It is estimated that approximately seven million divers are active worldwide and 500,000 new divers are training annually. Moreover, professional divers actively carry out diving operations for the purposes of commercial, scientific or military diving. The underwater environment is unique and any exposure to it presents a number of stresses to the human system. The human body makes physiological responses to adapt to the environmental changes. Moreover, diving equipment, training, knowledge and skills also minimize stresses and increase safety while diving. In rare cases, certain hazards can occur to divers, such as nitrogen narcosis, oxygen toxicity and decompression illness (DCI).

The persistence of a fetal heart characteristic
The right side of the human heart contains venous blood with a low oxygen content, and the left side contains arterial blood, rich in oxygen and nutrients. In the unborn foetus, the lungs are not fully formed.

In order for the foetus to constantly receive oxygenated blood, there is an opening in the wall between the two atria, the foramen ovale. The foramen ovale (Latin for oval hole) is a flap valve in the septum (the wall of the heart) separating the right and left atria. It is a one-way valve, allowing direct blood flow from the right upper chamber of the heart (right atrium) to the left upper chamber (left atrium). The foramen ovale allows oxygenated blood coming from the mother via the placenta to the right atrium and then directly to the left atrium of the foetus. The left atrium pumps the blood into the foetus circulation, providing the oxygen and nutrients required for growth and healthy development.

At birth, when the baby begins to breathe, a flap valve closes over the opening in the atrial septum and starts sealing the opening. This fusion is complete by the age of two in about 75 percent of the individuals, while in the other 25 percent, the foramen ovale is not fully closed. The reasons the PFOs fail to close are unknown and the size of PFO in individuals varies, ranging from one to 19mm.2,8 The persisting, “patent”, foramen ovale allows blood from the right atrium (blood from the veins) to move directly into the left atrium (blood from the lungs) and from there into the arterial circulation. Normally, this cardiac defect will cause no serious symptoms to those who have it because the pressure on the left atrium is always bigger than the right, which tends to keep the valve closed.

However, this differential pressure is reversed while performing a Valsalva manoeuvre or while engaging in strenuous activities, e.g., lifting heavy dive gear and climbing into the boat.9 Hence, PFO poses a concern for divers as free inert gas forming in the body during decompression or after surfacing, bypass the vital lung filter and enter into the arterial circulation.

PFO and decompression illness
Decompression illness is caused by bubbles in blood or tissue that are formed as a result of reduction in ambient pressure (decompression). The term includes both arterial gas embolism (AGE), in which alveolar gas or venous gas emboli (via cardiac shunts like patent foramen ovale or pulmonary vessels) are introduced into the arterial circulation, and decompression sickness (DCS), which is caused by...
in-situ bubble formation from dissolved inert gas. Small quantities of venous gas emboli are common in diving, although they are usually asymptomatic, “silent bubbles”, because most of the time they are effectively filtered by the pulmonary circulation. However, large numbers of venous gas emboli can cause DCI.\(^1\) (Fig. 1)

A patent foramen ovale is present in about 27 percent of the normal population, and theoretically, some venous gas emboli could enter the arterial circulation and even reach the central nervous system (CNS). It was first suggested in 1986 by Dr Wilmshurst and colleagues that a right-to-left cardiac shunt may be important for venous gas embolism (VGE) in scuba divers. They observed neurological decompression sickness in recreational scuba diver after a 15-minute dive to 38 metres, and attributed its cause to a right-to-left cardiac shunt.\(^4\)

Closing a PFO contains some risks and has a complication rate of around two to five percent, while the risk of a DCS event in recreational diving is much lower—about 0.02–0.05 percent.\(^5\) Closure should only be performed after serious discussion and evaluation of the risks and benefits of such an operation. According to Dr Peter Germonpré from the Centre for Hyperbaric Medicine of the Military Hospital in Brussels, a systematic screening of PFO is not recommended since PFO is so common and DCI is so rare. Testing for a PFO is useful only in instances where there have been several DCI incidents of a type known to be PFO-associated. In short, having patent foramen ovale is not considered an absolute contraindication to diving by dive physicians.

Conclusion

Patency of the foramen ovale is a risk factor for DCI and all divers should be aware of this. Dive training organizations should indicate the patent foramen ovale as a reason of caution. Dr Vann, Department of Anaesthesiology and Centre for Hyperbaric Medicine and Environmental Physiology, Duke University Medical Centre, points out that PFO is a common anomaly in the general population and many individuals that suffered from DCI did not have it. Therefore, there is not a causal link between patent foramen ovale and an individual case of decompression sickness.\(^3\) The primary cause of DCI is the inert gas bubbles, not the PFO. A study shows that a reduction of inert gas when diving, i.e. by performing shallower dives, non-decompression dives, avoiding repeat dives, and breathing oxygen-enriched mixtures (nitrox) under air profiles, helps to significantly reduce the risk of a decompression illness. The average DCI risk could be reduced by a factor of 10 in divers with a PFO and up to 40 times in divers without a PFO.\(^10\)

The editorial staff wish to thank Dr Neil Pollock of DAN for his assistance with this article.

REFERENCES

10. BOVE F. MORE ON PFO. HTTP://SCUBA.BLOGSPOT.DK/ [ACCESSED 19/1/2015]
11. RIGHT-TO-LEFT SHUNT AND PFO. HTTP://WWW.DIVEDEDICATED.COM/DIVING-ACCIDENTS/RIGHT-TO-LEFT-SHUNT-PFO. [ACCESSED 22/1/2015]