Eye Surgery Using Intra-Operative Gas and its Suitability for Use in Scuba Diving

One of the most difficult challenges in scuba diving is the prevention of accidents linked to the presence of gas in the human body. In fact, while the liquids in our body are practically impossible to compress, gases respond to variations in tissue pressure with variations in the volume occupied by the gas itself. With an increase in tissue pressure, the gases drop in volume and tend to dissolve into organic liquids.

With the decrease of tissue pressure however, the gases increase in volume and tend to pass from a liquid state to a decompression, forming bubbles. The latter is the cause of so-called "decompression sickness." In normal conditions, where do we usually find gases in our body? As all scuba divers know, gases are found in the lungs, in the airways, in the middle part of the ear, in the paranasal sinuses, in the intestine etc.

However, there are some unusual circumstances in which a gas is present in parts of the body where it should not normally be. Excluding some unusual pathological conditions, the most common cause of this unusual presence of gas is iatrogenic, that is to say, induced by medical procedures.

Gases are also used by doctors for diagnostic and therapeutic purposes. For diagnostic purposes, they are sometimes used in radiology. For example, in examining the colon. For therapeutic purposes, gases are sometimes used during surgical procedures. For example, in certain phases of abdominal surgery, gynaecology and opthalmology. In these cases, the presence of gas in the post-operation period can constitute a contraindication in scuba diving.

In this article, we will look at the use of gas in eye operations, in particular in vitreo-retinal surgical procedures, and how this use can cause patients to reduce the amount of scuba diving they do following the operation. To make this easier to understand for all readers, we will avoid using mathematical formulae and we will explain physics concepts, the meanings of which can sometimes be difficult to grasp.

Background

The first observations of a gas bubble in an animal’s eye date back to 1607. Robert Boyle built a hyperbaric chamber and put different animals into it. A viper was subject to decompression with his machine, and the presence of a gas bubble in its eye was observed. However, he was unable to explain exactly how it was formed. In reality this can be considered the first example of laboratory engineered decompression sickness in the history of medicine.

However, the use of gas in eye surgery dates back to the beginning of the last century. The first attempt to use intravitreal gas in treating retinal detachment dates back to 1909. The gas used was air. In the second half of the last century, eye surgeons started using air to assist in scleral buckling surgical procedures for retinal detachment. Subsequently, long lasting pure gases and mixtures of gas were used, and they are still in use now, in operations for vitreo-retinal conditions, in particular in pneumatic retinopexy and vitrectomy operations.

The use of gas in eye surgery nowadays

In operating the anterior segment of the eye, in particular he cataract and glaucoma, the gas used is actually only air. The use of gas in this type of surgery is quite rare nowadays, as some substances with visco-elastic properties have, at least in more modern surgical practice, replaced the use of air. The

function of gas in these cases is to create space and a means of separating the endo-ocular structures which the surgeon has to operate on.
Given that the quantity of air used in the anterior chamber is very small, the gas is reabsorbed within one or two days and therefore does not cause problems for patients who then decide to scuba dive after the operation wound has healed.

However, it must be noted that, even if there is no more gas in the eye, it is recommended to wait at least 2 months after the operation before diving again, to avoid infections or knocking the operation wound.

In operating the posterior segment of the eye

Long lasting gas inside the eye can cause serious problems for those patients who are too quick in wanting to get back to scuba diving. These gases are used in vitreo-retinal surgery, in particular in surgery for retinal detachment or macular disease. In these cases the function of the gas is not to ''make space,'' or to help visualise endo-ocular structures (which, on the contrary, makes them more difficult to identify), but that of tamponade.
Tamponade means the force of the gas pressing against the retina to facilitate its re-positioning into its natural position when the retina is detached. Retinal detachment is a condition in which the retina is separated from the wall of the eye to which it is normally attached. By means of comparison, in order to understand this better, let's imagine the eye is a room.

The room's interior is covered with wallpaper. A tear in wallpaper is the most fitting analogy for retinal breaks. If the wallpaper is torn, humidity can get through it and unstick it all. The causes of retinal breaks can be found in the posterior detachment of the vitreous, a substantially physiological condition which most people usually experience once past a certain age.

We shall not go into too much detail about this complex argument, but it must be said that this condition can, in some cases, lead to the retina being torn, provoking retinal breaks with varying degrees of severity. The majority of retinal breaks do not cause retinal detachment. However, many of these breaks can be given laser treatment, when the eye surgeon decides that they are dangerous and potential precursors for retinal detachment (Figures 1 and 2).

Some other retinal conditions , predisposing to retinal breaks can also be treated with laser. When the break develops into retinal detachment, between the retina and the wall of the eye, a layer of liquid is formed which prevents normal metabolic exchanges between the retina and the choroid layer, rich in blood vessels, which usually provides nourishment for retinal nerve cells.

Detachment, if left untreated, tends to extend across the whole retina, causing blindness. The aim of retinal detachment surgery is to close the retinal break, and allow the liquid under the retina to be re-absorbed. Closing the tear in the retina can be obtained with socalled epischeral surgery, in which an indenting element is positioned (generally made of silicon sponge or silicone rubber) on the external wall of the eye. In this case, the wall of the bulb is pushed against the retina from the outside, obtaining functional closure of the break.

However, closure of the retinal break can be obtained from the interior with a vitrectomy operation, in which they remove the vitreous with appropriate instruments, and a tamponade element is introduced (in the form of gas or liquid) which pushes the retina against the wall of the eye, from the inside, closing the break and allowing re-absorption of the liquid under the retina.

The progress of surgical technique in retinal detachment surgery has led to an increase in the use of gas in operations. Over the last few years, in a few select cases, surgeons have started using a mini-invasive procedure called pneumatic retinopexy which consists of an injection of gas into the eye followed by laser treatment of the retinal break, (the cause of retinal detachment).

In this way, retinal detachment is cured without the use of surgical instruments, but with the injection of gas which pushes the retina against the wall of the eye, re-attaching it. The bubble of gas introduced in this way tends to ‘’float,’’ that is to say fixes into place, in the higher part of the eye (see figure 2).

If the patient is lying down, the bubble pushes against the crystalline lens. If the patient is standing or sat upright, the gas bubble compresses the retina in the upper part of the eye. It is therefore necessary, in the first 24-36 hours following the operation, that the patient remains in a position decided by the surgeon, so that the gas bubble compresses the exact area of the retinal break from which retinal detachment comes. In general, within a month, the gas put into the eye is completely reabsorbed by the ocular tissues.

The length of time gas remains in the eye after the operation

Different types of gas remain for different amounts of time in the eye. After the injection into the eye, initially the volume of air does not change, while other gases such as Sulfur hexafluoride and perfluorocarbon gases tend to spread out and increase in volume in the first days following the operation, to then gradually be completely re-absorbed.
When the initial expansion is not required, the eye surgeon insert a mixture of gases with air into the eye, rather than pure gases, especially calculated in order to avoid causing an initial expansion of the eye.

Whether it be with pure gases or with gas mixtures, after a few days, reabsorption of gases begins in the tissues, with a decrease in the size of the intra-ocular bubble. The total time required by the tissues to reabsorb the bubble completely varies according to the type of gas. Sometimes tamponade of the retina is needed for 3 or 4 weeks. In general however, after little over a month, all types of gases are re-absorbed into the ocular tissues.

Intraocular pressure

Intraocular pressure is usually measured by an eye specialist with an instrument known as a tonometer. Intra ocular pressure (which it would be better to call relative intraocular pressure) comes from the difference between the absolute pressure inside the eye and absolute air pressure in the doctor’s office.
Pressure between 10 and 20mm of mercury is considered normal. This therefore means that the absolute pressure inside the eye is normally from 10 to 20mm Hg higher than that of absolute atmospheric air.

When gas is inserted into the eye in an operating theatre, after an initial increase in intra ocular pressure which lasts a few hours, the pressure stabilizes and returns to 10-20 Hg, as there is a slow exchange of gas between the bubble and the ocular tissues. As we are about to see, when a gas bubble is present in the eye, rapid changes in external pressure, (for example when diving or flying) set off variations in intra ocular pressure.

In fact, the intraocular gas bubble cannot leak out from the eye or be absorbed by tissues quick enough. As we said before, intra ocular pressure comes from the difference between absolute internal pressure and that of the exterior.
Therefore, in the presence of an intraocular gas bubble, if external pressure decreases, when flying for example, intra ocular pressure increases.

Again, when in presence of an intra ocular gas bubble, if the external pressure increases as it does in scuba diving, intra ocular pressure decreases. An increase in intra ocular pressure is dangerous for the damage that the expanding gas bubbles can cause to the intra ocular structure, increasing in volume. A decrease in intra ocular pressure is also dangerous for the compression of periocular tissues on the ocular bulb (which incidently, becomes floppy).

Intraocular gas and scuba diving

Now let's consider diving with unprotected eyes or with contact lenses, but without a diving mask. During descent underwater, the external pressure of the water passes through the ocular tissues. In this case, the external pressure of the water corresponds to that of the internal pressure in all parts of the eye. Intra ocular pressure (relative) as defined previously, tends to remain stable, but the absolute intraocular pressure increases compared to that present at the water's surface.

If a gas bubble has been introduced into the eye before the dive, the hyperbaric environment causes a decrease in its volume, which then leads to the collapse of the ocular wall, with potential damage to the endoocular structures. In reality, scuba divers usually wear a mask full of air. Therefore, calculating pressure is complicated by the presence of the air bubble in the mask. The interface between air and the face of the scuba diver is the critical point of the pressure gradient.

If the pressure in the airspace in front of the diver's eyes is not increased with the "mask pressure compensation manouver" (blowing air into the mask trough the nose), the air pressure in the mask becomes inferior to that outside the water.The result is ''suction"; the so-called "Mask squeeze.'' Tissue of the eye and face with a pressure superior to that inside the mask, are pushed to enter into the mask itself.

This phenomenon is known as the "mask squeeze'' in the scuba diving world. However, the result is a deformation and displacement of tissues in the eye towards the inside of the mask, an oedema of the tissues and sometimes hemorages. In fact, with descent underwater the difference between the pressure in the blood vessels and the interstitial tissues and the pressure of the air in the mask increases considerably, compared to the situation at the water surface.

Therefore, scuba diving incidents in which pressure in the mask is not compressed properly cause damage of the ocular area, with pain and subconjunctival hemorrhages. Fortunately, damage and hemorrhages inside the eye are uncommon. For an underwater scubadiver who has a gas bubble in the eye, if the pressure in the mask is the same as that of the external pressure of the water, the endoocular gas bubble, as described in the case of the unprotected eye underwater, reduces in volume and the eye can collapse.

Variations in pressure inside the mask, as with the external pressure of the water, can provoke variations in the volume of gas inside the eye. In the case of the ''mask squeeze,'' pressure in the mask inferior to that of the water (and therefore to that of the eye) can cause an increase in the volume of the intraocular gas bubble.

This can end up stretching the bulb, and a displacement forward of the crystalline lens and other ocular structures. The opposite is not possible,as the pressure in the mask, when superior to that of the water (and therefore of the eye) leads to the leak of air from the mask and the re-balancing of pressure in the mask which becomes equal to that of the outside.

In light of these physical and physiological considerations, it is recommended not to dive so long as gas remains in the eye after a surgical procedure. This recommendation also features on the instruction sheet of the producers of gas bottles used during surgery.

Intraocular gas and flying

Scuba divers often travel long distances to reach remote diving locations. Flying is dangerous for the eye if intraocular gas is present. Air pressure in the cabin of aeroplanes is generally the same as atmosphereic pressure in the mountains at about 1500 metres above sea level.

Absolute intra ocular pressure, as defined previously, tends to remain stable, but relative pressure (that is, compared with the outside), increases compared to that of the airport you departed from (obviously if the airport is under 1500 m above sea level).
Aboard an aircraft, this leads to expansion of the gas bubble inserted into the eye at room pressure (in an operating theatre) at atmospheric pressure generally closer to that of sea level, and therefore higher. The gas bubble expanded in this way, can lead to intraocular damage displacing and compressing intraocular tissues. Therefore, air travel should be avoided when one has a gas bubble in the eye.

Suitability for scuba diving

Laser treatment for retinal breaks.
Divers often ask for more information about this procedure. In some cases, it is associated with the insertion of gas (pneumatic retinopexy) which will be discussed further later in this article. In most cases however, it is carried out without inserting gas into the eye.
This is prophylactic treatment of retinal breaks, which is carried out to prevent the occurrence of retinal detachment. In some cases, a small localized detachment can be bordered with laser treatment, which blocks its extension to other parts of the retina, therefore avoiding further damage.

In some types of surgical procedues for retinal detachment, laser treatment is carried out after the retina has been re-attached with episcleral or endoocular (vitrectomy or pneumatic retinopexy) surgical techniques. All laser treatment cases consist of provoking microscopic burning of the retina which, when scarring, block the infiltration of liquid from the vitreous towards the tissues under the retina.
Controindications in scuba diving do not exist after laser treatment for retinal breaks or retinal degeneration without retinal detachment if gas has not been inserted into the eye. Obviously, one must avoid eye trauma or strenuous activity for about 3 weeks after the procedure, until the retinal scar heals. ’’Mask squeeze’’ must also be avoided during diving.

Cataract operations, pneumatic retinopexy, vitrectomy, episcleral surgery for retinal detachment.
As a precautionary measure, It is advised to refrain from diving and airtravel for about 2 months after these surgical procedures. This recovery time allows for the gas used during the operation to be re-absorbed into the ocular tissue. Scuba diving and air travel can be allowed again after the all-clear from an eye specialist even earlier, if gas is not inserted into the eye during surgery or, if gas has been used,when the eye specialist does a check up and finds that intraocular gas is no longer present and the operation wound has completely healed.

Fig. 1	Fig. 2	Fig. 3

Acknowledgements

Special thanks go to Diego Dick,Giorgio Orlandelli, Doctor Paolo Perosa from the Cala Lunga diving center in La Maddalena, for their help in compiling this article.