Lung Squeeze: Coughing your lungs out...or not!

Introduction:

'Lung squeeze' is a condition that is practically unique to Breath-Hold Diving. Scuba divers are not really aware of it and, sadly, most doctors have never heard of it, let alone learnt to treat it. There are many urban legends about this rather poorly defined and largely misunderstood phenomenon. So, let's "dive" into the topic and hopefully avoid getting a brain squeeze in the process!

Definition:

'Lung squeeze" is also known as chest squeeze or more formally as *pulmonary barotrauma of descent (referred to as PBT in the rest of the article)*.

PBT is thus: *Damage or injury to the lungs as a result of the effects of increased environmental pressure on the closed gas spaces of the lungs during Breath-Hold Diving.*

The description and definition refers to what happens to the lungs because of increased pressure during descent. Some authorities include tracheal squeeze as part of the broader concept of PBT.

So, using this imperfect definition, let's consider what these effects actually are; how does increased environmental pressure affect the closed gas spaces of the lungs?

Physics and Physiology:

To better understand PBT we need to revisit some basic physics and physiology.

First, Boyle's law: *"The volume of a given mass of gas is inversely proportional to its pressure, if the temperature remains constant."*

By this gas law, it is understood that the volume of gas in a closed system or space will decrease as the ambient pressure increases and vice versa. In Breath-Hold diving, our lungs represent the closed gas containing space, with the increased ambient pressure provided by the water's hydrostatic pressure during descent. For every 10 MSW (metres of Seawater) an additional 1 atmosphere (ATA) of pressure is incurred. Take note that this inverse volume decrease as pressure increases follows an exponential curve, as shown in Figure 1 below:

Depth	ATM/BAR (Atmospheres of Pressure)	Lung Volume	Volume Ratio
0 m	**1**	**8 l**	**1**
10 m	**2**	**4 l**	**½**
20 m	**3**	**2.66 l**	**1/3**
30 m	**4**	**2 l**	**¼**

Fig 1.

Secondly, some basic understanding of lung volume is required. The Total Lung Capacity (TLC) of a 1.7m, 70 kg male is roughly 7 litres. As the lung volume is emptied down to the absolute minimum the lowest volume is called the residual volume (RV) The other volumes are not of major significance to the topic and are added for reference purposes.

Figure 2 below shows the lung volume and constituents of a Breath-Hold Diver.

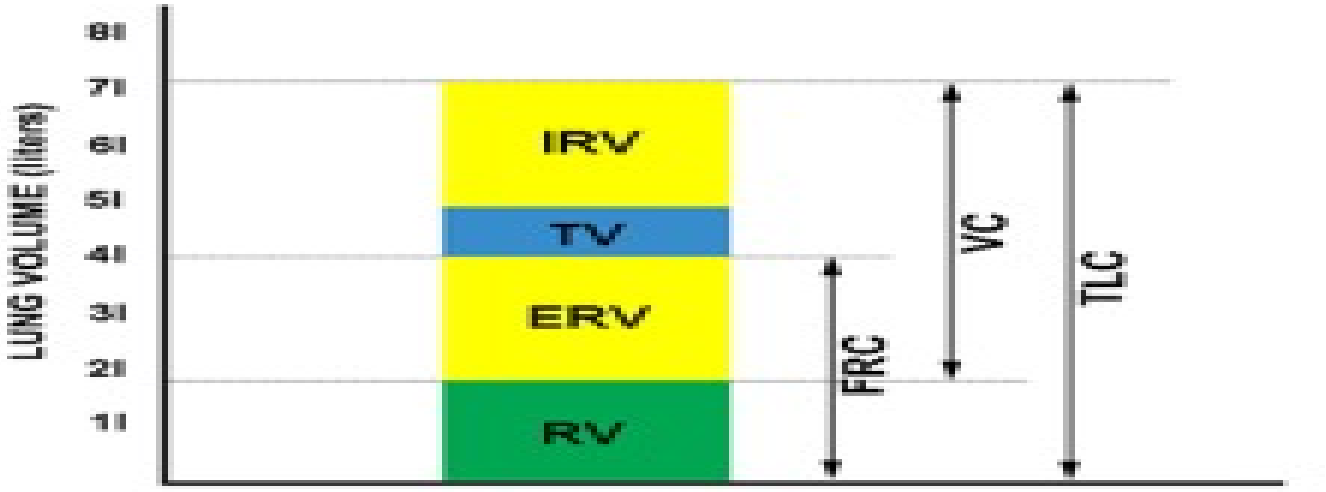

Fig 2.

TLC = Total Lung Capacity

VC = Vital Capacity

FRC = Functional Reserve Capacity

RV = Reserve Volume

ERV = Expiratory Reserve Volume

IRV = Inspiratory Reserve Volume

TV = Tidal Volume

Originally, the assumption was that residual volume (RV) represented the minimum volume that the lungs could achieve before mechanical damage would start to ensue. In other words, it should be safe to dive on breath-hold to a depth where the compression effect on the lungs does not exceed a volume reduction to less than residual volume. RV is usually 20 to 25% of the total lung volume after full inhalation. Thus, according to Boyle's Law, RV would be reached at about 35 to 45 MSW (i.e., 4.5 to 5.5 ATA) making this the breath-hold depth limit. Clearly, this is not the case, however, as free diving depth records now exceed 200 MSW. This prompted the discovery of other physiological mechanisms that play a role. Besides actual partial collapse of the chest cavity itself, the most important additional compensatory mechanism is central pooling of blood in the chest from the surrounding tissues. This allows for the accumulation of up to 1.5 L of blood in the blood vessels of the chest.

Essentially the central pooling of blood in the chest equalises the pressure gradient when the RV is reached and thereby decreases the effective RV thus allowing for deeper depths to be attained safely. This mechanism increases the pressure in the pulmonary vascular bed and subsequently in the pulmonary capillaries with rupture and haemorrhage being a possible consequence.

In practice, these mechanisms allow the lungs to be compressed down to about 5% of Total Lung

Capacity in highly-trained breath-hold champions. This begs the question of whether this would set the absolute limits for Breath-Hold Diving? Even so, it is not uncommon for these athletes to cough up blood, and the feats they achieve do not translate to everyone!

Symptoms and signs:

Although it may seem that PBT is limited to very deep dives there are several reports of PBT occurring with shallow diving – typically repetitive dives with short surface intervals, even as shallow as 4 MSW. It may be that more is going on than compression. It is well known that fluid can accumulate in the lungs simply as a function of being in water (as in so-called head-out immersion) or with surface swimming. Individual anatomical, physiological, pathological and day-to-day variations all play a role in the development of PBT.

Not all cases of PBT are recognised as they occur. Some features are transient. Others may be confused with common chest ailments like flu or pneumonia. When it both manifests and is recognised, the following symptoms (i.e., complaints) and signs (i.e., actual demonstrable abnormalities) are associated with PBT:

Symptoms: chest pain; shortness of breath; sensation of fluid in lungs; coughing; fatigue; sensation of squeezing or constriction of chest during descent; dizziness; nausea; weakness; paraesthesia; faintness.

Signs: hyperventilation; coughing up bright red blood; coughing up foamy blood, vomiting; respiratory distress; disorientation; loss of consciousness, neurological fallout; cardio-respiratory arrest; death.

From the long list of manifestations it can be seen that PBT may range from mildly irritating to fatal. In terms of duration, it can be very short or last up to a few months. Re-occurrences are common and the question of permanent damage arises.

Avoidance and Mitigation:

Whether you are a competitive breath-hold diver or simply spend a lot of time in water, it is worth considering some of the following tips to try to minimise or avoid PBT:

- Maintain your fitness, especially respiratory fitness.
- Build up your CO? tolerance to reduce lung contractions. These contractions are involuntary gasps against a closed glottis or mouth in breath-hold divers as the physiological breakpoint is reached due to CO? levels stimulating breathing efforts.
- Warm up to reduce contractions at depth.
- Avoid stretching out at depth with arms or neck. No excessive or violent movements are required or desired.
- Improve and train your ribcage flexibility.
- Dive to depths you are comfortable with and avoid panic.
- Turn before you experience contractions at depth.
- Build up slowly when starting to dive to depth.
- Avoid deep dives immediately after prolonged travel, especially if you have changed time zones or experienced jet lag. Recover completely first.
- Learn techniques to relax while diving, especially at depth, and concentrate on releasing

tension from around the chest area specifically.
- Learn the Frenzel / mouth-fill technique for equalisation as it is gentler and uses less air.
- If you have a history of PBT, rest the day after a deep dive as there appears to be an increased risk of a PBT on the second day, even at shallower depths.
- If you start to experience symptoms similar to a previous PBT while diving terminate the dive...
- Maintain regular depth training sessions during your off-season as well.
- Start exhaling just before the surface. Prior training in this regard is recommended.

Management of PBT:

Management of PBT follows basic emergency medical management principles, with the level of care being escalated or maintained depending on the initial clinical presentation and progression of the problem.

A sensible protocol includes:

- Stop diving and ensure the safety of the injured diver.
- Stop any physical activity. Let the dive buddy assist in buoyancy and towing of the injured diver to a location where exiting the water can be accomplished.
- Allow the injured diver to rest and ensure comfort.
- If available and possible let the injured diver breathe 100% medical oxygen.
- Encourage oral fluid intake if the injured diver's airway is secure and the diver is fully conscious, but avoid alcohol.
- Access emergency medical services as quickly as possible depending on available facilities and expertise. The DAN hotline is a good choice for first contact as they can be of great assistance in accessing medical services and they “speak the language of divers”.
- Seek medical consultation, preferably with a Diving Physician as soon as possible.
- Rest for at least two weeks before resuming diving and preferably after being cleared fit to dive by a Diving Physician.
- Precautionary planning is better than playing catch up.

Conclusion:

PBT is a curious and much debated problem amongst Breath-Hold Divers. There is still much to learn about this condition and there are various ways in which it can be avoided or mitigated. Perhaps it is indeed the absolute depth barrier to deep Breath-Hold diving? Who knows? Today’s barriers are tomorrow’s trophies. In the mean time, dive safely and don’t forget to enjoy it.