Aspects of Diving: Assessment and Management

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Objectives

- Differentiate between commercial and recreational diving, and list the equipment used
- Describe the basic principles of diving physiology
- Demonstrate an awareness of the aetiology of diving related illnesses
- Communicate effectively with the key personnel involved in the diving operations

Introduction

Much of the content in this module will be unfamiliar or indeed new to you, therefore this is based at a more basic level. You should consider this as being no more than an introduction to the subject, if you are required to work with Divers you will be required to complete the two-week Diver Medic Technician Course or the OSM Diving Awareness course at DDRC. For further information, please call Training at DDRC or speak to your trainer on arrival.

As an Offshore Medic you might be required to treat a sick or injured Diver however this would be unlikely unless you are employed to work on a DSV as regulation dictate that:

For bell* diving operations at a depth exceeding 50 metres and for diving operations involving the use of a mixed gas there should, as from 29 April 1991 be present and not diving at least one person who has successfully completed an approved course as a Diver medic. **

* See *Glossary of Terms* (section 7)

** See *Key Personnel* (within section 5)

For all types of commercial diving the contractor must decide whether to employ a diver medic, in fact on Saturation Dive Vessels it is the norm to have at least one diver medic in each team if not more and also have an HSE Offshore Medic on board who also holds the DMT Certificate.

Preparation

Before you read any further you should ensure that you are okay with the basic physics of gasses and liquids. Please also refresh your knowledge on the respiratory system using your chosen Anatomy and Physiology textbook. The recommended book on diving medicine is:

Diving and subaquatic Medicine by Edmonds, Lowry and Pennefather. Published by the Diving Medical Centre, sold and distributed by Biomedical Marine Services, 25 Battle Byde, Seaforth, 2092, Australia.

Or Bove and Davis Diving Medicine

Warm-up question: Take a few minutes to write down how many types of diving injuries you can think of. You will find the answers as throughout.

1. Diving

There are two types of diving that you need to consider, these are:

- Recreational
- Commercial

Commercial

Offshore diving work takes place on rig supports, pipelines and underwater well heads, jackets, this list is not exhaustive. Dive Support Vessels working for the Offshore Industry are in great demand at this time and many more are in the process of being built.

Commercial diving takes place wherever work must carried out underwater for example in tunnels, on bridge supports, in outflow pipes from sewage, bomb disposal by the military clearance divers and police divers searching for bodies or other evidence.

Divers may be working at depths between 3.3 and 330 metres of water (10-1000 feet) in reservoirs, rivers dams, lakes plus in the North Sea and all around the globe. We have listed below some of the tasks they might be expected to complete in very difficult conditions.

- Carry out non-destructive testing, measurements, surveys etc
- Clean metal using high powered water jets or shot blasting
- Cut and weld using welding gear, hydraulic shears or high-pressure water cutters (used to cut pipes).
- Dismantle and reassemble flanges and clamps
- Lay heavy concrete mats to protect pipelines
- Work with slings and lifts from the Dive Support Vessel

Recreational

To give you some idea of the numbers there are about 2 million recreational divers in the US and about 70 thousand in the UK. This is a very popular sport but not without its hazards, there are about 150 diving related injuries/illness per year and on average 15 deaths are attributed to recreational diving each year.

This sort of diving mostly takes place in places of interest such as on shipwreck sites and close to the rocky shoreline where colourful fish and interesting life is in abundance. Tropical seas are a popular destination for such sights but there are also a lot of wrecks in UK waters.

Case History

Two men were working off the Norwich coast, water depth approximately 33 meters (100ft). One Diver was working alongside a shipwreck the other was in a boat. The unconscious diver suddenly appeared on the surface and was quickly pulled back into the boat. There was a Dive Support Vessel nearby working alongside a Gas Production Platform.

The injured diver was taken alongside and placed in one of the Saturation Decompression Chambers alongside his diver who rescued him. Soon after entry the unconscious diver suffered a grand mal convulsion. The Offshore Medic was called from the Platform and instructed to enter the Chamber to treat the diver.

Because of the serious condition of the diver, it was necessary for the Offshore Medic and the other diver to remain in the chamber for three days. With support from a doctor who was later flown out to the Vessel, the medic monitored the patient, introduced an intravenous Cannula so IV fluids could be given to rehydrate the diver and inserted a urinary catheter to monitor the divers urine output.

The chamber was less than 1.5 metres in diameter and 2 metres long, with nothing more than two bunks.

This case history illustrates a very rare case where an HSE Offshore Medic has been committed to enter a chamber to treat a patient. Under normal circumstances today, the diver would be treated by another qualified diver medic and the medic on board would relay information into the chamber from a Topside Diving Doctor Specialist onshore.

Personal Equipment

We should now consider four aspects of PPE:

- Breathing
- Diving Suits
- Buoyancy
- Equipment

Breathing

To survive and work under water the diver needs to either use portable tanks to give him an air supply or take air from a hose, which is supplied by a surface supply on board a boat or pontoon. These are the two basic methods that enable him to receive a good air supply:

Method 1: To allow the diver to breathe naturally the air is piped into a helmet which encloses his head. The air fills the helmet and slowly escapes the helmet through a valve set along with his exhaled breaths, this in turn passes directly into the water. This method prevents a build up of carbon dioxide inside the helmet.

Method 2: A much more common system used today is where the inlet of air is controlled by a regulator that only provides air when the diver inhales. The exhaled air again passes directly into the water. This type of regulator is called a demand valve; this is particularly advantageous for the diver who breathes from a tank as the supply can be rationed allowing the diver to stay in the water working for longer periods.

Diving Suits

Divers need to be protected from the cold and elements and there are two types of suits available today.

- Neoprene wet suit, the type and thickness used depends on the depth and length of the dive. As the dive deepens the protection from the Neoprene is lost as it is compressed thus making the protective layer thinner. A wet suit becomes wet inside however the thin layer of water quickly warms up to insulate the diver from the cold for a limited time.
- Dry suits, these are made of a thin membrane which is itself not compressed. The membrane keeps the diver dry and allows the diver to wear warm clothing underneath.

If the divers are working at depth or in very cold water they may use dry suits that are called hot water suits, this is like being inside a hot water bottle, and the supply of hot water is regulated from a surface supplied hot water set-up

Buoyancy

Because divers are naturally buoyant they may have to wear weights in the form of a belt to allow them to dive. You might remember the very old diver set up, there suits were very buoyant so the diver had to wear a heavy plate around the neck and heavy boots on their feet.

- Old Fashioned - The Diver of yesterday wears a large copper helmet that is bolted to his rubberised canvas suit. The diver would then wear thick warm clothing underneath the suit. He would receive his air supply freely into the helmet; the air would also enter the suit and act as an insulator. As you can see by the photograph he is also heavily weighted.
- Modern - The modern diver wears a lighter helmet made out of metal or fibreglass which is weighted and sealed around the neck giving them much more mobility. The suit is made from thick Neoprene and is separate from the helmet. He breathes air

through a demand valve; he wears fins or yellow boots, and has a reserve tank of air on his back in Case the surface/Vessel air supply fails.

Equipment

Have a look at the pictures below, this shows the difference between the old fashioned and modern diver.

Figure 1:

Old Fashioned Standard Diving Dress

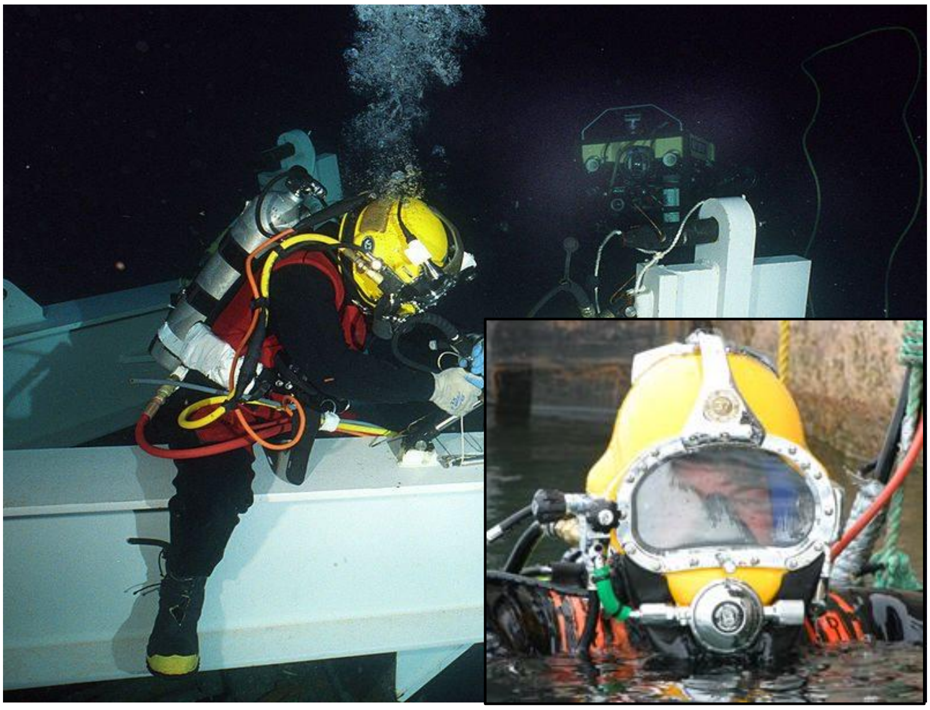

Figure 2:

Modern Commercial Diver.

Inset – Commercial Diver's Helmet

The recreational diver also uses Neoprene, but they do not wear a helmet. Instead, they wear a face mask which enables them to see and breathe through a demand valve retained by a special mouthpiece gripped between the teeth.

The recreational diver will also wear buoyancy Compensator (BC) or adjustable lifejacket (ABLJ); this is normally in the form of a vest with bags that can be inflated from a direct feed, or an alternative small cylinder. The BC or ABLJ are rescue devices – should the diver get into difficulties they can return to the surface rapidly by inflating the BC.

Commercial Diving Systems

Simple Systems

In the Simplest form a diving system comprises of the diver with his air supply being provided by a pump in a boat, the boat would have one or more attendants. This is known as surface supplied diving.

Diving Support Vessels

These systems tend to be a lot more elaborate, for example there could be 18 Saturation Divers on board in Saturation at any time, with two diving bells working in eight-hour shifts. Often these types of operations would see teams of technicians, gas men, sat supervisors and dive supervisors working 24 hours a day to look after the divers, the divers themselves often spend 28 days under pressure.

Figure 3:

Dive Support Vessel (DSV) alongside a Jacket. A Jacket is the legs that support the platform/rig.

Figure 4:

Saturation Divers from the commercial world working on a Jacket; the jacket is the legs that support the platform/Rig. The diver will be dressed as in the photograph and the long hose attached to the diver is known as an umbilical.

The umbilical carries a:

- Communications cable linking the diver to the dive supervisor who works Topside on the Vessel. The operation is normally talked through move by move and everything is recorded on CD or hard drive. The dive supervisor would also be in contact with the DPO/Ships Captain and Offshore Manager. The DPO (Dynamic Positioning Officer) sits on the FWD/Aft Bridge and keeps the Vessel in a fixed position and only moves it if and when requested by the Dive Supervisor. The operations are normally followed very closely by the Vessels ROV Pilot (Remote Operated Vehicle) and team.
- Hose for air
- Water from a boiler on the Ship to the divers suit to keep them warm
- Depth measuring device which is monitored by the Dive Supervisor

Note that the diving systems operating from support vessels are limited by the weather, currents, and tides.

Diving Bells

To make diving operations on diving vessels more cost effective most of them are equipped with dive bells. Some of these are lowered overboard and moved on trolley tracks other DSV's have forward and aft bells that are lowered direct to the seabed or workstation through the moon pools on the Vessel.

The Diving Bell has a number of advantages, as it provides:

- A refuge for the diver
- A decompression chamber
- An umbilical connection to the surface vessel which is safer
- A transport device; the diver can be transported quickly and with ease to his workstation, this is especially beneficial when the weather is bad as bad weather and rough seas can cause treacherous conditions for the ship and the divers below

Saturation Diving

The principle here is that a team of saturation divers between 6 and 18 depending on the size of the setup will spend 28 days at a constant pressure, which is equivalent to the working depth and this is known as the (storage depth). The divers are shut up in an enclosed system of connecting steel cylinders called Chambers.

The conditions are cramped especially in the older chambers however, there is sufficiently space for the divers to eat, sleep, and rest in relative comfort although humidity is quite high. For divers over the height of 5ft 11inches it can be quite cramped as chamber are never that high, some sat divers have been known to be 6ft 7inches or taller. The divers normally work in three teams doing eight-hour shifts and travel to work via the bell that can connect to the system without a change in the ambient pressure. This means that by the end of the 4 weeks the divers only have to go through one slow decompression phase in order to get back to the surface decompression is normally about one metre per hour (a slow process) so divers working at great depth often take 3-4 days to decompress.

Recreational Diving Systems

The sport diver is well contained as he carried his supply with him – a self-contained underwater breathing apparatus or (SCUBA). All the Scuba diver requires is a boat to get them to the dive site and a buddy to dive with them. They should never dive below 50 metres (165ft). In open water the diver is always more vulnerable to weather and changing conditions so they should take adequate precautions.

ddrc professional services

2. The Underwater Environment

Physical Effects

Pressure

Air and water have mass and therefore are acted upon by gravity. They therefore have weight. This means that both of them can exert pressure on objects placed in them.

Air Pressure

At sea level, the atmosphere presses down with a mass of approximately one kilogram for each square centimetre of the earth's surface. This pressure is called atmospheric pressure and is the pressure of the air around us, that is, 1kg/cm2. In Imperial units, this is 14.7 pounds per square inch. Remember sea level is approximately equivalent to 1bar.

You can look at this in a different way; atmospheric pressure represents the height of a column of mercury that exactly balances the weight of a column of the atmosphere. At sea level the height of the column is about 760mm (29.92 inches). There are a number of ways of expressing atmospheric pressure but as scientific units are expressed in metric units we will use these measurements throughout the rest of the unit.

Water Pressure

The layers of water pressing down on the seabed have weight. At a depth of 10 metres, the pressure is equal to one atmosphere. So, an object at the surface is subject to a pressure of one atmosphere, and at 10metres below the surface a pressure of 2 atmospheres.

Or, for every 10 metres in depth there is an additional increase of 1 atmosphere pressure. The total pressure on an object under water is the atmospheric pressure plus the water pressure. This is called the absolute atmospheric pressure, ATA (Atmospheres Absolute).

Question A: What do you think the pressure in ATA will be on an object or diver at a depth of 100 meters?

Water pressure will have an effect on a submerged air-filled container. If the container has rigid walls or bulkheads, it will be able to retain its shape as long as it's in shallow depths where the Absolute Air Pressure (measured in ATAs) is not great enough to affect the containers rigidity and thus crush it.

However, the deeper the depth the container the greater the greater the ATA's. The challenge for the Subsea engineers is to create a bell that can withstand the ATA's experienced at the depths required to complete the work.

Gas Laws

Boyle's Law

This is a very simple law that is very important in diving. The volume of a fixed mass of gas is inversely proportional to the pressure applied to it.

Pressure x Volume = Constant

Look at this example. If 1000 ml of gas is taken from the surface to a depth of 10 metres, it will be subjected to a pressure of 2 ATAs. Its volume will decrease to 500 ml. So, while the pressure has increased from 1 to 2 ATA - that is doubled, the volume has decreased from 1000 - 500 ml that is halved.

For diving, it is important to remember that when you are surfacing, the pressure reduces and the volume of gas increases. You will see why this is a problem shortly

Dalton's Law of Partial Pressures

Air is a mixture of gases: oxygen, nitrogen, and small amounts of carbon dioxide, water vapour and rare gases.

At the earth's surface, the air pressure is one atmosphere. Each of the constituent gases in air exerts its own pressure according to its physical properties. The amount of pressure exerted by each gas in the mixture is proportional to the percentage of the gas in the mixture. This is the pressure that the gas would exert if it alone occupied the same volume as the mixture. It is called the partial pressure.

So, Dalton's law of partial pressures states:

Pressure = p1 + p2 + ……

The pressure of a mixture of gases is the sum of the partial pressures of its constituents.

The two main constituents of air are oxygen, 20%, and nitrogen, 80%. For simplicity, air is regarded as this mixture. Therefore, for an air pressure of 1 atmosphere, the partial pressure of oxygen (ppO2) is 0.2 atmospheres, and that of nitrogen (ppN2) is 0.8 atmospheres.

Question B: What do you think the partial pressure of oxygen and nitrogen will be at a sea depth of 100 meters? Remember to use ATAs.

Henry's Law

This is another law that is very important in diving:

V = constant x P1

For diving, the most important consequence of this law is the amount of nitrogen that is forced into the blood supply at depth. This, of course, is directly related to decompression sickness as we shall see shortly.

Physiological Effects

Vision

When water comes in direct contact with the cornea the divers vision is distorted (you will probably know this from your own experiences of swimming underwater). Divers therefore require protection to make a safe barrier between their eyes and the water; this is achieved by way of providing them with a glass fronted mask or full helmet.

Because of optical distortion caused by the Glass or Perspex cover all objects become magnified, and at depths of 10 meters most objects look blue or green, there is also a problem with silt and debris floating in the water this is often made worse when commercial divers are clearing the seabed.

Sound

Sound waves are carried much better in water than in air but it is very difficult for divers to communicate with their supervisors on the Vessel because voice production is distorted by pressure. It can be very difficult to understand conversations with the diver and there are many systems developed now to try and overcome this. You can imagine how stressful it can be for a Dive Supervisor sitting in their control room talking to a team of divers for an eight hour shift, explaining every move they have to make, looking out for their safety on the visual screens whilst writing an ongoing report as the job progresses.

Pressure Volume Changes

There are a number of air-filled cavities within the human body, the intestines, the lungs, the sinuses, and the middle ear, pressure from diving will therefore compress the air in these spaces. Pressure in the middle ear can be equalised with external pressure by opening the Eustachian tube this is achieved by:

- Pinching the nose, closing the mouth and blowing gently, repeatedly, and briefly

- Yawning
- Swallowing
- Moving the Jaw from side to side

The sinuses will clear automatically if they are not blocked.

The lungs are equalised because they are supplied with air at or above the ambient pressure – otherwise it would prove impossible for the diver to breathe.

Pressure decrease with ascent to the surface does not usually present a problem because the cavities usually equalise themselves naturally.

Nitrogen

Nitrogen is described as an inert gas, it passes into the body during inspiration and is dissolved in the tissues. At any given environmental pressure, the amount of nitrogen dissolved in the body's tissues will reach equilibrium with the ambient pressure. An increase of environmental pressure, as a result of diving will cause an increase in dissolved nitrogen and so a decrease in pressure will cause nitrogen to leave the tissues.

The deeper and longer the dive lasts the more nitrogen will be absorbed by the tissues, the illustration below shows how nitrogen moves from the lungs to the blood stream to the tissues. When the diver ascends, this process is reversed. The Nitrogen moves from the tissues to the lungs. If the pressure is lowered too fast, the lungs cannot exhale the nitrogen fast enough. Nitrogen builds up in the bloodstream and tissues causing effects commonly known as decompression sickness, or the bends. We will discuss this further in a moment.

Position of diver	Air		Lungs		Blood		Tissues
At surface	$p1N_2$	=	$p1N_2$	=	$p1N_2$	=	$p1N_2$
Diving	$p1{+}nN_2$	→	$p1{+}nN_2$	→	$p1{+}nN_2$	→	$p1{+}nN_2$
At depth	$p2N_2$	=	$p2N_2$	=	$p2N_2$	=	$p2N_2$

Where p1 = Initial pressure
p2 = Final pressure
p1+n= Changing pressure
N_2 = Nitrogen

Table 1: Nitrogen balance

3. Diving Related Disorders

Diving disorders can occur when divers ascend and descend to and from the seabed or place of work. There are four main causes of diving disorders:

- Pressure / Volume changes: Descending
- Pressure / Volume changes: Descending
- Effects of Breathing Gas: Descending
- Effects of Breathing Gas: Ascending

Pressure / Volume changes: Descending

Subheading

When the diver descends, the middle ear pressure must be equalised by the methods described earlier in this module. If this is carried out incorrectly, the diver will experience intense pain in the affected ear. There are two things that could happen to relieve the pressure.

- The diver could ascend and thus decrease the pressure
- The ear drum could rupture and release the pressure

The sinus cavity could also be affected causing severe pain and a nosebleed although this is more uncommon.

Both conditions normally occur when a diver that has not respected the old saying - never dive with a common cold. This is often a problem for the medic on board a DSV because they are responsible for conducting pre-dive and post-dive medicals, often sat divers will not disclose the fact that they have a cold because that could result in them failing the pre-dive medical losing 28 days' work. There are other implications to this for example they have paid for travel to work and don't want to waste the money and they also won't want to be seen to be causing problems for the company as a sick diver could mean not enough men to work in a team which can have a huge effect on productivity.

Note: You must bear this in mind if you ever have to conduct pre dive medicals offshore.

Pressure / Volume changes: Ascending

Consider the lungs as two air filled bags. Remember that the air in the lungs will expand as the ambient pressure is reduced.

Question C: A diver breathing air from a tank is diving at 10 metres. He becomes snagged in netting and panics; he suddenly inflates his buoyancy compensator and shoots to the surface. His lung volume at 10 metres was 5.5 litres. What will his lung volume be at the surface? And what do you think might happen?

Pulmonary Barotrauma

This term is used to describe the over inflation of the lungs that is caused by a sudden decrease in pressure. The air in the lungs expands too quickly and cannot be expelled through the mouth. This can also happen if a diver ascends to the surface whilst holding their breath. Submariners' are also at risk from this type of injury when they go through a mandatory submarine escape procedure as they are trained to ascend from a great depth, breathing out slowly as they rise to the surface however, there have been occasions when some crewmembers have not adhered to the procedure and subsequently died. In these circumstances air breaks out of the lungs, leading to various effects.

- Air might burst through the pleura, entering the chest cavity causing a collapse of the lungs, which is called a Pneumothorax.
- Air may rupture the Pulmonary Vein, and then enter the blood that is circulating back to the Heart, and so enter the general circulatory system, this can then enter the cerebral circulation, blocking the circulation to the brain resulting in a stroke. This is called an air embolism.
- Air might rupture the vessels in the neck causing a condition known as interstitial emphysema.

Please note that diagnosis of this type of injury will have to be derived from the circumstances leading up to the incident.

The patient's symptoms may present almost immediately during ascent to or on reaching the surface. Symptoms might include:

- Chest Pain
- Breathing difficulty
- Cough
- Bloody sputum (indication of Pneumothorax)

- Sudden collapse
- Loss of consciousness (indication of cerebral Embolism)

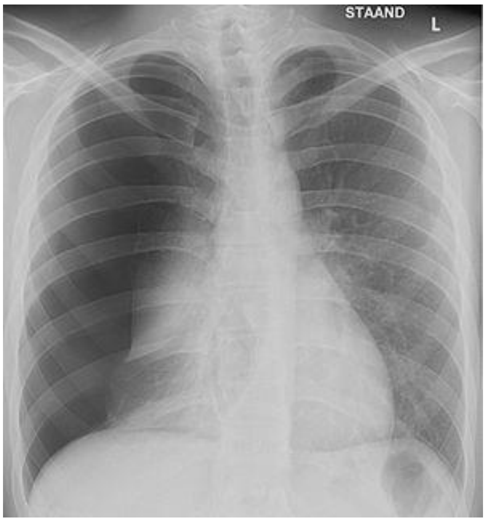

Figure 5:

An X-Ray showing a Pneumothorax.

Effects of Breathing Gas: Descending

Oxygen is required to sustain life; however, if Oxygen is breathed at an ambient pressure above atmospheric pressure it can be harmful. This effect is known as Oxygen Toxicity.

There are many toxic effects noted during animal studies into the effects of Oxygen toxicity however in man there are two main clinical effects.

- Chronic pulmonary toxicity where the breathing becomes difficult
- Acute central nervous system toxicity, where the oxygen can cause a grand mal convulsion

Note: The crucial factor is the pressure at which oxygen is being breathed

Acute Central Nervous System Toxicity

It is worth noting that any healthy individual, who breathes oxygen at a pressure greater than 2 ATA, is liable to suffer a grand mal convulsion. This is identical to a fit experienced by an epileptic but is caused by oxygen. We do not need to be too concerned about the reasons for this in fact the precise Aetiology of CNS toxicity is unknown. It is obvious however, that it could be fatal to suffer a grand mal fit whilst underwater.

Oxygen at this pressure may be breathed in a mixture or as pure gas. Pure oxygen breathing is used to hasten decompression during routine diving operations, and is usually the treatment for decompression sickness. In these circumstances, care has to be taken to ensure oxygen is at a safe level of pressure. It is worth mentioning that most individuals can tolerate a higher oxygen pressure in a dry chamber than they can when diving. For this reason, treatment of decompression sickness is carried out at 2.8 ATA.

Chronic Pulmonary Toxicity

This is the second of the oxygen toxicity clinical effects; here the effects are proportional to the partial pressure of oxygen and the duration of exposure. It can commence at pressure between 0.5 and 0.8 ATA. Clinical effects can range from:

- Mild chest soreness with a persistent cough
- Increasingly severe breathlessness with reduction of lung vital capacity

When oxygen is used to treat a diver, suffering from decompression sickness the diver may have to breathe oxygen at 2.8 ATA for many hours. The duration of therapy is determined by a treatment table. To lessen the effects of pulmonary oxygen toxicity the oxygen breathing periods are broken up into sections by periods of air breaks (or air breathing cycles).

Nitrogen

Nitrogen is the main constituent of air, with increasing underwater depth and therefore pressure, nitrogen in the tissues distorts motor and intellectual functions. This effect is solely depth related and can be reversed once the pressure is reduced, that is on ascent.

The clinical effects appear at about 50 metres although this depends on each individual's susceptibility to the condition. The severity of the symptoms is also depth related, including:

- Mild Euphoria
- Loss of Inhibitions
- Sense of feeling woolly-headed
- Inability to concentrate thought (especially dangerous for commercial divers)
- Loss of reason power (again dangerous when working at depth)
- Confusion
- Stupor
- Unconsciousness

Many aspects of diving illnesses are not fully understood but it is believed that the so-called "narcotic" effect of nitrogen overcomes the convulsive effects of oxygen at depths of 90 metres or more.

Therefore, to allow diving to take place at depths greater than 50 metres, an alternative gas to nitrogen has to be used. Helium was discovered to be the best substitute for nitrogen. The divers breathing mix is artificially made up from compressed oxygen and helium gases. Helium can only be obtained from natural sources therefore, it is very expensive to use. In modern commercial diving system, Helium is reclaimed and recycled.

Question D: Can you work out the depth at which a diver breathing air could suffer with central nervous system toxicity?

Effects of Breathing Gas: Ascending

Using Henrys law it is clear that more gas dissolves in a liquid as its partial pressure increases. So, as nitrogen gas it not used by the body it will be in a steady state for any given ambient pressure.

Diving whilst breathing air causes more nitrogen to dissolve in the tissues, the longer and deeper the dive the more nitrogen is taken up by the tissues.

With ascent, the pressure of the body decreases and the solubility of the nitrogen decreases. Therefore, the nitrogen leaves the tissues. Provided the ascent and the pressure drop is slow enough the excess nitrogen will leave the body as it entered, through the lungs.

Decompression Sickness (The Bends)

If a diver's ascent is too fast, they can be struck down by a disorder known as decompression sickness. Because the lungs cannot get rid of the excess nitrogen fast enough, the tissues become saturated with nitrogen. It is at this point that the bubbles of nitrogen form within the tissues and veins. As the bubbles can form anywhere in the body it must be anticipated that the effects will be widespread. Some of the clinical effects and their comparative frequency are shown in the table below.

Symptoms	No. of Cases	% of cases
'Bends' (joint pains)	3278	88.78
'Bends' with local manifestations	9	0.26
Pain with prostration	47	1.26
Central nervous system symptoms: 1. Hemiplegia 2. Spinal cord	4 80	0.11 2.16

Vertigo (‘staggers’)	197	5.33
Dyspnoea (‘chokes’)	60	1.62
Partial or complete unconsciousness	17	0.46

Clinical Effects of Decompression Sickness

Decompression sickness has been recognised for over 100 years. Experiments showed that decompression sickness was an inevitable consequence of diving but that it could be controlled with ascent. The reduction of pressure that is, decompression can now be determined by tables, see example of US Navy Standard Air Decompression Table below on page 25.

Tables come in large manuals. They have been derived from calculation and experimentation. For each ten feet increment of depth and ten-minute period of bottom time there is a depth/time profile. The diver follows the profile as he ascends hence avoiding decompression sickness. The table below is for diving at 80 feet. It remains standard practice in the USA and UK to keep to the non-metric system. You can see both imperial and metric measurements on the table provided.

Depth (feet): 80

Bottom time (min)	Time first stop (min:sec)	Decompression stops (feet) 40	30	20	10	Total decomp. time (min:sec)
40					0	1:20
50	1:10				10	11:20
60	1:10				17	18:20
70	1:10				23	24:20
80	1:10				31	34:20
90	1:10			7	39	47:20
100	1:10			11	46	58:20
110	1:10			13	53	67:20
120	1:10			17	56	74:20
130	1:10			19	63	83:20
140	1:10			26	69	96:20
150	1:10			32	77	110:20
180	1:10			35	85	121:20
240	0:50		6	52	120	179:20
360	0:50		29	90	160	280:20
480	0:50		59	107	187	354:20
720	0:40	17	108	142	187	455:20

Table 3: US Navy Standard Air Decompression Table for 80 feet

Should the diver be at a depth or time that falls between the given values on the table, he will follow the next higher value. For example, if he dives 76ft for 78 minutes, he will follow the 80ft/80 min table. Please also note that for each depth and time spent at that depth there is a staged ascent. The time spent at the “stops” get longer the nearer to the surface the diver ascends. In practice, this is carried out by a weighted rope that is marked with depths and hangs below the dive boat.

Recompression Techniques

A dive should always be pre planned so the diver knows how long they can spend at each stop on their ascent. For deeper and longer dives, the diver might be required to wait at a level in the water for an hour or more.

This method was found to be unsatisfactory and not cost effective in commercial diving as no useful work could be carried out during the waiting periods also, the weather could change and the diver could get very cold and hungry. Once commercial diving began, often in deep and dangerous waters, a faster way of retrieving divers was required.

There are two basic techniques:

- Surface recompression
- Use of a Diving Bell

Surface Recompression

Very rarely used today, the technique utilises oxygen and is only suitable in waters up to 40 metres in depth – it is sometimes known as a form of aborted decompression sickness. The techniques requires that the diver can return to the surface and enter a recompression chamber on the support vessel and be recompressed all, within the space of 5 minutes. You can see a photograph of a typical decompression chamber on page 27. Once the diver is inside the chamber, the pressure is increased to a pre-determined depth equivalent.

The diver breathes 100% oxygen from a mask over times cycles, whilst pressure in the chamber is slowly brought back to atmospheric pressure.

Use of a Diving Bell

The bell is lowered to the diver and the pressure in the bell is increased until it is equivalent to the pressure at which the diver is working. The diver then enters the bell, shuts the door and both diver and bell are returned to the surface. The pressure in the bell is slowly reduced so the diver does not suffer from decompression sickness.

The advantage of this system is that it is an extremely safe way of diving and is used routinely in the commercial diving sector; however, it is very expensive and requires a large support network of dive supervisors, sat supervisors and dive technicians.

The recreational diver will not normally have any access to such facilities however if they plan the dive correctly, they should have no problems. In the past, most recreational divers did not dive deep enough or long enough to need to worry about decompression sickness. Accidents happened due to too rapid ascent or from drowning. With the introduction of more sophisticated equipment, the recreational diver now has to take into account their nitrogen load. This means following the old, staged ascent system.

Question E: What problems do you think might be associated with the technique of surface decompression?

4. Case Histories

The following case histories show how dives do not always go as per plan.

Case History 1: Gall Stones

Situation

3rd of June @ 19.15 hours. The North Sea medical centre was contacted about 23 year old diver carrying out commercial air diving of the coast of the UK.

Patients Symptoms

Severe abdominal pain, colicky in nature, located in right iliac fossa radiating to the right Hypochondrium. Exacerbated by movement and deep inspiration. No nausea or vomiting reported and no diarrhoea.

Diving History

Last dive 0800hrs, 30 metres of seawater (msw) for 22 minutes. 'No stop dive' One before on the 21st of June at 12.00 hrs, 40 msw for 11 minutes.

Further history

Pain commenced at approx, 0600hrs, 2 hours before last dive, and 42hrs after previous dive.

On examination

Pyrexia of 38.4c Nil of significance discovered.

Management

Surgical registrar flown out from local hospital.

Conclusion

Acute abdominal pain

Action

Registrar arranges to admit the patient to hospital

Conclusion reached at hospital

Either a slow leak from a perforated ulcer or biliary colic with peritonism

Outcome

Patient treated conservatively with a 'drip and suck' regime. Made a rapid recovery. On the 17th of July - elective surgery, none functioning gall bladder removed; diseased and full of small stones.

Discussion

Divers who fall ill always present difficult problems, as one always has to think of diving related illness, especially if the disorder arises after a dive. In the North Sea Medical Centre series of cases, 35% of divers who presented with some sort of abdominal pain, in fact had decompression sickness affecting the spinal cord. The pain experienced by the diver is thought to be from a focus of decompression sickness in the spinal cord. The treatment is invariably recompression, which needed to be carried out as soon as possible. The most available chamber is the one on the work site.

Note: To remove a diver who is unwell from their work site is to remove him/her from the very facility that they might need for recovery. In the case history, the diver reported that his symptoms began 2 hours before his last dive and some 42 hours after his previous dive.

Case History 2: SCUBA Diver

A 36-year-old SCUBA diver dived to 50 meters (165ft) for 43 minutes, ran out of air, returned to the surface for a fresh cylinder, performed inadequate in water decompression and vomited 10 minutes after surfacing. He was examined two hours later and was found to be disorientated and suffering from memory loss. He also complained of soreness in his scapula area, pain in his neck and weakness in his arms. He was unable to sit up and had swelling of the left leg and a loss of sensation to pinprick and temperature of the left leg.

The right leg was completely anaesthetic; he had no reflexes in his knees or ankles.

He had acute retention of urine and then became quadriplegic and unconscious.

He was compressed to 18m (60ft) initially then 50m (165ft) for more than one hour without any improvement. He was treated for 42 hours with 9 hours of intermittent oxygen breathing.

He recovered consciousness; recovered movement in his arms and trunk, and on decompression, his general condition was excellent on reaching the surface.

He suffered a degree of paraplegia which was treated with alternate dives, 9m (30ft) oxygen surface tables.

The patient was able to walk without the aid of a stick – excellent result.

5. System of Management

We need to consider the following

- Key personnel
- Communications
- Special Advice
- The Medics role offshore

Key Personnel

It is important that you understand the roles and responsibilities of the following key personnel.

Diving Supervisor
They are in charge of all diving operations and activities related to diving, including therapeutic recompression in a chamber. He is the pivot around which all activities concerning the treatment of a sick diver will revolve. He will liaise with the diving medical specialist. He will give instruction to the Diver Medic and/or the Offshore Medic.

Diver
The patient.

Diver Tender
A fit diver who can care for the sick diver in the chamber.

Diver Medic
A diver who has received special training in diving medicine and the management of diving related illnesses. It is unlikely that he will have any medical knowledge prior to this special training, so his competence will be at a fairly rudimentary level. He will not be able to move in and out of the chamber to examine the diver and provide medical attention, unless he is in a saturation environment in which case he is stuck in with the diver.

Diving Medical Specialist

A physician who has specialist knowledge and experience of the management of diving related Medical Specialist illnesses. He will be located onshore and will have access to a shore-based recompression chamber. He will generally provide advice over telephone but may need to travel offshore if the problem is a difficult one to resolve.

Every diving company will have planned for the possibility of having to treat a case of decompression sickness and will have a well-established treatment regime available. The regime may have developed in-house or may make use of standard treatment tables developed by a civilian or military research unit.

A commonly used treatment schedule is one developed by the US Navy. The diver is introduced into a decompression chamber and depressurised to a depth equivalent of 18 metres of seawater (2.8 ATA). He breathes 100% oxygen by mask on a cyclical basis, for example, 20 minutes oxygen, 5 minutes chamber air, 20 minutes oxygen and so on. The pressure is reduced gradually over a period of hours until atmospheric pressure is regained.

Because treatment has to be instituted rapidly, the diver is usually recompressed prior to full assessment having taken place.

The Diving Medical Specialist is generally called once the diver has been compressed to treatment depth.

Note: Throughout the treatment period, the Diving Supervisor is ultimately in control.

The role of the Diver Medic is to enter the chamber and carry out an assessment of the diver's condition. He will report his findings to the Diving Supervisor.

The Diving Supervisor will maintain regular contact with the diving Medical Specialist throughout the treatment.

The Diving Medical Specialist will advise the Diving Supervisor of any need for special medical treatment. This may take the form of an intravenous infusion, catheterisation, and drugs. The Diver Medic will administer these inside the chamber.

The Diving Medical Specialist may also advise the Diving Supervisor of an alternative scheme for decompression, should the conventional treatment scheme not be working. The Diving Medical specialist may also give advice to either the Diver Medic or the Offshore Medic.

In the absence of a Diver Medic, you as the Offshore Medic may have to fulfil a similar role. For reasons given shortly, the Offshore Medic should avoid entering the chamber.

Should additional medical treatment be required the Offshore Medic may have to instruct the Diver Tender how to perform the task. This is not ideal.

Communications

In many countries, commercial diving practice is regulated. There is an onus upon the diving company to make arrangements with a Diving Medical Specialist to provide an advisory service for the diving operations. The Diving Supervisor should have the means to contact the Specialist at any time. If this is not possible, then any of the following could be carried out:

- Telephone the ODD
- Telephone the local hospital
- Obtain a copy of Diving Regulations which contain a list of treatment centres. Telephone the nearest centre.

As an Offshore Medic, you are unlikely to have much regular contact with diving operations unless you enjoy recreational diving. It is useful to have an aide-memoire at hand for emergencies. The Aide Memoire for Recording and Transmission of Medical Data to Shore pro-forma was developed by a group of diving specialists (document DMAC 1). It could form the basis of your aide-memoire. If you need to use the form, complete it as fully as you can before making contact with the diving specialist. You will be able to see a copy of this on the Practical Course.

Specialist Advice

It is very important that you can work effectively with the diver and/or his team and provide advice from a Diving Medical Specialist in the management of a diving related illness.

Any illness occurring after diving, particularly within the first hour, should be treated as an illness specific to diving. For example, an ache around the chest after a dive may feel like a pulled muscle, a pain in the shoulder may be an aggravated old injury - both should be treated as decompression sickness.

Note: Over 50% of decompression sickness cases develop symptoms within one-hour post dive, and 90% within 6 hours.

Most commercial divers recognise the dangers of decompression sickness and will report any symptoms to their supervisor. Sometimes divers collapse with a major illness. In this case, the diver should be immediately recompressed. Diving medicine differs from conventional medical practice here, in that treatment is often initiated before a full history and examination have taken place. Instead, the Diver Medic Recompression will reverse the acute effects of pressure/ volume changes, the movement of nitrogen out of solution, and compress the bubbles that have formed in the tissues and bloodstream. As the diver is once again under pressure, in order to reduce the uptake of further nitrogen and to encourage the elimination of nitrogen from the body, the diver is provided with 100% oxygen to breathe through a mask (hyperbaric oxygen).

This procedure forms the mainstay of decompression sickness treatment, although treatment plans vary from one centre to the next. Most treatment plans have been devised in Naval Medical Departments.

Your Role as the Offshore Medic

Your role in diving medicine can be summarised as follows:

- Information gathering using the pro-forma
- Communication with the onshore Diving Medical Specialist
- Liaison officer between the Diving Supervisor and the Diving Medical Specialist
- Instruction to the Diver Tender concerning the examination of the patient
- Supply of medication to the Diver Tender as instructed by the Diving Medical Specialist
- Instruction to the Diver Tender concerning the administration of medication
- Medical emergency refresher training for diver before they enter Saturation

Note: Do not administer any treatment without prior consultation with the onshore Diving Medical Doctor

Note: Avoid entering the decompression chamber at all costs

The reasons for avoiding entry to the chamber are as follows:

- Everyone should have a special medical examination prior to going under pressure
- You may not be able to relieve the extreme discomfort in your ears as you go under pressure
- You may be unable to think clearly, and you should make no decisions whilst under pressure
- You may suffer with claustrophobia
- You are exposing yourself to the risk of developing a diving related illness
- You cease to be of use where you are most needed, that is, outside the chamber

6. Flying After Diving

Ascent in an aircraft produces a fall in ambient pressure. Hence, all the effects of pressure/volume changes already considered will apply to any diver who flies after diving. The following recommendations for flying after diving have been produced by the Diving Medical Advisory Committee and cover:

- Air diving

- Mixed gas diving
- Following therapy for dysbaric illness
- Decompression illness in flight

Air Diving

The reasons why the altitudes shown in the tables have been chosen is because 2,000 feet (600 metres) is the maximum height to which the diver should ascend following a dive, when travelling in a non-pressurised aircraft, and 8,000 feet (2,400 metres) refers to a normal aircraft with a pressurised cabin.

	200 ft / 600 meters	8000ft / 2400 meters
1. Non - stop dives Total time under pressure less than 60 minutes within previous 12 hours 2. All air diving (less than 4 hours under pressure)	2 hours 12 hours	4 hours 12 hours
3. Air or Nitrox saturation (More than 4 hours under pressure)	24 hours	48 hours*

* Experience in this range is extremely limited, and this recommendation should be interpreted with caution

Mixed Gas Diving

No flying at all for at least 12 hours following return to atmospheric pressure following diving involving the use of specialised gases.

Following Therapy for Dysbaric Illness

	2000ft / 600 metres	8000ft / 24000 metres
1. Successfully treated	24 hours	48 hours
2. Cases with residual symptoms must be decided on an individual case by case basis by a Diving Medical Specialist	.....	......

Decompression Sickness in Flight

Where the diver's symptoms consist of only pain in a limb, they should be treated with analgesics, oxygen if it is at hand and the plane can continue to its destination without any change of plans or adjustment to altitude.

When the diver has other symptoms advice should be sough immediately from a Diving Medical Specialist. It might be necessary to reduce the altitude of the plane and or divert it to the nearest airport. In the meantime the patient should be given Oxygen if available.

All of the information provided in this section is for your information only and any decisions regarding flying after a diving incident should be first of all referred immediately to a Diving Medical Specialist.

7. Glossary of Terms

Key Points

Diving and diving medicine is a specialist subject with its own team of key personnel. You might however become involved at some stages or you might even decide to complete the DMT course and work full time on a DSV.

- Oxygen can be used in the treatment of decompression sickness, but brings with it its own medical problems.
- There are three laws of physics that relate to pressure and gas in the underwater environment.
- It is useful to carry an aid memoir relating to diving emergency protocols and keep it readily at hand.
- Diving related disorders usually occur on descent and ascent from the workplace.
- Divers use a mixture of gases to overcome the physiological effects of individual gases.
- The usual immediate response to a suspected diving disorder is to recompress the diver.
- There are strict guidelines for flying after diving.
- As the Offshore Medic you should avoid entering the decompression chamber at all costs

Glossary

ABLJ - Adjustable Buoyancy Life Jacket.

Ambient - Surrounding, as in ambient temperature and ambient pressure.

ATA - Atmosphere Absolute. The pressure upon object immersed in water equal to the pressure of the water plus the pressure of the atmosphere above the water.

Barotrauma - Damage to the tissues induced by change in ambient pressure.

BC – Buoyancy Compensator.

Bell – A hyperbaric transport chamber.

Chamber – A hollow steel cylinder large enough to accommodate one or more men, capable of retaining an internal pressure greater than atmospheric.

DCS – Decompression sickness.

Decompression Sickness – An illness produced by a fall in the ambient pressure.

Dysbarism – Any medical disorder induced by a change in ambient pressure.

FSW – Feet of seawater

Hyperbaric – At a pressure greater than atmospheric

MSW – Meters of seawater

N2 – Nitrogen

O2 – Oxygen

PP – Partial Pressure

Saturation Diving - A type of diving system in which the diving team remain at the pressure of the working depth for up to a month.

SCUBA – Self-Contained Underwater Breathing Apparatus

Questions

Question 1: Look at the list of diving factors, in the context of diving related illnesses, which of the factors are more likely to be related to commercial diving and which to recreational and which might be to both?

Factor	Recreational	Commercial	Both
Lead boots			
ABLJ			
SCUBA gear			
Weight belt			
Time			
Face mask			
Helmet			
Ascent time			
Bottom time			
Diving chamber			
Oxygen			
Stops			
Pressure/volume changes			
Demand valve			

Question 2: The partial pressure of oxygen in a deep diving system is maintained at 0.4 ATA. The system is diving 90 metres. You have a mix of oxygen and helium to provide the correct pp02, what percentage of oxygen would you use?

Question 3: Look at the six diving related disorders below and indicate whether or not the disorder has an immediate/gradual onset and is due to an increase/decrease in ambient pressure.

A = Immediate in onset
B = Gradual in onset
C = Due to a decrease in ambient pressure
D = Due to an increase in ambient pressure

The first one has been completed for you:

Cerebral Embolism	A, C
Surgical or Interstitial Emphysema	
Decompression Sickness	
Chronic Pulmonary Toxicity	
Ruptured Ear Drum (Middle Ear Barotrauma)	
Narcotic effect of Nitrogen Narcosis	

Question 4: List four reasons why it is ill advisable to enter a decompression chamber.

Question 5: Read this account of treatment given for a diving related illness and the key personnel involved. Complete the account using the number of the relevant operative. You may use some numbers more than once and not all the personnel listed are involved. You should read the account a couple of times before filling in the blanks. We've done one for you:

1. (Onshore) Diving Medical Specialist
2. Liaison Officer
3. Diver Tender
4. Diver Medic
5. Diving Supervisor
6. Offshore Medic

Following a dive, a commercial diver reported symptoms, strongly suggestive of decompression sickness, to his ___5____ . As a result of considering these symptoms, the _______ instructed the diver to enter the recompression chamber. The diver was accompanied by a _______ (who was only First Aid trained). A ____________ was not part of the diving team so the__________ was asked to attend. The __________obtained a history from the diver via the chamber intercom, passed some examination equipment to the ___________ in the chamber and instructed him on how to examine the diver. With the information obtained, the __________ telephoned the_________ . Following this conversation, the _________ spoke with the __________ about the recompression and then gave the ___________ advice about medical treatment.

ddrc professional services

Questions for your tutor

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Answers:

Question A: 11 ATA

Question B: Oxygen = 2.2, Nitrogen 8.8

Question C: The pressure changes from 2 ATA to 1 ATA on ascent. Using Boyles law this means the pressure is halved and the volume is doubled. The diver's lung volume would therefore increase to 11 litres; this would result in a ruptured lung which could well have fatal consequences.

Question D: The partial pressure of oxygen in air at a surface pressure of 1 ATA = 20% x 1 = 0.2 ATA. CNS toxicity occurs at 2 ATA or greater. Thus, a partial pressure of oxygen in air representing 2 ATA occurs in 10 ATA (2 ATA is 20% of 10 ATA).

An underwater pressure of 10 ATA = 1 ATA surface pressure + 9 ATA water pressure

The depth equivalent of 9 ATA = 9 x 10 metres = 90 metres

Answer = 90 metres

Therefore, if a diver descends to 90 metres or more, he could, in theory suffer an oxygen induced convulsion, however this does not happen for reasons that will be discussed later – the "Narcotic" Effects of Nitrogen.

Question E: Decompression and Oxygen Toxicity

Question 1:

Factor	Recreational	Commercial	Both
Lead boots		X	
ABLJ	X		
SCUBA gear			X
Weight belt			X
Time			X
Face mask	X		
Helmet		X	
Ascent time			X
Bottom time			X
Diving chamber		X	
Oxygen			X
Stops			X
Pressure/volume changes			X
Demand valve	X		

Question 2: At 90 metres depth the pressure = 10 ATA. Therefore, this pressure = ppO2 + ppHe. Therefore, 10 ATA = 0.4 ATA + 9.6 ATA. Expressed as a % the oxygen partial pressure = 4%.

Question 3:

Cerebral Embolism	A, C
Surgical or Interstitial Emphysema	A, C
Decompression Sickness	B, C
Chronic Pulmonary Toxicity	B, D
Ruptured Ear Drum (Middle Ear Barotrauma)	A, D
Narcotic effect of Nitrogen Narcosis	B, D

Question 4: Four from the following:

- Everyone should have a special medical examination prior to going under pressure.
- You may not be able to relieve the extreme discomfort in your ears as you go under pressure.
- You may be unable to think clearly, and you should make no decisions whilst under pressure.
- You may suffer with claustrophobia.
- You are exposing yourself to the risk of developing a diving related illness.
- You cease to be of use where you are most needed, that is, outside the chamber.

Remember: Avoid entering the chamber at all costs...

Question 5: Following a dive, a commercial diver reported symptoms, strongly suggestive of decompression sickness, to his **5**. As a result of considering these symptoms, the **5** instructed the diver to enter the recompression chamber. The diver was accompanied by a **3** (who was only First Aid trained). A **4** was not part of the diving team so the **6** was asked to attend. The **6** obtained a history from the diver via the chamber intercom, passed some examination equipment to the **3** in the chamber and instructed him on how to examine the diver. With the information obtained, the **6** telephoned the **1**. Following this conversation, the **1** spoke with the **5** about the recompression and then gave the **6** advice about medical treatment.