THE BODY & EFFECTS OF DIVING

Lesson Objectives

Having introduced in the previous presentation how air and water pressure affects divers in relation to Basic and Scuba Equipment, this session looks in more detail at the Human Body and the effects of diving on it. Understanding the body and some of the effects of diving provide a background to future lessons on diving disorders, prevention and treatment.

Achievement Targets

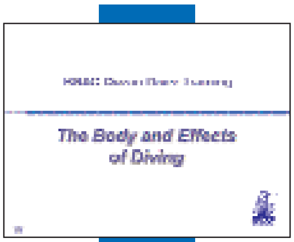
At the end of this lesson students should

- Have a basic understanding of the Body Mechanisms, Metabolism, Respiration and Circulation
- Understand the effects of diving on the ear and sinuses
- Understand that thermal protection prevents heat loss
- Have a basic understanding of buoyancy and how diving equipment can alter a diver's buoyancy.
- Understand the need for general awareness and fitness before diving

Following items will be useful as additional Visual Aids

Different types of diving suits. A weightbelt

THE BODY AND EFFECTS OF DIVING



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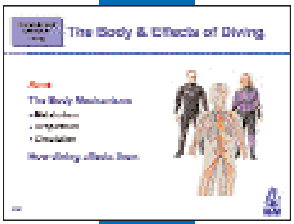
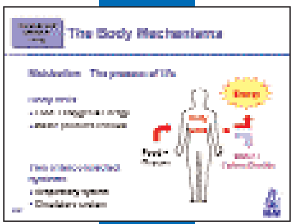


Explain that this session will introduce students to the human body mechanisms of metabolism, respiration and circulation. A basic knowledge of how these work under "normal" conditions will help students understand how diving affects them and also provides information that builds into later presentations on this course.

BODY METABOLISM



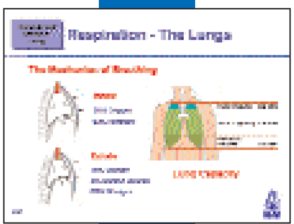
The human body is composed of millions of cells, each with a particular function - they are the body's building and storage blocks.

- Body cells need food and oxygen for energy. Food is taken in via the digestive system. To release energy in a form that the cells can easily use, the food must be broken down by a series of chemical reactions within the cells and oxygen is a vital ingredient in this process
- Waste products, carbon dioxide and water, are produced and need removal

The body can store many of the substances it needs e.g. body fat, as an energy reservoir, but it cannot store more than a couple of minute's worth of oxygen. It needs a constant supply of oxygen to the cells and removal of the waste produced, carbon dioxide. This continuous demand is handled by two interlinked systems

- Respiration - The lungs and breathing
- Circulation - the Heart and blood

RESPIRATION - THE LUNGS



The lungs accomplish two things, firstly they draw in the oxygen and secondly, they expel the carbon dioxide. There are sensors in the body that detect the build up of carbon dioxide. When it reaches a level beyond which it will become poisonous to the body, sensors activate a trigger response, the stimulus to breathe, to expel it through the breathing mechanism.

THE MECHANICS OF BREATHING

The lungs are enclosed in a cavity - the ribcage and chest muscles form the sides and the diaphragm, an arched sheet of muscle, the bottom.

Inhalation

- The diaphragm contracts and flattens downwards. At the same time muscles lift the ribs up and outwards. This action increases the lung volume and draws the air in
- Inhaled air comprises approximately 21% oxygen and 79% nitrogen.

  Nitrogen plays no part in normal cell metabolism, it just 'washes' in and out of the body. However, its presence in the body does affect a diver, which is looked at in a later lesson

Exhalation

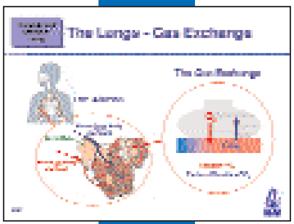
- The diaphragm relaxes back to its arched position; the muscles relax allowing the ribs to return downwards and inwards. This reduces the lung volume and the contents are expelled
- A proportion of the inhaled oxygen has been utilised by the body cells and this has been replaced by the waste product, carbon dioxide

  The exhaled air thus comprises approximately 79% nitrogen, 17% oxygen and 4% carbon dioxide

Lung Capacity

Lung size depends on body build so varies from person to person but the average adult lung capacity is 6 litres.

- The maximum lung volume that can be used, even with the deepest inhalation/exhalation, is 4.5 litres, known as the vital capacity
- During normal quiet breathing, only a little of vital capacity is used, around 0.5 litres
- The lungs retain an amount of air to maintain the lungs' working capability. This capacity, known as the residual volume, is approximately 1.5 litres and cannot be expelled



THE LUNGS - GAS EXCHANGE

The oxygen drawn into the lungs needs to be transferred to the blood for delivery to the body cells.

- Air passes from the airway into the two branches entering each lung (the bronchi) that divide and sub-divide into smaller air tubes until they become as thin as fine hair. At the end of each 'hair' are microscopic bubble shaped air sacs called alveoli.

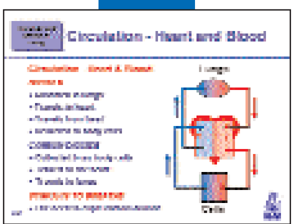
The Alveoli

- There are about 300 million in each lung. This huge number means that all their surface areas combine to create a large total surface area to cater for the body's demand for oxygen - spread them out and they are about the size of a tennis court.
- Surrounding the alveoli is a network of tiny blood vessels called capillaries.

The Gas Exchange

Gas exchange takes place through the very thin walls of the alveoli and capillaries. Gases always try to maintain a constant balance and tend to diffuse from a higher concentration to a lower concentration when air and liquid come into contact.

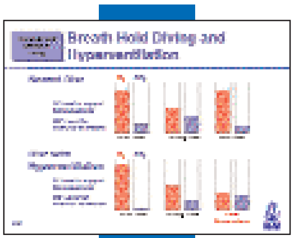
- On inhalation, the alveoli contains oxygen at a higher concentration than that in the returning blood from the body cells and some oxygen diffuses into the blood to equalise
- At the same time, carbon dioxide, the waste product of metabolism, is at a higher concentration in the blood than in the alveoli and so diffuses out of the blood into the alveoli to equalise
- Exhaling expels the "waste" air and this is replaced by "fresh" oxygen rich air on inhaling



CIRCULATION - HEART AND BLOOD

- Oxygen diffused in the blood travels
  - From the lungs to the heart - the pump that continuously circulates the blood around the body
  - From the heart to the body cells
- Carbon dioxide is collected and is
  - Returned back to the heart
  - From the heart it returns it to the lungs
- The stimulus to breathe is triggered by the build up and need to expel carbon dioxide

Of the 21% oxygen inhaled, the 4% used may seem quite low, but the body cells cannot metabolize a higher concentration. If the cells are working hard, the 'burn' (also known as 'cell respiration') is faster with oxygen being used and carbon dioxide being produced more quickly. This increases the breathing rate and the heart pumps faster to speed up the blood delivering oxygen and removing carbon dioxide.



BREATH HOLD DIVING AND HYPERVENTILATION

On dry land there may be different lengths of time that individuals can hold their breath but, ultimately, they have to succumb to the stimulus to breathe to expel the carbon dioxide.

Normal breath hold dive

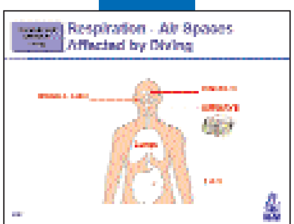
- At the start of a dive, following exhalation/inhalation the carbon dioxide and oxygen are at normal levels
- During the dive, the level of oxygen is reducing and carbon dioxide is rising to the level that triggers the desire to return to the surface to breathe. This happens before the level of oxygen drops to the minimum level to support consciousness
- At the end of the dive, exhalation/inhalation returns the oxygen and carbon dioxide to their start levels

Hyperventilation

This is an attempt to override the normal respiratory control mechanisms by rapid, unusually deep breathing. The mistaken belief is that it increases the intake of oxygen to allow the diver to remain under water longer. The increase of oxygen is minute and this is where the danger lies.

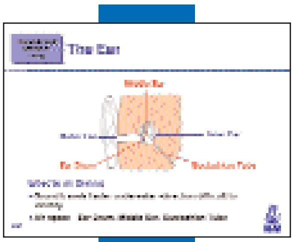
- Hyperventilating at the start of a dive increases the level of oxygen by only a very small amount but it does reduce the carbon dioxide to quite a low level
- During the dive, oxygen is used as normal, and carbon dioxide is produced but, as its level had been reduced at the start of the dive, its rise to the level that triggers the stimulus to breathe is delayed
- The oxygen level continues to fall and reaches the point where it cannot support consciousness before the carbon dioxide reaches its level to stimulate the need to breathe. On land a person will faint, which allows the still breathing body a period of recovery back to consciousness. If a breath hold diver 'faints' and becomes unconscious underwater (‘known as shallow water black out’) with lungs reduced in size (Boyle's Law), they will sink and drown
- Hyperventilation is a practice that should be avoided at all costs. The breath hold diver should start the dive in a relaxed state and should take no more that two or three medium breaths

If students raise any points about the sport of Free Diving where breath hold divers go to extreme depths and are seen hyperventilating, the Instructor should clarify that free divers have gone through a very long training regime to incredible levels of fitness. In an attempt to reduce cell oxygen demand while attempting this type of diving. They always have in-water support because many do go unconscious underwater, or on their return to the surface and some have not survived.



RESPIRATION - AIR SPACES AFFECTED BY DIVING

- The effect of diving on the lungs as a flexible airspace and the mask, an extension of the airway, has already been discussed in the previous lesson
- There are other air spaces in the body that are affected by diving, the middle ear and sinuses, rigid air spaces within the skull bone. The gut is a flexible air space that naturally adapts to pressure changes with is own involuntary method of equalisation that everyone is probably aware of, either by sound or smell!



THE EAR

The ear is divided into three sections

- The outer, middle and inner ear. Thin membrane 'dividers' separate each section.

Sound waves are funnelled into the outer ear to the first of the membrane dividers, the eardrum, which vibrates in response to the sound waves. These vibrations are transmitted into the middle ear, an air space that connects with the back of the throat via the Eustachian tube. The eardrum's vibrations are transmitted by a set of small interconnecting bones that arch across the middle ear to the next membrane divider. The vibrations pass through the membrane into the fluid filled inner ear as 'pressure waves'. These are sensed by nerve endings and converted into messages for the brain to analyse. Also housed deep inside the inner ear are sensors that are important for the body's sense of balance and position.

- Diving affects the ear in two ways

  Firstly, sound travels faster under water than in air. The ear can still 'hear' sounds underwater but is unable to identify direction of the sound because of its higher speed

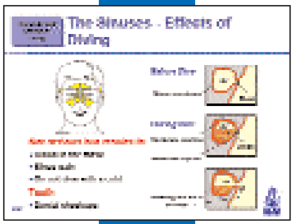
  Secondly, as an air space, ambient water pressure in accordance with Boyle's Law affects the middle ear

EFFECTS OF DIVING ON THE EAR

In everyday life, the equalisation of pressure between the middle ear and ambient air pressure happens with involuntary swallowing of saliva that opens the Eustachian tube to air at the back of the throat. There are times when a conscious effort is needed to equalise the ears - such as the quick increase in ambient pressure when a train rushes through a tunnel. With increased ambient pressure and lower pressure in the middle ear, the eardrum flexes inwards and causes discomfort. A conscious action, called a Valsalva manoeuvre, of swallowing or gently breathing out against a pinched nose, will open the Eustachian tube and introduce air from the throat to equalise the middle ear.

- Diving produces the same effect. The ears are very sensitive to the rapid increase in ambient water pressure on descent, so divers will need to equalise or "clear their ears" at quite shallow depths and frequently during a descent. As ambient water pressure increases the eardrum consequently flexes inwards. A Valsalva manoeuvre will equalise the pressure and allow the eardrum to return to its normal position. Ascending from a dive does not normally need a conscious effort to clear the ears, as the expansion of air in the middle ear will naturally open the Eustachian tube
- Problems arise, even in shallow water, if there is a blockage that prevents equalisation. The most common is mucus congestion in the Eustachian tube preventing clearing and discomfort will be felt. The only way to resolve this is to ascend a little to relieve the discomfort and try ear clearing again. The blockage may clear allowing the diver to continue the descent. However, if the ears will not clear, the diver should ascend and either dive at a shallow depth (depending on the type of dive) where the ears are not affected or abort the dive
- Less common is a blockage in the outer ear. A tight fitting hood may block off the ear canal with trapped air between the blockage and eardrum. Equalising the middle ear by Valsalva action will push the eardrum towards the lower pressure with the resultant discomfort. Ensure water is free to enter the outer ear and never wear earplugs when diving
- To force ear clearing or continue descending whilst still experiencing discomfort or pain is foolhardy. This will cause ear tissue damage and most likely burst the eardrum. Cold water entering the middle ear will upset the balance organs in the inner ear causing giddiness. Ear damage will curtail diving for some considerable time, affect hearing and, in severe cases, may stop diving altogether

- Remember that ear problems on descent may be resolved by re-ascending slightly
- Do not dive with a cold, congestion or infection



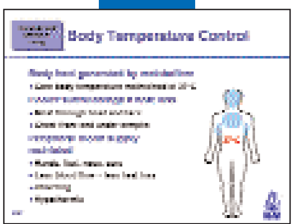
THE SINUSES - EFFECTS OF DIVING

The sinuses are 'hollows' deep inside the skull bone, above and below the eyes and around the ears. The function of the sinuses is unknown but it is thought that one of the main purposes is to lighten the skull. Air pressure within them normally equalises naturally. They are lined with a mucous membrane containing tiny blood vessels (akin to the lining of the nose).

- A blockage, generally the result of a cold or infection, can result in sinus "squeeze". Ambient pressure is transmitted through the body to the tiny blood vessels in the mucus membrane lining. Without equalisation, the membrane swells in an attempt to equalise the pressure and the small blood vessels may tear and bleed, flooding the air space. If the bleeding continues this will increase the pressure and force the blockage out together with excess blood
- Although it might appear alarming, a slight nosebleed during or after a dive is a common sign of a mild sinus blockage
- However, if the diver experiences sinus pain during a descent (caused by damage to the mucous membrane nerve endings) they should abort the dive. If, after diving, sinus pains occur with regularity, the diver should seek medical attention to check the sinus airways
- To prevent sinus problems, don't dive with a cold, congestion or infection

TEETH

- Mention to students that cavities in the teeth are also air spaces and pressure changes can lead to a tooth 'squeeze' following the same pattern as sinus squeeze. During ascent increased pressure on the tooth can be painful and it may result in bleeding or, in very rare cases, break the tooth. A regular visit to the dentist by divers is recommended!

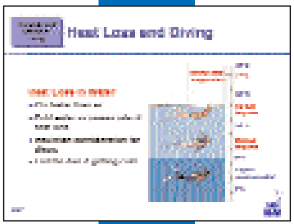


BODY TEMPERATURE CONTROL

- Human bodies give off heat as a natural process due to the heat generated by the cells and metabolism
- The body has temperature sensors to maintain the 'core' body temperature at 37°C. The core consists of the important body areas; brain, spinal cord, chest organs, abdomen and pelvis and these are surrounded by a peripheral 'shell' consisting the limbs, muscles and skin. The core temperature is controlled within very narrow limits, plus or minus 2 degrees, while the peripheral shell is subject to greater variation. For example, if the body gets too hot, the sensors trigger sweating and its evaporation on the skin surface draws heat from the body cooling it down
- Heat loss from the body depends on many factors but the main one is a cooler temperature around the body drawing heat away. The greatest heat loss, around two fifths, is through the head and face. Other main heat loss areas are the front of the chest and under the armpits
- With insufficient insulation in these areas, the body begins to protect the core temperature by narrowing the blood vessels and therefore reducing blood supply to the peripheral shell. As the blood flow is less, the heat loss is reduced. The initial peripheral areas affected are the hands, feet, nose and ears - they look bluish in colour because the blood supply is reduced and also begin to feel numb
- If the peripheral cooling continues, the muscles begin contracting and relaxing quickly to generate body heat - the "shivering mechanism". This is a clear indication that the body needs to increase insulation against the

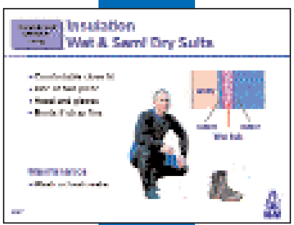
cold either by moving to a warmer environment or adding additional clothing

- If nothing is done to remedy the situation and shivering stops, the body is sinking into a state called hypothermia, which can become a very serious condition with the body slowly shutting down



HEAT LOSS AND DIVING

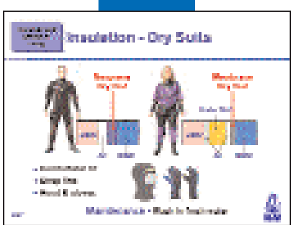
- Water is an excellent conductor of heat and the rate of conduction is 25 times faster than in air
- A human body immersed in cold water loses heat far more quickly than in air
- Divers need to consider insulation protection. The rate of heat loss in water for divers depends on the water temperature, the amount of energy heat the body creates by swimming or finning and the time in the water, but as a general guideline:
  - Diving in water not less than 21°C the body is generally comfortable with minimal insulation
  - Between 20°C and 10°C a minimum of a wet or semi dry suit is required
  - Below 10°C a Drysuit is strongly recommended
- Common sense dictates that feeling cold on a dive is an indication to leave the water to prevent further heat loss



Insulation - Wet and Semi Dry Suits

Many suits are made of neoprene that has been "foamed and expanded". This means there are gas bubbles trapped in the neoprene fabric so the suit does not act like a sponge. It provides effective insulation combined with elasticity to allow movement and for this reason can be a close "fit". This does not prevent water entering the suit but this has an advantage. A relatively stable amount of water directly in contact with the body is warmed by the body's heat but protected by the suit from the surrounding cooler water. So the wetsuit and warmed layer of water act as insulation. The semi dry suit uses the same principle to a greater extent, with generally thicker neoprene than wet suits, has tighter seals at wrists and feet to reduce the water ingress even more. Less water = semi dry!

- The fit should be reasonably close but allow movement. Too loose and more water will flush through the suit drawing more heat from the body and leading to more rapid heat loss
- Variation in styles means divers can choose between one or two piece suits. Some designs have an integrated hood
- Divers can choose whether to wear a hood or not with these suits depending on the water temperature but remember that heat is lost predominantly through the head. Gloves are also another option
- Shoe fins can be worn but where a diver chooses to wear neoprene boots to protect or keep feet warmer, strap fins will be needed
- Maintenance of the suit is to wash the suit with fresh water after every dive and dry thoroughly. A mild disinfectant wash can also be used

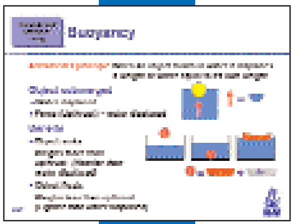


INSULATION - DRY SUITS

Made from neoprene, crushed neoprene or other waterproof materials, dry suits do not allow water entry because of seals around the neck and wrists, integrated boots and waterproof zips. The body warms the air within the suit providing insulation. Depending on the suit fabric and the water temperature, clothing or under-suits need to be worn to increase the insulation. To allow equalisation of air within the suit during a dive, air is introduced via a direct feed and excess air can be expelled via a dump valve - both similar mechanisms to those on a BC.

- Fit needs to allow for movement

- Because of the dry suit boots, strap fins will be needed
- Hood and gloves will be needed
- Maintenance of the suit is to wash the suit with fresh water after every dive and dry thoroughly. A mild disinfectant wash inside the suit is recommended from time to time
- Wax zips for protection
- French chalk on seals help to prolong their life



BUOYANCY

- It was a Greek philosopher, Archimedes, who worked out the principle –

  When an object is submerged, its weight pushes down moving water out of the way. The water pushes back in an upward force (upthrust) equal to the weight of water displaced by the object. Any object immersed in water therefore apparently loses weight. Lifting someone out of a swimming pool is easy while most of their body is still in the water; the more they are lifted out of the water the heavier they become.

Density

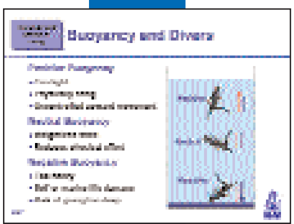
- An object will sink if it weighs more than the upthrust - it is heavier than the water it displaces
- An object will float if it weighs less than the upthrust - it is lighter than the water it displaces

As an example

- A solid ball of plasticine or modeling clay will sink in a bowl of water - it is heavier than the water it displaces. The water displacement makes the level of water rise
- If the ball is reshaped into a boat, the volume of the object has increased

  The boat and the air that it contains displace a greater volume of water so the upthrust has been increased and the boat floats. (With the greater displacement, the level of water in the bowl is higher than the submerged ball)

Steel ships weighing thousands of tons float because of their large 'displacement' and they contain a large volume of air



BUOYANCY AND DIVERS

The only time divers want to be able to float on the surface is at the beginning and at the end of the dive. It is underwater where we need to control buoyancy.

- **Positive Buoyancy**

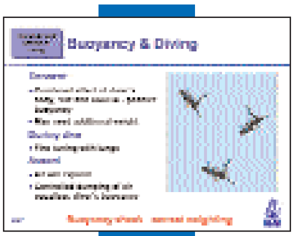
  Too light – positive buoyancy, and the ensuing struggles to remain below the water are physically tiring. More importantly, being too light risks possible over expansion of the lungs as ambient pressure reduces

- **Neutral Buoyancy**

  This is a state of the diver being in equilibrium with the surrounding water. It is a weightless state that eases physical effort. A diver's buoyancy needs adjustment throughout the dive to maintain neutral buoyancy - to be able to hover above, below or to the side of interesting marine features. Happiness is neutral buoyancy!

- **Negative Buoyancy**

  Too heavy – negative buoyancy is also physically tiring and bouncing off the sea bed can damage the marine life and diver's equipment. Being too heavy will also risk descending below safe diving depths



BUOYANCY AND DIVING

A diver with no equipment will float on the surface. Each piece of added diving equipment has a weight and a volume, some will increase the diver's buoyancy and others will decrease it.

Start of the Dive - Surface

- The combined effect of the diver's body, their suit and SCUBA equipment will normally result in positive buoyancy, which is compensated for by adding weight on a weightbelt to allow the diver to descend

Descent

- Having left the surface and increasing ambient pressure during descent will compress the bubbles in the wet/semi dry suit material or the air held within the drysuit resulting in buoyancy loss
- To balance this loss of buoyancy, air is introduced to either the BC if wearing a wet/semi dry suit, or the drysuit

During Dive

Moving around or over underwater features can be effected by using the lungs to fine tune neutral buoyancy.

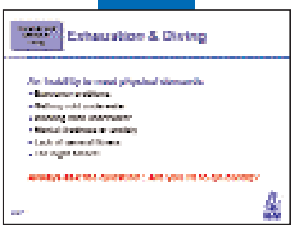
Ascent

Air introduced at depth in a BC or drysuit will, as a diver rises, expand with reducing ambient pressure. Removing or dumping the air in a controlled manner will equalise the diver's buoyancy as they ascend.

Correct Weighting

Divers need to set the amount of additional weight they carry on a weightbelt not just to assist the descent, but for the control that will be required on an ascent. Air in the cylinder has weight and having used it during the dive, the cylinder contents and weight will be reduced. Buoyancy checks before diving should take account of this by adding 1-2 kilos to allow for air consumed during a dive so that neutral buoyancy can be maintained for the end of the dive.

The salt content, or salinity of the water, can vary and affect a diver's buoyancy. Divers weighted for fresh water diving in quarries or lakes will need to add some weight for sea diving. Conversely, divers weighted for sea diving will need to remove some weight for diving in fresh water.



EXHAUSTION AND DIVING

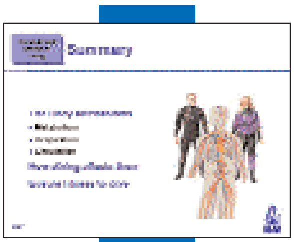
Exhaustion is the inability to meet physical demands on the body during diving, this can be affected by:

- Buoyancy problems – overweight or underweight and struggling to maintain neutral buoyancy
- Getting cold underwater – lack of thermal protection
- Working hard underwater – excessive finning, restrictive equipment
- Mental tiredness or anxiety – breathing increases
- Lack of general fitness - breathing increases
- Effects of the night before – dehydration and the impact of alcohol on the blood's ability to deliver oxygen and remove carbon dioxide

Always ask the question

- 'Are you fit to go diving?'

  – it is never worth the risk of placing yourself in a vulnerable state when underwater



SUMMARY

This lesson has covered some further effects of diving on the body including a basic understanding of the body mechanisms of metabolism, respiration and circulation.

The effects of pressure changes on the ears, sinuses and teeth.

The appropriate measures to take to protect the body from heat loss while diving, together with the principles and practicalities of buoyancy control.

All the above underline the need for general fitness for diving.