# Oxygen First Aid

Medical Considerations

Technical Considerations

General Aspects

SCUBA
Courses & Publications

Oxygen First Aid for Divers
Scuba Publications – Daniela Goldstein
Jan Oldenhuizing

## Table of Content

Medical Considerations ........ 1

Technical Considerations ........ 17

General Aspects & Preview for the Practical Part ........ 28

## Introduction

Recreational diving has excellent safety statistics. The level of knowledge expected from recreational divers and the available equipment make it possible to avoid injury and illness. However, training and equipment cannot eliminate all the risk. Being a recreational diver means that you accept a reasonable level of risk related to the activity.

If something goes “wrong”, it is very likely that the ill or injured diver has hypoxia. Decompression sickness (DCS), lung overexpansion injuries, near drowning, carbon monoxide poisoning are examples of potential consequences of being underwater. Being subjected to changing pressures affects the respiratory and circulatory system and can lead to hypoxia – either affecting a part of the body or all body tissues.

There is only one “cure” for hypoxia, which is oxygen. In some cases the oxygen in the air could be enough; in others as high a concentration as possible should be given. This requires that the person who is giving basic life support and first aid can recognize a need for additional oxygen has a thorough understanding of what the oxygen does in the body of the patient and knows how to use oxygen equipment to provide as high a concentration as possible.

This book covers both the medical and technical considerations for the administration of oxygen.

# Medical Considera-tions

In virtually all diving courses, the recognition of medical emergencies is addressed. This information often consists of lists of signs and symptoms. Just reading such a list (and memorising it) does not develop understanding of what is actually going on in the body of the diver.

Some diving emergencies can be recognised by only few factors out of a wide range of possible symptoms. These are emergencies in which the oxygen supply to only a part of the body is affected (embolism, decompression sickness and other). The range of possible symptoms is simply too big to learn by heart. Understanding of the underlying mechanisms that provoke the symptoms allows a rescuer to explain what is happening. That level of understanding is the goal of this chapter.

*Describe the meaning of hypoxia and anoxia.*

Hypoxia is a lack of oxygen. The cells in the human body need oxygen to function and to stay alive. Nerve cells are very sensitive to a lack of oxygen. Damage could result after as little as 4 to 6 minutes without oxygen. Anoxia is similar to hypoxia, but means “no oxygen“, rather than “too little oxygen”.

If you have too little oxygen, the only functioning medication is oxygen. Administration of oxygen does not take priority over artificial respiration and CPR. If confronted with a non-responsive diver, you should initially take care of basic life support. Administration of oxygen takes more or less the same priority as shock management.

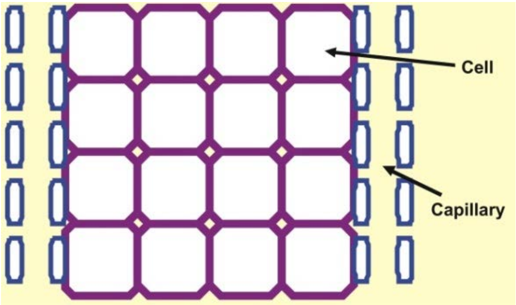
*Describe the signs and symptoms of hypoxia.*

Almost any diving related medical problem involves hypoxia to a certain extent. The extent to which the body is lacking oxygen depends on the type problem and can be either local or involve the entire body. If there is a lack of oxygen for the entire body, the skin is also affected. This will result in signs which are easily recognized, such as a grey/blue skin. Somebody with hypoxia affecting the entire body looks as if he is not doing well and needs first aid. Such a situation could be caused by a near drowning or cardiac arrest.

Recognition of a local hypoxia is more difficult. The affected person might look perfectly healthy on first sight. The skin is not affected, so the person does not immediately appear to have a medical problem. A closer look might reveal things such as limping, local pain, problems focusing and others. Many of these are not signs, but symptoms. This means that you have to rely on the information the patient is giving you. If you know what to look for, you might notice mild signs of hypoxia and can then react by interviewing the diver to confirm what you have seen. To do this, it is necessary to understand what hypoxia is doing and what you achieve when you give oxygen. We'll explore these issues in detail.

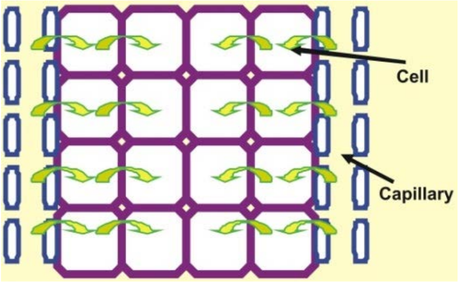
*List three key features of capillaries and describe how capillaries deliver oxygen to cells.*

This drawing is a simplified illustration of some tissue with two capillaries. Normally you find more cells between two capillaries, but to illustrate what happens in hypoxia, 4 cell-rows serve all purposes. You have an enormous amount of capillaries. How great would you estimate the chance to stick a needle through the skin and have no blood coming out of the wound? There are more than 4 rows of cells between two capillaries, but the distance between the two is small.




There are 3 things you need to know about capillaries:

- You have just enough of them. If you were to go in an environment with less oxygen (mountains) you would get more capillaries. If you move to an area with more oxygen you would lose capillaries. If you gain weight, you not only become fatter, but also acquire the additional capillaries needed to supply the fat with blood.
- Capillaries are semi-permeable, meaning that they let through oxygen, nitrogen, salt, sugar, liquid, etc. They are meant to exchange molecules between the blood and the tissues.
- The walls of capillaries are made out of living cells. Also the capillary itself needs oxygen to live.

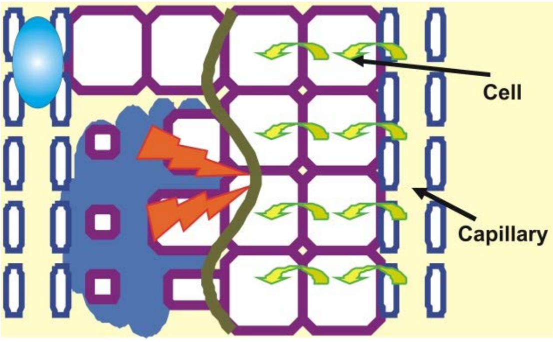


When breathing air, you inhale 21% of oxygen. You live in an air environment, so your body (and thus the amount of capillaries) is adapted to that. In this drawing each capillary supplies the two rows of cells next to it with oxygen.

If the capacity of a capillary were adequate to provide three rows of cells with oxygen, the next capillary would be further away. There is no membrane between the rows of cells, but if one capillary stopped functioning, the next capillary would not have enough oxygen available to supply all the cells – a local hypoxia could develop.

*Explain the risks related to a blockage in the circulation.*

Most of the mass of the human body is water (liquid). The biggest part of this liquid is in the cells. Cells maintain their stability by assuring that they are completely filled with water and are under tension. This tension is achieved by having a higher salinity within the cell than in the surrounding liquid. Liquid is continuously attempting to enter the cell in order to achieve equilibrium in salinity. Because of the limits in flexibility of the wall of the cell this equilibrium will never be achieved, but the attempt to enter liquid keeps the cell under sufficient tension (osmotic pressure) to maintain stability.




Cells release fluid when they are dying of unnatural causes (such as hypoxia). The released fluid has a higher salinity than the salinity of the free liquid in the body. Now, there is no more cell-wall available to limit the liquid in an attempt to reach equilibrium in salinity. An unnatural amount of liquid will accumulate in the affected area. An oedema (or swelling) is the result. This swelling can irritate nerves which can develop symptoms: pain, fatigue, etc. If the capillary was supplying a nerve with oxygen, the nerve can die – neurological damage – leading to symptoms such as paralysis, losing the ability to walk, remember, speak or see, numbness, etc.

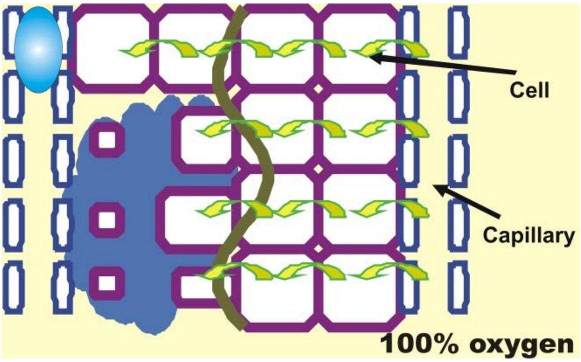
The swelling can exert pressure on the next capillary. As a result that capillary is also going to be blocked (capillaries have a diameter which is just large enough to allow red blood cells to pass through. If they are flattened by the oedema, red blood cells will block the capillary). This then creates a snowball-effect – the oedema expands.

Four medical conditions provoke the same symptoms. The cause is different, but the further development of the oedema is the same.

- Nitrogen bubbles from DCS Type II block the bloodstream.
- Air bubbles from an Arterial Gas Embolism block the bloodstream.
- Solid material blocks the bloodstream in thrombosis.
- A stroke starts with a ruptured blood vessel (or thrombosis in an arterial vessel supplying the brain).

*List the first two beneficial effects of oxygen.*

The distance between capillaries is based on a supply with 21% oxygen. When we now give the patient 100% oxygen, each capillary is transporting more (not 5 times as much, because of haemoglobin limitations) oxygen and can supply more tissue – a neighbouring capillary can take over the duties of a blocked capillary. This will bring oxygen to the isolated cells and, if they haven't already died, this oxygen can help them to survive.



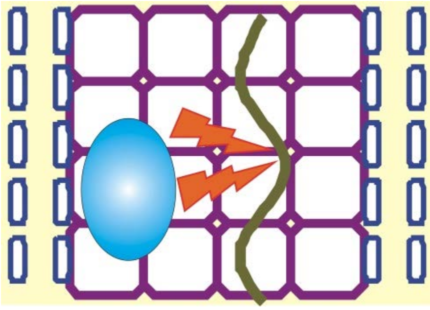

Oedema results from dead cells. For these cells the oxygen comes too late, but cells that are still alive can stay alive because of the oxygen that is now available. The oedema will not develop any further. The snowball-effect is stopped.

This explains the first two benefits of the administration of oxygen. Hypoxia is cured and oedema is stopped at the level to which it has developed.

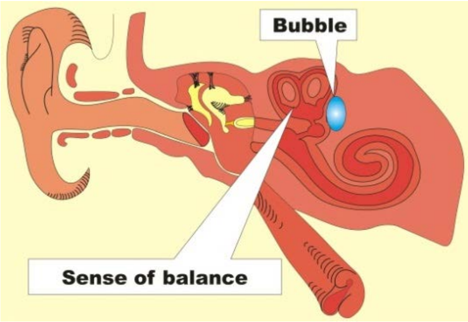
*Explain what decompression sickness Type I is and describe related symptoms.*

With decompression sickness, bubbles may also develop in the tissue itself – not in the bloodstream (and cause mechanical damage). In this case the bloodstream is not blocked, so there is oxygen flowing to the tissue. The cells will not die due to lack of oxygen. This is called Type I decompression sickness.

The symptoms are caused by irritation of nerves, which results from the pressure exerted by the bubble. Once the bubble is gone, the symptoms are gone. There is no neurological damage, so chances of healing are rather good.



The symptoms can include pain in the limbs, irritation, itching and other manifestations, but there is normally no neurological damage and thus no neurological symptoms such as paralysis, problems with seeing, talking, walking, etc. Normally, the patient does not lose consciousness and is alert. However, there are exceptions.




*Explain what happens if a bubble is located in the inner ear or in the spinal cord.*

If a bubble forms in the liquid of the inner ear, the sense of balance is irritated; leading to vertigo and the patient may vomit following each movement of the head. In this case there is no neurological damage, but the symptoms appear to be neurological and might be misinterpreted.

A bubble in the inner ear occurs frequently. Because the sense of balance is affected, the diver will have extreme vertigo and will throw up at short intervals. This type of decompression sickness can be healed completely, but the treatment will take long. Probably it will take at least a week with multiple treatments in a recompression chamber each day. The reason for this slow process is the lack of living cells in the liquid in the inner ear. This mechanism will become clear when we cover the next two benefits of oxygen on the following pages.

Another exception is a bubble in the spinal cord. If a bubble forms in the spinal cord, but not in the bloodstream, it can still block the flow of blood. In the spinal cord the capillaries and nerves are surrounded by bone. There is no room available for a bubble. If a bubble forms, it will push away the capillaries and nerves, but these cannot move out of the way. The pressure from the bubble will flatten them, restricting the blood flow. In this case we do risk neurological damage. Symptoms are initially comparable to a hernia, but can develop into paralysis from the affected area down. The diver may limp or completely lose control of the legs. The diver may have problems with urination, or may feel tingling in a leg.

For this type of decompression sickness recompression can be urgent. During recompression the size of the bubble is reduced immediately, which will allow blood flow in the affected area and, in turn prevent neurological damage.

The bubbles resulting out of decompression sickness are nitrogen bubbles and the bubbles resulting from embo-

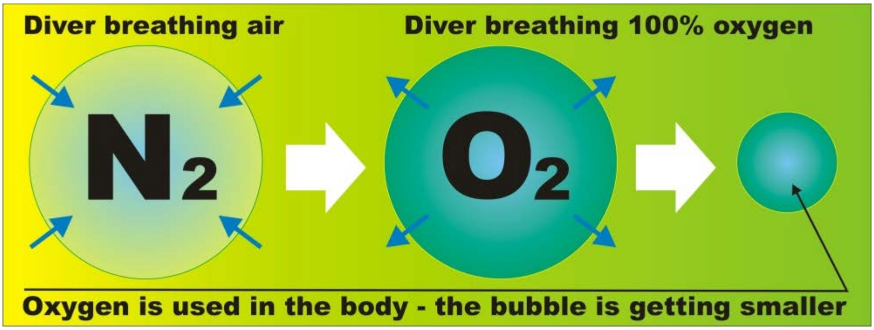
*List two further beneficial effects of oxygen by means of explaining the law of Henry.*

lism are air bubbles. In both cases, most of the gas in the bubble is nitrogen.

Nitrogen is an inert gas and when breathing air, the bubble is surrounded by approximately 80% of nitrogen. Nitrogen is not used in the body and the bubble will not reduce in size.


When breathing 100% oxygen, the bubble will, after a while, be surrounded by pure oxygen. Due to Henry's law, the bubble will give off nitrogen and take up oxygen in an attempt to achieve an equilibrium with its new environment. The nitrogen bubble will become an oxygen bubble.

Oxygen is a consumable gas. The living cells surrounding the bubble will consume oxygen constantly. As a result there is always a lack of oxygen in the tissue surrounding the bubble. The bubble will supply this missing oxygen to the surrounding tissue and will reduce in size. Eventually the bubble will disappear completely. How long this takes depends on the size of the bubble and the speed of the metabolism in the surrounding cells. If there is no neurological damage, the symptoms can disappear with the bubble.

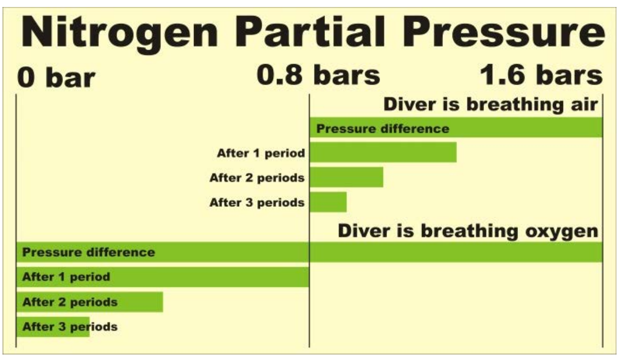



If there is a difference in tension, salinity, pressure or other factor, it will reduce to half of its previous value periodically. How long a period takes depends on the characteristics of the tissue. How much the variation within a period is, depends on the difference in tension. We can hardly alter the characteristics of a tissue, but we can change the difference in pressure.

We will want to eliminate as much nitrogen as possible in the body of the diver to prevent existing bubbles becoming bigger and new bubbles forming. With less nitrogen in the tissues the chance of bubbles becoming bigger or new bubbles developing is reduced or eliminated.

Let's assume that a certain tissue after a dive has a nitrogen partial pressure of 1.6 bars and that the characteristics of the tissue allow the difference in pressure to reduce to half of its previous value in 5 minutes. If this diver is breathing air, the nitrogen partial pressure in the lungs and the arterial blood is approximately 0.8 bars. The difference in nitrogen pressure between the tissue and the blood is now from 1.6 bars to 0.8 bars = 0.8 bars. This difference will, in this case, reduce to half of its previous value in 5 minutes. After 5 minutes the nitrogen partial pressure in the tissue will be 0.4 bars less, which is 1.2 bars.

The new gradient in nitrogen partial pressure is 1.2 bars to 0.8 bars (we are still breathing air) = 0.4 bars. After 10 minutes the nitrogen partial pressure in the tissue will be 1 bar. Following the same calculation, the partial pressure in this tissue after 15 minutes will be 0.9 bars.




If the same diver were to breathe pure oxygen, the initial difference in the nitrogen partial pressure would be 1.6 bars to 0 bar = 1.6 bar (if we are breathing pure oxygen, the nitrogen in the lungs and arterial bloodstream is reduced to virtually zero). This means that in the first 5 minutes the nitrogen partial pressure in the tissue will drop to 0.8 bars (already less than after 3 periods breathing air). After 10 minutes we are at 0.4 bars and after 15 minutes at 0.2 bars. How long a period is for a certain tissue depends on the density of the tissue and the distance between capillaries in that tissue.

When giving oxygen to an ill or injured diver, the diver can feel better. There are two benefits which are directly related to the increased oxygen content in the breathing gas. You are fighting hypoxia and the oedema is stopped.

*Summarize the beneficial effects of oxygen for the ill or injured diver.*

What makes diving somewhat special, compared to other medical problems, are the elevated nitrogen levels in the body of the diver at the end of a dive. This condition is rare and is only seen in people who have been exposed to pressure (or at least elevated nitrogen partial pressure), such as divers. As a consequence, the diver does not only benefit from breathing more oxygen, but also from not breathing nitrogen. The absence of nitrogen brings two additional benefits. Nitrogen bubbles become oxygen bubbles and are then consumed (disappear) and the accumulated nitrogen in the tissues is eliminated quicker.

The absence of nitrogen in the breathing gas is thus important for a diver, but is not so important for people with “normal” medical problems. We want to opt for equipment that gives the highest possible oxygen percentage reaching the lungs. “Normal” oxygen equipment design does not necessarily take divers into consideration – it will give the advantages of an increased oxygen percentage, but will not do the maximum with respect to the absence of nitrogen because it may not bring 100% oxygen to the lungs.

For this reason we will concentrate on the percentage of oxygen that different units can provide to the diver. Not all oxygen units that are good in “normal” situations are adequate for first aid for divers.

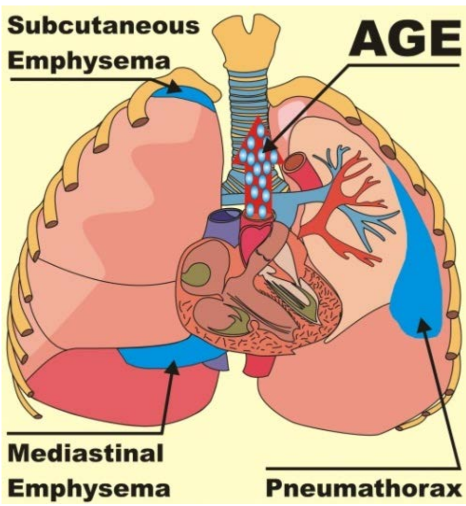
A diver suffering from a lung overexpansion injury must receive oxygen. We distinguish between four types of lung overexpansion injuries. In three types,

*Describe the four different lung overexpansion injuries.*

the air leaves the airspace of the lung and is trapped between tissues. The name of the injury indicates where the escaped air has accumulated.

The lung is a passive organ. It cannot move by itself. The lung is "packed" in a vacuum. Movement of tissue around the lung is transferred into lung (breathing) movement. Between breaths the lung reduces to its natural volume (exhaled). When we inhale, the lung is expanded. The lung also expands when we ascend without exhaling. If the lung is expanded too much, a lung overexpansion injury can result. If both the lung and the "lining" rupture, emphysema develops. If only the lung or only the "lining" is affected, this will cause a pneumothorax.

- Subcutaneous emphysema – the air leaves the lung and accumulates around the collar bone and at the base of the neck.
- Mediastinal emphysema – the air leaves the lung and accumulates between the lungs and around the heart.
- Pneumothorax – the air accumulates between the tissue of the lung and the membrane around the lung. In this condition the trapped air pushes the lung to the side, leading to a loss of volume.




In the fourth type, the air does not accumulate between organs or tissues. In this case, the air is entering the bloodstream. This can happen because of the pressure differences between the bloodstream and the surrounding tissue. The arteries have a high pressure (this is why they are far inside the body with enough tissue surrounding them). In the veins (many very close to the skin) the pressure drops to just above ambient pressure. The key to the development of an embolism is that the heart sucks blood from the lung after having pumped blood at high pressure into the arteries.

If the blood pressure is higher than the ambient pressure, blood will flow out of the blood vessel. If the blood pressure is less than the ambient pressure, air will enter the blood vessel. The moment the heart sucks, the blood pressure between the lung and the heart falls below ambient pressure. If a capillary (surrounding alveoli) were to be damaged due to an overexpansion injury, air is sucked into the bloodstream (at all other locations blood would flow out) and via the heart introduced into the arteries.

As air is lighter than blood, it tends to travel to the highest possible point, the brain. That is the worst place you can imagine for an AGE (Arterial Gas Embolism).

*List the three main types of decompression sickness.*

Decompression sickness is another reason to provide oxygen as a first aid measure. It is not always easy to tell if you are dealing with an overexpansion injury or decompression sickness. That is the reason why (for the purpose of first aid) we address both under the same names – decompression illness or decompression incident.

There are three main types of decompression sickness. For first aid this does not really matter, because we provide the same care in all decompression incidents and some patients are affected by more than one type at a time.

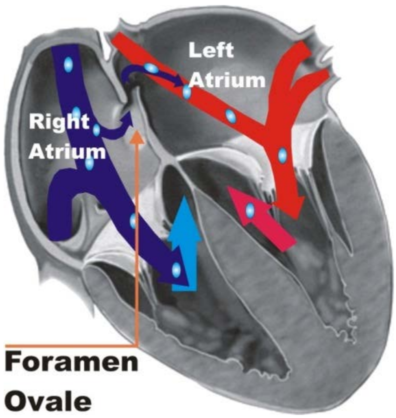
Type I DCS normally results from long exposures to pressure. It is also referred to as "mechanical decompression sickness". In this case the bubbles have formed in the tissue itself and exert pressure on nerves. The bubbles do however not block the oxygen supply to the tissue. There is no hypoxia and thus no neurological damage. Symptoms include pain, itching and the like.

In DCS type II, we are dealing with nitrogen bubbles in the bloodstream. This is a more serious problem because, just as in stroke, AGE and thrombosis, hypoxia can develop with neurological damage as a result. Nerves can die due to lack of oxygen. Neurological symptoms can include a local numb feeling, problems seeing, hearing or speaking, paralysis, etc. Where patients with DCS I have good chances of a full recovery after treatment, victims of type II in many cases have irreversible damage and will have to deal with a reduction in quality of life after treatment is completed.

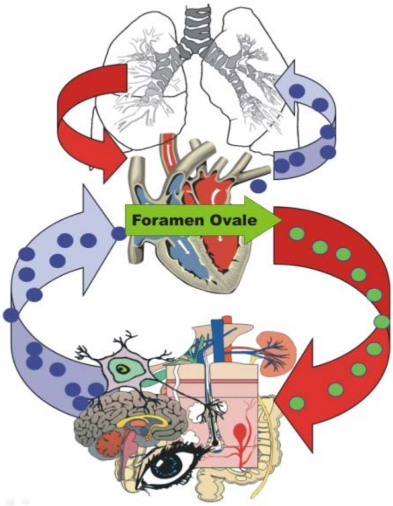
Damage resulting from decompression sickness which does not cause immediate symptoms is sometimes referred to as DCS Type III. In this case there are bubbles in the body, but they do not block the supply of blood and do not irritate nerves. There is no immediate medical indication of a problem. Type III can have a negative effect on long term. A typical example is necrosis. The spinal cord and joints degrade over time.

*Explain why the foramen oval plays a role in the development of decompression sickness Type II.*

From a theoretical standpoint, type II could not happen. The nitrogen comes from the tissues, so it enters the veins to be transported to the lungs. The veins have small diameter where the nitrogen enters, but the diameter increases on the way to the heart. Bubbles could pass without problems and would not block the bloodstream. It is believed that the main cause for bubbles entering the arteries (the arteries decrease in diameter on the way from the heart to the tissues) is the foramen ovale. This opening between the two sides of the heart can allow bubbles to pass from the veins to the arteries rather than following their normal path to the lungs where they are filtered out of the blood.



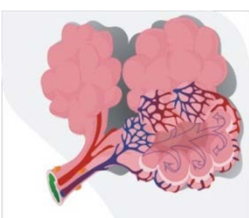

Before you are born, your foramen ovale is open to allow an even distribution of blood throughout the body. The foramen ovale is kept open by the relation in blood pressure (higher pressure in the small circulation than in the big circulation). Shortly after birth, the relation in blood pressure changes. The expansion of the lungs reduces the blood pressure in the small circulation, while the big circulation increases blood pressure to fight gravity. The now greater blood pressure in the big circulation closes the foramen ovale and the distribution of blood is adapted to the new situation (using the lungs for the oxygen supply). If the blood pressure in the small circulation becomes higher than the pressure in the big circulation, the foramen ovale could be forced open again. This can happen when many of the blood passages in the lungs are blocked with bubbles, when coughing, when holding breath with maximum inhalation, when lifting heavy loads while holding breath, etc. In some people the foramen ovale is never completely closed.




When the blood with bubbles from the veins passes into the arteries, the consequences are the same as with an arterial gas embolism (AGE). A part of the body will not be supplied with oxygen and nerve tissue can die, leading to neurological damage.

*List other situation in which oxygen can have a beneficial effect.*

Carbon monoxide (CO) binds with haemoglobin. The haemoglobin which carries CO is no longer available for the transport of oxygen. The reduced transport capacity will cause hypoxia, affecting the entire body. When breathing oxygen, we increase the transport capacity of the blood plasma. This can partly or completely compensate for the loss of transport capacity of the haemoglobin and thus reduce or eliminate the hypoxia. Carbon monoxide poisoning can be recognized by an unnatural red colour of the lips and the tissue under the fingernails. It also causes symptoms of hypoxia, such as headache, dizziness, loss of coordination, tunnel vision and (in extreme cases) unconsciousness.



In near drowning, the exchange of gases between the lung and the bloodstream is impaired. Also a diver who has inhaled water, but was able to cough and solve the problem himself, should be considered near drowning. When giving oxygen, you make better use of the exchange capacity that is still available. Whenever water enters the lungs, surfactant is affected and the exchange capacity is reduced. Medical attention is required

Aquatic live injury by itself does not require oxygen, but if the symptoms include respiratory or circulatory problems, oxygen can be beneficial. The same goes for "normal" medical problems that affect the respiration or circulation, especially stroke and heart problems. Any time the supply of oxygen to the tissues is impaired, the patient will benefit from the additional oxygen you administer as a first aid measure.

Sometimes divers wonder if it is a problem to administer oxygen to a patient who has been exposed to high oxygen partial pressures during a dive, such as a dive on Nitrox or with a rebreather. The answer is that these divers must also receive oxygen during first aid. A patient suffering from a diving related injury or illness is likely to develop hypoxia and in that case the only remedy is oxygen.

*Explain how to recognize potential problems.*

In cases where the entire body is affected by hypoxia, it is not difficult to recognize that the patient is not doing well and needs oxygen. The colour of the skin will reflect the lack of oxygen and can be grey or blue. It is more difficult when the hypoxia is local, as we see in decompression sickness type II and Arterial Gas Embolism (AGE). In these cases the patient may on first sight look perfectly healthy.

Signs and symptoms of decompression sickness and AGE can initially be mild. Feeling weak, tired or feeling as if flu is coming on are typical. The diver can simply not feel entirely well, might limp a bit, be dizzy, feel some mild pain or find it hard to concentrate.

"Good divers respect the no-decompression limit" is something most have heard in their beginner course. The consequence of this is that many translate having decompression sickness as "not being a good diver". Because of this idea, the diver may deny the possibility of decompression sickness and think the symptoms come from other problems and will disappear with time ("I hurt my elbow on the ladder, climbing back on the boat" or "I think I am


going to be seasick" or "I did not have breakfast"). This would cause a delay in the diver stepping forward to indicate that he might have a problem. Statistically for more than 60 per cent of all divers needing treatment in a recompression chamber, this comes as a complete surprise. They were of the opinion that they did all correctly according to their training.

Delay means that damage can increase and an oedema and neurological symptoms might develop further. The sooner oxygen is given, the better the chances of full recovery and the shorter and easier the treatment in a hospital or recompression chamber may be. It happens rather often that divers who received oxygen immediately after an incident do not need any additional treatment. This means that divers should observe their buddies and peers after a dive. If you observe unexpected behaviour or body language, start asking questions.

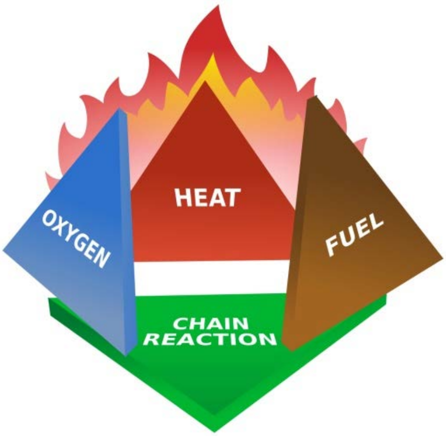
If you are not sure pains are caused by bumping the elbow at the ladder or if you really just feel bad because of an upcoming flu, just assume you are dealing with decompression sickness.

By now it should be clear that a diver has the most benefit from 100% oxygen (a complete absence of nitrogen in the breathing gas). If you are of the opinion that a diver should breathe oxygen, then give the highest possible concentration you can. Do not reduce the concentration. It is better to breathe pure oxygen as long as the supply lasts than to breathe a lower percentage for a longer time. How to achieve this will be covered in the technical part of this booklet.

# Technical Considerations

On first sight, some equipment for first aid with oxygen looks very similar to the regulators scuba divers are used to. This may give the impression that they are used in exactly the same way. This is not the case. Equipment for first aid with oxygen is constructed in such a way that the patient is always able to breath, even when you have forgotten to open the cylinder. This feature requires additional considerations.

In order to use the equipment in an appropriate manner, you must be able to identify with which type you are dealing. You must then be aware of the correct procedure for use. This is the subject of this chapter.




*Describe how to administer oxygen in a safe manner.*

Oxygen in high percentages increases the risk of fire and explosion. Oxygen itself does not burn, but matter that can burn will do so faster and more intensely in the presence of elevated oxygen partial pressure. This means that certain contaminations in or on the oxygen equipment could auto-ignite. Think of a gasoline engine that does not need sparks to initiate combustion in the cylinders of the engine. It is enough when the cylinder is warm and the pressure rises during compression.

There is no reason for irrational fear. People are handling oxygen and working with oxygen every day. A few simple precautions will keep the risk within acceptable levels.

Oxygen can also be dangerous when it is inhaled under pressure. Starting at a partial pressure of 1.6 bars, oxygen could become toxic. To make sure that a diver doesn't take an oxygen cylinder by mistake and goes diving with it; oxygen cylinders have a different connection for the first stage than diving cylinders do.

To avoid fire or explosion, you should not use grease or silicone on oxygen equipment. There are special lubricants that can be used with oxygen equipment, but this applies to the annual service only. As the user you do not need to lubricate the equipment at all.

A fire can be started and will burn when there is sufficient oxygen, fuel and heat. Removing any of these three will prevent a fire from starting or will extinguish it. We are dealing with 100% oxygen, so it becomes important to ensure the absence of the other two factors – fuel and heat.

Heat cannot be completely controlled as we have to work in a given environment. Within the equipment oxygen-cleaning prevents the presence of traces of fuel. You should handle the equipment in a way that reduces the risk of contamination to a minimum. You should also handle the equipment in a way that prevents rising temperatures.

Your patient will not use all the oxygen you give. Some of the oxygen will escape from the mask and the patient will exhale most of the oxygen inhaled. This results in an accumulation of oxygen around the patient. A nearby fire would start burning more intensely, which could cause other things around it to catch fire. Make sure you don't use oxygen near open fire.

Both for safety and for the comfort of the patient it is best to use oxygen in a well-ventilated area. If you are inside, opening a window will do, in most cases. Open the cylinder valve slowly to avoid an abrupt burst of high pressure into the first stage. Some units constructed in the nineties had aluminium parts in the first stage. In some cases an abrupt opening of the cylinder caused the first stage to catch fire.

To make sure that no grease, dirt, or other material that can burn, gets on the high pressure connections, it is best to keep the unit assembled (this also assures that the unit is immediately ready for use in an emergency). Keep the cylinder closed during storage.

Equipment for diving makes use of O-rings and the first stage is lubricated with silicone. It may be tempting to modify an old regulator to be used as an oxygen unit, but you should not. Just cleaning and removing all silicone and rubber parts is not enough. Regulators for oxygen have a different design from diving regulators.

Oxygen doesn't go bad with time. The only time-limit for storing oxygen is the interval of hydrostatic testing for the cylinder (in many cases 10 years). If there is corrosion on the inside of the cylinder, you would lose some pressure, but the oxygen in the cylinder will not change its quality and it can still be used for first aid.

There are many brands and models of oxygen equipment. Not all of these were made with diving emergencies in mind. There are several reasons to give oxygen and not all of them make it necessary that the patient receives 100%. In many cases it is enough if the patient only receives some additional oxygen. The same would apply to people who use oxygen to compensate for the lack of oxygen at high altitude.

There are three basic types of first stages for oxygen equipment. As divers we must pay attention to the type and the performance of a first stage to make sure that we can provide 100% oxygen to a patient.

*List three types of first stages for first aid with oxygen and their differences.*

Fixed flow units have a free-flow exit to which we can attach a thin oxygen hose. We cannot change the flow as it is set by the manufacturer (the model in the middle in the illustration).

Most of these units are designed to add oxygen to the breathing gas. You'll find these for example in airplanes for use by the cabin staff in case a plane loses cabin pressure. Many are set for a relatively small flow of oxygen (as little as 2, 4 or 6 litres per minute). The average breathing gas consumption of a human is 15 litres per minute. Hence, a first stage with lower flow cannot cover the breathing demand of a patient and will only add some oxygen to the air he is breathing. To cover the demand of the diver the unit must give 15 litres per minute at least.

Units with adjustable flow (at the right in the picture) typically allow you to set for flows up to 25 litres per minute. This makes this type of unit more useful than the ones with fixed flow, because you can adapt to the breathing needs of the patient. Like the fixed flow units they have a connection for a thin oxygen hose. In first aid the flow is initially set for 15 litres per minute. If this is the maximum flow the unit can provide, then the knob for adjustment is useless (you would set it on the maximum and not touch it again).

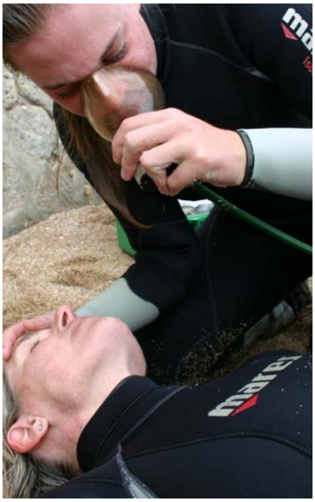
First stages with intermediate pressure (MP) outlet (at the left in the picture) allow you to connect intermediate pressure hoses to the first stage, which are meant to supply demand valve regulators for oxygen. It is the simple first stage – intermediate pressure hose – second stage assembly that divers are used to. This is the preferred type of equipment for oxygen administration. The outlets have one-way valves which open upon connection of the intermediate pressure hose. This assures that no oxygen flows from the outlets when a second stage is not attached.

*List the different functions that can be fulfilled by a single first stage.*

Some models combine more than one option in a single first stage. The first stage in the picture (left) has two intermediate pressure outlets and a barbed adjustable flow outlet. The knob on the side allows you to set the flow from "off" up to 25 litres per minute. The knob has no influence on the MP outlets; it only sets the flow for the barbed outlet.

*List the different face masks that can be used and indicate what the best option is for a breathing patient.*

If you have a first stage with intermediate pressure connections, you can use a demand valve (or second stage) to provide oxygen. This is your best option, as it allows delivering oxygen at a concentration of almost 100%. A demand valve can only work with intermediate pressure. It has the advantage that no oxygen is wasted as would be the case with all constant flow options.



Dead airspace is limited and with a good sealing mask and a first stage that delivers enough oxygen at intermediate pressure, no air from outside the mask would enter the lungs. Pay attention though! As a safety precaution, the mask is equipped with a valve that allows the patient to breathe a supplement of air when too little oxygen arrives at the second stage. Even if the cylinder is closed or empty, the patient would still be able to breathe (air). The moment air enters the demand valve via its safety features; the patient is no longer breathing pure oxygen. This means that the user needs to monitor the equipment closely for proper functioning.

Fittings for oxygen equipment are standardized. You can fit almost any facemask to the demand valve. A pocket mask, the mask from an AMBU and many others can be used. At least one of these masks should allow you to have an adequate seal on the patients face. For a patient with an extremely big nose, you could consider fitting a mouthpiece from a diving regulator. In that case the nose of the patient needs to be closed.

If a first stage only has a constant flow connection (adjustable or fixed flow) you cannot use a demand valve. In that case a mask with a reservoir bag is your second-best option. Masks of this type are also an alternative when the patient cannot tolerate a demand valve or if the patient is breathing too weakly to activate the demand valve. If you must give oxygen to more divers at once and only have one demand valve, then the mask with reservoir bag will allow you to do this (provided your first stage has multiple connections).

People inhale approximately 15 litres of oxygen per minute. This is done in about 12 inhalations, each lasting about a second. During the other 48 seconds (in a minute), the patient is either exhaling or not breathing. If the patient were to breathe directly from the oxygen hose, the flow would need to be at least 75 litres per minute to cover the demand during inhalation. This is the function of the reservoir bag. It fills itself with oxygen during the time the patient exhales and has a breathing pause. The moment the patient inhales, not only the 15 litres per minute from the oxygen hose are available, but also a completely filled reservoir bag. A valve prevents the patient from exhaling into the reservoir bag. The exhaled gas escapes the mask via the valves on the side (this is why they are sometimes called non-rebreather masks).

The construction and the seal (you cannot fit different facemasks as you can with a demand valve) of these masks will allow a certain amount of air to enter the mask, leading to a mix of pure oxygen and air. The continuous flow option on your first stage must provide at least 15 litres per minute; otherwise this type of mask is useless. If the reservoir bag does not completely fill itself before the patient inhales, the flow needs to be adjusted above 15 litres per minute.

Whenever you have the choice between a demand valve and a mask with a reservoir bag, you should choose the demand valve.

Rebreather type masks are not very common in diving and there is a good reason for that. If you breathe pure oxygen, you exhale oxygen, $CO_2$ and nitrogen. Based on Henry's law, your body seeks equilibrium with the environment. Off-gassing nitrogen is one of the reasons why we administer oxygen. A diver would exhale much more nitrogen after a dive than a person who has not been diving.

In rebreather type masks, the patient exhales into a reservoir bag. When the patient inhales, the exhaled breathing gas from the diver passes from the reservoir bag through a canister with soda lime, where exhaled $CO_2$ is taken out of the system. Only enough oxygen is added to the system to replace the consumed oxygen, which may be as little as 0.5 up to 1.5 litres per minute. At the highest consumption (1.5 l/min) your oxygen supply would still last 10 times longer than with a non-rebreather mask (15 l/min)

The problem is the nitrogen (which is not taken out by the soda lime). The oxygen percentage in the system drops rapidly with each time the diver exhales due to the exhaled nitrogen that keeps circulating in the system. To solve this problem the system needs to be purged completely and then filled with oxygen again. The frequent purging brings the use of oxygen close to the quantity used with a normal mask. This leaves you with all the inconveniences of a rebreather system, but not the benefits. The objective is that the patient breaths as close as possible to 100% oxygen.

In remote areas these systems might be useful in any case. If a diver has used about half of the oxygen supply with a demand valve, the off-gassing of nitrogen is rather advanced. If the diver then switches to a rebreather system, the exhaled gas would hardly contain any nitrogen anymore and the rebreather system would work appropriately. This method could allow first aid with oxygen for several hours with only a limited oxygen supply.

You may find other mask systems that could be used for a breathing diver, but when they are not a demand valve or a mask with a reservoir bag, they are normally not designed to achieve the goal of breathing close to 100% oxygen.

Masks without a reservoir bag (such as a Pocket Mask with oxygen connection) will let the patient breath more air than oxygen. In many cases a diver would be better off breathing the remaining Enriched Air that is still in a cylinder after a dive than breathing from an oxygen mask other than a demand valve or a mask with reservoir bag.

A mask with a reservoir bag without a one way valve would cause an accumulation of $CO_2$, provoking a feeling of suffocation for the patient.

Masks with holes, made to let air enter the system are not much use. The patient is breathing more air than oxygen. You mostly find these masks connected to first stages providing very limited flow. Do not use these types of masks if any of the options discussed before are available. Most will not harm the patient, but for first aid for a diver they don't do much of good either.

*Describe how to administer oxygen to a non-breathing patient and when to do that.*

All masks we discussed require the patient to breathe independently. For a non-breathing diver your first concern is artificial respiration and likely CPR. Oxygen is secondary to that. It is rather seldom that oxygen is used on a non-breathing diver as a first aid procedure. Don't waste time on preparing equipment, but start with artificial respiration, CPR and defibrillation without delay.

If you have the chance to switch to oxygen once basic life support is completed, it will do your patent good. Also in that case you want to get as close to 100% as possible. An easy and good way is to inhale oxygen yourself and then give artificial breaths to the patient.

If you do the procedure of inhaling oxygen yourself and then give breaths to the patient, you need one hand to hold the oxygen mask or demand valve. This makes mouth-to-mouth impractical as you would need one hand to position the head of the patient and another to pinch the nose. You will find that mouth-to-nose or mouth-to-pocket mask is easier when you have one hand occupied.

Emergency medical professionals could consider connecting a demand valve or a reservoir bag to the inlet of an AMBU. It is not always easy to make the facemask of an AMBU seal on the face of the patient and if you are not trained to do so and do not have recent practice, an emergency is not the moment to start experimenting. For those who are trained, the method is ideal, because you get very close to 100% oxygen.

Most regulators with positive pressure to do artificial respiration with pure oxygen are meant to be used by trained medical staff. Some models are also available for the general public, but the overpressure relief valve of such units is often set so sensitively that it is hard to get oxygen into the patient's lungs. For a heavy build diver, or a diver wearing a tight wetsuit, chances are that the oxygen will escape via the overpressure relief valve rather than entering the lungs of the patient.

If you are not sure if breathing gas is entering the lungs of the patient, you can observe the mask to see if the patient exhales. Whenever the patient exhales moisture will fog the inside of the mask. You can also look or feel to see if the chest of the diver rises and falls with breathing.

*Calculate the size of cylinder needed and explain the different connections.*

You need to adapt the supply of oxygen to the circumstances of the dive site you are visiting. Assume that you need to help two patients at a time and calculate at least 15 minutes on top of the time you would need to reach the nearest hospital or the time an ambulance would need to reach you.

For your calculation you can assume that every litre cylinder volume at a pressure of 200 bars allows you to give 12 minutes oxygen to a diver. This means that a 5 litre cylinder at 200 bar would last one hour for a single diver and half an hour for two divers.

The cylinder needs to be hydrostatically tested and needs to meet local requirements. In most countries oxygen cylinders need to be hydrostatically tested every 10 years. In some countries there are requirements for the transport of oxygen cylinders. For smaller cylinders these rules are normally flexible, because there are many people that need oxygen for medical problems.

Oxygen cylinders have special valves to insure that a regulator that is not oxygen compatible is fitted to an oxygen cylinder. In different countries and for different sizes of cylinders, you can find different fittings.

The PIN and inverted DIN connections shown in the pictures are the most common for small cylinders. When traveling from one country to another you may need an adapter to fit your oxygen regulator or to have your oxygen cylinder filled.

# General Aspects & Preview for the Practical Part

The knowledge presented in the medical and technical chapters is rather abstract. First aid with oxygen is done in context, which is the reason for this last chapter. Throughout the years there has been some misunderstanding amongst divers with respect to the possibilities and limitations for using oxygen to help an ill or injured diver. We will first address some of these concerns. This booklet is then completed with two lists of questions that can guide you during the practical part of your training.

## General Aspects

*Explain why oxygen is not dangerous for divers.*

Some people wonder if giving oxygen can harm a diver. Theoretically this could be possible, but it is very unlikely, even if you intended to do so. We will take a look at some common concerns.

What about convulsions due to oxygen poisoning (CNS)? This cannot happen on land at an ambient pressure of 1 bar. The minimum pressure at which this could happen is an oxygen partial pressure of 1.6 bars. Since the total atmospheric pressure is 1 bar, this is not possible. Convulsions on land rather indicate a need for oxygen.

What about full-body oxygen-poisoning and oxygen poisoning of the lungs? These are little else than the body adapting to a new environment. You could lose capillaries. The production of haemoglobin could also stop or be reduced. This could be a concern, but looking at the NOAA tables for oxygen exposure, it is not realistic to assume that you could get into these conditions giving first aid. At 100% of oxygen at 1 bar, you would have to give 5 hrs of oxygen before starting to consider these concerns. At 90% of oxygen at 1 bar (which is more likely with the available equipment) it would be 6 ½ hrs and even passing these limits would not immediately provoke medical complications.

What about suppressing respiration? This would apply mostly to people with severe illnesses, involving their breathing impulses based on the level of $CO_2$. People with these conditions are very ill and normally hospitalized. They would not pass a medical to be fit for diving.

What about irritation of the lungs and damaging surfactant? Again this is not something that would apply to a diver. This can happen to children in the first days after they are born and to people with diseases to the lungs like asthma. In both cases, diving is out of the question.

When you limit yourself to providing oxygen to divers, the chance of doing harm to the patient is theoretical.

It would be logical to give medical oxygen to a patient in a medical emergency, but this is not always possible. Some people need oxygen for a medical problem and to make sure that these people are reimbursed, oxygen was made a medicament. In many countries this means that a prescription is required and using medical oxygen for first aid purposes is not allowed.

*List the different types of oxygen and which of those can be used for first aid.*

In most countries it is no problem to buy oxygen at the same quality as medical oxygen (at least 99.5% oxygen and tested for the absence of CO). This is not a medication and giving it to a diver who expressed his consent is basically the legal equivalent of giving a glass of water. This is the oxygen used to blend Nitrox or the oxygen used in planes.

In many countries industrial oxygen for welding is of the same quality as medical oxygen, but in others it is not. It is not advised to use industrial oxygen for first aid purposes if you are not sure of the quality. But, the bottom line is – $O_2 = O_2$


## The Practical Part of Your Training

There are many recommendations for the administration of oxygen, which you learn in the practical sessions. The checklist on the inside cover in the back of this booklet can help you during such practical sessions.

# Index

-A-
Adjustable flow 22
AGE 14
Anoxia 4
Artificial breaths 27

-C-
Capillaries 5
Carbon monoxide 16
Consumable gas 10
Cylinder 28

-D-
DCI Type I 8
DCS Type II 7
DCS Type III 15
Decompression sickness 8
Demand valve 23

-F-
Fire or explosion 20
Fixed flow unit 22
Foramen ovale 15

-H-
Henry's law 10
Hypoxia 4

-I-
Inner ear 8
Intermediate pressure 23

-L-
Local hypoxia 4
Lung overexpansion injury 12

-M-
Mediastinal emphysema 13
Medical oxygen 32

-N-
Near drowning 16

-O-
Oedema 6
Osmotic pressure 6
Oxygen 20
Oxygen poisoning 31

-P-
Pneumothorax 13

-R-
Rebreather type masks 25
Reservoir bag 25

-S-
Spinal cord 9
Subcutaneous emphysema 13
Suppressing respiration 31
Swelling 7

-V-
Valves 29

## For demand valve

- Did the rescuer ask enough questions to get a clear picture of the situation?
- Did the rescuer also ask about a possible buddy?
- Did the rescuer ask the patient to lie down?
- Was the cylinder opened slowly?
- Did the rescuer breathe from (not exhale) the unit before presenting it?
- Did the rescuer ask for the patient's consent?
- Did the rescuer ask the patient to hold the mask?
- Did the rescuer relax the patient?
- Did the rescuer start to prepare other available equipment?
- Was the cylinder placed appropriately and was the pressure verified?
- Did the mask have a correct seal and, if not, what action was taken?
- Did the rescuer verify breathing?

## For a mask with reservoir bag

- Did the rescuer ask enough questions to get a clear picture of the situation?
- Did the rescuer also ask about a possible buddy?
- Did the rescuer ask the patient to lie down?
- Was the cylinder opened slowly?
- Was the first stage set for 15 litres per minute?
- Was the reservoir bag inflated before giving the mask to the patient?
- Did the rescuer ask for the patient's consent?
- Was the mask adapted to the face of the patient correctly?
- Did the rescuer relax the patient?
- Did the rescuer adjust the flow to adapt to patient's breathing rate?
- Was the cylinder placed appropriately and was the pressure verified?
- Did the mask have a correct seal and, if not, what action was taken?
- Did the rescuer verify breathing?