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DCS AND DECOMPRESSION THEORY – BASIC PRINCIPLES PART I

In the last article we briefly looked at the early history of decompression sickness (DCS) and started to show how the uptake and elimination of inert gas from the body follows an exponential curve. If we dive down to 10 metres depth at the beginning of a dive and stay there, the partial pressure of nitrogen (pN2) in the air we are breathing will be 1.6 atmospheres (ata) while the pN2 in out bodies will be 0.8 ata. Over time, the pN2 in our bodies will rise as N2 is absorbed until it is the same as the pN2 in the air that we are breathing (we have become saturated).

A fascinating fact is that the amount of time it takes the pN2 to rise from 0.8 ata to 1.2 ata (1/2 of the way from 0.8 ata to 1.6 ata) will be exactly the same amount of time it takes the pN2 to go from 1.2 ata to 1.4 ata, and exactly the same amount of time it takes the pN2 to go from 1.4 ata to 1.5 ata, etc. This is a common occurrence in many processes and the amount of time it takes to effect ½ of the change is called a 'half-time'. In one half-time the tissue can be said to be 50% saturated, in two half-times it will be 75% saturated, in 3 half-times 87.5% saturated, in 4 half-times 93.75% saturated, in 5 half-times 96.875% saturated, in 6 half-times 98.4375% saturated, etc.

If this process is shown on a graph, an exponential curve is revealed (an 'exponential equation' can be written to describe the curve). Although the curve will never quite reach 100%, after 5 or 6 half-times for all practical purposes saturation has been achieved. The fact that the uptake and elimination of inert gas by the body follows an exponential curve was first discovered by John Scott Haldane in the early 1900s and was his first 'principle'.

A related fact is that we absorb inert gas much faster at deep depths than at shallow depths. For example, if we descended to 40 metres at the beginning of a dive, the pN2 in the air we were breathing would be roughly 4.0 ata (80% of 5 ata total pressure). Therefore, the pressure pushing N2 into our bodies would be 3.2 ata (4.0 ata minus 0.8 ata). However, if we descended to only 10 metres the pressure pushing N2 into our bodies would be 0.8

THE RATE AT WHICH WE BREATHE DOES NOT HAVE ANY SIGNIFICANT EFFECT ON THE AMOUNT OF NITROGEN THAT IS ABSORBED BY OUR BODIES

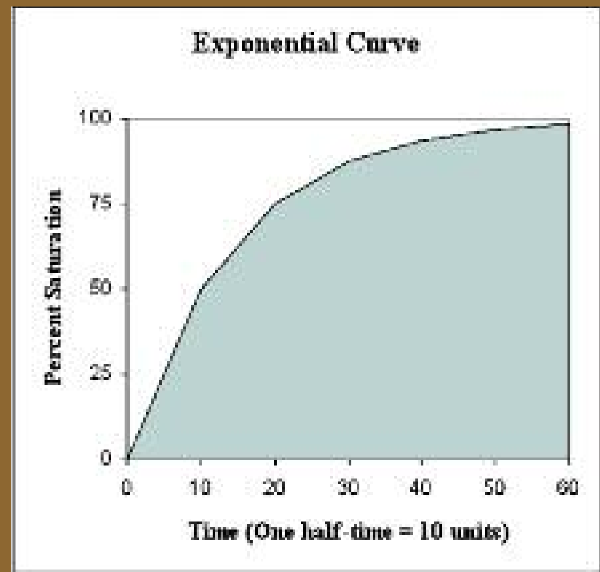
ata (80% of 2 ata total pressure = 1.6 ata pN2 in the air we are breathing – 0.8 ata pN2 in our bodies = 0.8 ata driving pressure). Therefore, at 40 metres we are four times deeper than at 10 metres but we will absorb inert gas into our bodies five times faster.

We now need to move from physics to physiology. Haldanes' second principle, that the rate of saturation varies from tissue to tissue, is based on several facts. Except for a trivial amount of nitrogen that dissolves in our skin (if we are wearing a dry suit while diving) the only way in which nitrogen can reach the tissues of our bodies and be absorbed is to be carried from our lungs to the tissues by the blood. The amount of nitrogen that can be carried by the blood is directly related to the pN2 of the gas in our lungs. The pN2 in our lungs is the same as the air we are breathing at normal rates of respiration. Breathing faster and deeper does NOT significantly change the pN2 of the gas in our lungs. Therefore, the rate at which we breathe does not have any significant effect on the amount of nitrogen that is absorbed by our bodies. This important fact is frequently misunderstood.

The amount of nitrogen absorbed by our bodies is directly related to the pN2 we are breathing, the time we breathe it, and the amount of blood passing from our lungs to the tissues. Therefore, from a physiological perspective, the critical factor is the amount of blood moving from the lungs to the tissues. The amount of blood moving through the lungs is equal to the amount of blood being pumped by the heart and is called the 'cardiac output'.

The cardiac output of an average 70 kg person at rest is approximately 5 litres per minute. At maximum exercise the cardiac output can increase to 30-40 litres per minute depending on the fitness level and size of the person. Therefore, the amount of blood moving through the lungs, absorbing nitrogen and carrying it to the tissues increases six to eight times from rest to maximal exercise.

Cardiac output is a function of the heart rate (number of times the heart beats each minute) and the stroke volume (the amount of blood being pumped with each beat). Although stroke volume does change (it increases as we become fitter, it increases with exercise, it changes with the heart rate, etc.) the change in stroke volume has a smaller effect on cardiac output than the change in heart rate. Therefore, we can approximate cardiac output by measuring the heart rate.



Fundamental Concepts for Decompression and DCS

1. The uptake and elimination of inert gas by the body follows an exponential curve.
2. The rate at which inert gas is absorbed into our bodies increases with depth.
3. Nitrogen delivery to tissues is a function of the pN2 we are breathing and our cardiac output.
4. On a hard working or stressful dive, nitrogen will be absorbed into the body at approximately twice the rate assumed by decompression models.
5. Nitrogen is 4.5 times more soluble in fat than in water.
6. Obese people have an increased risk of altitude DCS (decompression from saturation).

Cardiac output is related to the level of exercise but it is also related to a person's level of anxiety. At rest, most people have a heart rate of 60-100 beats per minute (fit individuals are often less than 60). At maximal exercise the heart rate is approximately equal to 220 minus a person's age. However, I have seen fit young divers, resting in the water before an experimental dive with a heart rate of 160 due to anxiety!

If you really understand these concepts you will have realized that a diver who is working hard and most 'stressed' divers will have an increased breathing rate, increased gas consumption and that this will be related to increased risk of DCS. However, an anxious person may have a normal breathing rate. The important point is that it is the cardiac output, not the breathing rate that matters.

These factors can be very significant in diving. Most decompression tables/models/computers are developed for a relaxed diver doing light work. Many new divers are very anxious and will have very high heart rates and cardiac outputs during a dive. If they are diving a profile that is anywhere near the no-decompression limits, they can easily absorb more nitrogen than predicted by the tables and develop DCS after the dive.

In the same way, a diver who is working hard during a dive will absorb far more nitrogen than assumed by the table and have an increased risk of DCS. As a rough rule of thumb, on a dive where you are working moderately hard (not maximal work) for the entire dive or a dive where you are 'stressed' and have a high heart rate, you will absorb approximately twice as much nitrogen as assumed by

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decompression models. Therefore, you should double your bottom time to determine your true decompression requirement based on the amount of nitrogen you have absorbed.

For example, most decompression models have a no-decompression limit of approximately 50 minutes for a dive to 18 metres. Therefore a dive to 18 metres for only 30 minutes should have a very low risk of DCS. However, if the diver was stressed and/or working hard during the dive they could easily absorb the same amount of nitrogen as the tables calculate for a dive to 18 metres for 60 minutes (10 minutes beyond the no-decompression limit). Even though they only did a dive to 18 metres for 30 minutes, if they ascend directly to the surface they will have missed several minutes of decompressions stops that are required to eliminate some of the excess nitrogen in their bodies, and they will have a significant risk of developing DCS.

The next important fact that determines why the rate of saturation varies from tissue to tissue is that nitrogen is 4.5 times more soluble in fat than in water. What this means is that if fat and water are exposed to the same elevated pN2, nitrogen will dissolve into the fat and water at the same rate but it will take 4.5 times longer for the pN2 in the fat to rise to the same pN2 as the surrounding gas, and when it does the fat will contain 4.5 times more nitrogen than the water, even though the pN2 in the fat and the water would be the same.

This fact is very important for altitude DCS (decompression from saturation) where an obese person will have a much larger amount of nitrogen in their bodies than a thin person, and a much higher risk of developing DCS.

The contribution of obesity to the risk of DCS after diving is much more complicated and will be discussed in the next article.

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