Fitness and Bubbles.

Helsingfors 29 – 30 januari 2011.

Finska sportdykarförbundet och Finska dykläkarförbundet tillsammans med DAN Europe arrangerade sista helgen i januari 2011 ett symposium med temat Fitness and Bubbles.

Programmet framgår nedan och på de följande sidorna finner ni bilderna från mitt föredrag ”The role of oxygen and carbon diaoxide in the transport of inert gases.” Ett sammandrag av konferensen kommer att finnas i tidningen Sukeltaja eller http://www.sukeltaja.fi/content/en/11501/83/83.html

AGENDA

SATURDAY 29.1.2011

9.00	Registration and coffee

Morning session

Chairman Prof. Seppo Sipinen (SSLY)

10.00	Opening session (Prof. Seppo Sipinen SSLY & Dr Matti Anttila, Finnish Divers' Federation)
10.30	Prevention of decompression sickness - issues beyond decompression algorithms (Prof. Simon Mitchell)

DAN Divers' Day

11.30	Diving accident statistics among domestic divers in Finland (Dr Jari Suvilehto)
12.15	Lunch
13.45	What is DAN? (Mr Steve Clark)
14.15	Recent advances in recreational diving medicine research (Prof. A. Marroni)
15.15	Coffee
15.45	Decompression safety aspects in technical diving (Dr O. Hyldegaard)

Afternoon session

Chairman Prof. Seppo Sipinen (SSLY)

16.45	Aerobic exercise for DCS prevention (Prof. Alf Brubakk)
17.15	Close
19.45	Dinner party (Restaurant Botta, Museokatu 10, Helsinki)

SUNDAY 30.1.2011

9.00	Registration and coffee

Morning session

Chairs Mr Mika Rautiainen (Finnish Divers' Federation) & Dr Timo Jama (SSLY)

10.00	The role of oxygen and carbon dioxide in the transport of inert gases (Prof. Hans Örnhagen)
10.45	Carbon dioxide: big, bad and hard to measure, relevant to any diver (Prof. Simon Mitchell)
12.00	Lunch

Afternoon session

Chairs Prof. Seppo Sipinen (SSLY) & Dr Matti Anttila (Finnish Divers' Federation)

13.15	Cold and DCS (Prof. Alf Brubakk)
14.15	Respiratory physiology at extreme depth (Prof. Simon Mitchell)
15.00	Panel discussion
16.00	Close

The role of oxygen and carbon dioxide in the transport of inert gases.

Hans Örnhagen, MD, PhD Director of Research (Ret)
hans@ornhagen.se
Consulting physician Swedish Sport diving Federation

For a better understanding of inert gas transport some basic knowledge is needed.

- Composition of air
- Diffusion, mass flow and perfusion
- The function of Hemoglobine and Carboxy anhydrase
- The concept supersaturation and bubble formation
- Partial pressure of a gas and fraction of a gas in gases
- Partial pressure of a gas and amount dissolved of the gas in liquids
- Physical solution of a gas in a liquid and total amount carried in blood

There is no special carrier for inert gas in the blood but two chemical compounds that facilitate inert gas transport indirectly

these are

- **Hemoglobine** through transport of oxygen
- **Carboxy anhydrase** through convertion of CO_2 to bicarbonate and back to CO_2

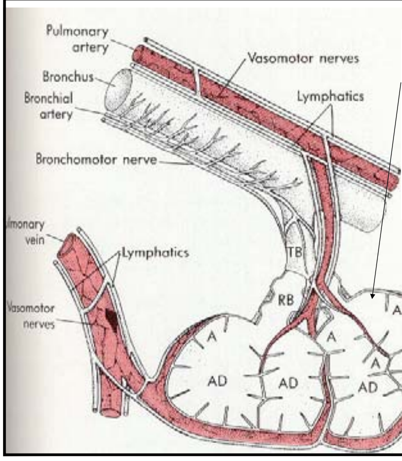
Partial pressures of gases (kPa) in dry air and in the lung

	Dry air	In the lung
N_2	78	74,0
O_2	20,9	13,4
Ar	1	0,9
CO_2	0,004	5,4
H_2O	0,1	6,3
Total pressure	100 kPa	100 kPa

Humidification, addition of CO_2 and extraction of O_2 are responsible for the changes.

In the lungs

- A large diffusion area (70 – 80 m^2) and a short diffusion distance (2 µm) give the arterial blood the same partial pressures as the alveolar gas.
- The blood contains 0.01 ml N_2 per ml blod at a PN_2 of 75 kPa (air breathing)
- If we breathe 100 % oxygen the arterial blood will be nitrogen free



If the alveolar gas is not humidified to 100% the alveolar lining would dry out.

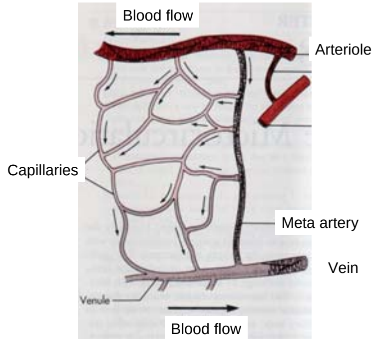
To allow fast gas transfer the alveolar membrane must be thin.

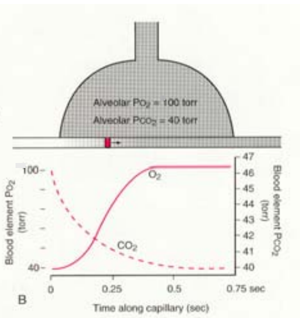
The liquid film prevents drying and the surfactant reduces the surface tension, which makes it easier to inhale and makes it possible to have large and small alveoli in the same bronchial

A cup of water on the floor

The pulmonary circulation contains approximately 200 ml or 0.2 liters

Take this amount of water (a cup) and spread it on the floor of a room of 70 m. This shows how thin the air to blood layer is in the lungs.





A red blood cell spends about 0.75 seconds in a pulmonary capillary. As seen in the diagram the transport of CO_2 and O_2 is finished after 2/3 of this time. There is thus a spare capacity for an increase in cardiac out put, but after a 50 % increase more capillaries have to be opened to allow complete equilibration between alveolar gas and blood.

In a gas mix, diffusion is inversly proportional to the square root of the molecular weight
In liquids, diffusion of a gas is directly proportional to the solubility of the gas in the liquid

To get the optimum pH in our body 7.4 the dissociation of CO_2 in water has to be balanced at a PCO_2 of 5.5 kPa (40mmHg)

CO_2 + H_2O -> HCO_3 + H
Carbon dioxide is transported in blood as bicarbonate.

Carboxy anhydrase in red blood cells facilitate this. **As important to life as hemoglobine**

How much gas is there in the body liquids at normal pressure?

Oxygen

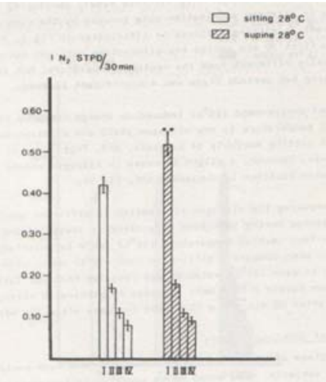
• Arterial blood (Hb bound)	200 mL
• Venous blood (Hb bound)	600 mL
• Muscles (Myoglobine bound)	250 mL
• 75 L water and fat (@ 7 kPa O_2)	75 mL
Total	1125 mL

Carbon dioxide

• Bone (Calcium carbonate)	123 000 mL
• Muscles (Bicarbonate)	9 600 mL
• Blood (Bicarbonate)	7 000 mL
Total	139 600 mL

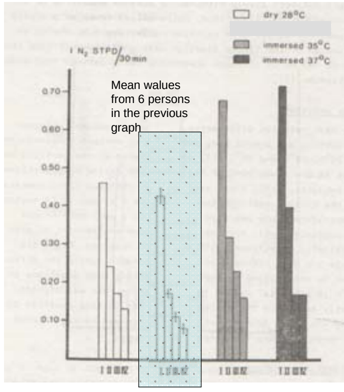
The body contains nitrogen already at 1 atmosphere

- We are ”saturation divers” at 100 kPa (1 atm). PN_2 in the lungs is 75 kPa
- The body contains:
  in the water phase 65 kg (0.75x0.012x65) 580 ml N_2
  in the fat phase 15 kg (0.75x0.062x15) 680 ml N_2
  which means a total of appr 1.3 liter of N_2
- If we go to, and stay 12 h, at the doubble pressure 200 kPa the another 1.3 liter N_2 is dissolved in the body.



Nitrogen wash out during oxygen breathing. Mean values from six persons of normal body weight sitting and supine.
I = 0 – 30 min
II = 31 – 60 min
III = 61 – 90 min
IV = 91 – 120 min

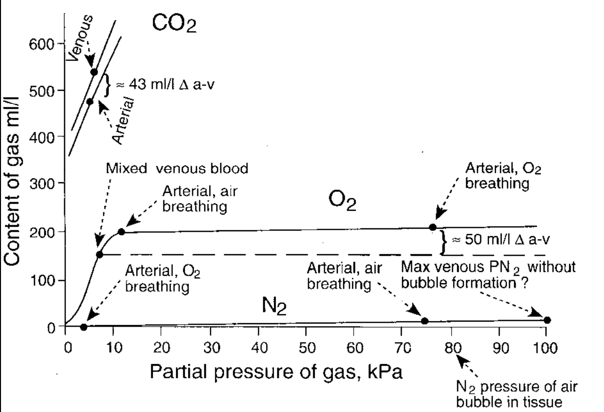
(From Ul Balldin 1973)



Nitrogen wash out during oxygen breathing in one person with 20 kg above normal body weight sitting dry and immersed at two different water temperatures.
I = tid 0 – 30 min
II = 31 – 60 min
III = 61 – 90 min
IV = 91 – 120 min

(From Ul Balldin 1973)

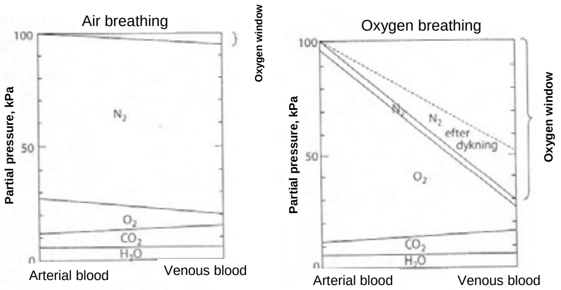
Gas content of blood at atmospheric pressure (100 kPa)



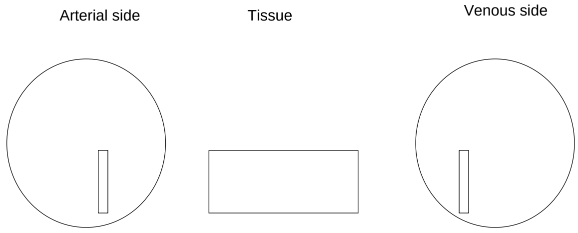
	Gas partial pressures (kPa) during air and oxygen breathing						
Air		**H_2O**	**O_2**	**CO_2**	**Inert**	**=**	**Tot**
	Outside air	**2**	**21**	**0,004**	**77**	**=**	**101**
	In lungs	**6,3**	**13,4**	**5,5**	**75,8**	**=**	**101**
	In arteial blood	**6,3**	**13,2**	**5,5**	**76**	**=**	**101**
	In venous blood	**6,3**	**7**	**6,5**	**76**	**=**	**95,8**
				Oxygen window			**5,2**
Oxygen							
	Dry oxygen	**0**	**101**	**0**	**0**	**=**	**101**
	In lungs	**6,3**	**87,2**	**5,5**	**2**	**=**	**101**
	In arteial blood	**6,3**	**87**	**5,5**	**2**	**=**	**101**
	In venous blood	**6,3**	**8**	**6,5**	**5**	**=**	**25,8**
				Oxygen window			**75,2**

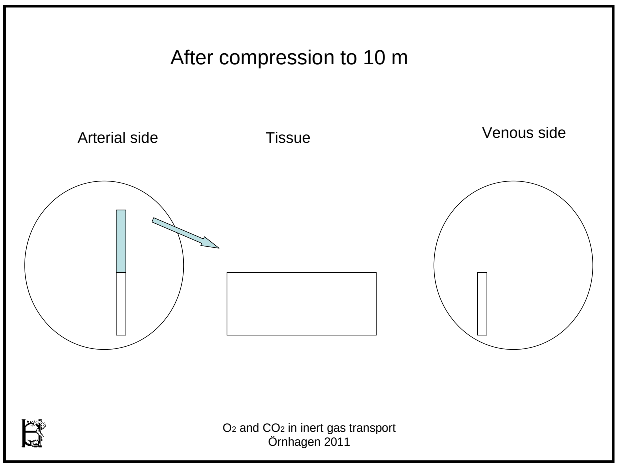
Oxygen window during air breathing and oxygen breathing

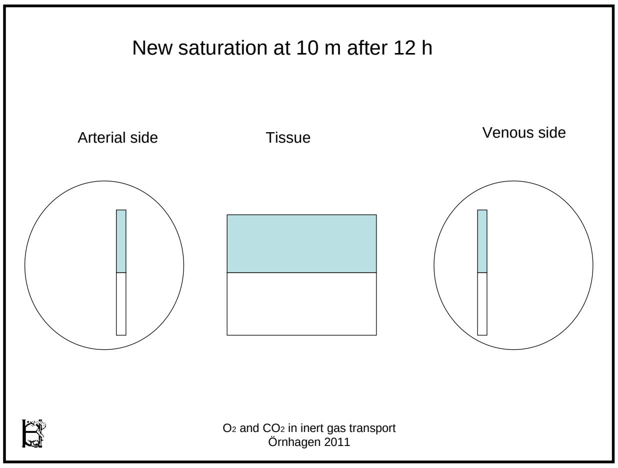
Please note that after a dive the amount of N_2 transported in the blood can vary depending on the degree of supersaturation

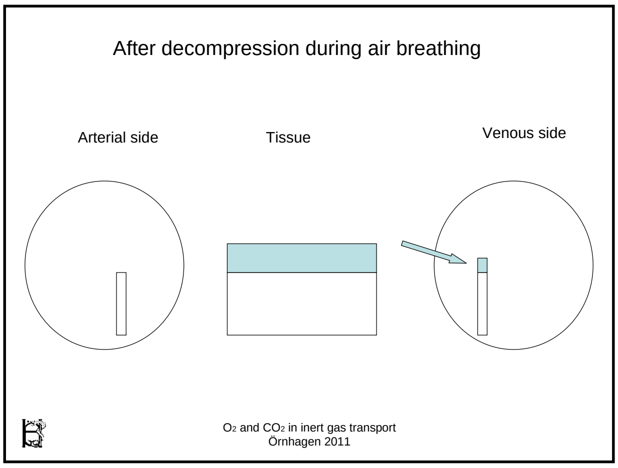


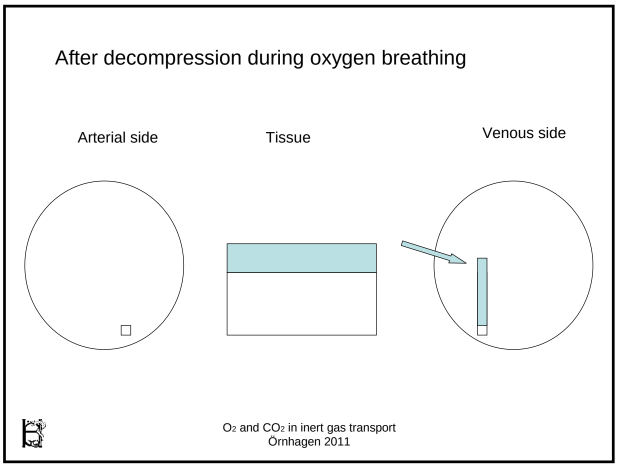
”Saturation” at surface (1 atm) breathing air

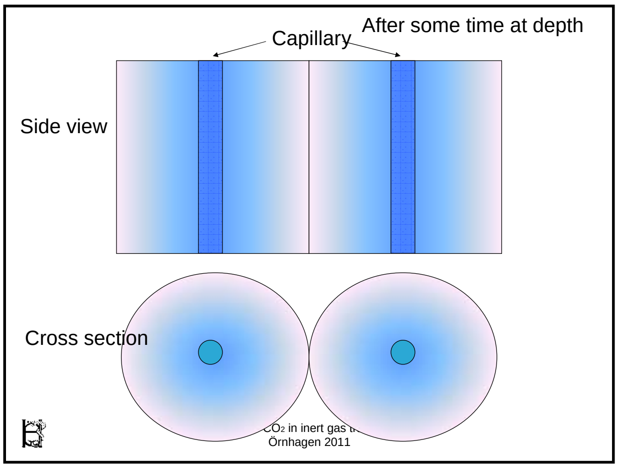


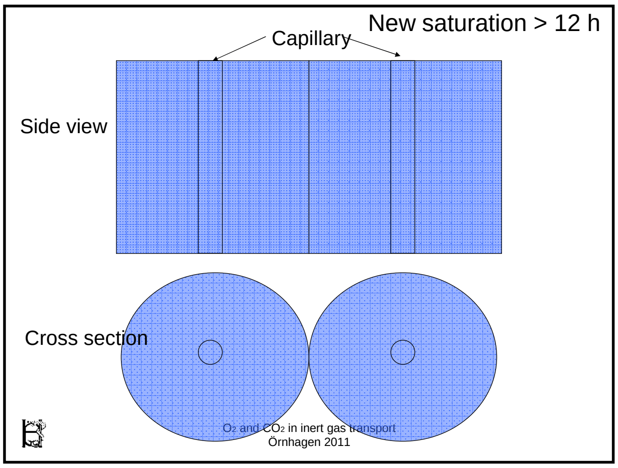

After compression to 10 m
Arterial side
Tissue
Venous side
O_2 and CO_2 in inert gas transport
Örnhagen 2011

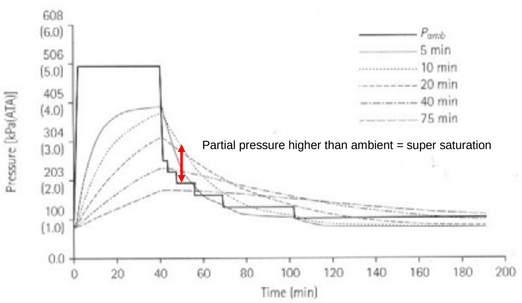

New saturation at 10 m after 12 h
Arterial side
Tissue
Venous side
O_2 and CO_2 in inert gas transport
Örnhagen 2011


After decompression during air breathing
Arterial side
Tissue
Venous side
O_2 and CO_2 in inert gas transport
Örnhagen 2011


After decompression during oxygen breathing
Arterial side
Tissue
Venous side
O_2 and CO_2 in inert gas transport
Örnhagen 2011

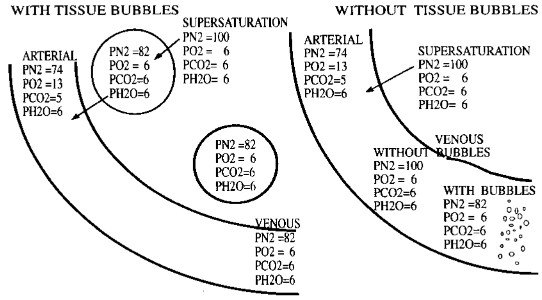

After some time at depth
Capillary
Side view
Cross section
CO_2 in inert gas
Örnhagen 2011


New saturation > 12 h
Capillary
Side view
Cross section
O_2 and CO_2 in inert gas transport
Örnhagen 2011



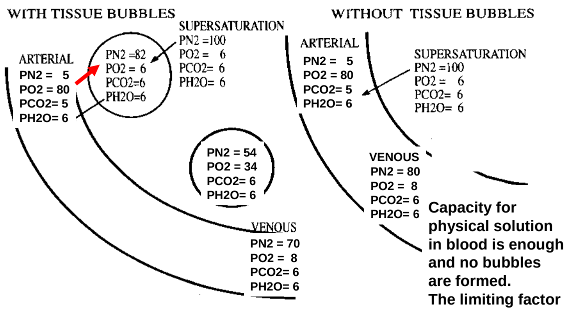
O2 and CO2 in inert gas transport
Örnhagen 2011

Partial pressures of gases in tissue and blood after diivng. Please note that if bubbles are created in the tissue the gas pressure and super saturation is lowered and the gradient and gas transport to the blood will be reduced



O2 and CO2 in inert gas transport
Örnhagen 2011

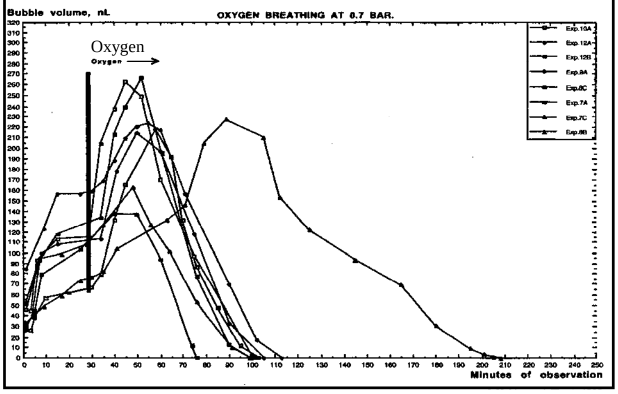
OXYGEN BREATHING



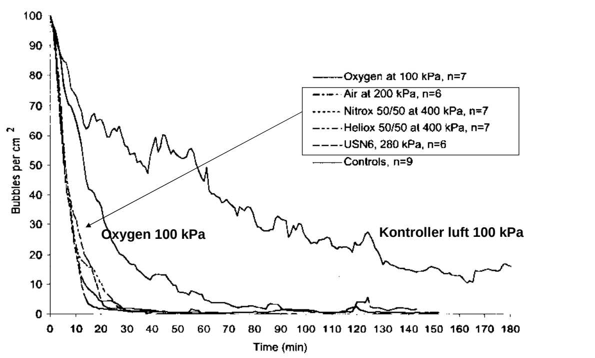
Capacity for physical solution in blood is enough and no bubbles are formed. The limiting factor is diffusion from tissues.

O2 and CO2 in inert gas transport
Örnhagen 2011

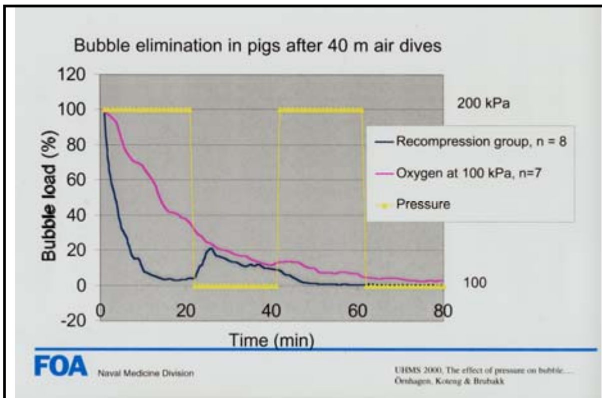
Change in volume of bubbles in mesenterial fat after a dive.
Experiments in rats.



Time course for disappearance of bubbles in venous blood after diving.
Data from ultra sound measurements on mini pigs exposed to air 40 minutes at 40 m.

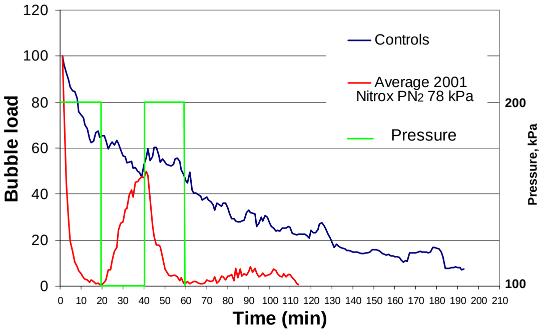


Koteng, Örnhagen and Brubakk. EUBS 1998



O2 and CO2 in inert gas transport
Örnhagen 2011

Bubble wash out in anestetized pigs after dry air dives breathing air at 100 kPa or 78 kPa nitrox at 200 kPa.



O2 and CO2 in inert gas transport
Örnhagen 2011

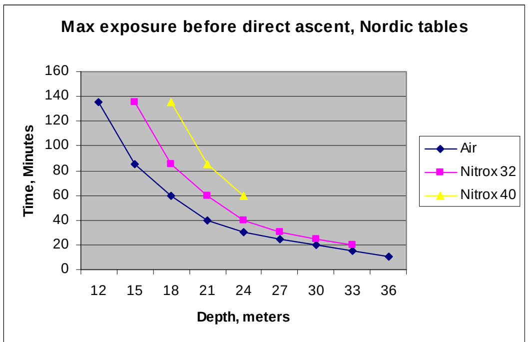
With this knowledge

- You can increase the rate of saturation decompression
- You can shorten decompression time in bounce diving
- You can reduce bubble load and treat decompression illness

But you can also use oxygen prophylactically

- Nitrox or oxygen enriched air

O2 and CO2 in inert gas transport
Örnhagen 2011



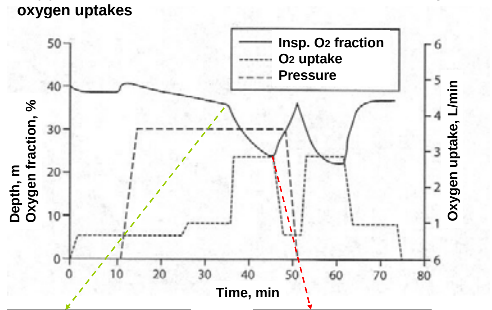
O2 and CO2 in inert gas transport
Örnhagen 2011

Nitrox is easy and safe at shallow depth and open demand systems.

In rebreathers you need to know the exact oxygen fraction or partial pressure

O2 and CO2 in inert gas transport
Örnhagen 2011

Oxygen fraction in a semiclosed rebreather at different depths and oxygen uptakes

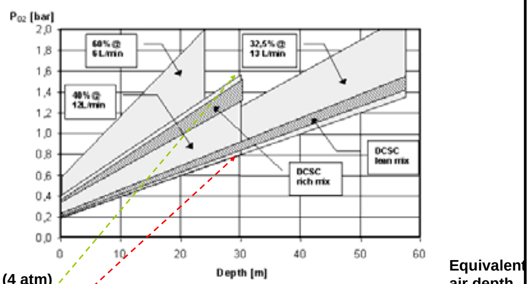


PO2 1.4 hence PN2 2,6 equivalent air depth 23 m

PO2 0,9 hence PN2 3,1 equivalent air depth 29 m

O2 and CO2 in inert gas transport
Örnhagen 2011

PO2 during rest and 2.5 l/ min oxygen uptake using two different types of semiclosed rebreathers. (Graph from Teknosofen.se)



At 30 m (4 atm)

		Equivalent air depth
Resting	(0,5 l/min O2 uptake) PO2 is 1,6 and the PN2 2,4 atm	20 m
Working	(2,5 l/min O2 uptake) PO2 is 0,8 and the PN2 3,2 atm	30 m

O2 and CO2 in inert gas transport
Örnhagen 2011

Please remember

- It is the carboxyanhydrase that does the trick through production of bicarbonate, which reduces the blood PCO2 and the sum of partial pressures in the venous blood and makes it possible to transport inert gas without too high super saturation.

O_2 and CO_2 in inert gas transport
Örnhagen 2011