Isobaric Inert Gas Counter diffusion

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-How does it work?

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Inert gas isobaric counter current diffusion or ICD is a term used to describe the process of two Inert (non metabolised) gases diffusing in opposite directions (counter current) according to their respective partial pressure gradients, without there being a change in ambient pressure (isobaric), usually one gas diffuses into and the other out of a particular tissue. If the relative masses of the respective gases differs greatly there is a resultant difference in the speed of diffusion, this can lead to excessive saturation as one gas diffuses out slower than the other diffuses in, leading to excessively high total inert gas tension, exceeding the M-value of that particular tissue leading to decompression sickness. Depending on location and type of ICD, this can vary from severe vestibular or inner ear involvement to skin lesions when the victim is exposed to a different gas than is inspired.

It was first described by Graves, Lambertsen, Idicula and Quinn in 1973 where they observed superficial isobaric counter diffusion in individuals breathing a mixture containing comparatively heavy inert gases such as nitrogen whilst being in a hyperbaric chamber surrounded by a lighter inert gas mixture, heliox. Following the initial studies, the various mechanisms of ICD have been further explored through experimentation in hyperbaric chamber environments. Both vestibular and skin signs and symptoms were observed,

depending on the mechanism applied: Transdermal counter diffusion (surrounded by a different gas than was breather) and neurological/vestibular when different gases were breathed in sequence.

The two main forms are superficial ICD or Steady State ICD and deep tissue ICD or Transient ICD. These describe both the location and the process of ICD in each case.

Superficial ICD refers to transdermal ICD induced symptoms of DCS where the individual breathes one gas mix and is surrounded by another: Breathing Air or nitrox whilst being surrounded by heliox. This is induced in a controlled chamber environment for experimental purposes, experienced in a dry diving bell environment during commercial saturation dives or in the unfortunate event that a light gas is used as dry suit inflation gas, which highlights the fact that a gas mix containing helium should never be used as dry suit inflation gas. In the chamber environment this has shown to produce a very high number of gas emboli thus leading over an extended period of time to potentially lethal bubble counts in the body.

Deep tissue ICD or transient state ICD refers to manifestation of symptoms when the diver switches to a gas with a different inert gas, usually switching to a heavy nitrox after breathing helium rich trimix when approaching decompression as was common practice on deep technical dive. This heralds the possibility of inducing a state of transient super-saturation causing inner ear DCS as described by Doolette and Mitchell in their recent study of inner ear DCS .Another hypothesis why these gas switches cause ICD induced DCS was described by Steve Burton who proposed that the greater solubility of nitrogen compared to helium which would also lead to transient super-saturation as the increase in nitrogen dissolving in the tissues increases total gas tension in the tissue. Originally it was described by Lambertsen that care must be taken when switching from a heavy gas like air or nitrox after breathing it for a considerable time and switching to trimix. This would cause high inert gas tension though the fast influx of helium into a nitrogen rich tissue

Following examples show two dive plans for the same depth/time profiles however with different decompression/travel gases. The first plan is an example of a plan with a high risk of ICD induced DCS, the second highlights a plan with reduced potential for ICD.

A diver using a breathing gas with very high helium and low nitrogen content switches to a gas with comparatively high nitrogen content and no Helium on his decompression stop.

A hypothetical plan to highlight the effects of gas switches on isobaric counter diffusion:

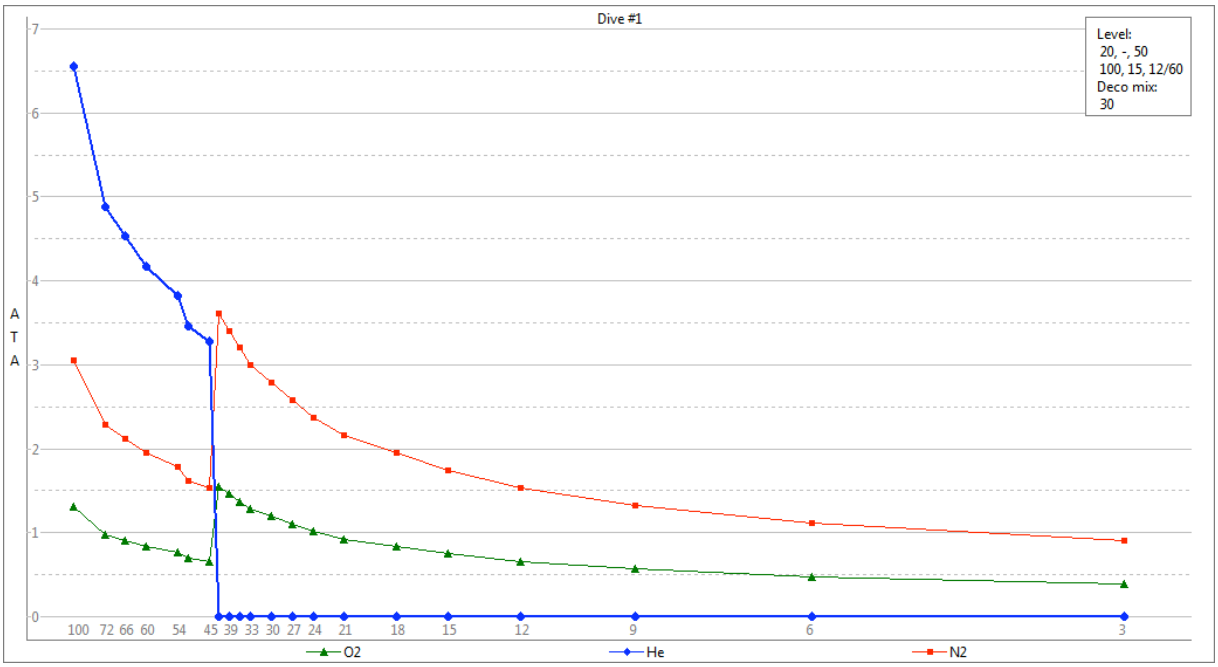
Plan: 100m 15min

Bottom mix: Tmx 12/60

Deco gas 1 and travel gas: EAN30

Deco gas 2: Oxygen

On the gas switch fromTmx12/60 to EAN30, the dive schedule as generated by V-planner gives an Isobaric counter diffusion warning. Notice the very fast drop of helium (steep drop of blue line) and the sharp rise of nitrogen (steep rise of red line)



This means that due to the extremely high pressure gradient resulting from the fast drop in inspired helium and fast rise in inspired nitrogen pressure, the total gas pressure exerted by the movement of those gases might exceed the M-Value in a particular usually fast half time compartment, leading to decompression sickness.

In the next example a much gentler transition is achieved through the use of additional decompression gases that contain helium thus reducing the risk of isobaric counter diffusion induced decompression sickness

Plan: 100m 15min

Bottom mix: Tmx 12/60

Deco gas 1 and travel gas: Tmx 21/50

Deco gas 2: Tmx 30/30

Deco gas 3: Ean 50

Deco gas 4: 100% oxygen

A logistically much more challenging situation due to the additional cylinders which have to be carried or staged but as can be observed above: the first gas switch to Tmx 21/50 creates a much smaller pressure gradient as the previous example where the switch was made directly to Nitrox. The helium in the decompression gas which is also the travel gas used to reach a safe depth to switch to the bottom mix aids in making the transition to gases richer in oxygen and nitrogen gentler and thus healthier. Upon ascent the first gas switch back to the travel gas/first decompression gas results in a steady decline in nitrogen and helium pressure and only really a rise in oxygen partial pressure, making the transition much gentler thus reducing the risk of decompression sickness

The real issue here is to avoid increasing the total gas tension of the tissue by making gentle gas switches and by reducing total overpressure through planning for deeper gas switches thus total gas tension is further away from a ceiling, M-value of that compartment.

Some rules have been stipulated as to ratios concerning decrease of helium content versus increase in nitrogen content on decompression. One such rule is the $1/5^{th}$ rule: That the increase in nitrogen content can be maximum $1/5^{th}$ of the decrease in helium content: A 10% decrease in helium content would therefore only allow a 2% increase in nitrogen. This is in order to avoid increasing the total gas load in the tissue.

It is due to these observations over the past years that we can now say that careful planning and choice of gases contributes to the safe outcome of our dive. Isobaric inert gas counter diffusion is a real risk and must be taken into account when planning future dives where breathing mixes rich in helium are used. On such dives, intermediate and for the shallower stops, even hyperoxic trimixes can greatly improve a safety and wellbeing after the dive, making another potential cause of decompression sickness more controllable.

In one account of a deep cave dive carried out by Sheck Exley, his decompression schedule had him switch from Tmx10/50 to air at 80mfw. Previous accounts of vestibular ICD hits experienced by fellow divers caused him to gradually phase in the air. During the switch he took one breath of air followed by switching back to Tx10/50 then back to air for two breaths, then one further breath from the Tx10/50 before finally switching fully to air. No symptoms of vestibular ICD were experienced.

Signs and symptoms of an ICD hit depend on the affected area, superficial or deep tissue ICD. As mentioned above superficial ICD involves the diffusion of gases through the skin. A lighter gas is entering the tissues adding to the total gas pressure therein. Signs observed in previous experiments included skin lesions, only observable though at extreme pressures. Symptoms however occur long before the signs and these include most prominently itching to severe itching, again dependant o the severity of the gas differential and total pressure. This can be observed in a chamber environment and was deliberately induced in a series of experiments researching ICD.

Deep tissue ICD occurs when various gases of different molecular weights are breathed in sequence. This form of ICD usually involves rather fast tissues such as the inner ear and as more recently discovered the cerebellum. The transient nature of this form of ICD leads to comparatively quick resolution of symptoms when the gas tension is reduced. This form of ICD yields mainly symptoms, strong vestibular derangement, and loss of balance inducing nausea vestibular symptoms causing severe loss of orientation. Currently cerebellar involvement in these symptoms is being explored. It is believed that direct involvement of the inner ear is the cause of these symptoms however the brain tissue of which the cerebellum is one, being of rather fast half time is believed to be involved as well. It is the cerebellum which receives and processes information regarding balance and gait. Direct involvement of the cerebellum in ICD would therefore yield similar symptoms as when the inner ear is affected itself.

Treatment for ICD induced follows standard oxygen recompression protocol as for regular forms of DCS according to locally used treatment protocols.

Severe symptoms usually subside after the gas tension is reduced and the fast gas gradually dissolves out of the affected tissue. Full recompression therapy should however be undertaken, at least to treat the secondary damage done by the bubbles, previously present in the tissue.