

A heart under pressure

Diving is a very relaxing but also physically demanding hobby and descending several meters underneath the water surface means exposing the body to the pressure of the great quantity of water above the diver. That is why divers are being taught exercises to help their body adapt to the pressure changes and to equalise the pressure in the middle ears with the ambient pressure underwater. These maneuvers start a chain of internal pressure changes, allowing your body to accustomise itself to the new environment. However, what happens if there is a small defect in your body, let's say in the heart, causing a disruption in the chain of your body's automatic adjustments? What could be the implications of a defect in the heart, so small that in normal circumstances it would pass by unnoticed, but when put under pressure in diving, may cause serious risks? I am talking about a Patent Foramen Ovale (PFO), a small opening in the interatrial wall/septum separating the two upper heart chambers and the health concerns it may create for a diver.

Scientific studies have shown that the Valsalva maneuver, performed by using your hand to block your nostrils and trying to exhale against a closed mouth and nose, sets a series of pressure changes in your body, in motion. The Valsalva maneuver starts by inhaling deeply, decreasing the pressure in the pleural cavity between the lungs (intrathoracic pressure). Subsequently, you exhale against the resistance of a tapped nose and mouth for several seconds. The strain of this maneuver causes a high intrathoracic pressure. The pressure in the thorax hardly allows the blood to flow into the heart during a time-lapse of some seconds. Finally, the release of the Valsalva maneuver leads to a fall in pressure in the thorax and the blood, that during the strain could not flow into the heart, is now pooled out into the right upper chamber. This rebound blood loading increases pressure in the right part of the heart in expense of the left and pushes against the wall dividing the two heart chambers, causing a leftward bulging of the interatrial wall. In case of a Patent Foramen Ovale, a trans-esophageal echocardiography showed that this pressure reversal from the left to the right chamber creates a marked opening of a PFO.

A PFO is a rather common phenomenon and many divers may have an opening in the atrial septum (the internal wall) without even knowing it. As the Valsalva maneuver is used in diving and other maneuvers to equalise may have a similar pressuring effect on the heart, DAN Europe realized the need to study if these maneuvers can cause the same internal pressure changes and have the same effect on a diver's PFO. DAN did a research study on sixteen experienced divers, 4 females and 12 males, age ranging between 22 and 39 years. The divers were asked to do the following maneuvers used in diving: Control, Gentle Valsalva, Forced Valsalva, Calibrated Valsalva, Cough, Knee Bend with Valsalva, Free-breathing Knee Bend, and Final Isometric Contraction. The researchers analysed the level of intrathoracic pressure caused by the exercises and the measured values were compared to the original pressure value. In this way, it could be calculated whether a maneuver caused a rise or fall in intrathoracic pressure. The gathered data of each maneuver were compared to one another the results of the study showed that the Valsalva maneuver used in diving and other usual maneuvers for equalisation, only cause a slight increase in intrathoracic pressure. It is unlikely that these small changes in pressure cause a major blood shift through a PFO. On the contrary, if a Valsalva maneuver is forced, meaning using the abdominal muscles, DAN researchers found that it caused pressure changes in the right part of the heart large enough to allow significant blood flow through the PFO.

As said earlier, such an opening in the heart atrial septum is not uncommon and people do straining

exercises, that causes blood to flow through the opening from the right upper chamber into the left, on the daily. So how come a PFO only becomes truly dangerous when diving? The reason is because it allows bubbles to travel! The blood containing these bubbles, which were created during the dive, passes through the right upper heart chamber and the blood will normally be sent to the lungs, where the bubbles are captured and the nitrogen is exhaled. Now, when the blood shifts through the PFO from the right upper chamber to the left upper chamber, the nitrogen bubbles can flow from the right part of the heart to the left part. The left upper chamber will send the blood with the bubbles back into circulation and these bubbles will thus remain longer in the blood flow, creating a risk for nitrogen gas emboli. DAN encountered cases where older and experienced divers, who never had any problems while diving, suffered unexplained Decompression Sickness after a dive, even though they had followed all diving safety rules. In many of these cases, on a trans-esophageal echocardiography, a large PFO could be detected.

DAN's research study showed that the "forced" Valsalva Maneuver caused a rise in intrathoracic pressure high enough for the rebound blood in the right chamber to cause an opening of a PFO. A diver should therefore always be taught to avoid forceful Valsalva maneuvers. The study pointed out that other, less straining equalisation maneuvers do not lead to significant changes in intrathoracic pressure and do not create a risk for divers with PFO. Special attention should be paid during dive training to rely on these maneuvers, that only use jaw and throat and not the abdominal muscles, for equalisation. As a direct result from this study, the advice from DAN researchers to divers with a PFO is to never perform maneuvers that increase the intrathoracic pressure while ascending. It is also recommended not to do abdominal straining exercises, such as climbing the ladder with the gear still on or inflating orally the BCD on surface, or strenuous leg or arm exercises after a dive. Silent bubbles can be present in the veins until two hours after a dive and these activities, using the abdominal muscles, will put pressure on the heart, opening the PFO and allowing the blood to flow in the wrong direction, carrying travelling bubbles around. So after a dive, just relax and don't put your heart under pressure!