PFOs (shunt/by-pass) **and the Diver**

Introduction

The US Space Agency NASA nearly lost a mission because of a PFO, and there have been five NASA cases of decompression illness in space! That's right, not UFOs, PFOs. Many doctors have yet to make the connection between PFOs and people under pressure - and that means not only astronauts but divers.

PFO stands for Patent Foramen Ovale. Translated from Latin, patent = open; foramen = aperture and ovale = oval, so a PFO is an oval hole, with a flap, between the right and left top chambers of the heart, or atria.

Which is right and which is left? The human body is usually described from the patient's point of view.

A PFO is a remnant from our time in the womb. Before birth, before our lungs are used for breathing, oxygenated blood supplied by mum bypasses the lungs by flowing from the left to the right atrium.

At birth, the foramen ovale should close and seal, but in a number of people it doesn't seal fully. Some of these PFOs require surgery; most do not. Some 25-30% of people are thought to have a PFO, which of course includes divers. In normal life a minor PFO causes no serious problems, but for some divers under certain conditions, large PFOs can become problematic.

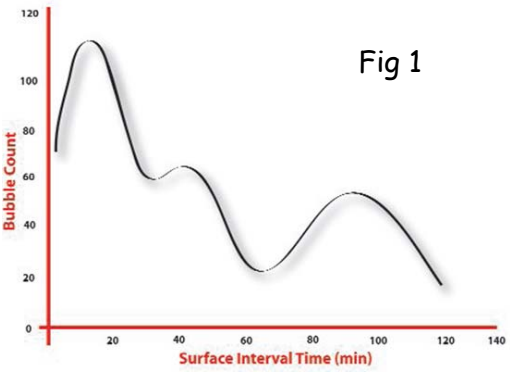


Fig 1

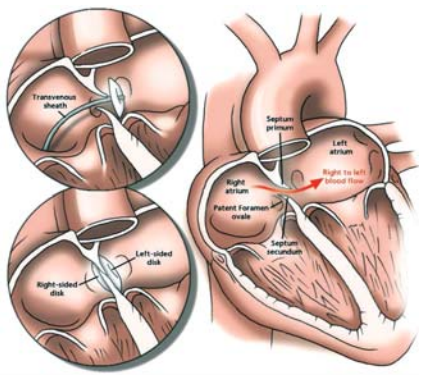
During any ascent from 10m and below on air, bubbles are formed. These are washed with the venous blood into the alveoli of the lungs. They become trapped here, then, almost instantly, dissolve out, releasing their excess nitrogen and other gases to be breathed out in the normal way. It

is the supply of micro-bubbles (MBs) that is important. MBs arriving at the lungs reach their peak in numbers within 15-20 minutes of surfacing, and then diminish in three broad reducing waves over the next 180-200 minute, see Fig 1 above.

Poor ascent control can overwhelm the pulmonary system with micro-bubbles, leading to DCI. The lungs, which catch MBs, are sometimes referred to as the "pulmonary filter". Bubbles are seen by the immune system as alien, and this may activate a response that can lead to tissue damage, wherever they are in the body. By controlling our ascents, stops and surface intervals properly, we reduce MB generation to a minimum. A PFO is not just a hole in the heart between the right and left atrium. It is more like a short tube, up to 7mm long. The flap, in the left top atrium, acts as a one-way valve that, when open, allows blood to flow from right to left only. see Fig 2. For about 95% of the time (the cardiac cycle), the pressure in the left side of the heart is higher than that on the right. This tends to keep the flap valve closed. However, there are times during normal living, such as during a Valsalva manoeuvre, when the right-side heart pressure can exceed that of the left.

Fig 2

PFO and Closure



Blood and any debris (clots, bubbles etc) may then flow through this opening, by-passing the filter of the lungs and entering the arterial circulation. Crossing blood clots can lead to a stroke; crossing bubbles can cause DCI.

Antonio-Maria Valsalva (1666-1723)

Antonio-Maria Valsalva was an Italian physician and anatomist who studied the ears. He coined the term "Eustachian Tube", and described the aortic sinuses of Valsalva in his writings, published posthumously in 1740. In a Valsalva Manoeuvre (VM), a person tries to exhale forcibly with a closed windpipe so that no air exits through the mouth or nose - as, for example, in strenuous coughing, straining during a bowel movement, or lifting a heavy weight. Divers use VMs to equalise middle-ear pressures during descent, by pinching the nose and blowing to open the Eustachian tube. Valsalva actually described the technique as a method of expelling pus through a perforated eardrum.

For over 18 years I've been trying to persuade divers to clear their ears without using VMs. I first published this advice in my book **Decompression and Computer Assisted Diving** (1993). A number of divers, including trainees, say that they can clear their ears only by using VMs, to which I say, keep practising. If used, VM ear-clearing must be "gentle", but how many times have you seen someone hanging on a line, pinching their nose with the other hand and blowing like hell? Usually, this approach simply causes the Eustachian tube to lock up but, more seriously, it could well open any lurking PFO. This is not an issue on the day's first dive, but may be important on dive two and three, if residual micro-bubbles are present!

As well as the 25-30% of people with a PFO, Divers Alert Network (DAN) estimates that least 10% of folk have a right-to-left pulmonary shunt (arteriovenous pulmonary malformation). Normally, the lungs filter out micro-bubbles, which get stuck in the very small capillaries of the alveolus, but in these people a section or sections of these alveolus blood vessels are big enough to allow normal MBs to pass through.

PFOs may be Dynamic

In a recent study by DAN Europe, a group of divers were re-tested after a 6-8 year period and a number of changes were observed. Twelve per cent had a bigger PFO than before, a further 12% had acquired one where none had existed, and one had closed. No reason was found for the changes, but it is

thought that the very small PFOs seen originally in some of the divers had enlarged over time.

Putting PFOs and Diving in Perspective

If you find all this alarming, remember that of the PFOs found in 25% of autopsies, only 3% are of the 10mm-plus size thought necessary to have a significant right-to-left shunt. We are not seeing high numbers of divers getting DCI from these causes. It is thought to occur only to those with the largest shunts, though this would still put around 5% of us at risk.

Mother Nature, as always, is working to protect you. Three mechanisms limit the incidence of DCI cases from this cause; the fact that the PFO is a one-way valve restricting right-left blood flow; that the one-way valve is kept closed 95% of the time and that returning blood from both veins mixes turbulently within the right atrium and is swept, with any micro-bubbles, away from the entry of any PFO.

How can you tell if you have a PFO?

Fairly recently doctors have linked some "migraines with aura" with the presence of a PFO, though this has yet to be confirmed. If you suffer from these, check with your GP and then, if necessary, with your local Hyperbaric doctor. Unfortunately, there is no non-invasive PFO testing method, and doctors won't routinely test for PFOs during normal diver medicals, because of the risks and cost involved. Most people with a PFO find out only after suffering an unearned DCI, particularly where a skin bend is involved. If a PFO is found it can be surgically closed, and the benefits are more than just diving-related, because patients with a PFO are also at greater risk of a stroke. However, some hyperbaric doctors feel that the risks of PFO DCI are too small to warrant concern or repair, particularly as repair has its own share of risks. Dr Richard Vann of DAN USA told me of a diver who got bent again after having a PFO repaired. Dr Phil Bryson, of Plymouth's Diving Diseases Research Centre, told me that he also has such a patient, and two others who want their PFO closures removed. So having a PFO fixed doesn't make you

immune to DCI. No dive is risk-free, and closing a PFO only reduces the risk to that of a diver with a normal heart.

As there is no medical consensus on DCI and PFOs, they are not considered an absolute bar (contra-indication) to diving.

Better control of micro-bubbles by means of superior dive profiles, better ascent control, decompression/safety stops at the correct depth and diver behaviour as outlined in the panel below reduce the risk. No MBs = no DCI.

I'm sure many experienced divers reading this appendix will shrug and think: I've been diving all these years and I'm still all right. It was what happened to two of my friends that led me to write this. They had been diving for 30+ years (5000+ dives) and 12+ years (2000+ dives) respectively with no DCI problems - until recently. The first got a vestibular bend (ear/CNS - very serious) from a 24m dive that was much shorter than the allowable no-stop bottom time, with no ascent violations. The other had a very serious neurological hit from a normal, non-provocative dive profile, with extra time spent at the last stop. Later, both were diagnosed with PFOs. Even after all their years of diving experience, they had no idea of what was in store for them. One has elected for surgery, the other has not. Both have moderately changed their behaviour before, during and after diving. The recommendations below will cost you very little but may save you a lot. Think of them as an insurance policy.

Modifying your Behaviour

PFOs become less important for divers if there are fewer or, preferably, no free-gas (bubbles). Modest changes in diver behaviour can help reduce the amount of free gas and limit PFO opening and micro-bubble wash-through. Divers can best protect themselves by learning to work with, rather than against, Nature. For example, some technical divers de-kit in the water and let others do the lifting - sounds good to me! They also use many of the other techniques mentioned here:

As a Minimum:

1. Maintain your hydration. Drink plenty of water and check that your

urine is no darker than a pale straw colour.

2. Avoid VMs for ear-clearing - use a procedure such as swallowing.
3. Skip-breathing causes CO_2 retention. Breathe long and slowly, using your diaphragm, not your upper chest.
4. Don't dwell at depth, and ascend at 10m/minute.
5. Use deep stops to help manage your ascents.
6. Have longer surface intervals - three hours or more, the length of time it generally takes for MBs to disperse.
7. Avoid hot baths/showers and sunbathing for three hours after diving - heat promotes bubbling.
8. Avoid unnecessary carrying or lifting of heavy items for at least three hours.
9. Avoid straining during a bowel movement after diving.

If you have a PFO, and medical clearance to dive:

10. Avoid carrying too much on the boat at one time: make two trips with heavy items or use a trolley.
11. Breathe pure oxygen for about 15 minutes with a nose-clip fitted before diving.
12. Use the richest Nitrox possible for the planned depth.
13. Treat the Nitrox as if it were air and decompress accordingly.
14. Breathe pure oxygen for about 30 minutes with a nose-clip fitted after diving.
15. For the first three hours get someone else to do your lifting and carrying.
16. Avoid deep or long dives, too many dives in one day, stage-stop diving and reverse dive profiles.

PFO Closure (*Transcatheter Closure of Atrial Septal defect*)

A PFO closure is achieved without opening the chest or heart. In effect, a special wire with a button closure (some of the available devices: Amplatzer, Starflex, BioSTAR) is fed into a vein in the groin up to the right top chamber of the heart and through the PFO. The device is released in the PFO and forms what looks like a tight cuff link, see the two circular sections in Fig 2 on page 2.

Pregnancy and PFOs

Most people won't find out that they have a PFO unless they

suffer a bend and only then if the attending doctor orders a PFO scan. However, there is one class of diver that is known to always have at least one PFO and may be even more and that's the pregnant woman. The number of PFOs present will depend on how many of babies are being carried. To this number we could, of course, add another: that of the mother.

Concern has centred on the foetal susceptibility to decompression illness (DCI). The foetal circulation differs from that of adults. In the adult almost all the output from the heart travels through the lungs where micro-bubbles as a result of diving are filtered out. In the foetus, circulation bypasses the foetal lungs. Any bubble that develops via either the foetal tissue or the placental tissue will travel through the foetal foramen ovale (F-PFO) into the foetal arterial circulation and embolise to the developing tissues. This could cause damage to these tissues, and if this occurs in sensitive areas such as the nervous system of the unborn child there could be significant consequences. However, there are no data regarding human foetal gas loading and the outcome of pregnancies in mothers who have been treated for DCI in hyperbaric chambers has, in the main, gone undocumented.

Conclusion

As can be seen, there is no satisfactory outcome to this dilemma. Furthermore to state the blindly obvious, foetal PFOs can't be closed! However, the risk of a foetal DCI remains a distinct theoretical possibility. Clearly, if micro-bubbles enter the foetal circulation, the baby's lungs can not filter them out. With the existence of such doubts the recommendation can only be: if you are pregnant or trying to become pregnant and you want to avoid problems that may be caused in this way modifying diver behaviour is too uncertain - refrain from diving.

Safe Diving and Kind Regards

Bob Cole, SAA Decompression Officer and CMAS Technical Director