# PHYSIOLOGY

RAID™

## OPEN WATER FREEDIVER + FOUNDATION FREEDIVER

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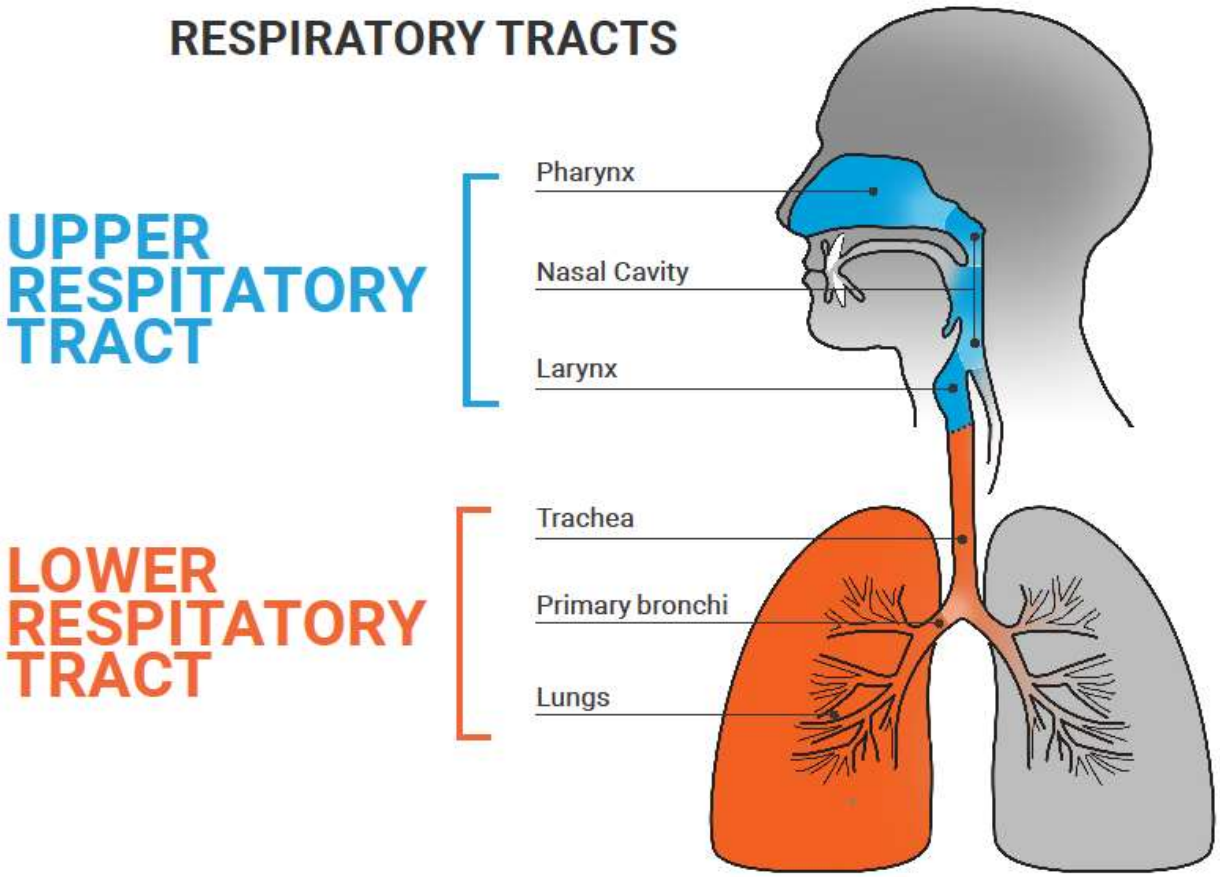
# INTRODUCTION TO PHYSIOLOGY

Understanding how our physiology is affected by freediving is critically important as we progress and begin to explore our limits. In this section we'll explore the respiratory and cardiovascular systems as they pertain to freediving.

## THE RESPIRATORY TRACT

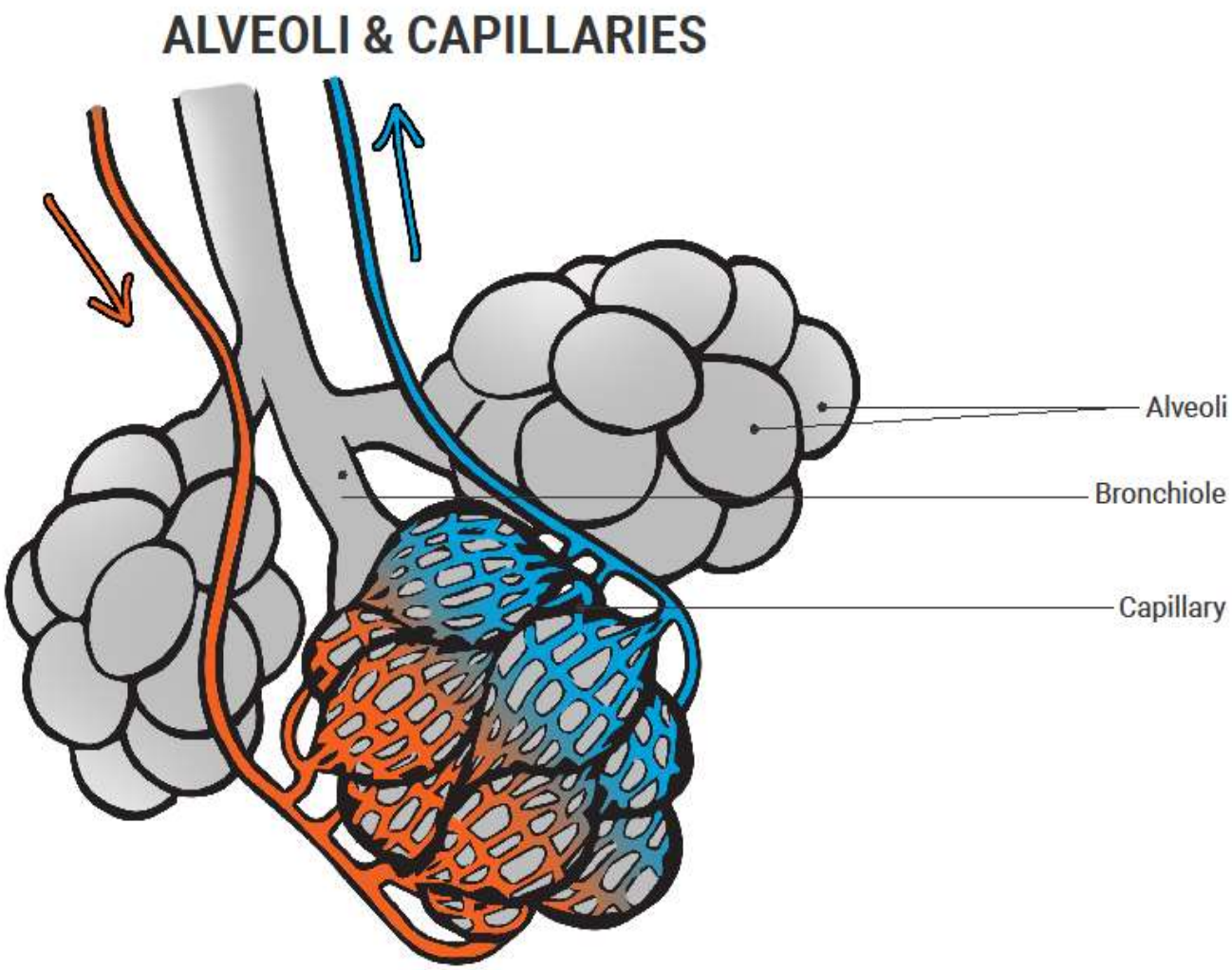
The respiratory tract is divided into two parts: upper and lower.

- The upper respiratory tract consists of the nasal cavity, mouth and larynx (voice box).
- The lower respiratory tract consists of the trachea, bronchial tubes and the lungs.




During inhalation air flows through the nasal cavity and mouth, passes through our voice box (which includes the glottis) and into the trachea. It continues down through the trachea which splits into the bronchial tubes, before further splitting into lots of tiny sacs called alveoli. The alveoli are surrounded by capillaries, where the exchange of gas from the lungs to the bloodstream occurs.

The alveoli are very flexible, enabling our lungs to change size as we breathe. The trachea and bronchial tubes are made of cartilage and are relatively rigid.




## OXYGEN STORAGE

There are three places where oxygen is found in the body - the myoglobin in our muscles, the haemoglobin in our red blood cells and the air in our lungs. When we breathe in, oxygen enters our lungs, passes through the alveoli and bonds with the haemoglobin in our red blood cells. The haemoglobin carries the oxygen to our tissues, releasing it into the myoglobin in our muscles.

When we use our muscles, oxygen is used to help break down glucose and create energy. This is called aerobic respiration. During rest, whether watching TV, sitting on a bus or floating at the surface before a freedive, our muscles and blood are fully saturated with oxygen. If you use an oximeter during rest, it should read 96 - 99% saturation.

When oxygen is depleted our muscle tissues shift to anaerobic respiration to create energy. One of the by-products of anaerobic respiration is lactic acid. This causes the burning feeling you get in your muscles during high intensity exercise or a long dive.

Another by-product of anaerobic respiration is free radicals. These are unstable molecules that are missing an electron. They take an electron from stable molecules that are part of your body, causing cell damage and leaving you feeling very tired. Many incredibly fit people still feel exhausted after a day of freediving.

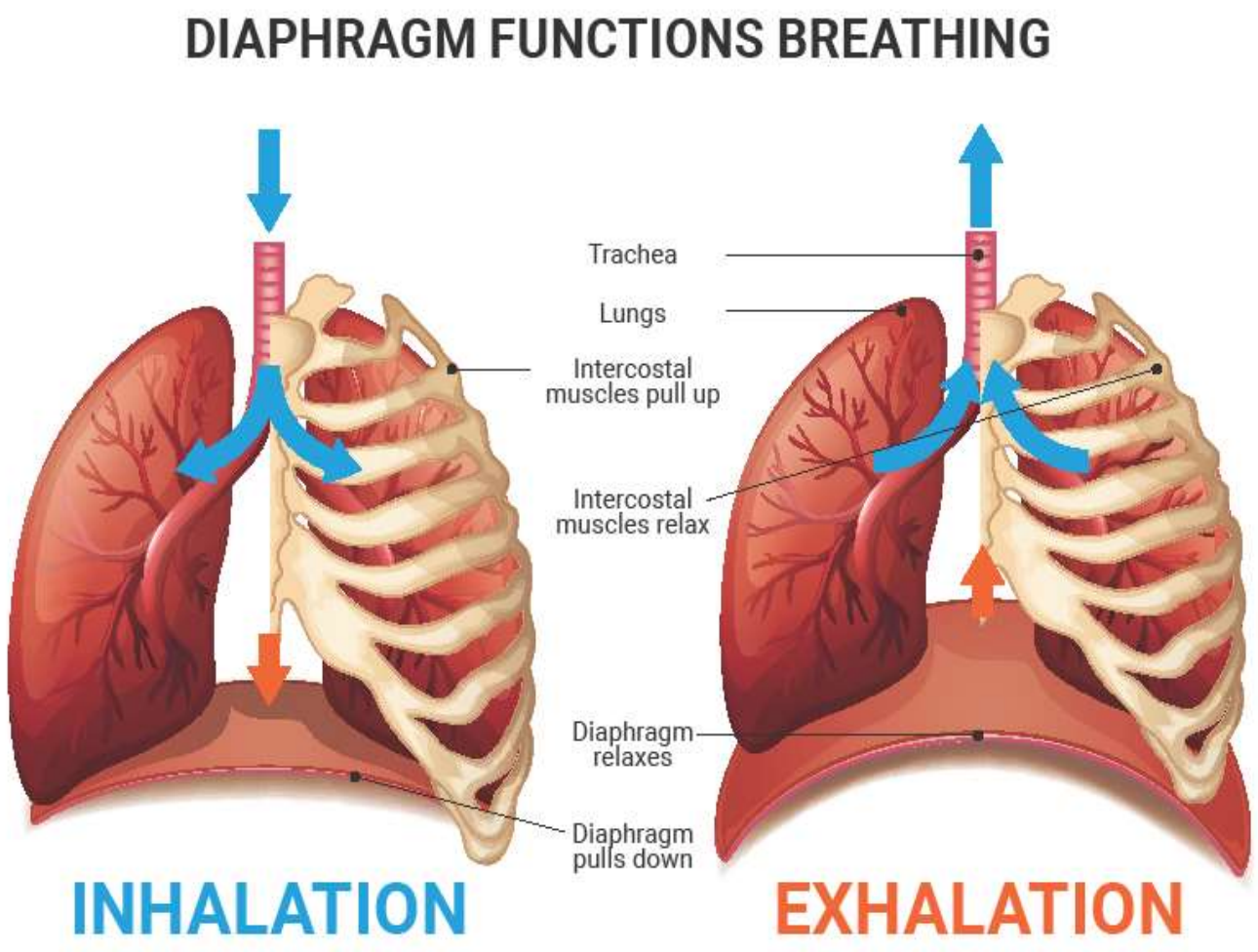
To counteract this, it's important to stay hydrated and get plenty of rest. Eating foods high in antioxidants also helps counter the effects of free radicals. *(A more thorough discussion of the role of diet in freediving is found in the Advanced and Master Freediver courses)*

# RESPIRATORY MUSCLES

There are three main muscle groups involved with breathing. The diaphragm, the rib cage muscles (intercostals) and the abdominal muscles. Each group acts on a different area of the respiratory system.

The main breathing muscle is the diaphragm, which contracts to pull air into the lungs. When the diaphragm relaxes it allows air to flow out of the lungs.

The intercostal muscles control the chest, affecting the upper part of the lungs. The abdominal muscles help breathe deeply into the lower part of the lungs.




## CARBON DIOXIDE & BREATHING

The by-product of aerobic respiration is carbon dioxide ($CO_2$).

Carbon dioxide is acidic and enters the blood, combining with the blood plasma, water, and haemoglobin to be transported back to the alveoli, where it diffuses into the lungs and can be exhaled.

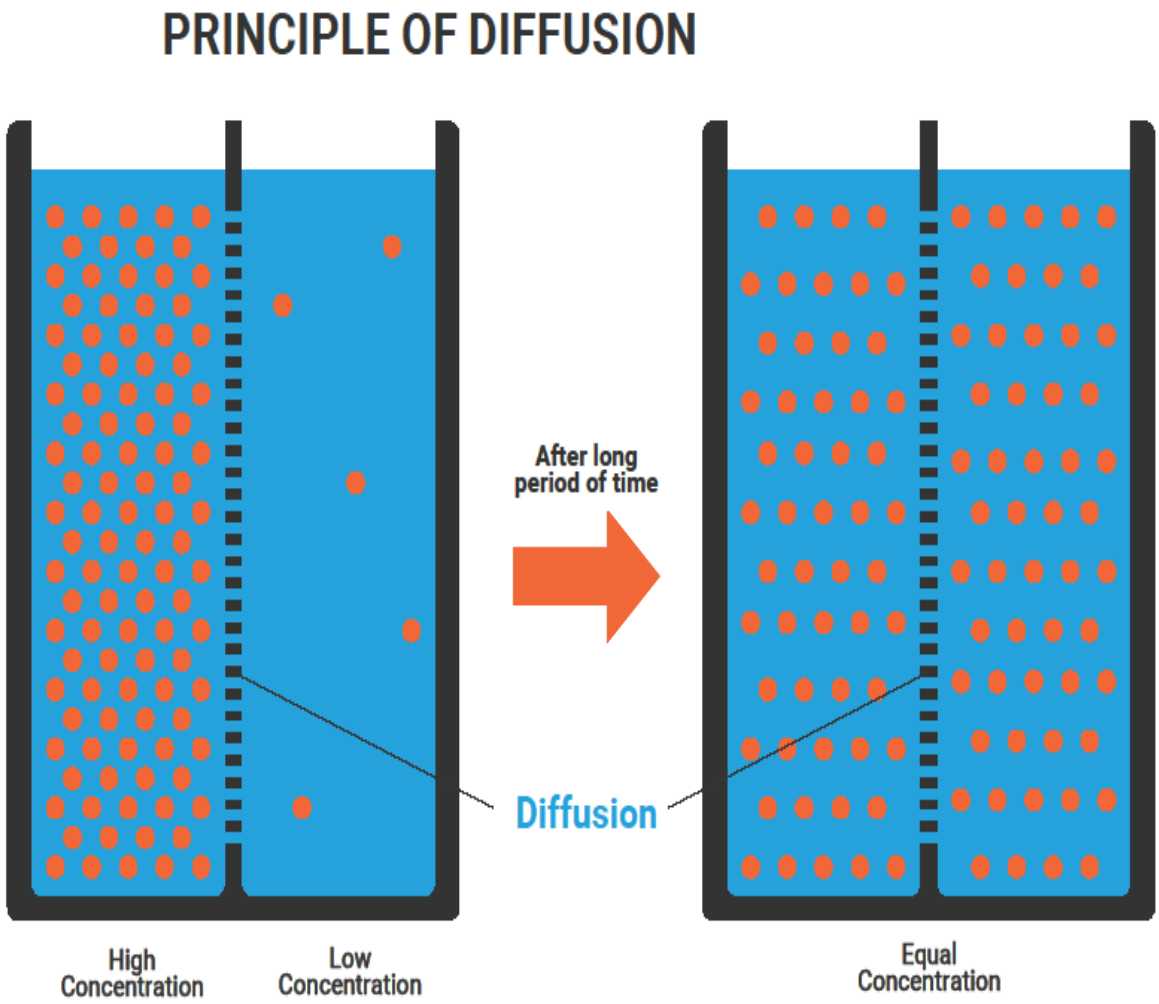
The body monitors how much $CO_2$ is in the blood and wants to keep the blood slightly alkaline. This is what determines when the urge to breathe arises, and how intense it is.

**RAID NOTE: It is the acidity caused by the presence of $CO_2$ that stimulates the urge to breathe - and not the absence of oxygen.**

The more we exercise, the more $CO_2$ we produce and the more we breathe. When we hold the breath, our body continues to respire. The longer the hold, the more $CO_2$ accumulates in our blood and the stronger the urge to breathe becomes.

## PRINCIPLE OF DIFFUSION

Diffusion is the flow of molecules from an area of high concentration to an area of lower concentration. The larger the difference in concentration between two areas, the greater the rate of diffusion.




The less oxygen you have in your lungs, the slower the movement of oxygen through the alveoli and into the bloodstream.

In the RAID Open Water Freediver Rescue manual we look at recovery breathing at the surface after a dive. The principle of diffusion is important in understanding how recovery breathing works to quickly restore oxygen levels in our blood.

Diffusion also governs Decompression Sickness (DCS) - a condition that can arise when Nitrogen accumulates in our blood and tissues faster than our bodies are able to remove it.

**RAID NOTE:** We'll discuss DCS and its relevance to freediving later in the **Rescue manual.**

# BASIC LUNG MEASUREMENTS

In this course we're concerned with three primary measurements of lung volume.

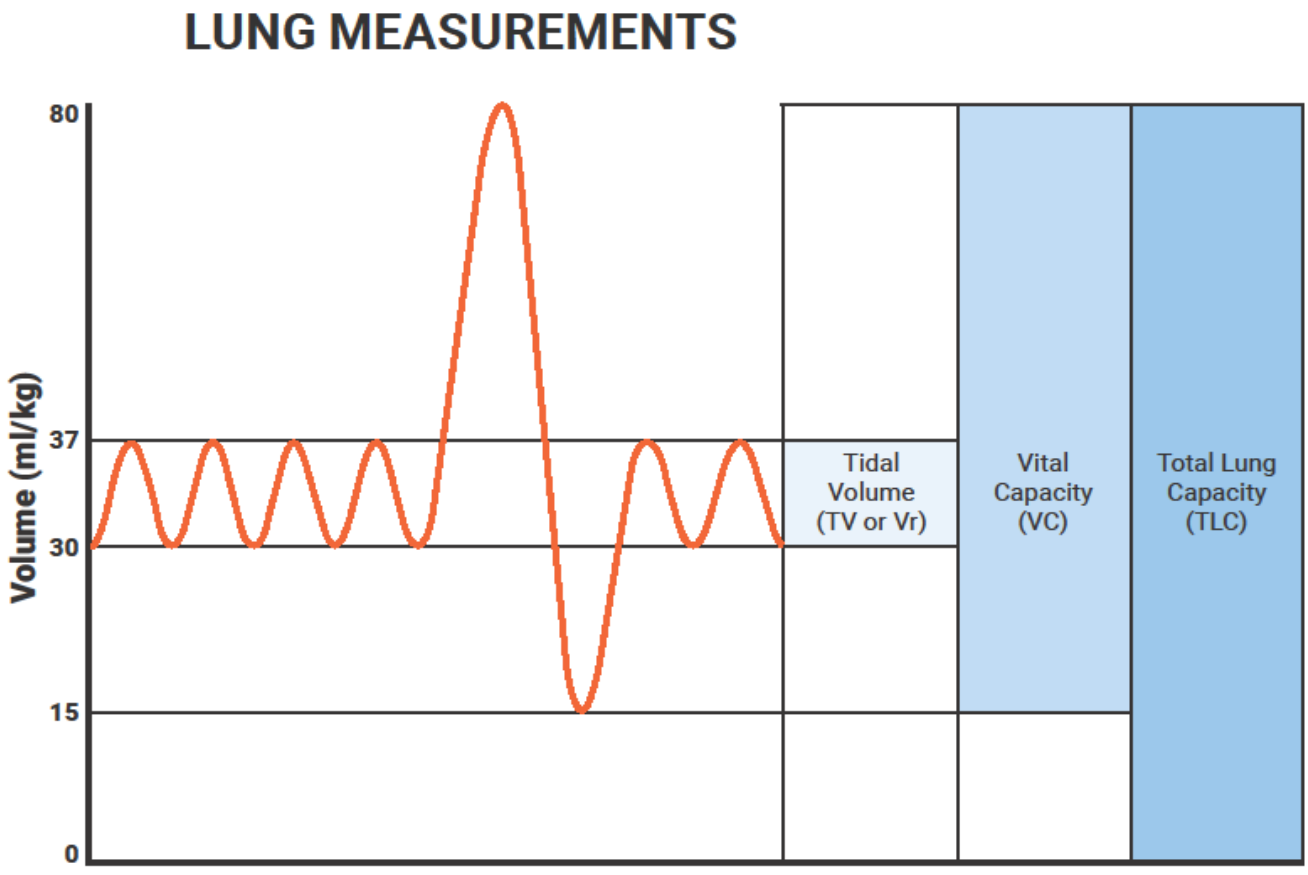
## TOTAL LUNG CAPACITY (TLC)

Total Lung Capacity is the volume of air in your lungs after a full inhalation. The average TLC of a healthy adult is about 6 litres, depending on age, gender, and body composition.

Your TLC will increase slightly as you work with the breath and relaxation. There are techniques to increase TLC specifically, but these must be undertaken with great care and are covered in the Advanced and Master courses.

## VITAL CAPACITY (VC)

Vital capacity is the amount of air you can forcefully exhale after a full inhalation. On average, this is around 4.5 litres. Even after a forced exhalation your lungs still contain approximately 1.5 litres of air.




## TIDAL VOLUME (TV)

TV is the volume of air you breathe while at rest. During tidal breathing you gently activate your breathing muscles to breathe in and passively relax to breathe out. Due to the tendency to breathe more as you begin paying attention to the breath, it's important to be aware of what tidal volume breathing is so you can avoid **hyperventilation.**

**RAID NOTE:** Hyperventilation is discussed at length in the Breathing for Freediving section of the **Confined Water Training manual**

The RAID Advanced Freediver and RAID Master Freediver courses cover a few other lung measurements. Understanding these becomes important as we approach depths of 30 meters/100 feet and more.

# MAMMALIAN DIVE RESPONSE (DIVE REFLEX)

The mammalian dive response (also known as MDR) consists of a series of physiological adaptations that occur when a mammal is holding its breath and/or submerged in water.

Together they can increase blood haemoglobin levels, reduce $O_2$ consumption, lower $CO_2$ production and protect the lungs from the effects of pressure. These changes occur in whales, dolphins, seals, humans, and other mammals. Although the mammalian dive response has evolved to assist mammals holding their breath underwater, it can be triggered on land by prolonged breath-hold and, with training, even by visualizing a dive.

With time and practice the MDR in humans becomes more pronounced - with more rapid onset and deeper effects

## BRADYCARDIA

Bradycardia is a reduction in heart rate. High level freediving athletes have seen their heart rate drop into the twenties when performing deep dives or long breath-holds. Cold water facial immersion alone has been shown to lower the heart rate by 5-6 beats per minute.

The video shows a breath hold done after a passive exhale and no preparation. As you can see, the heart rate slows as the breath hold continues.

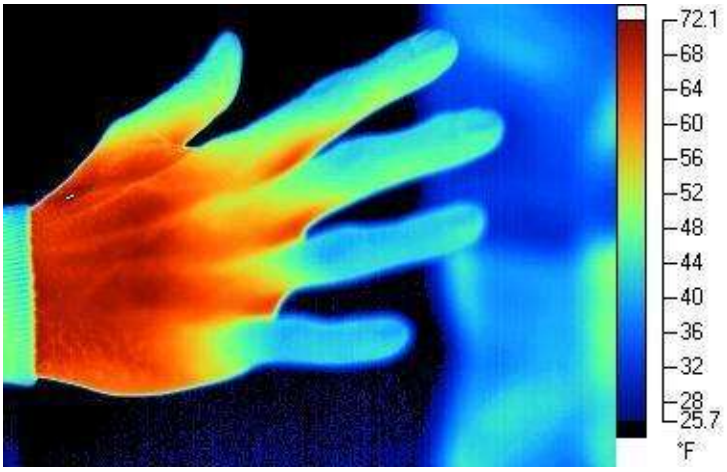
Bradycardia demonstration - video for Physiology manual .mp4

Bradycardia lowers both $O_2$ consumption and $CO_2$ production. As stated in the RAID Open Water Freediver Rescue manual, hyperventilation before a dive counteracts this effect and should be avoided.

## PERIPHERAL VASOCONSTRICTION

During a long breath-hold capillaries in the extremities contract, pushing blood towards the brain and vital organs where oxygen is most needed.

Peripheral vasoconstriction deprives muscle tissue of oxygen, causing the muscles to work anaerobically. After a long breath-hold you may notice burning in your muscles caused by the buildup of lactic acid from anaerobic respiration.




## BLOOD SHIFT

This is directly linked to peripheral vasoconstriction. As mentioned in the equalization chapter, gas in the lungs compresses as we descend. To cope with the reduction in volume, blood moves from the extremities into the vital organs and thoracic (chest) cavity. The blood fills the empty space caused by the compression of air at depth. The fluid in the thoracic cavity will not be compressed by higher pressures due to increased depth, thus protecting the lungs.

Blood shift comes into play during very deep dives, when the lungs are compressed beyond Residual Volume (RV). It greatly reduces the risk of lung barotrauma and occurs more quickly and easily with training. Adaptations like this, and others in the MDR, are enhanced with careful, gradual training.

### IMMERSION DIURESIS

Peripheral vasoconstriction causes immersion diuresis - increased urination. Due to an increase in fluid around the core, the body believes it is over-hydrated, triggering frequent urination to expel what it thinks is excess fluid. The electrolytes, potassium, and sodium are also eliminated along with the urine.

It's a good idea to bring along an electrolyte solution, particularly during a long diving session, to stay hydrated and replace these important electrolytes.

### SPLEEN EFFECT /SPLENIC CONTRACTION

The spleen is a small organ in the upper left side of the abdomen. After several dives the spleen contracts and releases more red blood cells into the circulatory system.


This increases your blood's capacity for $O_2$, prolonging breath-holds and making them easier.

Like the other elements of the MDR, splenic contractions occur more easily with practice.

### REDUCED METABOLISM

Non-essential metabolic processes like digestion slow as part of the Dive Reflex, reducing the consumption of oxygen. A side effect of a reduced metabolism can be acid reflux, if there is food remaining in the stomach. This is one of the reasons not to eat too much immediately before a freediving session.

At the same time, freediving is a very energy intensive activity, so it is important to consume enough calories. Choose a small meal that you know you can easily and quickly digest and will not cause rapid fluctuations in blood sugar.

### HYPERVENTILATION

One of the triggers for the mammalian dive response is raised levels of $CO_2$. Hyperventilation reduces the amount of $CO_2$ in your blood, inhibiting the mammalian dive response. Avoid over-breathing before a dive.

**RAID NOTE: Hyperventilation** is covered in greater detail in the Breathing for Freediving section of the **Confined Water Training manual**

## EQUALIZATION

Atmospheric pressure changes occur gradually. As we change altitude in an aircraft or car, we feel these changes in our middle-ears as a slight pressure. When we swallow, yawn, or move our jaw to relieve this pressure, several muscles act to raise the soft palate and open the throat.

One of these muscles also opens the eustachian tubes - letting air in or out of the middle ear, depending on the pressure difference. Allowing the air pressure inside the middle ear to become equal to the pressure outside is called equalization.

Underwater, pressure increases very rapidly with depth - reducing the volume of air in our bodies and masks. To avoid serious injuries to our ears, eyes, and sinuses we must equalize frequently, using techniques that differ from those that work in air.

The principles that govern the changes in the volume of a gas under pressure are explained by Boyle's law. In the following sections we'll explain Boyle's law, how it affects us as freedivers, and the techniques we use to counteract those effects.

## BOYLE'S LAW

***"If the temperature remains constant, the volume of gas is inversely proportional to the absolute pressure."***

Atmospheric pressure is measured in 'bar' or 'atmospheres". The pressure at the surface of the ocean is defined as 1 bar.

For every 10 meters/33 feet of depth in sea water the pressure increases by one bar.

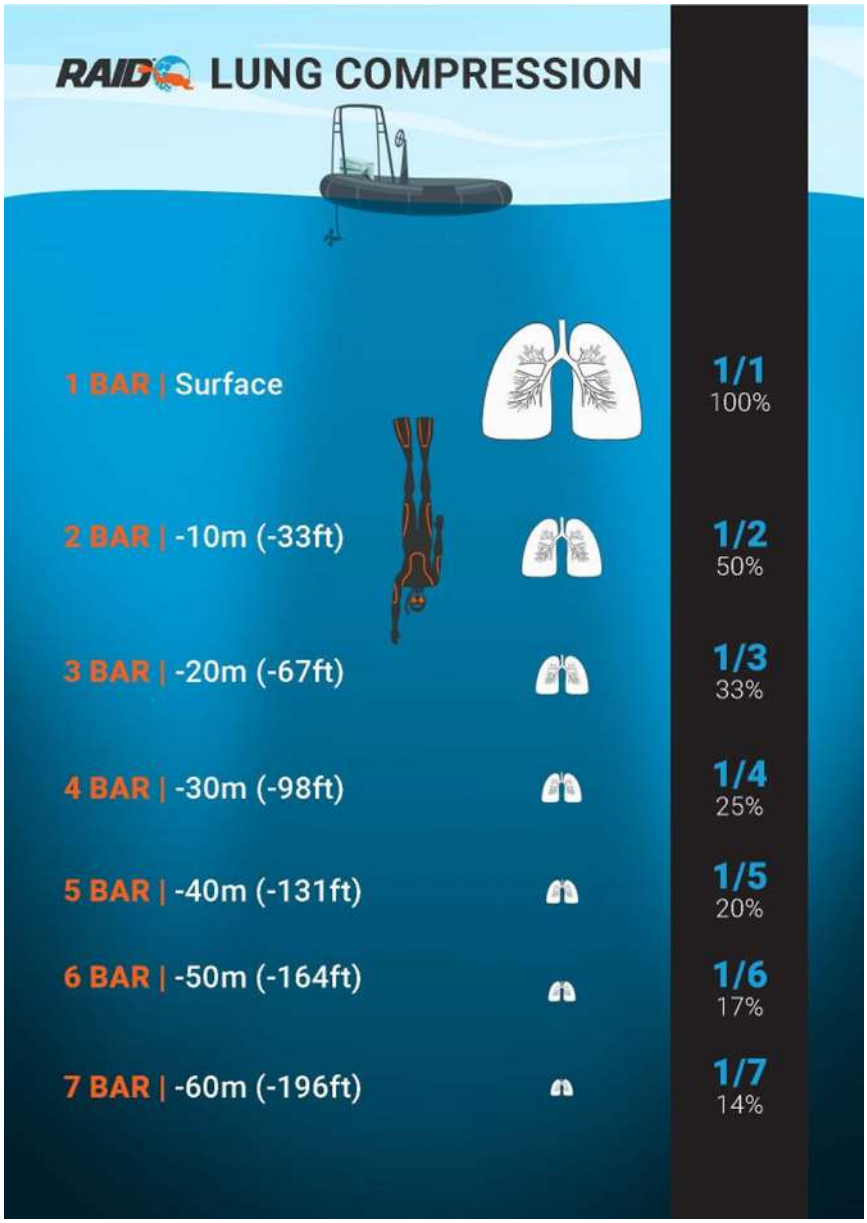
- Surface = 1 bar / 1 atmosphere
- -10m = 2 bars / 2 atmospheres
- -20m = 3 bars / 3 atmospheres
- -30m = 4 bars / 4 atmospheres

The effect of depth on the volume of air can easily be expressed by fractions.

- 1/1 Surface Volume
- ½ Surface Volume at 10m
- ⅓ Surface Volume at 20m
- ¼ Surface Volume at 30m

As you can see, the biggest change occurs in the first 10 meters/33 feet - where the volume of air in our dive mask and respiratory tract becomes ½ what it was at the surface. During this stage of the dive, we need to equalize continuously - at least once every meter/3ft.

Until we dive (with a full breath!) beyond around 30-40m/100-130ft our lungs easily conform to the increased pressure by becoming smaller, just as they do when we exhale. Sinuses, middle ears, and dive masks are less flexible and must have air added to counteract the loss of volume.

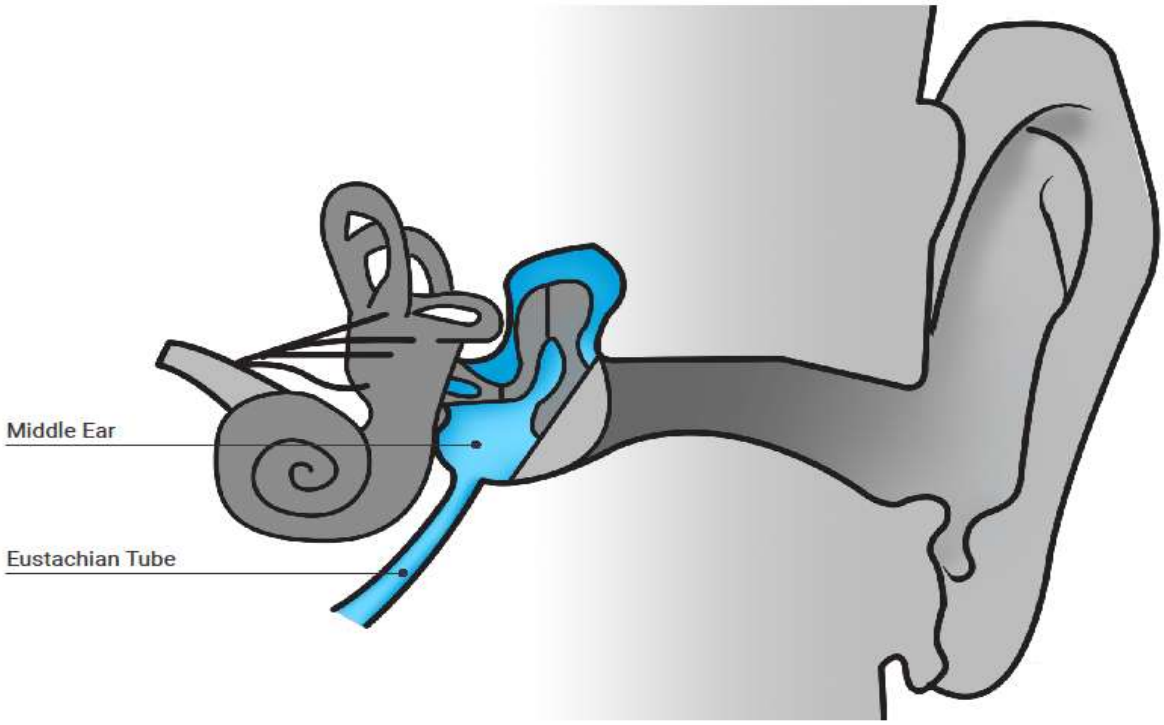



In the following sections we'll discuss the anatomy and methodology of equalization in Freediving.

## ANATOMY

### Middle Ear and Eustachian Tubes

The middle ear is the airspace behind the eardrum. It contains three tiny bones called 'ossicles' that transmit sound vibrations from the eardrum to the inner ear. The middle ear also contains the eustachian tube, which connects to the nasal cavity and makes equalizing the airspace possible.




During a dive, air in the middle ear decreases in volume (Boyle's Law) creating negative pressure which pulls on the eardrum and stresses the delicate tissues in the ear and eustachian tubes. Failure to equalize this space can result in pain, inflammation, and a damaged eardrum.

When equalizing, the eustachian tubes open to allow air to either enter or leave, equalizing pressure in the middle ear. If the eustachian tubes become inflamed or clogged with mucus, equalizing can become difficult-to-impossible. Among the causes of problems with the eustachian tubes are; delayed equalization, irritation caused by getting water up your nose, allergies, and infections.

## SINUSES

The sinuses are airspaces in the front of the skull near the cheekbones, eyebrows, and forehead. They are connected directly to the nasal cavity. Among their roles are filtering unwanted particles and adding moisture and heat to the air as we breathe.

The sinuses are not connected to the eustachian tubes, but they are similarly affected by delayed equalization, inhaling water, allergies, and illness. They normally equalize without our being aware of it.

### Equalizing the Mask

The simplest way to equalize the mask is to simply let go of one nostril between each equalization. The small amount of air left in the nose will be sucked into the mask, helping balance the pressure*. If you feel the mask compressing on your face, exhale additional air into it through your nose.

Delaying equalization of your mask will make it more difficult, and can result in ruptured capillaries in your eyes.

**RAID NOTE:** For more details on mask choice and equalisation of the mask, see the 'Mask' section of the **Equipment Manual**.

## Equalizing the Hood

Air can become trapped between your wetsuit hood and outer ear. This air will compress as water pressure rises, resulting in a phenomenon freedivers call 'hood squeeze'.

Hood Squeeze happens when negative pressure caused by compressing air trapped over the outer ear draws the eardrum outward. To prevent this just pull open your hood along the sides and let water in before you begin a dive.

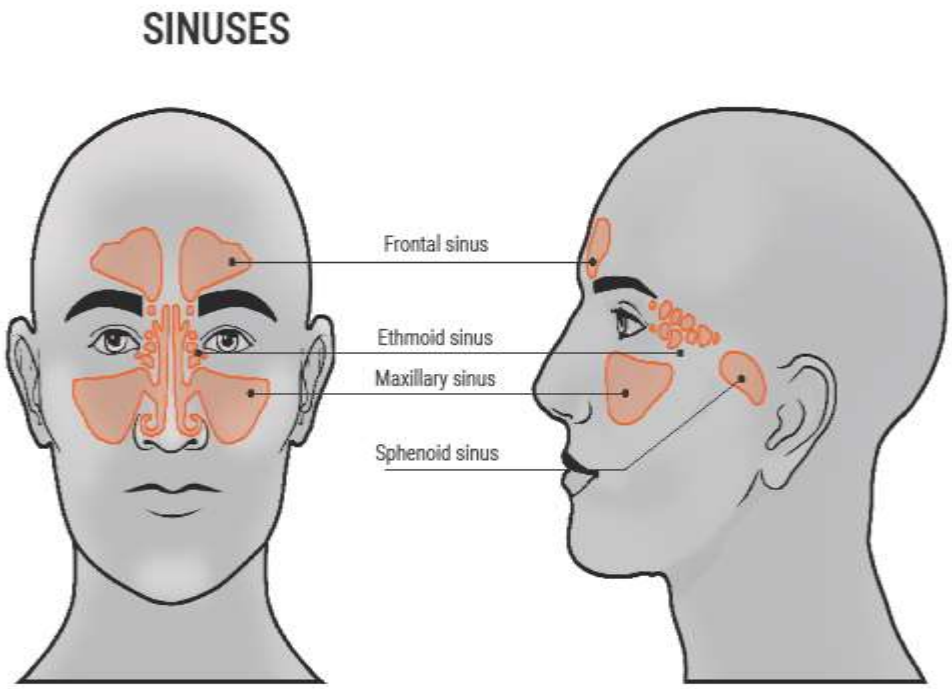
## The Sensations of equalizing

### Ears

Because of their proximity to the ears, we can usually hear the eustachian tubes open. They are held closed by a sticky coating of mucus which makes a wet clicking sound as they are pulled open by muscles in the upper throat. It's common to hear this sound when yawning or swallowing.

As air flows through the eustachian tubes and pressurizes the middle ear you may also hear a 'pop' and an increase in pressure. Often one ear will equalize before the other.

It's important to be patient when equalizing. Exert firm but moderate pressure and slow your dive if you are having trouble. If you are unable to equalise your ears and are feeling pressure on the eardrum, you should abort the dive.



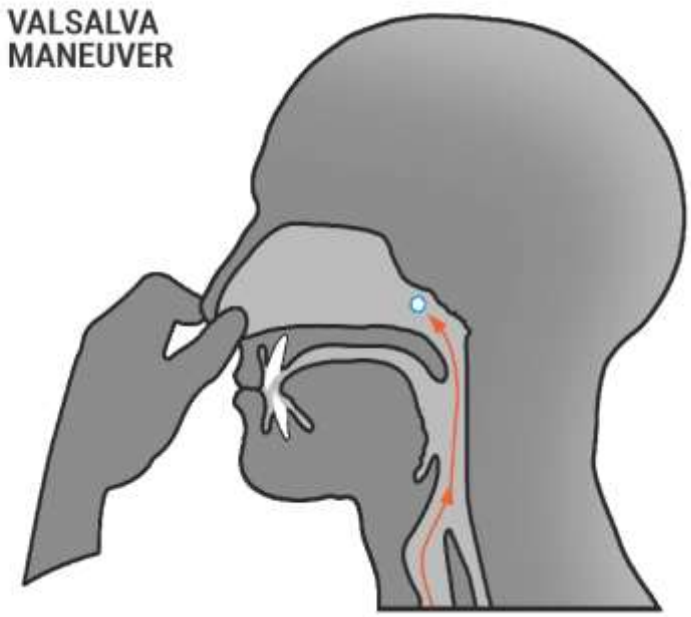

### Sinuses

The sinuses normally equalize at the same time as the ears. But unlike the ears, your sinuses are directly connected to the nasal cavity and do not rely on the eustachian tubes.

Since the ears and sinuses have independent mechanisms of equalization, it is possible for one to become obstructed while the other remains clear.

If your sinuses are obstructed, you will feel increasing pressure in your face or forehead as you descend. As you go deeper this can become quite painful.

Never force equalization. Instead slow your descent and apply firm, steady pressure. Pushing when you cannot equalize may result in injuries that can take weeks or months to heal. If you are unable to equalise, you should abort the dive




## VALSALVA MANEUVER

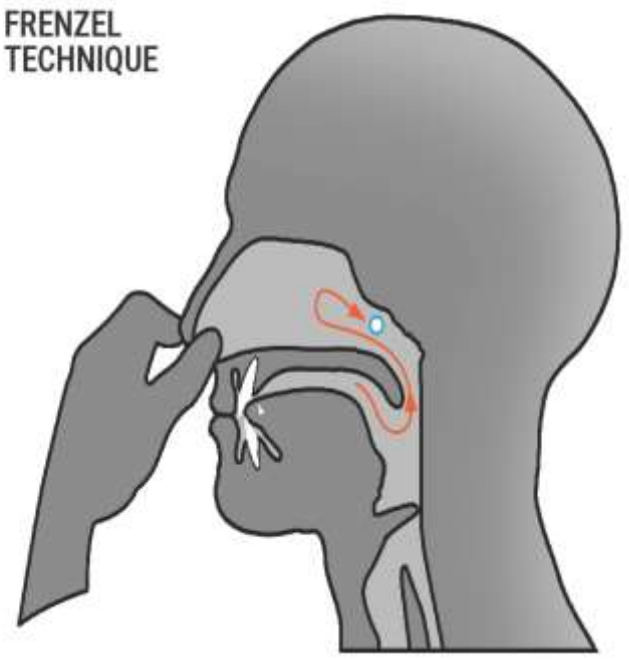
The Valsalva Maneuver uses the abdominal muscles to create pressure and force air into the eustachian tubes.

To perform it keep your mouth closed, hold your nose, and push the air into your middle ears by tensing your abdomen.

Valsalva is the most common and instinctive way to equalize. However, it does not allow for as fine control as Frenzel and becomes dangerous as we dive beyond 30m/100ft.

## FRENZEL TECHNIQUE

This is the preferred technique for dives to down to 30m/100ft - beyond which a modified version is used. Frenzel requires less effort than Valsalva and provides much finer control. Frenzel equalization is performed by shutting the glottis and lifting / moving the larynx to push air through the eustachian tubes into the middle ear.



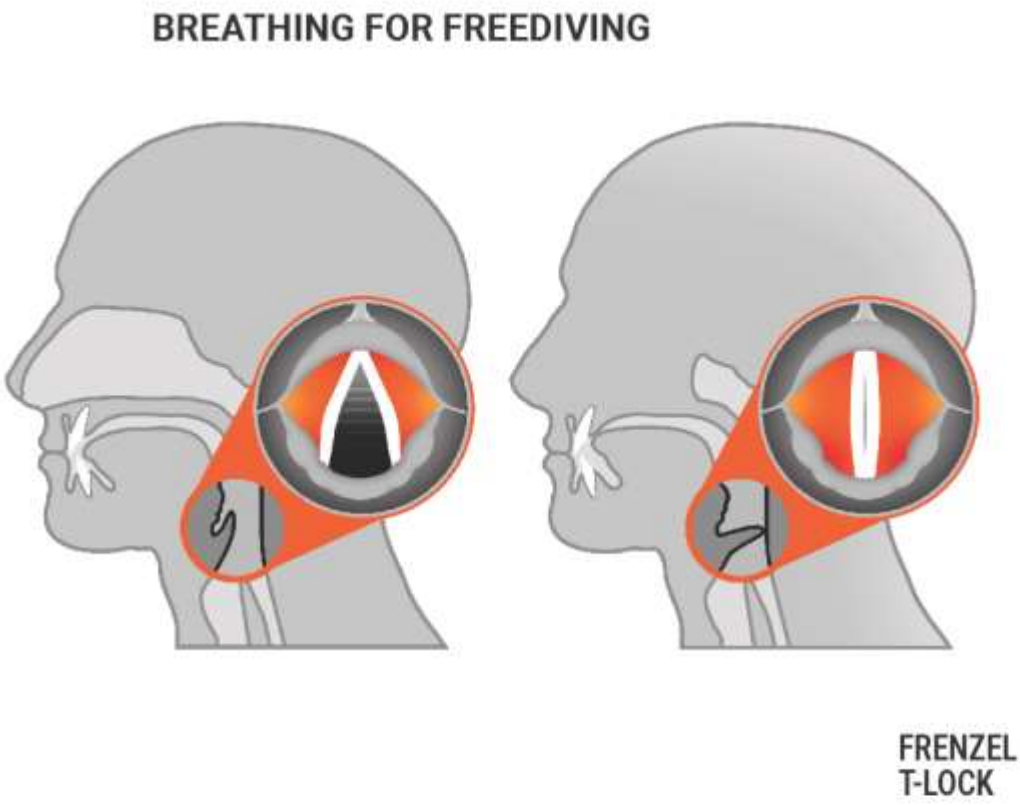

To feel the glottis close, hold your breath with your mouth open. Try this now and bring focus to your throat where the closed glottis is holding your breath.

To lift your larynx, in front of a mirror stick your tongue out as far as you can. You should see your larynx lift slightly. Now try lifting the larynx without sticking out your tongue. This may take a few attempts.

Once you are able to close your glottis and lift your larynx simultaneously, pinching the nose should equalise your ears. Your instructor can help you with techniques on your RAID course.

There are two 'tongue locks' that may be used to help perform Frenzel, the 'T lock' and the 'K lock'. The position of the tongue itself does not impact on the frenzel, but may help to give a comfortable position in which to keep your tongue and retain a mouth seal while equalizing.

# EQUALIZATION




## T LOCK

Begin pronouncing “T” and bring you attention to where the tip of your tongue is.

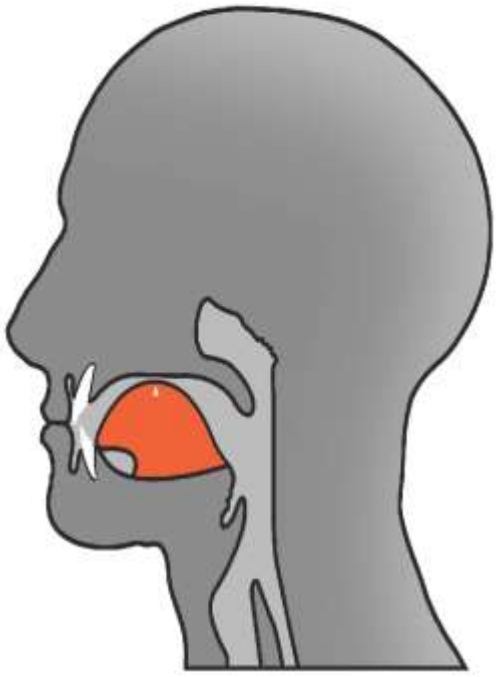
Try saying “T” again, but don’t release the tongue - instead push it against the back of the teeth or palate.

Now pinch your nose and perform Frenzel equalization with the tongue in the ‘T lock’. Focus on the pressure and movement / lifting of the larynx with the tip of your tongue just behind the upper front teeth. Feel the air pressure created in the nasal cavity, looking at the flared nostrils in a mirror.

### K LOCK

The 'K lock' is very similar to the 'T lock' however the tongue position is slightly different. Try saying the letter "K". Notice that the tip of your tongue is floating or down near the bottom teeth (it doesn't really matter) and the middle to back of your tongue is touching the top of your mouth.


Like the 'T lock', we want to lift the larynx to create pressure just before you hear the "K" sound. We're not looking for the actual "K" sound, we just want the pressure and movement of the larynx with the middle of the tongue touching the top of the mouth.



It is personal preference which lock you use; some people find one more natural than the other.

**Drop the Tongue**

Be sure to relax your tongue and allow it to drop back into its natural position between equalizations. Otherwise, you may find that it feels sucked to the top of the mouth with a kind of vacuum effect, preventing equalization.

## TIPS FOR EASY EQUALIZATION

Delaying equalization allows increased negative pressure, requiring more force to equalize. This creates a cycle of excessive compression and forced compensation that irritates the ears, eustachian tubes, and sinuses - resulting in inflammation and making equalization increasingly difficult. Equalize frequently, with only as much force as is needed. Learn to pre-empt equalization - equalize before you feel the need to.

Practice isolating the muscles needed for equalization. Experiment with controlling your eustachian tubes from time to time during the day. During Frenzel equalization, keep your abdomen relaxed. In Valsalva, release the abdomen immediately after equalizing. Avoid scrunching your face and any other unnecessary movements.

During descent avoid raising your head to look where you are going. Craning your neck makes you less hydrodynamic and creates tension that makes equalizing difficult. Keep your head, neck and spine aligned and relaxed.

If you have problems equalizing, slow down! Descend slowly or, if you have a dive line, practice pulling yourself up and down while paying careful attention to equalizing. Practicing on a line in a vertical head-up position can help if you are having problems equalizing head-down.

Stay hydrated. Equalization issues are made worse by dehydration.

### COMMON MISTAKES

Some common mistakes with equalization include:

- Failure to relax and lower the tongue between each equalization (Frenzel only).
- Failure to relax the abdominal muscles.
- Not equalizing often enough.
- Not pre-equalizing on the surface just before your dive.

- Forgetting to release one finger from a nostril between each equalization to equalize the mask.
- Failure to equalize both ears.
- Craning your neck to look where you are going during descent.

### CONGESTION

Mucus can block the eustachian tubes making it impossible to push air through to perform an equalization. Common causes for congestion are illness, air conditioning, lactose, and gluten.

**Solutions for congestion include:**

- Steam inhalation.
- Neti pots (sinus rinsing - be sure you fully understand this technique and use distilled salt water - using impure water can result in serious infections).
- Cutting out dairy products, gluten, and sugar. This may take a few weeks or more to take effect.
- Cranial osteopathy.
- Sinus massage. This uses gentle pressure and heat from the fingers to release much buildup in the sinuses. An example of sinus massage is given below.
    - Place the thumb of both hands underneath the brow bone either side of the nose. Applying gentle pressure move along the brow bone from the inner corners of the eyes to the outer corner of the eyes. Apply pressure for a few seconds at each point and repeat for about 30 seconds.
    - Using the index and middle fingers of both hands, place your fingers on the centre of the brow bone. Using a circular motion, gently massage the area, moving out towards the temples. Repeat for approximately 30 seconds.
    - Place index and middle fingers either side of the nose between your cheekbones and upper jaw. Using a circular motion gently massage this area for about 30 seconds.

**IMPORTANT: If you feel sick or congested, don't dive**

## BAROTRAUMA (PRESSURE-RELATED INJURY)

If you descend without equalizing often enough, you will eventually suffer barotrauma. As negative pressure inside unequalised airspaces increases, something will have to give. Don't wait until you feel pressure in your ears before you equalize.

Never try to force an equalization and do not continue to descend if you cannot equalize. Pushing equalization risks serious and lasting injury.

### MIDDLE EAR BAROTRAUMA

Stressing the middle ear with too much pressure and forced equalization can result in an accumulation of fluid. Often this fluid cannot drain because the same stress that causes it has also inflamed the eustachian tubes. The results can include loss of hearing (particularly high frequencies), the feeling and sound of having 'water in your ear', and potentially serious ear infections. In the event of any ear trauma - be sure to consult with your doctor.

### EARDRUM BRUISING

A mild form of barotrauma caused by negative pressure stretching the eardrum. It results from either slow equalization or hood squeeze. The eardrum will be painful and can take a few days or more to heal.

Don't start diving again until you can equalize with no pain.

## EARDRUM PERFORATION

If you equalize too late or continue to descend without managing to equalize the middle ear, the eardrum will flex inwards as the negative pressure increases. This can result in a small tear in the eardrum and water leaking into the middle ear.

**Symptoms can include**

- Pain.
- Dizziness.
- Vertigo.
- Nausea.
- Disorientation.

**IMPORTANT: If you think you have perforated an eardrum, you must discontinue diving and seek medical attention.**

## EARDRUM RUPTURE

Similar to a perforated eardrum but can take much longer to heal. In some cases, you may need skin graft surgery to rectify the problem. With any ear injury or infection, keep your ears dry until they are completely healed. Always seek medical advice.

## HOOD SQUEEZE

As mentioned earlier, there can be a small pocket of air between the outer ear and the hood. If you forget to equalize the hood, the eardrum can bulge outwards. This can cause eardrum bruising, perforation, or rupture.

## SINUS BAROTRAUMA

As we mentioned earlier, sinuses normally equalize along with the middle ears. Sinus barotrauma occurs when a blockage prevents air from reaching the sinus cavities during a dive. Pain from a failure to equalize sinuses can be in the cheeks, forehead, teeth, eyes and even the back of the head.

This pain can occur at any depth; however, you will usually notice a sinus block in the first 10 meters/33ft.

Symptoms of a sinus squeeze can include pain and bleeding (blood may come out of your nose or drip down the back of your throat).

It is possible to get a sinus squeeze without feeling much pain. Be aware that if you end up with a bloody nose, this could be the cause.

**IMPORTANT: Discontinue diving immediately if you experience sinus pain or bleeding.**

Sinus squeezes usually get better within a few days; however repeated trauma can cause lasting damage. Do not dive if congested and never try to force equalization to get through a sinus block.

## REVERSE BLOCK

During ascent there is no need to equalize. The air in your middle ears, sinuses and mask expands as the water pressure drops, and travels back through the eustachian tubes into your throat, out of your nose and the sides of your mask.

A reverse block occurs when the expanding air fails to escape your middle ears or sinuses during ascent. Symptoms include pain or pressure in the ears or sinuses.

To relieve a reverse block of the middle ear, you can try pinching your nose and swallowing. If that doesn't work, try a shallow dive, (or slow pull down if you have a dive line). Open your mouth, stretch, and move your jaw from side to side, and turn your head to stretch the eustachian tubes.

Sinus blocks can be difficult to deal with. If you feel like you may have one during ascent, try slowing down. Pinching your nose and equalizing, then reverse equalizing by inhaling through the pinched nose may help loosen any blockages. Be sure not to use force.

Your instructor will help you with these techniques.

Reverse blocks are often caused by repeatedly forcing equalization. If you consistently equalize too late, or force equalization, the eustachian tubes become inflamed, making it difficult for them to relax and open. Equalize regularly and never force equalization!

## LUNG BAROTRAUMA

Lung barotrauma, or 'lung squeeze' occurs when the lungs cannot compress any further. Like other forms of barotrauma, something has to give to compensate for the reduced volume. In this case, the alveoli rupture and blood enters the lungs.

Lung barotrauma is extremely unlikely at the depths covered in this course. This is because, as they compress, healthy lungs are still working through their normal range of motion until we reach depths of around 30-40m/100-130ft. Lung Barotrauma becomes most likely when the lungs are compressed beyond the volume of a normal full exhalation.

This can happen if we dive on less-than-full lungs.

For example: If you exhale half the air in your lungs after a full inhalation, and dive to 10m/33ft - your lungs will compress to half of that volume - or ¼ your Total Lung Capacity (TLC). This is the same effect as a dive to 30m/100ft on full lungs.

Normal Residual Volume (RV) - the amount of air left in your lungs after a full exhalation - is ¼ to ⅕ TLC. Safely diving to depths where your lungs are compressed beyond RV requires gradual acclimatization and advanced techniques.

Another risk factor for Barotrauma is any condition that reduces the ability to exhale fully and/or affects the resilience of lung tissues.

**These can include:**

- COPD (Chronic Obstructive Pulmonary Disease).
- Emphysema, a lung condition that causes shortness of breath due to alveoli damage.
- scarring of the lungs.
- chronic bronchitis.
- other pulmonary/respiratory conditions.

Diving with any of these medical conditions must be approached very conservatively and under the guidance of a medical professional. Physical tension or straining while at depth is also a risk factor, as is diving relatively deep in cold water.

Symptoms of a lung barotrauma include difficulty breathing, chest pain, and coughing up pink foam or blood.

If you feel the urge to cough after a dive, check for blood by spitting on your hand or another light coloured surface. If there is blood, you may have suffered a lung squeeze.

A diver suffering lung squeeze will often have low oxygen levels. Observable warning signs include blue, grey, or pale lips, and blue, pale, or blotchy skin. Extreme fatigue can also indicate low $O_2$ levels.

If you suspect lung barotrauma, exit the water, and immediately seek medical attention. If an oxygen supply is available, breathe $O_2$ for at least 20 minutes. Recovery time depends on the severity of the barotrauma but can be anywhere from a few weeks to a few months. The key to avoiding a lung squeeze is gradual acclimatization to depth, and training until the techniques needed for deep dives become second nature. Diving to deeper depths should not be rushed.

### TRACHEA BAROTRAUMA

Trachea barotrauma has the same causes as a lung barotrauma, but instead of the alveoli in the lungs giving way, the trachea (made of cartilage) splits and is deformed out of its normal shape.

The main symptom of this is a tickly throat, making you want to cough. Symptoms are very similar to lung squeeze, and the two may occur together. Depending on severity, trachea barotrauma often heals faster - anywhere from a week to a few months.

Trachea barotrauma is less common than lung squeeze and is often the result of stretching or extreme exertion at depth.

### EYE BAROTRAUMA

This is caused by a failure to equalize the mask. If you continue to descend without equalizing, at some point, the capillaries in the eyeball will rupture and your eye will be bloodshot or even bleed. It can also cause bruising around the eye or anywhere inside the mask.

Wearing your mask too tightly can conceal the sensations of mask squeeze and make it more difficult to equalize by forcefully sealing off your nose. Your mask should be no tighter than it needs to be to prevent leaking.

## PRACTICING EQUALIZATION

Equalization is easily and safely practiced out of the water. The more you practice, the more you will strengthen your neurological pathways, making equalization underwater easier. You can practice with a full inhale, with a passive exhale and after fully exhaling.

**Equalization Recap**

1. Equalize frequently and pre-empt equalization.
2. Tuck your chin in.
3. Slow your descent if necessary.
4. Don’t dive with a cold or congestion.
5. Release the pinch on the nose between each equalization to equalize the mask.
6. Pre-equalize on the surface immediately before starting the dive.
7. Stay hydrated.
8. Drop the tongue between each equalization (Frenzel only).
9. Relax the abdominal muscles between each equalization (Valsalva only).

**IMPORTANT! - if you cannot equalize, stop your descent**

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