**Assess the scene**	• Is the scene safe? • Is it safe to approach the injured diver? • Is the ventilation adequate to use oxygen? • Are any other hazards present?
F	**Find oxygen unit, first aid kit and AED**	• Take them to the injured person • First aid kits contain critical supplies such as barriers
E	**Exposure protection**	• Use barriers such as gloves and mouth-to-mask barrier devices • Don gloves, and inspect them for damage

Objectives:

- Establish responsiveness of a simulated injured/ill diver.
- Demonstrate current sequence of providing care with proper ventilations and compression rates.

Follow these simple steps to assess responsiveness and provide basic life support.

Remember S-A-F-E.

Assess responsiveness.

- State your name, training and desire to help.
- Ask permission to help.
- If unresponsive,
  - Tap on the collarbone.
  - Shout, **"Are you OK?"**
  - If no response, call for help and activate emergency medical services (EMS).

Assess breathing.

- While you assess responsiveness, determine if the diver is breathing normally. If they are unresponsive and not breathing normally, initiate CPR, beginning with 30 compressions.

If the diver is breathing normally and you suspect a diving emergency, initiate oxygen first aid, and put your emergency action plan into motion.

- CPR is not generally taught as part of this course, although your instructor may offer it as an additional module. If an AED unit is available, deploy it. Discuss other training opportunities with your EO2 Instructor.

SKILL: Demand Inhalator Valve

Objectives:

- Provide emergency oxygen to a responsive, breathing injured diver using the demand inhalator valve and oronasal mask.

Follow these simple steps to provide emergency oxygen to a responsive or unresponsive breathing injured diver with the demand inhalator valve. This is the preferred method of providing emergency oxygen to any breathing injured diver.

Remember S-A-F-E.

Deploy the oxygen unit.

- Open cylinder valve with one complete turn.
- Check cylinder pressure.
- Ensure that there are no leaks in the system.
- Constant-flow setting should be in "off" position.
- Take a breath from the demand inhalator valve, and exhale away from it.
- Inform the injured diver that oxygen may help. State: **"This is oxygen, and it may make you feel better. May I help you?"**
  - If the diver is unresponsive, permission to help is assumed.

Place the mask over the injured diver's mouth and nose.

- Adjust the elastic strap for snug fit.
- Check the mask for any leaks around the injured diver's face.

Instruct the injured diver to breathe normally from the mask.

- Reassure and comfort the injured diver. ***The injured diver may hold the mask to help maintain a tight seal. Monitor the injured diver and the oxygen pressure gauge.***
- Listen for the demand inhalator valve to open during inspiration.
- Observe mask fogging during exhalation and clearing with inhalation.
- Watch the chest rise during inhalation and fall with exhalation.

Activate emergency action plan.

- Call EMS or other appropriate medical facility.
- Contact DAN for consultation and coordination of hyperbaric treatment.

SKILL: Nonrebreather Mask

Objectives:

- Provide emergency oxygen to an unresponsive, breathing injured diver using the nonrebreather mask.
- Discern when options for oxygen delivery are not working adequately, and switch to another as appropriate.

Follow these simple steps to provide emergency oxygen to a responsive or unresponsive breathing injured diver with the nonrebreather mask. The nonrebreather mask is ideal when you have two injured divers or an injured diver who will not tolerate the demand inhalator valve.

Remember S-A-F-E.

Ensure airway and breathing.

Deploy the oxygen unit.

- Remove nonrebreather mask from bag.
- Stretch oxygen tubing to avoid kinks.
- Attach oxygen tubing to barbed constant-flow outlet on the multifunction regulator.

Set constant-flow control to an initial flow rate of 10-15 liters per minute (lpm).

Prime mask reservoir bag.

- Place a thumb or finger inside the nose-piece, closing the nonreturn valve until the reservoir bag fully inflates.

Inform the injured diver that oxygen may help.

- State: **"This is oxygen, and it may make you feel better. May I help you?"**
- If the diver is unresponsive, permission to help is assumed.

Place the mask over the injured diver's mouth and nose.

- Check the mask for any leaks around the injured diver's face.
- Adjust the elastic band around the head to hold the mask in place.
- Squeeze the metal clip over the nose to improve the seal and prevent oxygen leakage.

Instruct the injured diver to breathe normally.

- Adjust flow rate (increase or decrease) to meet the needs of the injured diver.
  - Ensure that the reservoir bag does not collapse completely during inhalation (some deflation is normal and expected).
- Reassure and comfort the injured diver.
- Place the injured diver in the proper position.
- If responsive, instruct the injured diver to hold mask to maintain a tight seal.
- Monitor the injured diver and the oxygen pressure system.
- Look for the reservoir bag to slightly inflate and deflate and for movement of the nonreturn valves.
- Observe mask fogging during exhalation and clearing with inhalation.
- Watch the chest rise during inhalation and fall with exhalation.
- Activate the emergency action plan.
- Call EMS and DAN.

SKILL: Ventilation with a Bag Valve Mask

Objectives:

- Provide emergency oxygen to a nonbreathing or inadequately breathing injured diver using the bag valve mask.

Follow these steps to ventilate a nonbreathing or inadequately breathing injured diver using a BVM. This skill requires two rescuers.

Remember S-A-F-E.

Rescuer One

The first rescuer begins single-rescuer CPR as soon as possible and continues while the second rescuer prepares the oxygen equipment. When the oxygen equipment is ready, Rescuer One ventilates the injured diver by compressing the bag about one-third of the bag volume.

- Bag compressions should be slow and gentle, lasting about one second for the ventilation phase. Allow the chest to fall completely before beginning each new ventilation.
- Watch the stomach for signs of distension to prevent regurgitation.
- Each ventilation should last about one second. Deliver two ventilations.
- Deliver chest compressions between ventilations if used as part of CPR.

Rescuer Two

The second rescuer prepares the oxygen equipment, while the first rescuer performs CPR. When the equipment is ready, the second rescuer should do the following:

- Connect the BVM tubing to the constant flow barb on the oxygen regulator.
- Turn on constant flow to initial setting of 15 lpm, and allow the reservoir bag to inflate.
- Seal the mask in place using the head-tilt chin-lift method, pulling the diver's jaw up and into the mask.
- Maintain the airway.
- Monitor the oxygen supply.
- Activate your emergency action plan.
- Call EMS and DAN.

SKILL: Using an MTV

Objectives:
- Provide emergency oxygen to a nonbreathing or inadequately breathing injured diver using an MTV and oronasal mask.

Follow these steps to ventilate a nonbreathing or inadequately breathing injured diver using an MTV. Two rescuers are required for this skill.

Remember S-A-F-E.

Rescuer One
The first rescuer begins single-rescuer CPR using an oronasal resuscitation mask as soon as possible and continues while the second rescuer prepares the oxygen equipment. When the oxygen equipment is ready, Rescuer One ventilates the injured diver by pressing the resuscitation button carefully while observing the chest, releasing the button quickly.
- Watch for the chest and abdomen to rise.
  – Ventilations should take about one second.
- Release the resuscitation button as soon as the chest begins to rise. Deliver two ventilations.
  – Leaving one hand gently on the center of the chest can help to assess that ventilations are adequate and not excessive.
- Watch for distension of the stomach.
- Deliver chest compressions between ventilations.

Rescuer Two
When the equipment is ready, the second rescuer should do the following:
- Test the safety valve to ensure that it functions properly.
- Press the ventilation button, then block the oxygen outlet of the MTV with his or her hand. The oxygen flow should stop, and the gas should be released.
  NOTE: If the safety shutoff does not work, do not use the MTV.
- Connect the oronasal mask to the MTV adapter.
- Position the mask over the mouth and nose of the injured diver.
- Seal the mask in place using the head-tilt chin-lift method, pulling the diver's jaw up and into the mask.
- Maintain the airway, and hold the mask in place, while the first rescuer pushes the ventilation button on the MTV and delivers chest compressions.
- Monitor the supply of oxygen attentively, and be prepared to resume mouth to mask ventilations if the supply is exhausted.
- Activate your emergency action plan.
- Call EMS and DAN.

SKILL: Emergency Assistance Plan

Objectives:
- List the components of an emergency assistance plan.
- Develop an emergency assistance plan for the local diving area.

The following information is critical in managing scuba diving injuries and illnesses.

Diver information
Name: ______________________ Age: ________
DAN Member # ______________________
Address: ______________________
____
Emergency contact phone: ______________________
Current complaint: ______________________
____
Significant past medical history (medications, allergies, previous injuries, etc.):
____
Dive Profile (including S.S./deco) Depth Time Surface Interval
Dive #1 ______________________
Dive #2 ______________________
Dive #3 ______________________
Dive #4 ______________________
Dive #5 ______________________
Exit water time: ________ AM/PM Breathing gas: air/nitrox/mix ____________%

Emergency assistance plan
Initial contact information: ______________________
Emergency medical assistance: ______________________
Nearest medical facility directions: ______________________
____
Phone: ______________________
Diving medical consultation information
Divers Alert Network (DAN): +27-828-10-60-10

Other important information: ______________________
____
Phone: ______________________

Summary

Scuba diving is a safe and enjoyable sport, but on rare occasions injuries do happen. Providing oxygen is the primary first aid action for scuba diving injuries when they occur.

Recognizing and responding to dive-related injuries is the first aid provider's role. There are no medical contraindications for providing emergency oxygen to an injured scuba diver, so always provide the highest-possible concentration of oxygen for as long as possible or until a higher level of medical care is available.

Remember, an injured diver's condition can change rapidly, so never leave him or her alone or unattended except to call for assistance. Maintain both your CPR and Oxygen Provider skills to ensure you are prepared to handle an emergency should one occur. In the unlikely event a diver becomes injured or shows signs of decompression illness, initiate emergency oxygen care, activate emergency medical services and/or transport him or her to the nearest medical facility. Contact DAN at +27 828 10 60 10 after activating local EMS.

As a final note, remember:

- Use oxygen only in well-ventilated areas.
- Extinguish all burning materials before using oxygen.
- Never combine oxygen and flammables, such as petroleum products.
- Treat the injured diver and his or her family and friends with respect.
- Act in a decisive manner, and perform to the best of your abilities according to your knowledge and skill level.

Review Answers

Chapter 2, Page 10
1. a
2. c
3. b
4. b
5. a
6. d
7. b

Chapter 3, Page 19
1. a
2. d
3. c
4. d
5. a

Chapter 4, Page 29
1. c
2. a
3. c
4. b
5. d
6. d
7. d
8. a
9. a
10. a

Chapter 5, Page 34
1. a
2. e
3. e
4. a
5. d
6. b
7. d
8. b
9. a

Chapter 6, Page 38
1. a
2. e
3. d
4. d
5. b
6. d
7. b

Chapter 7, Page 52
1. c
2. a
3. a
4. a
5. a
6. b
7. a
8. a
9. d
10. d
11. a

Glossary

alveoli — microscopic air sacs in the lungs where gas exchange with the circulatory system occurs

anoxia — absence of oxygen in the circulating blood or in the tissues

aorta — the largest artery in the circulatory system, from which the main arteries carrying oxygenated blood branch out and subdivide into smaller and smaller vessels arterial gas embolism (AGE) — gas bubbles in the arterial system generally caused by air passing through the walls of the alveoli into the bloodstream

arterial gas embolism (AGE) — gas bubbles in the arterial system generally caused by air passing through the walls of the alveoli into the bloodstream

arteriole — small artery

atelectasis — the collapse of all or part of a lung

atrium — chamber of the heart that provides access to another chamber called the ventricle

bronchi — plural of bronchus, which is a division of the trachea

bronchiole — small branch of the bronchus that carries air to and from the alveoli

bronchospasm — bronchoconstriction, or the sudden narrowing of the smaller airways, of a spasmodic nature

capillary — microscopic blood vessels where the gas exchange takes place between the bloodstream and the tissues or the air in the lungs

carbon dioxide (CO_2) — a waste gas produced by the metabolism of oxygen in the body

carbon monoxide (CO) — a highly poisonous, odorless, tasteless and colorless gas formed when carbon material burns with restricted access to oxygen. It is toxic by inhalation since it competes with oxygen in binding with the hemoglobin, thereby resulting in diminished availability of oxygen in tissues.

cartilaginous — pertaining to or composed of cartilage

cilia — long, slender microscopic hairs extending from cells and capable of rhythmic motion

CPR — cardiopulmonary resuscitation

Glossary continued

decompression illness (DCI) — dysbaric injuries related to scuba diving; DCI includes both decompression sickness (DCS) and arterial gas embolism (AGE).

decompression sickness (DCS) — a syndrome caused by bubbles of inert gas forming in the tissues and bloodstream that can evolve from ascending too rapidly from compressedgas diving

dehydration — an abnormal depletion of water and other body fluids

Diameter Index Safety System (DISS) — intermediate pressure port where a hose attaches, leading to demand valve or other apparatus

EMS — emergency medical services

epiglottis — thin structure behind the tongue that shields the entrance of the larynx during swallowing, preventing the aspiration of debris into the trachea and lungs

erythropoietin — a hormone that is synthesized mainly in the kidneys and stimulates red blood cell formation

esophagus — portion of the digestive tract that lies between the back of the throat and stomach

fossa ovalis — oval depression in the wall of the heart remaining when the foramen ovale closes at birth (**See patent foramen ovale.**)

gradient — a difference in pressure, oxygen tension or other variable as a function of distance, time, location or another continuously changing influence

hypoxemia — inadequate oxygen content in the arterial blood

hypoxia — inadequate oxygen content

incontinence — absence of voluntary control of an excretory function, especially defecation or urination

inert — having little or no tendency to react chemically

intercostal muscles — the muscles between the ribs that contract during inspiration to increase the volume of the chest cavity

ischemia — inadequate blood flow to a part or organ

larynx — the organ of voice production, also known as the voice box; the opening from the back of the throat into the trachea (windpipe)

lpm — liters per minute; a measurement of a flow rate of gas or liquid

mediastinum — the space within the chest located between the lungs, containing the heart, major blood vessels, trachea and esophagus

metabolism — the conversion of food into energy and waste products

nystagmus — spontaneous, rapid, rhythmic movement of the eyes occurring on fixation or on ocular movement

oblique — an indirect or evasive angle

occlude — to close off or stop up; obstruct

oxygen (O_2) — a colorless, odorless, tasteless gas essential to life, making up approximately 21 percent of air

patent foramen ovale — a hole in the septum (wall) between the right and left atria of the heart

pericardium — a double-layered membranous sac surrounding the heart and major blood vessels connected to it

pharynx — portion of the airway at the back of the throat, connecting mouth, nasal cavity and larynx

platelet — a round or oval disk found in the blood of vertebrate animals that is involved with blood clotting

pleura — membranes surrounding the outer surface of the lungs and the inner surface of the chest wall and the diaphragm

prescription — a written order for dispensing drugs signed by a physician primary assessment — assessment of the airway, breathing and circulation (pulse) in an ill or injured person; also known as the ABCs

psi — pounds per square inch; a measurement of pressure respiratory arrest — cessation of breathing

sign — any medical or trauma condition that can be observed

supine — lying face up

surfactant — a substance produced in the lungs to reduce surface tension in alveoli and small airways

symptom — any nonobservable condition described by the patient

thorax — the upper part of the trunk (main part of the body) between the neck and the abdomen that contains the heart, lungs, trachea and bronchi

trachea — the air passage that begins at the larynx and ends as the beginning of the principal right and left bronchi

Valsalva maneuver — the forced inflation of the middle ear by exhaling with the mouth closed and the nostrils pinched

venous gas emboli — inert gas bubbles in venous blood (that return to the heart and lungs)

ventilation — the exchange of gases between a living organism and its environment; the act of breathing

ventricle — thick-walled, muscular chamber in the heart that receives blood from the atrium, pumping it through to the pulmonary or systemic circulation

venules — small veins

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Additional Reading

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Divers Alert Network Southern Africa (DAN-SA) is an international, nonprofit organisation dedicated to improving dive safety through research, education, medical information, evacuation support, products and services.

Among the services DAN-SA provides to the diving public is the DAN Emergency Hotline (0800 020 111 (local) or +27 828 10 60 10 (int.)). This hotline is available 24 hours a day, seven days a week for anyone who suspects a diving injury, requires assistance or needs to activate your DAN evacuation benefits (an exclusive benefit of DAN membership). Callers are connected directly with a member of DAN's Medical Services department, who can facilitate medical consultation with dive medicine specialists and co-ordinate evacuation to ensure appropriate care.

DAN-SA's non-emergency safety resources include the DAN Medical Information Line DAN-SA (0800 020 111 (local) or +27 828 10 60 10 (int.)), the online Health & Diving libary (http://dansa.org/dan-resources.htm) and Alert Diver magazine, the DAN Shop, the DAN-SA Podcast, a blog and more.

Membership dues and dive cover support DAN's nonprofit efforts. DAN members enjoy benefits such as access to the DAN Dive Accident Cover, medical evacuation support, access to the electronic Alert Diver magazine, safety guides and more.

Your participation in this DAN training course demonstrates your commitment to dive safety. Continue your education and your commitment by supporting the industry's only organisation dedicated solely to improving dive safety. Join DAN today.

To learn more about DAN-SA and the multitude of resources it provides, or to become a member, please visit DANSA.org.

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