BAROTRAUMAS

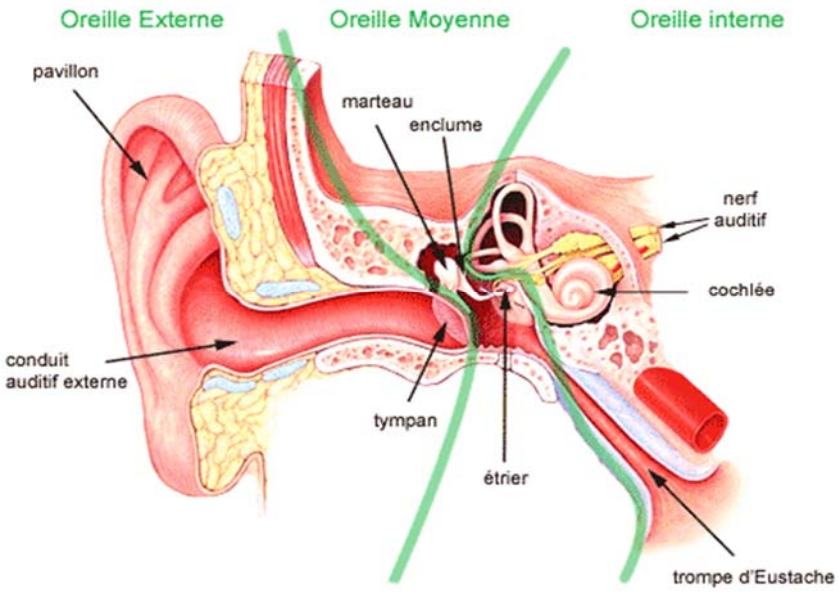
TECHNICAL SHEET

PRESSURE RELATED PROBLEMS

The term barotrauma often evokes risks inherent to underwater diving, but did you know that certain barotrauma can also happen in our swimming pools, and even outside of water? We will approach this vast subject by presenting the different mechanisms of these injuries caused by changes in pressure in certain cavities of the human body. We will then tackle decompression sickness (caisson disease), arterial gas embolism, as well as other problems related to nitrogen and oxygen during underwater diving.

EAR SQUEEZE

Let us take the example of the ear, more specifically three situations where barotraumas can occur. We will see what happens in the ear during pressure changes.



Source : http://www.interson-protac.com/3.47122.probleme-d-audition.html

Climbing in altitude

When climbing in altitude in a plane or while going up a large hill in a car, you have probably felt a pressure on your eardrums. This sensation is caused by a diminution of pressure. Generally, when the latter decreases, the volume of a given quantity of air increases. In other words, air expands as pressure decreases, and vice versa. The discomfort thus comes from the increase in volume of the air behind the eardrum at the same time as a decrease in pressure during the ascent. Most of the time, a single movement of the jaw is enough to allow the Eustachian tubes (the small canal linking the middle ear to the nose) to open and let air out of the nose and the pharynx. As long as the excess air can be expelled, there is no risk of barotrauma. However, in case of malformation or infection in the sinus, nose or ear, the Eustachian tubes can be obstructed (for example by pus during an otitis), which prevents air from circulating freely. The sudden increase in air volume in the middle ear caused by a rapid ascent will increase the pressure exerted on the eardrum (the air will push from the inside to the outside of the ear). A pain can then be felt and ultimately the eardrum could rupture. This situation is however quite rare, since planes are pressurized, which minimises pressure changes.

Underwater diving

When diving in a diving tank, the pressure exerted by water increases. As such, the volume of air contained inside the middle ear diminishes, which creates a negative pressure in the middle ear (or an inward suction on the eardrum). This is the pressure felt in the ear. The solution is simple: pinch the nose and blow through it. This maneuver allows air to enter into the middle ear and restore pressure balance. This technique is called the Valsalva maneuver. It must be repeated during the descent every time pressure is felt on the eardrum. The same situation can also happen during a rapid descent in an airplane, the difference being that in this case, there is no water pressure as aggravating factor. In any case it is important to restore pressure balance inside the ear to avoid rupturing the eardrum.

Ascending too quickly

The third scenario is a combination of the first two. If you balance your eardrums while descending to the bottom of a diving tank, you are letting air into your middle ear. During the ascent, the volume of air contained in the ear increases. If you ascend too quickly, the pressure in the middle ear will increase, since the air will not have enough time to escape from the Eustachian tubes (especially if they are obstructed by an infection, for example). This can cause a rupture of the eardrum[1]. The solution is to ascend slowly all the while expiring, which facilitates the expulsion of air from the middle ear through the Eustachian tubes.

These examples highlight the importance of balancing our ears during underwater diving or ascension. It is thus easy to understand the reasons why is it forbidden to dive in the shallow end with earplugs; these can create air cavities between the plug and the eardrum, which make it impossible to balance the ears.

PRESSURE: CAUTION!

Barotraumas happen in the case of injuries caused by pressure changes which modify the amount of gas inside a cavity of the body, such as the lungs, ears, sinus, intestines and a cavity under a dental filling. Even blood vessels contain gasses such as oxygen, carbon dioxide (CO_2) and nitrogen. When the body undergoes changes in atmospheric pressure (pressure of the surrounding air) or pressure exerted by water, this creates direct changes to the volume of gasses in its cavities. The closer we get to the center of the Earth, the greater the pressure, since there is more air or water above us. By opposition, the higher in altitude we get, the lesser the pressure, since there is less air or water above us. As pressure decreases, the gas inside bodily cavities increases in volume, taking more and more space; inversely, an increase in pressure creates a decrease in the volume of gas. This is a well-known law of physics, which is taught in high school or in CEGEP: Boyle's law of gasses (P1V1 = P2V2). Even though the gas remains inside the body, it is still subjected to the effects of the surrounding pressure, which can be significant: sometimes a variation of a few meters can be enough to create considerable pressure or volume changes.

[1] For more information, see « Technical sheet – Traumas »

OTHER BAROTRAUMAS

Now that you have a good understanding on the volume and pressure variations exerted on the body during ascent and descent, you can apply this principle to all cavities of the body that can contain gasses or air.

The sinuses

Sinuses are bone cavities in the face which are filled with air. They are located mainly around the nose and in the forehead. The sinuses are closely related to the nose, to which they are connected. When suffering from sinusitis, the air can get stuck in the sinus because of the swelling caused by the inflammation and the mucus. This contributes to the pain of the sinusitis. It is not recommended to take the plane or to go underwater diving in case of sinus problems.

The teeth

Have you ever felt pain in your teeth while you were on a plane or underwater diving? This could mean you have an air bubble under a filling or a dental sealant. When this air bubble undergoes pressure variations, its volume increases or decreases, which can result in pain, since the air cannot enter or escape the filling. This is not very dangerous per se, but it is better to consult a dentist in case of doubt.

The intestines

Whatever we might think, nobody can escape it: our intestines contain gasses. Part of it comes from the air we swallow when we eat – another part is produced by the bacteria present in our intestines. This gaseous volume is also subject to variation, depending on pressure. When the air volume increases in the digestive system, the gasses are expelled naturally as burps or flatulence. However, if air is not expelled naturally, the intestines, the stomach and the abdomen could become dilated, creating abdominal cramps. This phenomenon is improbable in a swimming pool, but could happen when ascending too quickly while underwater diving or on a plane.

The lungs

There are two types of barotraumas that can affect the lungs – pneumothorax and gaseous pulmonary embolism.

Pneumothorax happens during underwater diving using a compressed air bottle (in a tank or in a natural environment). If the diver ascends too quickly and does not expire while ascending, the air will expand until it ruptures the alveoli. This rupture allows air to enter the thoracic cavity, leading to a gradual, sometimes quick, closed pneumothorax. This injury is a vital emergency that can lead to a pressured pneumothorax, and to death. If you suspect a pneumothorax, you must quickly communicate with emergency medical services to ensure the victim is transported to a medical center.

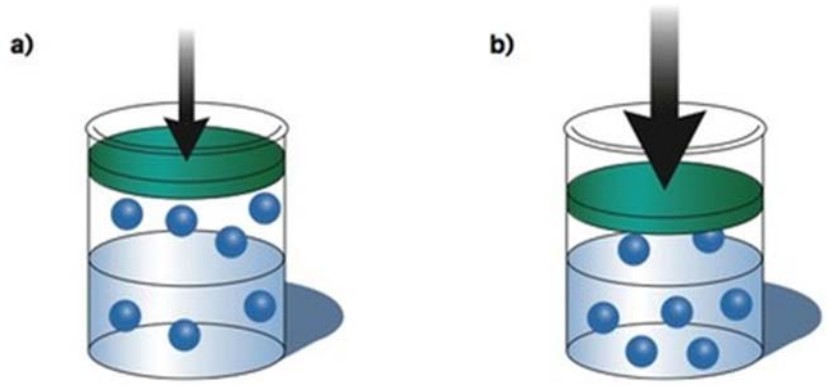
Prevention

Even though our tanks and pools are not very deep, certain barotraumas can happen. Vigilance is thus essential to avoid most of these barotraumas. Just follow these simple rules:

1. If you are sick (sinusitis, otitis or infection in the upper airways), do not dive.
2. Before going diving, free-diving or underwater diving, make sure you are able to balance your ears using the Valsalva maneuver. If you can't, refrain from diving.
3. During the ascension, expire continuously; never hold your breath.
4. If you feel pain during the dive, try to balance your ears. If that does not work, ascend back to the surface.

Decompression syndrome

During underwater diving, the air contained in the lungs can be subjected to strong pressures exerted by the surrounding water. This pressure causes the gas molecules to draw closer to each other, as well as a diminution of the air's volume. It could be said that the air in the lungs is compressed, as is the case for the air in the bottle worn on the diver's back. The deeper we dive, more the greater this effect. The ease with which gas, such as oxygen and nitrogen, can enter the blood or the human body's tissues is also influenced by this pressure. The more pressure there is on this gas, the easier it will enter the bloodstream and the body's tissues (muscles, organs, etc.).



a) Near the surface, less nitrogen is diffused into the blood when the water exerts a pressure on the body.

b) With the increasing pressure, the diffusion of nitrogen in the blood accelerates.

When diving, the problems are mostly caused by nitrogen (N_2), since this large molecule can accumulate rapidly in the bloodstream and the body's tissues. The deeper and the longer we dive, the more nitrogen accumulates. Problems related to decompression happen at the moment of the ascent, as well as in the hours following it. During the ascent, the pressure exerted on the body decreases and thus the gas contained in the tissues tends to go back to its normal volume. When the diver ascends too quickly, the gas molecules do not have enough time to escape from the lungs and expand too much. The gasses then get stuck between the tissues and create bubbles that can get lodged anywhere in the body. This is what explains why the signs and symptoms of decompression syndrome can be rather varied and happen quickly or after a long period. These are usually manifest as pain in the articulations and muscles (bends) which happen on both sides of the body (usually on the upper or lower body). When this syndrome affects the brain (central nervous system), it can present itself as unusual fatigue, vision problems, loss of sensation, vertigo, loss of hearing, paralysis, etc. If large enough bubbles appear in the blood stream, a gaseous embolism can appear and lead to severe consequences.

Decompression accidents mostly happen when divers do not respect diving rules and tables which guide the maximum diving time (according to the accumulation of nitrogen in the body) and the ascension time, as well as the decompression stops.

Gas embolism

When diving, two main events can cause a gas embolism: ascending too quickly can lead to a pneumothorax characterized by the rupture of alveoli (addressed above) or a to a decompression syndrome. In both cases, bubbles of nitrogen or of other gasses can find their way into the bloodstream and block the supply of blood to an important organ. When blood move with difficulty or is incapable of circulating through the lungs or any other organ, this stops oxygenation and CO_2 elimination. The symptoms can thus be severe and appear quickly. The particularity of pulmonary embolism associated

with underwater diving is that it happens suddenly during the ascent, or until a few minutes after exiting the water and can be characterized by a brutal loss of consciousness or varying symptoms depending on the affected organs. A rapid treatment of oxygen is thus recommended.

GAS TOXICITY

Usually, toxicity means that a substance is in high enough quantity that it causes dysfunctions in the body. In the context of underwater diving, gas toxicity rather refers to a situation where pressure pushes an exceedingly large amount or concentration of gas into the organism, which will lead to certain symptoms during the dive.

Nitrogen narcosis (N_2)

Nitrogen narcosis usually starts when compressed air is breathed at a depth of about 30 meters (98 feet). This causes similar symptoms to the state of inebriation caused by alcohol; hence why is it often called rapture of the deep. A diver intoxicated by nitrogen can see their personality, their behaviour, their judgement, their intellectual or neuromuscular (reflex) performance altered. The apparition of these symptoms feels euphoric, but insidious – the diver could have difficulty realizing they are affected. This decrease in judgement has in fact lead to the drowning of many divers. Below 90 meters (295 feet), a depth forbidden in sports diving, the concentration of nitrogen in the organism is such that it can lead to hallucinations and loss of consciousness. It is thus primordial to know yourself very well and to watch for any strange behaviour that could affect your diving partner.

Oxygen poisoning (O_2)

In sports diving, oxygen poisoning is rarer since is usually happens on average at a depths of 57 meters (187 feet) when using compressed air. This phenomenon can however happen at higher depth when diving using nitrox, a mix of oxygen enriched with nitrogen. Since this mix has a higher concentration of oxygen than air, it has a higher risk of oxygen poisoning than air. Thankfully, to dive with nitrox, you must undergo a specific training. Moreover, divers that use nitrox can be easily recognized thanks to the green and yellow label on their diving bottles.

Oxygen poisoning can lead to symptoms such as sensitivity loss, convulsions, vertigo, nausea, vomiting, field of view reduction, loss of consciousness, and respiratory arrest, which can lead to drowning. These symptoms would be caused by vasodilatation in the brain provoked by the effect of the formation of oxygen free radicals. The only thing to do is to ascend back to the surface. Breathing ambient air (normal, not enriched) should be enough to treat the symptoms. Then, provide first aid depending on the victim's symptoms.

Carbon dioxide poisoning (CO_2)

In underwater diving, the main cause of carbon dioxide poisoning (CO_2) is hypoventilation, in other words a slow or weak breathing that doesn't allow CO_2 to be properly exhaled. This hypoventilation can be caused by a diving suit that is too tight, overworking, deep water diving, or a low respiratory reflex (can be caused by drugs, alcohol, certain medication, etc.). A malfunctioning pressure regulator (the device through which the diver breathes) causing a contamination of the air by the expired gasses can also be the source of the CO_2 intoxication. Since CO_2 is a waste product of the human body and is the main responsible for the triggering of the breathing process, this intoxication can lead to symptoms like shortness of breath, and somnolence, and in more severe cases, nausea, vomiting, headaches, confusion, quick breaths, hot flashes, convulsions, and loss of consciousness. Similarly to oxygen poisoning, CO_2 poisoning can generally be treated by ascending back to the surface and by treating the cause, if possible – for example, by removing the tight diving suit. Providing oxygen can also be beneficial in the case of CO_2 intoxication.

Carbon monoxide poisoning (CO)

Carbon monoxide poisoning occurs when the compressed air inhaled by the diver has been contaminated when the bottle was refilled. Since CO binds to hemoglobin instead of oxygen, this leads to symptoms of hypoxia. The signs and symptoms felt are variable; they can manifest as nausea, vomiting, headaches, weakness, convulsion, loss of consciousness and can even lead to death. The main treatment is administration of oxygen. CO being odorless and colorless, it is impossible for the diver to realize that their air is contaminated. This is why it is essential to have the bottles refilled at approved and recognized shops and to be extremely vigilant when practicing underwater diving when travelling. If, in that context, the bottles are provided on location, it is recommended to at least inspect the refilling installations and, if your budget allows it, to buy a gas analyzer.

IN CONCLUSION

Certain of the barotraumas presented here unlikely to occur outside of underwater diving. However, whether you practice this sport or not, you might be called to intervene as lifeguard for a diving accident. The best way to treat these barotraumas is through prevention, teaching, vigilance and recognition of signs and symptoms. In case of doubt about barotrauma, quickly contact emergency medical services or an emergency intervention center for diving accidents.

In case of discrepancy between the original and the translation, the original version in French will prevail.