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diving medicine

the facts°

PULMONARY BAROTRAUMA - NORMAL LUNGS - I RECENTLY RECEIVED THE FOLLOWING QUERY AND WAS APPALLED AT THE LACK OF UNDERSTANDING EXHIBITED BY THE DIVER. THEREFORE, IN THIS COLUMN I WILL REVIEW A BASIC BUT CRITICALLY IMPORTANT TOPIC, PULMONARY BAROTRAUMA.

I AM A MED STUDENT AND I WORK AS A DIVEMASTER FOR FUN. TODAY WAS A PERFECTLY NORMAL 2 TANK DIVE BUT AFTER I CAME UP FROM OUR SECOND DIVE I WAS TALKING LIKE DAFFY DUCK. I HAD NO OTHER SYMPTOMS. IT HAS BEEN ABOUT TEN HRS NOW AND MY CHEST AND THROAT ARE SORE UPON INSPIRATION AND I HAVE A TINY BIT OF CREPITUS ON THE ANTERIOR PORTION OF MY NECK BUT NO NEUROLOGICAL CHANGES AT ALL. THE ONLY THING I CAN THINK MIGHT HAVE CAUSED THIS WAS THAT I HAD TO CHASE AFTER A DIVER THAT ASCENDED UNCONTROLLED ALL THE WAY TO THE SURFACE AND PULL HIM BACK DOWN, SO I GUESS I STRAINED TOO HARD DOING THAT. HOW LONG WILL THIS LAST AND DO I NEED TO DO ANYTHING ELSE BESIDES REST?

Every diver knows that as pressure is decreased the volume of a gas will increase (Boyle's Law, P1V1=P2V2). The lungs are very sensitive to this problem as they contain large volumes of gas, and that gas is at the same pressure as the surrounding water. Therefore, as the diver ascends towards the surface, the gas in their lungs will expand. If the expanding gas can not escape through the mouth, it will rupture the lungs and go elsewhere. This is a shallow water problem. Each 10m of water depth exerts a pressure equal to the pressure of the atmosphere (ata) at sea level.

If a diver ascends from 30m to 10m, the pressure changes from 4 ata (3 due to the water and one due to the atmosphere) to 2 ata and the volume of the gas in their lungs will double. When the diver ascends from 10m to the surface the pressure changes from 2 ata to 1 ata and the volume of the gas in their lungs will double again. It should be clear from these basic facts of physics that for each meter you ascend the change in the volume of the gas in your lungs will be greater the closer you are to the surface.

To really understand this problem, you have to have a basic understanding of the anatomy of the lungs. As you take a breath, air travels through your mouth, throat, and through the trachea. The trachea is a single tube that divides into two smaller tubes that go to your left and right lungs. These tubes divide into smaller and smaller tubes and eventually they divide into tiny tubes that have a wall only one cell thick and they end in little air sacks called alveoli.

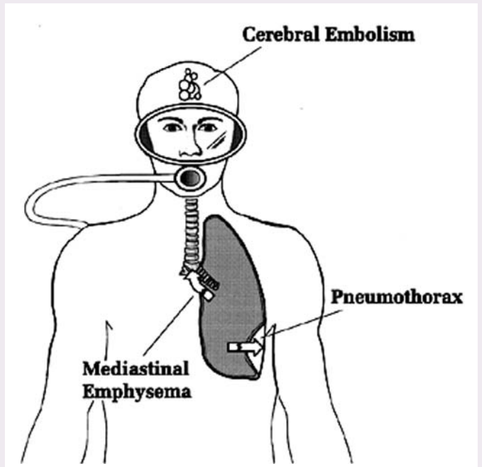
Normal lungs have several million alveoli and the total surface area of the walls of the alveoli are approximately the same as the area of a tennis court!

The walls of the alveoli are composed of only one very thin cell that lies against another very thin cell that forms the wall of the capillaries. It is reasonable to think of each alveolus as a small balloon almost completely surrounded by a thin layer of blood in the capillaries, with a few small areas taken up by airways, veins, arteries, etc.

Each lung is coated by a very tough membrane called the visceral pleura. A lung resembles a very soft sponge that shrinks and expands as we breathe.
If a diver takes a breath from their regulator and ascends holding their breath, the gas in their lungs will start to expand. No problem will develop until the lungs have expanded to their maximum volume.

As the diver continues to ascend the pressure in the lungs will rise as the gas in the lungs tries to expand but can not do so because the lungs can not expand any more.
The lungs are composed of extremely weak tissues and a pressure of only 50 to 90 mm Hg is sufficient to tear them. This pressure is caused by an ascent through the water of 0.7 to 1.2 meters. Therefore, after your lungs have expanded to their maximum volume, ascending only ONE more meter will be sufficient to tear them!

There is at least one documented case of diver who took a breath from a regular in a swimming pool, held their breath, ascended to the surface, and died. The pool was less than two meters deep!
When the alveoli rupture, the gas enters the circulation approximately 80% of the time. This happens because the alveoli are almost completely surrounded by blood. This gas is carried with the blood to the left side of the heart and pumped out to the body. The first major branches off the aorta after it leaves the heart (carotids) supply 80% of the blood to the brain.



Therefore, in arterial gas embolism much of the gas goes to the brain.
Occasionally the alveoli rupture and the gas does not go into the circulation but into the potential spaces in the lung tissue around the blood vessels, bronchi, etc. From here it moves up the lungs towards the center of the chest and ends up in the mediastinum, around the heart. This is called mediastinal emphysema (air in the mediastinum). Sometimes this gas continues to move and follows the large blood vessels into the neck where the gas ends up under the skin. This is called subcutaneous emphysema (air under the skin). These two events happen in about 20% of cases of pulmonary barotrauma.
Very rarely, less than 1% of the time, the alveoli that rupture are on the surface of the lung and somehow the tough membrane surrounding the lung also ruptures and the gas ends up in the potential space outside the lung causing a pneumothorax. This is so unlikely in a diver with normal lungs that I will not discuss it any further in this column.

Arterial Gas Embolism
When bubbles of gas move through the arteries that supply the brain, they eventually become trapped when the vessel gets too small, and the flow of blood becomes stopped to that area of the brain. The signs and symptoms of this problem depend on the function of the area of the brain that is now not getting oxygen. In arterial gas embolism, many small bubbles are scattered throughout the brain so the diver can present with a wide variety of very confusing signs and symptoms.
Virtually any neurological sign or symptom is possible including loss of consciousness, confusion, aphasia (inability to speak), visual disturbances, paresthesia (numbness), vertigo, convulsions, hemiplegia (paralysis on one side of the body), focal weakness, focal hyperesthesia (increased sensitivity), headache, etc. The bubbles can also block the arteries that supply the heart muscle and therefore you can also get chest pain and cardiac arrest (heart attack).
The bubbles are formed during ascent and block the blood flow to the brain almost immediately. The brain can only function for a few minutes without blood flow (and therefore, oxygen), and therefore the signs and symptoms of AGE occur almost immediately upon surfacing. If it has been more than 10 minutes since the diver surfaced and they develop a neurological sign or symptom it is unlikely to be AGE (think decompression sickness).
If the diver who develops AGE has only done a very short and shallow dive, the brain tissue will contain very little excess inert gas. The bubbles will stop the circulation to areas of the brain for a while but they will clear fairly quickly and the signs and symptoms will improve or they may completely resolve.
However, if the diver who develops AGE has done a long and deep dive, the brain tissue will contain a large quantity of excess inert gas. In this circumstance, as soon as the bubbles stop moving in the circulation, gas will rapidly move from the brain tissue into the bubbles, causing the bubbles to grow even larger. The only direction the bubbles can grow is backwards inside the arteries. The end result in animal research is that a few small bubbles turn into a complete air cast of the circulation of the brain in less than 30 seconds. If nothing is done, the animal is dead in a few minutes.

There are many human stories that fit this description. Divers who have done moderate dives will fall in between these extremes.
Obviously, AGE is a life threatening problem. Treatment is with 100% oxygen and transportation to the nearest recompression chamber as quickly as possible. An unconscious diver should be moved while lying on their side so that if they vomit they will not aspirate. With very rapid treatment in a chamber, results are quite good. However, AGE is a relatively common cause of death in divers.

Mediastinal/Subcutaneous Emphysema
The signs and symptoms of mediastinal emphysema include substernal pain that is worse on inspiration, coughing, and swallowing. There may be x-ray evidence of mediastinal widening or frank (obvious) air but respiratory symptoms are present only in severe >

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cases. It is usually accompanied by subcutaneous emphysema. The signs and symptoms of subcutaneous emphysema include swelling of the neck, crepitus (air bubbles) under the skin of the neck, sore throat, brassy or monotone voice, and dysphagia (painful swallowing). Syncope (fainting), shock, and unconsciousness are possible but rarely encountered. The onset of symptoms may be delayed and brought on by coughing or straining after surfacing with damaged lungs. Air may be seen under the skin on soft tissue x-rays of the neck.

The investigation and treatment of both mediastinal and subcutaneous emphysema include chest x-rays, the standard supportive measures of bed rest, oxygen, observation, and careful neurological assessment to rule out AGE. It is vitally important to remember that mediastinal/subcutaneous emphysema can and often do co-exist with arterial gas embolism, however, in isolation they do not need to be treated with recompression.

It is very important to reduce the likelihood of pulmonary barotrauma as much as possible. You should always ensure that you have the required training and experience for the planned dive, and that you are fully prepared for the dive so that the possibility of panic is reduced as low as possible. This entire discussion has assumed that the diver has normal lungs. Many cases of pulmonary barotrauma are the result of a diver with abnormal lungs who did not panic, did not hold their breath, ascended normally and still ruptured their lungs! The diving medical you had before you started diving, if done correctly, should have identified all those individuals with pre-existing lung problems that would make them unfit diving. However, any diver who develops a lung problem should seek the advice of a knowledgeable diving physician before they return to diving. This includes a cough and any difficulties with breathing. We will look at these types of problems in the next column.

So what happened to the divemaster who contacted me? It should be fairly obvious by now that he almost certainly held his breath while he was chasing the other diver to the surface, suffered pulmonary barotrauma in which the gas tracked back to his mediastinum and up under the skin of his neck. He does not seem to have suffered any arterial gas embolism. As long as he does not develop any neurological signs or symptoms he does not need any specific treatment. The critical question is how long he has to wait before returning to diving. I will deal with this question in detail in the next column but the best short answer is that he should NEVER return to diving.

THE WINNER

OF THE FRONTA TORCH
BEST SUMMER DIGITAL SHOT IS DAVID LAND

From Christies Beach, South Australia

"This photograph I took recently at the famous but remote Rapid Bay jetty. I liked the photo as the two Old Wives were getting a bit frisky and I managed to capture them in a flirtatious vertical descent, capturing the jetty legs in the process".

David said he would donate the torch for use in their programs at his club "to improve skills of our novice/junior divers"

Congratulations David!