ISOBARIC Counter diffusion

WHEN , WHY , HOW TO AVOID IT

BY : ANTONIO PASTORELLI

When we are facing to ICD

Firstly, Isobaric counterdiffusion concerns hypoxic trimix dives.

Introduction

US Duke University researches made and experiment in collaboration with US Navy.
Some divers while they were saturated in Heliox mix at 7 bars of ambient pressure, start breathing a Nitrox mix, had in just some minutes skin irritations and itchings.

Also in Comex Hydra V experimentations while using Hydreliox (mix with both H2 and He), they noticed that divers developed bubbles during decompression phase and needed to be recompressed.
They discovered that more gradual changes in gas mix were able to prevent this problem.

Why

Inert gas counterdiffusion means cross diffusion of two or more inert gasses without change of depth (same pressure = Isobaric).

Gas switches cause changes in gas gradients between tissues and new inspired mix, and also jumps in END.

Differences in molecular weight of gasses in mix (often we use terms "heavy gas" and "light gas" with reference to molecular weight) are at the origin of ICD.

More precisely, molecular weight is used to calculate total decompression schedule (fast, medium and slow tissues).
This means that when using Decompression softwares, your runtime is calculated on **gas diffusability** basis, which is function of molecular weight.

But … when changing gas mix at deco stops there are "instant" changes in gas partial pressures in fastest tissues (fats, lipids) which are related to **gas solubility**.

To "manage"' ICD risks we must put focus on gas solubility in lipids instead on their diffusability.

What occurs when changing a gas mix at given constant depth?

Changes in gas mixture involves a redistribution of partial pressure of each gas in a mix, such as He, N2, H2, Ne, Ar, but each gas (*we're speaking of inert gasses, so we do not care about oxygen and metabolic gasses as carbon dioxide, water vapor etc.*) has a different solubility, so a different speed in entering and leaving rapid tissues (especially lipids), assuming that two phases are made at same speed.

Due to differences in solubility, this ***redistribution of partial pressures can have the weird effect***, while a diver is in decompression phase, ***of increasing the overall gas loading in rapid tissues***, instead, as espected, of decreasing it!!!

Therefore, if the overall rapid tissues loading increases this represents an ICD risk.
As mentioned before, this can cause bubble formation, skin irritations and itchings and also, IEDCS (Inner Ear Decompression Sickness).

To clarify the phenomenon let's start with taking a look at gas solubility table.

GAS SOLUBILITY AT 37 °C/99°F

	Mol. weight	Water solub	Fat solub
Nitrogen	28	0.013	0.067
Argon	40	0.026	0.140
Hydrogen	2	0.016	0.048
Helium	4	0.0085	0.015
Oxygen	32	0.024	0.120

<u>In this table we can see that :</u>

N2 is 4.46x more soluble than He
(0.067 : 0.015)

H2 is 3.2x more soluble than He
(0.048 : 0.015)

TIP:

If you want to calculate diffusability (used by decompression algorithms) you must use ***Graham's law***.
This law says that diffusion speed of a gas is inversely proportional to the square root of it's molecular weight.

Translated into mathematics:

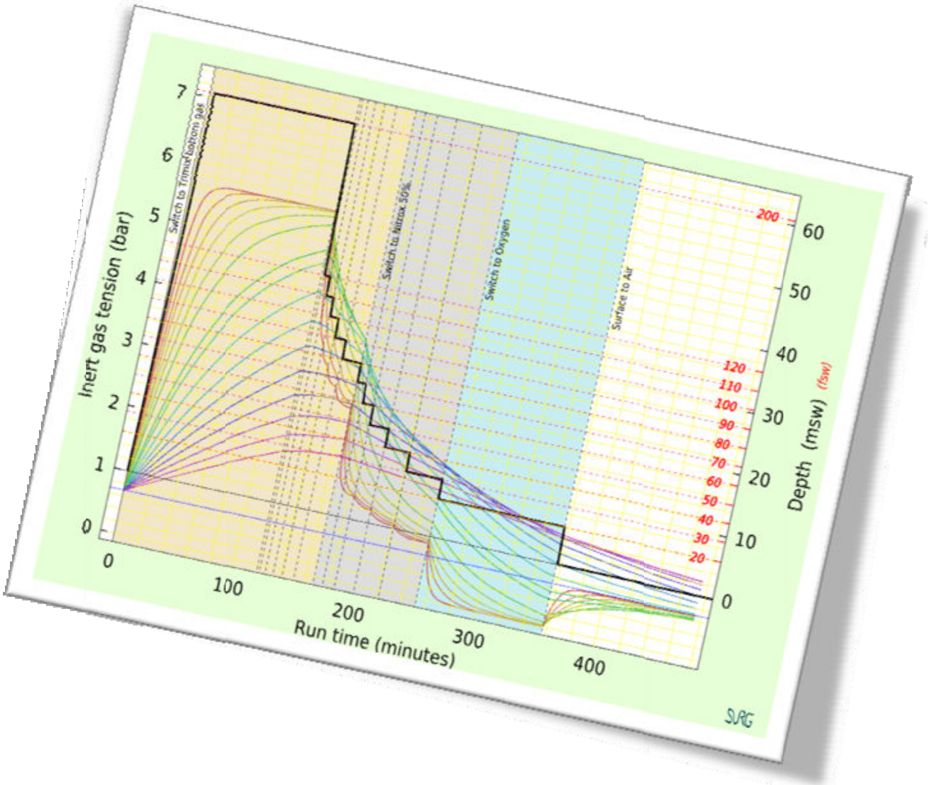
$$Diff = \frac{1}{\sqrt{Mol.\ weight}}$$

so, for Nitrogen we have:

$$Diff = \frac{1}{\sqrt{28}} = 0.1889$$

and for Helium:

$$Diff = \frac{1}{\sqrt{4}} = 0.5$$



To understand why gas switches may cause an ICD risk let's try to calculate changes in partial pressures and in rapid tissues gas loading, with an example.

DIVE EXAMPLE

100 meters / 328 feet, Tx 12/65

Let's imagine a dive to 100m. (328f), with Tx 12/65 as bottom gas and we want to switch to Tx 22/15 at 60m. (197 f) deep.

When diver arrives at 60m./197f (*ambient pressure 7 bars/102psi*) with bottom gas, inert gasses partial pressures are:

Helium (65%):	4.55
Nitrogen (23%) :	1.61

Switching to Tx 22/15, <u>while staying at same depth :</u>

Helium (22%):	1.54
Nitrogen (63 %):	4.41

Immediately, we can observe a big jump in END (PpN2).

Overall rapid tissues gas loading when breathing bottom gas is:

He 4.55 x He fat sol. 0.015 + N2 1.61 xN2 fat solub. 0.067 = 0.176

Overall rapid tissues gas loading after gas switch is:

He 1.54 x He fat sol. 0.015 + N2 4.41 xN2 fat solub. 0.067 = 0.332

As we can see, instead of decrease overall gas loading (decompression) we have raised it.

DIVERS CONCERNED

As ICD is due to a gas swaps between gas mixes with significant changes in N2/He percentage, or other gasses with significantly differences in solubility, ***this occurs only in hypoxic trimix dives***.

Dives at depth more than 70m. requires a high percentage of He for bottom mix to limit both narcotic effects of N2 and Oxygen toxicity (this means low N2 fraction).

While ascending and switching mixes, we cannot rapidly reduce He fraction without drastically increase Nitrogen fraction, which is 4.46 times more soluble than Helium.

In this case, in rapid tissues, we have (much) more gas entering than leaving tissues).

ICD PREVENTION

How to calculate the correct gas Mix for swaps while in decompression phase?

We saw that Nitrogen solubility in rapid tissues (fats) is 4.46 times more than Helium.
Fat solubility ratio between Helium and Nitrogen is 1:4.46, which is equal to 22,42%.

What this means?

By limiting the raise of Nitrogen fraction in a gas mix to 22,42% of Helium fraction drop, we are sure that there will be no increase in overall rapid tissues gas load.

Coming back on our example, what gas can we use at 60m./102psi (7 bars of ambient pressure)?

Bottom gas: Trimix12/65

Helium Pp: 4.55
Nitrogen Pp: 1.61

Deco gas: 22/52
Helium Pp: 3.64
Nitrogen Pp : 1.82

So, after gas switch, overall rapid tissues gas loading is:

He 3.64 x 0.015 + N2 1.82 * 0.067 = 0.176

which is the same as before gas switch:

He 4.55 x 0.015 + N2 1.61 x 0.067 = 0.176

In this case we've reduced He fraction by 13 and increased Nitrogen fraction by 3 (about 23% of drop of He fraction, *due to rounded values*).

This proofs that limiting the raise in Nitrogen fraction while reducing He fraction can prevent Isobaric counterdiffusion.

In case of Helium / Hydrogen (or any other gas) mix switches, the same process can be applied, using adjusted fat solubility ratios.

Another method to evitate ICD problems is the use of binary mixes, such as O2/He (Heliox), and reducing inert gas fraction while decompressing, up to oxygen.
In this case there is only one inert gas, so no counterdiffusion at all.

Some divers have also tested Argon in shallow decompression mixes.
Due to its high narcotic power it cannot be used in deep stops.
The advantage is that Ag is a ***"heavy gas"***: Helium diffuses 2.65 times more rapidly than N2 and 3.164 time more than Argon.
This means that there is no counterdiffusion with He, N2 or H2 (all these gasses are ***"lighter"*** than Argon.

However, there is no enough data on use of Argon in decompression phase to say that it's a good practice.

Insights:

Kunkle and Strauss observed ICD in laboratory bubbles.
ICD in divers was described in1978 by Idicula and Labertsen.
They observed that in subjects breathing a gas mix but surrounded by another, the gas diffusion in different directions, without depth change, can generate bubbles without decompression.

In detail, there are two types of ICD: superficial ICD and Deep ICD.

SUPERFICIAL ICD

In this form of ICD, breathed gas diffuses slowly compared to inert gas surrounding the diver body.
If diver body is surrounded by a gas mix rich in Helium while breathing a mix rich in Nitrogen (e.g. air) this results in Helium diffusing fastest than Nitrogen diffuses outside.

This may occur when inflating dry suit with bottom mix (Trimix rich in He) when breathing Nitrox or Air or while making ***"Air breaks"*** using bottom mix.

DEEP TISSUE ICD

This occurs when changing breathing gas in decompression phase.
As saw in example we made previously, new breathing gasses diffuses faster than gasses in tissues (overall inert gasses gas load).

From recent studies of Doolette and Mitchell concerning IEDCS (Inner Ear Decompression Sickness), switching from Trimix to Nitrox on ascent may cause a supersaturation on inner ear resulting in a DCS.

Switches must be made at maximum allowed PpO_2 in consideration of oxygen toxicity.