EMERGENCY OXYGEN FOR SCUBA DIVING INJURIES

STUDENT HANDBOOK

DAN SOUTHERN AFRICA

EMERGENCY OXYGEN FOR SCUBA DIVING INJURIES STUDENT HANDBOOK

DAN Medical Information Line: 0860 242 242 (local) or +27 11 266 4900 (Int.)
DAN Emergency Hotline: 0800 020 111 or +27 828 10 60 10 (Int.)

Authors: Nicolas Bird, M.D. MMS; Matias Nochetto, M.D.
Contributors and Reviewers: Jim Chimiak, M.D.; Petar Denoble, M.D., D.Sc.; Matias Nochetto, M.D.; Patty Seery, MHS, DMT

This programme meets the current recommendations from the October 2015 Guidelines Update for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care issued by the International Liaison Council on Resuscitation (ILCOR)/American Heart Association (AHA).

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DAN SOUTHERN AFRICA

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1 Emergency Oxygen for Scuba Diving Injuries Course Overview

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

The Emergency Oxygen for Scuba Diving Injuries course is an entry-level training programme 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 non-fatal 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 Responsibilities

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 programme. Certification is accepted from any recognised organisation. If you are not yet certified in CPR, please talk with your EO_2 Instructor about becoming CPR certified before starting this course. There is no minimum age requirement to participate in this course. Some countries, provinces 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 non-divers 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 non-divers 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 EO_2 Instructor can provide information about these programmes.

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 with the word "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 those students who want to know more

Terminology
The Emergency Oxygen for Scuba Diving Injuries 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.

2 Overview of Atmospheric Gasses

CHAPTER 2 OBJECTIVES

1. What is oxygen (O_2)?
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 gas?
6. What is carbon monoxide, and why is it dangerous?

The air we breathe is made of many different gasses. 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 gasses and the role they may play under pressure.

Oxygen (O_2)

Oxygen is a colourless, odourless, tasteless gas that comprises approximately 21% of the Earth's atmosphere. It is a vital element for survival and is needed for cellular metabolism. Essential for life, 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). Haemoglobin is the oxygen-carrying molecule within erythrocytes responsible for binding both oxygen and carbon dioxide. At rest, humans consume approximately 5% of the 21% oxygen in the air. Exhaled air therefore contains about 16% oxygen. These percentages will vary somewhat by individual and level of activity, but they provide a tangible example of oxygen use. This effect has practical importance for rescue breathing, as 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 ventilations.

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 haemoglobin saturation – the percent of haemoglobin binding sites occupied by oxygen – through a colour shift between oxygenated and deoxygenated blood states. Normal values while breathing air are 95-100% 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.

2

Carbon Dioxide (CO_2)

Normal air contains very little CO_2, only about 0.033%. CO_2 is a waste product of cellular metabolism. Exhaled gas from respiration contains approximately 4-5% CO_2. Elevated levels of CO_2 in a breathing-gas mixture can lead to shortness of breath, drowsiness, dizziness and unconsciousness – this is especially true when diving or breathing under increased atmospheric pressure.

ADVANCED CONCEPTS

CO_2 is heavily concentrated in blood as bicarbonate (HCO_3-) and serves a critical role in acid-base buffering. The remaining CO_2 is found either dissolved in plasma or bound to haemoglobin.

NOTE

Although exhaled air contains higher levels of CO_2 than air, rescue breaths, if performed correctly, should not result in significant elevations in the victim's CO_2 levels. In all cases where ventilations or other respiratory devices are used (bag valve mask or positive pressure device), supplemental oxygen is recommended.

ADVANCED CONCEPTS

An elevation in exhaled CO_2 levels, relative to inhaled air, is an indication of metabolic activity. In some medical settings, CO_2 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, N_2 comprises about 78% of the Earth's atmosphere and in this form is physiologically inert, meaning it is not involved in cellular metabolism. In non-divers who remain at a constant ambient pressure, the concentration of N_2 in the exhaled air is also about 78%. 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 off-gassing. However, since nitrogen is an inert gas, it does not interfere with resuscitation efforts during rescue breathing.

Inert gas (nitrogen and helium) absorption is associated with decompression sickness (DCS). Further discussion of DCS and the role of oxygen occurs later in this course.

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 gasses such as carbon monoxide (CO) interfere with tissue oxygen delivery. CO binds more fiercely to haemoglobin, and inhibits both the uptake of oxygen and the delivery to tissues. CO poisoning can lead to fatal tissue hypoxia. Even small amounts of CO in the breathing gas of a diver can be hazardous. Inspired gas partial pressures increase with depth, so even small fractions of CO within a tank can become toxic when breathed under pressure.

The body requires a constant supply of oxygen to maintain cellular metabolism. In the absence of oxygen, the body's cells will rapidly deteriorate and die. Some cells are more sensitive than others to hypoxia. Nervous tissue (forming the brain, spinal cord and nerves) is typically very sensitive and will sustain irreversible damage within minutes of inadequate oxygen delivery.

CHAPTER 2 REVIEW QUESTIONS

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

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

3. **The air we exhale contains ____ % 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 plasm

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 ____ % 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

Answers to review questions are on Page 70.

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3 Respiration and Circulation

CHAPTER 3 OBJECTIVES

1. What is hypoxia?
2. Why is oxygen necessary for life?
3. Where does gas exchange occur in the body?
4. Which body structures comprise the respiratory system?
5. Which 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), we may experience severe discomfort, unconsciousness or death.

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 O_2 and removal of CO_2).

CO_2 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. Elevated levels of CO_2, not low levels of O_2, provide the primary ventilatory drive. The rapid elevation of dissolved CO_2 during short periods of breath-holding provides quick insight into the power of its influence on respiratory drive.

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 membranes is a potential space 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 oesophagus. The opening to the trachea is protected from food (solids and liquids) during swallowing by a flexible flap of tissue called the epiglottis. The oesophagus, located behind the trachea, is a conduit for food and fluids en route to the stomach.

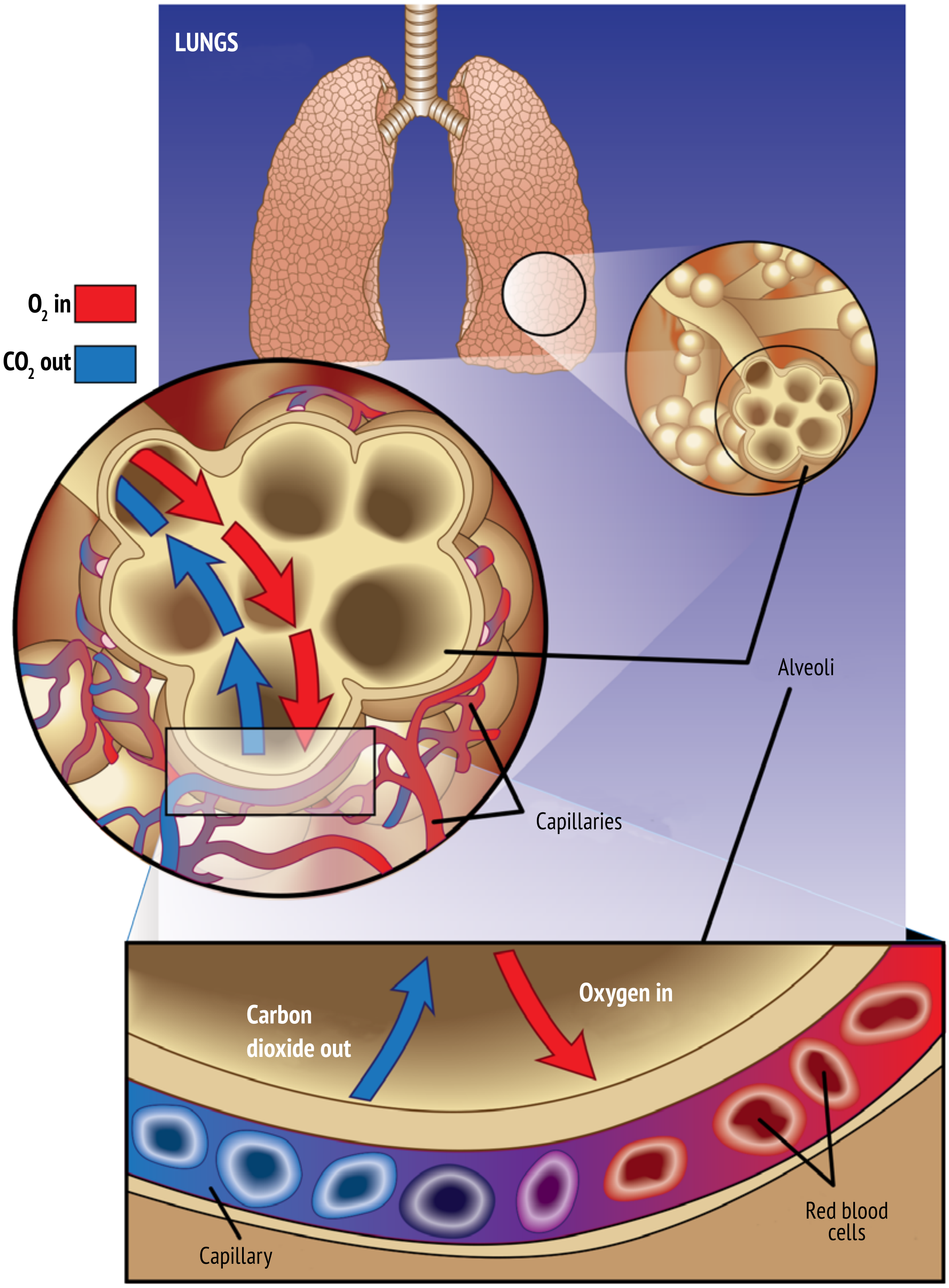
In contrast to solids and fluids, air travels from the pharynx through the larynx (voice box) and into the trachea. The trachea consists of a series of semicircular cartilaginous rings that prevent collapse. The trachea passes down into the chest cavity, and branches into the right and left bronchi, 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.

ADVANCED CONCEPTS

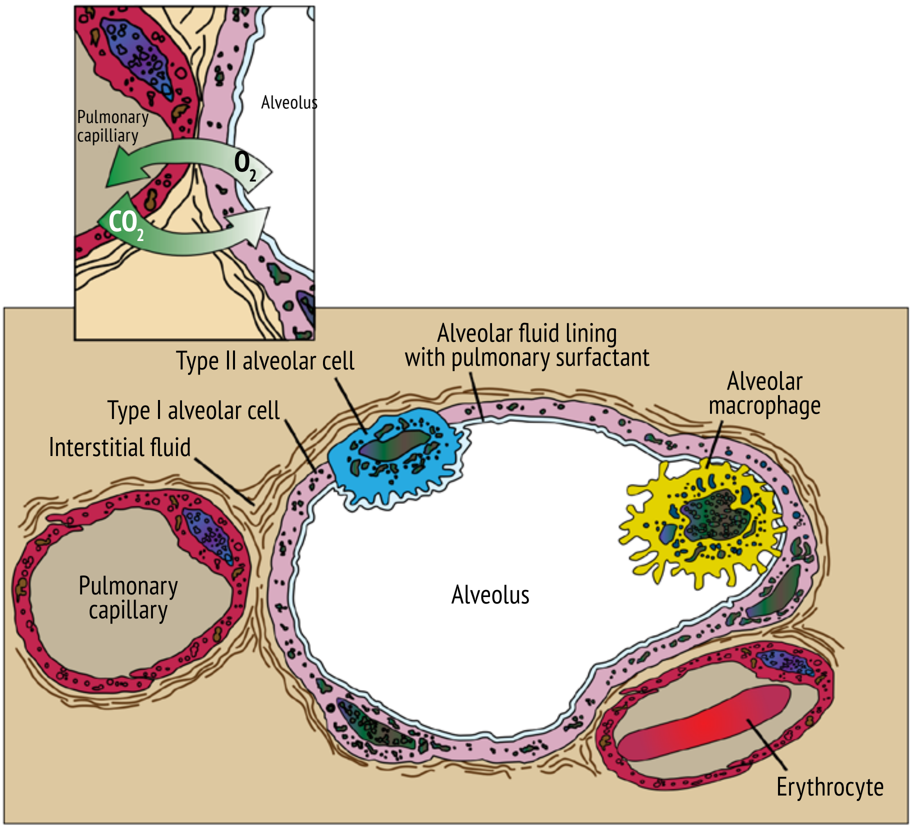
The double-layered pleural membrane is made up of the parietal layer, which lines the thoracic cavity, and the visceral layer, which coats the lungs. These two layers normally remain closely adherent due to a slightly negative pressure that keeps them from separating. Because there isn't a separation between these membranes, this area is known as a potential space and only becomes a true space 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.

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.

In both lungs, millions of alveoli cover a combined surface area of around $70m^2$, or roughly the size of a tennis court.



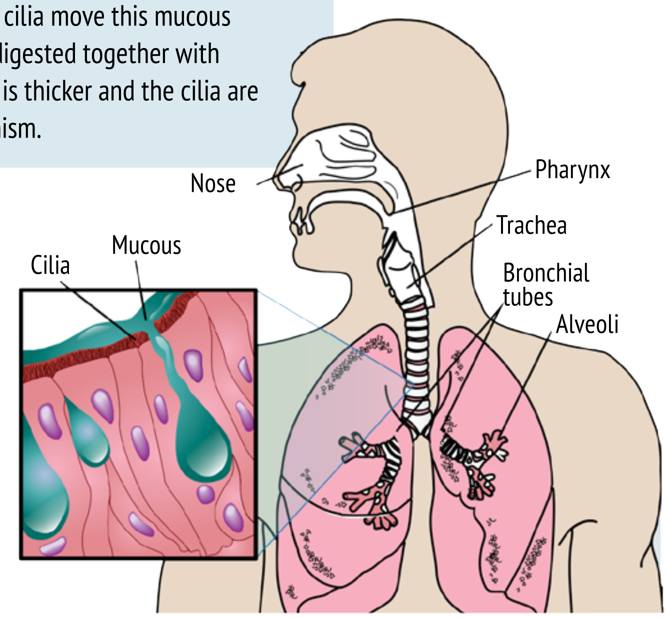
A detergent-like substance, known as lung or pulmonary surfactant, coats the inner surface of the alveoli. Pulmonary surfactant decreases the surface tension of water within the alveoli and thus reduces its tendency to collapse at the end of expiration. If the surfactant is removed, as may occur in a 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.



The average adult alveolus has an estimated diameter of 200-300 μm 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 CO_2 and O_2. The thin alveolar-capillary 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 course.

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 mucous substance up into the pharynx, where it can be swallowed and digested together with any trapped foreign particles. In the case of smokers, the mucus is thicker and the cilia are damaged, which hinders the lungs' natural self-cleaning mechanism.



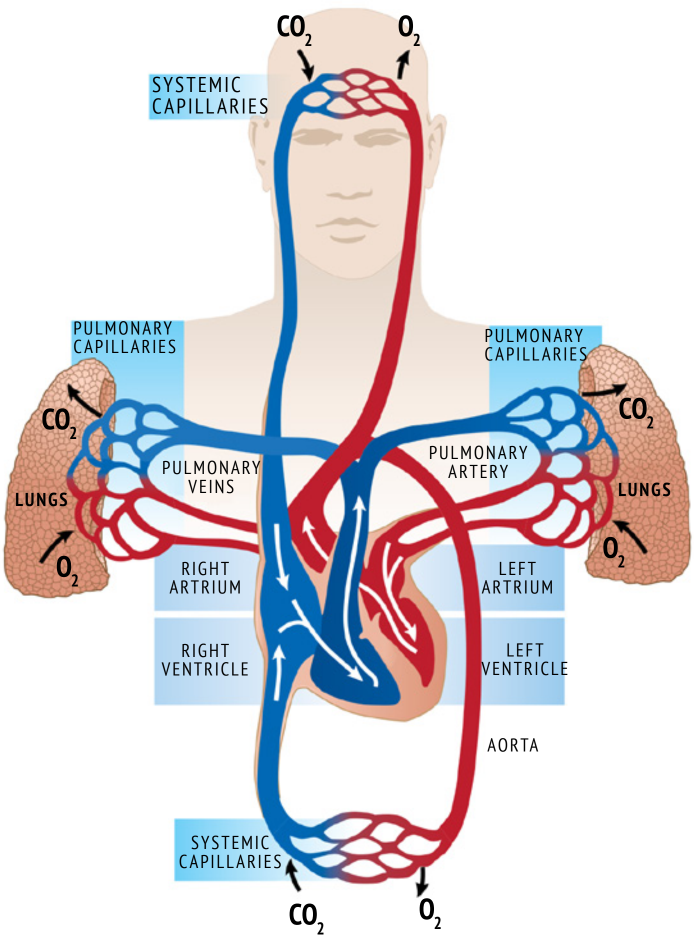
The Cardiovascular System

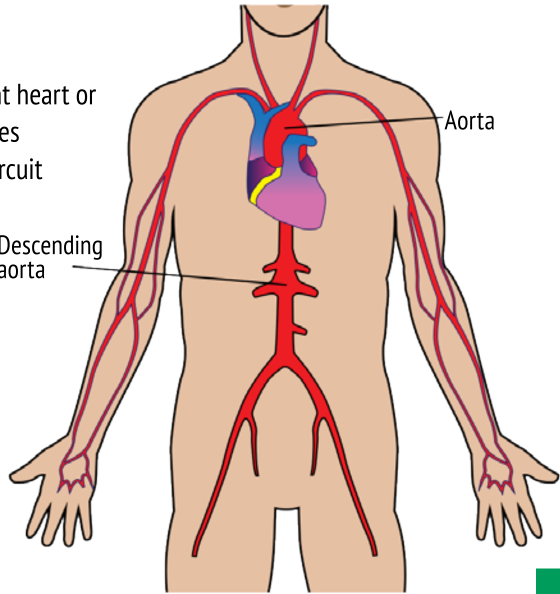
The cardiovascular system includes the heart and blood vessels. It is a closed-circuit system with a primary purpose of pumping blood, transporting oxygen and nutrients to tissues, and removing waste products.

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[7]). Every minute, approximately 6 litres of blood is pumped throughout the body. When exercising, this output may double or triple depending upon the amount of exertion.





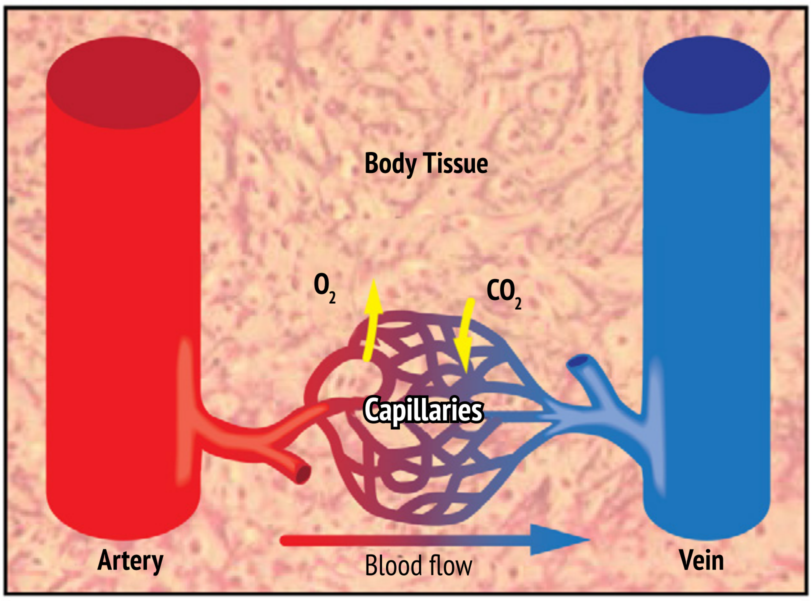
The heart is divided into a right- and left-pump system (also known as the right heart or pulmonary circuit, and the left heart or systemic circuit). The right heart receives deoxygenatedblood from the venous system and pumps it to the pulmonary circuit to exchange gasses. Oxygenated blood is returned 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 leading to progressively smaller branches, which give rise to capillaries, the smallest of all blood vessels. Through these thin capillary walls, gasses 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 CO2 and other metabolic waste products.

From the peripheral capillaries, the blood is gathered into small, thin-walled 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.



3

ADVANCED CONCEPTS

Fetal Circulation

Within the uterus, the foetus 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 foetus, gas exchange takes place in the placenta, drawing available oxygen from the mother's blood.

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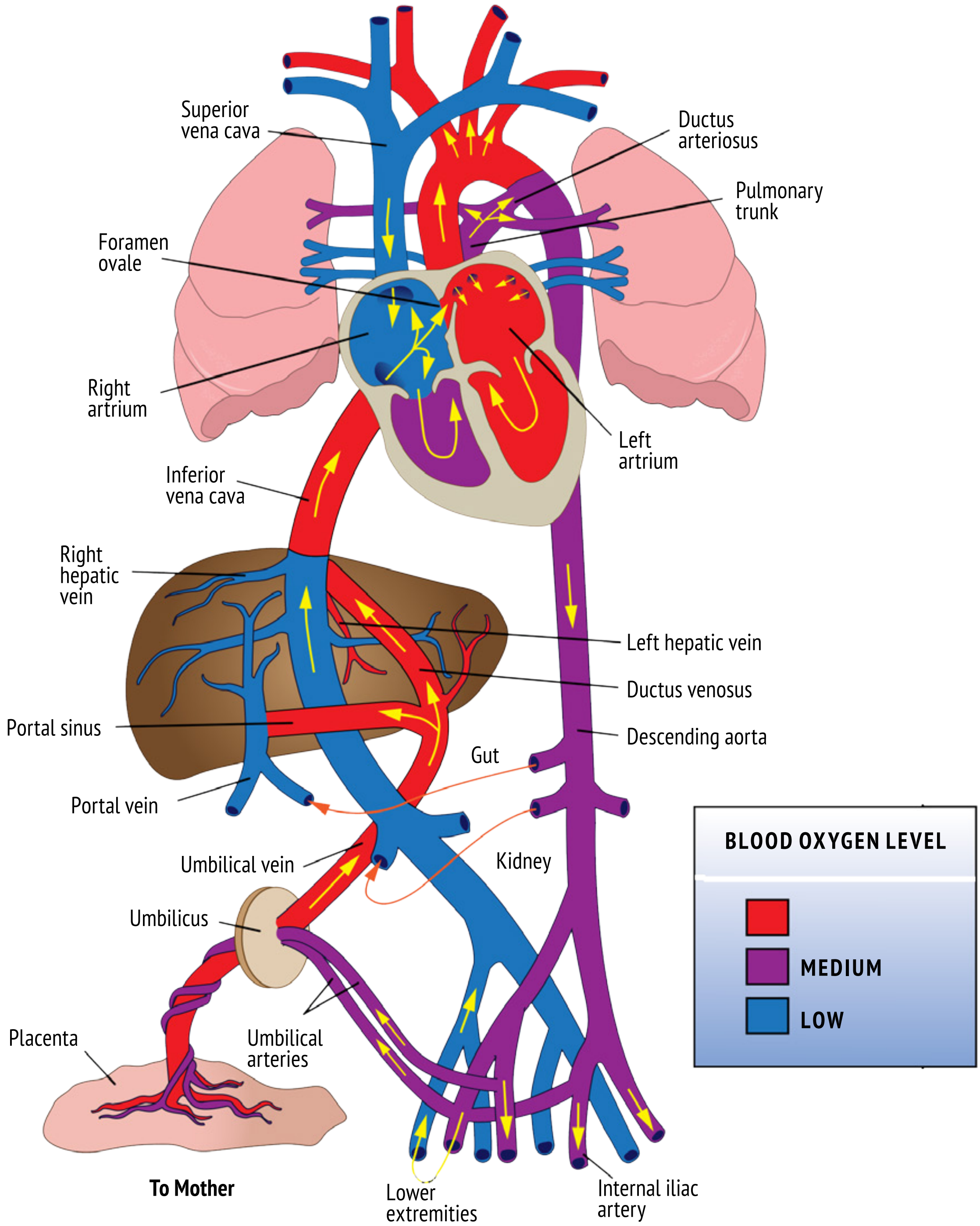

ADVANCED CONCEPTS

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There are two unique passages in the foetal circulation that allow blood to bypass the lungs. These two portals, known as the ductus arteriosus and foramen ovale, usually close soon after birth and 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 non-functional 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% 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

Blood is a specialised fluid (actually a distinct organ system) that links the respiratory system to the rest of the body. Approximately 55% 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 gasses. 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, cell fragments responsible for initiating the clotting process.

NOTES:

CHAPTER 3 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. **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 includes the**
   a. heart, lungs, brain
   b. arteries, spinal cord, nose
   c. nose, trachea, lungs
   d. bones, muscles, skin

5. **The cardiovascular system includes the**
   a. veins, arteries, heart
   b. mouth, lungs, stomach
   c. skin, bones, muscles
   d. nose, lungs, pharynx

Answers to review questions are on Page 70.

4 Decompression Illness (DCI)

CHAPTER 4 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. Which 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

- decompression sickness (DCS)
- arterial gas embolism (AGE)

While the underlying cause of these two conditions may be different, their initial medical management (first aid) is the same.

NOTE
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 physiologic 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 affect 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.

DCS is rarely life-threatening. Early treatment with high concentrations of O_2 (as close to 100% as possible) has been shown to speed symptom resolution and optimise the impact of recompression therapy.[8] Though symptom resolution is a desired effect of oxygen first aid, it is important to emphasise that it should not be considered a definitive treatment or arbitrarily stopped when symptoms resolve.

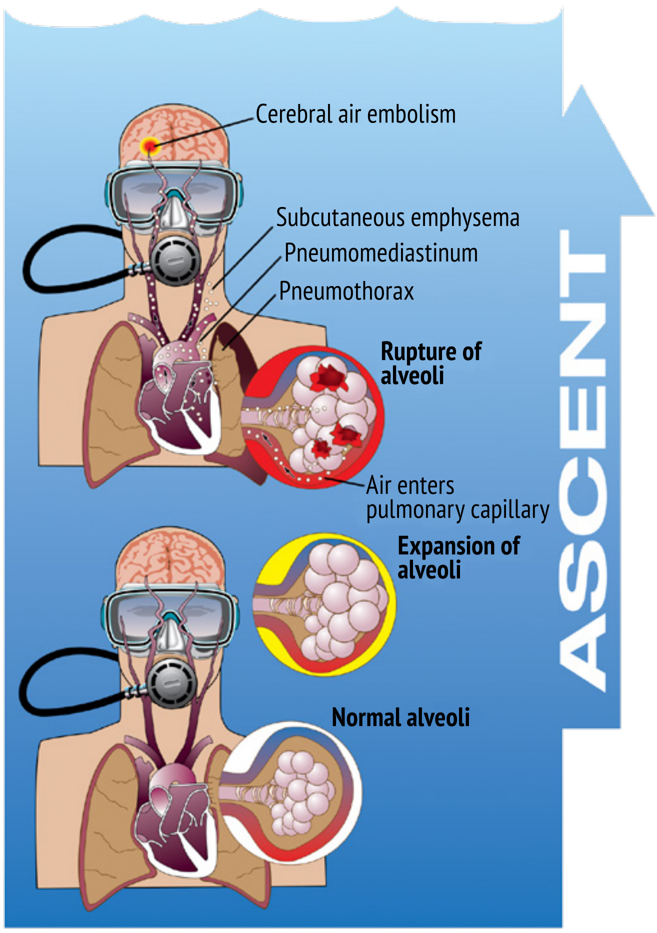
4

Arterial Gas Embolism (AGE)

Arterial gas embolism 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 m of sea water. 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.

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.

It is important to state that not all pulmonary tissue injuries result in AGE (this includes lung-overexpansion injuries in divers). Pulmonary trauma from stab wounds, projectiles or blunt force can also lead to lung-tissue damage and enable the escape of intrapulmonary (within the lungs) air without causing arterial bubbles. Signs of pulmonary barotrauma include extra-alveolar air (air outside the lungs) such as pneumothorax, subcutaneous emphysema (air beneath the skin), mediastinal emphysema (air in the mediastinum) and pneumopericardium (air trapped around the heart). 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 colouration of the lips).



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

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 arterialised bubbles is from the venous system and not pulmonary barotrauma. It is important to note that while bubbles in the systemic system are undesirable, their presence does not automatically cause symptoms. Bubbles have been visualised in the left heart following decompression in subjects who have not gone on to develop symptomatic DCI.

Oxygen and the Importance of Proper Medical Evaluation of DCI

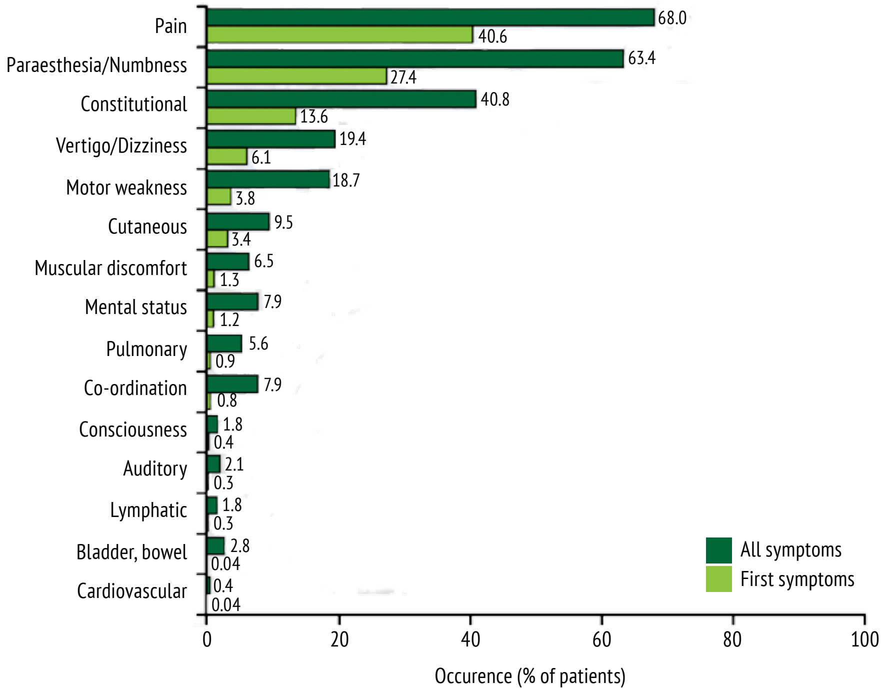
The diagnosis of DCI is based on history and clinical findings — there is no diagnostic test. Symptoms can range from very mild to severe and, particularly in the former case, may be dismissed by divers or appear to resolve by the time medical care is sought.

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.

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. The list is ranked in order of presentation frequency, based on Project Dive Exploration (PDE) data from 2,346 recreational dive accidents reported to DAN between 1998 and 2004.



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

Pain (Initial symptom in 41% of cases)

Commonly associated with neurological symptoms, the pain has been characterised 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 affected 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 illness such as viral infections, muscle or joint pain, fatigue from exertion and other non-specific discomforts

Paraesthesia/Numbness (Initial symptoms in 27% of cases)

- Paraethesthia/anaesthesia/dysaesthesia are terms that refer to altered sensations and may present as abnormal feelings (paraesthesia), decreased or lost sensation (anaesthesia) or hypersensitivity (dysaesthesia). Paraesthesia is commonly characterised 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% of cases)

- These are generalised 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 and Dizziness (Initial symptoms in 6% of cases)

- *Vertigo:* Vertigo is generally described as an acute "sensation of spinning" (i.e., environment moves around diver or 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, indicative of inner-ear/vestibular involvement
  - There are several causes not related to DCI for such symptoms. These include round- or oval-window rupture (associated with difficulty equalising), 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 characterised as lightheadedness, and is commonly associated with nausea

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Motor Weakness (Initial symptom in 4% of cases)

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

Cutaneous (Skin) Symptoms (Initial symptom in 3% 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). Affected areas may be tender or itch and are thus often confused with allergies or contact dermatitis.

Pulmonary Issues (Initial symptom in 0.9% 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.

Co-ordination/Cerebellar Function (Initial symptom in 1% of cases)

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

Altered Mental Status (Initial symptom in 1.2% of cases)
Symptoms may include confusion, personality changes or speech disturbances (slurring of words or nonsensical speech).

*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 initial symptom in 0.4% of cases
- *Audiovestibular or inner-ear DCS:* This is an alteration of balance or hearing that can be associated with vertigo
- *Lymphatic DCS:* Identified as an initial symptom in only 0.3% of cases but deserves mention as this symptom does not immediately resolve with successful recompression treatment. It is often characterised as localised swelling affecting the trunk and shoulders
- *Visual disturbance:* Loss or blurring of vision or loss of visual fields
- *Bowel and bladder:* Spinal cord DCS may injure the nerves responsible for bladder and bowel control. Urinary catheterisation is often indicated to relieve injury to the bladder
- *Cardiovascular:* 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 Decompression Illness
DCI is an uncommon event but, nonetheless, it warrants attention and concerted efforts for prevention. Based on 441 confirmed or possible incidents of DCI, referenced in the 2008 DAN *Annual Diving Report*, 3.9% were classified as possible AGE.[1]

The occurrence of DCS varies by population. Based on DAN data, the per-dive rate among recreational divers is 0.01-0.019%, among scientific divers it's 0.015%, for U.S. Navy divers it's 0.030% and for commercial divers it's 0.095% .[1,2]

Previously published per-dive DCS rates based on 135 000 dives by 9 000 recreational divers were 0.03%. This rate was higher in those who performed deep cold-water wreck dives versus the group aboard warm-water liveaboards. The incidence of DCS was 2/10 000 (0.0002) from warm-water liveaboards and 28/10 000 (0.0028) among cold-water wreck divers in the North Sea.[3]

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 from the time of injury. As one might expect, sudden neurological injury that leads to unconsciousness may result in drowning.

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 co-ordination 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.

CHAPTER 4 REVIEW QUESTIONS

1. **Decompression illness (DCI) includes**
   a. decompression sickness (DCS)
   b. arterial gas embolism (AGE)
   c. both of the above

2. **The most important initial actions in responding to diving accidents are recognising there is a problem and administering 100% 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 proper medical evaluation in cases of suspected DCI since**
   a. symptom resolution with oxygen first aid does not mean DCI has been resolved
   b. symptoms may return without hyperbaric treatment
   c. recurrence of symptoms may be reduced with hyperbaric treatment
   d. all of the above

6. **The single most common symptom of DCI is**
   a. numbness
   b. constitutional symptoms (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. **Returning to diving following decompression illness should be done in conjunction with a physician knowledgeable in dive medicine**
   a. True
   b. False

Answers to review questions are on Page 70.

5 Oxygen and Diving Injuries

CHAPTER 5 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 non-fatal drowning?
9. What is the first responder's role in a non-fatal drowning?

The most common diving injuries for which oxygen use is recommended are arterial gas embolism (AGE) and decompression sickness (DCS). In the case of AGE, bubbles may enter the arterial system secondary to 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 following decompression. Bubbles may cause tissue disruption, compromise blood flow and/or trigger inflammatory responses, which may result in symptoms.

Though most cases of DCS are mild and do not pose an immediate risk to life, impaired circulation or function of 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.

In contrast to DCS, AGE is commonly associated with lung-overexpansion injury and can result in acute neurological symptoms, including unconsciousness. Bubbles entering the arterial system through damaged lung tissue can quickly travel to the brain and interrupt circulation. The goal of first responders is to enhance blood oxygen levels and speed bubble size reduction by establishing a gas gradient.

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, on a relative basis, 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 can also reduce pain and swelling (oedema), and limit or reverse hypoxic injury.

Once oxygen delivery to an injured diver has started, continue oxygen use until the injured diver has reached a definitive care facility or until the oxygen supply is depleted. Do not reduce oxygen flow to the injured diver to make the supply last. High concentrations of inhaled oxygen, even if delivered over a shorter period of time, will be more beneficial. Lower concentrations of inspired oxygen may not be as effective, even though the rescuer can deliver oxygen for a longer period of time.

Vomiting or seizures can occur during first aid care. In the case of vomiting, temporarily discontinue oxygen use until after vomiting has ended. Then evaluate the airway, clear if necessary, and resume providing emergency oxygen at the earliest possible moment.

If the injured diver has a seizure, the rescuer may have to remove the oxygen. Seizures occurring during surface oxygen administration are usually the result of a hypoxic event to the brain. Resume oxygen delivery as soon as possible.

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

Oxygen Flow Rates

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

Two variables affect delivered oxygen concentrations: mask fit and flow rate (measured in litres per minute or lpm). When using demand valves, proper mask fit and seal are critical because the flow rate is not adjusted manually. When using constant-flow systems, mask fit is still crucial because leaks result in decreased inspired fractions of oxygen (FiO_2). Enhanced flow rates are an inefficient way to compensate for a poor-fitting mask.

Delivery Device	Flow Rate	Inspired Fraction+
Oronasal mask (no reservoir bag)	10 lpm	⩽ 0.5–0.6 (50%–60%)*
Non-rebreather mask	10-15 lpm	⩽ 0.8 (80%)**
Bag valve mask	15 lpm	⩽ 0.9–0.95 (90%–95%)
Demand valve	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 summarises 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%). Simple face masks may deliver fractions of 0.5-0.6 at flow rates between 10-15 lpm.

Non-rebreather 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 maximising 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 patient comfort. Any perceived or suspected worsening in a diver's condition should prompt reassessment.

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.

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 pressures 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 the cellular antioxidant defenses. Initial symptoms may include substernal (behind the sternum) irritation, burning sensation on inspiration and coughing. The most severe symptoms may occur after about 12 to 16 hours of exposure at 1 ATA.4 The time to initial symptom onset is expected to reduce at higher partial pressures (greater than 1 ATA). Symptoms may be seen from 8 to 14 hours at 1.5 ATA5 and from 3 to 6 hours at 2 ATA.4,5 At higher pressures, symptoms may occur more quickly but are often less severe, due to limited exposure times. The prevailing concern with PO2 levels greater than 2.5 ATA and 3 ATA is CNS toxicity.[4,5,6]

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 at ground or sea level for less than 12-24 hours.

Non-fatal Drowning

Non-fatal 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 non-fatal 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.[8]

Symptoms of non-fatal drowning may include difficulty breathing, bluish discolouration of the lips, abdominal distention, chest pain, confusion, pink frothy sputum, irritability and unconsciousness. Victims may also be anxious or cold and would benefit from removal of wet clothes and possibly treatment for hypothermia.[8]

As a first responder, your primary role is to monitor vital signs, provide supplemental oxygen and arrange transport to the nearest medical facility as soon as possible. If the victim is unresponsive and not breathing, ventilations (versus compressions) are the priority. Begin CPR with ventilations using supplemental oxygen if available, followed by compressions in line with the ABC protocols of CPR. Refer to your prerequisite CPR training for additional information.

NOTE

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

CHAPTER 5 REVIEW QUESTIONS

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

2. **The primary goal of providing 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

3. **Percentage of oxygen delivered when using a demand valve is influenced by**
   a. flow rate and mask fit
   b. mask fit and mask seal
   c. mask seal and flow rate

4. **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

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

6. **Oxygen toxicity, whether CNS or pulmonary, is not a concern when providing oxygen first aid to an injured diver**
   a. True
   b. False

7. **Which of the following is not a symptom of non-fatal drowning**
   a. difficulty breathing
   b. rapid pulse
   c. cyanosis (bluish coloured lips)
   d. abdominal distention
   e. chest pain

8. **As a first responder to a non-fatal drowning, your primary role is to**
   a. monitor vital signs
   b. provide supplemental oxygen
   c. transport victim to the nearest medical facility
   d. all of the above

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

Answers to review questions are on Page 70.

NOTES:

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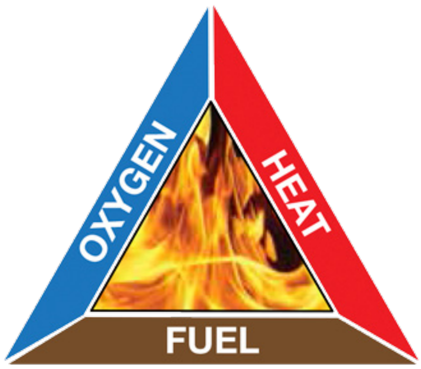
6 Handling Oxygen Safely

CHAPTER 6 OBJECTIVES

1. What is the fire triangle and how is oxygen involved?
2. What two steps should be implemented to reduce the risks of handling oxygen?
3. What safety precautions should be implemented when using oxygen equipment?
4. What grade of oxygen should be used for diving first aid?
5. What documentation is required to receive an oxygen fill?
6. How should an oxygen unit be stored?
7. When should an oxygen unit's components and cylinder pressure be checked?
8. 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. 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.

Emergency Oxygen Providers should reduce the risks of handling oxygen. Be sure that the hazards from both the fuel (oil deposits and hydrocarbons are commonly used as lubricants for diving and are found on dive boats) and heat from the sun, and rapid opening of the oxygen cylinder valve are minimised.



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 vapour. 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 for Emergency Oxygen Providers to consider are:

- aviator-grade oxygen
- medical-grade oxygen
- industrial-grade oxygen

Each grade must be 99.5% 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 odour test be conducted and the cylinder contents be evacuated before the fill. When odours are detected or damage to the valve or cylinder is observed, medical-grade oxygen cylinders are cleaned before returning them 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 gasses 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 from 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. The result may be a fire
- Oxygen cylinders should not be exposed to temperatures higher than 52°C in storage (for example, 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 pressurise. This will reduce the possibility of an oxygen fire if combustible contaminants have been introduced into the system. Once the system is pressurised, open the valve at least one full turn
- Remember to provide adequate ventilation when using oxygen. In a confined, poorly ventilated space (the cabin of a boat, for example), 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

Oxygen Cylinder Filling

Medical-grade oxygen is considered a prescription drug in many areas, 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. Like your scuba diving certification card, your Emergency Oxygen Provider card is your documentation of appropriate training. Since retraining is required every two years, you will need to maintain your skills by taking an oxygen refresher programme. Ask your EO_2 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 can provide this prescription.

Some countries, provinces 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 facilities' 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 an oxygen unit in excellent working conditions 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/or the regulator depressurised. 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

CHAPTER 6 REVIEW QUESTIONS

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

2. **The risks of handling oxygen can be reduced by**
   a. keeping the oxygen units free of hydrocarbons found in oils and lubricants often kept on dive boats
   b. slowly opening the oxygen cylinder
   c. keeping the unit away from the heat of the sun
   d. all of the above

3. **Contact with grease and exposure to high temperatures are of no concern with oxygen equipment**
   a. True
   b. False

4. **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

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

6. **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

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

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

Answers to review questions are on Page 70.

7 Oxygen Delivery Systems and Components

CHAPTER 7 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 two to 10 years; the hydrostatic testing requirement in South Africa is every four years.

Oxygen cylinders should be clearly labelled. For easy identification and to minimise the risk of using a cylinder and/or its contents for an unintended purpose, oxygen cylinders are colour coded.

Common oxygen cylinder colour combinations include:

- green (United States)
- black with a white shoulder (Australia, New Zealand, United Kingdom and others)
- white (Canada and Europe)

Ask your EO_2 Instructor for the colour-coding requirements of your region.

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. Non-portable oxygen cylinders can last up to eight hours or more. DAN Oxygen Units come with a 2,5 liter 200 BAR steel oxygen cylinder (500 liters).

A 15-minute oxygen supply may be all that is needed if diving from shore where emergency medical services (EMS) are in place and can respond quickly. A one- or two-hour supply may be required when diving off a boat close to shore. When diving far offshore and assistance is hours away, consider carrying a non-portable oxygen cylinder or multiple portable oxygen cylinders. Consult your EO_2 Instructor about which cylinder size is most appropriate for your use.

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

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

For example, if a cylinder holds 640 litres and the oxygen flow rate is 15 litres per minute, the cylinder will last approximately 43 minutes. At 10 litres 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 litres per minute. Demand-style delivery is preferred because no oxygen is wasted and the oxygen supply usually lasts longer.

A partially filled oxygen cylinder should be changed to a full one when the pressure drops below 200 psi (14 bar). However, if only one cylinder is available, 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 constant-flow 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 gasses 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.

Ask your EO_2 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 multi-function regulator combines the features of both the demand and constant-flow regulators.

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

All DAN Oxygen Units come equipped with multi-function regulators.

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

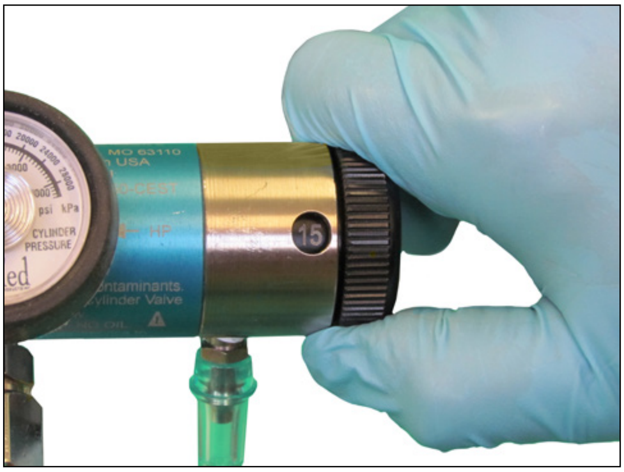
Flow meter. The flow meter, an integral part of the pressure regulator, indicates the oxygen flow rate delivered through the barbed outlet to the constant-flow device (non-rebreather mask or oronasal resuscitation mask with supplemental oxygen inlet). Oxygen flow is measured in litres per minute (lpm). 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 multi-function regulator is designed to deliver up to 25 lpm. DAN recommends an initial flow rate of 10 lpm when used with either a non-rebreather 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 non-portable ones.

Oxygen system adapters are available commercially. To minimise the risk of fire and explosion, they should be oxygen cleaned. Avoid home-made adapters and the use of scuba regulators with high oxygen concentrations.

It should be noted, however, that the CGA discourages use of adapters.



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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 is typically green, indicating it is intended for oxygen delivery.

Certain types of constant-flow masks provide oxygen-safe, clear plastic tubing to connect the mask to the regulator's constant-flow barb. The flow meter adjusts the flow volume through this hose to the mask.

Oxygen Masks and Delivery Devices

An oxygen mask held 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% inspired oxygen as possible. In contrast, common constant-flow masks provide from 35 to 75% 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.

Non-rebreather mask

The non-rebreather 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 non-rebreather mask consists of a mask with three non-return valves — one on either side of the mask and one separating the mask from the reservoir bag. 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 non-return 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 non-rebreather mask is an effective way to deliver a high concentration of inspired oxygen using the constant-flow feature of the regulator. However, this mask 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 non-rebreather 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 non-rebreather mask. Adjust the flow rate to the non-rebreather 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 non-rebreather mask may deliver inspired oxygen concentrations up to 80%.

NOTE

Caution: If the oxygen supply to the non-rebreather 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 non-rebreather mask. Remove any mask before turning off the gas supply.

Several other oxygen delivery devices, such as the partial rebreather mask, 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, or regular air via the constant-flow barb on the oxygen regulator. It aids rescuers in providing ventilations to both a non-breathing 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%, compared with the 16-17% 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 overexpand 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 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 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 minimised 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.

Newer 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.

7

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. 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 non-return 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 re-entering 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. 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 re-enter when the reserve bag is used if there is insufficient gas to allow the ventilation bag to refill.

Manually Triggered Ventilators

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 non-breathing 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 minimise the gas waste.

NOTE
Lower tidal volumes are recommended with manually triggered ventilators. 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 manually triggered ventilator. 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 rescue breathing 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 non-breathing 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 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. 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 acoustic alarm that alerts the operator of excessive levels of pressure in the airways.

As with all oxygen-assisted ventilation techniques, when the oxygen supply is exhausted, these units can no longer be used.

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 Pack

This standard DAN Oxygen unit is specially developed to treat injured divers and includes a 2,5 liter Pin Index Oxygen cylinder.

The Unit Delivers

- 100% oxygen using the demand valve,
- about 75% when using the non-rebreather mask and
- about 50% when using an oronasal resuscitation mask.

This unit can provide oxygen to 2 divers simultaneously and has the option to connect an extra demand valve making it possible to deliver oxygen to 3 divers or to 2 divers using the demand system only. The demand valve is the preferred oxygen delivery system as it provides the highest concentration of oxygen and no oxygen is wasted.

The Pin Index system is the most common oxygen cylinder valve system available worldwide for small cylinders. Check if this valve is available in your country. If in doubt contact us for advice

Dimensions

Interna: 480mm x 360mm x 198mm
Externa: 550mm x 420mm x 215mm

Included Items

- Waterproof "DAN Oxygen Unit" case (for a 43cm cylinder)
- Oxygen on Board Sticker
- Pin Index Medical Oxygen cylinder (empty)
- DAN Demand valve with white hose
- DAN Oronasal Resuscitation MASK
- Tru-Fit Mask
- Non-Rebreather Mask
- Pin Index Multifunction Oxygen Regulator (CE version)

Mini Oxygen Unit

This Pin Index Mini Oxygen unit, also called charter boat unit contains the same oxygen components as the standard Pin Index Oxygen unit but is housed in a smaller orange waterproof case. This unit is specially interesting for those having a big, fixed, oxygen cylinder on their boat.

The Unit Delivers

- 100% oxygen using the demand valve,
- about 75% when using the non-rebreather mask and
- about 50% when using an oronasal resuscitation mask.

This unit can provide oxygen to 2 divers simultaneously and has the option to connect an extra demand valve making it possible to deliver oxygen to 3 divers or to 2 divers using the demand system only. The demand valve is the preferred oxygen delivery system as it provides the highest concentration of oxygen and no oxygen is wasted.

The Pin Index system is the most common oxygen cylinder valve system available worldwide for small cylinders. Check if this valve is available in your country. If in doubt contact us for advice

Dimensions

Internal: 305mm x 230mm x 137mm
External: 335mm x 290mm x 155mm

Included Items

- Waterproof Case
- Oxygen on Board Sticker
- DAN Demand valve with white hose
- DAN Oronasal Resuscitation MASK
- Tru-Fit Mask
- Non-Rebreather Mask
- Pin Index Multifunction Oxygen Regulator

CHAPTER 7 REVIEW QUESTIONS

1. **Which of the following is not part of an oxygen-delivery systems?**
   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. Distance to medical aid
   c. Cylinder markings

3. **A multi-function 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 visual and hydrostatic testing**
   a. True
   b. False

6. **Oxygen cylinder marking colours are standardised 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 rescue breathing
   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 non-breathing or inadequately breathing divers
    b. can also function as a demand valve
    c. is 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 the demand inhalator valve or when there is more than one injured diver is a**
    a. non-rebreather mask
    b. oronasal resuscitation mask
    c. bag valve mask

Answers to review questions are on Page 70.

NOTES:

8 Oxygen Provider Skills Development

SKILL OBJECTIVES

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

1. Oxygen equipment identification, disassembly and assembly
- Identify the component parts of the DAN Oxygen Unit
- Disassemble and reassemble the DAN Oxygen Unit or equivalent with minimal assistance

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 or ill diver
- Demonstrate correct 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. Non-rebreather mask
- Provide emergency oxygen to a simulated unresponsive, breathing, injured diver using the non-rebreather 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 non-breathing or inadequately breathing, injured diver using the bag valve mask on a CPR manikin

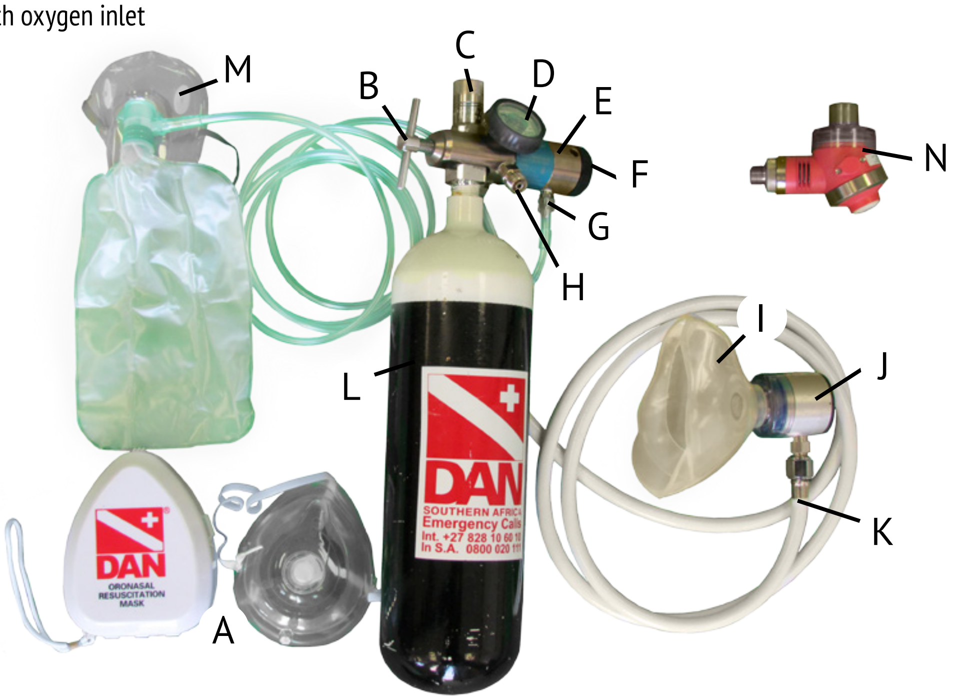
7. MTV
- Provide emergency oxygen to a simulated non-breathing or inadequately breathing, injured diver using an MTV and oronasal mask on a CPR manikin

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 EO_2 Instructor will guide you through this skill development section.

Oxygen Equipment Identification

A. Oronasal resuscitation mask with oxygen inlet
B. T-handle
C. Handwheel wrench
D. Pressure gauge
E. Multi-function regulator
F. Constant-flow controller
G. Barbed constant-flow outlet
H. DISS threaded outlet
I. True-Fit® mask
J. Demand inhalator valve
K. Intermediate pressure hose
L. Oxygen cylinder and valve
M.Non-rebreather mask
N. MTV



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Oxygen Equipment Assembly and Disassembly

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 depressurised
- Open constant-flow control
- Check pressure gauge
- Remove multi-function regulator from the oxygen cylinder valve
- Secure oxygen cylinder
- Remove oxygen washer from multi-function regulator

NOTE

Washer is different from standard scuba O-ring.

- Remove oxygen hose from multi-function regulator
- If the fitting is too tight, use handwheel/wrench to unscrew the hose

NOTE

Check valves; ensure oxygen does not flow from threaded ports.

- 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

Scene Safety Assessment

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 scene
- Is the scene safe?
- Is it safe to approach the injured diver?
- Is the ventilation adequate for oxygen?
- Any other hazards present?

F – Find and secure oxygen, first aid kit and AED unit
- First aid kits contain critical supplies such as barrier devices

E – Ensure exposure protection
- Use barriers such as gloves and mouth-to-mask barrier devices

8

Initial Assessment with Basic Life Support

Objectives

- *Establish responsiveness of a simulated injured or ill diver*
- *Demonstrate correct 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 shoulder
    - 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 he is 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 EO_2 Instructor

Demand Inhalator Valve

Objective

- *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.

- Check the mask for any leaks around the injured diver’s face

8

Instruct the injured diver to breathe normally from the mask.
- Reassure and comfort the injured diver

Instruct the injured diver to 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 co-ordination of hyperbaric treatment

Non-rebreather Mask

Objectives
- *Provide emergency oxygen to an unresponsive, breathing, injured diver using the non-rebreather 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 non-rebreather mask. The non-rebreather 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 non-rebreather mask from bag
- Stretch oxygen tubing to avoid kinks
- Attach oxygen tubing to barbed constant-flow outlet on the multi-function regulator

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

Prime mask reservoir bag.
- Place a thumb or finger inside the nosepiece, closing the non-return 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 non-return 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

Resuscitation with a Bag Valve Mask

Objective:

- *Provide emergency oxygen to a non-breathing or inadequately breathing, injured diver using the bag valve mask (BVM)*

Follow these steps to resuscitate a non-breathing or inadequately breathing, injured diver using a BVM. Ventilating a non-breathing or inadequately breathing, injured diver using the BVM 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 to a depth roughly 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

Rescuer two

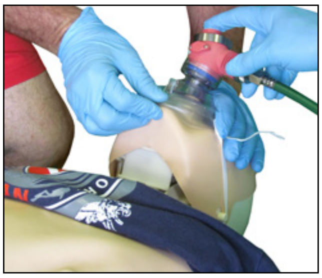
The second rescuer prepares the oxygen equipment while the first rescuer performs CPR. When the equipment is ready, the second rescuer should do the following:

- 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

Using an MTV

Objective:

- *Provide emergency oxygen to a non-breathing or inadequately breathing, injured diver using an MTV and oronasal mask*



Follow these steps to resuscitate a non-breathing or inadequately breathing, injured diver using a manually triggered ventilator (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 a rise in the chest and abdomen
  - 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 rescue breathing if the supply is exhausted
- Activate your emergency action plan
- Call EMS and DAN

8

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	Depth	Time	Safety Stops/Deco	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

Emergency contact information: ______________________________

Emergency medical assistance: ______________________________

Nearest medical facility directions: ______________________________

____

Phone: ______________________________

Diving medical consultation information: ______________________________

Divers Alert Network (DAN-SA): **0800 020 111 (local) or +27 828 10 60 10 (int.)**

** This number may be called collect in an emergency.*

Other important information: ______________________________

Phone: ______________________________

Notes: ______________________________

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9 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.

Recognising 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 0800 020 111 (local) or +27 828 10 60 10 (int.) after activating local EMS.

As a final note, remember

- Only use oxygen 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

Glossary

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

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

aorta – the largest vessel of the systemic arterial 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

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 – a waste gas produced by the metabolism of oxygen in the body

carbon monoxide – a highly poisonous, odourless, tasteless and colourless 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 haemoglobin, 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

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 compressed-gas 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 synthesised 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 – the difference in pressure, oxygen tension or other variables as a function of distance, time or other continuously changing influence

Glossary (continued)

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 – litres 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 – a colourless, odorless, tasteless gas essential to life, making up approximately 21% 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 non-observable 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 at the beginning of the principal right and left bronchi

Glossary (continued)

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 gasses 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

References

1. POLLOCK, N.W. (2008) *Annual Diving Report.* Durham, NC: Divers Alert Network.
2. VANN, R.D. et al. (2011) *Decompression Illness.* Lancet. 377. p.153-164.
3. VANN, R.D. et al. (2005) The risk of decompression sickness (DCS) is influenced by dive conditions. In GODFREY J., SHUMWAY, S. (Eds). *Diving for Science 2005.* Proceedings of the American Academy of Underwater Sciences 24th Annual Symposium. p.171-177.
4. COMROE, J.H. JR. et al. (1945) Oxygen toxicity: the effect of inhalation of high concentrations of oxygen for twenty-four hours on normal men at sea level and at a simulated altitude of 18 000 feet. *Journal of the American Medical Association.* 128. p.710-717.
5. CLARK, J.M. et al. (1999) Effects of prolonged oxygen exposure at 1.5, 2.0, or 2,5 ATA on pulmonary function in men (Predictive Studies V). *Journal of Applied Physiology.* 86. p.243-259.
6. CLARK, J.M. et al. (1991) Pulmonary function in men after oxygen breathing at 3.0 ATA for 3.5h. J*ournal of Applied Physiology.* 71. p.878-885.
7. MAYO CLINIC. *What's a normal resting heart rate?* [Online] Available from: http://www.mayoclinic.com/health/heart-rate/AN01906.
8. LONGPHRE, J.M. et al. (2007) First aid normobaric oxygen for the treatment of recreational diving injuries. *Undersea and Hyperbaric Medicine Journal.* 34. p.43-49.
9. RICHARDS, D.B. & KNAUT, A.L. (2009) Drowning. In: MARX, J.A. et al. (eds.). *Rosen's Emergency Medicine: Concepts and Clinical Practice.* 7th ed. Philidelphia, PA: Mosby Elsevier.

Additional Reading

BOVE, A. & DAVIS, J. (2004) *Bove and Davis' Diving Medicine.* 4th ed. Philadelphia, PA: Saunders.

BRUBAKK, A. & NEUMAN, T. (eds.) (2003) *Bennett and Elliott's Physiology and Medicine of Diving.* 5th ed. London: Saunders.

NEUMAN, T. & THOM, S. (2008) *Physiology and Medicine of Hyperbaric Oxygen Therapy.* Philadelphia, PA: Saunders/Elsevier.

First Aid Guidelines

NEUMAR, R.W. et al. (2015) American Heart Association Guidelines Update for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. *Circulation Nov 2015.* 132 (18). suppl 2.

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Divers Alert Network Southern Africa

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.

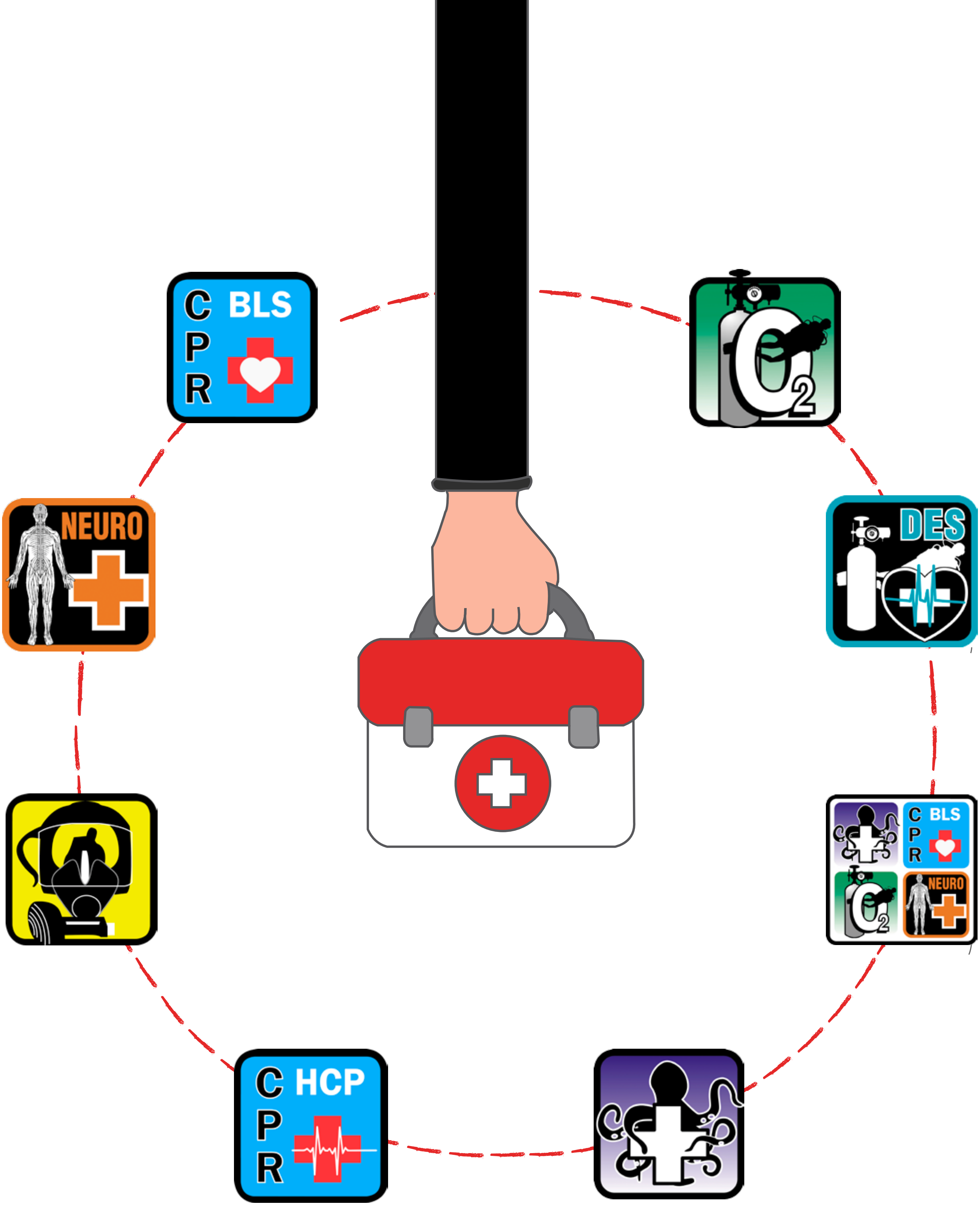
Among the services DAN-SA provides to the diving public is the DAN Emergency Hotline (0800 020 111 (local) or +27 828 10 60 10 (int.)). This hotline is available 24 hours a day, seven days a week for anyone who suspects a diving injury, requires assistance or needs to activate ***your DAN evacuation 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 and the multitude of resources it provides, or to become a member, please visit dansa.org.



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