EQUIPMENT BAROTRAUMA

by Dr. David Sawatzky

Barotrauma is simply tissue damage due to pressure changes (trauma due to baro) and it's the most common cause of medical problems in divers. Equipment barotrauma can occur in three situations.

Sucking Face

This most common form happens with the air trapped against your face by the dive mask. If you don't add air to it during descent water pressure becomes much greater and, increasingly, forces your face into the mask. If you don't equalize the pressure by blowing air in through your nose the effect will feel rather like having the business end of a big vacuum cleaner applied to the front of your head. Blood vessels in the sclera (white part) of your eyes will burst and bleed, blood vessels in your skin will leak fluid into the tissues (swelling or edema) and they may rupture, bleeding into the tissues (bruising or hemorrhage). All this can be dramatic to look at but, thankfully, it's not all that serious. The tissues heal without problem. In the event of such a face squeeze, a critical check should be to ensure that your vision is clear or at least as good as it was before the dive. If it's any consolation, facemask squeeze is common among new divers as they navigate through their basic open water dive course.

Science Class

Understanding gas laws, some basic anatomy and physiology allow a more detailed understanding of this particular phenomenon.

Matter exists as a gas - which is mostly empty space - when its molecules are flying around freely colliding only occasionally with other molecules. Temperature affects molecule speed; more heat, more speed. When gas molecules hit the surface of a container they bounce off creating pressure. The amount of pressure is related to the number, weight and speed of the molecules. Therefore, at a fixed temperature gases with heavier molecules will be moving at a slower speed than gases with lighter molecules. This is known as the kinetic theory of gases and with it in mind gas laws are easier to understand.

Boyle And His Law

Boyle's Law states that, 'at a constant temperature, the pressure of a gas is inversely proportional to the volume'. This can be expressed as P1xV1 = P2xV2 where P1 equals the starting pressure and V1 is the starting volume. The final pressure and volume are represented by P2 and V2. The 'at a constant temperature' part of Boyle's Law means that the speed of the gas molecules does not change with a change in pressure or volume. Compressing five liters of gas to 2.5 liters simply means more molecules in a smaller space so we get more collisions or greater pressure.

Getting Hot

The effect of temperature on volume and pressure is straightforward. As I said earlier, temperature speeds things up. If volume is constant, pressure rises with temperature: P1/T1 = P2/T2 where T1 equals the initial temperature and T2 equals the final temperature. Conversely, if the pressure is held constant, the volume will rise as the temperature rises: V1/T1 = V2/Tx. To keep the pressure constant, a smaller number of molecules must collide with the sides of the container so the density of the gas must decrease as the temperature rises. The only way this can happen is for the volume of the gas to increase.

Meet Kelvin And Rankin

Temperature starts at absolute zero where molecules have no motion of any kind. Therefore, temperature is expressed using a scale that starts at absolute zero. The Celsius scale starts at the freezing point of water - O°C - and absolute zero is - -272.13°C (rounded to -273°C). So, for temperature in Celsius, add 273 to the temperature before it's entered into the equation. This temperature scale is called Kelvin; water freezes at 272K. The Fahrenheit scale also starts at the freezing point of water - 0°F - but the units are smaller. Absolute zero is -459.72°F (rounded to -460°F), and so for temperature in Fahrenheit add 460 to the temperature before entering it into the equation. This temperature scale is called Rankin; water freezes at 460R. Putting these relationships together gives us the General Gas Law P1xV1 / T1 = P2xV2 / T2.

Tanks For The Explanation

In diving the effect of temperature on volume or pressure relates to the effect of temperature on dive tank pressure. Practically speaking, the volume is constant. Therefore, the relationship is P1/T1 = P2/T2. Compressing a gas increases temperature; fill a scuba tank and the gas heats the tank. If a tank is filled to its maximum working pressure and is hot, it follows that when the tank and gas cool, the pressure will drop. In the same way, if you read tank pressure on the surface on a warm day and then jump into cold water, the pressure in the tank will drop as the cylinder and its content cool to water temperature, even if you are not breathing from it. Finally, if a tank is filled slowly and/or it's kept cool in a water bath during the fill, you get what we call a 'good fill', meaning the tank is at working pressure at room temperature. If a tank is left in the sun or even worse, in the trunk of your car in the sun, the pressure in the tank will increase. As the pressure rises above the tanks working pressure the burst disk might rupture. The worst case, but very unlikely scenario, is that the tank explodes. Simply covering your tanks with a towel (preferably wet) is a simple and effective solution to this potential problem.

Nice Atmosphere!

The major concern with the General Gas Law and diving is in this area of pressure change on volume and it underscores the importance of Boyle's Law - P1xV1 - P2xV2. Pressure changes in diving are considerable. On the surface we're exposed to the pressure of the air, which at sea level is approximately 14.7 pounds per square inch (psi) or 101 kPa. To make the discussion (and the math) much easier, we usually call this pressure 'one atmosphere' (ata). Diving down, that 14.7 psi is added to the weight or pressure of the water above us. Because water is so much heavier than air we can add another 14.7 psi at just 33 feet (10m) of seawater versus the entire air atmosphere at sea level! So, at that depth the pressure is two atmospheres - one of air and one of water. Go another 33 feet (10m) to a depth of 66 feet (20m) and total pressure is three ata, and so on. Volume decreases with depth so that, for example, at 132 feet (40m) pressure is five times surface pressure and gas volume is five times smaller.

The reason pressure/ volume changes are a common problem in diving is that gas spaces often cannot change their volume with changes in pressure. If the volume of a gas space is not allowed to change as we change depth, a pressure difference will develop between the gas space and the surrounding water or tissue. This can be a problem when our equipment traps gas against our skin, and it can be a problem with gas trapped in our bodies. And that brings us back to equipment barotrauma.

Suit Squeeze

The second form it takes was very common in the earlier diving days of stiff canvas dry suits. On descent, gas inside the suit compressed, volume decreased, folding the garment's bulk around the diver. The rigid folds could not completely collapse so they trapped gas and as the outside pressure increased a pressure differential developed (as with the face mask) vacuuming the diver's flesh into the fold. This could be very painful and left a spider web of red lines on the skin. If the diver kept the suit inflated by adding gas, no problems developed. Today's dry suits are made of materials that are much more flexible than canvas so the folds usually collapse, eliminating the unpleasant vacuum effect. You can still see minor effects of this problem on people who, either in the tropics or during local summer weather, wear a dry suit with only a swimsuit underneath.

Game Over

The final version of equipment barotrauma can occur in surface supplied diving. In this situation the diver wears a helmet and gas is pumped down from the surface in a hose. If the pressure on the surface is lost (cut or disconnected hose, compressor failure, etc.) the diver is pushed up the hose with a force equal to the weight/pressure of the surrounding water. This has happened and, of course, causes instant death. The need to install a one-way valve at the hose/helmet interface eliminates the problem although poor maintenance can cause valves to stick open. For sport divers equipment barotrauma is avoided with basic understanding of pressure. I hope this review helps.

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