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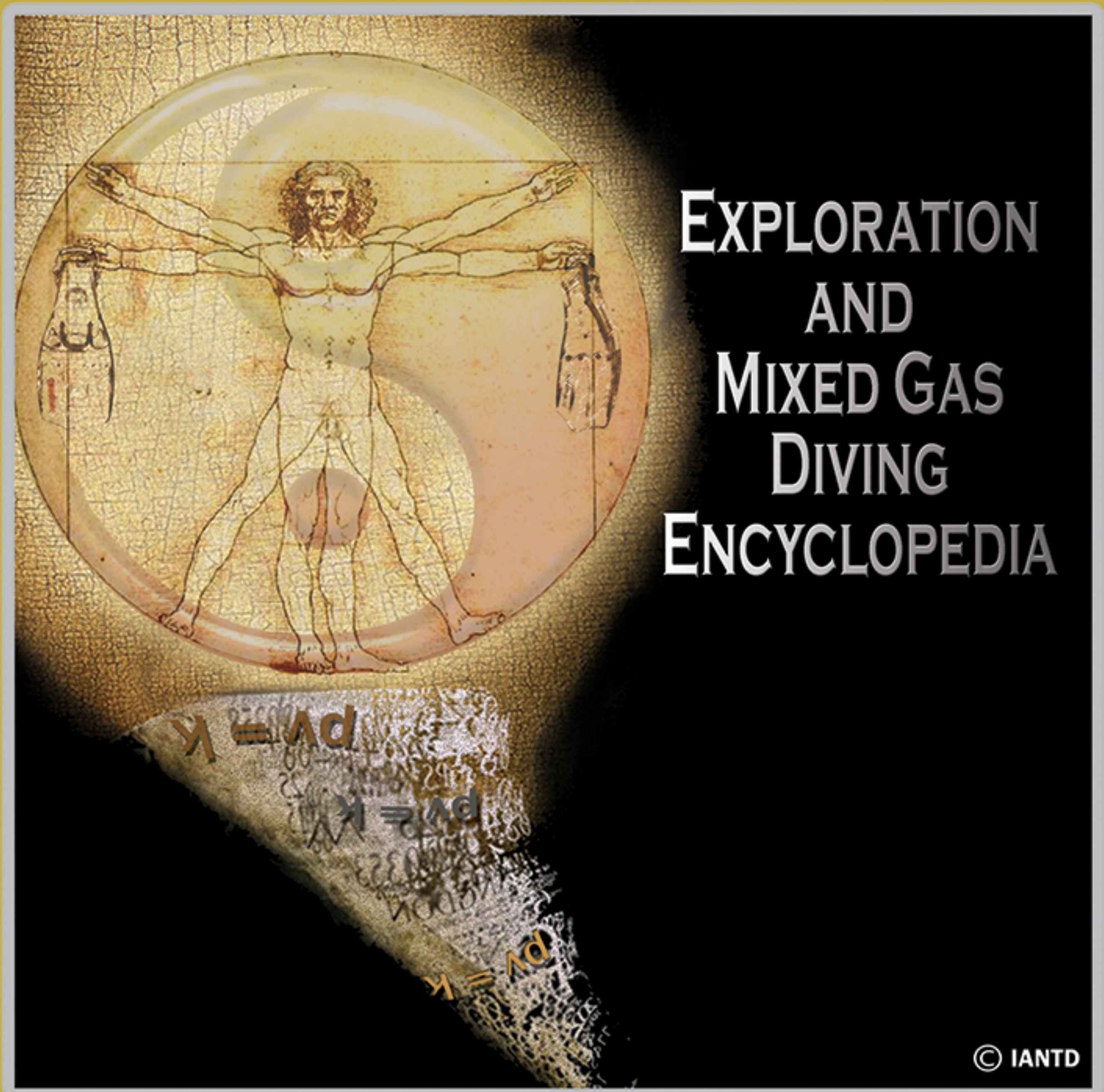

NORMOXIC TRIMIX MANUAL

Compiled chapters from the Exploration and Mixed Gas Diving Encyclopedia - The TAO of Survival

Student Manual by
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Exploration and Mixed Gas Diving Encylopedia
The Tao of Survival Underwater

Disclaimer

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Chapter One
The Basics Of Physiology For Technical Divers

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Introduction

We expose ourselves as divers to numerous environmental, physiological, and operational events that affect our well being and safety. Ideally, a technical diver will seek out more information and thereby develop a comprehensive understanding of anatomy, physiology, and behavior mechanics. Given the space allotted for this chapter, we cannot provide as much in-depth knowledge in these areas as we wish. However, we can provide the technical diver with a foundation in these areas. We are also able to encourage technical divers to engage in their own research as to how our physiology and anatomy functions on a day-to-day basis, as well as how diving affects our bodies. It is difficult to avoid activities that may predispose us to injury without an understanding as to how the body works. A prudent diver will use this chapter to structure their own quest for knowledge.

Technical diving not only exposes us to various diving maladies, it also presents opportunities for physical injury and strain due to the weight bearing nature of the sport. Due to the physical stresses of diving, one should also maintain a level of fitness beyond that of the average person in order to avoid injury. The following discussion concerns the circulatory, neurological, and respiratory systems, and combines with an overview of PH balance. This chapter also includes a section on exercise, which emphasizes exercise as applicable to divers. We feel this is only the minimum a technical diver should explore, as in technical diving all of our anatomical and physiological systems are at risk. To reduce the threat please stay informed. Understanding physiology is the first step toward becoming a survivor.

The Circulatory System

The circulatory system is a closed-loop system consisting of the heart, arteries, veins, tissue capillaries, and lung capillaries. The circulatory system provides a steady source of blood to the body and a continuous supply of oxygen to the tissues. The circulatory system also removes carbon dioxide from the tissues. Nutrients are also delivered to the body's cells through the circulatory pathway. Along with carbon dioxide, the circulatory system removes the body's metabolic wastes. The complete circuit goes from one side of the heart to the other side of the heart.

The heart is the pump that propels blood through the circulatory system. The heart's contractions produce blood pressure, propelling blood, which carries gasses and nutrients to the arteries. In order to maintain an adequate flow of blood to all parts of the body, it is necessary that the body's physiology sustain a certain level of blood pressure. The force and amount of blood pumped and the size and flexibility of the arteries determine blood pressure. Since the heart adjusts its blood pressure to meet the body's needs, blood pressure changes constantly. Your blood pressure depends on your activity level, temperature, diet, emotional state, posture, physical state, and medication use. The carotid sinuses, which are a type of artery found in the neck, are pressure-sensing nerves that are highly sensitive to fluctuations in the blood's

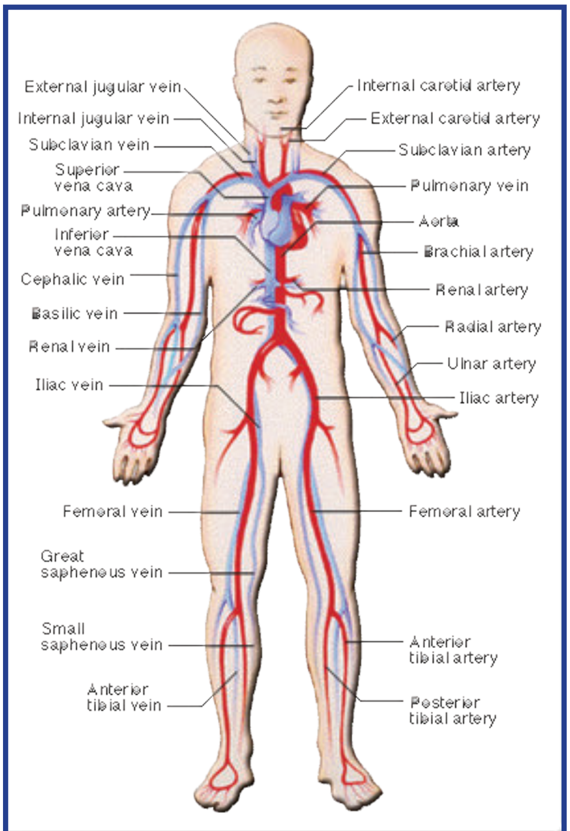


Figure 1-1: The Circulatory System
Courtesy the American Medical Assoc.
www.ama-assn.org

pressure throughout the body. The carotid sinuses aid in regulating overall blood pressure by informing the brain, via impulses, about any changes in blood pressure.

Oxygen, which is critical to life, binds with an iron-rich protein found in red blood called hemoglobin. Arteries and capillaries transport oxygenated hemoglobin to the body's cells. The body's tissues absorb the oxygen, use it, and give off carbon dioxide (***CO_2***). CO_2 then combines with the de-oxygenated hemoglobin and returns to the lungs via the veins. Correct breathing technique insures that the hemoglobin maximizes its capacity to transport oxygen efficiently. Improper breathing such s shallow or erratic breathing results in the "clumping" of oxygenated red blood cells (***RBC***), whereas proper breathing results in a smooth distribution of oxygenated RBC. See Figure 1-1 for a diagram of the circulatory system.

It is notable that the circulatory system functions as one system containing two separate subsystems, the pulmonary system and the systemic system. The pulmonary system supports the circulation dedicated to the lungs, while the systemic system services the body tissues. Nerve impulses,which transfer information regarding the body's physiological state to and from the brain control these systems. By studying the diagram of the circulatory system below, it is apparent that the circulatory system functions as a transport mechanism for gas to travel to and from the tissues.

The overall health of a person depends on the body's ability to maintain a healthy circulatory system. Any alteration to the circulatory system will have a corresponding effect on gas transport. These alterations can include blood vessel injuries, fat concentration, blood vessel disease, or even the effects of prescription or common across-the counter drugs.

Blood Transport & the Circulatory System

To improve one's understanding of the circulatory system and the role blood transport, pressure, and flow has in maintaining life, please refer to the ***Cardiovascular System*** section on the website of ***Anatomy and Physiology***, which details the role of veins and arteries in blood transport (***Please Note: Diagram placement was altered for formatting purposes.***) **To quote:**

Blood Vessels

Blood vessels are the channels or conduits that distribute blood to body tissues. The vessels make up two closed systems of tubes that begin and end at the heart. One system, the pulmonary vessels, transports blood from the right ventricle to the lungs and back to the left atrium. The other system, the systemic vessels, carries blood from the left ventricle to the tissues in all parts of the body and then returns the blood to the right atrium. Based on their structure and function, blood vessels are classified as arteries, capillaries, or veins.

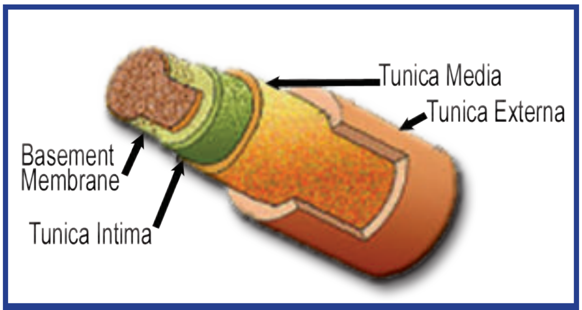


Figure 1-2: The Artery Wall

Arteries

Arteries carry blood away from the heart. Pulmonary arteries transport blood with low oxygen content from the right ventricle to the lungs. On the other hand, systemic arteries transport newly-oxygenated blood from the left ventricle to the body tissues. Blood pumps from the ventricles into large elastic arteries that branch repeatedly into smaller and smaller arteries until the branching results in microscopic arteries called arterioles. The arterioles play a key role in regulating blood flow into the tissue capillaries.... The wall of an artery consists of three layers....The middle layer... is usually the thickest layer. It not only provides support for the vessel but also changes vessel diameter to regulate blood flow and blood pressure....

Veins

Veins carry blood toward the heart. After blood passes through the capillaries, it enters the smallest veins, called venules. From the venules, blood flows into progressively larger and larger veins until it reaches the heart. In the

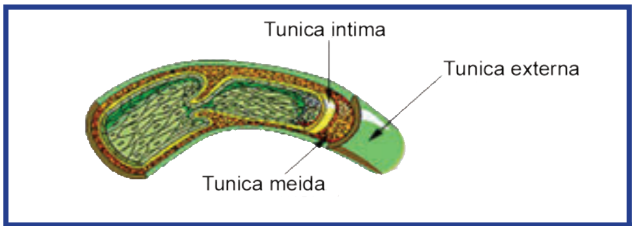


Figure 1-3: The Vein

pulmonary circuit, the pulmonary veins transport blood from the lungs to the left atrium of the heart. This blood has high oxygen content as it recently passed through the lungs. Systemic veins transport blood from the body tissue to the right atrium of the heart. This blood has reduced oxygen content, as oxygen depletes during metabolic activities in the tissue cells…. Almost 70% of the total blood volume is in the veins at any given time…. Medium and large veins have venous valves…. Venous valves are especially important in the arms and legs, where they prevent the backflow of blood in response to the pull of gravity.

Capillaries

Capillaries, the smallest and most numerous of the blood vessels, form the connection between the vessels that carry blood away from the heart (***arteries***) and the vessels that return blood to the heart (***veins)***. The primary function of capillaries is the exchange of materials between the blood and tissue cells. Capillary distribution varies with the metabolic activity of body tissues. Tissues such as skeletal muscle, liver, and kidney have extensive capillary networks because they are metabolically active and require an abundant supply of oxygen and nutrients. Other tissues, such as connective tissue, have a less abundant supply of capillaries…. About 5% of the total blood volume is in the systemic capillaries at any given time… In addition to forming the connection between the arteries and veins, capillaries have a vital role in the exchange of gases, nutrients, and metabolic waste products between the blood and the tissue cells...

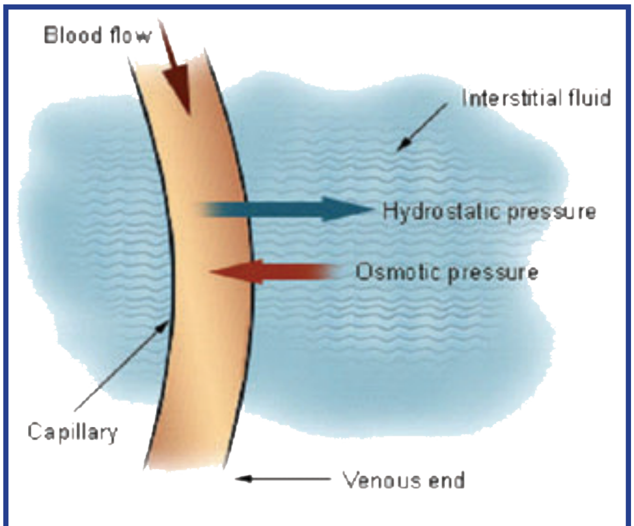


Figure 1-4: Capillary Microcirculation

The rate, or velocity, of blood flow varies inversely with the total cross-sectional area of the blood vessels. As the total cross-sectional area of the vessels increases, the velocity of flow decreases. Blood flow is slowest in the capillaries, which allows time for exchange of gases and nutrients. In blood vessels, most of the resistance is due to vessel diameter. As vessel diameter decreases, the resistance increases and blood flow decreases. Very little pressure remains by the time blood leaves the capillaries and enters the venules. Blood flow through the veins depends on skeletal muscle action, respiratory movements, and constriction of smooth muscle in venous walls.

Pulse refers to the rhythmic expansion of an artery that caused by ejection of blood from the ventricle. The pulse is felt where an artery is close to the surface and rests on something firm. In common usage, the term blood pressure refers to arterial blood pressure, the pressure in the aorta and its branches. Systolic pressure is due to ventricular contraction. Diastolic pressure occurs during cardiac relaxation. Pulse pressure is the difference between systolic pressure and diastolic pressure.

Blood: Plasma & Serum

Blood plasma and blood serum are important components in blood, which, among other uses, measures overall blood volume and hydration level. When dehydrated, blood volume reduces; therefore maintaining proper levels of hydration assures adequate gas exchange on dives. **Moreover, dehydrated divers may be more prone to decompression illnesses, oxygen toxicity, and other diving maladies. According to the the online encyclopedia, Wikipedia, in conjunction with online blood bank clearing house, Blood Plasma Donation Center:**

> Blood plasma is the liquid component of blood.... Plasma is the largest single component of blood, making up about 55% of total blood volume.... Blood plasma contains many vital proteins including fibrinogen, globulins and human serum albumin.... "***Serum***" refers to blood plasma in which clotting factors (such as ***fibrin***) have been removed.... Plasma resembles whey in appearance (transparent with a faint straw color). It is mainly composed of water, blood proteins, and inorganic electrolytes. It serves as a transport medium for glocose, lipids, amino acids, hormones, metabolic end products, Carbon Dioxide and Oxygen (O_2). The oxygen transport capacity and oxygen content of plasma is much lower than that

of the hemoglobin in red blood cells; the CO_2 will, however, increase under hyperbaric conditions...

A simpler explanation of blood plasma and serum, is provided by Professor John Waters of Penn State University's Biology Department; he says: ***If you take a sample of whole blood, and remove all of the formed elements, the liquid that remains is call blood plasma. Blood plasma is comprised of clotting proteins that help blood clot to seal broken blood vessels, osmotic proteins that help keep the blood isotonic to the extracellular fluid, and blood serum.***

Blood serum is comprised of:

- Dissolved nutrients such as glucose, amino acids, and fats
- Dissolved wastes, mostly urea
- Dissolved gasses, such as oxygen, carbon dioxide, and nitrogen, and
- Dissolved electrolytes such as sodium, potassium, and chloride.

Blood: Clotting Mechanisms

The human body does not handle excessive blood loss well. Therefore, the body has ways of protecting itself. If, for some unexpected reason, sudden blood loss occurs, the blood platelets kick into action. Platelets and fibrinogen are important clotting mechanisms in blood. They are essential for healing injuries. Their sticky surface lets them, along with other substances, form clots to stop bleeding. When a wound occurs, the platelets gather at the site and attempt to block the blood flow. The mineral calcium, Vitamin K, and a protein called ***fibrinogen***, help the platelets form a clot.

A clot begins to form when blood meets air. The platelets sense the presence of air and begin to break apart. They react with the fibrinogen to begin forming fibrin, which resembles tiny threads. The fibrin threads then begin to form a web-like mesh that traps the blood cells within it. This mesh of blood cells hardens as it dries, forming a clot, or "***scab***." Calcium and vitamin K must be present in blood to support the formation of clots. A healthy diet provides most people with enough vitamins and minerals, but vitamin supplements are sometimes necessary.

A scab is an external blood clot that we can easily see, but there are also internal blood clots. A bruise, or black-and-blue mark, is the result of a blood clot. Both scabs and bruises are clots that lead to healing. However, some clots can be extremely dangerous. A blood clot that forms inside of a blood vessel can be deadly because it blocks the flow of blood, cutting off the supply of oxygen. A stroke is the result of a clot in an artery of the brain; without a steady supply of oxygen, the brain cannot function normally. If the oxygen flow is broken, paralysis, brain damage, loss of sensory perceptions, or even death may occur. Moreover, when bubbles form in the bloodstream while diving under pressure, the clotting process can contribute to bubble massing. **Janis O. Flores, a well known medical author, elaborates on the clotting process in a Gale Group article; she says:**

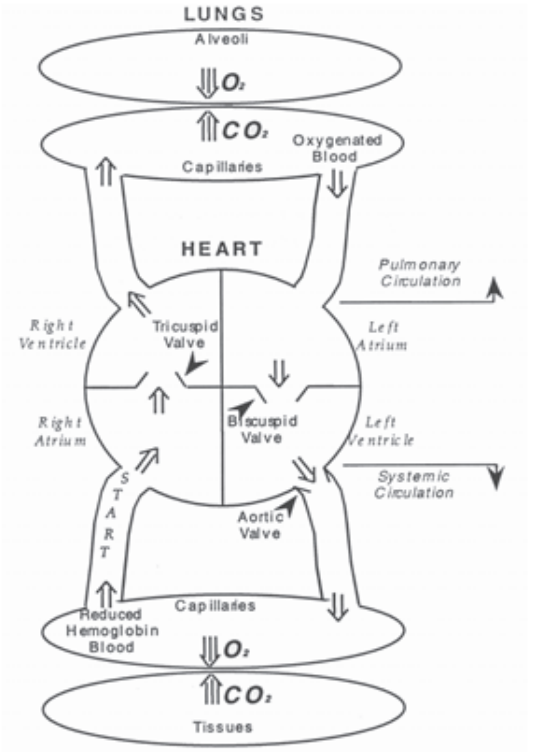
Fibrinogen plays two essential roles in the body: it is a protein called an acute-phase reactant that becomes elevated with tissue inflammation or tissue destruction, and it is also a vital part of the "***common pathway***" of the coagulation process. In order for blood to clot, fibrinogen must be converted to fibrin by the action of an enzyme called thrombin. Fibrin molecules clump together to form long filaments, which trap blood cells to form a solid clot.

The conversion of fibrinogen to fibrin is the last step of the "***coagulation cascade***," a series of reactions in the blood triggered by tissue injury and platelet activation. With each step in the cascade, a coagulation factor in the blood is converted from an inactive to an active form. The active form of the factor then activates several molecules of the next factor in the series, and so on, until the final step, when fibrinogen is converted into fibrin.

When fibrinogen acts as an "***acute-phase reactant***," it rises sharply during tissue inflammation or injury. When this occurs, high fibrinogen levels may be a predictor for an increased risk of heart or circulatory disease. Other conditions in which fibrinogen is elevated are cancers of the stomach, breast, or kidney, and inflammatory disorders like rheumatoid arthritis…

Oxygen & the Circulatory System

The transport of oxygen, which is vital to metabolism, is among the circulatory system's most important functions, see Figure 1-5. If the oxygen tension and concentration within the circulation varies outside of a known limit, it will produce adverse effects to the organism. Virtually every cell in our bodies requires oxygen, nutrition, and waste removal in order to survive. Diseases such as hardening of the arteries reduce the supply of both oxygen and nutrients to every cell, including the brain. Our memory,



Brent Blunt

Figure 1-5: Circualtory Pathway

learning skills, and virtually all our mental cognitive skills depend on a steady supply of oxygen and nutrients. For a more in-depth understanding of blood chemistry, please refer to the material presented online by the Linus Pauling Institute at Oregon State University.

Maintaining Circulatory Health Through Diet & Exercise

Diet is a vital aspect of overall health; we actually are what we eat. A fitness program that disregards the importance of diet provides minimal results. Our diets should feature a balance in five essential areas: water, grains, fruits, proteins, and vegetables. Ideally, each of these is included in every meal. Maintaining the correct amount of protein, carbohydrates, and fat is extremely important for our long-term health. The USDA recommends that the normal diet for human beings be composed of 14% protein, 25% fats, and 60% carbohydrates.

It is interesting that the USDA recommends almost the exact same diet for fattening hogs. Thus, one may want to consider using different diet guidelines. When selecting fats to be included in a diet, emphasize the Omega 3 group and avoid as many Omega 6 fats as possible. The fat in the daily diet should not exceed 30% of the total calories and should represent at least 10% of our daily intake. (I recommend 20 to 25% of good fats.) Protein should be between 20 to 40%, while the total of fat and protein should be 60 to 70% of the daily diet.

Carbohydrates provide our natural sugars and are essential for energy. Carbohydrates may range between 15 to 40% of our total calories. One's activity level and individual physiology will dictate the exact distribution of calories. Processed sugars should be minimal and completely avoided if possible. Too much sugar has adverse effects on our circulatory system and our bodies in general. Moderation is the essential word in maintaining a healthy diet. Attempt to fill sugar needs and cravings from natural substances such as fruits and vegetables.

Most adults in the USA have some degree of circulatory disease due to poor dietary and exercise habits. However, this is a reversible situation by altering certain factors, such as improving eating habits, supplementing the diet with nutrients and vitamins, and implementing a cardiovascular exercise program.

One of the most common diseases of the circulatory system is arteriosclerosis. Plaque buildup in the blood vessels leads to this condition. As the plaque accumulates, the vessel clogs and its effective diameter reduces. Arteriosclerosis results in less circulatory efficiency, which causes the heart to work harder and reduced circulation means less oxygen to tissues. The three areas of the body that are hypersensitive to decreased oxygenation are the heart, the legs, and the brain.

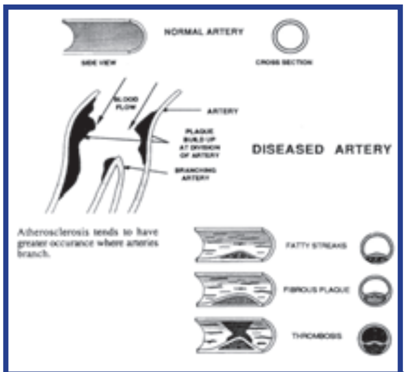


Figure 1-6: Arterial Disease

Free Radicals

Free radicals are implicated in the development of arteriosclerosis, among other illnesses. Free radicals are volatile, short-lived chemicals that are a byproduct of specific types of diet, poor exercise habits, and certain metabolic processes. Free radicals, such as the superoxide radical, have one missing electron with a single covalent bond. These radicals attack any double bond within the system, such as fatty acids and intracellular membranes.

Once the free radicals produce an injury site, plaque forms and, eventually, cholesterol attaches to it, producing circulatory system disease. The following foods produce free radicals in the human organism: fried foods, cooked fats, cooked cholesterol, alcohol, and tobacco smoke. Divers who consume a high fat diet which is similar to the Standard American Diet (***SAD***) and contains 40% fat, are at serious risk of increased free radical development and low-density cholesterol. This combination leads to circulatory problems and illnesses.

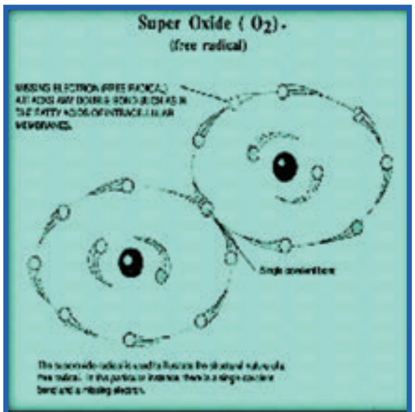


Figure 1-7: O_2 Free Radical

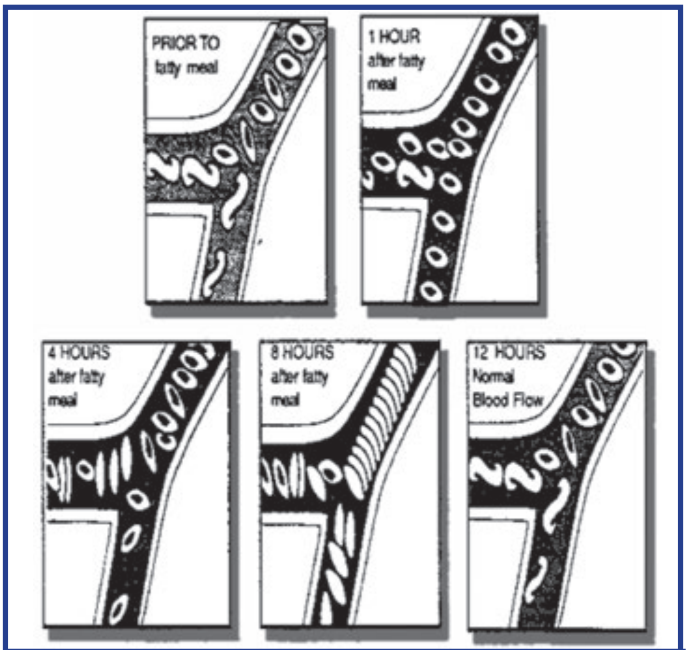


Fig. 1-8: Effects of Fatty Meals on Blood Flow

Fats

When fat and cholesterol combine, especially if the cholesterol is exposed to air and heat such as when cooking red meat, ***cholesterol oxide*** forms. Cholesterol oxide, which acts as a free radical, damages the lining of the arteries. A fatty meal produces immediate changes in the circulatory system. Within an hour of completing a fatty meal, the red blood cells begin to stick together and form clumps. As this process continues, circulation slows down, which creates a phenomenon described as ***sludging***. About six hours following the meal, the sludging is severe enough that circulation in the smallest of blood vessels almost halts. This has several effects on the body, including reduced O_2 to the tissues and a lessened ability to remove CO_2 and waste from the system. Figure 1-8, shows the time release effects of fatty food intake and sludging.

In diving, we are concerned with the transport of inert gas as well as metabolic gases. Circulatory diseases, circulatory inefficiencies, and the physiological changes associated with fat ingestion will all interfere with the elimination of inert gases while diving.

In the case of circulatory disease and the corresponding decrease in the diameter of the blood vessel, it is easy to see that gas transport will not be effective. Sludging, which decreases gas transport efficiency throughout the cardiovascular system, is associated in the literature with decompression sickness (***DCS***).

Further, if sludging occurs and a bubble of inert gas forms, the bubble is more likely to lodge in the blood vessels. This outcome increases the chance bubbles will remain in the vascular system rather than filter out through the lungs. Such a bubble has a greater likelihood of growing and creating DCS-related problems. Moreover, the changes in blood gas given sludging contributes to a host of other issues, including an increased susceptibility to oxygen toxicity, inert gas narcosis, helium tremors, carbon dioxide retention, and changes in the blood's PH balance.

However, keep in mind that not all fats are "bad," and so we need to mention "good or "cis" fats as well. Good fat produces High Density Cholesterol (***HDL***) which is thought to pick up cholesterol from body tissues and return it to the liver for reprocessing or excretion. Although this type of fat is good for us, we must be aware of the quantity we consume; the old adage, "… ***too much of a good thing***..." should be kept in mind, as obesity can strike those on an overly-high HDL diet. Foods that are high

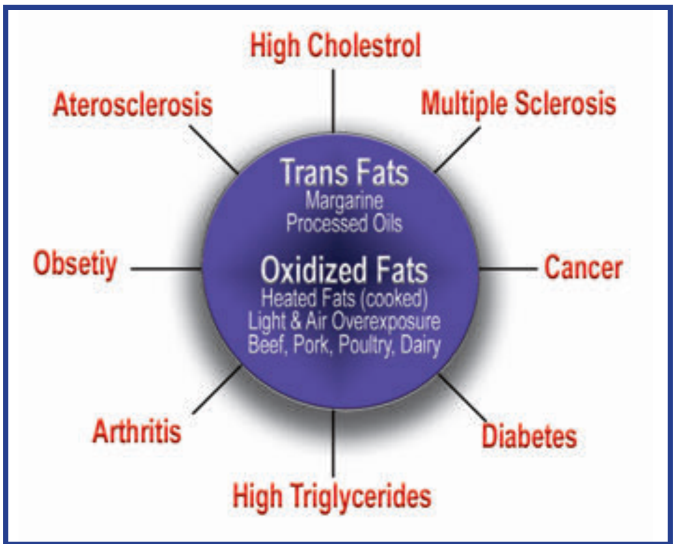


Fig. 1-9: Danger of Trans Fats and Oxidized Fats

in HDLs include certain fish and dark green vegetables, whole grains, certain fruits, and oils such as olive, flaxseed, and canola oil. Fats group into two types: ***Omega 3***, which is "***good***" fat, and ***Omega 6***, which is "***bad***" fat. In general, one should avoid the Omega 6 fats and insure some Omega 3 fats are in the diet.

Figure 1-9, the ***Trans Fats and Oxidized Fats*** chart, shows the type of fats and their effects. Much of the trans fats in the American diet come from hydrogenated vegetable oils. Other sources include red meats and margarine. Trans fats cause the mitochondria to swell. Since metabolism occurs in the mitochondria, trans fatty acids interfere with metabolism and increase blood cholesterol up to 15% and triglycerides by 47%. In contrast to trans fats, cis fats such as butter are necessary for vision, nerve function, coordination, memory, and the vital functions of life itself.

In addition, cis fats may reverse the effects of trans fats. Oils such as olive, fish, krill, flax, corn, and sesame all represent forms of cis fats and are beneficial to cells.

Antioxidants & Fiber

Antioxidants such as Vitamin E do much to reverse the development of free radicals in the body. Vitamin E elevates HDL levels and provides numerous health effects. Other antioxidants include Vitamin C, Beta-carotene, Co-enzyme Q-10 (***CoQ-10***) and Melatonin. These substances, when combined with nutrients and vitamins, especially the B-vitamins, are effective in promoting a healthier body and circulatory system. In addition to antioxidants, a healthy circulatory system needs fiber; therefore, fiber helps reduce diving-related injuries.

Figure 1-19, ***Fats/Oils and Their Prostaglandins*** shows some interesting effects of fiber on cholesterol levels in the blood.

Sugar

The body needs sugar for energy expenditure and prolonged endurance. A warm muscle will burn fat and use the sugars gained from the carbohydrates we eat. Explosive action by muscles not properly warmed up tends to burn only sugar. Thus, prior to exercise or a dive, it is wise to take a few moments to stretch and warm up the muscles before placing a demand on them. However, too much sugar, especially processed sugars, is harmful. Excess sugar forces the pancreas to secrete additional insulin, which increases the liver's efforts at storing and releasing glucose.

Aortas examined by Howard A. Neuman, Ph.D. disclosed that in areas where the sugar intake is low, people have high chromium levels and a lower incidence of arteriosclerosis. In the USA, where sugar uptake is high, chromium levels are lower, and there is an higher incidence of arteriosclerosis. This finding is associated with the pancreas' inability to

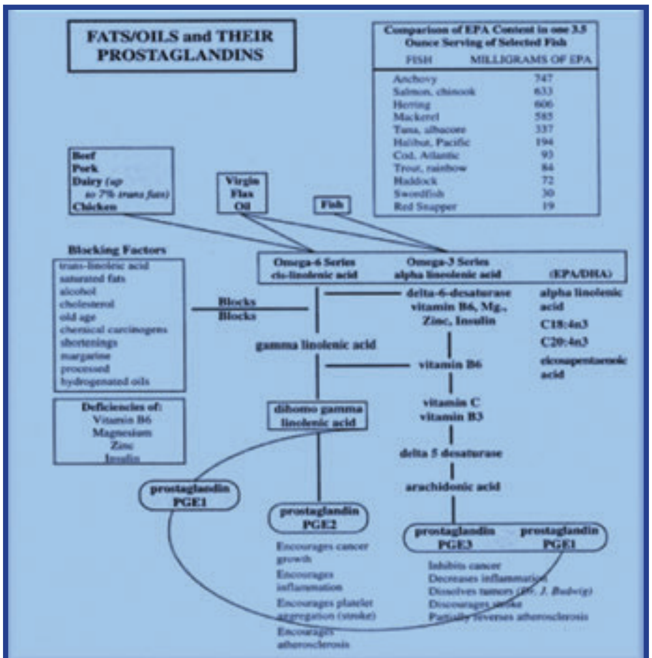


Fig. 1-10: Fats/Oils and Their Prostaglandins

meet insulin demands, which in turn raises the amount of blood fats in the circulatory system.

Increased sugar also has the side effect of weakening the immune system's ability to fight off bacteria. In one test, individuals given sucrose and fructose experienced a depression of white blood cells that lasted for up to five hours. If you are becoming ill, avoid all sweets.

High levels of sugar are also bad for the heart. By now, you should realize that a combination of excessive sugar and fats could be very damaging to the circulatory system. Certain supplements may be helpful in enhancing the heart and circulatory system's performance. In contrast, particular prescription drugs and specific supplements react in a way that is harmful to our physiology. Therefore, if you are taking prescription medications consult with your health care provider to ensure there are no drug interactions.

Supplements & Herbs for Increased Health & Well-Being

A possible effect of heart supplements that is of special interest to divers is that such supplements lower cholesterol levels in the blood vessels. Therefore, these supplements may reduce the possibility of micro bubbles that many feel contribute to decompression issues. Those who experience irregular heart beat (***arrhythmias***) should consider the supplement Taurine to assist in prevention of cavitation effect in the heart valves as this could also contribute to bubble formation. Most people would benefit from taking 30 to 60 mgs a day of CoQ-10 to strengthen the heart and act as a strong antioxidant. Anyone who has a form of heart disease should consider 150 to 300 mgs a day of CoQ-10. However, such individuals should consult with their healthcare provider about an appropriate healing strategy.

There is no need to take all of the supplements listed in this chapter. Choose one to three from each list at most, and add them, in moderation, to your diet.

The following is a list of supplements to consider for improved heart and circulation:

- **Beta 1.3 Glucan** is a polysaccharide. It helps maintain safe cholesterol levels. Beta 1.3 Glucan tends to raise the HDL and lower triglycerides, and works as an overall immune system enhancer. It also is effective in killing tumor cells and increases bone marrow production. Additionally, Beta 1.3 Glucan is effective in healing sores and ulcers in women who have underwent a mastectomy. The suggested dose is 2.5 milligrams (***mgs***) per day.
- If you suspect you may have clotting problems, consider using **Bromelain**, which aids in preventing blood clots and reducing inflammation. For divers, this may be a better option than aspirin, which some divers insist on taking. The suggested dose is 500 mgs per day.
- **CoQ-10** should be on everyone's "must take" supplement list. 60 mgs per day is appropriate for normal maintenance, and up to 300 mgs per day may be used as part of a cardiac recuperation regimen. CoQ-10 strengthens the heart, fights allergies, develops energy, stimulate the immune system, increase tissue oxygenation and may be a valuable anti-aging supplement. One six-year study at the university of Texas found that people being treated for congestive heart failure taking CoQ-10 in addition to conventional medicine had a 75% chance of survival after three years, as opposed to a 25% survival rate for those using conventional therapy only. Several studies here and in Japan reflect the CoQ-10 is effective in lowering blood pressure without using conventional medication. CoQ-10 has also been widely used in treating neurological abnormalities such as schizophrenia and Alzheimer's disease. CoQ-10 is also frequently used to fight obesity, candidiasis, multiple sclerosis, and diabetes. This supplement appears to have universal benefits. It should be used by all, and especially by those who are older, given its positive effects on the cardiac and cognitive processes. CoQ-10 is available in capsules; however, the liquid or oil form is preferable. Recent research reviewed in the magazine *Life Extension* February/ March 2008 edition provides in depth coverage of CoQ-10 and its affect on our physiology. It also points out our natural loss with age and loss due to statin and other drugs. This is necessary read fro all interested in ultimate health. It is especially important to aging divers, and those who may have heart issues or those being treated for cancer. The article also

states the only way higher levels in people with heart conditions are obtained are with ***ubiquinol*** and are not with the traditionally used ubliqinone. According to research cited in this publication, CoQ-10 from ubiquinol_absorbs into the blood stream eight times better than CoQ-10 from ubliqinone. This paper goes on to explain patients in the studies quoted who uses CoQ-10 from ubiquinol, who follow up with echocardiograms experience a recovery of up to 88%. It points out an even more insidious reason why more cardiac patients are dying is due to the prescribing of statin drugs without sufficient CoQ-10 intake.

- **Flax Seed Oil** is good for the heart, as it is rich in Omega 3 acids, magnesium, potassium, and fiber. Findings indicate that Flax Seed Oil lowers blood cholesterol and triglyceride levels, and reduces cholesterol's hardening effects on cell membranes.
- **Ginkgo Biloba** enhances blood circulation and increases the availability of oxygen to the heart, brain and other body parts. Ginko biloba also improves memory, reduces muscle pains, and acts as an antioxidant. Moreover, Ginko biloba has anti aging properties, reduces blood pressure, inhibits blood clotting, and is helpful for tinnitus, vertigo, hearing loss, and Reynaud's disease.
- **Hemp Oil** helps prevent heart disease, is good for pain, and works as a skin refresher. The suggested dose is 1000 mgs per day.
- **L-Carnitine** is involved in carbohydrate and protein metabolism, as well as in fat transportation to the mitochondria. Studies reflect the L-Carnitine reduces damage to the heart associated with cardiac surgery, helps the heart and legs use oxygen, and assists in prevention of memory loss.
- **Olive Leaf Extract** protects the heart and increases the immune system's capabilities. The standard dose is 500 mgs, 1 to 3 times per day.
- **Taurine** strengthens the heart, as it has an effect similar to digitalis. In Japan, it is used to treat heart disease. Since Taurine helps regulate the heart, it is an effective treatment for cardiac arrhythmias. In addition, Taurine lowers blood pressure and cholesterol levels, restores heart muscle. Taurine reduces fat deposit levels, increases vitamin C levels. Taurine is also used to treat anemia, and is believed to be effective in preventing Alzheimer's disease. Do not take Taurine in conjunction with heart medication in the form of drugs unless advised by your health care physician. In particular, do not take Taurine with Digoxin. However, under the guidance of a health care provider, Taurine is an excellent replacement for Digoxin. The standard dose is 500 mgs, 1 to 3 times per day.

- **Trimathylglycine (*TMG*)** lowers Homocystein levels, which reduces the risk of heart disease, as high levels of Homocystein increase the risk of heart disease to three times that of the normal population. Trimathyglycine is also thought effective in preventing Alzheimer's disease. The standard dose is 100 mgs, 1 to 3 times per day.
- **Polifcosanol** appears to slow down the synthesis of cholesterol in the liver, while increasing the liver's absorption of LDL and HDL. Polifcosanol works well when combined with L-Arginine (such as in Polifusia) or taken with CoQ-10.
- **Magnesium** is known to increase cardiovascular health. One of the leading contributors to heart disease is low blood magnesium levels. Most adults in the United States of America (***USA***) have low blood magnesium. Magnesium can be taken orally, or massaged into the skin.
- **Calcium** should be taken in conjunction with Magnesium and Vitamin C, as magnesium and Vitamin C help the body to absorb calcium. A good combination supplement is Cal-Max, which is a blend of 400 mgs of Calcium, 200 mgs of magnesium, and 500 mgs of Vitamin C.
- **Vitamins C and E** also have beneficial effects on the heart.
- **Choleslo, Chitosan or Chelation therapy** may help lower blood cholesterol levels.
- **Medium Chain Triglycerides (*MCT*)**, which derive from coconut oil, are some of the saturated fats that benefit the body. Moreover, since MCTs provide an energy boost, assist in weight loss, and improve endurance by lowering blood cholesterol,

they may also have a positive effect on cardiac health.

- **Resveratrol** may assist in preventing heart disease by inhibiting blood clots from forming. Resveratrol also plays a role in metabolizing Cholesterol, thus decreasing the likelihood of developing clogged arteries. Resveratrol also appears to be very effective in warding off many forms of cancer. Using human subjects, researchers found that Resveratrol turned malignant skin cancer cells back to normal.

This list concerns herbs for heart support:

- **Artichoke** promotes heart health by reducing cholesterol. It also enhances liver function. The standard dosage is 500 mgs up to four times per day.
- **Butchers Broom** improves circulation and reduces swelling in the hands and feet. The standard dosage is up to 3 capsules a day or 20 drops of extract added to juice or water.
- **Celery** is proported to lower blood pressure.
- **Garlic** helps prevent heart disease by reducing blood pressure and blood lipids. The standard dosage is 1 to 3 capsules a day. For ear aches, put warm garlic drops in the ear.
- **Ginko Biloba** improves circulation throughout the body. The standard dosage is 60 mgs, 2 to 3 times per day.
- **Green Tea** helps prevent heart disease; drink as many cups a day as desired.
- **Pine Bark Extract** protects against heart disease and stroke, and keeps the immune system strong
- **Red Yeast Rice** is excellent for the heart. However, it should only be taken under the guidance of a health care provider.

This list concerns supplements that support muscle building, muscle toning, or fat burning. In addition, some of these supplements relieve spasm and cramps:

- **Beta-hydroxy beta methylbutyrate (*HMB*)**: 1000 mgs has been shown to increase athletic ability and for those who workout to increase muscle mass while reducing fat. Many hail HMB as a safe alternative to anabolic steroids which also builds muscle but has serious side effects that may be life threatening. As a natural supplement HMB has no side effects other than assisting muscle growth for those who workout and reducing fat. It works even better if combined with Creatin. The recommended dose is 3 grams per day.
- **Hydro Citric Acid (*HCA*)**: Ideal for weight management, this supplement suppresses hunger, and prevents the body from turning carbohydrates into fat by inhibiting the action of an enzyme called ATP-citrate lyase. HCA enhances the ability of the muscles and liver to store glycogen therefore reducing fat production. It also prevents the brain from stimulating our appetites. HCA is believed to be an effective supplement to prevent heart disease by lowering blood triglyceride levels. Take up to 1500 mgs per day (total) one half hour before meals. HCA may provide additional energy for strenuous workouts.
- **L-Carnitine** is good for increasing the heart's ability to use oxygen. The dose is up to 1500 mgs per day. The increased capability to use oxygen results in being able to do more intense workouts and thus contribute to muscle or endurance development. (See a more complete description under heart supplements.)
- Amino acid complexes result in a balance of muscle support and the ability to recover from workouts. Some blends such as **L-Arginine** (which should not be taken independently by those who have herpes simplex) and **L-Ornthine** are felt to stimulate the production of growth hormone.
- **MCT** may assist in weight loss, stimulate the production of more energy, which increases athletic endurance, aids in muscle recovery, lowers cholesterol, and improves athletic performance.
- **Pyruvate** burns fat increased cardiovascular health increases energy levels.
- **Vanadyl Sulfate** is effective in normalizing blood sugar levels and is used with diabetics. It also has become popular as a supplement among athletes due to improving nutrient support. This results in increased energy and it stimulates muscle growth. The typical dose is 10 mgs one half hour before workout.
- **Cordyceps** is known to improve endurance. This is believed to be due to opening up breathing passages,

thus enabling the body to use more oxygen. The increased use of oxygen contributes to strength as well as endurance. The standard dose is 2 capsules of 525 mgs each per day with meals.

- **Creatin Monohydrate** reenergizes tired muscle cells, allowing for longer intense workouts. One study reported that people who take creatin with exercise gain more muscle and lose more fat than control groups working out but not taking creatin. Creatin is most useful for development of large muscles and not as effective for endurance sports where speed counts, as mass may interfere with speed. Creatin was found, in a study at the Cooper Clinic and Texas Women's University, to lower both cholesterol and Triglycerides with a recommended daily dosage of 5000 mgs per day.

Exercise

The second prime need for a healthy circulatory system is cardiovascular exercise. Exercise benefits the respiratory system by producing healthier lungs. Healthy lungs in turn provide better ventilation. The in-shape diver's ***VO_2 max***, which measures the body's ability to utilize oxygen efficiently, is higher than that of a non-fit diver. The increased VO_2 max allows the conditioned diver to work harder without a dramatic increase in RMV. In life threatening situations, this respiratory efficiency may prove to be the dividing line between survival and non-survival.

Another advantage of regular exercise is that it places demands on every organ in the body. The liver responds to exercise by producing glycogen more efficiently. Insulin and glucose regulation is fine-tuned by the pancreas as a reaction to exercise. The heart and lungs deliver more oxygen, and the circulatory system builds more capillaries. LDL cholesterol drops while the level of good cholesterol and HDL elevate. The mitochondria enlarge and produce additional adenosine triphosphate (***ATP***), thus providing us with more energy. As an added benefit, the body's ability to burn fat increases. The more intense the aerobic program, the better the VO_2 development. Tour-de-France cyclists have among the highest VO_2 max of all athletes. It is this high pulmonary efficiency that allows them to perform well on a long-endurance race. A diver in good physical condition is able to swim farther, successfully assist another diver, and get out of bad situations more often and with better results than an out-of-shape diver.

Progressively Accelerated Cardiopulmonary Exertion (*PACE®*) & Exercise

Divers should also take into account the need for short-duration, high energy output. This type of training is useful for diver rescue, and many researchers are currently in agreement that a regimen incorporating this form of cardiovascular and muscular development significantly increases overall fitness, as well as improving the heart's ability to withstand stressors. Please keep in mind that this exercise technique differs from cardio and long-distance endurance training. Dr. Albert Sears, who developed the PACE® program outlined below, is an excellent reference source for additional information. Dr. Sears publishes on the internet.

In an overview, the program consists of:

1. A warm up
2. A short high-intensity exercise period that can be either distance or time derived
3. A low intensity exercise segment following the high-intensity workout phase which acts as a recovery period. This process repeats in sets.

An example of this method that I might use in one of my Martial Arts classes is:

1. **Warm up**
2. **Set One:** Full out attack on heavy bag. Maximum power and maximum speed for one minute followed by two minutes low intensity exercise while heart and breathing rates recover
3. **Set Two:** Full out attack on heavy bag. Maximum power and maximum speed for 45 seconds followed by two minutes low intensity exercise while heart and breathing rates recover
4. **Set Three:** Full out attack on heavy bag. Maximum power and maximum speed for 30 seconds followed by two minutes low intensity exercise while heart and breathing rates recover
5. **Set Four:** Full out attack on heavy bag. Maximum power and maximum speed for 15 seconds followed by two minutes low intensity exercise while heart and breathing rates recover

This approach may adjust to running, cycling, swimming, stair masters, tread mills, elliptical machines or any other exercise where high intensity, cardio-strength training is possible. An ideal work out of this nature is approximately a 10 to 20 minute routine. This type of program combines two issues that are often at odds: Cardio/strength conditioning and time consideration. Although my regimen includes separate weight, cardio, and strength/agility training in order to stay fir for Martial Arts and diving, I include this program into my overall routine and that of my martial arts students. Since we added the PACE® approach to our regimen, both my students and I have experienced noticeable, and in some cases dramatic, improvement in fitness levels.

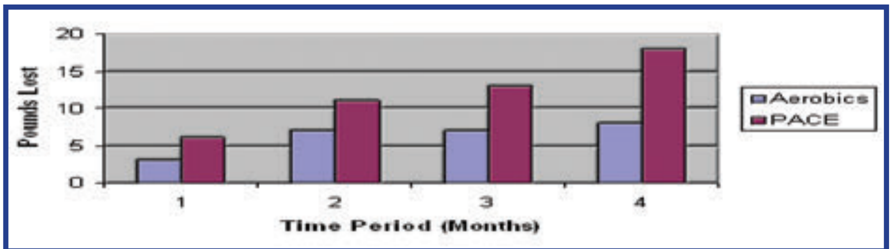


Fig. 1-11: Weight Loss Comparison PACE® Program vs Aerobic Activity

Whether you choose to incorporate the program into a current routine or use it as a stand-alone system, I personally assure you it will provide you with increased energy, endurance, and the ability to sustain an explosive use of energy. It may be the best form of cardio conditioning for those in fields such as firefighting, where there is a need for a quick and strong cardiac output without risking overstressing the heart.

Although Dr. Sears does not emphasize the benefit his program offers endurance athletes, I firmly believe that his program potentiates, when combined with a cardio regimen, thereby significantly increasing overall conditioning.

Dr Al Sears, in one of his newsletters, gives additional insight into the PACE® program and expounds on its usefulness as a weight management program as well. According to Dr. Sears:

"Researchers at George Washington University looked closely at how well diet, aerobic exercise, and dieting combined with aerobics work to help you lose weight… the researchers analyzed 25 years worth of study results to see what is most effective for weight loss…"

People using diet alone to lose weight lost an average of 10.7 pounds. A person using both together lost an average of 11.1 pounds… adding aerobic exercise to a weight loss diet makes hardly any difference at all. It's no wonder aerobics leave you feeling disappointed and frustrated. It's just a poor weight loss tool.

Now contrast this to the results of my PACE® program from my "twin" study. Over 4 months, the "***PACE®***" twin lost over 18 pounds of fat. The "***aerobics***" twin lost just 7 pounds. And the "aerobics" twin also lost 2 pounds of critical muscle mass. What's more, the PACE® twin's workouts lasted less than 15 minutes. Her "aerobic" sister sweated for hours….What works when it comes to weight loss is a different kind of activity.

Researchers from Laval University in Quebec compared long duration cardio exercise with short duration high intensity workouts. For 20 weeks, half the participants did five 45-minute workouts a week at moderate intensity. The other half did 19 high intensity interval workouts… over the course of 15 weeks.

Although the second group spent less time exercising, and only did half the work as the first group, they increased their aerobic capacity by 30 percent. What's more, the second group lost nine times as much body fat as the first group 2. That's right... they lost ***nine times more fat.***

So what is PACE®? Well first of all, it's simple, fun, and it's easy to stick with. ***PACE®*** stands for ***P***rogressively ***A***ccelerated ***C***ardiopulmonary ***E***xertion. It's a type of workout that uses short duration bursts that slowly get stronger as you get more fit.

Exertion periods are always followed by recovery periods. Together, they make an exercise set. So let's use this 10-minute program to get a better idea of how it works.

Look at the program chart in Figure 1-12, above. After an easy warm-up, your first minute is an exertion period. For the next sixty seconds, you're going to exercise at a pace that gives your heart and lungs a challenge.

If you're new to exercise, or feel out-of-shape, take it easy for the first two weeks. The speed and intensity of your exertion period should be fast enough for you to break a sweat, but not so intense that you can't finish the 10-minute program.

Let's say you're in the gym and you decide to try the stationary bike. First, make sure you're comfortable. Adjust the seat and choose a level of resistance that will give you a slight challenge. On a stationary bike, the resistance will make it harder to pedal.

Begin to pedal and make note of the time. Your first exertion period is just 60 seconds so time yourself accordingly. After your first exertion period, begin your first recovery period. During your recovery period, slow down to an easy pace - as if you're walking. If you need to stop, you can. Otherwise, simply slow down and go at a slow, easy speed. This gives your body a chance to rest and recover.

Your recovery periods are crucial. They're more than just empty spaces between the repetition intervals. Recovery is the flip side of exertion. Training your body to recover is one of the keys to your success. During your recovery periods, focus on your breath and feel your heart rate starting to slow down. Feel your heart and breath returning to a resting level before you move on.

Now that you have a feel for it, repeat the process. Start your next exertion period and follow it with a recovery period. You'll soon get into the groove of exercising in short bursts followed by periods of rest."

Getting your feet wet with the basics will help you get started right away. What's more, it will prepare you for a deeper level of your PACE® program, which adds other dimensions like acceleration, intensity, and duration.

The combination of exercise and prudent diet habits will produce a healthier body, reverse circulatory problems that may already exist, and act as a preventative step for most diving-related illnesses. In short, it is not logical to eat a fatty diet, be a couch potato, and participate in a strenuous form of diving or in other activities. In numerous studies, regular exercise has been shown to lower the incidence of heart disease. It is effective both in lowering blood cholesterol levels and in conditioning the heart. Exercise stimulates collateral circulation. If blood vessels leading to the heart are clogged, collateral vessels can take over the job of supplying the tissues with circulation. Exercise increases the amount of collateral circulation, and thus reduces instances of sudden death from heart attack.

However, before starting any exercise have a complete physical exam, and ask your healthcare provider to arrange

	Warm Up	Exertion	Recovery
Warm-up	2 Minutes		
Set 1		1 Minute	1 Minute
Set 2		1 Minute	1 Minute
Set 3		1 Minute	1 Minute
Set 4		1 Minute	1 Minute

Figure 1-12: Sample PACE® Style Workout

ether a stress test or VO_2 max test to ensure that you are healthy enough to increase your fitness level. As a indicator of what is going on in your body, once a base line stress test has been accomplished, follow up every other year with an additional stress test. Another advantage of the stress test and its associated echocardiograms is they can detect problematic areas that a complete physical would not reveal. These areas may be either due to disease or genetically driven. My personal example of the importance of a stress test is reflected below. Note in my case that I have exercised and maintained good physical condition since I was nine years old (1948), except for one year (1981) that I only dived. The following events occurred in 2006.

A Personal Account

I always told mysely that someday I had needed to have a stress test so I could have a base line from which to work. In November of 2006, I went to Physician who is both a Doctor of Osteopathy (***D.O.***) and a Doctor of Pharmacology (***Pharm. D.***) I had her do my complete physical, plus every form of blood work, including intracellular nutrient use. I went off supplements for 3 months prior to the blood work. This enabled me to see what my body produces and uses on its' own. (This is something I would also recommend to everyone.)

Essentially all my blood work came back excellent. The only negative I had was higher heavy metal toxins than expected. To correct this I started Zinc supplements. We then made a custom vitamin & nutrient program. My Cholesterol was fine, as my HDL was high, with a low LDL. According to the blood work I was in excellent condition; I passed the physical with "flying colors."

I requested a stress test as at age 68 (03-21-07) it was about time to do so. In the past, I have completed two VO_2 max tests but not a stress test. Dr. Diaz arranged for me to go

Some benefits of having a high rate of O_2 uptake due to an increased VO_2 max from excercise include:

- ◊ **Lower Blood Pressure**
- ◊ **Better Heart Regualation**
- ◊ **Stronger Tendons and Ligaments**
- ◊ **Thicker Cartilage**
- ◊ **Larger Muscles**
- ◊ **Greater Blood Volume**
- ◊ **More Hemoglobin**
- ◊ **Less Body Fat**
- ◊ **Denser Bone**
- ◊ **More Effiecient Lungs**
- ◊ **Heart Pumps More Blood w/Each Stroke**
- ◊ **More Oxygen Extracted from Blood**
- ◊ **More Capillaries**
- ◊ **Lower Heart Rate**

to a Dr. Sende at Mount Sinai Medical Center in Miami Beach Florida in early February 2007. The scan, stress test, post-scan, and echocardiogram were completed at that time. Although I "maxed" the stress test, the post-scan and the echocardiogram picked up some cardiac abnormalities. After reading the post scan and echocardiogram findings, Dr. Sende scheduled me for a procedure known as cardiac catheterization. The outcome of the "cardiac cath" is as follows: My aorta was 7 centimeters (***cm***) wide, whereas it should be around 3 cm wide. The enlarged aorta was causing blood to regurgitate back into my heart (essentially an aneurysm), leading to dilation of the left ventricle.

Based on aortic size, I had a 32% probability of a sudden death heart attack at any moment, as the aorta could rupture. The doctors were shocked that I was ***asymptomatic*** given my arduous exercise levels. They were even shocked I was still alive!

I was sent to Dr. Williams, a cardiac surgeon believed to be one of, if not ***the***, best in South Florida. Dr. Williams recommended a mechanical valve, but once I researched mechanical valves, I discovered such valves require that the patient remain on blood thinners for the rest of their life. Blood thinners increase the risk of severe bleeding if a cut or deep bruise occurs. Bruises are a given in contact martial arts, and both bruises and cuts are common with wreck and cave diving. In addition, one has to have the discipline to take a medication every day of their life.

I elected to have the surgeon implant a tissue valve instead of a mechanical valve. Post surgery, the cardiologist and surgical resident agreed that with my lifestyle the tissue valve, which does not require any continued medication use, was the best choice for me.

Pre-surgery, members of the cardiac team performed an ultra-sound on my blood vessels (with an accent on my carotid artery) and the technician told Patti (Mount) and I that I have the circulation of a 15 year old and should live "forever." The surgery was a success. Later I discovered the aortic valve dilation was a genetic issue that my mother had and it is believed my uncle also had, as he died of a sudden death heart attack. It is suspected that my grandfather may have had the same problem, as he was in perfect health until age 77 at which time he had a stroke that left him paralyzed until his death a few months later.

Open heart surgery is tough on the body. Post surgery I had problems trying to stay warm, my endurance was totally whacked, and I lost a lot of muscle, even though I immediately became active. In my case, I lost over 20 pounds, which I feel was all muscle loss. My waist remained the same size before and after surgery so it was only arms, chest, and legs that became smaller. My chest was very tender, as they literally cut everything in the middle of the chest cavity to do the surgery. My hemoglobin count dropped to about 11 from 16, thus I was unable to utilize as much oxygen as before surgery. For the first time in my life, my blood pressure was high. Moreover, the heart has to undergo a remodeling process during the healing phase; therefore, I had to use medication to ensure proper cardiac functioning.

According to my surgeon and cardiologist, I was to take a large quantity of the aforementioned drugs, gradually build up to a one quarter mile walk and not to lift more than 10 pounds for three months in order to allow the chest, bones, muscle attachments, etc. to heal. I was told not to do any weight lifting, jogging, or martial arts for at least three months and after three months gradually ease back into diving. They did reassure me I could do everything, and most likely better than, I had before, once healed.

However, during the first week home I started with a one and one half mile walk. At the second week, I started weight lifting with 10 to 20 pounds, and 3 pounds for shoulders and curls. Each week I added weight and by week 6 was using 80 pounds for benches, laterals, triceps, and biceps, with 20 pounds for lateral and shoulder work

Figure 1-14: Tom Mount excersizing near his home in Florida

and 200 pounds on the leg press. I increased my walk to three and one quarter mile, and by the third week, my best pace was 65 minutes.

On the fourth week, I added in jog-walking for the same distance. At first, I could only jog about the width of a house. My endurance, as measured by my jogging, was slow to return. By week 9, I started taking one of my dogs on the walk jog routine; at this time I had the times down to 36 minutes and change. Within two weeks, or week eleven, I had the walk jog routine down to 35 minutes and two seconds. Competing with oneself is always a form of survival training. At the beginning of week 16, I had the time down to 31 minutes and 35 seconds. It was at this time, I knew I would soon be back to normal with the distances being in a full jog mode and times in the 8 to 9 minute a mile range. I plan to reduce the days of jogging to 2 days (from experience know my knees do better with this plan) and cycle 2 days so I can take advantage of cross training more effectively.

I started back diving at week nine, and made my first 200 fsw (60 msw) dive post surgery at week ten. I had also returned to light martial arts by week three, and by week twelve, I was back to full workouts, with the exception of sparring. I also started back to doing four sets of 100 pushups; two sets on my knuckles and two sets on my palms. I held off on sparring and ***take downs*** until week sixteen. Both my cardiologist and doctor said they certainly did not recommend what I did/do but it works for me - therefore ***keep it up and see you at the next 3 month appointment***. When I started back into diving (week nine) I threw all my medications away, after having reduced the dosages slowly to a fraction of what was prescribed. I replaced them with natural substances to accomplish the same goals.

Exercise, Naturopathy, Homeopathy & Conditioning

As a Naturopathic Doctor (***ND***) I self-prescribed, and also used the homeopathic remedies my wife, Patti, recommended, as she is a homeopath. If you are to go this route, be sure to consult with a health care provider before removing yourself from medications and starting supplements and herbs. Do not combine supplements with medications unless you have your physician's permission due to possible interactions. Exercise has also been shown to be a release of good HDL, therefore improving its' chance of reducing LDL cholesterol. The preferred type of exercise for circulatory conditioning is an aerobic or PACE® program. To accomplish an aerobic level of exercise, you must work at an elevated heart rate that is safe, yet high enough to effect physical change.

To determine a maximum safe heart rate, subtract your age from 220. During aerobic exercise, your target heart rate should be 80% of your safe heart rate. For example, if your age is 60, subtract 220 - 60 = 160 ***x*** 0.80 = 132. If your age is 30, subtract 220 - 30 = 190 ***x*** 0.80= 152. It is apparent that aging reduces the target aerobic rate. The aerobic workout is performed at least two times a week with a minimum time of 20 minutes per session. Ideally, one hour per day, 5 to 6 days a week will be devoted to some form of physical training.

Seek out a training program with which you will be happy. There are many machines on the market that tone both the upper and lower body and some even double as strength exercises. General swimming, swimming with fins on to duplicate diving activities, cycling, jogging, rollerblading and so forth are all excellent for cardio-vascular conditioning. For added benefit, and to prevent boredom, incorporate cross training by doing more than one form of exercise. One day you can cycle and the next day row or swim.

If you are limited on time include interval training or utilize the PACE® program. In this do maximum output for seconds to a couple of minutes then allow your body to recover and repeat. This type of exercise will let you crowd in a 15 minute routine rather than an hour. My personal philosophy is to use both interval (due its increased intensity) and endurance training, as one's life may depend on endurance in extreme environments. Numerous research programs indicate short intense interval training may even be better for cardio than our established theories of longer times.

On the web page ***Heart Matters***, author Jeremy Likeness, a specialist in performance nutrition discusses recent findings regarding exercise capacity. **He writes:**

> "Heart rate can still be a useful tool for training, but you must learn to use your body as the tool, not the equation. For example, if you want to understand what your anaerobic zone is, instead of plugging away at a formula, why not perform anaerobic work? I can guarantee that you will be using your ATP-CP system (a completely anaerobic system) when you perform a one-rep max. So instead of taking 90% of 220 minus your age, just strap on a heart rate monitor the next time you perform a maximum lift. Then, instead of relying on statistics, your body will tell you what your "anaerobic" zone is.
>
> Once you have this useful information, you can apply it to your training. If you are performing high intensity interval training, and would rather have your heart dictate the intervals than your perception, let your body be the guide. Start by walking on an incline for several minutes. This is your low intensity zone. Now go outside and perform an all-out sprint. This will be your high intensity zone. Now you simply build intervals between those two heart rates for your training…
>
> As a final note, heart rate can apply to resistance training as well… Pick a target rate for your training. Your "75% effort" (somewhere between your sprinting and incline walking) could be the bottom line. Simply rest until your heart rate drops to that level, and then perform the next set. This will ensure your heart rate is always elevated to a minimal level while allowing sufficient recovery to move on. When you are training for strength or heavy lifts, how long should you rest... Again, why not let your body decide? Rest until you fall to the fat-burning zone or even less, then start the next set… The key is that your body is telling you when sufficient recovery has taken place to perform the next set…
>
> When you are training, don't forget the most important muscle: your heart. Not only is it an indicator of health, it is a tool that can help to improve your health… You can use your heart as an interactive gauge to tailor your workouts to your own unique body. Learn that the heart matters and use the powerful information it provides to build your peak physique."

Shorter intervals maximize your exercise potential and prevent boredom. You may even do cross training within an individual workout. Ideally, develop a program and keep your commitment to that program. Make this an integral part of your normal daily habits. Place its priority above all other items during the time you select as a daily exercise time. Most people are more prone to maintain an exercise regime if they do it in the morning before becoming involved in daily activities.

To gain more insite into heart rates and exercise capacity refer to following web pages:

www.bodybuilding.com/fun/moser9.htm
www.wikihow.com/Calculate-You-Target-Heart-Rate
www.heartmonitors.com/zone_calc.htm
www.freewebtown.com/provenbrands/data/aerobics-cardio/35374.html

Another area that may be of interest to those involved in fitness training is determining their VO_2 max, which is usually determined in a clinical setting. As we are aware, The circulatory system is vital to our overall health. However, there are programs that can help you approximate your VO_2 max at home. The following list of web pages is a guide to practical VO_2 max computations; however, please remember that there is greater room for error in a non-clinical, rather than a clinical, setting. Of the three web pages offered below, the third may be the simplest to use.

www.rajeun.net/vo2max.html

www.nismat.org/physcor/max_2.htmlformulafitness/vo2max.htm#impatient

If the recommendations discussed in this chapter are adhered to, circulatory problems will most likely be reduced and gas transport will improve. This in turn will help protect the body from decompression illness and other diving disorders. If you are going to be a serious diver, be prepared to take serious actions, including lifestyle change, to insure your safety.

The Nervous System

The Central Nervous System (***CNS***) controls the actions of all the other systems that make up our bodies. However, before starting our discussion, let's review some terms:

- **Central Nervous System:** The brain and the spinal cord

- **Nerves:** One or more bundles of fibers that transmits electrical signals, or impulses, to and from the CNS
- **Neurons:** Electrically excitable cells in the nervous system that process and transmit information. Neurons are composed of a cell body, or soma, a dendritic tree made of branching dendrites, and an axon. Neurons are the main component of the central nervous system
- **Axons:** Long, slender nerve fibers that carry the nerve's outgoing impulses
- **Dendrites:** Branched projections of a neuron that conduct the electrical signals received from the axon of other neural cells to the cell body
- **Afferent Neurons:** A type of neuron that carries nerve impulses from the receptor site to the CNS. In other words, this type of neuron transmits the body's messages to the brain for processing.
- **Efferent Neurons:** Are neurons involved in muscular control that convey central nervous system signals to muscles, glands, and other physiological structures
- **Peripheral Nervous System (*PNS*):** The part of the nervous system that resides outside of the CNS and serves the limbs and organs. The PNS consists of two parts: the autonomic and the somatic nervous systems.
- **Autonomic Nervous System (*ANS*):** The nervous system that regulates involuntary and glandular activity through two separate nervous systems: the **Sympathetic** and **Parasympathetic System**.
- **Somatic Nervous System:** This part of the CNS processes sensory information and controls voluntary muscular systems within the body.

A brief and simple explanation of the nervous system may be found published at the website "***The Autonomic Nervous System***."

Overview

"The nervous system therefore has a tremendous part to play in enabling us to survive in the world. It can be thought of as the telecommunications system of the body. Sending information from various sources to a vast computer network (the brain) which analyses and solves the problems presented to it and then passes the appropriate information out to the field workers (muscles, glands, etc.) enabling the appropriate actions to take place in a coordinated and logical fashion, The nervous system works in close conjunction with another body system known as the endocrine system. This has effects on the body's function by producing organic chemical substances known as hormones, Taking the analogy above and relating this to the endocrine system, it can be likened to a road & rail network communication system transporting bulk items (***hormones***) around the body to enable essential works to be carried out.

…The CNS may be thought of as the Master Computer it ultimately controls all functions based on the feedback from its "feedback" systems. Like computers, it makes decisions based on the information fed to it and then processed. It can receive good or bad information based on environmental conditions, the consciousness of the person and the learned traits that have become habitual within the ANS. Its influence on health is also dependent on the nutrition of the brain."

The staff at the Buckinghamshire School of Nursing, London, gives us additional insight on the CNS and PNS; they write:

> "The cranial nerves run from the head and neck to the brain by passing through openings in the skull, or cranium. Spinal nerves are the nerves associated with the spinal cord and pass through openings in the vertebral column. Both cranial and spinal nerves consist of large numbers of processes that convey impulses to the central nervous system and also carry messages outward... Afferent impulses are referred to as sensory; efferent impulses are referred to as either somatic or visceral motor, according to what part of the body they reach. Most nerves are mixed nerves made up of both sensory and motor elements."

Within the PNS there are 12 pairs of cranial nerves (which link directly to the brain) and 31 pairs of spinal nerves (which link to the spinal cord and then to the brain.) Cranial nerves are distributed to the head and neck regions of the body, with one conspicuous exception: the tenth cranial nerve, called the Vagus.

In addition to supplying structures in the neck, the Vagus nerve is distributed to structures located in the chest and abdomen. Vision, auditory and vestibular sensation, and taste are mediated by the second, eighth, and seventh cranial nerves, respectively. Cranial nerves also mediate motor functions of the head, the eyes, the face, the tongue, and the larynx, as well as the muscles that function in chewing and swallowing.

The Nervous System

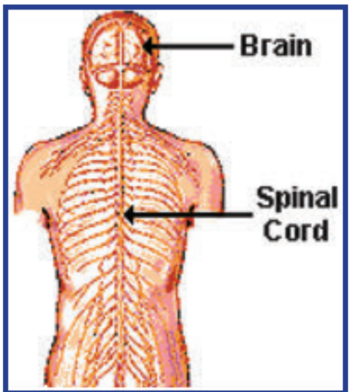


Fig. 1-16: Spinal Cord

The **Autonomic Nervous System (*ANS*)** regulates functions such as secretion, salivation, lung control, heartbeat, emotions, and temperature regulation. By assuming control over some functions of the ANS, breathing can be controlled and, thus, our internal environment. The **ANS** is divided into the **Sympathetic (*SyNS*)** and **Parasympathetic (*PaNS*) Systems**. The sympathetic system is composed of two vertical rows of ganglia, nerve cell clusters, on either side of the spinal column. These branch out to glands and viscera in the thorax and abdomen, forming integrated plexuses, or energy centers, with nerves ending in the parasympathetic system.

The sympathetic and parasympathetic nervous systems insure body/nerve functioning and reaction to stimuli. The parasympathetic system tends to slow the heart, while the sympathetic system speeds the heart up. Therefore, the sympathetic nervous system may play a role in our innate "***fight or flight***" reactions to stress or trauma.

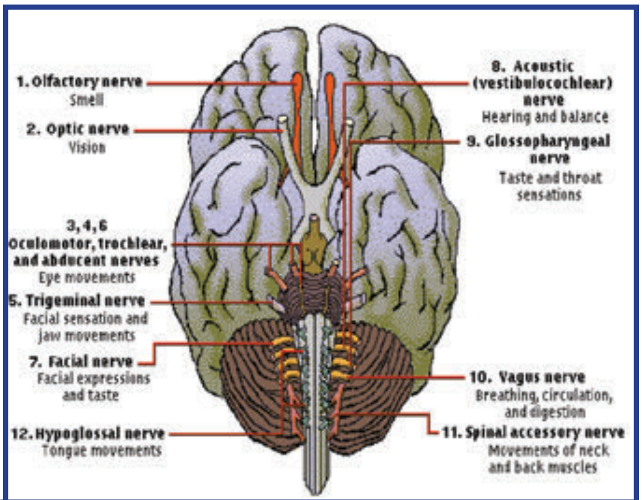


Figure 1-15: The nerve endings in the brain
Courtesy of Washington University

The parasympathetic and sympathetic systems regulate heart activity, and keep our bodies in balance. Although the ANS is responsible for maintaining so-called "automatic functions," the ANS can be affected by our habits. Thus, we may change how the ANS works and modify it to our advantage in both stressful situations and everyday life.

"The Autonomic Nervous System" continues:

"The ANS is part of the peripheral nervous system PaNS. It has an important function in maintaining the internal environment of the human body in a steady state. This role is vital in returning the body to a homeostatic state after trauma. As various changes occur within the environment, both internal and external, the ANS reacts by regulating such things as the Blood Pressure, Heart Rate, and Concentration of salts in the Blood Stream… If the body becomes dehydrated… the SyNS will pick up sensory information on the depletion of body fluid and the ANS will activate the mechanisms that conserve and replenish body fluids.

The ANS is also involved in many other body activities such as, waste disposal, response to stress, and sexual response. The functions of the ANS underlie the physiological aspects of coping during stress and forms a major link between the nervous system and the endocrine system during these times. The system generally works automatically without voluntary control… We do not consciously direct the rate of our heart beating nor are we normally aware of the diameter of our blood vessels or the need to stimulate our salivary glands to produce saliva. However, the effects of the ANS do impinge upon our consciousness, especially at times of heightened emotion. For example, most of us have experienced fear, either real or imagined, at some time in our lives and have been aware of our hearts beating faster. The increased heart rate is due to the effects of the ANS.

Once physiologists believed the system was wholly independent of the CNS. However, we now realize that this is not quite the picture and that there is some CNS component involved. This includes the spinal cord, the brain stem, and the hypothalamus. The hypothalamus is probably the most important area of the brain involved with the ANS but other areas such as the medulla oblongata and parts of the limbic system of the cerebral cortex have an important part to play…"

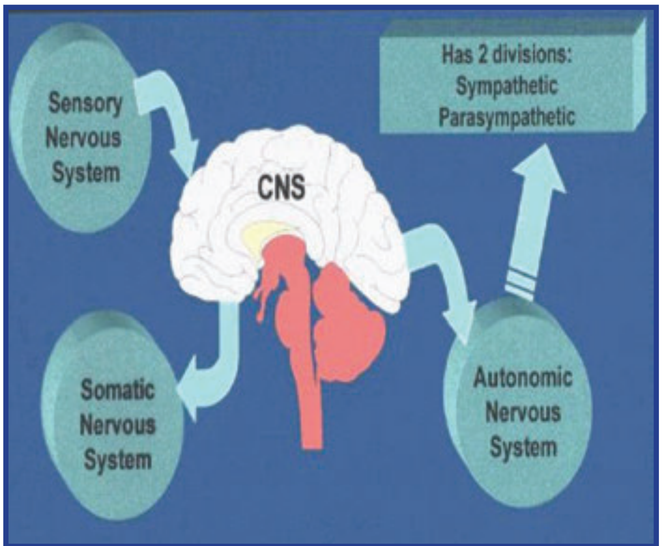


Figure 1-17: The Central Nervous System Courtesy of Yahoo Images

Studies of people practicing Transcendental Meditation claim that it is possible to gain conscious control over autonomic activities… Heart beat, metabolic rate and blood pressure decrease and alpha-waves are shown to increase when brain activity is monitored by electroencephalogram (***EEC***). The studies have also suggested that the body's response to noradrenaline (sometimes known as ***norepinephrine***) is lowered. As we shall see later, noradrenaline is a hormone important in autonomic response.

In recent years, "***biofeedback***" techniques have been developed in order to teach people to relax by controlling their brain wave patterns. These techniques provide the individual with some recognizable indication of the status of their autonomic functioning. By using biofeedback readouts as a guide, subjects learn to exert some conscious control over certain aspects of the ANS such as blood pressure, blood sugar levels, and abnormal heart rhythms. People also learn to prevent or reduce pain from problems such as headaches and panic responses.

It is quite easy to understand how the ANS influences all of our actions, and given its' effect on all our bodily and mental functions, it becomes clear as to how our reactions form. Moreover, it is evident that habit influences ANS functioning. As we train or are trained in certain actions such as adopting incorrect breathing patterns, the ANS transforms these learned responses into automatic reactions. Therefore, in order for internal change to occur, we must review the habits driven into ANS memory. We can then alter these habits by practicing the correct methods; essentially, we are retraining the ANS. Meditation and affirmations are two ways in which the ANS memory may be changed. Keep in mind that ingrained habits, when converted to automatic responses, will determine how we react to stress and trauma.

We should also be aware that in a diving environment many environmental features contribute to ANS effects. The partial pressures of gases at depth can, like drugs, modify our reactions due to their influence on the nervous system. CO_2 retention is known to create confusion, and may lead to panic. Imagine then the combined effects of drugs and the increased partial pressures of nitrogen, carbon dioxide or oxygen. To increase their chance of survival in life threatening situations, divers should have a thorough understanding of the ANS. With such knowledge, divers can increase their control over their own physiological response system. Such knowledge and control could, in some situations, be the difference in living and dying.

Moreover, by studying our physiology, habits and automatic responses, as well as developing breath control techniques, we increase our mastery of the self, improve our ability to heal, and increase our resistance to diseases. In addition, with correct breathing, one develops the ability to control the right side of the brain, which improves the ability to control the mind. It is thought that many diseases are due to an imbalance in energy, which is tied to improper breathing, stress, and negative mental states.

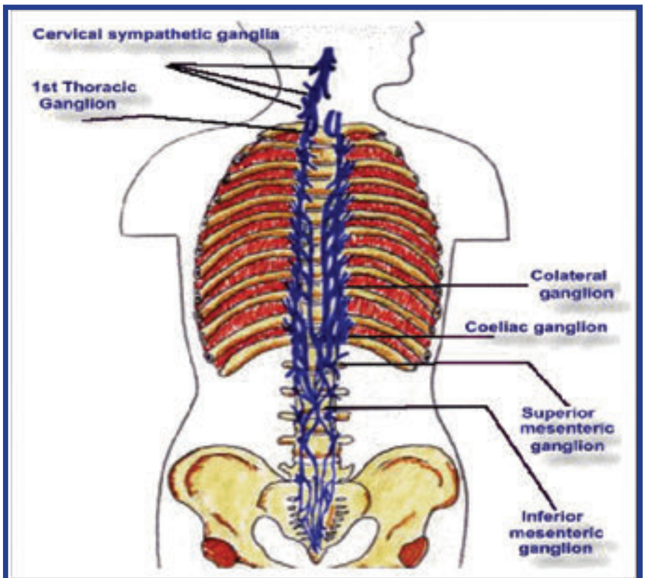


Figure 1-18: Autonomic Nervous System Courtesy of Yahoo Graphics

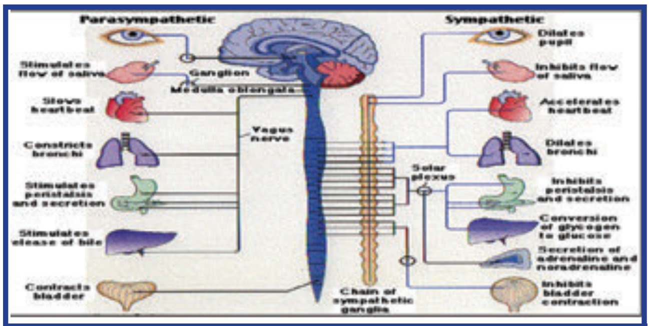


FIGURE 1-19: THE AUTONOMIC NERVOUS SYSTEM

If you search your past, you may remember that at times when a great deal of stress existed in your life, there was probably a corresponding lowering of your immune system and an increase in your susceptibility to colds and other disease. We suggest that you regularly practice good breathing techniques, meditation, and some form of physical toning, not only to lower your stress levels but also to improve your diving controls. In doing so, you may experience less mental fatigue and, perhaps, a healthier body.

As explained, there are two ways we can gain control over the involuntary nervous system (*ANS*). The first, and easiest to accomplish, is the control of respiration. This can be accomplished through the practice of breathing exercises, which will not only make us better divers, but can also be incorporated into our everyday lives. Breath control regulates heart function by bringing the right vagus nerve under control. This action allows access to the involuntary nervous system, or ANS, and its conscious direction. The second means of controlling the ANS is by developing a stronger will. What we mean is, through meditation, we can sharply focus mental energy, thus gaining access to our minds. To maximize our self-control, we need to incorporate both correct breathing and meditation.

Supplements for the nervous system that may improve functioning include:

- **Vitamin E and C** are foundation vitamins that everyone should take. Vitamin C should be at least 500 mgs per day and Vitamin E should be 400 IUs per day. Do not overdose Vitamin E; if one takes this vitamin in larger doses do so under the guidance of a health care provider

- **Taurine** is the building block of all the other amino acids, as well as one of the key components of bile, which is necessary for the digestion of fats, the absorption of fat-soluble vitamins, and the control of serum cholesterol levels. Taurine provides a protective mechanism for the brain, especially under the strain of dehydration. It is also used in treating anxiety, epilepsy, hyperactivity, poor brain function, and seizures

- **Calcium** and **Magnesium** combined (see heart supplements)

- **Valerian** is used as a relaxant as it acts as a sedative, therefore reducing anxiety levels. It also reduces cramps and spasms. It is often used to treat pain, blood pressure irregularities, insomnia, irritable bowel syndrome (*IBS*), and ulcers

- **St. John's Wort** is good for depression and nerve pain. It aids in the control of stress and some studies suggest it protects bone marrow and intestinal mucosa from X-ray damage

- **DMG** boosts mental activity, and enhances the immune system. It also reduces elevated cholesterol levels. It improves oxygen utilization by the body and brain

- **GABA** is an amino acid that acts as a CNS neuronal transmitter, and is essential for brain metabolism. Its function is to regulate neuronal activity, thereby inhibiting nerve cells from firing excessively. When combined with niacin and inositol, GABA may prevent anxiety- and stress-related messages from reaching certain areas of the brain. However, excess GABA produces increased anxiety, shortness of breath and numbness around the mouth. Therefore this supplement should be used sparingly. Although youthful, healthy divers most likely do not need GABA, older divers may benefit from it in moderation, taken on a cycle of three days on and one day off

- **Garlic** is a viable healing herb, as it helps eradicate heavy metal toxins, oxidants, and free radicals from the body. Aged garlic protects against DNA, liver, and vessicular damage. Garlic also prevents blood clots, is an immune system stimulant, and is a natural antibiotic. Garlic is also a strong memory-enhancing herb. Ideally, it should be part of everyone's daily diet

- **L-Asparagine** helps maintain emotional balance by keeping anxiety and euphoria levels within tolerable limits. L-Asparagine also releases energy that the brain and nervous system use for metabolism

- **L-Phenylatanine** is able to cross the blood-brain barrier, and as a result has a direct effect on brain chemistry. This amino acid, like others, converts to various forms and thus plays a role in alertness, elevate mood, decrease pain, aid in memory and learning capability, It has been used to treat depression, migraines, Parkinson's disease, and schizophrenia
- **L-Tryosine** is important to our overall metabolism. It is a precursor of adrenaline and the neurotransmitters norepinepthrine and dopamine. As such, it stimulates mood. A shortage of L-Tryosine in the nervous system contributes to depression, and low blood levels are associated with hypothyroidism. However, those who use MAO inhibitors should consult a physician before adding L-Tryosine supplements to their diet or eating foods rich in L-Tyrosine
- **TMG** reduces unusually high levels of homocysteine, and helps prevent Alzheimer's disease, improves memory, assists in preventing depression, lowers the risk of birth defects, and reduces the risk of heart disease and some forms of cancer
- **CoQ-10** (also see heart supplements) is a "must" supplement as it supports all systems in the body
- **L-Glutamine** is critical for normal brain and immune function. It helps build muscle, aids in the production of **Human Growth Hormone (*HGH*)**, and is effective as a part of bone marrow transplant therapy for cancer victims.
- **Zinc** aids in the detoxification of heavy metals stored in the body
- **NADH** protects the brain and improves memory. It is also an effective adjunctant treatment for Alzheimer's disease, and works as a preventative against Alzheimer's. NADH taken daily improves cognitive function and memory. Do not exceed two 5 mgs doses per day unless under the direction of a health care provider
- **Ginkgo Biloba** increases the nervous system's ability to transmit information. It also increases the capacity to problem solve by enhancing higher-order thinking
- **Magnesium** is essential for nerve cell regulation and plays a role in controlling the response of neurons. Magnesium is another "must take" supplement for the whole body health
- **Pregnenolone** boosts learning skills; it is thought by many researchers to be the most potent memory enhancing agent known to date
- **Phosphatidylserine** is exceptionally beneficial in treating memory impairment (***forgetfulness***)
- **Acetyl-L-Carnitine (*ALC*)** is considered one of, if not the best, supplement for memory disorders, especially Alzheimer's dementia. It enhances brain metabolism, slows down memory deterioration and reduces the production of free radicals
- **S-Adenosylmenthionine (*SAMe*)** lowers unusually elevated homocysteine levels. It is felt to be of value in treatment of Alzheimer's or other memory-related disorders. Do not take this supplement if you have a manic-depressive disorder or are on prescription anti-depressants

The Respiratory System

Respiration is a major body function. Breathing is the source of all life-sustaining energy. Breathing dictates emotional stability, health and happiness. A stressed person produces even more stress by breathing incorrectly. This type of individual will tend to breathe shallow and rapidly. This pitfall can be avoided by concentrating on slow, deep breathing to release stress and tension.

The respiratory system functions in conjunction with the circulatory system, as it provides hemoglobin with an appropriate environment for gas exchange. When the body is at rest, the body's breathing cycle starts. First, the nervous system detects an increase in carbon dioxide, which alters blood PH levels, is the primary stimulus for initiating breathing. The increase in CO_2 combine with the decrease in blood O_2 levels to stimulate afferent nerve impulses, which relay this information to the brain. The brain, in turn, fires efferent nerves in the lungs, which initiate inspiration of breathing gasses.

Stress and increased exercise levels also affect breathing rhythms. As our CO_2 level increases, a signal is sent to the "***inhalation***," or inspiratory, center in the medulla oblongata, which is located at the base of the brain, and controls autonomic functions by relaying nerve signals between the brain and spinal cord. In this case, the medulla oblongata transmits a signal telling the respiratory muscles to contract. When this happens, the diaphragm contracts, causing the lungs to expand. The lungs are composed of billions of alveoli which are coated with a surfactant-type protein substance. The alveoli are the final branchings of the respiratory tree and act as the primary gas exchange units of the lung. This surfactant reduces surface tension. Surface tension maintains the shape of the alveoli as well as the lungs themselves.

Turbulent Versus Smooth Gas Flow

In order for inhalation to occur, the contraction of the respiratory muscles must overcome this surface tension. Upon relaxation of the muscles, the surface tension draws the lungs back to a "normal" shape and the chest and diaphragm follow this action. Inhalation and exhalation at rest is caused by the contraction and relaxation of respiratory muscles combined with alveolar surface tension.

The human respiratory system is a complex arrangement of tissue groups beginning with the nasal and oral cavities and extending to the diaphragm. When air is drawn down the trachea, or the airway that allows air to move from the throat to the lungs, the air is divided between the bronchi that serve the two lungs. The bronchi transport the air from the trachea to the lungs. The bronchi resemble branches of a tree, becoming smaller until they terminate into bronchioles which end in a series of tiny air sacs, or alveoli. Once initiated, inhalation continues until the stretch sensors within the lungs sense an adequate degree of expansion and the cycle is completed.

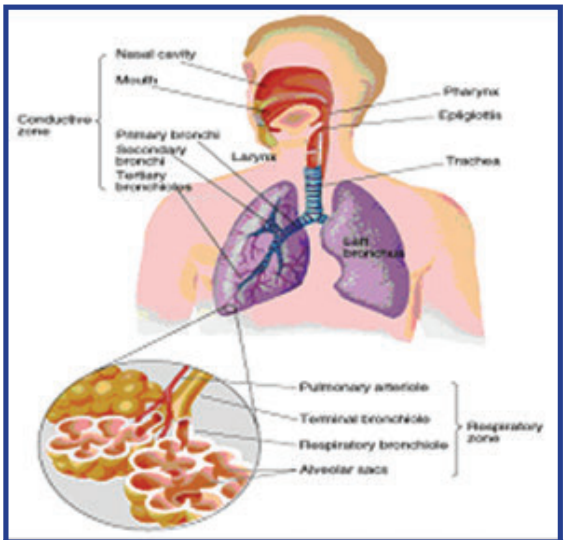


Figure 1-20 The Respiratory System Courtesy of Peason Education - A Global Leader in Educational Publishing

During inhalation, gas traveling through an airway may meet frictional resistance caused by gas molecules bouncing off the trachea's walls. These molecules oppose the flow of additional gas, which results in a turbulent flow. Turbulent breathing patterns are inefficient and may lead to hyperventilation. Inadequate ventilation generates a sensation of gas starvation. If the autonomic nervous system reacts to this sensation, it will stimulate an increased breathing rate. In divers, turbulent breathing results in "gulping" gas. This pattern, if left unchecked, precipitates improper ventilation, producing stress, and, most certainly, ending in panic caused by the perception of a gas failure.

To avoid this reaction, it is important that divers be trained to inhale and exhale slowly. The volume should be deep and evenly paced. In other words, the respiratory rate and **Respiratory Minute Volume (*RMV*)** should be slow and deep. An RMV of this nature avoids turbulence, maintains Laminar flow, or the smooth flow of gas from the trachea through the lungs. Laminar flow assures the diver of proper ventilation. Deep, slow breathing causes a greater fraction of the tidal volume to enter the alveoli. Shallow breathing causes a smaller fraction of the tidal volume, or the amount of air breathed in or out during normal respiration, to enter the alveoli. Gas exchange does not begin until inhaled gas reaches the alveoli. A complex network of capillaries surround the alveoli, allowing O_2 from the lungs to enter the circulatory system. At the same time, CO_2 is transferred from the bloodstream and exhaled.

Blood & Breathing

Blood is a complex, multi-faceted liquid tissue that evolved to meet the complex demands placed on the circulatory system. Among its many functions are the supply of oxygen and nutritional materials to the body's cells, the removal of waste and waste gases, and the activation of the body's immune system.

The quantity of blood in the lungs is not evenly distributed, and it is gravity-dependent. When we are upright, more blood is in the lower portion of our lungs than in the middle and upper parts. Conversely, the flow of gases is at its peak in the upper portions of the lungs. Thus, gas transfer is not as efficient as one would assume. To provide gas to the lower third of the lungs and to their rich vascular network, slow, deep diaphragmatic breathing is essential. If the alveoli are injured due to a physical accident, they become inefficient.

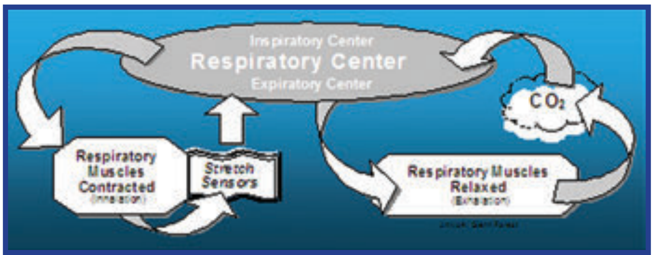


Figure 1-21: The Respiratory System Courtesy of Pearson Education - A Global Leader in Educational Publishing

Tobacco smokers (or smokers of other substances) will eventually lose pulmonary efficiency. This loss is called emphysema. Smoke produces a breakdown in the lining of the lungs, resulting in a "***visible hole***." This hole reduces the amount of surface area available for oxygen to come into contact with blood across the alveoli. This decreases the amount of gas exchanged across the alveoli. To simplify, there is a significant difference between the lungs of a non-smoker and those of a smoker.

The diffusion of gases across the alveoli results from a difference in hydrostatic pressures. Upon inhalation, the gas in our lungs has a higher oxygen level than does the blood in the alveoli, causing a pressure difference that is equalized through gas exchange. Once in the alveoli, oxygen diffuses into the pulmonary capillaries. At this point, we have high oxygen pressure. Upon exhaling, the blood in our capillaries contains a reduced volume of oxygen. Moreover, the carbon dioxide (***PCO_2***) bonded to our hemoglobin is high. The pressure created by the increase in carbon dioxide forces the gas into our blood. The carbon dioxide buildup in our blood then enters the alveoli, where it is exhaled.

Red blood cells (erythrocytes) carry the majority of the oxygen required by the body's tissues. Red blood cells transport oxygen via hemoglobin, a molecule capable of easily bonding and unbonding with oxygen.

Once oxygen has been diffused into the pulmonary system,

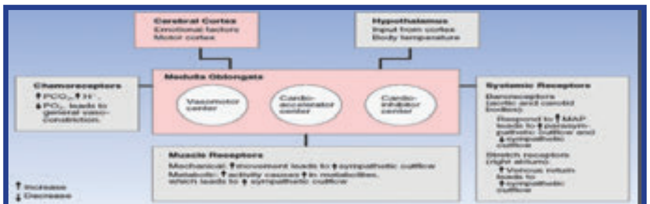


Fig. 1-22: The Autonomic Nervous System Interface with the Respiratory System Courtesy of Pearson Education

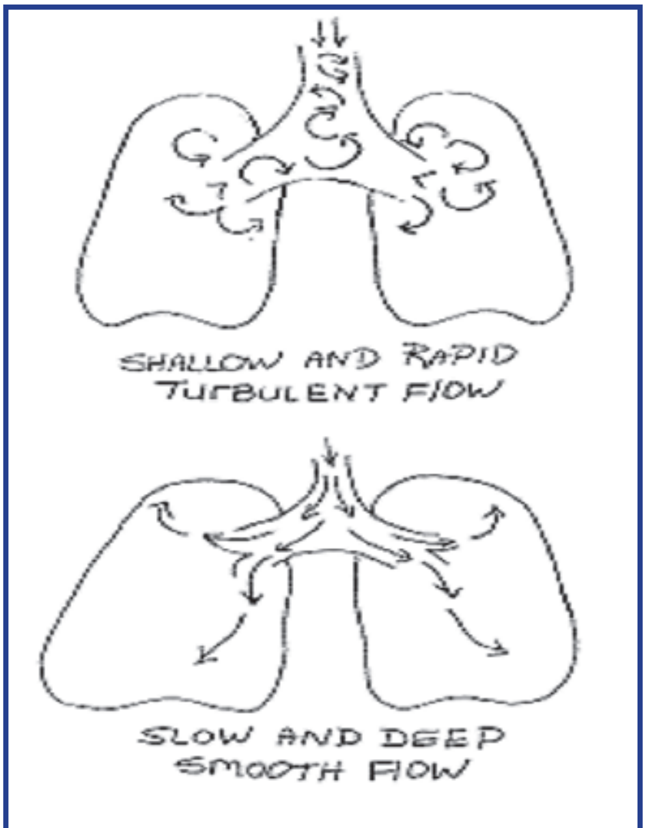


Figure 1-23: Gas flow in the lungs

it is transported by two mechanisms. Some oxygen will remain in simple solution or blood plasma. However, most of the oxygen will bond to hemoglobin. Hemoglobin is composed of four protein chains attached to one atom of iron. It is the iron in hemoglobin that attracts oxygen. This enables the circulatory system to transport oxygen.

Blood turns bright red when hemoglobin becomes oxygenated. People who have low hemoglobin levels are called anemic. People who suffer from severe anemia should be very cautious when diving. They should be especially careful when making deep dives, as the increased partial pressures of oxygen and carbon dioxide may complicate the anemic condition. Hemoglobin also transports carbon dioxide from the body's cells. This CO_2-enriched hemoglobin turns the blood a bluish color.

With proper gas supplies, the only gases that will combine with hemoglobin are oxygen and CO_2. However, if the gas supply contains carbon monoxide (***CO***), it will combine with hemoglobin 250 times more readily than O_2. In diving, CO poisoning generally originates from a contaminated air supply. It is colorless, odorless, and tasteless.

Carbon monoxide will not support life and renders one anemic and hypoxic quite rapidly. If unchecked, high levels of CO may lead to unconsciousness and possible death. Smokers can have 5% to 15% of their hemoglobin combined with CO. As depth increases, so does the partial pressures of all gases in the breathing medium. This compounds the effects of CO.

Respiration: Breathing

As inhaled gas diffuses across the alveoli, it travels from the capillaries in the lungs and enters the heart via the pulmonary veins. The heart pumps this oxygen-enriched blood via the arteries, where it then enters the capillaries and nourishes all the cells in the body. The body eliminates CO_2 by transporting it back to the lungs where it diffuses across the alveoli and is exhaled.

In addition to oxygen, blood transports nourishment absorbed from the body's digestive system. When the body's cells receive the oxygen and nourishment, a chemical reaction occurs, creating a type of "fuel." The fuel comes from the carbohydrates and fats we consume. Oxygen "burns" the fuel, producing energy. This reaction, which is known as metabolism, takes place within the cells in an area known collectively as mitochondria. Mitochondria contain specialized protein molecules, or enzymes. The particular type of enzyme that produces the fuel we are referring to is cytochrome oxidase. These enzymes take energy released from the oxidation of food (fuel) and transfer it to an energy storage molecule called adenosine triphosphate (*ATP*). ATP stores energy within our cells.

As energy is produced, wastes are generated and carbon dioxide, which is also considered a metabolic waste,is produced. Carbon comes from the food "burned" at the cell level in an oxygen-rich environment. The result is carbon dioxide. The pressure of CO_2 rises as a result of oxidation, which forces CO_2 into the venous capillaries. Larger and larger veins then transport the CO_2 until it is returned to the heart and the cycle begins again. If the body retains CO_2 or has a reduced capacity to eliminate it, it has an adverse physiological effect on the body.

Respiration at Depth

Divers must compensate for gas density as they dive deeper. The typical ANS response to increasing gas density is to breathe faster, which is a reaction that increases turbulence in the airways. This in turn leads to reduced breathing efficiency. As the water depth or workload increases, it becomes important for the diver to discipline him-or her-self to maintain slow, deep breathing. There are some techniques that may help improve breathing habits. While swimming, experiment with a swim pace that balances pace with the ability to maintain a slow, deep breathing pattern. Swimming faster than this is inefficient, as it alters one's breathing pattern, which could cause increased turbulence in one's airway, possibly leading to an inadequate gas supply to the alveoli.

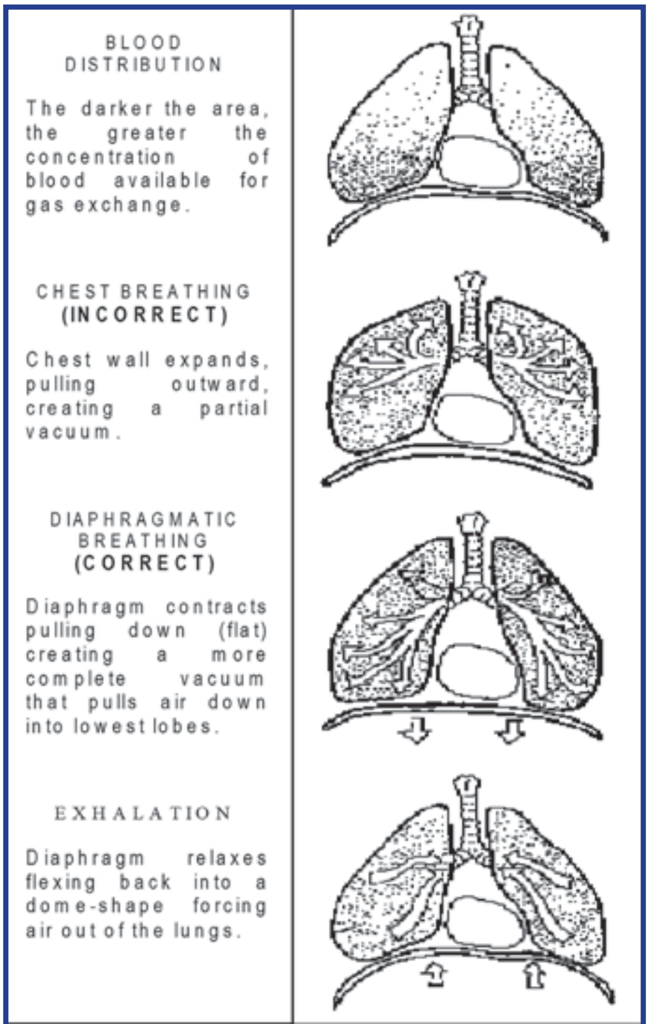


Fig. 1-24: The Interaction of Blood & Breathing

Frequently, divers will accelerate their swim pace under stress. This may lead to a loss of breathing control. Conversely, divers in an air-sharing situation will drastically slow their pace. This could leave them with insufficient gas to reach the surface. Therefore, the aware diver's conscious reaction to a gas sharing situation should be to maintain a normal pace that allows a balanced swimming pace in harmony with safe breathing patterns.

Surface breathing is usually done through the nose. It takes up to 150% more effort to pull gas through the nose than the mouth. Nasal breathing filters, moisturizes, directs gas flow, warms and conditions the gas, produces the sense of smell, brings in oxygen, creates mucus, provides drainage for the sinuses and affects the nervous system. However, the diver must be equally capable of mouth breathing as nasal breathing. If breathing through the mouth leads to a sense of discomfort, stress will enhance that feeling, which could lead to situations where the diver, in a state of high anxiety, dispenses with his or her regulator in order to return to the more natural nasal breathing. Spitting out regulators when tanks are full is not uncommon among panicked divers.

Supplements for the Respiratory System

- **Astragalus** is excellent for bronchial irritation and the treatment of chronic bronchitis. It is a long-term immune tonic, so it is ideal for boosting the immune system when the body is under duress It is effective in preventing colds, allergies, upper respiratory infections. It also works well with people who are subject to asthma, and is beneficial in treating edema. Its ability to activate immune cells such as macrophages, or natural "killer" cells known to destroy cancer cells has made it popular among those who have cancer

- **Bee Pollen** is excellent for hay fever. Many people find it to be their first choice when a hay fever attack starts. It is useful for treating allergies, depression, and for increasing energy and endurance. A few people are allergic to Bee Pollen, so if used, make a gradual introduction; should any negative reaction occur, discontinue use.

- **Elderberry Defense** is effective against the flu and upper respiratory infections

- **Echinacea** boosts the efficacy of our immune systems. It is ideal for use with colds, as it speeds recovery, minimizes symptoms, and fights mild infections

- **Golden Seal** has numerous uses that attributed to its antibiotic, anti-inflammatory, and astringent properties. It soothes irritated mucus membranes, aiding the eyes, ears, nose, and throat. Take at the first signs of respiratory problems, colds, or flu

- **Herbal Teas**, such as Elderflower, relieves cold symptoms and sinus problems

The Role of Potential Hydrogen Imbalance on PH; Health & Safety Underwater

Rebreather use, and the possible flooding of absorbent canisters possibly leading to a "***caustic cocktail***," which occurs when a mixture of water and soda lime enters the rebreather diver's "breathing loop," breathing mixed gases, and switching gases, may have localized or systemic effects on the body's PH level. Therefore, the diver of today must understand what changes PH and how a change in PH may affect the diver underwater and on the surface.

Our blood PH has a great influence on health. Moreover, our reactivity to changes in systemic or local PH levels is on a continuum from nil to catastrophic. Divers expose themselves to numerous environmental elements that may affect local or systemic PH levels. Changes in PH levels can be life threatening. Severe metabolic alkalosis, defined as a blood PH >7.55, is a serious medical problem. Researchers

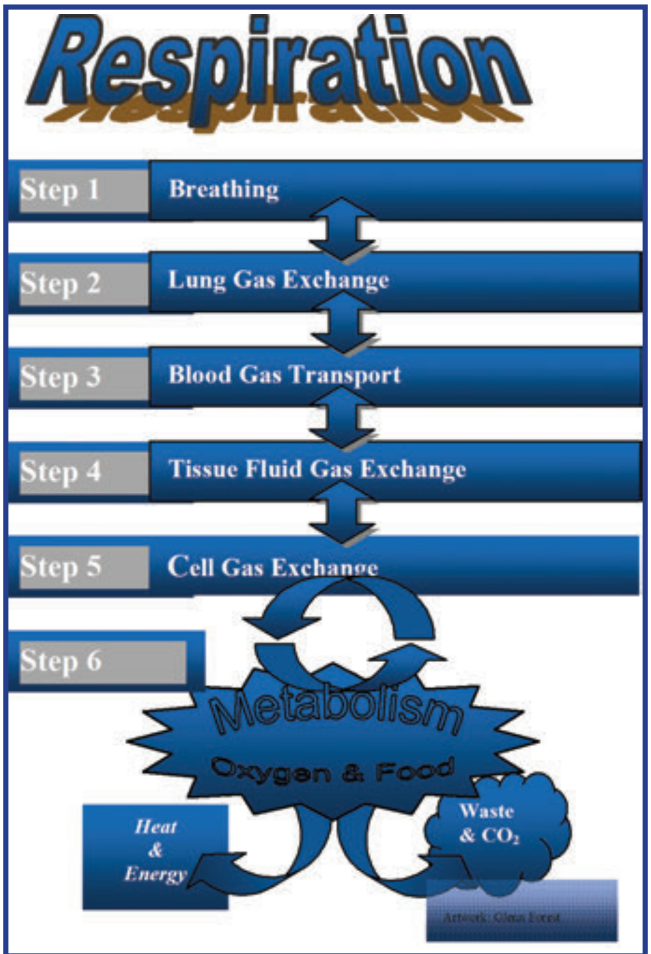


Figure 1-25: The Respiratiory Cycle
Artwork by Glenn Forest

When PH Goes off...

MICROBES in the blood can change shape, mutate, become pathogenic.

ENZYMES that are constructive can become destructive.

OXYGEN delivery to cells suffer.

ORGANS of the body can become compromised, like your brain, or your heart.

MINERAL assimilation can get thrown off.

Figure 1-26: The effects of PH on the body

report mortality rates as high as 45% in patients with an arterial blood PH of 7.55, and such rates jump to the 80% range when blood PH is greater than 7.65. On a scale of 0-14, an extremely severe caustic cocktail could raise metabolic alkaline levels to between 7 and 13.

Metabolic alkalosis is almost always associated with hypokalemia, or low calcium levels, which can cause neuromuscular weakness and arrhythmias, and, by increasing ammonia production, it can precipitate hepatic encephalopathy, or kidney failure, in susceptible individuals. Alkalosis also suppresses coronary blood flow, thereby lowering the threshold for anginal symptoms and again increasing the chance of cardiac arrhythmias. Moreover, alkalosis decreases cerebral blood flow, which may lead to delirium, seizures, and decreased mental status. In addition, metabolic alkalosis causes hypoventilation, which may lead to hypoxemia, or deficiency in the concentration of oxygen in arterial blood. High alkaline levels are also associated with headaches, lethargy, and neuromuscular excitability.

With high PH values, our immune system becomes less efficient. While the immune system assists us in warding off normal disease it also determines our resistance to diving related "***illnesses***." If our acid content is too great, we may be predisposed to oxygen toxicity. Moreover, as PH effects respiration and gas transport, PH may play a role in all diving maladies, including decompression illness and inert gas narcosis. A wise diver will try to maintain a diet an exercise program to ensure PH remains in the 7 to 7.4 range. A simple manner to track ones PH is to use PH strips and do test periodically. PH strips may be found from a variety of sources on the internet and at many health food stores.

Moreover, mild, yet chronic PH imbalances relate to various disease states. Steven Charles, Director of Biomedx, an online resource for bioengineering and biotechnology students, has a very informative article available on the Biomedx website regarding PH regulation and its effect on human physiology. **According to him:**

The PH Regulatory System of the Body

"PH… is the degree of concentration of hydrogen ions in a substance or solution. It is measured on a logarithmic scale from 0 to 14. Higher numbers mean a substance is more alkaline in nature and there is a greater potential for absorbing more hydrogen ions. Lower numbers indicate more acidity with less potential for absorbing hydrogen ions… PH controls the speed of our body's biochemical reactions … by controlling the speed of enzyme activity as well as the speed that electricity moves through our body."

The Disease Paradigm Shift

"…most disease is caused by some imbalance in the body. The imbalance occurs in some nutritional, electrical, structural, toxicological, or biological equation... The human body strives to maintain the PH of the blood at around 7.3. Above or below this level, the colloids in your blood merge into forms… One contention is that these forms constitute pathogenic microbes… that affect immune function.

…According to many health researchers, total healing of chronic illness takes place only when and if the blood is restored to a normal, slightly alkaline PH… The magnitude of meaning behind this research is of incredible importance to someone who is fighting a disease, overcoming an illness, or just desiring to feel better… When PH goes off, microbial forms in the blood can change shape, mutate, mirror pathogenicity, and grow … enzymes that are constructive can become destructive… and oxygen delivery to cells suffers. More and more research is showing that low oxygen delivery to cells is a major factor in most if not all degenerative conditions. Nobel laureate, Dr. Otto Warburg of Germany, won his Nobel Prize for his discovery of oxygen deficiency in the cancer growth process… Cancer thrives under an acid tissue PH/

oxygen deficient environment.

As the PH of the blood goes more acid, fatty acids, which are normally electro-magnetically charged on the negative side switch to positive and automatically are attracted to and begin to stick to the walls of arteries, which are electro-magnetically charged on the negative side… When the body has an excess of acid it can't get rid of, the acid gets stored for later removal in the interstitial spaces, or the spaces around the cells. If the body has an acid overload, it stores the acid in the tissues… and the blood compensates and becomes alkaline.

Minerals on the lower end of the atomic scale can be assimilated in a wider PH range, and minerals higher up on the scale require a narrower PH range in order to be assimilated by the body. For example, sodium and magnesium have wide PH assimilation ranges. It narrows somewhat for calcium and potassium, and more for iodine… Iodine is one of the most important minerals for proper functioning of the thyroid. Malfunctioning thyroids are connected to arthritis, heart attacks, diabetes, cancer, depression, overweight, fatigue and more.

With rising alkalinity, blood can increase its oxygen uptake; therefore, the blood cells can hold more oxygen… The Bohr effect states that with rising blood alkalinity, the red blood cells can saturate themselves with ever more oxygen. The problem is, they can't let go of it! If the blood cells can't let go of oxygen, then the oxygen isn't getting down to the other cells of the body… This state could be termed an anaerobic or overly anabolic condition. The opposite state… would see blood shifting to the acid side... This leads to an anaerobic or overly catabolic condition."

Smoking & Respiratory Health

The lungs, which consist of alveoli, are divided into five lobes. The right lung contains three lobes and the left lung has two lobes. If all the alveoli that compose the lungs were laid out on land, they would cover more than half of a tennis court. The airways connecting the lungs to the nasal passage and mouth are lined with thin, membranous cells called "***ciliated epithelial***" cells. The cilia, which are small or microscopic hairs, prevent pollutants and dirt laden particles from entering the lungs.

When a person smokes, there is an immediate effect on the nervous, circulatory and respiratory systems. One early effect is to paralyze the cilia's actions. A single cigarette will stop cilia action for 20 minutes. Smoking also causes an immediate increase in mucus production and interferes with oxygen uptake. Moreover, smoking creates a faster respiratory rate. This increased respiratory rate combined with density at depth leads to turbulent airflow, which increases the work of breathing and, as stated before, causes carbon monoxide (***CO***) to bind with the blood. Moreover, the CO released into the lungs by lighting a cigarette displaces the oxygen in hemoglobin. CO combines with hemoglobin 210 times more readily than oxygen.

Further, smoking causes the heart to work harder, thereby producing a higher pulse rate and increasing blood pressure. At the same time, blood flow decreases, due to the constriction of blood vessels reacting to tobacco smoke. This eventually predisposes one to heart disease, but more immediately, increases a diver's susceptibility to decompression sickness, as it reduces circulatory efficiency. Smoking also creates a reaction that causes a drop in body temperature.

One additional risk that divers who smoke face is the possibility of mucus plugs trapping gas and behaving as if it were a gas bubble. In addition, these plugs form a base for bubble attachment and may prevent the lungs from filtering bubbles. Given the smoker's characteristic lung congestion combined with damaged alveoli, there is a marked probability of gas trapping and a higher risk of pulmonary barotrauma.

A Prescription for Diving Health

As stated at the outset, this chapter contains information

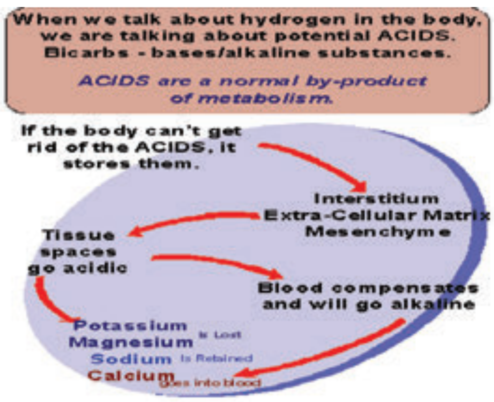


Figure 1-27: Acids in the body

!Tom Mount's note: "*Anaerobic*" is a technical term for '"without air;" "*anabolic*" refers to cell growth and differentiation, and "*catabolic*" is the metabolic process that breaks molecules down into smaller units.

from two worlds: Western science and Eastern metaphysical doctrines. Keeping an open mind, digesting all that is essential to your personal needs, learning how to breathe correctly, and continuing to practice correct breathing techniques will help you become a better diver and quite possibly improve your health. We're certain you'll be amazed at the overall results.

If we eat correctly, avoid smoking cigarettes and other substances, keep alcohol consumption to no more than one to two ounces a day, and exercise daily, we will enjoy both a safer dive and better overall health. Many common diseases derive from a failure to take the basic preventative steps necessary to ensure good health. Although it is our choice to be fit or unfit, the more fit we are, the safer our dives will be. Choose to smoke a cigarette, eat a donut, and drown the donut with a six-pack of beer or a couple shots of whiskey, and you will eventually discover the ills such behaviors bring to your body. Conversely, you can be moderate in your habits, avoid cigarettes, exercise regularly, limit alcohol intake and enjoy a healthier lifestyle. It isn't just the benefit of feeling good day to day; the increased resistance to diving related injuries that a fit and smoke free lifestyle will reward you is more than worth the effort.

Other Supplements of Interest to Divers

As a health guard, supplements may prove a valuable resource for divers. Most supplements and the majority of herbs do not have adverse side effects. However, many of both do have negative interactions with certain drugs. For those who are taking prescription medication, a consult with a health practitioner, such as a medical doctor, naturopathic doctor, osteopathic physician, energy practitioner, homeopath, or herbologist. In this chapter, we have included numerous supplements and herbs that benefit various systems within the body, some of which may provide additional buffering from dive related injuries such as DCI. From a decompression-diving viewpoint, the supplements that promote healthy blood vessels are ideal. Below are additional supplements divers in particular may find beneficial.

- **Silymarin** protects the liver and may be helpful in treating cirrhosis and other forms of liver damage. Studies reflect that patients taking Silymarin live longer than those who did not. These patients also enjoyed better health in addition to longevity
- **Phosphatidylcholine (*PC*)** supports liver functions and, according to numerous studies, reverses and heals liver damage
- **Cynarin** lowers blood lipids and also enhances liver function. It is related to Milk thistle
- **Milk Thistle** is an excellent liver tonic. It is widely used by those who have liver damage, as it stimulates liver repair and cleansing
- **Saw Palmetto** is a supplement all men over 40 should take as an aid to keep the prostate healthy
- **Lycopine** reduces the risk of prostate cancer
- **SAMe** is an excellent antidepressant which also reduces joint pain
- **Organic Lithium** calms and provides a relaxing mood. This supplement is useful for depression and other psychological disorders

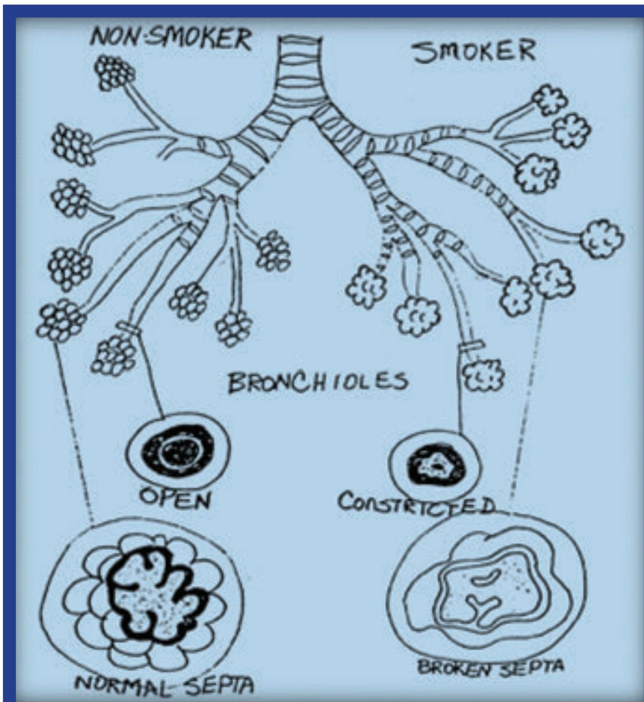


Figure 1-28: Comparison of bronchioles of a non-smoker versus a smoker Art work: Carla Ram


Leigh Bishop

Christina Campbell with a CCR System is Launched into the Aegean Sea to Explore the *HMHS Britannic*

- **5 HTP** may replace Prozac, as it works as an antidepressant with adjunctive appetite suppressant effects. Moreover, 5 HTP promotes sleep. However, take this supplement on an empty stomach
- **Rutin** is good for bruises
- **Arnica** is tremendous for reducing the swelling and pain caused by muscle injuries and strains (my martial arts students and one of my editors and divers, who tends to fall off her trail bike, "live" on this)
- **N-Acetyl Cysteine (*NAC*)** increases glutathione and assists in preventing ear and lung infections. It also speeds up recovery from exercise
- **Monolaurin** fights viral infections
- **Lacteferrin** is a natural antibiotic
- **Hudroxyapatite** is good for burns
- **Malic Acid** is useful for the treating fibromyalgia, a chronic condition noted for widespread pain
- **Deglycerrhizineted Licorice** is an anti-inflammatory agent
- **Lycine** is good for keeping skin tone, may prevent herpes, and helps control herpes reoccurrences. The standard dosage is 500 to 1000 mgs per day
- **Lutien** is good for the eyes; most people would benefit from its use
- **Alpha Lipoic Acid** reduces free radicals, protects diabetics from free radical damage, enhances workouts, and is a treatment for strokes, which can be caused by clots interrupting blood flow to the brain, brain bleeds, or a sudden, transient loss of the blood supply to the brain
- **Grape Seed Extract** is useful for toe and finger fungus and also fights yeast infections
- **EMU Oil** helps heal bruises and cuts when rubbed onto the injured surface
- **Eldeberry Extract** is good for influenza attacks and head-colds
- **DHEA** is necessary only if blood work indicates a need for this supplement
- **DHA** is a strong immune enhancer, but should not be taken if someone has prostate or breast cancer
- **Maca Herb** improves energy; and is nature's version of Viagra. It is also known as "***Peruvian Ginseng***." Maca is also used for anemia, tuberculosis, menstrual disorders, menopause symptoms, stomach cancer, and sterility. Maca also stimulates the immune system, and enhances memory. Moreover, it can stabilize blood pressure, boost immunity, and increase the body's overall vitality

A Word to the Wise

It is highly recommended that prior to undertaking a complete supplement regimen a comprehensive set of blood work with ultra cellular testing, a PH check, and urine samples is completed in order to note which supplements will be of the greatest benefit. As a rule, taking inadequate or inappropriate types and or amounts of supplements may not harm, but could be a waste of effort and money. For general usage consider a multi vitamin combined with Vitamin C at 500 mgs per day, a calcium-magnesium supplement, CoQ-10 at 60 mgs per day, and Vitamin E at 400 IUs per day. The most effective method for determining which supplements one needs is to visit your health care provider for a full work-up of blood, urine, and PH levels.

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Chapter Two
Inert Gas Narcosis

David J. Doolette Ph.D.

Introduction

The narcotic effects of breathing compressed air at depths greater than 100 fsw (30 msw)[1] are probably familiar to most divers. The collection of neurological effects from breathing air at high pressure, including intoxication, slowing of mental processes and reduced manual dexterity are generally referred to as "nitrogen narcosis." Such effects can be produced by breathing many other inert gases[2] in addition to nitrogen, so the condition is more generally known as inert gas narcosis. After describing the signs and symptoms of inert gas narcosis, this chapter will show that such narcosis can be interpreted as the effects of anesthesia prior to unconsciousness. Although the underlying mechanisms of narcosis and anesthesia are not completely understood, a number of features of both theoretical and practical interest will be presented, including features other than inert gas partial pressure which modify narcosis.

Historical Descriptions

Intoxication of caisson workers and divers was noted by the middle of the 19th century when engineering advances allowed work at sufficiently elevated pressure. The seminal work describes the narcotic effect of deep air diving dates from the 1930s. Narcosis was encountered during the first Royal Navy deep air diving trials to 300 fsw (91 msw) and was appropriately described as a "slowing of cerebration" or "as if ... under an anesthetic," but was at that time attributed to "mental instability" in some deep diving candidates (Hill and Phillips, 1932). The role of raised inspired partial pressure of nitrogen in producing narcosis was suspected by 1935 and the use of an alternative breathing gas mixture to eliminate narcosis was proposed[3] (Behnke et al., 1935). Since then, the threshold pressure for air diving that consistently produces a decrement in diver performance has been considered to be 4 ATA [100 fsw (30 msw)]. Confirmation of the role of nitrogen in narcosis came with the report of Max Nohl's 410 ffw (128 mfw) fresh water dive using a Heliox Rebreather of his own design (End, 1938).

Divers preparing for a wreck dive off the coast of Miami - L to R, Director IANTD Korea: Jang-Hwa Hong, Eric Cooper & IT Georges Gawinowski

Signs and Symptoms of Inert Gas Narcosis & Behavioral Modification

Classification of Signs & Symptoms

Inert gas narcosis is an alteration of function of the nervous system that produces behavioral modifications that may impair a diver's ability to work effectively or even survive. In order to recognize all the potential performance impairments resulting from inert gas narcosis and to help understand the causes of narcosis, it is useful to classify the various effects. Behnke originally divided the effects of narcosis into three categories: emotional reactions, impairment of higher mental processes and impairment of neuromuscular control (Behnke et al., 1935). A similar classification is used here: subjective sensations, impaired cognitive function, slowed mental activity and impaired neuromuscular coordination.

The effects of inert gas narcosis on cognitive function includes:

- Difficulty assimilating facts
- Slowed and inaccurate thought processes
- Memory loss

In the laboratory, inert gas narcosis is measured by tests for impaired cognitive function including:

- Conceptual reasoning
- Sentence comprehension
- Mental arithmetic ability
- Short-term memory

Subjective Sensations

Subjective sensations are the sensations that any diver would associate with inert gas narcosis. These include euphoria, intoxication hyper-confidence, recklessness and various altered states of consciousness and attention. Subjective sensations of inert gas narcosis can be assessed using questionnaires asking for a global estimate of the magnitude of narcosis and responses to adjectives, checklists describing work capability (for instance, ability to work, alertness, concentration) and body/mental sensations (for instance, intoxicated, reckless, dreamy, uninhibited) (Hamilton et al., 1992; Hamilton et al., 1995).

Slowed Mental Activity

In addition to increased errors in cognitive function tests, narcosis significantly reduces the speed at which such problems are solved. Apparently information processing in the central nervous system is slowed, and this can be measured in two ways: the rate at which test problems are attempted, or by testing reaction time. Reaction time measures the time between receiving a sensory signal and reacting with the appropriate response and represents the speed of higher mental processes, particularly decision making. Inert gas narcosis slows the reaction time. In a typical laboratory reaction time test one of a series of LEDs is illuminated and the time until it is extinguished by pushing its matched microswitch is measured.

Reduced Neuromuscular Coordination

Neuromuscular coordination (***manual dexterity***)[4] is impaired by inert gas narcosis, but usually only at greater depths than the intellectual impairments described above. Neuromuscular coordination is often assessed by peg board and screw board tests that involve assembly and disassembly of patterns of nuts, bolts and pegs.

Inert Gas Narcosis at Extreme Depth on Air

Air breathing at depths greater than 300 fsw (91 msw) produces altered states of consciousness including manic or depressive states, hallucinations, time disorganization and lapses of consciousness[5].

Thermoregulation

In addition to the obvious actions of narcosis on brain activity, other body activities are affected as a result of changes in the nervous system. Of particular importance to divers, but less widely known, is the distortion caused by inert gas narcosis of the physiological and behavioral control of body core temperature (***thermoregulation***). Narcosis reduces shivering and therefore the production of body heat (***shivering thermogenesis***), the main defense against body cooling. As a result, narcosis allows a more rapid drop in body core temperature than expected during cold water (Mekjavic et al., 1995). Additionally, despite body core cooling, perceived thermal comfort is greater with narcosis than otherwise expected. (Mekjavic et al., 1994). As a result, the diver may neglect to take action to reduce heat loss (***behavioral thermoregulation)***.

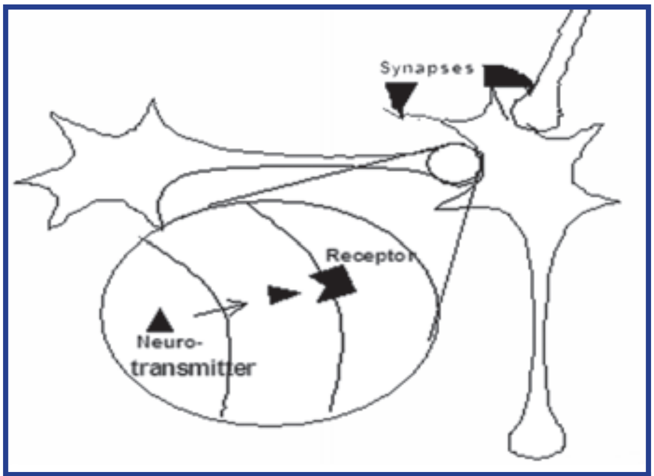

Figure 2-1: Mechanism of Anesthesia

Mechanism of Inert Gas Narcosis Anesthesia

It is apparent that the signs and symptoms of inert gas narcosis result from an alteration of the function of the nervous system. It was noted prior that breathing air at depths greater than 300 fsw (91 msw) produces lapses of consciousness. At much greater depths, air will cause complete unconsciousness (***anesthesia***)[6]. Indeed, many of the inert gases will produce anesthesia, each such gas having a characteristic anesthetic potency. For instance, the approximate inspired partial pressure required to produce anesthesia for nitrogen is 33 ATA, for argon is 15 ATA, for nitrous oxide is 1.5 ATA and for halothane[7] is 0.008 ATA. (Smith, 1986). Some inert gases, notably helium and neon, have no practical anesthetic potency. Owing to its similarity with anesthesia, inert gas narcosis is now generally accepted to be a manifestation of the effects of anesthetic gases at sub-anesthetic doses (***incipient anesthesia)***. The severity of narcosis increases as the inspired partial pressure of the inert gas approaches the anesthetic level.

Different Inert Gases & Anesthetics Produce Identical Narcosis

The narcotic effects of the inert gases and other anesthetics are identical. In specific test of narcosis in either monkeys or humans, argon, nitrogen, nitrous oxide and other general anesthetics have identical effects (although at different partial pressures). Nitrous oxide, which is sufficiently potent to produce narcosis at the surface, has been used extensively in laboratory tests to simulate nitrogen narcosis.

Mechanism of Anesthesia

The mechanism by which any anesthetics, including the inert gases, produce anesthesia is not entirely understood. However, it is widely accepted that the site of anesthesia and narcosis are the synapses in the central nervous system[8]. The majority of drugs which act on the nervous system work by modifying chemical synaptic transmission (see Figure 2-1). Anesthetics enhance the action of a variety of the inhibitory neurotransmitters (particularly ***GABA***) at their specific post-synaptic receptors[9], resulting in a reduced frequency of action potentials. Such depression of central nervous system activity ultimately produces anesthesia. Synapses (enlarged in Figure 2-1) between neurons. Signals in the brain are carried along neurons in the form of an electrical potential called an action potential.Signals are transmitted across the synapse between neurons by chemicals called neurotransmitters, released in response to an action potential. Neurotransmitters combine with specific receptor proteins on the post-synaptic (***target***) neuron. Some neurons release inhibitory neurotransmitters which make the target neuron less likely to fire an action potential while other neurons release excitatory transmitter which make the target neurons more likely to fire an action potential.

Meyer-Overton Correlation & the Critical Volume Hypothesis

Early hypotheses of anesthetic mechanisms pre-date the discovery of chemical synaptic transmission. The most famous of these is the Meyer-Overton correlation, which originated at the turn of this century. Meyer (1899) and later Overton (1902) noticed that there exists a remarkably strong correlation between an anesthetic's potency and its solubility in olive oil. The Meyer-Overton hypothesis states that anesthesia occurs with certain molar concentration of a compound in the lipid (***fat***) of a cell[10]. An elaboration of this hypothesis was proposed by Mullins[11] (1954), and states that narcosis occurs as the volume of some hydrophobic site[12] (probably lipid) expands due to uptake of inert substance (Smith, 1986). It is implied in both these hypotheses that the lipid site is the neuronal cell membrane and that anesthetics work by dissolving in the cell membrane and disrupting the voltage-gated ion channels which allow the neuron to conduct electrical impulses[13].

It is no longer widely believed that the membrane voltage-gated ion channels are the site of anesthesia because evidence has accumulated that any effects of anesthetics on neuronal membranes are physiologically insignificant. Anesthetics may act by occupying hydrophobic pockets inside the neurotransmitter receptor proteins[14] and it is not altogether surprising that a strong correlation exists between anesthetic potency and hydrophobicity. Also, the receptors are embedded in the cell membrane and lipophilic compounds will diffuse rapidly through the membrane and reach high concentration surrounding the receptors. Additionally, lipid soluble compounds readily cross the blood-brain-barrier. So, rather than explaining anesthesia, the Meyer-Overton hypothesis is a useful, incidental relationship. Indeed, it was the low lipid solubility of helium that originally suggested it be tested as a non-narcotic breathing gas diluent (Behnke, et al., 1935).

Narcosis Produces Slowed Mental Processing

Many of the actions of narcosis can be attributed to slowed information processing in the central nervous system. The slowed processing model is a useful tool to understand and investigate narcosis (Fowler et al., 1985). The slowed processing model suggests that decreased arousal due to the anesthetic properties of inert gases slows the processing of information in the central nervous system and results in the some of the behavioral modifications typical of inert gas narcosis. In order to understand this model one must consider the underlying model of information processing and then how it is affected by narcosis.

Information Processing Model

Information processing occurs in a series of stages. For instance, a simple information processing task such as a reaction time involves a perceptual and evaluation stage, a decision making stage and an effector stage. An example of a reaction time is the delay between seeing a red stop light while driving and applying the brakes. Recognizing a red stop light amongst the thousands of other stimuli occurs in the perceptual and evaluation stage. The decision whether or not to brake, involving calculating speed, distance and chance of a collision, occurs in the decision making stage. Activating the neuromotor programs to operate the leg muscles occurs in the effector stage. There are three aspects of such a system that could be influenced by narcosis. Firstly, is the structure of the system. Each information processing stage occurs in a different brain area and narcosis could disturb those areas. Secondly, the functional aspect of this model is the overall performance of the system due to the speed of information processing at each stage. Within limits, decreasing the speed of information handling at any stage impairs performance. Thirdly, the strategy for information handling includes distribution of attention, decision criteria, rehearsal strategies, and speed-accuracy trade-offs.

Functional Component

Slowed processing of information due to inert gas narcosis is evident in laboratory tests of cognitive function where the number of problems attempted is reduced (Hesser, et al., 1978; Fothergill, et al., 1991) and in increased reaction time (Hamilton, et al., 1995; Fowler, et al., 1986; Fowler et al., 1993). Considerable experimental data indicates that narcosis produces a general functional deficit rather than distorting the structural components[15] (Fowler, et al., 1986; Fowler, et al., 1985). This functional deficit can be explained as slowed processing at any of the stages owing to decreased arousal (decreased general level of brain activity) or reduced activation (reduced readiness for activity). It is now thought that narcosis may influence multiple processing stages. Reaction time tests in combination with recording of brain electrical events indicate that slowed processing by narcosis seems to involve both slowing of the perceptual evaluation stage and also reduction of motor readiness at a later effector stage (Fowler, et al., 1993). The notion of narcosis resulting from slowed processing is supported by the effects of amphetamine which increase arousal and reduce the effects of narcosis and by the effects of alcohol which reduce arousal and increase the effects of narcosis. (Hamilton, et al., 1989; Fowler, et al., 1986).

Strategic Component

Decreased accuracy on cognitive function tests with narcosis (Moeller, et al., 1981; Hesser, et al., 1978; Fothergill, et al., 1991) may be due to strategic changes in information handling attempting to compensate for slowed processing. One strategic variable is the speed-accuracy trade-off and a shift in this variable can mean that accuracy is sacrificed in an attempt to maintain the speed of responses (Fowler, et al., 1985; Hesser, et al., 1978). Curiously, such a rapid guessing technique has been found to be typical of one population of occupational divers at the surface (Williamson, et al., 1987).

Modification Dive Profile

Since inert gas narcosis is dependent on the partial pressure of the narcotic gas, it is depth dependent. As already noted some effects are more apparent at shallower depths, with other effects becoming evident deeper. The onset of narcosis upon breathing a narcotic partial pressure of gas is rapid but not instantaneous. The time to onset of narcosis should represent the time for a narcotic tension of inert gas to be achieved in the brain, and thus can be characterized by the half-time of the brain[16] and on the depth of the dive. For typical descent rates, narcosis will onset during compression past 100 fsw (30 msw) or soon after arriving at depths. Rapid compression can temporarily raise alveolar carbon dioxide levels that can exacerbate narcosis causing a temporary higher peak level of narcosis.

Oxygen

Theoretical and experimental evidence suggests that oxygen is also narcotic, producing performance deficits similar to inert gases. Although central nervous system oxygen toxicity prevents pure oxygen breathing at sufficiently high partial pressure to cause subjective sensations of narcosis, it can produce cognitive function impairment alone or in gas mixtures containing another narcotic gas. Lipid solubility predicts oxygen could be two times as narcotic as nitrogen and cognitive function tests indicate oxygen may be three to four times as narcotic as nitrogen (Hesser, et al., 1978). It is therefore prudent to include oxygen in any calculations of equinarcotic depths in mixed gas dive planning.

Carbon Dioxide

Carbon dioxide (**CO_2**) produces a form of narcosis that is somewhat different to inert gas narcosis, and probably involves a different mechanism (Hesser, et al., 1978; Fothergill, et al., 1991). Whereas inert gas narcosis decreases both speed and accuracy in cognitive function tests, carbon dioxide tends to decrease the speed only without influencing accuracy. CO_2 is relatively more potent than inert gases at reducing neuromuscular coordination. CO_2 is narcotic at extremely small alveolar partial pressure and can be debilitating alone or can act additively with inert gas narcosis. An increase in alveolar CO_2 from its normal level of 5.6 - 6.1 kPa to 7-8 kPa causes significant narcosis. Alveolar carbon dioxide can easily rise to this level due to respiratory resistance from poor equipment or the high breathing gas density of nitrogen mixtures at depth, breathing equipment dead space or inadequate pulmonary ventilation. For instance, a diver swimming at a fast sustainable pace breathing less than 15 litres/min (***BTPS***) may be at risk of alveolar CO_2 reaching narcotic levels due to inadequate alveolar ventilation.

Anxiety

Anecdotal evidence suggests that anxiety can enhance narcosis. There is some experimental evidence, mostly arising from greater test score decrements under open-sea conditions suggested to produce anxiety in comparison to chamber tests. In one study describing the effects of narcosis in a cold open-water test at 100 fsw (30 msw), urine adrenaline and noradrenaline was elevated (a sign of stress) in those subjects showing the worst narcosis on cognitive function and dexterity tests (Davis, et al., 1972).

Arousal: Fatigue, Drugs & Alcohol

According to the slowed processing model of inert gas narcosis, any condition that influences the level of arousal will modify narcosis. Fatigue would be expected to enhance narcosis and this is in fact the case. As previously described for amphetamine and alcohol, any drugs which produce increased or decreased arousal are likely to interact with narcosis.

Tolerance or Adaptation

Tolerance

Drug tolerance is the phenomena of reduced effect of a drug due to repeated exposure. In the context of narcosis, development of tolerance would imply a reduced narcotic potency of inert gas with repeated diving exposure, but this is apparently not the case since repeated diving exposure does not reduce the objective behavioral measures of inert gas narcosis. Five successive daily chamber air dives to 7 ATA each produce the same deterioration compared to 1.3 ATA in cognitive tests, reaction time and dexterity tests (Moeller et al., 1981). Body sway (a measure of intoxication) is similarly increased by narcosis at 5.5 ATA compared to 1.3 ATA over 12 successive daily air dives (Rogers and Moeller, 1989). Clearly, tolerance to the narcotic actions of inert gases does not develop; repetitive diving exposures do not reduce the anesthetic potency of inert gases.

Subjective Adaptation

Adaptation is the adjustment by an organism to its environment; in the case of narcosis, adaptation would be a rearrangement of behavior that allows a performance enhancement[17]. Repeated diving produces a dissociation of behavioral and subjective components of narcosis. It is unclear whether this represents a true tolerance[18] or an adaptation. During five consecutive daily dives to 6.46 ATA on air, reaction time does not improve relative to 1 ATA, but subjective evaluation of narcosis does change. Global estimates of the magnitude of narcosis begin to decline by the third daily dive as does identification of body/mental sensations associated with intoxication; however, subjects continue to describe their ability to work as being equally impaired (Hamilton, et al., 1995). It is evident that it is inappropriate to use the intensity of sensations of intoxication sensation as a gauge for underwater efficiency.

CCR Diver Mark Danzinger in Grand Cayman

Specific Adaptation & Individual Variability

It is deeply entrenched in the diving community that some individuals can work effectively at depth and that diving experience improves performance during deep dives. Indeed, as with any biological phenomena, there is some individual variability in susceptibility to narcosis, but whether adaptation specific to the narcotic situation occurs with repeated exposures is speculative. For instance, reduction in subjective sensations of intoxication may allow better focus of the task at hand. Also, some individuals may adopt more appropriate adaptive strategies to cope with narcosis and experience may also help identify such strategies. For instance, it is possible to control accuracy on tests for narcosis, allowing only speed to decline (Fowler, et al., 1993), so a potential strategic adaptation could be to choose an appropriate speed-accuracy trade-off. Indeed, one of the earliest observations of narcosis is that using deliberately slow movements can lessen neuromuscular impairment (Behnke, et al., 1935).

Summary & Practical Strategies

Some inert gases possess anesthetic properties, narcosis results from breathing these gases at sub-anesthetic doses and is an unavoidable consequence of air diving beyond 100 fsw (30 msw). A possible explanation of the effects of narcosis on behavior is a slowing of information processing in the central nervous system, often combined with a shift in the speed-accuracy trade-off making the diver more prone to errors. The subjective sensations of inert gas narcosis include intoxication and repeated diving may reduce these sensations. Objective laboratory tests of narcosis show slow and inaccurate cognitive function, slowed reaction time, and decreased neuromuscular coordination. Performance on such objective tests does not improve with repeated dives. A less well appreciated action of inert gas narcosis is impaired thermoregulation which can result in greater heat loss during water immersion. Since narcosis is enhanced by factors such as carbon dioxide retention, anxiety and fatigue, narcosis can increase during a dive without further change in depth.

Mel Clark

Divers on the Doc Demille, Florida

Strategies to enhance performance while under the influence of narcosis might exist. Although the nature of such strategies is unknown, some issues are worthy of consideration. First, it is important to recognize that narcosis will reduce overall efficiency during air dives deeper than 100 fsw (30 msw). Also, owing to subjective adaptation, it is inappropriate to use the intensity of intoxication as a gauge for underwater safety and efficiency. Secondly, over-learned skills are less likely to be influenced by impaired information processing. Furthermore, subjective adaptation may be of some value particularly for performing over-learned tasks. On the other hand, subjective adaptation will be of no value to novel situations or situations that require cognitive information processing or memory (for instance, gas management or decompression calculations). Thirdly, if some of the performance decrement is due to an inappropriate shift in speed-accuracy trade-off, training may allow more appropriate information processing strategies to be implemented. Finally, it must be recognized that such strategies may improve performance with moderate levels of narcosis but are unlikely to protect against the debilitating effects of extreme narcosis.

By far the best choice is to avoid narcosis where feasible and in particular where safety may be reduced. The level of narcosis is primarily influenced by inspired partial pressures of nitrogen and oxygen and therefore the depth of a dive and the breathing gas mixture. The use of helium as a partial or complete replacement for nitrogen as a breathing gas diluent reduces or eliminates inert gas narcosis and owing to lower breathing gas density reduces the level of narcosis due to CO_2 build-up.

Notes

1 Depths quoted as meters sea water gauge (***MSWG***) imply the information results from open-water dives whereas pressures quoted as atmospheres absolute (***ATA***) imply chamber tests. Approximate conversions to feet sea water gauge (***FSWG***) are included.

2 Inert gases exert biological effects without change in their own chemical structure. In terms of respiration, inert gases exclude oxygen, carbon dioxide and water vapor.

3 Helium had been proposed as a breathing gas diluent that might accelerate decompression but the cost of helium required for standard dress had prevented human dives.

4 Neuromuscular coordination, also called manual dexterity, is a consequence of not only muscle contraction, but the nervous system control of muscle contraction and the neuromotor (movement) programs in the central nervous system.

5 Reports by divers of lapses of consciousness might actually be memory lapses.

6 Anesthesia can be defined as an unconscious state that eliminates response to surgical pain.

7 Halothane is used for clinical anesthesia.

8 Neurons are the cells that carry the electrical signals

in the nervous system, synapses are a type of junction between neurons.

9 Many drugs alter synaptic transmission owing to a chemical similarity with particular neurotransmitters; however, anesthetics do not resemble neurotransmitters. How such a variety of chemically different anesthetics exert similar effects on the nervous system is an area of ongoing research. Some evidence suggests that the mechanism by which inert gases produce their anesthetic actions may be slightly different to other general anesthetics.

10 According to Henry's Law, molar concentration = partial pressure ***x*** solubility. According to the Meyer-Overton correlation the potency of an anesthetic should be determined by its solubility in lipid.

11 Miller (1971) later expounded Mullins idea in the form of the critical volume hypothesis to explain the opposing actions of narcosis and high pressure nervous syndrome.

12 Solubility in water and lipid are often inversely related. Non-polar compounds typically have a low solubility in water (***hydrophobic***) and a high solubility in lipid (***lipophilic)***.

13 There is an electrical potential difference across a neuronal cell membrane (***inside negative***) that is maintained by an unequal distribution of small charged particles called ions. There are channels in the membrane through which ions can flow, but these are closed in the resting state. Opening of these channels causes a brief, localized reversal of the membrane potential called an action potential. These channels open in response to small voltage changes (***voltage-gated ion channels***) and thus are triggered by electrical activity in an adjacent area of the membrane, propagating the action potential. Neurotransmitter receptors produce smaller, decaying electrical potentials by opening different ion channels (***receptor-gated ion channels)***.

14 In support of a protein site for anesthesia is another strong correlation, that between anesthetic potency in mammals and luciferase (***firefly light emitting protein***) activity depression over 100,000 range of potency.

15 Using the additive factor method where stimulus intensity is varied under control and narcotic conditions, a parallel shift, rather than a change in slope, of the stimulus intensity/response relationship indicates that narcosis produces a general functional deficit rather than interfering with structural stages.

16 Unpublished experiments in my laboratory indicate that the half-time of the brain after a step change in arterial nitrogen partial pressure should be approximately 1 minute.

17 Adaptation also has a meaning similar to tolerance but is a reduced nervous system response to continual stimulation, this is not implied here.

18 Development of tolerance would imply that narcosis produces these subjective effects by a different mechanism to the other behavioral effects that are not altered by repeated exposures.

Footnotes

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Chapter Three
Oxygen & Its Affect On The Diver

David Sawatzky M.D.

Introduction

Oxygen (***O_2***) is a vital necessity for life, and a frequent cause of death in divers. In open circuit diving, divers frequently die from hyperoxia (too much O_2) and occasionally from hypoxia (too little O_2). In CCR diving, hyperoxia and hypoxia are two of the major problems and frequent causes of death (hypercarbia, too much CO_2, is the third). The physiology of O_2 and O_2 toxicity is fairly complex, but it is worth learning as much as possible so that you can dive in a safer fashion. In this chapter we are going to look at the physiology of O_2, acute hypoxia, O_2 toxicity, acute hyperoxia, and some of the potential longer-term effects of hyperoxia.

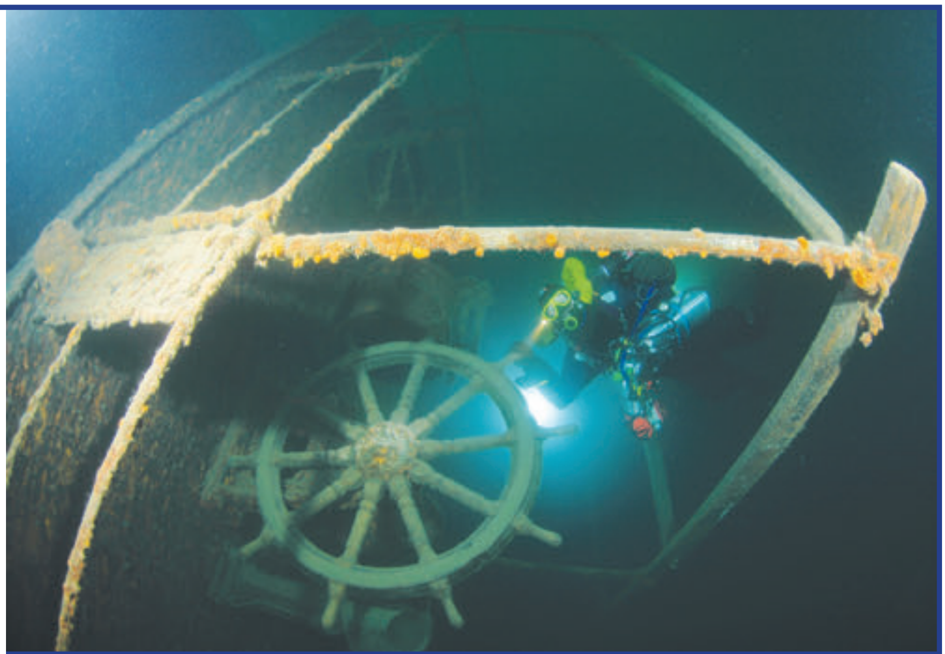
Physiology of O_2 Transport at the Surface

Oxygen has atomic number 8, which means the nucleus is composed of 8 protons and 8 neutrons. It is a colourless, odorless, tasteless gas and by volume, air is composed of 21% O_2. Therefore, the partial pressure of O_2 on the surface is 0.21 ATA, or approximately 160 mm Hg (1 ATA is 760 mm Hg ***x*** 21% = 160 mm Hg). Oxygen normally exists as a molecule made up of two oxygen atoms.

When we take a breath, the air we inhale is mixed with the air that remained in the mouth, airways and lungs at the end of the last breath. This air contains approximately 17% O_2 and 4% CO_2. In addition, water vapor is added to the inspired air until it is 100% saturated at body temperature (water vapor pressure of 47 mm Hg at 37^{o}C). The net effect is that the gas in the alveoli has a partial pressure of O_2 (***PO_2***) of around 105 mm Hg.

It takes a small difference in PO_2 to drive the O_2 across the alveolar walls into the blood, and some blood passes through the lungs without completely equilibrating with the air in the alveoli so that the arterial blood leaving the lungs and being pumped by the heart to the tissues of the body has a PO_2 of around 100 mm Hg in a normal, healthy person.

However, PO_2 is only part of the story. What we really care about is the ***amount*** of O_2 the blood is carrying to the tissues. At a PO_2 of 100 mm Hg, approximately 0.3 ml of O_2 will dissolve in every 100 ml of blood. This is a trivial amount of O_2 and not nearly enough to sustain life. The secret of life is hemoglobin (***Hb***). Hemoglobin is a complex protein that is designed to carry 4 molecules of O_2. It is contained inside Red Blood Cells (***RBC***) and gives blood its' red colour. The amount of Hb in blood varies from approximately 12 to 18 grams per 100 ml with 15 gms being a normal value in males (slightly lower in females). One gram of Hb can carry 1.36 ml of O_2 and at sea level in a normal healthy person, Hb is approximately 97% saturated with O_2 when it leaves the lung.



Mel Clark

Gordy Hendrickson on the stern of the *Gordy Kamloops, Isle Royale*

Therefore, the Hb in every 100 ml of blood can carry 15 ***x*** 1.36 ***x*** 0.97 = 19.8 ml of O_2. When we add the 0.3 ml of O_2 dissolved in the plasma, each 100 ml of blood can carry roughly 20 ml of O_2. How much O_2 is off loaded in the tissues depends primarily on blood flow and how much O_2 the tissues are using. In most tissues, the blood leaving the tissues has a PO_2 of 40 mm Hg. When the O_2 requirement of a tissue increases (a muscle starts to work), the tissue has some capacity to off load more O_2 from the blood but the primary mechanism used to deliver more O_2 to a working tissue is to increase the amount of blood going to the tissue. For example, a muscle working at maximum capacity will have a blood flow approximately 100 times greater than the same muscle at rest.

It is also important to understand that tissues cannot "store" a significant amount of O_2. Muscle contains a small amount of myoglobin. Myoglobin is a protein like Hb, but it can only bind one molecule of O_2. The rest of the O_2 in tissues is dissolved in the fluid, and we have already seen that very little O_2 dissolves in body fluids. Finally, O_2 is used in the cells to generate Adenosine Triphosphate (***ATP***). ATP is the molecule that actually "makes things happen," like causing muscles to contract. A small amount of energy is also stored as creatine phosphate (***CP***) but the combined energy stores of ATP and CP will only supply enough energy for a hard working muscle for a few seconds. The bottom line is that tissues need a continuous supply of O_2 to continue functioning.

Table of approximate O_2 stores in a person breathing air at sea level:

450 ml O_2 in the lungs
850 ml O_2 in the blood
50 ml O_2 in dissolved in body fluids
200 ml O_2 bound to myoglobin

When asleep (totally at rest), a 150 pound (70 kg) person requires about 250 ml of O_2 per minute. When that same person is exercising at their maximum capacity, they will require up to 4000 ml of O_2 per minute (if they are a highly trained athlete). An average, reasonably fit technical diver will require 3000 to 3500 ml of O_2 per minute at maximum exercise.

The reason I went through the above explanation is that it is critical for a technical diver, and especially a CCR diver to fully understand what happens in the normal person on the surface so that they can understand what happens when we breathe gases other than air, and when we breathe those gases under increased pressure.

Physiology of O_2 Transport & Absorption When Diving

Does breathing Nitrox deliver more O_2 to the cells? When we are breathing Nitrox 40 on the surface (PO_2 of 0.4 ATA), the PO_2 in the alveoli will be approximately 200 ml Hg, or about twice what it is when we are breathing air. Therefore, the blood leaving the lungs will have about 0.6 ml of O_2 dissolved in every 100 ml of blood, and 19.8 ml of O_2 attached to Hb in every 100 ml of blood. The total amount of O_2 carried by the blood will have increased only 0.3 ml for every 100 ml of blood, even though we have doubled the inspired PO_2! This point is VERY important. Breathing O_2 at elevated pressures does not significantly increase the amount of O_2 being carried by the blood. What happens in the tissues? The amount of O_2 in the tissues does not change significantly, but the PO_2 will increase. The important point about using Nitrox is not that we are breathing more O_2, but that we are breathing less nitrogen.

Extending this discussion to CCR diving, we know that PO_2 is kept constant by the rebreather. If we use a set point of 1.3 ATA, we will have a PO_2 in arterial blood roughly 6.5 times higher than breathing air on the surface. Therefore, we will have 6.5 ***x*** 0.3 = 1.95 or 2 ml of O_2 dissolved in the plasma of every 100 ml of blood. This is still a very small amount compared to the 20 ml of O_2 carried by the Hb in the same 100 ml of blood. Even though we are breathing the equivalent of 130% O_2 on the surface, the amount of O_2 being delivered to the cells is not significantly changed.

As with Nitrox, the primary reason we dive with an elevated PO_2 when diving rebreathers is to reduce the amount of inert gas we are breathing and thereby absorbing during the dive. A lot of technical divers "push" the PO_2 during the bottom phase of a dive. Does this make any sense? Let's look at an example. We are going to do a dive to 300 ft (90 m). At this depth, the total pressure will be 10 ATA (9 ATA water pressure plus 1 ATA for the atmosphere). If we use a PO_2 of 1.6 ATA, we will be breathing 8.4 ATA of inert gas (84%). If we use a set point of 1.3 ATA, we will be breathing 8.7 ATA of inert gas (87%). The risk of having an O_2 convulsion with a PO_2 of 1.6 ATA is far higher than with a PO_2 of 1.3 ATA. It makes no sense to dramatically increase the risk of an O_2 convulsion to reduce the inert gas percentage by only 3%, as this will have a very small effect on the required decompression time.

Another vital factor is O_2 absorption and use when diving. We mentioned above that the average person will use between 500 ml and 3000 ml of O_2 per minute, depending on their activity level. A vital fact to understand when CCR diving is that the amount of O_2 used by the body does NOT CHANGE WITH DEPTH! This is critical. When you are working while diving, the muscles require the same number of molecules of O_2 to make ATP as they do on the surface. Depth is not a factor.

Matti Antilla at Fountain de Trouffe

When you increase the PO_2 of the inspired gas, slightly more O_2 will dissolve in the blood, but there is no significant change in the amount of O_2 delivered to the cells and no change in the amount of O_2 used by the body. So who cares? CCR diving is unique in that only the O_2 your body uses is added to the loop (ignoring O_2 lost in bubbles, but there shouldn't be any at constant depth).

So what happens when we are sitting breathing on the surface? There are approximately 6 liters of gas in your lungs at full inspiration, and very roughly 4 liters of gas in the scrubber and loop for a total of 10 liters of gas. If we use a set point of 0.7 ATA, how long will the O_2 in the system sustain us at light work (1.0 liter of O_2 per minute)? We have 10 liters of gas at 1.0 ATA, 70% is O_2 so we have 7.0 liters of O_2 that we are using at 1.0 liter per minute, so the O_2 will last 7 minutes. (In reality we would loose consciousness after about 6 minutes as the PO_2 drops towards 0.1 ATA.) Of course we will have to add diluent to maintain the breathing volume as the O_2 is absorbed, but that will add more O_2 and make the gas last even longer.

Now, what happens at depth? If we take the same situation at a depth of 300 ft (90 m) where the total pressure will be 10 times surface pressure, the gas will be 10 times as dense. Therefore the 10 liters of gas in the loop and our lungs will contain 10 times as many molecules. A common mistake (unfortunately one I have made in print) is that there will be 10 times as many O_2 molecules and therefore the gas should last 10 times longer. This would be true if we were breathing 70% O_2 ATA depth. However, if the CCR set point is maintained at 0.7 ATA, we will be breathing the surface equivalent of 7% O_2 at depth and this means there will be exactly the same number of O_2 molecules in the loop as at the surface. Therefore, at the same work level it will last the same length of time. In reality the set point will almost always be elevated to around 1.3 ATA at depth and therefore the gas will contain almost twice as many molecules of O_2, and will last almost twice as long.

Acute Hypoxia

We will examine the fairly complex situation in CCR diving and then review what happens with hypoxia while open circuit diving.

When diving CCR, one of the primary concerns is having enough O_2 in the breathing mix. There are several ways the concentration of O_2 in the breathing mixture can decline, including solenoid failure closed, O_2 tank turned off, O_2 tank empty, O_2 tank containing something other than O_2, electronic failure, etc. Our purpose here is not to review these failure modes, but to examine the physiology of what is happening when they occur.

For discussion purposes, let's look at what happens to the CCR diver who leaves the O_2 tank turned off and does not check their gauges. They get dressed and start breathing on the rebreather. The gas in the rebreather is most likely a fairly high percentage Nitrox if they have celebrated their O_2 sensors. As they continue to breathe, the CCR will remove the CO_2 they produce and the PO_2 will slowly fall. If the diver continues to breathe the loop on the surface, they will loose consciousness after several minutes as explained above.

Usually the diver will enter the water and start to descend before this happens. As they descend, the gas in the loop will be compressed and they will add diluent (air or Nitrox) to maintain a breathable volume of gas. This fresh gas adds O_2 to the breathing loop. In addition, as the diver descends the increasing pressure will increase the PO_2 in the breathing loop (therefore the diver will have lots of O_2). Once the diver reaches the bottom, the PO_2 in the loop will very slowly fall. Eventually, they will become hypoxic, but this might not happen until 10 minutes or more into the dive! Factors that determine how long this takes include the initial PO_2 in the loop, the initial volume of the loop, the rate at which the diver descends, the rate at which the diver uses O_2, the PO_2 of the diluent, the amount of diluent that is added, etc.

As we reduce the PO_2 in the inspired gas, the PO_2 in the alveoli and therefore the arterial blood starts to fall. The body is very well designed however and Hb is very effective in savaging O_2 from the gas in the lungs, even when the PO_2 is less than normal. The Hb/O_2 dissociation curve shows that if the PO_2 in the blood falls from 100 mm Hg (normal) to 60 mm Hg, the Hb saturation will fall from 97% to approximately 85%. In this part of the curve a relatively large fall in PO_2 causes a small fall in Hb saturation. Therefore, a virtually normal amount of O_2 is being delivered to the tissues by the blood even though the inspired PO_2 is significantly less than normal.

If the PO_2 in the blood continues to decline, say from 60 mm Hg to 20 mm Hg, the Hb saturation will fall from 85% to approximately 25%. In this part of the curve a small change in PO_2 results in a large change in Hb saturation. This feature is critically important to the normal functioning of the body and results in large amounts of O_2 being off loaded in the tissues. Unfortunately, in the situation of hypoxia this means that a slowly falling PO_2 in the blood will result in no symptoms initially and then fairly rapidly cause loss of consciousness.

The brain is a tissue that is totally dependant on O_2 to function. Most of the other tissues in the body have alternative biochemical pathways that do not involve $O_2$to generate small amounts of energy. These pathways are very inefficient, and they generate waste products that build up and ultimately limit the ability of the cells to function, but they do allow muscles to work for a few minutes at a level greater than can be supported by the amount of O_2 being delivered to the muscle by the blood. The brain does not have this capability and it also does not have the O_2 stores that muscle contains (no myoglobin and very little CP). The end result is that the brain is very sensitive to inadequate O_2 supplies and it is the cause of most of the signs and symptoms of hypoxia.

In open circuit diving hypoxia is usually the result of breathing from the wrong tank, filling the tank with the wrong gas, or having the O_2 consumed by oxidation in the tank before the dive (water in a steel tank that has sat for a long time). The seriousness of the hypoxia will be determined by the percentage O_2 in the tank and the resulting PO_2 as determined by the depth of the diver. In general we have no signs or symptoms of hypoxia even at maximum exercise until the PO_2 is less than 0.16 ATA. At rest we are usually asymptomatic until the PO_2 is less than 0.12 ATA. Therefore, an open circuit diver should not breathe a mixture of less than 16% O_2 on the surface. This is one of the reasons a travel gas is required on a deep Trimix dive.

A special situation exists when the diver breathes a pure inert gas. Many tech divers use argon for suit inflation and some rebreathers use pure inert gas as the diluent. Unfortunately, many divers have ended up breathing pure inert gas by mistake. If a person breathes a pure inert gas the PO_2 in the lungs becomes extremely low after a couple of breaths. The blood returning from the body to the lungs normally has a PO_2 of around 40 mm Hg and contains almost 60% of the O_2 it started with. This O_2 moves from the blood into the lungs and when the Hb returns to the tissues it REMOVES O_2 from the tissues. What happens is that the person looses consciousness after only a few breaths of a pure inert gas and after a minute or two they become virtually impossible to revive and they die. For this reason many people (including the author) believe that pure inert gases should NEVER be used in diving. (Argon provides only a trivial reduction in heat loss by the body so purchase better drysuit underwear.)

Signs & Symptoms of Hypoxia

Loss of consciousness is often the first sign of hypoxia, especially if the fall in PO_2 is rapid. Other signs include poor performance and in-coordination. Symptoms of hypoxia include euphoria, over confidence, apathy, fatigue, headache, and blurred vision. Hyperventilation is usually not present if the PCO_2 is normal. Defective memory and impaired judgment are common. These often cause the diver to respond inappropriately to an emergency, and to ignore other signs and symptoms of hypoxia. Therefore, loss of consciousness is very common in hypoxic divers.

A further problem is that many of the signs and symptoms of hypoxia are the same as those of narcosis, O_2 toxicity, and elevated PCO_2. In addition, these problems are additive. For example, if the PCO_2 is slightly elevated (scrubber starting to break through or the diver is working) and the PN_2 a little high (diving a bit deep on Nitrox), the resulting mental impairment will be far worse than expected from either one alone. If the PO_2 is also slightly high or low, the diver will be in serious trouble. This is why the first response to any perceived problem while diving CCR should be to go OC on a safe gas until you have determined exactly what the problem is and have resolved it. It is also why most CCR units have alarms that go off when the PO_2 drops below 0.5 ATA, hopefully the diver will be able to recognize and correct the problem before the level of hypoxia impairs their thinking processes.

Hypoxia of Ascent

When we descend while diving CCR, we must add diluent to the loop to maintain a breathable volume of gas. At the same time, the gas in the loop is being compressed and the PO_2 is climbing. For example, if we used no O_2, added no diluent, and left the surface with a PO_2 of 0.7 ATA, when we arrived at 100 ft (30 m) the PO_2 would be 4 * 0.7 = 2.8 ATA. If we balance our rate of descent, work rate, and addition of diluent, it is often possible to leave the surface with a PO_2 of 0.7 ATA and arrive on the bottom with a PO_2 of 1.3 ATA, without changing the set point from 0.7 ATA, or injecting any pure O_2.

When we ascend, the gas in the loop is expanding and we must vent gas. At the same time the PO_2 is dropping. For example, if we leave the bottom at 100 ft (30 m) with a PO_2 in the loop of 1.3 ATA, used no O_2 and added no O_2, the PO_2 would be 1.3 ATA / 4 = 0.325 ATA when we arrived on the surface. Of course we use O_2 during ascent so the real PO_2 would be even less. A trick while CCR diving is to make sure you are at minimum loop volume when you start your ascent, and to vent frequently during ascent to maintain minimum loop volumes so that the unit will have to inject less O_2 to maintain the PO_2 as you ascend.

Oxygen Toxicity

In Open Circuit technical diving, O_2 toxicity is a relatively common cause of death (breathe a deco gas while deep by mistake). In CCR diving, O_2 toxicity is also a major cause for concern. To have a reasonable understanding of the danger of excessive O_2, we have to understand the physiology of O_2 toxicity.

The first and most basic point is that MOLECULAR OXYGEN IS NOT TOXIC! The problem is that whenever molecular O_2 exists, it forms other substances known as "oxygen radicals." Oxygen radicals are highly reactive molecules, formed from oxygen, which contain at least one extra electron. These molecules are formed from collisions between oxygen and other molecules, and as a result of metabolic processes in the cells. Examples include superoxide anions, hydrogen peroxide, hydroperoxy and hydroxyl radicals, and singlet oxygen. Oxygen radicals will bind to and react with the next molecule they come in contact with, often damaging or changing that molecule. Therefore, whenever you have O_2, you will have O_2

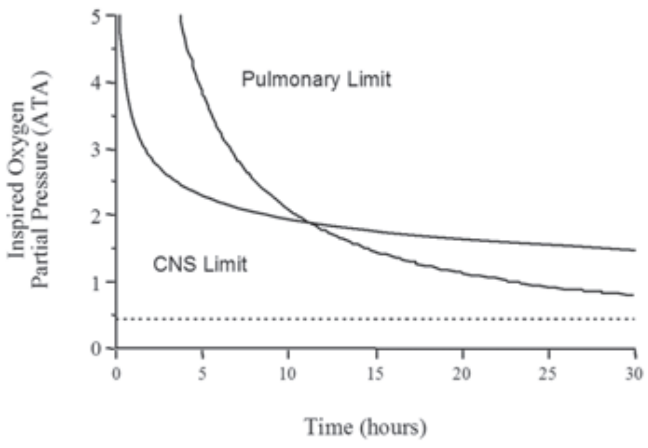


Figure 3-1: The Predicted Pulmonary and CNS Toxicity - Limits of Exposure to Varying Partial Pressures of O_2 Based on Data Bennett & Elliott *Physiology & Medicine of Diving* 4th Ed. pg. 155. 1993

radicals. The number of O_2 radicals is proportional to the partial pressure of O_2.

There are hundreds of specific chemical reactions that oxygen radicals can be involved in that damage the cell but in general terms there are three ways that they cause damage. The first is through inactivation of enzymes. Enzymes are proteins that work as catalysts, causing reactions to occur that would not normally occur at body temperature. They do this by holding the two molecules that are to react in exactly the right orientation to each other so that they join. The resulting molecule is released and the enzyme starts again, repeating the process thousands of times. If the shape of the enzyme is changed, the molecules will not be held in the right orientation and the reaction will not occur. Oxygen radicals cause cross-linking of sulphydryl groups, thereby changing the shape of the enzyme and inactivating it. They also cause changes in the shape of proteins responsible for transport of ions in and out of the cells across the cell membrane, stopping them from functioning. Finally, oxygen radicals cause peroxidation of the various lipids in the cells.

All cells in oxygen breathing animals have ways to inactivate oxygen radicals and to repair some of the damage done by them. The two main defenses are superoxide dysmutase and catalase. Both of these enzymes help maintain a good supply of reduced glutathione. Reduced glutathione has many sulphydryl groups and oxygen radicals will bind to them, and thus be unavailable to cause damage to the cell. Vitamins E and C are also antioxidants.

Oxygen radicals are not only important in diving, but are becoming very important in medicine. One of the methods white blood cells use to kill bacteria is to enclose the bacteria in a membrane and then to inject oxygen radicals into the vacuole. (The white blood cells makes the O_2 radicals.) The oxygen radicals actually kill the bacteria. In addition we now know that O_2 radicals are the final method of damage in many diseases. Oxygen radicals are therefore both "***good***" and "***bad***."

It would seem reasonable to conclude that if O_2 radicals cause cellular damage, taking ***antioxidants*** should help reduce the damage. So far, the results of many well-designed studies have failed to show any benefit from taking antioxidant supplements. Some benefit has been shown when increased amounts of anti-oxidants are consumed by eating foods high in anti-oxidants. This suggests that something else in the food is required to get the beneficial effect of the antioxidants that is not available in the supplements.

The bottom line is that anytime O_2 exists, O_2 radicals will be formed. The number of O_2 radicals is proportional to the PO_2. All of our cells have defenses against the damage caused by O_2 radicals. At normal PO_2s, our cells are more than capable of repairing the damage being caused by the O_2 radicals. As the PO_2, and the number of O_2 radicals is increased, a point is reached where the cells cannot repair the O_2 radical damage as quickly as it is occurring. Therefore, the damage will accumulate until the function of the cell is impaired or the cell dies.

Signs & Symptoms of Oxygen Toxicity

Given the above explanation, it should be obvious that the toxicity of O_2 will depend on the PO_2 and the time of exposure. The other factor is that we are all biologically different and some individuals will have more defenses against O_2 radicals than others. To further complicate the issue, our defenses against O_2 radicals also change greatly from day to day. Therefore, we have marked differences in sensitivity to O_2 radical damage in different people and on different days in the same person.

In general, the susceptibility of a cell to oxygen toxicity is related to its rate of metabolism in that a resting cell is relatively resistant. This makes sense in that O_2 radicals interfere with cell processes and the slower these processes are occurring; the longer it will take for the damage to matter. We also know that things that stimulate the cells, like caffeine, increase the risk of O_2 toxicity while things that slow down the cells have some protective effect.

Every cell in the body will eventually die if it is exposed to enough O_2 radicals. But in the intact person the lungs and the brain will suffer serious damage before the other tissues. The eyes can also suffer damage at relatively modest exposures.

The human body is able to tolerate increased levels of oxygen, up to about 0.45 ATA, without problem. At PO_2s of between 0.45 ATA and 1.6 ATA, the toxic effects are mainly on the lungs and take many hours or days to develop. At pressures over 1.6 ATA, the toxic effects are mainly on the brain (CNS) and may develop in a few minutes.

The majority of recreational divers will not have to worry about oxygen toxicity because the PO_2 will never be high enough, for long enough, to cause problems. However, the rapidly rising use of Nitrox makes O_2 toxicity a problem that all divers should understand. As technical divers, and even more as CCR divers, a thorough understanding of O_2 toxicity is critical.

Dr. J. Lorrain Smith first described the toxic effect of oxygen on the lungs in 1899. He noted that the severity of the effect increased with increasing PO_2 and that the effects where largely reversible.

The earliest sign of pulmonary (***lung***) oxygen toxicity is a mild irritation in the trachea (***throat***) that is made worse with deep inspiration. A mild cough develops next, followed by more severe irritation and cough until inspiration becomes quite painful and the cough becomes uncontrollable. If exposure to oxygen is continued, the person will notice chest tightness, difficulty breathing, shortness of breath, and if exposure is continued long enough, the person will die, from lack of oxygen! The progressive damage to the lungs eventually makes it impossible for the oxygen to get to the blood as it passes through the lungs.

The time to onset of symptoms is highly variable but most individuals can tolerate 12-16 hours of oxygen at 1.0 ATA, 8-14 hours at 1.5 ATA, and 3-6 hours at 2.0 ATA before developing mild symptoms. There are several ways to track developing pulmonary oxygen toxicity but the most sensitive and accurate is the development of symptoms. A second technique is to monitor the vital capacity. Vital capacity (the amount of air that can be moved in one large breath) decreases with increasing pulmonary toxicity. A reduction of approximately 2% in vital capacity correlates with mild symptoms while a reduction of 10% correlates symptoms so severe that most individuals will not voluntarily continue breathing oxygen. These mild effects are completely reversible and no permanent lung damage occurs. However, the damage will take 2 to 4 weeks to heal. The pathology of pulmonary oxygen toxicity is understood but beyond the scope of this discussion.

			Air ($21\%\ O_2$ $79\%\ N_2$)		Nitrox ($40\%\ O_2$ $60\%\ N_2$)	
Depth (fsw)	**Depth (msw)**	**Pressure (ATA)**	**PO_2 (ATA)**	**PN_2 (ATA)**	**PO_2 (ATA)**	**PN_2 (ATA)**
Surface	**Surface**	1.0	0.21	0.79	0.4	0.6
33	10	2.0	0.42	1.58	0.8	1.2
66	20	3.0	0.63	2.37	1.2	1.8
99	30	4.0	0.84	3.16	**1.6**	2.4
132	40	5.0	1.05	3.95	**2.0**	3.0
218	66	7.61	**1.6**	6.01	**3.0**	4.6
297	90	10.0	**2.10**	7.90	**4.0**	6.0

Figure 3-2: PO_2 and PN_2 of Air and EAN 40 at Various Depths

A third way to keep track, in rough terms, of pulmonary oxygen toxicity is to keep track of the oxygen exposure. This technique is called calculating the Unit Pulmonary Toxic Dose (***UPTD***) and one UPTD is equivalent to

CONVULSIONS	Grand Mal Siezure, usually without warning
VISION	Tunnel Vision or any other visual change
EARS	Ringing in the Ears or other hearing changes
NAUSEA	Mild to Severe, continuous or intermitent
TWITCHING	Usually facial muscles, most frequent symptoms
IRRITABILITY	Behaviour or Personality Changes
DIZZINESS	Vertigo, Disorientation

FIGURE 3-3: SYMPTOMS OF CNS OXYGEN TOXICITY

breathing 100% oxygen, for one minute, at 1.0 ATA. As a guide, 615 UPTDs in one day will cause a 2% reduction in vital capacity and 1,425 units will cause a 10% reduction. There are several different ways to calculate the UPTD (some try to correct for increasing toxic effects with increasing dose, in addition to the simple PO_2) and there is quite wide variation in individual tolerance so that symptoms are still the best guide. The situation where UPTDs are most useful is in planning a large number of dives, in a few days, all involving a large amount of oxygen decompression or CCR diving. Even then, the dive plan may have to be altered if the diver develops symptoms of pulmonary toxicity.

The first and most important method to prevent pulmonary oxygen toxicity is to limit exposure to the lowest possible PO_2 for the shortest period of time. If you dive only air and limit your depth to a maximum of 130 fsw (40 msw), pulmonary oxygen toxicity is unlikely to be a problem. The second method to prevent pulmonary oxygen toxicity is to provide air breaks. The damage to the cells is cumulative and if for every 25 minutes of oxygen exposure you provide the cells with a five-minute period where the diver breathes air, the diver can tolerate twice as much oxygen before toxic symptoms develop when air breaks are given compared to breathing oxygen continuously. Basically what happens is that during the air breaks the cells are repairing the damage due to O_2 radicals much faster than damage is occurring so they "catch up" on some of the damage. Therefore, it will take much longer for a given level of damage to accumulate.

Oxygen toxicity in the brain (CNS) is a problem of higher PO_2s for shorter periods of time. While breathing air, a PO_2 of 1.6 ATA is not reached until a depth of 218 fsw (67 msw). Therefore, CNS oxygen toxicity is not a problem for standard recreational diving. However, more and more divers are using Nitrox and if you dive breathing a 40% oxygen mixture, the PO_2 will be 1.6 ATA at a depth of only 99 fsw (30 msw) and if you decompress on 100% oxygen, the PO_2 will be 1.6 ATA at a depth of 20 fsw (6 msw)! Therefore, CNS oxygen toxicity is a serious problem for some recreational divers and a major problem for technical and commercial divers.

The first and most serious sign of CNS oxygen toxicity is often a grand-mal type convulsion. There are many other signs and symptoms of oxygen toxicity but there is no consistent warning that a seizure is about to occur. Even the EEG is completely normal until the convulsion starts. The convulsion due to oxygen toxicity is not believed to cause any permanent problems in and of itself because the body starts the convulsion with a surplus of oxygen on board and thus the hypoxia seen with normal seizures is not a problem. However, the diver who convulses while in the water may drown or, if they ascend while the glottis is closed, may suffer pulmonary barotrauma.

There is huge variation in the amount of oxygen individuals can tolerate before they show signs of CNS oxygen toxicity and of even more concern, a huge variation in the same person on different days. A diver may do many dives in which they are exposed to high PO_2s with no difficulties and falsely conclude that they are resistant to oxygen toxicity. Then, for no apparent reason, they may suffer a CNS hit on a dive where they are exposed to a lower PO_2. In general, people can tolerate more oxygen in a dry chamber than in the water. In fact, most divers can tolerate two hours of oxygen at 3.0 ATA (66 fsw or 20 msw) in a chamber with few difficulties. While exercising in the water however, several divers have had convulsions at PO_2s as low as 1.6 ATA. To make matters worse, in the chamber divers often have one of the less serious signs of oxygen toxicity such as tunnel vision, ringing in the ears or twitching, whereas in the water the first sign is often a seizure. The seizure starts with an immediate loss of consciousness and a period of about 30 seconds when the muscles are relaxed. All of the muscles of the body then contract violently for about one minute. The diver then begins to breathe rapidly and is very confused for several minutes afterwards. As you can well imagine, if this happens during a dive, the diver usually dies. The table gives a short list of the signs and symptoms of CNS oxygen toxicity but almost anything is possible.

There are some factors that are known to increase the risk of CNS oxygen toxicity. I have already mentioned two, submersion in water and working hard. The risk with working hard is that the PCO_2 in the body is increased and this increases the blood flow to the brain. Other causes of increased PCO_2 are skip breathing and increased carbon dioxide in the breathing gas. For the CCR diver, the primary cause of elevated CO_2 is scrubber failure. Increased stress on the diver and increased levels of adrenaline, atropine, aspirin, amphetamine and other stimulants (caffeine and some decongestants) all seem to increase the risk of CNS oxygen toxicity.

There are no drugs that can be used to prevent CNS oxygen toxicity. In animal experiments, the seizures could be prevented but the CNS cellular damage found after prolonged seizures still occurred. The only effective methods to prevent CNS oxygen toxicity are to limit the PO_2, the time of exposure, and to give air breaks during oxygen breathing.

As general guidelines, the PO_2 during decompression while at rest should never exceed 2.0 ATA and most divers use 100% oxygen at a maximum depth of 20 fsw (6 msw), 1.6 ATA. During the active part of the dive, the PO_2 should never exceed 1.6 ATA and many divers are using 1.5, 1.4, or even 1.3 as the maximum PO_2. NOAA, the US Navy, the Royal Navy, the Canadian Forces, and many other organizations have guidelines for acceptable PO_2s and the maximum time that may be spent at each.

Hyperoxic Induced Myopia

We have been discussing the effects of O_2 toxicity on the brain and the lungs and until fairly recently, that would have been the end of the discussion on O_2 toxicity in diving. However, with the rapid increase in popularity of diving rebreathers, and with the phenomenal bottom times possible when diving CCR, another problem has started to appear.

It has been known for years that if you do daily hyperbaric oxygen treatments in a chamber, over several weeks some people gradually develop progressive myopia (***near-sighted***). The rate of onset is approximately one diopter per month and the rate of recovery after the treatments are stopped is approximately the same. In most people their vision returns pretty much to its' pre-treatment level.

Several CCR divers have noted a similar problem after a series of prolonged CCR dives. One 47 year old CCR diver developed the problem after doing 47 dives in 12 days with a PO_2 of 1.3 ATA. The near-sightedness developed near the end of the trip and completely recovered over the next 2 months. He then did 16 dives over 11 days and the problem returned. Again, he recovered over about 2 months. Based on these and other case histories, it seemed that you needed to do at least 45 hours of diving in 12 days or less, and in general the problem did not occur before age 40.

In 2003, one of my students developed the problem after approximately 30 hours of dive time in 11 days with a PO_2 of 1.3 ATA. She was in her early 40s and fully recovered in a few weeks. Her problem was very mild but it developed with far less exposure than previously noted. A few divers have noted a hyperopic change (***far-sighted)***.

Not much is known about this problem. It seems to involve a stiffening of the lens and there is definitely a difference between people in their susceptibility to this problem. It does not seem to cause any permanent damage, but once you have experienced the problem, you seem to be more likely to have the problem in the future, with less provocation. The only treatment is to avoid elevated PO_2, and the only way to prevent the problem is to also avoid elevated PO_2s.

So what does this mean for the tech diver? First, it is yet another reason to be conservative with your O_2 exposures. If you are going to be doing a "lot" of diving in a short period of time, it makes sense to reduce the set point on your rebreather to a PO_2 of 1.2, 1.1 or even 1.0 ATA. You will need to do a bit more decompression, but the risk of O_2 toxicity will be greatly reduced. For open circuit divers, don't push the PO_2 during your dive or during decompression. Finally, if you notice your vision has degraded near the end of an intense tech dive trip, and if it recovers over the next several weeks of not diving, you most likely have experienced the problem and you will need to reduce you PO_2s for future diving.

Mike Fowler swims with Manta Ray - Photograph courtesy of Steven Frink

Chapter Seven
Decompression Injuries & Emergency Treatment

Joseph Dituri M.S.

Decompression Illness (DCI)

What's in a name? Decompression Illness (*DCI*) is commonly known as Decompression Sickness (*DCS*). However, DCI includes Arterial Gas Embolism (*AGE*) where DCS is only decompression-related. Also, this cluster of afflictions can be prevented. If a patient is suspected of having a DCI and a positive determination cannot be made, have the patient consult a Diving Medical Physician. DCI is broken down into three major categories: DCS Type I, DCS Type II and Pulmonary Over-Inflation Syndromes (*POIS*).

DCS: There is no clear source for DCS although there does seem to be a correlation between inert gas bubbles in the blood and patients who suffer from DCS. It is for this reason that the following theory of DCS is discussed in detail.

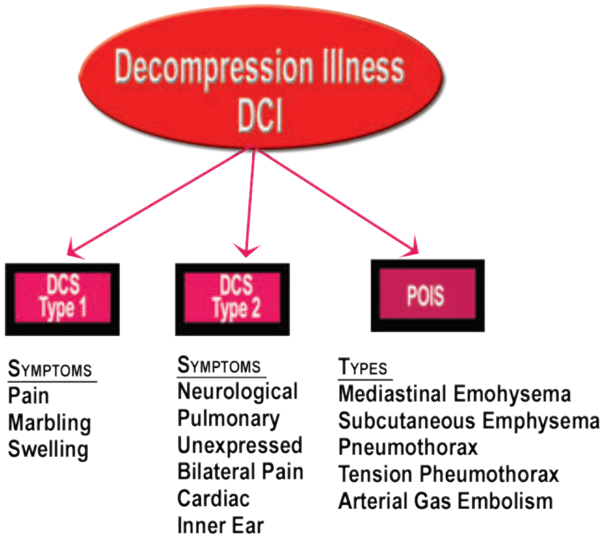


Figure 7-1: Types and symptoms of decompression illness

Tom Mount

Alexander Sotiriou and Jim Holt during a deco stop at Four Sharks Blue Hole, S. Andros Isle, Bahamas

Henry's Law governs DCS in divers. The amount of gas capable of absorption into a liquid at a given temperature is invariably proportional to the Partial Pressure of the gas (***PPgas)***. Only inert gases are of concern to divers with respect to DCS since oxygen will be metabolized prior to absorption. (Concern for high Partial Pressure of O_2 exists, but not when dealing with DCS.) DCS is believed to be a result of inert gas being absorbed into the tissues on compression and while at depth during the dive. They in turn do not have sufficient time to escape during the ascent to the surface. At surface pressure, body tissues are saturated with the inert gas being breathed. As pressure is increased with depth, the partial pressure of the gas inhaled increases. Simultaneously, due to the increased pressure, the body's tissues are capable of absorbing a proportional amount more of the inert gas being breathed. While maintaining a constant increased pressure (at depth), the tissues can absorb an amount of inert gas consistent to the pressure.

As the external pressure is reduced at a decreased depth, tissues begin the process of off-gassing. The tissues are attempting to return to equilibrium equivalent with external pressure by releasing the previously absorbed gas into the blood stream where it is carried to the lungs for filtering. The amount of blood filling the capillary bed at any one time is about 5% of the entire body's blood volume. The capillary bed is the area where the exchange of O_2 and other nutrients with CO_2 and wastes takes place. The exchange can only take place at the capillary bed because

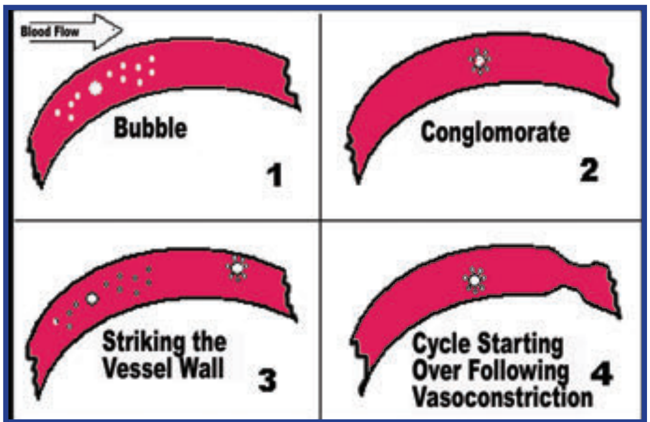
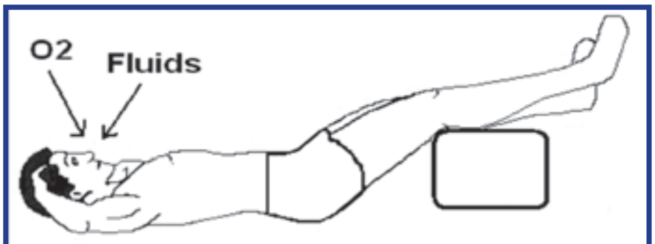


FIGURE 7-2: DECOMPRESSION SICKNESS BUBBLE FORMATION

they are lined with one thin layer of porous endothelial cells capable of allowing solutes smaller than proteins to diffuse between blood and tissue. The endothelial cells are surrounded by a basement membrane which does not interfere with diffusion but serves to hold the capillary together.

When the inert gas solubility capability is exceeded such that the gas is forced out of solution, a bubble is formed to transport the gas out of the system. Upon realizing the presence of the gas bubble, the body immediately sends antibodies to inspect this new foreign body. When it is discovered to be a foreign element to the body, the immune system dispatches phagocytes and leukocytes to attack and remove the bubble by attaching themselves onto the bubble. Another problem associated with the gas bubble trapped in the bloodstream is the surface of the gas bubble tends to attract other particles found in the blood stream such as fat. The result is a large mass consisting of the gas bubble, fat and phagocytes/leukocytes making its way through the blood stream.



Lie flat on back, elevate legs, treat for shock, administer O_2 & fluids, make victim as comfortable as possible.

FIGURE 7-3: TREATMENT FOR DECOMPRESSION ILLNESS

A common misunderstanding is that the bubbles lodge in the veins and block blood flow. While this may be true in the worst case scenarios, it is not the standard manifestation. Usually this conglomerate easily fits through all vessels. The problems arise when the conglomerate moves through the blood stream and ***bounces off the walls***.

When the endothelial cells on the blood vessel walls are damaged in any form by striking or grazing, the body reacts to ensure there is minimal loss of blood. These responses potentially worsen the DCI. The first response is the adhesion of the blood platelets to the exposed collagen fibers (in the wall of the injured vessel), which causes the release of serotonin from platelets resulting in strong vasoconstriction. This process of vasoconstriction and platelet aggregation instigates a vicious cycle which could eclude the vein after a series of conglomerates does its damage.

Categories of DCS: The first significant symptom of DCS is psychological, not physical; ***denial***. Divers believe that, "***This could never happen to me***," which often worsens the more concrete effects of DCS, which are categorized in the list below.

1. **Type I:** This is the less severe of the two types. Even though the symptoms are not very severe, they cannot be ignored. Common symptoms are pain, marbling and swelling

   a. **Pain:** Dull or aching type pain, usually in a joint. Pain origin is non-descript and can normally not be pinpointed, similar to a sprain. It may/may not get worse during movement, but is usually present at rest. It is generally confined to a specific area and is not attributable to another injury

   b. **Marbling:** Skin bends (***Cutis Marmorata***) Condition starts with intense itching and yields way to a bluish gray bruise like discoloration.

POINTS TO REMEMBER

DCS Type 1 Decompression Sickness

- **Simple joint pain**
- **Marbling of the skin**
- **Swelling of the lymph nodes**
- **Denial is common**

Skin will look marbled or mottled. Symptoms may get progressively worse. Symptoms which start as itching may not lead to marbling; itching alone is not DCS Type I

c. Swelling of the Lymph Nodes: Significant lymph node pain and swelling

2. Type II: Unlike Type I, Type II may not be readily apparent. A diver may feel "funny" or over-tired. Normally these symptoms would not be problematic. However, post dive they pose a significant health risk. Type I symptoms may/may not accompany these symptoms. Many of the symptoms of DCS Type II mirror those of an arterial gas embolism (*AGE*)

a. Unexpressed: These are symptoms such as over tired and weakness. They may become more severe as time progresses. If treatment is not provided, these "minor symptoms" could progress to a severe neurological deficit

b. Neurological: These are any symptoms which may be seen or discovered as a result of a comprehensive neurological assessment. Symptoms include, but are not limited to: numbness, tingling, increased or decreased sensation in an area, muscle weakness

c. Pulmonary: Commonly referred to as ***chokes***. A great deal of inert gas bubbles inundate the vascular area in the lungs. This is intravascular bubbling (***cavitation***). Substernal pain which is aggravated by inspiration along with an irritating possibly productive cough. This is generally accompanied by an increase in breathing rate and may progress to circulatory collapse, unconsciousness and death

d. Inner Ear: Sometimes called ***Staggers***. Tinnitus (ringing in the ears), hearing loss, vertigo, dizziness, nausea, and vomiting are some of the symptoms. Inner Ear DCS is associated with mixed gas diving and during decompression when the diver switched from breathing helium to air. Even though the symptoms are similar, Inner Ear DCS must be differentiated from ear barotrauma. The symptoms of the "***staggers***" may be due to neurological decompression sickness where symptoms of barotrauma may be due to a ruptured TM. A quick check of both ears by a medically trained individual will help to differentiate these problems

e. Cardiac: Very rare. One report of 1st degree AV block which responded to recompression. Symptoms are similar to heart attack or stroke

Points to Remember

DCS Type II Decompression Sickness

- **Any symptom following a dive that is not Type I DCS**
- **Similar symptoms to an AGE**
- **Watch for unexpressed symptoms**

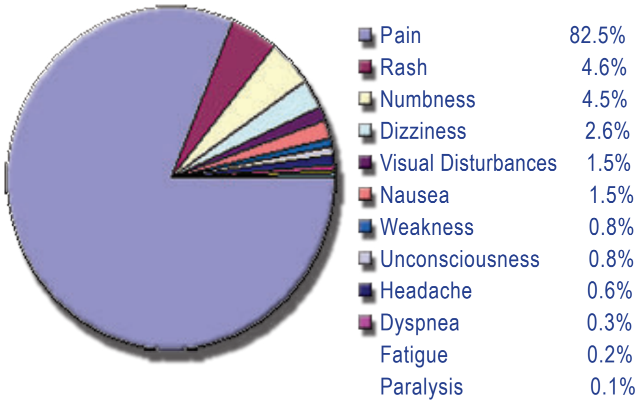


Figure 7-4: Decompression Sickness & the Distribution of Typical Symptoms

Pulmonary Over-Inflation Syndrome (POIS) & Extra Alveolar Air (EAA)

All POISs/EAAs are caused by an over-inflation or a rupture of the alveoli lining which leads to Pulmonary Interstitial Emphysema. It is caused by excessive positive pressure within the lung or some kind of blockage which does not allow the expanding air in the alveoli to escape during a decrease in external pressure. It could manifest itself by a permanently or temporarily congested or blocked brachial tubes, a diver failing to breathe continuously during ascent, or a diver who performs the Valsalva Maneuver on ascent. The route which the escaping gas takes determines the type of POIS and ultimately the treatment.

1. Mediastinal Emphysema: A mediastinal emphysema occurs when the bubble of gas which escaped from the rupture leaks into the mediastinal tissues in the middle of the chest. It is characterized by substernal pain which may be mild to moderate and is often described as a dull ache or a feeling of tightness across the chest. The pain may become worse with deep inspiration or coughing and may radiate to the shoulder, back or neck

2. **Subcutaneous Emphysema:** A subcutaneous emphysema is a mediastinal emphysema which has leaked upward into the subcutaneous tissues in the neck and lower face. It is characterized by a voice change, crepitating or the feeling/appearance of fullness in the neck, shoulder or collarbone area

3. **Pneumothorax and 4. Tension Pneumothorax:** In a pneumothorax the gas which has escaped, leaks into the space between the chest wall and the lining of the lung. This leak causes a pocket of gas which may cause respiratory distress. If the leak is an isolated incident, the gas will normally be reabsorbed with time. If the leak continues, the pressure within the cavity could force the whole lung or a lobe to collapse. This situation is severe. Indications of a pnuemothorax include a sudden sharp flank pain in the chest followed by breathing difficulty. A tension pneumothorax occurs when the lung collapses completely and presses on the heart. The collapsed lung pushes the heart and its blood vessels to the other side of the chest, and the heart cannot pump normally

5. **Arterial Gas Embolism (*AGE*):** An AGE is caused by entry of gas bubbles into the arterial circulation which then could act as blood vessel obstructions or similarly to any inert gas bubble such as those which come from decompression sickness. These emboli are frequently the result of pulmonary barotrauma caused by the expansion of gas taken into the lungs while breathing gas under pressure and held in the lungs during ascent. The gas might have been retained in the lungs by choice or accident. The organs that are especially susceptible to arterial gas embolism and that are responsible for the life threatening symptoms are the central nervous system (*CNS*) and the heart. In all cases of arterial gas embolism, associated pneumothorax is possible and should NOT be overlooked

Points to Remember

Pulminary Over-Inflation Syndrome

- Mediastinal Emphysema
- Subcutaneous Emphysema
- Pneumothorax
- Tension Pneumothorax
- Arterial Gas Embolism (*AGE*)

Initial first aid is a must. If a person is suspected of having a DCI, ***IMMEDIATELY*** administer fluids, oxygen and transport in supine position (***lying on the spine***) to the nearest hyperbaric facility. A POIS indicates a hole in the alveoli. For this reason, recompression is NOT normally recommended because of the risk of introducing more gas into the blood via the existing hole. AGE's are an exception to that rule because the result of the introduction of additional gas into the blood via the hole in the lung is overshadowed by the severity of the symptoms.

Risk Factors that May Hasten the Onset of DCS

Patent Foramen Ovale (*PFO*)

All fetuses have a hole between the chambers of the heart; the lungs are non-functional in the fetus so the hole allows blood to bypass the lungs. Technically, the hole is called a foramen ovale that is patent (***open***). Normally, this hole seals within 24 hours of birth. Adults have the advantage that blood is transported across the lung capillary bed which is insensitive to bubbles. The fetus does not have this advantage. The fetus does absorb nitrogen across the placenta, but any bubbles that may be formed in the fetus would end up in the fetus's circulation, or possibly in the placenta. This is why woman who think they are pregnant should not dive.

The PFO, or opening in the wall of the heart, is necessary to transfer oxygenated blood via the umbilical cord. However, a PFO can create a myriad of problems if it is found intact or only semi-closed more than 24 hours after birth. This patency can cause a shunt of blood from right to left, but more often there is a movement of blood from the left side of the heart (***high pressure***) to the right side of the heart (***low pressure***). People with shunt lesions are less likely to develop syncope or hypotension with diving than are obstructive valve lesions, but are more likely to develop pulmonary congestion and severe shortness of breath from the effects of combined exercise and water immersion.

Ordinarily, the left to right shunt will cause no problem; the right to left shunt, if large enough, will cause low arterial O_2 tension and severely limited exercise capacity. In divers there is the risk of paradoxical embolism of gas bubbles which occur in the venous circulation during decompression. Intra-atrial shunts can be bi-directional at various phases of the cardiac cycle and some experts feel that a large atrial septal defect is a contra-indication to diving. In addition, a Valsalva maneuver, used by most divers to equalize their ears, can increase venous atrial pressure to the point that a right to left shunt occurs, thereby transmitting bubbles that have not been filtered out by the lungs.

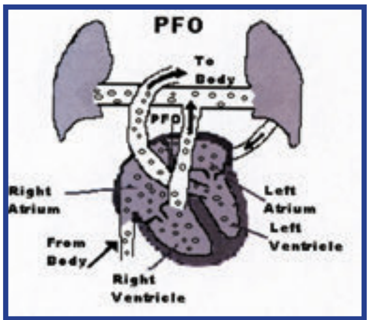


Figure 7-5: Patent Foramen Ovale

If a diver is concerned or is having some of the symptoms noted above he or she should seek medical attention. Normally a diver who already has dove to in excess of 100 fsw (930 msw) would have had problems before if a significant PFO was present.

Previous DCS or Problematic Areas

People who have been previously exposed to DCS are more likely to have DCS in the same area. The area where the former insult or previous injury was has probably developed scarring. The increase of scarred tissue over the area makes it less wide. When a bubble tries to pass, it may come in contact with the already scarred tissue faster than would have if there was no scar tissue present.

Age

More applicable than the specific numerical age is the fact that the body changes as people age. Increased body fat, degenerative joint disease, alterations in pulmonary function and cardiac disease are among those changes that increase the risk of DCS with age. This may or may not be the driving ideology, however we know that the U.S. Navy dive tables were established using Navy divers. These individuals are 18-25 years old and in top physical condition. Diving within the limits of the Navy dive tables may be ill-advised practice for an older person.

Body Fat

Fat has high nitrogen solubility. High nitrogen solubility increases nitrogen absorption and bubble growth. We also know that the U.S. Navy dive tables were established using Navy divers who are 18-25 years old and in top physical condition. Diving within the limits of the Navy dive tables may be ill-advised practice for a heavier person or someone who is less physically fit.

Post-Dive Exercise

Doppler scores and the likelihood of DCS increase with post dive exercise. The probable reason is the increase of circulation post dive pushes the decompression progress too far. Your body may attempt to off-gas too quickly causing bubbles to form. These bubbles decrease the tissue and arterial inert gas tensions which reduce the elimination rate.

Body Temperature

Cold decreases your body's ability to off-gas. The problem here is most divers start off relatively warm and as the dive progresses become increasing cold. At the point in the dive where the diver ascends to begin decompression they are cold.

Workload at Depth

Presumably this increase of risk is due to an increase in circulation allowing more inert gas to be absorbed.

Hydration Level

This is the largest contributing factor of DCS. Divers are dehydrated due to immersion diuresis as well as sun exposure and decreased fluid intake. This combination reduces circulation and the rate of off-gassing.

In-Water Recompression

No established course exists to certify anyone to perform in-water recompression. This procedure should not even be attempted if the patient is unconscious or vomiting. If

Jim Akroyd

Gen Akroyd inspecting a Mark V diving helmet

it must be attempted, a diver should always accompany the patient and observe his or her condition very closely as the incidents of CNS oxygen toxicity increase when the patient is in the water. The patient should use a full-face mask to decrease the problems associated with an oxygen convulsion. The volume of oxygen required to complete this treatment in water is about 300 cu ft. Using a rebreathing apparatus would reduce consumption to about 300 liters, but the patient must be trained in the use of a rebreather. As water removes heat 25 times faster than air, a patient should also have adequate exposure protection. Hypothermia is a major concern.

If there is no recompression chamber in a reasonable proximity, a stricken diver could be placed on 100% oxygen and brought to not greater than 30 fsw (9 msw). There should be some means of ensuring the patient is not able to descend deeper than 30 fsw (9 msw). A flat bottom is best for this purpose, however surge may be a factor if swells are high enough. The patient should stay a minimum of 60 minutes and a maximum of 90 minutes. The patient should ascend to 20 fsw (6 msw) and stay for 60 minutes. Repeat the 60 minute stop at 10 fsw (3 msw). Patients should continue to breathe 100% oxygen en route to the nearest hospital or hyperbaric facility.

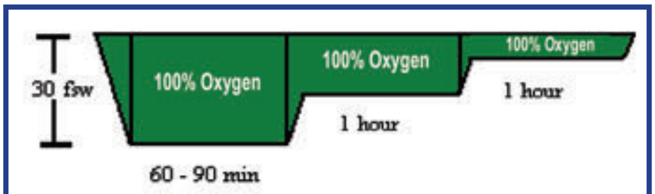


Figure 7-6: In-Water Recompression

The Effect of Cold on DCS

As most divers learned in the open water class, water conducts heat away from the body 25 times faster than air. However, heat escapes from the body several ways when in the water. Convection, conduction and evaporation are the methods of heat transfer although respiration is also applicable. Heat loss by convection occurs when warm air surrounding the body is pushed away by moving cool air. While this is not directly applicable to diving, indirectly, divers whose body parts come out of the water for periods of time (such as the head when surfacing) would be susceptible to convection.

A diver can get colder much more quickly when diving than he or she would in the same air temperature. This is due to conduction or the transfer of heat via direct contact. A diver can easily become chilled and then hypothermic in water whose temperature is less than 98.6ºF (37ºC) because the body is in direct contact with the water.


Courtney Platt & DiveTech

Robert Hew decompressing with squid family at Cobalt coast, Grand Cayman

Heat loss through evaporation is needed to regulate your body temperature in hot weather or when a diver is working hard. In cold conditions, evaporation can quickly suck away warmth, especially if you've been active and then are stationary, like when you are on the bottom working and then while hanging on decompression. Evaporation removes heat (***energy***) from the body as water is converted from liquid to gas. For this reason it is very important for deep divers to wear appropriate thermal protection to include (if wearing a dry suit) underwear that wicks water from the skin.

A primary indication of mild hypothermia in divers is uncontrollable shivering. Other indications include blue color and numbness. More severe signs include lack of coordination, weakness, weak pulse, confusion and death. Prior to a diver becoming cold enough to shiver uncontrollably, they should discontinue diving. Appropriate exposure protection should be used with consideration to water temperature, thermoclines and duration of dive.

Divers that are planning long exposures, such as those found in technical diving, should be adequately protected from the cold. This is particularly important when decompression diving. During a deep dive, the inert gas is absorbed while at depth when the diver is relatively warm because they just started the dive and they are working. The diver consequently becomes cold during decompression because of the reduced work with respect to being on the bottom and the duration of time in the water. When a diver is very cold, the body's protection system will shunt the blood to the extremities and heat the core. Because of the body's natural ability to protect the core, the diver will not have the same circulation to the extremities and there fore will not decompress efficiently which could lead to DCS. Wearing a hood on decompression dives is an excellent method for stopping heat reduction. Rebreather divers maintain a significant advantage with respect to cold temperatures because they are breathing a warm and moist media. Breathing media such as this promotes heat retention.

Conclusion

Since we do not know what the true cause of DCI is, it is difficult to prevent. Some people who have made seemingly innocuous dives have suffered from this malady, albeit others who have "earned" hits by skipping stops have gotten away without being bent. The bottom line with any

Points to Remember

Risk Factors

- **PFO**
- **Previous DCS or areas with previous problems**
- **Age**
- **Body fat**
- **Post dive exercise**
- **Body temperature**
- **Workload at depth**
- **Hydration level (*Largest Contributor*)**

Matti Anttila

Winter diving in the ice & snow has it's own specialized deco needs

DCI is that the symptoms should be treated. The cause is not relevant to treatment. The suggestions herein are merely suggestions. Your local Diver's Alert Network or hospital should be consulted to ensure you are affecting the correct type of treatment. None of these treatments should be performed without proper training. Divers should err on the side of safety when it comes to deep decompression and become as learned on the current theories as possible in order to make the best decisions in a bad situation.

Matti Anttila

Chapter Eleven
Dive Planning

Tom Mount D.Sc., Ph.D., N.D.

Dive planning is the process by which divers determine and clarify the objectives of a proposed dive, rehearse the specifics of the dive plan, and review their proposed actions in order to eliminate or minimize the associated risks. In order to accomplish these goals, there are four important processes that must be undertaken: information gathering, group planning, personal planning, and contingency planning. These allow for personal and environmental unknowns. Once a dive plan is developed, it should be followed according to the guidelines that will be explained in this chapter.

The basic elements of information gathering include:

- Gathering pertinent data on the dive environment
- Determining the history and qualifications of the participants
- Determining what equipment may be required
- Identifying mitigating or complicating factors

Information gathering, the first step in the planning process, should include all the facts necessary to prepare a safe plan of action on the dive, and should recognize the variables and unexpected contingencies that might occur. In technical diving, detailed information gathering is paramount to the safety and survival of the diver and/or dive team.

When gathering information on a given location, you should refer to all available resources to ensure that both an adequate amount of information is obtained, and that the information is accurate and current. The basic references should include visits to the dive site, conversations with any who have dived the site and collecting any printed reference materials such as cave maps or ship's blueprints.

Once this preliminary information is gathered, a basic dive plan can be formulated. If there are charts or maps of the location, carefully review them and ensure that each person on the dive team is familiar with the specifics of the location. While in the process of planning the route, duration and proposed actions of the dive, you should also discuss the impact your dive plan will have on the underwater environment.

Next, your dive team should determine what equipment would be needed to perform the dive safely, along with any additional specialty equipment that will enhance dive performance. The team should then follow the process of determining the correct gas mixtures to make the dive and to efficiently decompress.

When diving from the beach, for example, divers should determine the wave patterns, the probability of rip currents, the underwater topography and the location of safe areas of entrance and exit points. On cave dives, teams should anticipate the entrance and underwater conditions, including surface hazards, current, silting, passage size, expected depth, and so forth. If there are reversing currents, the team should establish an optimum dive window.

When boat diving, investigate the particulars of water entries and exits from the craft. If the dive will be a fixed anchor dive, be certain you make visual reference and know where the anchor (***upline***) is located. If using decompression stages, do not affix them to the anchor line as the line may break free.

If the stops are to be done as a drift dive, become aware of the procedure used by this particular diving operation/charter. There are numerous methods of securing drift decompression and ascent lines, so insist on having the

Craig Challen sports a twin Megalodon CCR during the Niagra Project in New Zealand system explained anytime you are diving from a new boat, are at a new location or are under different circumstances than those you are familiar with. When doing drift dives, be responsible enough to become informed of the procedures used at this location and by the dive operator or the procedures of those who are diving. Do not assume anything. Be informed and be safe. Be certain all divers in the group on open water dives have a lift bag so that if they should become separated, they will have a stable up-line and an indicator to the diving vessel of their location.

Ensure that each diver in the group has the adequate type of equipment and the appropriate amount of redundancy for a safe team dive. Prior to entering the water a safety drill (known as an ***S Drill***) should be performed. During this process, each diver will check their buddy's equipment for functionality and possible leaks. This includes breathing from the long hose, checking lights and seeing if there are any gas leaks in the tanks, valves, and regulators. In cave and shore based diving, the S Drill is to be performed in the water. Even when boat diving, a leak check should be made upon entry into the water if conditions allow.

Gas mix planning is a major concern for technical divers. The factors to be determined during this portion of the planning process include oxygen management, narcosis planning, gas density considerations and decompression planning. In general, the longer the dive or the deeper the dive, the more detailed the dive plan must be. In addition, when making repetitive dives, allowances must be made for tracking residual oxygen in the system.

One of the greatest hazards in technical diving is the risk of central nervous system (***CNS***) oxygen toxicity. Due to this risk, one must carefully plan out the combined risk of bottom mix gases and decompression gas. In most technical diving situations, an oxygen partial pressure (***PO_2***) of 1.4 ATA is the maximum target operating depth (***TOD***). The maximum operating depth (***MOD***) is a PO_2 of 1.5 ATA. For decompression, the maximum PO_2 is 1.6 ATA with 1.55 ATA being the recommended limit. In addition, on long decompressions following lengthy bottom exposures, it is often necessary to reduce the PO_2 to 1.5 ATA at decompression stops with bottom mix exposures well under the 1.4 ATA TOD limit. Environmental and dive performance factors also affect gas planning. In dives involving cold water and/or increased workloads, the bottom mix PO_2 should be reduced by 0.05 ATA per variable and decompression PO_2 reduced by 0.025 ATA

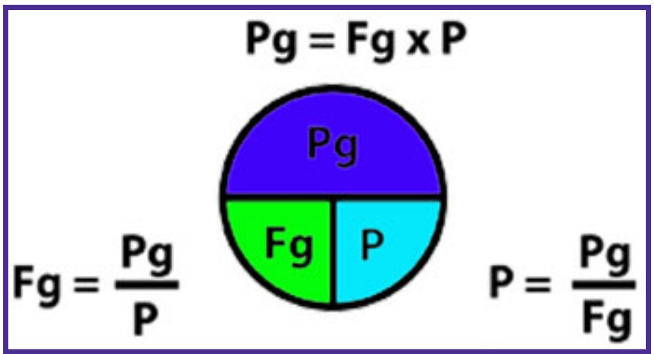


Figure 11-1: The Circle T is used for gas computations using Dalton's Gas Law

for each variable.

In addition to CNS exposure, a diver will need to track the accumulation of oxygen tolerance units (***OTU***), which effect whole body/pulmonary exposure. The OTUs are primarily a concern in saturation diving or when a need for treatment presents itself. As a rule of thumb, if a diver remains within a CNS exposure not exceeding 100% of the allotted dosage, OTUs remain within safe limits. On extended dive programs involving six or more continuous days of diving, the OTU limits may become the controlling factor in oxygen management.

When planning oxygen exposures, the first determination is the PO_2. To do this, refer back to the "***T***" formula, see Figure 11-1, and solve for the best mix. For example assume the dive is to 140 ft (42 m) and will be a combination of hard work, cold water and a bottom time of 50 minutes. To maximize safety, a PO_2 of 1.35 ATA will be used for the bottom mix.

$$\text{Best Mix Fraction of } O_2\ (FO_2) = \frac{PO_2}{P}$$

$$\text{Imperial - US: } \frac{1.35}{(140 \div 33) + 1} = 25.7\% \text{ or } 26\%$$

$$\text{Metric: } \frac{1.35}{(42 \div 10) + 1} = 25.5\% \text{ or } 26\%$$

In the above example, if once the gas has been mixed and the true analysis was EAN 28, the PO_2 at 140 ft (42 m) can be found by using the PO_2 equation.

$$PO_2 = FO_2 \times P$$

Imperial-US: $PO_2 = 0.28 \times (140/33 + 1) = 1.46$

Metric: $PO_2 = 0.28 \times (42/10 + 1) = 1.456$

As shown, this is too high of a partial pressure of oxygen to be used on the dive. Thus, the mix would need to be adjusted or the depth limit should be set shallower. To determine the maximum depth with this mix and our desired PO_2, use the MOD formula. The same equation is used for determining the target operational depth (***TOD***). The TOD is the actual planned depth of the dive whereas the MOD is the deepest possible depth available on the dive. Dive plans should consist of both a MOD and TOD for a given mix.

Target Operating Depth

$$TOD = \frac{1.35}{0.28} - 1 \times 33 = 126 \text{ ft}$$

(For **metric**, substitute 1 *x* 10 for 1 *x* 33 & the answer is 38.2 m.)

Maximum Operating Depth

$$MOD = \frac{1.50}{0.28} - 1 \times 33 = 143.7 \text{ ft}$$

(For **metric**, substitute 1 *x* 10 for 1 *x* 33 = 43.57 m)

In the selection of tables, the IANTD EAN 28 Tables would be used incorporating the accelerated schedule at 20 and 15 ft (6 and 4.5 m) using EAN 75.

To avoid mistakes in calculating PO_2, use the IANTD PO_2 Table C-3201B. You may also use the IANTD EAD/MOD Table C-3200 Imperial or C-3204 Metric to determine EAD, CNS %, OTU, and MOD/TOD values in a known mix. Each of the proceeding examples may be determined through use of these tables.

EANx Example

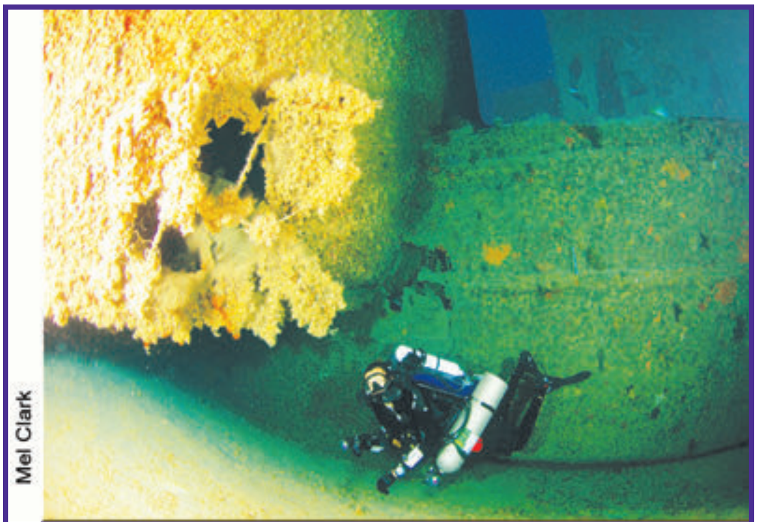
Part One

A dive is planned to a depth of 140 ft (42 m). The dive is on a wreck that has a maximum depth of 170 ft (52 m). The TOD will feature a PO_2 that cannot exceed 1.40 ATA. The MOD must remain at or below 1.50 ATA. Referring to IANTD PO_2 Table C-3201B, the best mix to allow the diver to meet both the TOD and MOD needs is EAN 24 in this case, although the TOD desired is 1.4 ATA PO_2. For safety in event of egress to the bottom, the MOD at 170 ft (51 m) of 1.5 ATA or less restricts the TOD PO_2 to 1.26 ATA. If the MOD requirement had been ignored, the diver could have used EAN 26.

Part Two

For decompression, a gas mix is going to be used that will be no greater than 1.45 ATA PO_2 with a gas switch at 20 ft (6 m). Referring to IANTD PO_2 Table C-3201B or IANTD EAD/MOD Table C-3200 Imperial or C-3204 Metric, we will find that EAN 90 provides a PO_2 of 1.45 ATA at 20 ft (6 m). In order to provide an accurate CNS % and OTU calculations, use IANTD CNS/OTU Table C-3201. To compensate for the oxygen clock during ascent employ the 2 + 2 Rule. This means you should add 2% to the CNS clock and 2 to the OTUs. This is simple and conservative and more than covers the oxygen clock additions on ascent.

To figure out the CNS %/Repetitive CNS % refer to IANTD PO_2 Table C-3201B; begin at the top left column with 100%. Read to the right and after the 30 minute S.I., you will read down the column to see that the diver still has 83% of the CNS O_2 clock loaded, while after 6 hrs. S.I., only 7% of the CNS O_2 clock will remain. All dives should be planned to avoid exceeding 100% of the CNS clock and within the daily OTU units.



Steven Guiterrez on the *RB Johnson* wreck near Ft. Lauderdale, Florida

Points to Remember

Waterproof Tables For Use Underwater

The Accelerated Decompression Tables using EAN 75 at 20 & 15 fsw (6 & 4.5 msw) & the Runtime Tables are available in waterproof versions from your local IANTD Facility.

Now, let's put all of the above noted tables plus the IANTD Waterproof Dive Tables to use by planning an actual dive. On this dive, the desired TOD PO_2 is 1.4 ATA. The dive is on a wreck with a maximum depth at the sand of 160 ft (48 m) and the planned dive depth on deck is to 140 ft (42 m). The MOD must be considered as one of the operational parameters even though the diver does not plan to dive to 160 ft (48 m). Thus, we must first determine a mix that does not exceed 1.5 ATA PO_2 at 160 ft (48 m). The second consideration is that the TOD PO_2 is to be no greater than the planned 1.40 ATA. By referring to the above noted PO_2 Table and EAD Table, we discover that at 160 ft (48 m) a mix of EAN 26 presents a PO_2 of 1.52 ATA, and we decide to accept the slight excess oxygen risk.

The second step is to ensure that EAN 26 will not exceed a PO_2 of 1.40 ATA at the TOD. Again, by going to a depth of 140 ft (42 m) with EAN 26, the PO_2 is found to be 1.36 ATA. As this is slightly lower than the planned TOD value, it is acceptable. It should be noted in this example that while we elected to accept the slight (0.02 ATA) excess as a MOD or "***What Ifs***" value, the same acceptance would not apply to a TOD value. The bottom time on this dive is to be 50 minutes. In addition to the IANTD PO_2 Table, the IANTD EAD/MOD Table can be referenced to determine TOD and MOD values at PO_2s of 1.3, 1.4, 1.5, and 1.6 as well as the equivalent air depth. The EAD/MOD Table also lists the CNS % per minute and OTUs per minute.

For the sake of example, we will work this dive in three different methods using the IANTD Waterproof Dive Tables, to reflect the differences in decompression time. The first dive will be on the IANTD C-3502 Accelerated Tables using EAN 26 throughout the decompression. The second will use the same table but follow the EAN 75 schedule at both 20 and 15 ft (6 and 4.5 m). The third method will be using the IANTD C-3602 EAN 25 Runtime Tables using EAN 78. The Runtime Tables do not feature EAN 26; thus, the EAN 25 Tables will be used. If the correct mix is used, the CNS% is given on the Runtime Tables. However, as our mix is EAN 26, we must calculate the CNS and OTU values. Once analyzed, our decompression gas is EAN 80.

Plan the gas actually needed on the dive by assuming the diver breathes 0.6 cu ft (17 L) while swimming on the bottom and 0.5 cu ft (14 L) at rest during decompression. For gas planning, plan the time to the first stop as part of the bottom mix requirements. For example if the ascent takes three minutes for gas planning then plan that ascent as if it were spent on the bottom. This provides a little more safety in the gas management plan. Once the actual gas needed has been determined then plan for the total gas to be carried. Remember that the dive must be made on bottom mix within the rules of thirds. Record the total gas needs under totals at the base of the worksheet or IANTD Technical Diver Logbook along with the CNS and OTU totals.

Please note, when planning the CNS and OTU exposure, do not be surprised if your answers vary slightly from those in the example. It is possible to have a minimum amount of variation depending on if the per minute values of CNS % and OTUs are used or if the set bottom time numbers are added. Calculators will also produce some minor variations based on where they round off.

Following the first dive, a second dive is planned to 110 ft (33 m) 3 hours later for 40 minutes using a bottom mix of EAN 29 with EAN 80 as a decompression gas. The dive will be made on the IANTD EAN 29 Runtime Table C-3603. Please read the following and work through the repetitive dive as you go through the dive worksheets. It is important that you understand these procedures.

Points to Remember

Minimum Gas Needed

To find the bottom mix needed, multiply the gas needed by 1.5. Decompression planning is not quite as conservative so, multiply the gas needed on decompression by 1.2

In the examples we are working on this series of dives, do the following:

- First Dive to 140 ft (42 m) on the IANTD EAN 26 Table C-3502 for 50 minutes. See the work sheets for decompression schedules, oxygen tracking and gas used. It is recommended that you work these to ensure you understand this phase of dive planning
- Go to the IANTD EAN 26 Accelerated Table C-3502 to get the beginning SIT group. In this case, "K"
- After three hours, a dive to 110 ft (33 m) will be made for 40 minutes on the IANTD EAN 29 Runtime Table C-3603
- Go to the IANTD EAN 28 Accelerated Table C-3503 to get the end of SIT group. In this case, "G"
- On the repetitive dive on IANTD Runtime Tables as the schedule will be an 80 minute schedule, then to convert to the real time runtimes subtract the 40 minutes residual from all the indicate runtime stops and this will correct the schedule for the actual bottom time. (See "IANTD/IAND, Inc. Technical Dive Planners" that follow for corrected runtimes.)
- **RNT:** 40 minutes + 40 minutes actual BT = 80 minutes equivalent nitrogen time/bottom time

When using the the C-3600 and/or C-3700 series of IANTD Runtime Tables, switch to decompression gas at a point that you are actually breathing it upon arrival at the stop requiring the gas switch. Do not wait until arrival to switch the regulator as this may take a minute or so to do. The IANTD Waterproof Runtime Tables are designed for you to leave the stop at the designated time for that stop depth. For instance if a schedule reads a BT 50 minutes it means that you leave that stop depth at 50 minutes. If a stop states 56 minutes you must ascend to the next stop as soon as you reach 56 minutes.

Points to Remember

Repetitive Dives Using Runtime Tables

The procedure is:

1. Go to the next lower EANx Accelerated Tables and get the beginning SIT group from that table.

2. Go to the next lower EANx Table from the Table the next dive is to be made on for the RNT

On a runtime table if you are using a 50 minute schedule but leave the bottom at 48 minutes, it is safe to subtract 2 minutes from each of the runtime depths. In other words if your first stop says 56 minutes, leave at 54 minutes. This keeps the actual stop duration the same, as it would be on the 50 minutes schedule.

If you leave the bottom late then you must go to the next greater schedule and subtract the time differences, just as you did in the above example. If the ascent rate is faster than the schedule, stop 10 ft (3 m) below the first scheduled stop for the time difference. If the ascent is slow but within 2 minutes of schedule then add the time to the runtimes at the stops. If the ascent is delayed more than 2 minutes switch to the next greater schedule.

$$EAD = \frac{FN_2\ (0.74)\ x\ [Depth\ (140_{fsw}) + 33]}{0.79} - 33 = 129.04_{fsw}$$

$$EAD = \frac{FN_2\ (0.74)\ x\ [Depth\ (42_{msw}) + 10]}{0.79} - 10 = 38.7_{msw}$$

Refer to the IANTD EAD/MOD Table and determine the EAD for this dive. Go to EAN 26, then to the actual depth of 140 ft (42 m), and down the page to the EAD depth. The EAD is 129 ft (38.7 m) for this dive.

This same problem could also be figured out by using the EAD formula.

When planning Nitrox dives, an important consideration is preparing the gas mixture. Detailed procedures for mixing gases are included in the IANTD Gas Blending Courses and the IANTD Gas Blending Student Manual and Workbook M-2116.

Closed Circuit Rebreather Planning

When planning CCR dives two of the greatest hazards are the risk of central nervous system (*CNS*) oxygen toxicity and Hypoxia. Due to these risks, one must carefully plan out the combined risk planned PO_2 plus bottom mix gases for both diluent and bailout needs. In most technical diving situations, an oxygen partial pressure (***PO_2***) of 1.3 ATA is the maximum target operating depth (***TOD***) while diving on a CCR. When diving on an SCR, it can as high as 1.4 ATA. For decompression, the maximum PO_2 is 1.4 ATA on CCR with 1.6 ATA being the recommended limit for SCR or OC.

When planning partial pressures for the dive, the first determination is the PO_2. To do this, refer to the "T" formula previously presented and solve for the best mix.

For example: Assume the dive is to 160 ft (48 m) the planned PO_2 is 1.3 ATA and the END is planned to be 100 fsw (30 msw). The diluent is planned to have a PO_2 of 1.0 ATA at the TOD. The mix contains 30% helium.

$$\text{Best } O_2 \text{ Mixture} = \frac{1.0_{ATA}}{(160 \div 33_{fsw}) + 1_{ATA}} = .17 \text{ or } 17\%\ O_2$$

$$\text{Best } O_2 \text{ Mixture} = \frac{1.0_{ATA}}{(48 \div 10_{msw}) + 1_{ATA}} = .17 \text{ or } 17\%\ O_2$$

$$\text{EAD} = \frac{FN_2\ (0.53)\ \boldsymbol{x}\ [\text{Depth } (160_{fsw}) + 33_{fsw}]}{0.79} - 33 = 96.48 \text{ fsw}$$

$$\text{EAD} = \frac{FN_2\ (0.53)\ \boldsymbol{x}\ [\text{Depth } (48_{msw}) + 10_{msw}]}{0.76} - 10 = 24.88 \text{ msw}$$

Next, plan the END of the dive. Refer to the EAD formula:

$$\text{END} = \frac{[\text{Target END } + 33_{fsw}\ \boldsymbol{x}\ 0.79]}{\text{Depth} + 33}$$

Thus to find the desired END of 100 fsw (30 msw) for this dive:

So, Helium = 100% – 54% N_2 – 17% O_2 = 29% He

Thus, the mix will contain 29% helium although the actual oxygen in the diluent will only be 17% based on a 1.0 ATA diluent PO_2.

You could also use the IANTD END Table C-3706 for 1.3 PO_2 at 160 fsw (48 msw) to determine the equivalent narcosis depth and FO_2. To determine the exact mix you should look down the END Table to 160 fsw (48 msw), then across until you are below the 100 fsw (30 msw) END value. Note the helium concentration, which would be a mix of 22 23 on the END Table.

For bailout an END of 120 fsw (36 msw) will be used, and a bailout PO_2 of 1.4 ATA will be needed for a dive that is in an overhead environment (in OW a bailout PO_2 of 1.6 ATA could be used).

Referring to the IANTD END Table C-3706, if we look at 160 fsw (48 msw) at a PO_2 of 1.4 ATA we discover the FO_2 is 24% and the helium content for an END of 120 fsw (36 msw) is 13%. Thus the bailout mix will be Trimix 24 13. Obviously, this could also be worked out with the END formula.

To avoid mistakes in calculating PO_2, use the IANTD PO_2 Table. You may also use the IANTD END Table for PO_2 of 1.3 ATA and 1.4 ATA. In addition, tables can be used for tracking of CNS % and OTUs. When they are combined with the appropriate chart the residual CNS % can be calculated as well.

To determine EAD, CNS %, OTU, and MOD/TOD values in a known mix, each of the proceeding examples may be determined by using the various IANTD Tables.

Dive Example

A wreck dive is planned to a depth of 200 fsw (59 msw). The diver will use a PO_2 of 1.3 ATA. The bailout PO_2 cannot exceed 1.4 ATA. On both the diluent and the bailout cylinder the desired END is 90 fsw (27 msw). The dive will have a bottom time of 40 minutes. For decompression, the PO_2 will be maintained at 1.4 from 40 fsw (12 msw) ata, up through the 20 fsw (6 msw) stop. At 15 fsw (4.5 msw), the PO_2 will be dropped to 1.3 ATA. To provide accurate CNS % and OTU calculations, follow the same procedures as in the open circuit examples.

Now, let's put all of the above IANTD Tables (plus the IANTD Constant PO_2 Dive Tables C-3101 through C-3105) to use as part of this dive plan.

By referring to the PO_2 Table, we find that a diluent PO_2 of 1.0 ATA will require a FO_2 of 0.14 (14%) and by using the END equation the nitrogen content is:

$$END = \frac{[90_{fsw} + 33_{fsw} \times 0.79]}{200_{fsw} + 33_{fsw}} = .417 \text{ or } 42\%\ N_2$$

$$END = \frac{[27_{msw} + 10_{msw} \times 0.79]}{59_{msw} + 10_{msw}} = .423 \text{ or } 42\%\ N_2$$

Therefore, the helium content in the diluent will be 100 - 14 - 42 = 44% and the diluent mix is Trimix 14 44. Plan the bailout mix by referring to the END chart. You will discover at 200 fsw (59 msw) a mix of 20 38 will provide a bailout with a PO_2 of 1.4 ATA and an END of 90 fsw (27 msw).

Plan the bailout gas actually needed by each diver as if this is a team of three divers. Base the calculation on the diver who has the highest RMV. In this case we will state the diver with the highest RMV breathes at a rate of 0.7 cu ft per minute (25 L/min). Also assume a bailout EAN 70 cylinder is at 40 fsw (12 msw).

Compute the gas needed, based on the needs of the diver breathing 0.7 cu ft (25 L) multiply ***x*** 1.5 and divide this number by 3.

Note that the diver, by himself, would need 19.6 cu ft (700 L) to bailout and ascend to the first stop at 140 fsw (42 msw). This value was calculated based on the max depth gas consumption which allows for stress at the time of the emergency and during decompression up to the staged deco gas at 40 fsw (12 msw) that the diver would use including the ascent from 200 fsw (59 msw). Thus a total of 66.11 cu ft of gas (2359 L, see worksheet for exact breakdown) is needed. The team would need to carry 66.11 cu ft ***x*** 1.5 or a total of 99.16 cu ft (2359 L ***x*** 1.5 = 3538.5 L) of gas. For safety, round off to 100 cu ft divided by 3 = 33.3 cu ft (3538 L divided by 3 = 1179 L) of gas per diver. The decompression gas needs will require another 114 cu ft of EAN 70 ***x*** 1.5 = 171.16 cu ft of gas (3228 L ***x*** 1.5 = 4842 L). To be staged or carried by the team if broken into individual team member responsibilities then each member would have to stage 57 cu ft (8 L) of EAN 70. In this case, each member could stage a 60 cu ft (8 L) cylinder. (The above gas calculations are for divers using CCR's.)

> **Points to Remember**
>
> **Bailout Minimum Gas Needed**
>
> **To find the bottom mix needed for the team bailout, multiply the gas needed by a diver by 1.5. Decompression planning is not quite as conservative so, multiply the gas needed on decompression by 1.2. These results are then split evenly among the team members.**

> **Points to Remember**
>
> Hypoxic Trimix
>
> **When using Trimix, the starting PO_2 may be a hypoxic mix at the surface. IANTD's EAD/MOD Table may be used for determining the safe depth to breathe the mix as well determining the MOD and TOD values for a given dive.**

Trimix Example

Part One

A dive on Open Circuit is planned on Trimix. The target operating depth (***TOD***) of the dive is 280 fsw (84 msw). The maximum depth obtainable is 320 fsw (96 msw), thus the MOD value PO_2 of 1.5 ATA is to be at 320 fsw (96 msw). A PO_2 of 1.35 ATA is selected for the TOD, with the MOD not exceeding 1.5 ATA PO_2. Using Table C-3700B, we will find the mix containing 14% oxygen will provide a TOD of 1.33 ATA PO_2 and a MOD of 1.5 ATA PO_2. From this table, we have determined the bottom mix FO_2 of 0.14 or 14%.

Part Two

To avoid hypoxic mixtures, the dive gas cannot be breathed until the partial pressure of oxygen is at a normal value. To provide a better decompression profile, many times a travel gas will be used. In the current example using the above FO_2 for bottom mix, refer to IANTD Table C-3700B to discover the minimum safe depth to switch to bottom gas.

This is 20 fsw (6 msw) - actually between 15 and 20 fsw (4.5 and 6 msw). For a decompression advantage, we will remain on the travel gas of EAN 40 until we reach a PO_2 of 1.37 ATA. Refer to IANTD Table C-3201B and it will determine that a switch from EAN 40 to bottom mix will take place at 90 fsw (27 msw).

Diving with Trimix produces more variables than diving with EANx mixtures. In addition to selection of the oxygen in the mix, a desired narcosis value must be determined. The amount of helium added to the mix will displace sufficient nitrogen to yield the desired narcosis loading. If we wanted essentially zero nitrogen narcosis, all we need to do is to mix helium and oxygen in the mix. The disadvantage of a mix of this nature would be extended decompression times unless the bottom time exceeds two hours. A second disadvantage is a higher probability of High Pressure Nervous Syndrome (***HPNS***). Typically, a mixture is derived to give an Equivalent Narcosis Depth (***END***) value of 80 fsw (24 msw) to 130 fsw (39 msw). The most recommended and common END is 130 fsw (39 msw) for the TOD value.

Part Three

We will use a Trimix mixture with a FO_2 of 0.14 (14%). The helium content is not known yet. To be safe, an END is desired that will not exceed a maximum of 115 ft (34.5 m) at the TOD depth. As a safety buffer, our MOD END is to be no greater than 160 ft (48 m).

Using the Helium END Table C-3700, it is assumed that the FO_2 is 1.4 ATA. Go across the bottom of the page to the TOD of 280 ft (84 m), then go up the page until you match the desired END of 115 ft (34.5 m); next, follow the diagonal line to the top of the page. This will produce a Fraction of Helium (***FHe***) of .48. Now check that the MOD END will be within the planned value of 160 ft (48 m). Follow the diagonal line at 48% helium until it crisscrosses the depth of 320 ft (85.6 m); at this point, record the END value.

From this we determine that the MOD END is approximately 140 ft (42 m) and is acceptable for the planned dive. The final bottom mix then will be Trimix 14 (oxygen %) 48 (helium %). With this mix, plan a dive for a 20-minute bottom time at 280 ft (84 m). Use the IANTD Waterproof Tables for this dive.

Personal Planning

Personal planning is the most important part of the dive plan. It is the individual and his/her perception and interpretation of the planned dive that yields an acceptable or unacceptable performance. There are many aspects involved in personal planning, and the key is being comfortable with one's role in the accomplishment of the dive. In this area, we will be discussing the key components of a personal plan.

Risk analysis, acceptance and management are the major portion of a personal dive plan. This should begin with an introspective look into oneself to determine how one truly feels about the dive. During this phase, basic questions should be raised and answered honestly.

Each phase of the dive should be mentally reviewed and the following questions answered:

1. What are the specific risks involved in this dive?
2. Do I understand the dive plan?
3. Am I comfortable with the parameters of the plan and my responsibilities within the dive plan?
4. Can I be depended upon - and not be dependent on - others?
5. Have all the "***What Ifs***" of this dive been covered, and have I established a personal management procedure for these variables?

In the process of answering the above questions, all items of the personal dive plan should be reviewed. As part of the risk analysis process, the diver should also review past histories of similar dives. The diver should determine if threatening situations have occurred on similar dives or if accidents have taken place. If either of these has been encountered, analyze what caused those events.

Once the cause has been discovered, develop a reaction response to compensate for the recurrence of a similar situation. List all the possible things that could affect dive safety and develop a response action to these possibilities. Decide if each risk to be encountered is worth the benefit of performing the dive. Prior to the dive, complete the checklist in tabular form on the next page.

When filling out this table, it may be prudent to discuss your evaluations with other dive team members. Under the Value column, a simple yes or no is sufficient. If the no answers outweigh the yes answers, you may wish to revise the dive objectives. If, in some instances, an overpowering ***no*** is encountered, this may be reason to dismiss yourself from the dive. In addition, listen to your intuitive voice; if you experience bad sensations about the dive, either postpone or cancel the dive, and limit your participation in this type of diving.

Risk #	Risk	Corrective Action/Managment	Benefit	Value
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
etc.				

Personal comfort must be taken into consideration. While it is true that unfamiliar situations may lead to an expansion of personal capabilities, for safety's sake, a diver should not be pushed too far from his present comfort level. Anxiety from overextending the comfort level of a dive may cloud good judgment. If a diver is forced to function outside his personal comfort level, anxiety will add to the stress and overall risk potential of the dive.

If you are in the process of expanding your comfort level, do it in small and personally acceptable increments. Do not depend on someone else to maintain your safety or establish your limits. Even with the best of intentions, other divers cannot enter your mind and evaluate your mental capabilities for a dive. Dive buddies are limited to watching your performance and your verbal and body language communication for interpreting your comfort level. Remember the three basic ingredients that ultimately evaluate your survival and comfort potential. These are:

Any time you have the slightest doubt in your ability to do any of these three, slow your progression toward more involved dives. A skilled buddy may be able to assist you for a short time if a swimming problem exists, but they cannot maintain that function indefinitely. No one can think or breathe for you, so avoid situations that cast doubt on your ability to complete the dive.

An additional factor that determines a diver's personal comfort level is the combined mental and physical fitness he maintains. A degree of physical fitness is needed to manage the equipment on land, and fitness is needed for propulsion skills.

Perhaps one of the most important aspects of fitness, however, does not become apparent until the diver is faced with adverse conditions. In this type of situation, watermanship and fitness may be the determining factors in survival. Even with superb physical fitness, a diver must also develop confidence and discipline combined with the ability to maintain mental focus. The mental fitness of a diver will be the determining factor in development of these attributes. Be sure you remain within both your physical and mental conditioning.

Individual "What If" situations are in addition to the team plan, but they should also be addressed before the final dive plan is agreed upon. These must be placed in the risk analysis table when deciding how to most efficiently deal with them. Exploration of the "*What If*" scenario includes both the environmental factors and risk associated with equipment dependency.

Listed below are sample "*What Ifs*" that may be encountered on a dive. Analyzing the individual risk associated with a dive can expand these reasons. List these in the Risk Table featured above on this page.

1. ***What If...*** I get lost? Determine a means of finding your way out or in being located by a surface crew/ boat. The exact solution will depend on the type of dive, the location, and the community standard for locating lost divers.
2. ***What If...*** I lose a decompression stage cylinder? In this case, if it is an air dive, you may bail out to an air table or air dive computer. If this is a mixed gas dive, it is recommended that a backup schedule be used, reflecting stops if either deco gas is lost. When tables are not available, then, as a rule of thumb, if the EANx was lost at the stops requiring the higher EANx, double the remaining decompression while breathing the remaining lower EANx mixture. If other divers are present, once they have completed their stops, have them leave the higher decompression mix and complete the stop on this mix. Once on the surface, breathe oxygen for at least 30 minutes. Under ideal conditions, the dive will employ safety divers who may be able to respond to this situation.

In this instance, the support divers would bring decompression cylinders to the diver. In addition, a backup decompression gas supply can be used, such as surface supplied gas on a boat, or, on inshore based diving, safety deco stage cylinders placed at central points along the return path to the entry point. In a worse case scenario, share gas with a dive buddy, provided sufficient gas is available. (The last means is to use up the remaining decompression gas from a buddy once they are finished with his/her personal gas needs for decompression.)

3. ***Think*** and continue this list until you have developed 10 or more personal "***What If***" scenarios.

Once personal "what ifs" are listed, determine the solution to each situation and visualize a method for overcoming them. Once you have identified the problem, developed the solution, and visualized its accomplishment, do not dwell on it. You have achieved the goal of overcoming this specific problem. Dwelling on problems will have two negative effects. First, you begin to worry about it. Worry creates stress and may lead to apprehension and result in either an incident or a dive that you do not enjoy. Secondly, by continuing to think about the problem, with so much emphasis on the problem, the mind may in fact create the circumstance.

Am I confident in my ability to manage rebreather specific emergencies when I am diving on a rebreather? This is the most important question to ask. Survival in an emergency requires a yes to this question. At this point, review and practice all emergency skills and responses taught at earlier levels of CCR training. Any oxygen or carbon dioxide problems will present themselves as confusion. This is one of the major (and usually undetected) symptoms. Considering this, if at any point a diver feels uneasy, first switch to a known safe breathing gas (off board/stage/bailout rebreather) and take a few sanity breaths. It may require more than one sanity breath to relax, or in some instances you may discover it's not a rebreather related problem. Regardless, take the time to determine if there is or is not a problem that needs to be corrected.

Generally, the common reasons for taking corrective actions vary from feeling unusual to recognized symptoms and include the following steps:

1. **Go to a known safe breathing medium and take sanity breaths as required:** A ***sanity breath*** is the act of going to an OC gas or back-up rebreather system, with an acceptable PO_2 and END plus adequate capacity for the depth to be breathed at. The sanity breath allows the diver to take one or more breaths as needed to evaluate any unusual feelings or symptoms they may be experiencing, as well as any suspected problems with the rebreather. Since the first symptom of hypoxia, hyperoxia, and hypercapnia is usually confusion, the sanity breath is a diver's safest reflex in these circumstances. The sanity breath will allow clear thinking; enabling the diver to analyze the problem, determine if one even exists, solve the problem or take other corrective action. At the end of the sanity breath, which may encompass

Formulas In Lieu of Tables

If END Table is not available, the END determinations could be found by working END and EAD equations:

Imperial-US: END = (Target END + 33)(0.79)/(D + 33) -> (115 + 33) (0.79)/(280 + 33) = 0.3735 FN_2

Metric: END = (Target END + 10)(0.79)/(D + 10) (34.5 + 10) (0.79) / (84 + 10) = 0.3739 FN_2

Total gases other than Helium, (37% N_2) + (14% O_2) = 51% -> The balance is 49% (He) Helium

An error of 1% occurs due to the FO_2 actually used being 14% FO_2 versus the chart value PO_2 of 1.40 ATA which provides an FO_2 of 14.8%

For the MOD END on this mix of 14 48 use the EAD formula -> FN_2 = 1.0 - (0.14 O2) - (0.48 He) = 0.38% N_2

Imperial: MOD END = [(FN_2)(D + 33)/0.79] - 33 -> [(0.38)(320 + 33)/0.79] - 33 = MOD END of 136.79 or 137 ft

Metric: MOD END = [(FN_2)(D +10)/0.79] – 10 -> [(0.38)(96 + 10)/0.79)] – 10 = MOD END of 40.98 m

one or several breaths, appropriate problem solving actions will be taken. In some cases you may have to do more than one sanity break to correct a given situation. Once the problem is corrected, return to the loop if a safe PO_2 is been verified. In the event of a canister breakthrough or other uncontrolled hypercapnia event, remain on OC and terminate the dive.

2. **Check the PO_2 and perform a diluent flush as or if needed:** For instance, if you have a set point of 1.3 and note the PO_2 has dropped to 1.1 it would be a good indication that the solenoid is not working and has most likely failed in the closed position. If the diluent PO_2 is 0.8, do not flush the unit. Flushing would drop the PO_2 more and you would need to add more oxygen. On the other hand if you noted the PO_2 was down to 0.4, you would want to flush the unit especially if you have been so careless to allow the PO_2 to drop to this level. It is most likely dropping in a state of momentum; therefore it is possible that the inspired PO_2 is even less than the displayed indication. If you are uncertain as to the accuracy of the PO_2 displayed then flush the system to see if the indicated PO_2 and diluent PO_2 match.

If you have just made a rapid descent and notice the PO_2 is at 1.45 then monitor the display closely to ensure that the increase is due to spiking from the rapid descent (provided the PO_2 does not continue to increase) simply breathe down to 1.3 where you can dive the unit by either manual control or solenoid control. If the spiked PO_2 exceeds 1.6, flush the system to bring the PO_2 back down to less than 1.6. Then breathe it down to the set point to be maintained and keep it at this value. If the flush does not bring the PO_2 down before you need to breathe, then take a sanity break, return to the loop, and flush the system down to less than 1.6. **When reacting to situations employ common sense.** Remember if the diluent PO_2 is too high you may not be able to flush the loop PO_2 down to an acceptable level. IANTD recommends the diluent PO_2 not exceed 1.0 at the planned depth.

3. **If it is a PO_2 problem, take the appropriate action to manage the particular problem:** For example, correcting a high PO_2 from either a failed solenoid or a leaking manual addition valve may require turning off the supply gas. Once the PO_2 is safe to breathe, manage the problem by going back on the loop and manually turning the oxygen supply valve off and on. At depth this requires ***barely*** cracking the valve and then turning it back off. Caution is required with this procedure. It requires practice and is critical to only open the valve partially. Each CCR requires developing a sense of timing in doing this process. Usually, if a diver waits to see the PO_2 increasing towards the desired upper range of the intended PO_2 they will discover that it overshoots that value. When manually controlling an open solenoid remember you must create a management range. For instance if the desired average is 1.2, allow the PO_2 to go up to 1.4 and then breathe the unit (with oxygen) down to 1.0. This will provide a fairly long interval between valve openings and give a stable, easy to manipulate condition. A second method to control an open solenoid: once the oxygen supply gas is turned off and the PO_2 is at a safe level to breathe, switch to a staged oxygen cylinder or even a diluent with a higher PO_2 than the onboard diluent by connecting it to the manual addition valve. On low PO_2 it is actually a more simple management procedure, since you will monitor the PO_2 closely and manually add oxygen into the loop, maintaining the planned PO_2. For divers who fly CCR manually, or at minimum loop volume, this will be a normal style of diving.

4. **If you have ascertained that you have a canister breakthrough, it is imperative to bailout to OC:** You must be able to problem solve by source management. This ability requires an in-depth understanding of failure points and of the unit as well. The things that lead to emergency situations on CCR all generate from a source. If the diver can identify the source of the problems, they can take a corrective action to manage it. In many cases going

Points to Remember

Personal Planning involves:

- **Risk Analysis**
- **Personal Comfort**
- **Individual what if situations**
- **Resonisbility**
- **Personal gas planning**

Mel Clark

CCR DIVERS INSIDE A WRECK

to the source of a problem may resolve it, and the unit may be "flown" in a normal method. In other situations the problem can be managed so the diver stays on the loop safely.

Source Identification

After you have completed your sanity breaths, and have regained control of the situation, you need to determine the source of the problems:.

Some potential situations include:

1. **Oxygen problems - source oxygen supply:** The first action following a sanity breath is to achieve a safe breathing gas and return to the loop. Use the techniques that you've been trained on and as discussed above.

   The second step is to identify the cause of the failure, while still managing the problem from the source. High PO_2 may be caused by the solenoid failing in the open position; in this case the practical solution is to continue managing the problem by controlling the oxygen supply valve. Second alternatives are turning off the oxygen supply valve and connecting a secondary oxygen supply (or even diluent supply) that has an acceptable PO_2 to the manual oxygen addition connector, and then control the PO_2 manually. A third method is having an extra off-board connector so that either an additional diluent or oxygen supply may be connected into the system. This avoids the need for switching connected gases underwater.

2. **What to do if you have a leak through a Schrader (LPI) valve or other design feature of your particular CCR:** If possible isolate the problem (i.e. disconnect the Schrader valve or other failed component of the CCR design), thus allowing the solenoid to control the set point.

3. **Spiking:** Flush the system down to a safe PO_2. This can only be accomplished with a diluent that is low enough to affect a drop in PO_2; it is recommended that the diluent PO_2 does not exceed 1.0.

4. **Improper calibration of the unit:** If you suspect the display PO reading to be inaccurate, either go to SCR mode of operation or bailout on OC or a bailout rebreather. Once on the surface recalibrate the unit. Low PO_2 may be caused by the solenoid failing in the closed position. In this case, the diver must dive the unit by manual oxygen addition. Of course, a safe breathing medium must be insured immediately.

5. **Loss of oxygen supply gas:** There are a couple of options. If an additional oxygen supply has been carried, the diver may hook this source into the manual addition of the CCR and fly manually from the alternate oxygen source. Another option is dependent upon the bailout cylinder mixture. Most of the time divers will plan a bailout gas with a PO_2 between 1.4 and 1.6 at the maximum depth of the dive. In this case (assuming the diluent is a PO_2 of 1.0 or less) simply plug in the bailout cylinder to the manual addition and add the higher PO_2 bailout gas diluent to maintain a more acceptable breathing mixture. At some point it may become necessary to switch to SCR mode and again use the highest (safe) PO_2 gas available. As the diver ascends it is wise to flush the system more frequently. Eventually you may want to switch to OC or a bailout rebreather in order to keep the highest PO_2 for decompression purposes.

   An alternate means of control is to plug into a dive buddy's manual addition low-pressure hose and inject

---

Points to Remember

Personal Planning

Only *you* can swim for you;

Only *you* can breathe for you; *and*

Only *you* can think for you!

---

enough oxygen to bring the partial pressure up to 1.5 then disconnect. This gives you several minutes before it is breathed down to 1.0, at which time the procedure may be repeated. In order to perform this action you must ensure that LPI connectors are compatible with your CCR's manual inlet port prior to entering the water.

If the oxygen is depleted during the 20 fsw (6 msw) stop, either do as instructed above (2) and inject oxygen from your dive buddy's unit or take a breath of OC oxygen and exhale it into the unit.

The following are some possible causes for low PO_2:

- **A.** Too rapid of an ascent
- **B.** Oxygen supply valve turned off
- **C.** Failure to have the solenoid activated electronically
- **D.** On SCR
  - **i.** Rapid ascent
  - **ii.** Over-breathing
  - **iii.** Breathing the loop down once the gas is turned off or exhausted
  - **iv.** Improperly keyed Passive SCR
  - **v.** On some Passive SCR inheritance due to over-breathing
  - **vi.** Mistake in gas planning for the dive
  - **vii.** Diving Active SCR beyond its design limitations

6. **Diluent related problems:** Diluent is continually flowing into the loop. If the unit has a diluent shut-off valve installed in-line, simply open and close it to control the addition of diluent into the system. If it does not have a cutoff valve then control the flow of diluent by opening and closing the diluent valve on the tank.

   If the system only features manual diluent addition and the Schrader valve is allowing diluent to leak into the system, you may address the problem by either disconnecting and reconnecting the diluent quick disconnect or by controlling the supply gas valve. Frequently, the valve on manual additions (this is true of both diluent and oxygen) will be stuck. Once the gas flow is under control the diver may be able to free the push valve and regain normal operation. Also, the Schrader valve may simply have debris in it. Disconnecting and shaking it some will clear this out and the diver may discover it works correctly once reconnected.

7. **Diluent PO_2 is above the planned set point of the dive:** In this case the diluent cannot be added into the system and the dive plan should be modified to shallower dive. If an unplanned event caused the diver to descend below a level where the diluent is at an acceptable level, avoid using diluent as much as possible until you ascend to a safe depth. Preplanning for the correct dive gas mixtures easily avoids this problem. Always remember if the diluent PO_2 exceeds the planned set point limits, it should not be used on that dive. Also, if the diluent is very close to the set point it will make it more difficult to flush the loop down in a high PO_2 situation.

PLEASE NOTE: **Imperial & Metric Examples will be rounded *UP* to approximate real-life tanks and breathing usage for the duration of this chapter.**

8. **Bail-out using onboard diluent:** Using onboard diluent for bailout with an appropriate PO_2 is an acceptable practice in shallow water. However, consider the safety of this practice in deeper water. If a diver breathes 0.7 cu ft (20 free liters) per minute at the surface, and bails out on a 20 cu ft (3 L) cylinder at 200 ft (60 m), then at depth they would be using 4.9 cu ft/min (138.74 L/min). Thus, the 20 cu ft (3 L) cylinder, even if at full capacity, will only last 4.08 minutes. It is apparent on deep dives that a diver should not use onboard diluent for bailout or for sanity breaths. You may wish to remove the onboard bailout system when diving deeper than 130 fsw (39 msw). Many experienced deep CCR divers regard bailout to an onboard diluent supply as suicidal. As an exercise it is recommended that divers compute how long an onboard diluent will last at all depths to 200 fsw (60 msw). Then, decide on the safety or danger of this feature for deeper dives.

9. **Onboard bailout is free flowing through the bailout mouthpiece:** Either block gas-flow to the mouthpiece if possible, or shut off the onboard diluent. If the onboard diluent is shut down, the diver may turn it off and on to satisfy diluent and buoyancy needs or shut off onboard diluent and use

off-board diluent (provided the diluent is acceptable at the depth of the switch). With most CCR designs the onboard diluent may have to be turned on and off for buoyancy control, or switch to the low-pressure inflator connector if it's compatible. An in-line shutoff valve is easily installed and provides the CCR diver with another control feature in the event of free-flowing gas.

10. **Sensor related problems:** Sensors are reading erratically: Switch to a set point that is lower then the diluent PO_2 and then flush with diluent. See if any sensors agree with the diluent. Often the sensors tend to settle down once they are flushed with dry gas. If the sensors disagree, keep the set point low and manually fly the unit based on the sensor(s) that agreed with the diluent flush.

11. **Two sensors read identically while the third sensor reads high or low:** Again, flush with diluent to determine if the two sensors are reading correctly. If the two sensors are correct, the CCR will operate normally based on its averaging circuits. However, one sensor agrees with the dilunet and the other two do not then the one felt to be out of range is in fact the correct one. In this case, one may set a low set point and turn the dive following the correct single sensor by keeping the desired PO_2 manually. If the decision is to fly the single correct sensor then flush the unit periodically to be sure this sensor still agrees with the diluent. The safe option would be to bailout on Open Circuit. On the other hand, if the sensor reading out of range is the accurate one, go to a low set point and fly the unit manually.

12. **All sensors are giving erratic readings:** Most likely this will happen only with either old sensors that are losing sensitivity at higher readings (if the unit has the ability to read MV on the sensors this should immediately be done) or if they are overly damp. Most of the time the sensors (or at least one or two of them) will read correctly at 1.0 or slightly below especially if they were calibrated pre dive. If this occurs while swimming at a constant depth and the diver was employing minimum loop volume, then: First flush the unit to determine the actual PO_2. Then maintain this PO_2 (not the original selected PO_2) by adding oxygen manually, as this should be1.0 or lower as long as safe to breathe the sensors will most likely read accurately. Once depths are changed if the mv or sensor reading still agree the PO_2, they may be safe to dive. If the sensors are becoming erratic, again the diver will have to dive the unit in SCR mode or bailout to OC or a bailout rebreather. Once a continuous ascent begins, the diver must bailout to OC or a bailout rebreather. At the 20 fsw (6 msw) deco, stop flush unit at least three times with oxygen and flush periodically to maintain a high partial pressure of oxygen. Of course, OC bailout or bailout to a bailout rebreather is always the safer choice. So in this predicament one has the following choices, the minimum loop volume maintaining the diluents PO_2 value, SCR or OC bailout. The choice of which, must be a personal decision based on comfort level of the diver. It seems since the unit is not reading correctly across any sensor, adding O_2 to maintain minimum loop volume might be unwise, especially if the O_2 in the loop is already high and/ or the correct value is unknown. The only way the diver could calculate the unknown is to perform a diluent flush.

13. **Sensors do not go above 1.2 even if oxygen is added or the set point is at 1.3 and the depth is 160 fsw (48 msw):** Suspect that the sensor voltage is low on all sensors (with units with mv read out check readings) and that they are not capable of reading above 1.2. Thus, the electronics cannot display the true PO_2. Flush the loop until the PO_2 is below the indicated 1.2. The sensors should read correctly if under the output value of the sensors. (It is important to change the set point slightly below the value where the solenoid might fire. Allowing the unit to continue firing the solenoid at the original set point may cause high PO_2 in the loop). Abort the dive and fly the unit at 1.0 to ensure the sensor output will be correct. Alternatively, the diver may do SCR bailout and still monitor the PO_2 when it is below 1.2. At 20 fsw (6 msw), flush the unit with oxygen for decompression. This is a rare event but has happened to at least ten divers I personally know including myself. . Staggering the replacement of sensors, helps prevent this even though some manufactures recommend replacing all sensors at the same time... Frequent checking of sensor output voltage with a meter, or within the system as is possible on some units, will also help avoid false readings. To be prudent do not dive sensors, whether they are staggered or changed at the same time, until failure. Bailing out to open circuit is always an option.

15. **All electronics are lost:** If this occurs while swimming at a constant depth, maintain minimum loop volume and manually add oxygen as it is metabolized. The best option is to use SCR or open circuit bailout. If minimum loop [volume is used the diver may continue the same technique until a depth change is required or ascent is commenced... In this situation at 20 fsw (6 msw) flush the system with oxygen for deco, if a bailout to OC has taken place go back on the loop and flush it with oxygen.

16. **Loop integrity problems:** The counterlung is filling with water: if the design permits it, loosen the counterlung dump valve and then perform a diluent flush while pressing the dump valve. Roll as needed to remove the water from the counterlung. Once the water is dumped remain alert for more water intrusion into the system and be prepared to repeat this sequence. By clearing the flooded counter lung there is a very low probability of having a totally flooded loop inclusive of the canister. If water begins to enter the counter lung a second time the diver should consider aborting the dive. Pre-dives tests and bubble checks at the beginning of the dive help identify problems before they get serious.

17. **The counterlung is filling with water, and does not have a dump valve to eliminate the water egress into it:** Check to see if the source/problem may be corrected. Swim with your feet slightly down to keep the water in the lower portion of the counterlung. If the problem continues it will eventually migrate into the canister. Be prepared to bailout to OC, or a bailout rebreather as the canister becomes flooded, or if breathing resistance becomes too great. It is recommended that divers add a dump valve or other water removal system to units that do not incorporate these. A flood on a deep dive or in an overhead environment can be catastrophic.

18. **The total loop is flooded and you are unable to breathe:** First bailout to OC. If the system is flood recoverable, invert and shake water into counter lung(s). Roll, press manual diluent addition, and purge water from the dump valve. You must bailout to OC or a bailout rebreather if the system is not flood recoverable. In either situation terminate the dive.

19. **The counterlung has been torn allowing water to egress into the system:** Try to pinch off the torn portion of counter lung to stop water entry and terminate the dive. Remain on the loop if possible. Open circuit bail-out is always an option.

20. **Pin-hole leak in counterlung:** In this situation (as long as there is a slight pressure in the counterlung) very little water will leak into the counterlung. The diver may not have to take a corrective action. At the end of the dive, you must repair counter lung.

21. **System has a torn exhalation hose:** Pinch hose together and blow water that has intruded into the counterlung. Terminate the dive. If the intrusion of water is beyond the system's ability to prevent a full loop flood, then bailout to OC or a bailout rebreather.

22. **System has torn inhalation hose:** It is possible the diver may breathe water and the canister may flood. As a preliminary step, pinch hose shut and stay on loop unless the canister floods or there is too much water in the inhaled gas. In this case, you should bailout to OC or a bailout rebreather.

23. **Canister problems:** The diver becomes aware of symptoms of hypercapnia while exerting. First stop activity, switch to OC for sanity breaths, return to the loop, flush the loop and see if symptoms persist. If no symptoms are present, terminate the dive and avoid exertion. If symptoms persist, you need to bailout to OC or a bailout rebreather and terminate the dive.

24. **An acidic taste develops from the inspired gas:** Suspect that water is in the canister, be aware that it is losing its ability to absorb CO_2, and that there is the probability of a caustic cocktail. If the diver elects to stay on the loop, avoid a head down posture. This will increase the possibility of a caustic cocktail. You must also remain vigilant for hypercapnia problems and flush the system at regular intervals. At the first sign of a caustic cocktail (or any unusual feeling such a shortness of breath) you must bailout to OC or a bailout rebreather. The dive should be terminated at the first detection of this situation.

25. **Symptoms of hypercapnia are noticed while swimming at an abnormal pace:** The first step is to switch to OC for a sanity break. Once stable, you may double check for symptoms. Go back on the loop and flush the system. Note how you feel at rest. If any unusual sensations exist, you need to

bailout to OC or a bailout rebreather and terminate dive. Do not try to over-use the scrubber material life expectancy. Change the scrubber material in accordance with manufacturer's guidelines.

26. The canister is on its second dive with the same absorbent and the diver just does not feel normal: In this case suspect that the canister was not sealed well between dives and the absorbent material is used up. Bail-out to OC or a bailout rebreather and terminate the dive.

27. The diver suspects the canister has failed and has symptoms of hypercapnia (even after sanity break, the symptoms return): In this case the only safe solution is to make a switch to OC bailout or a bailout rebreather.

28. The canister is flooded: The diver must bailout to OC or a bailout rebreather unless it is a flood proof canister, in which case the appropriate flood recovery technique may be used.

29. Bailout gas problems: Ensure bailout system is rigged correctly to provide low drag, ease of access, and free from being dragged in silt etc.

30. Leaking o-ring at connection point of first stage and valve: Turn gas off except while in use. If the gas is being actively used, turn on only when it is actually being breathed or add gas and then back off when inactive.

31. Second stage is flooding during OC bailout: In this case the non-return valve failed, there is a hole in the diaphragm or the second stage mouthpiece has a tear in it, so press purge while inhaling and this will blow the water out. You may also need to hold the regulator in your mouth to prevent the tear from opening and allowing water to enter.

32. Loss of bailout gas supply: Communicate to your buddy that you have lost the bailout system and the team must terminate the dive.

33. Bailout rebreather is flooded: Terminate dive and communicate the problem to the team members. The entire team must terminate the dive.

34. Bailout regulator OC is free flowing: Turn unit on while inhaling, and turn it off during exhales. Consider changing with another regulator on one of the other stage tanks.

35. Gas supply hose failure: If a gas hose fails turn off the regulator and use an alternate gas supply. If needed, switch regulators form another gas source.

In addition to correcting these problems, also ensure that if you're using a bailout rebreather that it is functioning and pressure is maintained in the loop at all times to avoid flooding. If using a bailout rebreather, frequently check that it has a safe PO_2 and that the END of the diluent for bailout is acceptable. Check functionality of system periodically.

Pre-dive Set Up and Pre-dive Breathe/System Check: These procedures are crucial in avoiding problems with the rebreather or your support systems. The purpose of the pre-dive check steps is to ensure the system is set up and functioning correctly and safely.

Pre-dive set up is the act of ensuring all cylinders are filled and analyzed, and that the system is properly assembled. During the assembly process O-rings must be inspected and lubed as needed. Sealing surfaces should be observed for integrity and all attaching surfaces should be secure. Sensors should be checked for voltage output and response time, periodically. A slow responding sensor is an indication the sensor is aging and may be marginal for diving.

On every third or fourth dive, at 20 fsw (6 msw), flush the system with oxygen and see if it will obtain a PO above 1.55. This will verify the voltage and response of the sensors. This is important. As sensors age, they may have adequate voltage to calibrate at 1.0 but may not be capable of indicating values above 1.2. If this happens a diver may read a display of 1.2 and actually have 2.0 in the loop. The occasional oxygen flush at 20 fsw (6 msw) will alert the diver to any possibility that the sensor output is not adequate to read above 1.0.

Responsibility: Evaluate both your physical and mental conditioning. Determine if you have what it takes to do this dive. This evaluation must be honest. Don't do a dive out of false bravado. Know in your heart that you can deliver 100% effort. Be certain the team can depend on you. The importance of both physical and mental conditioning cannot be overemphasized in technical diving. If you are going to participate, accept and pay the price of staying in good physical and mental condition. Understand in your own mind that you will not be a person that is dependent upon the other team members.

Another important aspect of responsible dive planning involves awareness. Are you absolutely aware of the dive's objectives and the technical components of the dive? While a level of trust is needed for every dive, there's a big difference between trust and a "trust me" attitude. The "trust me leader" expects you to put your life in their hands and follow them wherever they decides to go. Never, ever get yourself in this position.

If a dive is completely or partially exploratory, this fact needs to be established at the outset. If one member of the team is made the leader, their role must be defined. Responsibilities must be established. Conditions for dive termination must be fully defined. And, never forget one simple rule, ***always trust yourself and dive within your personal ability.***

When planning a dive, it's easy to get wrapped up in the technicalities and overlook the reasons why you're doing the dive in the first place. Anticipate the fun you're going to have. Visualize what you may see. Imagine how the members of your dive team will react to these aesthetic elements. As part of this exercise, develop an understanding that you are both a team member and a solo diver. Estimate the abilities of others in your dive team, but always mentally prepare yourself as if you are diving solo. This approach virtually guarantees that you will not exceed your personal limits and expose yourself to extraordinary risks. Besides, if you become separated or find yourself faced with a life-threatening event, you will most certainly face the situation alone. We repeat, when "the chips are down," only you can think, breathe and swim for you. Bearing this in mind, it is obvious that dives must be planned within your personal limits and abilities to rescue yourself. Not quite as apparent, it is also crucial that you remain within your abilities to assist or rescue a dive buddy. As a team member you are responsible to the other divers on the team. In return, ascertain that each of the team members also are capable of rendering help to you.

Personal gas management for OC and bailout for CCR: In this planning stage, the diver will become aware of their Surface Air Consumption (***SAC***) rate and the amount of gas in psig/bar they use when switching tanks. First, one must determine the SAC rate at a moderate swim pace. This can then be used as the normal swim rate SAC. To do this, swim at a predetermined constant depth for a period of at least 20 minutes. It is recommended that this be performed when a tank is between 1/2 and 2/3rds of its rated pressure. In addition, this provides a more realistic value if done once the diver has been in the water diving or doing skills for a sufficient duration to add some degree of fatigue.

To calculate a heavy workload modifier, repeat the above drill when swimming at full speed. On this second drill, note the following; Divers who are in good cardiovascular condition will have a slight increase in gas consumption and will be able to retain a more constant swim pace. Divers who are not in good cardiovascular condition will usually have a more dramatic increase in gas consumption and tend to reduce the pace over time.

Group Planning

Group planning is the process used by the overall dive team to determine understanding and acceptance of the objectives of the dive and the responsibilities of each diver. **The specific items addressed include but should not be limited to:**

- Establish gas management procedures
- Decide on the limits of the dive
- Determine the size of team and responsibilities of members
- Determine team member compatibility
- Ensure each diver is aware of the configuration of fellow divers
- Plan for the "***What Ifs***" that affect team safety

Gas management is a crucial portion of any dive. The more involved the dive, the broader it's objectives, the more important gas management becomes. Maturity and judgment reinforce the concept of proper gas management. Most technical divers, and all overhead environment divers, observe the gas management rule known as the Rule of Thirds when diving OC or bailout times 1½ on CCR. The cave diving community developed the Rule of Thirds after analyzing their accident history. The Rule of Thirds is conservative. It was designed to be so. More importantly, experience has taught us it works.

Every gas management rule devised depends on individuals functioning "normally." They must swim normally, breathe normally and function as expected. For a rule to be valid, unanticipated variations caused by the environment or changes in divers' abilities cannot occur. This means that events such as unexpected currents or having to maneuver through restrictions must not deter the diver's proficiency. If divers are forced to increase their swim pace, they will also increase gas consumption. Other changes in respiratory patterns, such as response to mental and physical stress, will also increase gas consumption. When divers slow their pace, gas consumption is reduced. However, you must never forget that your return speed must match your travel pace. You must cover the same amount of ground in the same time "coming back" as "going to" in order to ensure you won't run out of gas.

Once again, this is where mental and physical conditioning comes into play. With mental discipline and good physical fitness, it is much easier to remain "normal" during a stressful event. A physically conditioned person will have much less increase in gas consumption with increased workloads than an out of shape diver.

A diver who does not maintain good cardiovascular efficiency will experience tremendous changes in his/her gas consumption when going from light effort to harder work loads. A diver who maintains a cardiovascular training program will experience significantly lower changes in his/her respiratory minute volume when switching from light to heavy exertion than a comparable individual who does not train on a regular basis. The diver who is a weekend warrior and a couch potato during the week will also have less endurance and is more likely to experience increased use of gas when fatigued.

Changes in buoyancy will also affect gas consumption. Environmental changes such as silting or changes in current flow and direction will modify the swim pace. Alterations to swim posture can increase drag. Additional gas is needed to anticipate these changes, too. By now it should be obvious that every phase of a technical dive must be anticipated to ensure the effectiveness of the team and personal gas management rule.

Since dive teams are obviously composed of individuals, a "***team gas management***" rule must be established. This rule incorporates all the factors involving individual considerations with another dimension. People working together create this dimension. When you dive alone, you dive differently than you would as a member of a buddy or dive team. To understand these differences, think of dancing. You dance differently when holding someone in your arms. An effective team gas management rule takes time to develop. The team must do a lot more than just shake hands. Each member must learn other team members' dive style and ability. They must also practice emergency management skills.

The size of the dive team will dictate effective gas management. Obviously a two-person dive team is the most efficient from a dive performance standpoint. It needs less communication and requires less choreography. Both divers know where each other are. Swim pace is easier to regulate. A small team reduces the level of environmental management needed. For example, silting is just one of many factors that are easier to anticipate and prevent.

On the other hand, there are strong arguments to support the advantages of a three-person dive team. The group gas supply or bailout gas on CCR can go much further when shared between three people. Two people are usually better able to rescue an individual in trouble.

When computing a team gas management model, compensate for variations in both breathing volume (respiratory minute volume - ***RMV***) and varying tank capacities. In addition, plan out the known gas volumes for the dive. If a dive has a three-person team, the dive gas is matched automatically provided all use an honest Rule of Thirds. If a two-person team is used and the diver who uses the least gas also has the smallest gas supply, the divers must match gas. Gas matching ensures that if a gas failure occurs at the farthest point form the return area, both divers can safely travel on the lowest volume of gas in the team.

Developing a gas management profile for a hypothetical team in OC:

Diver #1, "Jan," consumes 0.37 cu ft (9.9 free liters) a minute. She uses double 100s (twin 15 L) at 3500 psig (232 bar).

Diver #2, "Bill," consumes 1.13 cu ft (32.6 free liters) a minute. He uses 121 cu ft (20 L) steel tanks at 2640 psig (180 bar).

When using the IANTD Gas Matching Table C-3202 & C-3202B, round to the most conservative value. This means round down for the diver who consumes the least gas and round up for the diver who consumes the most gas. In this example, round Jan's consumption down to 0.35 (9.91) and round Bill's up to 1.15 (32.57).

Using the IANTD Gas Management Table C-3202:

1. Follow the left margin side until you reach Jan's RMV, which is calculated at 0.35 (9.91)
2. Go across the top of the table to Bill's RMV of 1.15 (32.57), column #1

At this point, follow Bill's RMV down the column until it's adjacent to Jan's. Note the value 0.81. The number 0.81 represents a conversion factor of 81%. This means that Jan, instead of turning at 66% (0.66) of her gas supply, needs to turn at 81% (0.81). This should provide Jan with an adequate safety margin in case Bill needs to share gas on the way out.

Convert this safety margin into a usable number; Use C-3202 IANTD Gas Management Table:

1. Go down the Starting Cylinder Pressure Column along the left side to 3500 psig (238 bar)
2. Go across the top of the table showing SRFs from 0.67 to 0.81. The last column is labeled 0.81
3. Go down this column until it intersects with 3500 psig (238 bar)

The C-3202 Table shows Jan's turn pressure to be 2,835 psig (193 bar). Normally Jan would turn at 2310 psig (157 bar). The chart shows she must hold an additional 525 psig (36 bar) in reserve to compensate for Bill's increased RMV.

Even with proper gas matching, it is still imperative that all dives remain within normal parameters for these rules to work. When you start diving with new buddies, it's advisable to add a couple of hundred psig (extra bars) to any cutoff point. This practice should be continued until divers have sufficient experience to develop the discipline to function normally under stress. Many experienced divers develop the ability to actually reduce their RMV under stress and to maintain a normal swim pace under the most demanding of situations.

Gas duration required for the dive plan should be figured by anticipating the planned distance traveled, coupled with gas consumption. In this case, let's look at two divers who are planning a dive into a moderate outflow cave. This example employs a cave dive because cave dives generally employ more consistent swimming than open water dives.

Continuing with our example:

- Swimming into a dive, the divers will swim at a pace of 50 ft (15 m) per minute
- From gas planning, it has already been determined that the turn pressure will be 2400 psig (160 bar) from a starting press of 3600 psig (240 bar)
- It has already been determined (through steps explained earlier in dive gas planning) that the divers use 30 psig (2 bar) a minute at the planned dive depth of 90 ft (27 m)
- **To determine the turn pressure time:**
- First, compute the gas available: 3600 psig - 2400 psig = 1200 psig (240 bar - 160 bar = 80 bar)
- **Next, compute the amount of time unto reaching turn pressure:**

o Imperial-US: (1200psig)/(30 psig per minute) = 40 minutes

o Metric: (80 bar)/(2 bar per minute) = 40 minutes

- The divers, traveling at 50 ft (15 m) per minute, will penetrate 2000 ft (600 m)
- If the divers exit at 75 ft (22 m) per minute, it will only take 27 minutes to return. This will increase the safety of their gas management procedures
- However, what happens if the divers slow their return due to an emergency such as a silt-out or gas sharing problem? In this event, let's say the exit speed is at 25 ft (12 m) per minute. The exit will take 80 minutes
- In this delayed exit event, it will take (80 minutes) *x* 30 psig (2 bar) per minute = 2400 psig (160 bar) to exit
- If this is a not a gas sharing emergency, there is still a sufficient quantity of gas to exit with reserve. If a gas sharing emergency did take place at the maximum point of penetration, it would require 2400 psig (160 bar) *x* 2 = 4800 psig (320 bar), both divers combined gas needs to exit. This is not sufficient gas to return to the surface

Pre-Dive Check

1. Analyze all gases and make sure they are connected to the appropriate regulators.
2. Turn gases on, then off, and record pressure to determine if there is a leak in the gas systems.
3. Check that the inhalation, exhalation hoses, and their non-return valves are installed correctly and functional.
4. Do a positive loop test. Allow at least 5 minutes to observe for any leaks.
5. Perform a negative loop test. Allow it to sit for a minimum of 5 minutes. (Note that some systems require the negative test to be longer per manufacturer's instructions.)
6. Activate electronics. (The electronics are inside of the loop on some rebreathers and need to be activated upon set up.)
7. Check accuracy of all electronic displays and analog displays as relevant.
8. Check if the pressure in the oxygen and diluent supplies has decayed. If there is a leak, fix the leak before proceeding.
9. If applicable, ensure all gases and variables are correctly defined in the electronics and that manual and electronic readouts are consistent with each other.
10. Run check on systems that have an onboard technique for checking sensor voltage and ensure all sensors are within acceptable range.
11. Calibrate system: if doing a manual calibration, flush the system totally for at least 3 cycles. Often 4 or more cycles are required to have a 100% oxygen environment in the loop. While at 100% oxygen, (on systems that have the capability) check the sensor voltage to verify it agrees with the value for a partial pressure of 1.0.
12. When calibration is complete, observe the PO_2 readings. If they tend to drop off sharply, the calibration is most likely in error. In this instance redo the calibration.
13. If the system does not have a two-point calibration you may want (not mandated) to flush with diluent (again three times) and check that the diluent PO_2 is accurate. This also will provide an indication of sensor linearity. Prior to doing this, check that the set point is below the partial pressure of the diluent, that the system is turned off, that it is in manual mode or that the oxygen is turned off and gas is vented from the oxygen supply line. If applicable, check sensor voltage for correct output.
14. Check remaining battery time and be sure it is adequate for the planned dive.
15. On systems that "go to sleep" on the surface, be sure to activate the electronics prior to breathing on the loop. At least one system has a start dive mode that must be activated prior to diving.
16. Ensure that all manual gas control valves or switches are set in their correct position and are functioning.

17. Verify all electronic gas control functions and any switches that may be applicable are in the correct position and operational.

18. Conduct an S drill on the system. Check completely for any leaks or systems abnormalities. Check the bailout system to ensure it is functioning properly. If it is OC bailout, be sure there are no leaks, no free flows etc. Check that the low-pressure inflator hose and fitting will allow you to plug into the manual addition valve if the system is equipped with one. It is advisable to have an interchangeable low-pressure fitting on the counterlung, the BC and dry suit so the source gas may be switched in event of a failure. Check the manual addition valves for smooth and correct operation. Ensure the rigging of bailout systems allows them to be accessible and protected from damage. If a bailout rebreather is used, check its components in the same manner as the pre-dive check on the primary rebreather. If used, check lights and lift bags plus reels.

19. Pre-dive breathing: during this process the canister is conditioned. The diver verifies the solenoid is firing and that the displays are responding to the injection of oxygen. Check the set point is correct and held by the system and that a safe breathing gas is in the loop. The pre-dive check should be performed on a low set point. During the pre-dive check also breathe from the bailout system; check BC inflation, and all systems needed for the dive.

20. The pre-dive breathing sequence should be a minimum of 2 minutes in warm water and 5 minutes in cold water. Note! If a bailout rebreather is used the same procedures must be followed on it!

21. Immediately prior to entering the water verify that the unit is on, that there is a safe breathing mixture, that the automatic diluent addition valve (ADV) (if applicable) works and that any and all manual addition valves respond. Start he dive at the proper set point.

22. At depth, verify a change to the desired set point and that the solenoid still works. Even if controlling the system manually, you should still verify the solenoid fires provided the system uses a solenoid. Some CCRs, like the KISS model, may not use a solenoid as a standard component on the system.

Remember to check your dive log for any faults or developing issues identified in the last dive. Correct these problems before proceeding into the formal pre-dive check!

Another common problem in out-of-gas situations is that the divers' breathing rates increase. Let's assume the divers use some discipline but, due to stress, they increase their combined breathing rate from 30 psig (2 bar) per minute to 60 psig (4 bar) per minute. Let's allow for a normal swim rate equal to the penetration rate of 50 ft (15 m) per minute. The divers will exit in 40 minutes if gas has been matched. It will now take 60 psig (4 bar) per min. *x* 40 min. = 2400 psig (160 bar) per diver, 4800 psig (320 bar) for both divers sharing gas to exit. This is more gas than is available!

From these examples, it is apparent divers must function in a normal fashion even when responding to an emergency. Planning gas needs for decompression is also vital to a safe dive plan. A separate gas supply should be planned for decompression purposes. This gas supply must include the amount of gas needed plus a 1/5th reserve. In this case, determine the gas needed and multiply by 1.2 for the correct volume of gas to carry.

Points to Remember

Technical diving is a hostile environment for dependent divers

Avoidance is a key principle of technical diving. In this case, however, avoidance does not mean ignoring a potential problem. It means knowing what constitutes a small problem and what doesn't. It means knowing that a "tiny" free-flow could become a major problem. It means having the common sense to know if one part of your gas supply is not working properly, turn it off and use your alternate source. It means having the discipline to anticipate, to think ahead, and to immediately neutralize the source of problems.

By taking corrective actions with gas supply problems before those problems escalate, divers can begin sharing gas before the diver with the problem actually runs out. This is good stress management, because it allows the distressed diver to use their own gas whenever a restricted or hazardous point in the dive is reached, and to share air in the long, unobstructed passages.

In a 3-person team, the "out-of-gas diver" should be sandwiched between the two divers with gas. Every few hundred psig (***free liters/bar)***, the out-of-gas diver is rotated between donors. This allows the two divers with air to deplete their gas supplies somewhat evenly. When exiting an overhead environment dive, certain problem management techniques have been developed. For example, in three person teams, one of the "donor divers" negotiates a problem area, such as a restriction, ahead of the "recipient diver." Once the lead donor diver has safely reached a clear passageway, the "recipient diver" switches over to their own gas supply and swims to the lead donor diver. They resume sharing the donor's gas while waiting for the third member of the team to join them. This, of course, assumes the "recipient" is not out of gas.
In a true out-of-gas situation, the recipient would share gas with a buddy while the buddy goes through the restriction. At this time, the recipient will go into the restriction to a point where the long hose is dropped and continues until they reach the awaiting second stage of the diver who has already negotiated the restriction.

Two person teams must handle a gas supply problem differently. When negotiating a problem area, the "recipient diver" stops, takes 3 breaths (inhaling slowly and deeply) followed by 3 hyperventilation breaths and waits for the "donor diver" to reach an unobstructed area. Once the donor signals "clear," the recipient swims to the donor and shares gas. There's a good reason why the donor leads. At the point of separation, the recipient has adequate gas in their lungs to reach the donor. Moreover, there's a psychological edge provided by swimming toward a gas supply rather than away from it.

Gas management rules are occasionally modified when conditions warrant a change. Specialized equipment may mean altering normal gas turn around points. **For example:**

- When diving into caves with "siphons" or down-current on wrecks and other circumstances which will require an up-current swim to the exit or ascent point, gas management rules should be modified to account for the challenge of overcoming the in-flowing water. In this case, more conservative rules are implemented. This may be nothing more than adjusting to a different gas turn-around percentage or fraction. A good starting point for mild to moderate siphons is the Rule of Fourths. This is also a good starting reference when you first begin using a Diver Propulsion Vehicle (***DPV***).

- With experience in both technical diving and at a given location, it may be acceptable to make modifications to the basic thirds gas management rules. For example, a diver may use 40% of his gas supply swimming into a dive with a strong outflow. By riding the current out, the diver will not work as hard and will consume less gas. The "turnaround point" might then be adjusted to allow the dive team to adhere to the Rule of Thirds as it applies to this environment.

Such interpretations of gas rules can only be performed by accumulating experience. This experience comes from both the total number of dives logged and the number of dives performed at the specific location where the modifications are being applied. Modifications to gas management rules should be made in gradual increments. Each dive is followed by careful evaluation to determine if the modification did, in fact, allow a true $2/3^{rds}$ reserve gas for exiting the system. Regardless of the current, no more than 40% of the gas should be used when traveling into a dive.

We suggest you be very conservative before making changes to gas management rules. We recommend you make at least 100 total dives and 25 dives at a specific site before considering such modifications. Again, you must be able to prove that the modified turnaround point does provide $2/3^{rds}$ of the available gas is actually available for exiting. This availability is defined within a relationship of time, distance, and duration of gas.

A specific example of a modified Rule of Thirds could involve a dive into a strong current. After completing numerous dives at this location, you realize that upon exiting, you and your buddy team will finish the dive with half your gas. In this example, the management rules can be modified. If, for example, you had started with 3,600 psig (245 bar), the exit would be completed with 1,800 psig (122 bar) remaining in the tanks. Thus, $1/3^{rd}$ of the gas was used going in and only $1/6^{th}$ of the gas was used on return. In psig (bar) this equates to 1200 psig (82 bar) going in and 600 psig (41 bar) exiting. The Rule of Thirds allows for the use of an additional 600 psig (41 bar).

The experienced diver who is familiar with the dive site may now begin to modify the turnaround point to allow for a safety factor of one third. By familiar, we emphasize that it means you have made numerous dives at the site and encountered the same or very similar conditions.

In the above example, if a diver turns with 60% of the gas remaining, a turn around at 2160 psig (147 bar), the dive will reflect 1440 psig (98 bar) used going into the dive. It will require 1/2 of that to exit, or 720 psig (49 bar) with a remaining 1440 psig (98 bar). This works out to more than a 1/3rd reserve as the true "***3rd reserve***" would be 1200 psig (82 bar).

If a diver does not carry extra gas for decompression, it is necessary to plan for sufficient gas supply into the dive plan. In this instance, the diver must incorporate two phases of dive planning into the primary gas supply. These involve bottom gas and decompression gas.

Points to Remember

Always trust yourself first and dive within your personal ability.

Anticipated need for decompression gas must be planned. When planning the necessary gas, subtract the gas needed for the decompression stops and plan the dive as if that gas did not exist. For example, after careful planning, you determine that 30 cu ft (850 free liters) of gas is necessary for decompression. You would then multiply that value by 1.2 for reserve. Finally, you would subtract the deco gas from your primary gas supply and plan accordingly.

Whenever possible, decompression should be made using Enriched Air Nitrox (***EANx***) of 50% or more. Doppler studies have discovered bubble formation decreases as the oxygen level in the EANx mixture is increased. Many experts consider the practice of decompressing on bottom mix to be unsafe from a DCS standpoint.

Another consideration is the "solo" diver. In this instance, in addition to diving using the Rule of Thirds, it is recommended that the diver must also carry a stage bottle (referred to as the buddy cylinder) that is equivalent to one third of the back-mounted gas. This tank is reserved for emergency use only. It is only used if a failure of the primary gas system takes place. As an example, a diver with double 100s (15 L) has a total of 200 cu ft (38 L) of gas. The safety gas supply must be at least 66 cu ft (12.5 L).

CCR Planning

An advantage for CCR divers is that work rates make little difference on the gas used in the cylinders, thus allowing gas management to be more precise. However, if a diver must bailout then all the things that apply to OC gas usage come back into play. For this reason the team's total bailout gas must be adequate to get 1½ divers to the surface or to another staged dive gas. Each diver in the team must have adequate bailout gas factored into the team's gas to fulfill this requirement. All divers in the team must be competent in exchanging bailout out cylinders or alternate methods of gas exchange. For team safety, a diver forced off of the loop must surface. Ideally in the future, each diver will have a bailout rebreather for this purpose. If someone is diving in a non-team situation or there is a high probability that team members will become separated, then the diver must personally carry sufficient bailout gat to reach the surface or other staged gas.

In addition to the bailout gas management issue, divers need to plan the dive so that no one has less than one third of their oxygen supply gas upon surfacing or reaching a staged oxygen cylinder. To accurately plan for this, each team member's oxygen metabolism rate must be known. There is a significant variation between individuals with some divers using as much as double the amount of oxygen as their buddy, due to metabolic needs. Another factor is how efficiently he/she dives the unit. If an ADV is always used, you will breathe more oxygen each time the loop reaches a minimum volume because the diluent will add gas. This addition will lower the PO_2 and then the solenoid will fire to restore the PO_2.

In bailout planning, ensure each team member has either a dive computer, dive tables for the dive, a back up computer, and/or back up dive tables. The dive tables should also include the decompression for OC or bailout rebreather needs.

Also, as divers may have more than one style of CCR in the team, be sure the plan includes team bailout management that considers:

1. The valves may not permit gas exchanges between some different CCR designs, so an alternate gas management plan must be developed to deal with this
2. It is possible that all divers may not have the same diluent or bailout gases. In this event the decompression procedure and the ability to use bailout gases other than those the diver may carry must be included into the dive plan
3. If the team dives consistently with each other prior to arriving at the site, preplanning should ensure that the divers have compatible bailout gases and have planned around any inconsistencies in valve variations from one CCR to another. This may require adding extra low pressure hoses to be compatible with a team member's needs, or it each diver may need to add or change valves on their unit so the team is compatible in this area
4. Many divers (including the author) prefer to use all low-pressure fittings that are interchangeable with the counterlungs, BC, and the dry suit. In addition if all team members are of the same philosophy, then compatible fittings can be planned fort he entire team

In a dive team, if a diver has loop failure, the "off the loop diver" will go to their OC bailout. Then once 50% of the bailout gas is used, they will switch stages with another diver until 50% of this gas is used, and so on… This process will be repeated as dictated by the situation, but will ensure all divers have adequate bailout gas to reach the surface or other stages gases. If it is a three person team the "off the loop diver" will be positioned between the other two divers enabling the bailout gas to be rotated between all three divers.

Planning For Mixed Equipment Dive Teams

Diving within a team composed of divers who are using Closed Circuit, Semi-closed Circuit, and Open Circuit systems is definitely an exercise in "Multi-Cultural Diversity!" It can work, but it will ONLY work ***WELL*** if the members of the team display tolerance, understanding, and a willingness to accommodate the "special needs" of the other team members.

Specifically, this will be one of the most complex and difficult dive planning sessions that the team will have to participate in. By following the procedures laid down in this text by Mount, et al, the team members will find that the plan will be simple, easy to follow and above all safe. The key to the project is finding a "baseline," which will be established by the physical limits of the equipment involved (as has been discussed in previous chapters), and begin the mission planning from that point.

Some people take the approach that diving in "mixed" teams should be avoided, but experience reflects that this is not an uncommon practice. When teams are mixed, the OC diver is the one with the greatest disadvantage since he or she usually has limited or no understanding of the rebreathers and their operating requirements.

Logically the first step is to provide the OC diver with an overview of how the rebreather functions (CCR, SCR or both as the case may be). This must include a quick review of issues with the partial pressures of gases, and the fractions of gases in the mix on SCR. The significance of gas supplies, gas duration and canister limitations should also be covered. Then the OC diver should be introduced to recognition of rebreather problems and how they are solved. As many OC divers have great concern with the operating procedures and bailout systems a short course will need to take place explaining these issues. The OC diver in a team that has one or more CCR divers should be aware of the bailout options for the CCR diver should they have a malfunction of the system. Thus it must be explained that the CCR diver has a progression of bailout scenarios.

The options include:

1. If at a constant depth and the CCR diver has been employing minimum loop volume diving, remain on minimum loop until a depth change is encounter
2. Dive the CCR as if it is a SCR
3. Open Loop bailout
4. Bailout to OC
5. Bailout to buddy's OC

Of course this will take a brief description of the process. In some cases, the diver may have a bailout CCR, and if that is the case it will become the first option.

Explain to the OC diver how adequate bailout is predicted and the 1.5 minimum rule is used. Provide the OC diver with an example; How much gas would an OC team need to exit or return to the surface from a maximum point of penetration if one diver has a total loss of gas, requiring them to share gas. The OC diver is diving the rule of thirds, so the plan maintains a gas supply of one third for the buddy to use or to overcome problems on the dive.

Thus an example of planning an OC technical dive includes:

1. The OC dive team determining that the dive would require 85 cu ft (2400 L) to provide a single diver enough gas to complete the dive or return to staged gas or deco gas
2. The next step is to plan the dive so that the Rule of Thirds is included to provide gas for emergencies and gas sharing with team members. To determine the gas needed to incorporate the Rule of Thirds, the OC diver will take the total volume of gas to actually be used (based on highest RMV/gas matching) and then multiply the actual gas used by 1.5, for a total of 127 cu ft (3600 L). That figure equals 85 cu ft (2400 L) for the diver to use and 42.5 cu ft (1200 L) for emergencies and or gas sharing with a buddy

Points to Remember

Under stress, divers often slow their swim rate. Gas Matching & the Rule of Thirds rely upon maintaining a constant swim rate!

A disadvantage of gas management rules is they assume the divers will maintain the same exit/ascent rate, the same breathing rate and that there will only be a single failure. If a diver slows down their exit or return to surface swim rate, increases their RMV, or if there is an additional failure to the gas supply of the second diver then the rule will not prevail. When developing gas management rules, it was assumed that each of these variables was under control and that the probability of two people having a total gas supply failure was remote enough to not consider it. Historically these assumptions have worked well enough that the rule of thirds is accepted, it is believed to be a safe approach, and practiced in all OC technical diving circles.

Rebreather bailout principles are based on similar concepts. However when using a rebreather the OC gas plan does not have to include gas for use up to a point of failure (as in OC diving). In its broadest application, it also assumes the same constants the OC rule of thirds does, decontrolled RMV, swim rate and single system failures. The rebreather bailout concept also allows for a solo diver or a high probability of team separation. Each diver, based on their RMV, carries adequate OC gas or a bailout rebreather to surface or get to the staged dive gases. For normal confident diving, the team will remain intact until the end of the dive. Their gas is planned to provide OC bailout to get 1.5 divers out and/or up, or to a staged bailout gas. If we take the same example where we have determined the gas for a single diver in a team, this will be the diver with the highest RMV to return to the surface or other staged that value will be multiplied by 1.5 for the total team gas to be available.

An example of planning a CCR technical dive includes (using the same exit gas reference as on the OC dive):

1. The CCR diver or team will determine the amount of gas needed to exit or reach staged gas by the diver with the highest RMV (unless using a bailout rebreather)
2. In this case we will assume the emergency gas needed for an "out-of-gas" or "off-the-loop" diver is 42.5 cu ft (1200 L) (the same as for the OC example previously discussed). The bailout gas is for bailout or other emergencies and can be given to the OC diver should they have total loss of gas
3. If the team consists of more than one CCR diver(s) and one OC diver, then the CCR team would collectively carry 42.5 cu ft (1200 L) *x* 1.5 or 64 cu ft (1800 L) of team gas
4. In this application, each of the two CCR divers would carry a minimum of 32 cu ft (900 L) of bailout gas. In an emergency the bailout gas would be rotated between the divers. This actually provides an additional 22 cu ft (600 L) of reserve gas
5. If the dive team consists of one OC diver and one CCR diver, the CCR diver must carry adequate bailout gas to exit or reach the staged dive gas. In this case the CCR diver would carry 42.5 cu ft (1200 L) of gas. This provides the same emergency gas, as needed for the team of two OC divers

The above shows that when either diver is forced to go to a gas supply other than their primary gas, the CCR diver could use the OC diver's long hose and the exit would be the same as on any OC dive. If the OC diver is forced off their system, simply go to the CCR diver where they will most likely be given the stage cylinder with the 42.5 cu ft

Points to Remember

Divers under stress often increase their breathing rates. The results could be life threatening.

Gas Matching and the Rule of Thirds rely upon maintaining a constant breathing rate!

Points to Remember

Once any member of the dive team is using a back-up regulator, the dive should be terminated.

All divers should begin their pre-planned exits.

(1200 L) of gas. A stage hand-off to the distressed diver may take a brief moment, but then allows a simpler exit and less time is wasted than with an OC diver on a long hose. The stage hand-off eliminates the slow swim times that a long hose would require and problems associated with narrow openings or restrictions, etc.

On some rebreather systems the bailout gas is configured to go directly into the loop. In such a system, the rebreather diver may provide a long hose instead of handing off a stage.

Many rebreather divers, such as the author, prefer to carry two smaller cylinders that can be rotated in a manner to always allow the donor diver(s) to have some form of bailout gas. This also gives more flexibility if more than one diver experiences a system failure, especially considering the probability that two persons would have total system failures at the end of a dive. The 1.5 *x* Gas Needed rule should cover multiple failures and be easily managed if each diver carries their bailout in more than one cylinder. If the bailout is 43 cu ft (1200 L), then carry two 22 cu ft (600 L) cylinders.

Typically on CCR dive teams, once a diver uses 50% of their bailout gas they will exchange cylinders with another CCR diver and once again use 50% of that gas supply. If it is a three-person team, go to the third diver, switch, and repeat each time 50% of the gas in the cylinder is used. If it were a two-person team then the rotation would be between the two persons. On a team with an OC diver, if the CCR diver is the one with the problem they will use 50% of their cylinder, then go to the long hose of the OC diver, use 50% of his share of the OC diver gas, and then back to his cylinder - rotating back and forth in that manner. If another OC diver or rebreather diver is in the team, that diver will also be included in the rotation for gas. If the OC diver has had a problem, simply take the CCR diver's bailout gas. If it is a 2-person team, keep the cylinder until reaching the exit, surface, or other staged dive gas. If the dive has a three-person team the OC diver would follow the same rotational practices as the rebreather divers.

Another method, considering the difference in gas management between CCR and OC divers, is that the OC diver carries bailout gas. Plan the dive in the same manner as the rebreather diver. The primary gas supply will be used for the dive and the bailout stage(s) will be used for emergencies.

Advantages of the OC diver using the bailout concept:

1. Increases dive capability (in this case he would have two primary gas options)
   a. Devote the entire primary gas supply for use on the dive
   b. Use 80% of the primary gas for the dive (includes surface to surface gas) with 20% for emergency use
2. Carry bailout gas in addition to the primary gas based on the same rules as the rebreather bailout
   a. If diving solo or with a high probability of separation, carry adequate personal bailout gas to reach exit or staged dive gas
   b. If confident the team will remain intact, carry adequate team bailout for 1.5 divers. Apply distribution as explained previously
   c. Ideally carry multiple smaller cylinders. In an emergency they can be rotated to always ensure that each diver has onboard bailout

Use this approach especially when multiple cylinders are carried. It allows a better chance of survival in a multi systems failure situation.

An SCR diver using an active (***mass flow***) system is limited by the gas supply, flow rate and canister duration. A diver on a passive SCR will be limited by gas supply based on the ratio of the unit with the diver's RMV factored in, and canister duration. The OC diver is limited by their RMV and gas supply. The CCR diver is limited solely by canister duration.

The biggest issue is that the OC diver must be able to recognize CCR or SCR problems and understand the corrective action taken by these divers. Another point, in this scenario there is a higher probability of each diver being on varying gas mixtures. However, if the dive is planned as a ***team*** dive the bailout gases should be matched to the bottom mix used by the OC diver(s). A bailout by the OC diver to a rebreather diver's stage will not add to the decompression needs of the OC diver.

In an ideal world a rebreather diver will educate the OC diver on the rebreather to an adequate level regarding the different systems between everyone on the team. The OC diver may feel more comfortable if the CCR diver displays his/her PPO_2 read-out. This will ensure that the OC diver knows that the partial pressure of oxygen is acceptable. Also the OC diver may wish to check that the CCR diver is periodically checking his/her displays.

Points to Remember

The key is that all dives must be planned with the diver arriving at the surface with a minimum of one third of the origional gas supply

On decompression, the divers will most likely have variations in the stop times and total run time of the dive. Most likely the CCR diver will complete decompression first, especially on a multi level dive, then the OC diver and last the SCR diver. Additional gas switches by the SCR and OC divers can be scheduled to coordinate the run times.

In summary, prior to commencement of the dive, review all the objectives. During this phase of the plan, ascertain that each diver is aware of the responsibility assigned to him or her. If it is a complex skill, rehearse it through land drills as a team and visualize it. At the same time, discuss the absolute limits of the dive. In addition to gas management, consider factors such as partial pressure of oxygen, narcosis loading, gas density, decompression duration and contingency factors.

For open circuit diving under no circumstance should a bottom mix PO_2 exceed 1.4 ATA, and it is prudent on longer dives to drop to 1.3 ATA. For decompression, a maximum of 1.6 ATA is to be observed. On exceptional exposures, the dive gas design must allow for a total exposure to remain within team and physiological safety standards. Some projects actually limit the bottom mix to less than 1.35 ATA and decompression mixes to 1.50 ATA.

Jill Heinerth

Ali Akers & John Falcone diving as a mixed team in Madison Blue, Florida

Usually, these projects use multiple gas changes on stops and stay close to a range of 1.2 to 1.45 ATA throughout the entire stop times. Remember, to plan both the MOD and TOD (***limits for oxygen, nitrogen narcosis limits***) and gas density.

Define other limits such as penetration on a dive, duration, burn time of DPVs, lights and other support equipment used on the dive. Basically, sit down and detail all the events in the proposed dive and define the minimum and maximum risk values of each. The limits should remain within the agreed on team values, provided they are all within the personal risk acceptance of each individual.

Be careful not to challenge egos when planning complex dives. This is a time when each diver's self and team honesty is paramount to the safety of the project. Be certain the team members are compatible. On technical diving projects, one must be comfortable with the abilities of the team, have trust and respect for the members, and they should have compatible personalities. Remember that each of the members should be self-sufficient, yet aware that in unusual circumstances their lives may depend on a coordinated team effort.

Prior to entering the water, make certain that each diver is totally aware of each other's equipment configuration and its operational parameters. Each portion of the system is to be pre-dive checked and verified by a team member (buddy). When it is possible, do an in-water safety drill to ascertain that all components operate correctly and that each diver can use the buddy system. Divers must breathe from each other's second stage to be handed off and verify the functionality of equipment of the buddy diver. This act is a vital part of pre-dive checks. It should be approached in a checklist fashion.

A list of every "***What If***" that may effect team safety is to be laid out, and the corrective factors defined and rehearsed mentally and physically if possible. This list must include all safety parameters and all possible problem areas the team can identify. Be creative as you make up the list. Once the list is developed and each diver has had input on it, discuss all solutions and develop a "***What If***" plan of action for each. After this, verbally go through each item at least three times and then have the team visualize safely correcting the "***What If***" situations. Once this is accomplished, put it to bed and then visualize and enjoy a safe and productive dive.

In-Water Updates

The final aspect of dive planning is in-water updates. Mr. Murphy is always with us in all endeavors of life. Frequently, dive plans need alternation due to changes in the anticipated water conditions. Therefore, one must remain open-minded when beginning a dive and be prepared to modify the dive performance as dictated by environmental conditions.

Once the dive begins, allow for flexibility in performance. "Mother Nature" is often fickle. The dive may offer the unexpected, and you must be prepared to alter and to modify the dive plan. A degradation of visibility may provide grounds for altering the dive plan while in the water; if so, have that included as an agreed dive plan objective. Changes in the type of, the severity of, or the direction of current may be a sufficient cause for modifications in an existing dive plan. If a boat breaks anchor, or a guideline is broken, or other factors that influence either the exit or ascent of a dive, these are grounds for modification or cancellation of a dive.

You will also need to anticipate behavioral changes within the dive team. Simple things such as one diver becoming uncomfortable will modify the dive plan. Accident potential increases when you fail to modify the dive plan because of a diver's behavioral changes.

Awareness is the critical component in making a command decision to modify the plan of a dive already in progress. As you explore and discover, don't forget to periodically observe the members of your dive team. Set up a plan of intermittent contact.

Observation and communication play key roles. Observation helps you to know when a diver starts slipping. Communication overcomes the hesitancy of divers to tell you they are having a problem.

Guilt associated with failure is a key threat to dive safety. Divers will frequently feel guilty if they cause a dive to be terminated. Feelings of guilt, combined with a "***threatened ego***," produce a potentially dangerous combination if the dive is allowed to continue. When diving not every change is obvious. You must be aware of subtle changes that may occur. These would involve recognizing changes in coordination, swimming style or rhythm, and breathing patterns.

Points to Remember

In-water updates should include provisions for:

- **Changes in Currents**
- **Changes in Visibility**
- **Changes due to upline problems**
- **Changes due to team reaction**

Maturity and sound judgment play key roles in personal success and diving ability. The smart diver knows that cancellation is not the end of the world. Once they learn a dive cannot be accomplished as planned, they will terminate the present dive. They understand that a new plan must be developed to incorporate what has been learned. He or she knows that the price of continuing an unsafe dive skyrockets. It's not only foolish; it's deadly to continue diving with a marginal safety factor.

In summary, a safe dive plan requires divers to gather all information pertinent to the dive site. The entire dive team needs to discuss the dive comprehensively and establish a team plan. Each participating diver must search his or her mind and develop a personal plan of action. This personal plan should be based on self-sufficiency. It must allow for self-rescue ability and team rescue capabilities. Gas Management Rules must be carefully and comprehensively developed from actual field experience.

See Imperial & Metric Worksheets & Pre-Dive Preparation Check Sheets beginning next page...

Dive 1 Using IANTD/IAND, Inc. EAN 26 Accelerated Dive Tables – Imperial-US

FSW MSW	MIX	ATA	END	TIME	PO_2	%CNS	OTU	NEEDED
200 60		7.06						
190 57		6.76						
180 54		6.45						
170 51		6.15						
160 48		5.85						
150 45		5.55						
—	**26%**	5.24	**129**	**50**	**1.36**	**33.33**	**81.44**	**155.00** 3.1 x 50
130 39		4.94						
120 36		4.64						
110 33		4.33						
100 30		4.03						
90 27		3.73						
80 24		3.42						
70 21		3.12						
60 18		2.82						
50 15	**26%**	2.52	**45**	**2**	**.65**	**.32** .16 x 2	**.74** .37 x 2	**2.60** 1.3 x 2
40 12	**26%**	2.21	**35**	**6**	**.58**	**.83** .69 + .14	**1.57** 1.31 + .26	**6.60** 1.1 x 6
30 9	**26%**	1.91	**26**	**11**	**.50**	**0**	**0**	**11.00** 1.0 x 11
20 6	**80%**	1.61		**5**	**1.28**	**2.78**	**7.39**	**4.00** 0.8 x 5
15 4.5	**80%**	1.45		**26**	**1.16**	**12.38** 9.52 + 2.38 + .48	**34.37** 26.44 + 6.61 + 1.32	**18.2** 0.7 x 26
	26%			**3**		**2**	**2**	**9.30** 3.1 x 3

Add travel time to first deco stop into bottom time and use 2 + 2 Rule for CNS and OTU calculations.

TOTALS (include residual values): CNS%: 51.64 OTU 127.51 Run Time 103 Gas Needed: Bottom Mix (155+2.6+6.6+11+9.3) x 1.5 = 276.75 Deco Gas: (4 + 18.2) x 1.2 = 26.64

Dive 1 Using IANTD/IAND, Inc. EAN 25 Runtime Accelerated Dive Tables – Metric Version

FSW MSW	MIX	ATA	END	TIME	PO_2	%CNS	OTU	NEEDED
200 60		7.0						
190 57		6.7						
180 54		6.4						
170 51		6.1						
160 48		5.8						
150 45		5.5						
140 42	**26%**	5.2	**38.7**	**50**	**1.36**	**30.30**	**77.67**	**4400.0** 87.79 x 50
130 39		4.9						
120 36		4.6						
110 33		4.3						
100 30		4.0						
90 27		3.7						
80 24		3.4						
70 21		3.1						
60 18		2.8						
50 15	**26%**	2.5	**13.4**	**1**	**.65**	**.16**	**.37**	**35.0** 35 x 1
40 12	**26%**	2.2	**10.6**	**8**	**.57**	**1.11** .69 + (.14 x 3)	**2.09** 1.31 + (.26 x 3)	**248.0** 31 x 8
30 9	**80%**	1.9		**6**	**1.52**	**6.67** 5.56 + 1.11	**11.11** 9.26 + 1.85	**162.0** 27 x 6
20 6	**80%**	1.6		**4**	**1.28**	**2.24** .56 x 4	**5.92** 1.48 x 4	**88.0** 22 x 4
15 4.5	**80%**	1.45		**25**	**1.16**	**11.90** 9.52 + 2.38	**33.05** 26.44 + 6.61	**507.5** 20.3 x 25
	26%			**3**		**2**	**2**	**264.0** 88 x 3

Add travel time to first deco stop into bottom time and use 2 + 2 Rule for CNS and OTU calculations.

TOTALS (include residual values): CNS%: 54.38 OTU 132.21

Run Time 97 Gas Needed: Bottom Mix 4947 x 1.5 = 7420.5

Deco 757.5 x 1.2 = 909.0

Dive 1 Using IANTD/IAND, Inc. **EAN 25** Runtime Accelerated Dive Tables – Imperial -US

FSW MSW	MIX	ATA	END	TIME	PO_2	%CNS	OTU	NEEDED
200 60		7.06						
190 57		6.76						
180 54		6.45						
170 51		6.15						
160 48		5.85						
150 45		5.55						
140 42	**26%**	5.24	**129**	**50**	**1.36**	**33.33**	**81.44**	**155.00** 3.1 x 50
130 39		4.94						
120 36		4.64						
110 33		4.33						
100 30		4.03						
90 27		3.73						
80 24		3.42						
70 21		3.12						
60 18		2.82						
50 15	**26%**	2.52	**45**	**1**	**.65**	**.16**	**.37**	**1.30** 1.3 x 1
40 12	**26%**	2.21	**35**	**8**	**.58**	**1.11** .69 + (.14 x 3)	**2.09** 1.31 + (.26 x 3)	**8.80** 1.1 x 8
30 9	**80%**	1.91		**6**	**1.53**	**6.67** 5.56 + 1.11	**11.11** 9.26 + 1.85	**6.00** 1.0 x 6
20 6	**80%**	1.61		**4**	**1.28**	**2.24** .56 x 4	**5.92** 1.48 x 4	**3.20** 0.8 x 4
15 4.5	**80%**	1.45		**25**	**1.16**	**11.90** 9.52 + 2.38	**33.05** 26.44 + 6.61	**17.5** 0.7 x 25
	26%			**3**		**2**	**2**	**9.30** 3.1 x 3

Add travel time to first deco stop into bottom time and use 2 + 2 Rule for CNS and OTU calculations.

TOTALS (include residual values): CNS%: 57.41 OTU 135.98

Run Time 97 Gas Needed: Bottom Mix (155 + 1.3 + 8.8 + 9.3) x 1.5 = 261.60

Deco (6.00 + 3.20 + 17.5) x 1.2 = 32.04

Dive 1 Using IANTD/IAND, Inc. EAN 25 Runtime Accelerated Dive Tables – Metric Version

FSW MSW	MIX	ATA	END	TIME	PO_2	%CNS	OTU	NEEDED
200 60		7.0						
190 57		6.7						
180 54		6.4						
170 51		6.1						
160 48		5.8						
150 45		5.5						
140 42	**26%**	5.2	**38.7**	**50**	**1.36**	**30.30**	**77.67**	**4400.0** 87.79 x 50
130 39		4.9						
120 36		4.6						
110 33		4.3						
100 30		4.0						
90 27		3.7						
80 24		3.4						
70 21		3.1						
60 18		2.8						
50 15	**26%**	2.5	**13.4**	**1**	**.65**	**.16**	**.37**	**35.0** 35 x 1
40 12	**26%**	2.2	**10.6**	**8**	**.57**	**1.11** .69 + (.14 x 3)	**2.09** 1.31 + (.26 x 3)	**248.0** 31 x 8
30 9	**80%**	1.9		**6**	**1.52**	**6.67** 5.56 + 1.11	**11.11** 9.26 + 1.85	**162.0** 27 x 6
20 6	**80%**	1.6		**4**	**1.28**	**2.24** .56 x 4	**5.92** 1.48 x 4	**88.0** 22 x 4
15 4.5	**80%**	1.45		**25**	**1.16**	**11.90** 9.52 + 2.38	**33.05** 26.44 + 6.61	**507.5** 20.3 x 25
	26%			**3**		**2**	**2**	**264.0** 88 x 3

Add travel time to first deco stop into bottom time and use 2 + 2 Rule for CNS and OTU calculations.

TOTALS (include residual values): CNS%: 54.38 OTU 132.21

Run Time 97 Gas Needed: Bottom Mix 4947 x 1.5 = 7420.5

Deco 757.5 x 1.2 = 909.0

Dive 1 Using IANTD/IAND, Inc. **EAN 26** Accelerated Dive Tables **EAN 26** used for deco – Imperial-US Version

FSW MSW	MIX	ATA	END	TIME	PO_2	%CNS	OTU	NEEDED
200 60		7.06						
190 57		6.76						
180 54		6.45						
170 51		6.15						
160 48		5.85						
150 45		5.55						
140 42	**26%**	5.24	**129**	**50**	**1.36**	**33.33**	**81.44**	**155.00** 3.1 x 50
130 39		4.94						
120 36		4.64						
110 33		4.33						
100 30		4.03						
90 27		3.73						
80 24		3.42						
70 21		3.12						
60 18		2.82						
50 15	**26%**	2.52		**2**	**.65**	**.32** .16 x 2	**.74** .37 x 2	**2.60** 1.3 x 2
40 12	**26%**	2.21		**6**	**.58**	**.83** .69 + .14	**1.57** 1.31 + .26	**6.60** 1.1 x 6
30 9	**26%**	1.91		**11**	**.50**	**0**	**0**	**11.00** 1.0 x 11
20 6	**26%**	1.61		**7**	**.42**	**0**	**0**	**5.60** 0.8 x 7
15 4.5	**26%**	1.45		**57**	**.34**	**0**	**0**	**39.9** 0.7 x 57
	26%			**3**		**2**	**2**	**9.30** 3.1 x 3

Add travel time to first deco stop into bottom time and use 2 + 2 Rule for CNS and OTU calculations.

TOTALS (include residual values): CNS% 36.48 OTU 85.75 Run Time 136

Gas Needed: Bottom Mix (155+2.6+6.6+11+5.6 + 39.9 + 9.3) x 1.5 = 345.0 Deco gas needed ________

Dive 1 Using IANTD/IAND, Inc. **EAN 26** Accelerated Dive Tables **EAN 26** used for deco - Metric Version

FSW MSW	MIX	ATA	END	TIME	PO_2	%CNS	OTU	NEEDED
200 60		7.0						
190 57		6.7						
180 54		6.4						
170 51		6.1						
160 48		5.8						
150 45		5.5						
140 42	**26%**	5.2	**38.7**	**50**	**1.35**	**30.30**	**77.67**	**4400.0** 88 x 50
130 39		4.9						
120 36		4.6						
110 33		4.3						
100 30		4.0						
90 27		3.7						
80 24		3.4						
70 21		3.1						
60 18		2.8						
50 15	**26%**	2.5		**2**	**.65**	**.32** .16 x 2	**.74** .37 x 2	**70.0** 35 x 2
40 12	**26%**	2.2		**6**	**.58**	**.83** .69 + .14	**1.57** 1.31 + .26	**186.0** 31 x 6
30 9	**26%**	1.9		**11**	**.50**	**0**	**0**	**297.0** 27 x 11
20 6	**26%**	1.6		**7**	**.42**	**0**	**0**	**154.0** 22 x 7
15 4.5	**26%**	1.45		**57**	**.34**	**0**	**0**	**1157.1** 20.3 x 57
	26%			**3**		**2**	**2**	**264.0** 88 x 3

Add travel time to first deco stop into bottom time and use 2 + 2 Rule for CNS and OTU calculations.

TOTALS (include residual values): CNS% 33.45 OTU 81.98 Run Time 136

Gas Needed: Bottom Mix 6528.1 x 1.5 = 9792.15 Deco gas needed ________

Dive 2 (repetitive dive) Using IANTD/IAND, Inc. **EAN 29** Runtime Accelerated Dive Tables Imperial-US Version

FSW MSW	MIX	ATA	END	TIME	PO_2	%CNS	OTU	NEEDED
200 60		7.06						
190 57		6.76						
180 54		6.45						
170 51		6.15						
160 48		5.85						
150 45		5.55						
140 42		5.24						
130 39		4.94						
120 36		4.64						
110 33	**29%**	4.33	**96**	**40** **actual**	**1.26**	**22.22**	**59.09**	**104** 2.6 x 40
100 30		4.03						
90 27		3.73						
80 24		3.42						
70 21		3.12						
60 18		2.82						
50 15		2.52						
40 12		2.21						
30 9	**80%**	1.91		**7 (50)**	**1.53**	**7.78** 5.56 + (1.11 x 2)	**12.96** 9.26 + (2 x 1.85)	**7.00** 1.0 x 7
20 6	**80%**	1.61		**5 (55)**	**1.28**	**2.78**	**7.39**	**4.00** 0.8 x 5
15 4.5	**80%**	1.45		**27** **(82)**	**1.16**	**12.86** 9.52 + 2.38 + (.48 x 2)	**35.69** 26.44 +6.61+(1.32x2)	**18.9** 0.7 x 27
	29%			**3**		**2**	**2**	**7.8** 2.6 x 3

Add travel time to first deco stop into bottom time and use 2 + 2 Rule for CNS and OTU calculations.

TOTALS (include residual values): CNS%: 47.64 + 12 residual = 59.64 OTU 117.13 + 85.75 = 202.88

Run Time 82 RNT 40 (80 minute schedule)

Gas Needed: Bottom Mix 111.8 x 1.5 = 167.7 Deco 29.9 x 1.2 = 35.88

Dive 2 (repetitive dive) Using IANTD/IAND, Inc. **EAN 29** Runtime Accelerated Dive Tables - Metric Version

FSW MSW	MIX	ATA	END	TIME	PO_2	%CNS	OTU	NEEDED
200 60		7.0						
190 57		6.7						
180 54		6.4						
170 51		6.1						
160 48		5.8						
150 45		5.5						
140 42		5.2						
130 39		4.9						
120 36		4.6						
110 33	**29%**	4.3	**28.7**	**40 actual**	**1.25**	**20.51**	**56.00**	**2920.0** 73 x 40
100 30		4.0						
90 27		3.7						
80 24		3.4						
70 21		3.1						
60 18		2.8						
50 15		2.5						
40 12		2.2						
30 9	**80%**	1.9		**7 (50)**	**1.52**	**7.78** 5.56 + (1.11 x 2)	**12.96** 9.26 + (2 x 1.85)	**189.0** 27 x 7
20 6	**80%**	1.6		**5 (55)**	**1.28**	**2.78**	**7.39**	**110.0** 22 x 5
15 4.5	**80%**	1.45		**27 (82)**	**1.16**	**12.86** 9.52 + 2.38 + (.48 x 2)	**35.69** 26.44 +6.61+(1.32x2)	**548.1** 20.3 x 27
	29%			**3**		**2**	**2**	**219.0** 73 x 3

Add travel time to first deco stop into bottom time and use 2 + 2 Rule for CNS and OTU calculations.

TOTALS (include residual values): CNS%: 45.93 + 12 residual = 57.93 OTU 114.04 + 81.98 = 196.02

Run Time 82 RNT 40 (80 minute schedule)

Gas Needed: Bottom Mix 3139.0 x 1.5 = 4708.5 Deco 847.1 x 1.2 = 1016.5

Dive 1 Using IANTD/IAND, Inc. VPM B Constant partial pressure Dive Tables – This example is for CCR using the CCR tables also includes bailout.

FSW MSW	MIX	ATA	END	TIME	Set point	%CNS	OTU	18 / 38 Team deep bailout 100 cubic feet (33 each) 3538.5 L (1,1795 L each)
200 60	**14** **44**	7.06	85 26	30 CCR BO	1.3			
190 57		6.76						
180 54		6.45						
170 51		6.15						
160 48		5.85						
150 45		5.55						
140 42		5.24						
130 39		4.94		33 (1)				
120 36		4.64		34 34 (1.) (2)				
110 33		4.33		35 (1)				
100 30		4.03		36 36 (1) (2)				
90 27		3.73		37 38 (1) (2)				
80 24		3.42		39 41 (2) (3)				
70 21		3.12		42 44 (3) (3)				
60 18		2.82		45 49 (3) (5)				
50 15		2.52		49 56 (4) (7)		**CNS** **1.3.** **26.88**	OTU 1.3 71.04	
40 12		2.21		54 60 (5) (4)	**1.4** **E 70**			EAN 70 bailout 171.16
30 9		1.91		60 66 (6) (6)				
20 6		1.61		64 71 (4) (5)		**CNS** **1.4** **16.25**	**OTU 1.4** **40.75**	
15 4.5		1.45		84 93 (20) (22)				
Total				84 93		43.13	111.79	

This example is worked in the classroom with your IANTD Instructor and uses IANTD Waterproof Table C-3104. The IANTD Waterproof Bail-out Table is C-3717.

A repetitive dive is planned for two hours later to the same depth again for a 30-minute bottom time

Dive 1 Using IANTD/IAND, Inc. VPM B constant po2 table repetitive dive. Use the CCR tables 14/ 44 dil for repetitive dives.

FSW MSW	MIX	ATA	END	TIME	PO_2	%CNS	OTU	NEEDED
200 60	**14** **44**	7.0	85 26	30	1.3			18 / 38 Team deep bailout 100 cubic feet (33 each) 3538.5 L (1,1795 L each)
190 57		6.7						
180 54		6.4						
170 51		6.1						
160 48		5.8						
150 45		5.5						
140 42		5.2						
130 39		4.9		33 (1)				
120 36		4.6		34 (1)				
110 33		4.3		**35** **(1)**				
100 30		4.0		**36** **(1)**				
90 27		3.7		**37** **(1)**				
80 24		3.4		**39** **(2)**				
70 21		3.1		**42** **(3)**				
60 18		2.8		**45** **(3)**				
50 15		2.5		**49** **(5)**				
40 12		2.2		**54** **(5)**	**1.4** **E 70**			
30 9		1.9		**61** **(7)**				
20 6		1.6		**66** **(5)**				
15 4.5		1.45		**97** **(31)**				
				97				

**Add travel time to first deco stop into bottom time and use 2 + 2 Rule for CNS and OTU calcul

TOTALS (include residual values): CNS%: 48.61 OTU 117.13 Run Time 103

Gas Needed: Bottom Mix 5217.93 *x* 1.5 = 7825.5 Deco 637.8 *x* 1.2 = 765.36

Trimix Dive Using IANTD/IAND, Inc. Runtime Trimix Dive Tables – Imperial-US

FSW MSW	MIX	ATA	END	TIME	PO_2	%CNS	OTU	NEEDED
280 84	**14% 48%**	**9.48**	**118**	**20**	**1.33**	**12.12**	**31.07**	**114.00** 5.7 x 20
200 60		7.06						
190 57		6.76						
180 54		6.45						
170 51		6.15						
160 48		5.85						
150 45		5.55						
140 42		5.24						
130 39	**14% 48%**	4.94	**46**	**1 (24)**	**.69**	**.18** .18 x 1	**.47** .47 x 1	**2.50** 2.5 x 1
120 36	**14% 48%**	4.64	**41**	**1 (25)**	**.65**	**.16** .16 x 1	**.37** .37 x 1	**2.30** 2.3 x 1
110 33	**14% 48%**	4.33	**36**	**2 (27)**	**.61**	**.32** .16 x 2	**.74** .37 x 2	**4.40** 2.2 x 2
100 30	**36%**	4.03	**75**	**1 (28)**	**1.45**	**.72** .72 x 1	**1.70** 1.70 x 1	**2.00** 2.0 x 1
90 27	**36%**	3.73	**67**	**2 (30)**	**1.34**	**1.22** .61 x 2	**3.10** 1.55 x 2	**3.80** 1.9 x 2
80 24	**36%**	3.42	**59**	**2 (32)**	**1.23**	**1.02** .51 x 2	**2.8** 1.4 x 2	**3.40** 1.7 x 2
70 21	**36%**	3.12	**51**	**4 (36)**	**1.12**	**1.76** .44 x 4	**4.96** 1.24 x 4	**6.40** 1.6 x 4
60 18	**36%**	2.82	**43**	**4 (40)**	**1.01**	**1.48** .37 x 4	**4.32** 1.08 x 4	**5.60** 1.4 x 4
50 15	**36%**	2.52	**35**	**6 (46)**	**.91**	**1.88** 1.57 + .31	**5.50** 4.58 + .92	**7.80** 1.3 x 6
40 12	**36%**	2.21	**27**	**8 (54)**	**.80**	**1.77** 1.11 + (.22 x 3)	**5.22** 3.27 + (.65 x 3)	**8.80** 1.1 x 8
30 9	**80%**	1.91		**11 (65)**	**1.53**	**12.22** 11.11 + 1.11	**20.36** 18.51 + 1.85	**11.00** 1.0 x 11
20 6	**80%**	1.61		**6 (71)**	**1.28**	**3.34** 2.78 + .56	**8.87** 7.39 + 1.48	**4.80** 0.8 x 6
15 4.5	**80%**	1.45		**45 (116)**	**1.16**	**21.43** 19.05 + 2.38	**59.50** 52.89 + 6.61	**31.50** .7 x 45
	14% 48%			**3**		**2**	**2**	**17.18** 5.7 x 3

**Add travel time to first deco stop into bottom time and use 2 + 2 Rule for CNS and OTU calcula

TOTALS (include residual values): CNS%: 61.62 OTU 150.98
Run Time 116 Gas Needed: Bottom Mix (114 + 2.5 + 2.3 + 4.4 + 17.18) x 1.5 = 210.57
Travel gas (2 + 3.8 + 3.4 + 6.4 + 5.6 + 7.8 + 8.8) x 1.2 = 45.36 Deco (11 + 4.8 + 31.50) x 1.2 = 56.76

Trimix Dive Using IANTD/IAND, Inc. Runtime Trimix Dive Tables – Metric Version

FSW MSW	MIX	ATA	END	TIME	PO_2	%CNS	OTU	NEEDED
280 84	**14% 48%**	**9.5**	**35.7**	**20**	**1.32**	**12.12**	**31.07**	**3200.0** 160 x 20
200 60		7.0						
190 57		6.7						
180 54		6.4						
170 51		6.1						
160 48		5.8						
150 45		5.5						
140 42		5.2						
130 39	**14% 48%**	4.9	**13.6**	**1 (24)**	**.69**	**.18** .18 x 1	**.47** .47 x 1	**69.0** 69 x 1
120 36	**14% 48%**	4.6	**12.1**	**1 (25)**	**.64**	**.16** .16 x 1	**.37** .37 x 1	**64.0** 64 x 1
110 33	**14% 48%**	4.3	**10.7**	**2 (27)**	**.60**	**.28** .14 x 2	**.52** .26 x 2	**120.0** 60 x 2
100 30	**36%**	4.0	**22.4**	**1 (28)**	**1.45**	**.72** .72 x 1	**1.70** 1.70 x 1	**56.0** 56 x 1
90 27	**36%**	3.7	**20.0**	**2 (30)**	**1.34**	**1.22** .61 x 2	**3.10** 1.55 x 2	**104.0** 52x 2
80 24	**36%**	3.4	**17.5**	**2 (32)**	**1.23**	**1.02** .51 x 2	**2.8** 1.4 x 2	**96.0** 48 x 2
70 21	**36%**	3.1	**15.1**	**4 (36)**	**1.12**	**1.76** .44 x 4	**4.96** 1.24 x 4	**172.0** 43 x 4
60 18	**36%**	2.8	**12.7**	**4 (40)**	**1.04**	**1.48** .37 x 4	**4.32** 1.08 x 4	**15**200 60
50 15	**36%**	2.5	**10.3**	**6 (46)**	**.91**	**1.67** 1.39 + .28	**4.98** 4.15 + .83	**210.0** 35 x 6
40 12	**36%**	2.2	**7.8**	**8 (54)**	**.80**	**1.77** 1.11 + (.22 x 3)	**5.22** 3.27 + (.65 x 3)	**248.0** 31 x 8
30 9	**80%**	1.9		**11 (65)**	**1.53**	**12.22** 11.11 + 1.11	**20.36** 18.51 + 1.85	**297.0** 27 x 11
20 6	**80%**	1.6		**6 (71)**	**1.29**	**3.34** 2.78 + .56	**8.87** 7.39 + 1.48	**132.0** 22 x 6
15 4.5	**80%**	1.45		**45 (116)**	**1.16**	**21.43** 19.05 + 2.38	**59.50** 52.89 + 6.61	**913.5** 20.3 x 45
	14% 48%			**3**		**2**	**2**	**480.0** 160 x 3

**Add travel time to first deco stop into bottom time and use 2 + 2 Rule for CNS and OTU calculation

TOTALS (include residual values): CNS%: 61.37 OTU 150.24

Run Time 116 Gas Needed: Bottom Mix 3933.0 x 1.5 = 5899.5

Travel gas 1042.0 x 1.2 = 1250.4 Deco 1342.5 x 1.2 = 1611.0

IANTD®

PRE-DIVE ESSENTIAL DIVE PREPARATION VERIFICATION

Complete prior to boarding vessel or preparing to don equipment. Checks to be completed early enough to be able to fix problems if any exist without becoming stressed or rushed. All checks on this sheet to be completed by each diver and cross referenced between dive team members.

- ☐ **Verify self & buddy completed mfg. equipment set-up and mfg. Check Sheets.**
- ☐ **Verify gas delivery system CCR & Bailout operational.**
- ☐ **Verify system continues to hold during both positive & negative pressure checks.**
- ☐ **Verify analysis of all gases to be used on dive.**
- ☐ **Verify calibration.**
- ☐ **Verify cylinders are labeled for use.**

CCR "S" Self & Buddy Check (S = Safety = Survival)

Team safety depends on teamwork; safety and survival are enhanced by S drills completed for each dive. It is the team's responsibility to KNOW all systems are functional for everyone.

Note! Always do "S" Drill on surface. Environment dependent if possible repeat applicable steps in-water!

Within 15 minutes of starting ANY dive:

- ☐ **Reaffirm adequate bailout gas available. Self & Buddies**
- ☐ **Reaffirm gas pressure of all cylinders to be used on dive. Self & Buddies**
- ☐ **Confirm ALL gases are turned on. Self & Buddies**
- ☐ **Confirm no detectable leakages of gases or loop integrity. Self & Buddies**
- ☐ **Confirm gas addition oxygen (solenoid ECCR or orifice MCCR). Self & Buddies**
- ☐ **Confirm manual oxygen addition. Self & Buddies**
- ☐ **Confirm A.D.V. activates and manual operation. Self & Buddies**
- ☐ **Confirm bailout gas delivery system functional. Self & Buddies**
- ☐ **Confirm breathing loop delivery. Self & Buddies**
- ☐ **Confirm pre-breathe/PO_2 held & scrubber canister functionality on surface. Self & Buddies**
- ☐ **Confirm all electronic systems agree - primary, secondary, etc. Self & Buddies**
- ☐ **Confirm D.S.V. or B.O.V. functional -> Self & Buddies**
- ☐ **Confirm ability to switch to a bailout -> Self & Buddies**
- ☐ **Confirm compatibility of "pluggable" off-board gases in the dive team. Self & Buddies**
- ☐ **Confirm on completion CCR is functional (Gases on – Safe PO_2 in loop) – do not turn electronics or gases off until post dive. Self & Buddies**
- ☐ **Confirm support equipment (lights, reels, etc.) functional. Self & Buddies**
- ☐ **Confirm divers are familiar with each others systems & configuration. Self & Buddies**

Always Know Your PO_2 - Verify Buddy's PO_2 Frequently

Always Know Your Scrubber Canister Contents Is Within Safe Usage Limit

IANTD® THE LEADERS IN DIVER EDUCATION

Immediately prior to every submergence or water entry

Quick Individual Safety Check

- ☐ Reaffirm all gas delivery systems on and functional.
- ☐ Reaffirm safe PO_2 self & buddy - O_2 delivery working.
- ☐ Reaffirm A.D.V. is on if applicable.
- ☐ Reaffirm manual addition working.

In-water "S" Check

- ☐ Upon entry in water, if possible, leak check buddy if environment does not allow a surface check - leak check on descent or immediately upon completion of descent.
- ☐ Confirm self & buddy switch to desired PO_2 and maintain it.
- ☐ If practical, check bailout to ensure that it is completely functional.
- ☐ Be observant for any abnormal behavior in dive performance.
- ☐ Know and avoid the causes of accidents.
- ☐ *Enjoy the dive!*

Accidents don't happen by themselves

Be prudent and study common causes

Be responsible and choose not to create them

Practice survival skills and survival habits, ideally with dive partners

Go beyond drills, complete the intent of training; turn it into learning = knowing

Always Know Your PO_2 - Verify Buddy's PO_2 Frequently

Always Know Your Scrubber Canister Contents Is Within Safe Usage Limit

IANTD Isobaric Counter Diffusion Chart ~ Side 1

5:1 Ratio permits 1% increase in N2 for each 5% decrease in He

	% He																			
FO2	90	85	80	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5	0	FO2
.7	3	8	13	18	23	28	33	38	43	48	53	58	63	68	73	78				.7
.8	2	7	12	17	22	27	32	37	42	47	52	57	62	67	72	77				.8
.9	1	6	11	16	21	26	31	36	41	46	51	56	61	66	71	76				.9
.10	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75				.10
.11	0	4	9	14	19	24	29	34	39	44	49	54	59	64	69	74	79			.11
.12	0	3	8	13	18	23	28	33	38	43	48	53	58	63	68	73	78			.12
.13		2	7	12	17	22	27	32	37	42	47	52	57	62	67	72	77			.13
.14		1	6	11	16	21	26	31	36	41	46	51	56	61	66	71	76			.14
.15		0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75			.15
.16			4	9	14	19	24	29	34	39	44	49	54	59	64	69	74	79		.16
.17			3	8	13	18	23	28	33	38	43	48	53	58	63	68	73	78		.17
.18			2	7	12	17	22	27	32	37	42	47	52	57	62	67	72	77		.18
.19			1	6	11	16	21	26	31	36	41	46	51	56	61	66	71	76		.19
.20				5	10	14	20	25	30	35	40	45	50	55	60	65	70	75		.20
.21			%		9	13	19	24	29	34	39	44	49	54	59	64	69	74	79	.21
.22			N			12	18	23	28	33	38	43	48	53	58	63	68	73	78	.22
.23			I			11	17	22	27	32	37	42	47	52	57	62	67	72	77	.23
.24			T			10	16	21	26	31	36	41	46	51	56	61	66	71	76	.24
.25			R	→			15	20	25	30	35	40	45	50	55	60	65	70	75	.25
.26			O					19	24	29	34	39	43	49	54	59	64	69	74	.26
.27			G					18	23	28	33	38	42	48	53	58	63	68	73	.27
.28			E						22	27	32	37	41	47	52	57	62	67	72	.28
.29			N						21	26	31	36	40	46	51	56	61	66	71	.29
.30			(FN2)						20	25	30	35	39	45	50	55	60	65	70	.30
.31										24	29	34	38	44	49	54	59	64	69	.31
.32										23	28	33	37	43	48	53	58	63	68	.32
.33								%		22	27	32	36	42	47	52	57	62	67	.33
.34								N			26	31	35	41	46	51	56	61	66	.34
.35								I			25	30	34	40	45	50	55	60	65	.35
.36								T			24	29	33	39	44	49	54	59	64	.36
.37								R	→		23	28	32	38	43	48	53	58	63	.37
.38								O			22	27	31	37	42	47	52	57	62	.38
.39								G			21	26	30	36	41	46	51	56	61	.39
.40								E			20	25	29	35	40	45	50	55	60	.40
.41								N				24	28	34	39	44	49	54	59	.41
.42								(FN2)				23	27	33	38	43	48	53	58	.42
.43												22	26	32	37	42	47	52	57	.43
.44													25	31	36	41	46	51	56	.44
.45													24	30	35	40	45	50	55	.45
.46													23	29	34	39	44	49	54	.46
.47													22	28	33	38	43	48	53	.47
.48													21	27	32	37	42	47	52	.48
.49													20	26	31	36	41	46	51	.49
.50													19	25	30	35	40	45	50	.50
.55													18	20	25	30	35	40	45	.55
.60													17	15	20	25	30	35	40	.60
.65													16	10	15	20	25	30	35	.65
.70													15	5	10	15	20	25	30	.70
.80													14	0	0	5	10	15	20	.80
.99																0	0	0	1	.99

NOTE: increments of 5 ↓

Designed by Jeff Johnson IANTD Instructor/IT

1) Start on Chart Side 2 determine Max PO_2 1.6 for depth **2)** Go to Side 1 & locate the corresponding FO_2 line **3)** Slide across line to N_2 < or = N_2 of previous gas **4)** Look at top of column for appropriate % He -> N_2 may be increased by 1% for each 5% reduction of He **5)** Subtract N_2 increase from He to yield 100%

Example: 200 fsw / 60 msw make another gas switch from 12/60/28 (O_2/He/N_2) **1)** Go to Chart Side 2 to determine Max FO_2 in PO_2 section **2)** At 200 fsw /60 msw line cross to Max Safe PO_2 of 1.6 to find 22% O_2 **3)** Side 1 in O_2 column find 22% and slide right **4)** Our last N_2 was 28, if we slid right on the 22% O_2 we find 28 which is < or = our last gas N_2 **5)** 28 N_2 is in the 50% He column **6)** He has been reduced by 10% so N_2 can be increased 2% **7)** 28 + 2 = 30% N_2 **8)** Remove the 2 extra % from the He for a **22/48/30** (O_2/He/N_2) mix = 100%

END For use with IANTD Isobaric Chart END

Depth fsw / msw	140 / 42	130 / 39	120 / 36	110 / 33	100 / 30	90 / 27	80 / 24	70 / 21	60 / 18	50 / 15	40 / 12	30 / 9	20 / 6	10 / 3
400 / 120	31	29	27	26	24	22	20	18	17	15	13	11	9	7
390 / 117	32	30	28	26	24	22	21	19	17	15	13	11	9	8
380 / 114	33	31	29	27	25	23	21	19	17	15	13	12	10	8
370 / 111	33	31	29	28	26	24	22	20	18	16	14	12	10	8
360 / 108	34	32	30	28	26	24	22	20	18	16	14	12	10	8
350 / 105	35	33	31	29	27	25	23	21	19	17	15	12	10	8
340 / 102	36	34	32	30	28	26	23	21	19	17	15	13	11	9
330 / 99	37	35	33	31	28	26	24	22	20	18	15	13	11	9
320 / 96	38	36	34	32	29	27	25	23	20	18	16	14	11	9
310 / 93	39	37	35	32	30	28	26	23	21	19	16	14	12	9
300 / 90	41	38	36	33	31	29	26	24	22	19	17	14	12	10
290 / 87	42	39	37	34	32	30	27	25	22	20	17	15	12	10
280 / 84	43	41	38	36	33	31	28	25	23	20	18	15	13	10
270 / 81	45	42	39	37	34	32	29	26	24	21	19	16	13	11
260 / 78	46	43	41	38	35	33	30	27	25	22	19	16	14	11
250 / 75	48	45	42	39	37	34	31	28	25	23	20	17	14	12
240 / 72	50	47	44	41	38	35	32	29	26	24	21	18	15	12
230 / 69	51	48	45	42	39	36	33	30	27	24	21	18	15	12
220 / 66	54	50	47	44	41	38	35	32	29	25	22	19	16	13
210 / 63	56	52	49	46	43	39	36	33	30	26	23	20	17	13
200 / 60	58	55	51	48	45	41	38	34	31	28	24	21	17	14
190 / 57	61	57	54	50	47	43	40	36	32	29	25	22	18	15
180 / 54	64	60	56	53	49	45	41	38	34	30	27	23	19	15
170 / 51	67	63	59	55	51	47	43	40	36	32	28	24	20	16
160 / 48	70	66	62	58	54	50	46	42	38	33	29	25	21	17
150 / 45	74	70	66	61	57	53	48	44	40	35	31	27	22	18
140 / 42		74	69	65	60	56	51	47	42	37	33	28	24	19
130 / 39			74	69	64	59	54	49	45	40	35	30	25	20
120 / 36				73	68	63	58	53	48	42	37	32	27	22
110 / 33		FN2 →			73	67	62	56	51	45	40	34	29	23
100 / 30						73	67	61	55	49	43	37	31	25
90 / 27							72	66	59	53	46	40	34	27
80 / 24								72	65	58	51	44	37	30
70 / 21									71	63	55	48	40	32
60 / 18							FN2 →			70	62	53	45	36
50 / 15											69	59	50	40
40 / 12												68	57	46
30 / 9													66	53

PO2 (FO2)

Depth fsw / msw	1.6	1.5	1.4	1.3	1.2	1.1	1.0
400 / 120	12	11	10	9	9	8	7
390 / 117	12	11	10	10	9	8	7
380 / 114	12	11	11	10	9	8	7
370 / 111	13	12	11	10	9	9	8
360 / 108	13	12	11	10	10	9	8
350 / 105	13	12	12	11	10	9	8
340 / 102	14	13	12	11	10	9	8
330 / 99	14	13	12	11	10	10	9
320 / 96	14	14	13	12	11	10	9
310 / 93	15	14	13	12	11	10	9
300 / 90	15	14	13	12	11	10	9
290 / 87	16	15	14	13	12	11	10
280 / 84	16	15	14	13	12	11	10
270 / 81	17	16	15	14	13	11	10
260 / 78	18	16	15	14	13	12	11
250 / 75	18	17	16	15	13	12	11
240 / 72	19	18	16	15	14	13	12
230 / 69	20	18	17	16	15	13	12
220 / 66	20	19	18	16	15	14	13
210 / 63	21	20	19	17	16	14	13
200 / 60	22	21	19	18	16	15	14
190 / 57	23	22	20	19	17	16	14
180 / 54	24	23	21	20	18	17	15
170 / 51	26	24	22	21	19	17	16
160 / 48	27	25	23	22	20	18	17
150 / 45	28	27	25	23	21	19	18
140 / 42	30	28	26	24	22	20	19
130 / 39	32	30	28	26	24	22	20
120 / 36	34	32	30	28	25	23	21
110 / 33	36	34	32	30	27	25	23
100 / 30	39	37	34	32	29	27	24
90 / 27	42	40	37	34	32	29	26
80 / 24	46	43	40	37	35	32	29
70 / 21	51	48	44	41	38	35	32
60 / 18	56	53	49	46	42	39	35
50 / 15	63	59	55	51	47	43	39
40 / 12	72	67	63	58	54	49	45
30 / 9	83	78	73	68	62	57	52

Designed by Jeff Johnson IANTD Instructor/IT

Side 2

Helium REQUIRED for any mix with FO2 less than 21 percent

1. On Side 2 enter line at proposed gas switch depth: example: 200 fsw / 60 msw
2. Find FN_2 of proposed gas switch from Side 1 example of 28 + 2 = 30% N_2
3. Now go back to Side 2 & look up column to check END: in this example END is less than 60 fsw / 18 msw
FN_2 and FO_2 listed should not be used for mixing. They are rounded down to remain within safe parameters of field e.g., FO_2 is inside the safe PO_2 as listed and FN_2 is within limits of END

Gas 1

We are planning a dive to 400 fsw / 120 msw utilizing 8/60/32 (O_2/He/N_2)
Determine isobaric shift that is within 5:1 Rule
We'll calculate a bailout from CCR to OC which will, after initial bailout, be applicable to either OC or CCR

For every 5% Helium dropped, the N_2 can be raised 1%

1. Leaving 8/60/32 look at Isobaric Chart Side 2; PO_2 of 1.6 @ 400 fsw / 120 msw permits FO_2 of 12%
2. Chart Side 2 determines that Max PO_2 1.6 is 12% FO_2
3. Go to Chart Side 1 for isobaric determination
4. In O_2 column at 12% line slide right to 60% He column
5. Intersecting lines of O_2 and He fractions yields N_2 less than that in the previous mix for a safe isobaric switch from 8/60/32 (O_2/He/N_2) to **12/60/28** (O_2/He/N_2) at 400 fsw / 120 msw

At 200 fsw / 60 msw make another gas switch

Go to Chart Side 2 to determine Max FO_2 in PO_2 section

1. At 200 fsw / 60 msw line slide right to max safe PO_2 of 1.6 to find 22% O_2
2. Return to Chart Side 1
3. In O_2 column find 22% and slide right
4. Our last N_2 was 28; if we slide right on the 22% O_2 we find 28 which is equal to or less than our last gas N_2
5. 28 N_2 is located in the 50% He column
6. He has been reduced by 10% so N_2 can be increased by 2% --> 28 + 2 = 30% Nitrogen
7. Remove the 2 extra % from the He for a **22/48/30** mix (O_2/He/N_2) at 200 fsw / 60 msw

Next, we would like to perform another gas switch at 100 fsw / 30 msw

1. Check Chart Side 2 for Max PO_2 of 1.6 yielding an FO_2 of 39%
2. Go to Chart Side 1 and O_2 column, FO_2 line of 39%
3. Our last N_2 was 30; if we slide right on the 39% O_2 we find 30 which is equal to or less than our last gas N_2
4. Look up to the top of Column to find the He content of 30% which is a reduction of 18% He permitting an increase of 3% N_2 (per 5:1 Rule). This would yield **39/28/33** (O_2/He/N_2) at 100 fsw / 30 msw
5. Reduce the He % content by the amount that we increased the N_2 % content
6. In this case due to rounding on the chart we only need to decrease He by 2% (39 + 28 + 33 = 100%)
7. Note, the slower tissues control the shallower depth deco stops and are less susceptible to isobaric counter diffusion issues. The 5:1 Rule is also a guideline to limit the possibility however it is ***not*** an absolute

Gas switch desired to 50% FO_2?

1. Check Side 2 for Max PO_2 of 1.6 depth
2. We see that the switch can be made at 70 fsw / 21 msw
3. Go back to Chart Side 1 & slide right across 50% FO_2 line to find last gas N_2 or less (33%)
4. 30% N_2 is found in the 20% He column for a reduction of 8% He
5. We can increase the N_2 by 1% to 34%
6. Because we added 4% to the Chart N_2 of 30%, we will now subtract 4% from the He %
7. This yields a 50/16/34 (O_2/He/N_2) mix. Perhaps this is not the best mix so let's look for a better mix

Let's look at EAN 80

1. Chart Side 2 demonstrates that at a PO_2 of 1.6 a 30 fsw / 9 msw switch is possible
2. Chart Side 2 in the FO_2 column line of 80% shows that we have 20% N_2, which is less than the N_2 in our last mix thus permitting a safe 5:1 Rule switch with **EAN 80** at 30 fsw / 9 msw

The above example illustrates a CCR dive implementing 4 OC bailout gas switches beginning at 400 fsw / 120 msw all the way to the surface effectively managing PO_2 levels and isobaric counter diffusion issues.

Chapter Thirteen
Operational Safety

Kevin Gurr

Safety, while it should be of primary concern to all divers, becomes increasingly important as one venture into technical or extended range diving. In these more advanced forms of diving, the increased duration and scope of the dive plan will cause a corresponding increase in risk exposure. A simple analogy might be; ***If I stand in the street long enough I am more likely to get run over.***

The longer a diver remains underwater the more the effects of equipment reliability; diver error and environmental changes become an issue. Complex dives often involve extended decompressions, depth outside of the accepted sport limits, large amounts of gas and support equipment as well as sophisticated dive platforms such as boats and underwater habitats. The following is offered as a general guide of questions to be addressed when planning such dives.

Safety Divers

Historically ***safety*** or ***stand-by*** divers, as they are known in commercial diving, have been in the front line of diving safety. In the commercial diving world the stand-by diver often remains fully kitted for hours on deck waiting for an incident to occur, only being ***launched*** when required.

With the advent of technical diving, especially with deeper and deeper wrecks and caves being explored using Trimix, the safety diver has crept into the recreational diving world. So who is this group of divers, trapped between the surface and the draw of exploration being undertaken by those they protect? What does it take to be a safety diver and why would you ever want to be one?

As many Trimix dives are undertaken without safety divers why do we need safety divers?

Probability is the answer. The longer you stay submerged the more risk of incident. It's like if you walk in the middle of the street for long enough. You ***will*** get run over. Decompression dives can be long and complicated. More time spent submerged means nature has more time to ruin your day. Short projects or weekend Trimix dives often "get away" without using additional dive support such as ***Safety Divers***, ***Dive Supervisors*** or ***Medical Technicians*** simply because they're not "out there" long enough. That doesn't mean to say they will always remain safe. History tells us differently. Safety divers can at the very least improve your day and at best save lives. I have witnessed it on several occasions.

To be a safety diver takes as much skill and knowledge as it does to go to the bottom. Very often on extended projects, the most experienced members of the team elect to be the safety divers on the high-risk dives.

The skills list of a safety diver will include:

- IANTD Service Technician (for that exploding kit above and below the water)
- IANTD Diver First Aid and Oxygen Provider qualifications
- An in-depth knowledge of the dive profile and what to do if it changes
- Equipment capability (you will often carry as much or more cylinders and gear that any team member)

Mirja Denlay, Safety Diver, *HMHS Britannic* 1997

- The mental ability to work alone underwater
- A sixth sense of what will happen next
- Boat skills necessary to understand how the changing environment can affect boat/sea conditions and overall team safety
- Cook/tea person
- Insomniac

So safety divers need to be a bit more than 'one of your mates' who doesn't fancy going to the bottom.

What Does a Safety Diver Do?

Depending on the depth of dive (and team size) anything up to four safety divers can be easily used. I'll give a practical example of the work we did on the *HMHS Britannic* in 1997. Due to the high current and shipping lane we had one safety diver who stayed on the boat. His job was to launch if any of the divers became separated from the decompression system or if someone needed to be recovered close to the surface. They would be equipped with a twin set of air with a 6 ft (2 m) sharing hose and an emergency decompression line.

The second safety diver was to meet the divers at their deepest decompression stop. They would take any heavy equipment, such as scooters and cameras and clip them to a recovery line. They would also carry a twin set of the appropriate bottom mix (air if the stops were above 170 ft (50 m)) and decompression gases the same as the dive team. They would stay with the dive team during the deep-water decompression and handover at the next gas switch depth, usually 100 ft (30 m) to the next safety diver. The ***deep safety*** was the only safety diver allowed to get into decompression. After ***handing over*** they would complete their decompression and return to the surface ready to take over a shallow safety diver role later in the six hour decompression.

Wings Stocks being a caring Dive Supervisor

The safety diver at 100 ft (30 m) would stay out of deco and be in the water with the deep safety diver ready to take an injured diver directly to the surface (the deep safety diver only being able to ascend to 100 ft [30 m]). They would carry a twin set of nitrox and the bottom diver's mid range deco gas and oxygen. This mid-range safety diver would hand over to another safety diver at the next gas switch 30 or 20 ft (9 or 6 m). This safety diver (and the shallow one) would have wireless communications equipment with a link to a surface supervisor.

Finally, the shallow stops would be covered by two safety divers rotating, as time permitted.

Basically, there is a safety diver in the water at all times and by staggering their decompression schedules, a casualty can be taken directly to the surface at any time.

So, a summary of the work involved might include:

- **During the planning phase:** Dealing with some of the logistics. This could range from ensuring fluid is available for a simple dive to defining and assembling sufficient gas quantities and its management for an extended operational period
- **During preparation:** Ensuring all equipment is in place and that support is correctly loaded; assembling any emergency equipment and verifying its functionality

Prior to diving:

- Checking and tagging all decompression and dive gases
- Assisting the divers to "kit up." Deploying of the decompression station and any in-water emergency equipment

- Ensuring divers safely enter the water and all shallow water checks are conducted successfully

During the dive:

- At least one safety diver descends to the first gas switch point to ensure emergency gas is staged and functioning
- If possible, they wait until all divers have returned safely past the first gas switch point. The safety diver should then make sure all divers are safely on the decompression station prior to setting the station loose (if applicable)
- In a simple operation requiring two safety divers, one remains near the surface. In the event that a rescue has to be performed the "shallow water" safety diver is best suited to this role. Also, if one of the team becomes separated this safety diver is deployed to define the extent of the problem and assist where possible. (See other notes on deep and mid-range safety divers)

Post-Dive: Maintaining records. Assist the team with exiting from the water and de-kiting. Provide fluids and any surface gas for the team; stow equipment; help with an overall assessment of the operation and provide useful input for next time

In short, safety divers are essential parts of the dive team and team members rotate through the safety diver role.

Dive Supervisor

The designated Dive Supervisor remains on the surface during all dive operations. The Dive Supervisor may elect to nominate a replacement Dive Supervisor from within the team at any point during diving operations if they have tasks to perform which will take them away from the deck.

The Dive Supervisor is in overall control of the dive and rigging operations. The Dive Supervisor in conjunction with the safety divers is in control of all record keeping and final equipment checks prior to divers entering the water. The Dive Supervisor also reviews any safety issue after the day's diving operation with the team. The Dive Supervisor is responsible for controlling all emergency situations.

Kevin Gurr

Kevin Admiral Denlay, Dive Supervisor
***HMHS Britannic* 1997 ~ Note the Comms Gear**

Other Elements to Consider

Communications

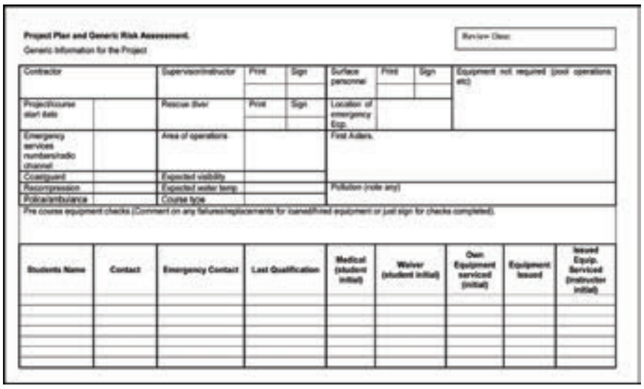
The vessel must have VHF radios. In addition, short wave headsets are used between key members of the team during any rigging operations. This is ideal between the main vessel and any tender as they can be hands free units and provide an element of privacy. The operation will 'log-out' with the Coast Guard on leaving port and contact them when on-site providing details of the day's operation. Upon completion of the working day, the operation will log back in on arriving at port.

Documentation

The Dive Supervisor will be responsible for keeping the daily dive log and completing a daily risk assessment plan. (See below.)

Points to Remember

One of the best weapons in your arsenal is you, provided that you are a prepared and practised, logical, thinking diver.

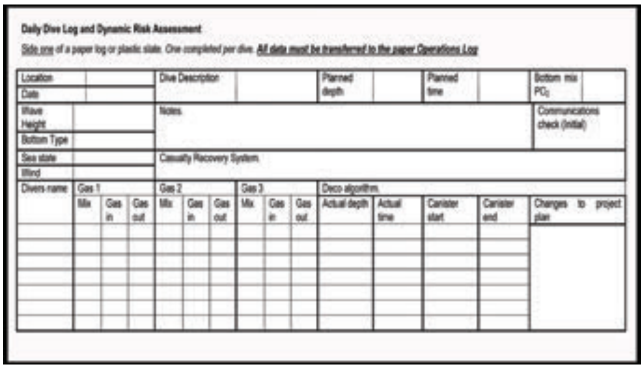


Project Plan and Generic Risk Assessment.
Generic Information for the Project

Review Date:

Contractor		Supervisor/instructor	Print	Sign	Surface personnel	Print	Sign	Equipment not required (post operations etc)	
Project/course start date		Rescue diver	Print	Sign	Location of emergency Eqp.				
Emergency services numbers/radio channel		Area of operations			First Aiders.				
Coastguard		Expected visibility							
Recompression		Expected water temp.			Pollution (note any)				
Police/ambulance		Course type							
Pre course equipment checks (Comment on any failures/replacements for loaned/hired equipment or just sign for checks completed).									

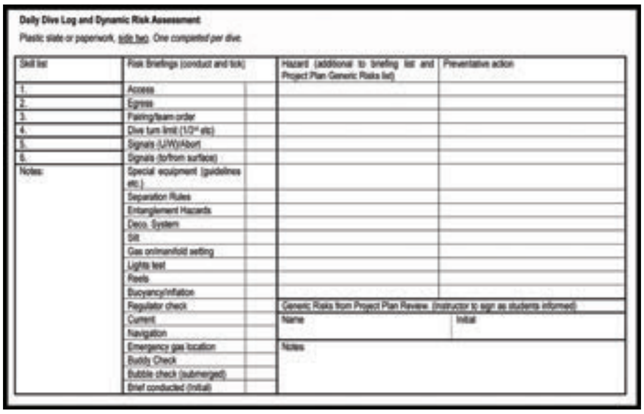
Students Name	Contact	Emergency Contact	Last Qualification	Medical (student initial)	Waiver (student initial)	Own Equipment serviced (initial)	Equipment Issued	Issued Equip. Serviced (instructor initial)



Daily Dive Log and Dynamic Risk Assessment
Side one of a paper log or plastic slate. One completed per dive. **All data must be transferred to the paper Operations Log**

Location		Dive Description		Planned depth		Planned time		Bottom mix PO_2		
Date										
Wave Height		Notes.						Communications check (initial)		
Bottom Type										
Sea state		Casualty Recovery System.								
Wind										

Divers name	Gas 1 Mix	Gas 1 Gas in	Gas 1 Gas out	Gas 2 Mix	Gas 2 Gas in	Gas 2 Gas out	Gas 3 Mix	Gas 3 Gas in	Gas 3 Gas out	Deco algorithm. Actual depth	Actual time	Canister start	Canister end	Changes to project plan



Daily Dive Log and Dynamic Risk Assessment
Plastic slate or paperwork, side two. One completed per dive.

Skill list	Risk Briefings (conduct and tick)		Hazard (additional to briefing list and Project Plan Generic Risks list)	Preventative action
1.	Access			
2.	Egress			
3.	Pairing/team order			
4.	Dive turn limit (1/3rd etc)			
5.	Signals (U/W)/Abort			
6.	Signals (to/from surface)			
Notes:	Special equipment (guidelines etc.)			
	Separation Rules			
	Entanglement Hazards			
	Deco. System			
	Silt			
	Gas on/manifold setting			
	Lights test			
	Reels			
	Buoyancy/inflation			
	Regulator check		Generic Risks from Project Plan Review. (Instructor to sign as students informed)	
	Current		Name	Initial
	Navigation			
	Emergency gas location		Notes	
	Buddy Check			
	Bubble check (submerged)			
	Brief conducted (initial)			

Decompression Systems

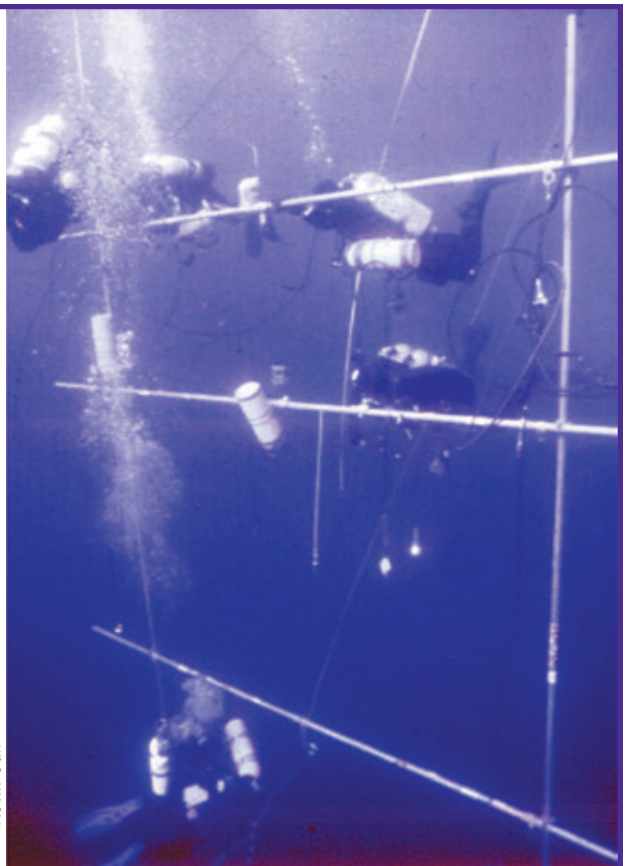
Introduction

As decompressions become longer and more complex, there is a need to use systems which improve individual and team safety and comfort. Long decompressions can be hazardous if conducted in shipping channels, tidal areas and cold environments. The decompression itself, as an additional hazard, can necessitate long uses of high oxygen mixtures. Well-constructed and planned decompression systems significantly reduce the risk.

When to Use a Decompression System

A good rule of thumb is any decompression that requires multiple decompression gases and/or is more than approximately 30 minutes long (meaning that single or pairs of divers surfacing on marker buoys would become significantly separated) requires the use of a decompression system. Let's look at the problems in turn.

1. Multiple decompression gases: the use of multiple decompression gases usually means long and possibly deep dives. In certain situations (especially on Trimix dives where deep-water decompression gases are needed) if a diver loses a deep-water decompression gas he/she may not be able to complete the decompression on their remaining gases. In open water this normally applies to dives over 260 ft (80 m) in depth (given "recreational[1]" bottom times). Hence, some kind of decompression system is used to stage safety gas for this phase of the dive. Better



Kevin Gurr

Decompression Station, *Britannic* 1997

still, this scenario is further covered by using safety divers who carry additional gas

3. Long decompressions: long duration decompressions, especially in tidal waters, means that individuals deploying surface marker buoys (SMB's) to decompress under will become separated. **This is a hazard for three reasons:**

   a. In the event of any one (or several) divers having an incident and surfacing, the boat skipper may just be in the wrong place at the wrong time and assistance may not be rendered quickly enough. Also, should an incident occur, the skipper may be forced to leave the vicinity with injured divers making the probability of loss of the remaining divers still in the water high

   b. In surprise adverse weather, divers can become lost

   c. In shipping channels, large vessels may try and avoid another boat but individual divers will not be seen on a boat's radar

Decompression Stations & Habitats

The function of a decompression station or habitat is to provide a stable platform on, or within, which the team can complete the decompression phase. Advantages and disadvantages of such systems are:

Advantages:

- A place to stage emergency equipment
- Allows the team to stay together in a tidal environment
- Provides a visual reference to assist with buoyancy control (stations)
- Allows the team to exit (or partially exit) the water (habitats)
- Provides extra safety in the event of an oxygen incident or where oxygen durations need to be extended. Use habitats because the casualty is dry. Use station because casualty can be assisted by the other divers or recovered by the safety divers.
- Reduces the effects of cold (habitats)
- Provides a common communication point

Disadvantages:

- High level of individual discipline required to act as a team
- Divers have to be able to return to the shot/anchor line/station
- Habitat set-up may be complex

Varying environmental conditions require different adaptations to the decompression station concept. Three basic layouts of decompression stations will be discussed as well as simple and complex habitats, although there are others.

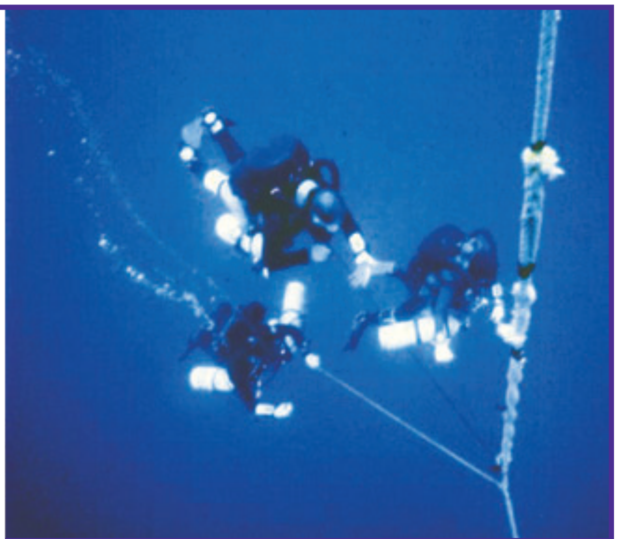
System 1

Use area: Low to medium tidal flow, good in water and generally good surface visibility. Small or large dive teams. Possibly heavy shipping traffic.

Method: This system normally involves the support boat being tethered into the wreck/reef on a fixed single point bow mooring. The boat then deploys a weighted drop- line under the stern of the boat which joins a horizontal line or bar at 20 ft (6 m) connected to the bow mooring line. In good visibility, where a return to the mooring line is simple, decompression cylinders may be staged on this 6 metres line or at a point on the mooring line where they will be first needed. The boat may also provide surface supplied O_2 or indeed any decompression gas. In current, divers may use Jon-lines to clip off to the mooring line.

One alternative to the single weighted drop line for larger groups of divers is to assemble a solid trapeze which is suspended on its own buoys and tethered to the boat. The base of the trapeze is again attached to the main down line by another horizontal line.

Safety Systems: Each diver carries an inflatable surface marker should they lose any of the lines. A dual color-coded system is used, one for ***alone but OK*** (orange) and one for ***Help, Need gas, etc.*** (yellow). Unless a return to the mooring line is guaranteed, divers will always carry all their own gases. Divers should carry some form of surface



Kevin Gurr

THE SEARCH FOR THE *PILAR,* GUAM 1998
JON-LINES USED IN HEAVY CURRENT

signalling device (flares/EPIRB).

System 2

Use Area: High tidal flow. Low in-water visibility. Possibility of poor surface conditions. Small or large dive teams. Possibly heavy shipping traffic.

Method: The main buoy line is sunk (shot or grapnel) to the site with a large surface buoy. The boat is not fixed to this line and works as a safety boat at all times. At the end of the dive the anchor or shot is retrieved and tied up the line several metres and hooked in place allowing the line to free-float with all divers using it as a visual reference. With Trimix diving, safety, travel or deep-water decompression gas may be staged at various gas switch points.

Safety Systems: Each diver carries an inflatable surface marker should they lose any of the lines. A dual color-coded system, one for ***alone but OK*** (orange) and one for ***Help, Need gas, etc.*** (yellow). Divers will always carry all their own gases. Divers will carry some form of surface signalling device (flares/EPIRB). The surface vessel will carry emergency gas to be deployed on measured and buoyed depth lines, (dependant on the dive plan) in the event of an emergency buoy being deployed. Slates can be attached to buoys for additional information. Boat must be equipped with radar and radios.

System 3

Use Area: High tidal flow. Low in-water visibility. Possibility of poor surface conditions. Small or large dive teams. Possibly heavy shipping traffic.

Method: The main buoy line is sunk (shot or grapnel) to the site with a large surface buoy. Two 30 ft (9 m) lines with a buoy at the top and a weight of 4.5-9 lbs. (2-4 kg) at each base. Each line will have loops every 10 ft (3 m). The lines are joined as in a trapeze with a movable bar 7 to 10 ft (2-3 m) long. This station is attached to the main buoy line by a ***jump*** or ***travel*** line. Dependant on the amount of tide expected, this line will be 20 ft (6 m) or longer than the point to the deepest decompression stop, allowing for the angle on the line due to the tidal effect. With Trimix diving safety, travel or deep-water decompression gases will be staged as appropriate. Adaptations to this system for larger groups may include several down-lines and a triangular bar system.

Safety Systems: Each diver carries an inflatable surface marker should they lose any of the lines. A dual color-coded system is essential for communications with surface support divers, one for ***alone but OK*** (orange) and one for ***Help, Need gas, etc.*** (yellow). Divers will always carry all their own gases. Divers will carry some form of surface signalling device (flares/EPIRB. The surface vessel will carry emergency gas to be deployed on measured and buoyed depth lines, dependant on the dive plan, in the event of an emergency buoy being deployed. The boat must be equipped with radar and radios.

Kevin Gurr

FREE FLOAT DECOMPRESSION PLATFORM
ENGLISH CHANNEL

System 4

Use Area: Good underwater and surface visibility, low volume surface traffic, small teams and minimal decompression schedules.

Method: Each diver or pair is allowed to deploy their own surface marker as the decompression starts.

Safety Systems: Each diver carries an inflatable surface marker should they lose any of the lines. A dual color coded system, one for ***alone but OK*** (orange) and one for ***Help, Need gas, etc.*** (yellow). The surface vessel will carry emergency gas to be deployed on measured and buoyed depth lines, dependant on the dive plan, in the event of an emergency buoy being deployed. Divers will normally carry some form of surface signalling device (flares\EPIRB).

Kevin Gurr

ALAN YEEND USING A DELPLOYED SMB

Team Management

With the use of Systems 2 and 3, as noted above, and in extreme tidal areas, team management is vital. If team members are late arriving back at the station the current may be so strong as to drag down the surface buoys and therefore sink the station. Should this situation occur the only option is to deploy the individual surface markers (orange) and commence solo decompression. To ensure team members return to the station within a safe tidal window, it is vital that tidal conditions are assessed and a team plan devised. The key is to define what is often known as a "cut-off time" or the time point in a run time schedule when the jump line will be disconnected from the main line, thus allowing the station to free float. This can either be a fixed time of day in the team plan or a time point in the runtime schedule of the last pair to enter the water (i.e. entry plus 30 minutes). Each team member signs in on a slate positioned where the jump line joins the main line. Should the majority of divers return within the time and other team members not yet be returned, the ***on station*** team has the option to disconnect the jump line at the station end (rather than descending again) at the cut-off time. Each team member must be able to navigate back to the line or be prepared to use a line reel.

Members not managing to return by the cut-off time will realise this and simply deploy their markers and not waste energy or gas trying to return to the station.

There may be several adaptations to this system. Whichever is employed, teams are advised to practice all eventualities before settling on a system.

The above systems are primarily focused on open water use. Cave or quarry dives have their own specific problems but generally involve the staging of gases and emergency equipment at fixed points. The use of any system that requires a return to a fixed point should employ visual markers such as strobes, reels or lights attached near the bottom to ensure a safe return.

Emergency Procedures

The main point of using any decompression system is to avoid team separation and improve safety. However, this does not always happen. To help reduce further problems as a result of separation, ***decompression drop stations*** are used.

Drop Stations

These are used when an emergency signal is seen from a diver at the surface. These are usually a specific color (yellow) SMB or two SMB's together. The drop station will be a line as long as the deepest planned gas switch. The line will have on it at least a cylinder of each of the deep-water decompression gases tied on at the maximum operating depth (MOD) of each gas. Cylinder valves will have been pressurised and turned off to prevent free-flows. In some cases the shallow decompression gas will also be on the line, but usually as there is more time to correct a problem when shallow, this safety gas will be carried on the boat and only dropped if the safety diver deems it necessary, or if an additional pre-arranged signal is seen. Too many cylinders make the drop station unwieldy and prone to tangling.

Often the drop station is launched with a safety diver descending with it to ascertain the problem. Whatever the problem the first assumption should be a gas failure and the station is always launched.

This system covers individual becoming separated from the main up-line or divers using individual SMB's.

Safety Boats

Where decompression systems are employed that require the vessel to be locked in to a down line and station, then a ***safety boat*** should also be used. This is a small, fast vessel capable of following and recovering drifting divers and in an emergency being able to take a casualty to shore or the nearest Medi-Vac point. **The checklist for a safety boat might include:**

- Radio
- First Aid Kit
- Oxygen Resusciation equipment
- Diver recovery system
- Emergency drop station with appropriate decompression gasses
- Navigation equipemtn (for relaying position)
- Drinking water
- Standard boat safety gear such as flares, tools, etc.

Habitats

Dependant on the climatic conditions, extended decompressions (where there is either cold or a risk of oxygen toxicity) should involve decompression habitats where the divers may partially or totally exit the water to complete the decompression phase. Habitats can be simple affairs that allow a portion of the diver to exit the water (almost like an up-turned bucket) or more complex arrangements that allow a complete team of divers to totally exit the water[2]. Habitats reduce the possibility of hypothermia as well as help control the risk of drowning should an oxygen convulsion occur.

Habitat construction can be a detailed science especially when one is designed for open water use. If a unit is to be constructed that is capable of allowing a team of divers to fully exit the water, this will take considerable engineering skill and resources.

Habitats have become popular with cave divers, mainly because exploration cave dives tend to be very long and the environment is more static than the open ocean, making habitat deployment and anchoring relatively simple. In cave diving the types and size of habitats vary considerably. From the large-scale Wakulla Project[3] unit to upside down plastic waste bins often found in places like the Emergence du Russel Cave system in France, each is correct for its task.

Operational Safety

Safety should be something we are all concerned about. With technical or extended range diving, where the diver is more likely to stay submerged for longer periods of time, there is a higher risk of problems occurring. A simple analogy might be: "If I stand in the street long enough I am more likely to get run over." The longer a diver remains underwater the more the effects of equipment reliability - diver error and environmental changes become an issue. Complex dives often involve extended decompressions, depth outside of the accepted sport limits, large amounts of gas and support equipment as well as sophisticated dive platforms such as boats and underwater habitats. The following is offered as a general guide to questions to be addressed when planning such dives.

To define a safe operating procedure we must first look at several specific issues:

1. The type of dive and it's associated hazards
2. Risk
3. Safety planning
4. Dive platforms
5. Safety divers
6. Rescue management and equipment

Types of Dive

The range of dives available to recreational divers is almost limitless. Over recent years the concept and scope of recreational diving has expanded into the realms of what has become known as technical diving. So there is recreational diving and there is technical diving, but what is the difference? Divers are often diving for fun past the recreational norms of 130 fsw (40 or 50 m), so depth is not necessarily the issue. It is now fairly common in certain parts of the globe to see divers hiring boats to take them out into 240 fsw (70 m) of water and do a ***recreational*** Trimix dive. So where does recreational diving really stop? Should the analogy be that as long as the diver is doing it for fun it is still recreational diving irrespective of depth and time submerged? What makes diving ***technical***?

Perhaps the difference is based on the functions of time and exploration. Exploration is going somewhere no one else has been before (which generates its own risks) and extending submerged times at any depth exposes us to risks outlined above. Taking open water diving as an example, this generally means going past the sport diving limits of 130 fsw (40 m+) ***and/or*** spending significant time at any depth, hence generating a considerable decompression obligation.

So a description of *technical diving* might be:

> "Technical diving is a range of knowledge, skills and suitable equipment which, when combined correctly, allow recreational divesr to increase their safety whilst underwater. This information may be employed in either shallow or deep-water, may be used to safely extend the divers submerged duration well into the realms of extended decompressions and is often used as a tool for exploration."

As readers are mainly interested in technical diving, this type of diving will be the focus. It is not to say that any dives planned would not benefit from some of the topics discussed in this chapter, of course they would.

Put broadly types of dives include:

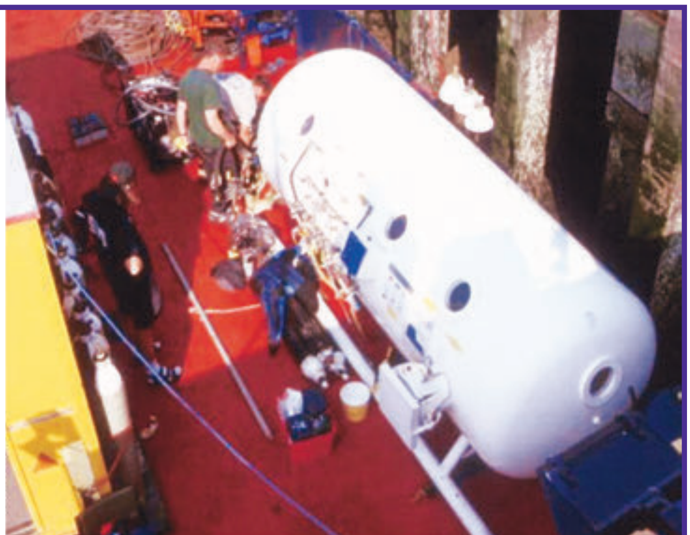
1. Shore dive
2. Boat Dive
3. Cave Dive

Whilst all types of diving (especially at a technical level) are generally similar; cave diving should and does command the most respect. Many of the techniques employed in technical diving were first used in caves.

The cave environment is both fascinating and challenging; both from a mental and a technical standpoint. Caves, although initially appearing benign, can soon turn into a diver's worst nightmare. As such, cave diver training is some of the most rewarding. If you think you are a good open-water diver, take a cave class! Cave diving is not the same the world over. Cave diving in the UK is a million miles apart from cave diving in Florida. However, most of the basic skills employed are generic and are covered within this text. Do not stray into caves without the correct training.

Diving Hazards

Items 1 & 2 can be subdivided in to ***reef*** or ***wreck***. All dives can obviously be fresh or salt water and may be at altitude or at night and there are a variety of different cave dives. Looking at each one in turn (and in order to identify the risk involved) let's list some of the hazards, see Figure 13-1. The table shows some, but not all the general hazards (both physical and environmental) which might occur. This should be completed for the specific dive being planned and where necessary, corrective actions defined for any high risk scenarios.



Kevin Gurr

Some expeditions get very technical with a chamber being installed on the project

Risk

Looking at all of the above, the overall risk for each item can be defined as a combination of the probability of any event occurring and how life threatening it is. As all dives involve risk, they should have varying levels of safety planning. In some cases such as gas supply failure where the probability of failure is potentially low (due to reliable regulators) but the life threatening potential is extreme - the combined risk is high and hence detailed safety plans should be made. In another situation the probability of losing a safe egress from a shore dive in bad weather is fairly high but the potential for rescue and hence the life threatening factor might be low, making the overall risk minimal.

In general, low-risk dives normally have their safety requirements covered by standard diving equipment and practises such as those often employed on a normal recreational dive. High-risk dives need specific emergency plans for any highlighted hazards. So how do we assess risk and define which scenarios need more planning than others?

We can generate a table to assess the risks. **The probability of a hazard occurring should be graded as:**

1. Not likely
2. Possible
3. Probable

Life threatening factors should be graded as:

0. No risk
1. Low
2. Medium
3. High

For example, looking at the table in Figure 13-2, in the first example a diver uses a single high quality regulator and a loss of gas is the defined hazard. This regulator however has a low failure probability of 1, but if it does fail (as there is only one) the potential for loss of life is high due to drowning, etc. Hence the overall risk is high (3). In this instance the most practical safety plan for this scenario would be to carry a backup or redundant regulator. The same type of assessment can be made for the other examples and a safety plan generated.

In summary:

- Define each hazard
- Define the probability of the risk occurring
- Define how life threatening it is
- Grade the probability and life-threatening factor to define the overall risk
- Plan for the specific safety procedure to instigate should the combined risk score be 3 or above

As all dives do involve risk the need to execute them must be balanced against that risk and the potential reward. In some cases the reward is worth the ultimate risk. The focus of this chapter is to make you think about the hazards and define which require detailed safety planning to reduce the overall risk.

Kevin Gurr

ENTRANCE TO GEORGE CAVE, DORDOIGNE VALLY, FRANCE

Risk is reduced by proper planning, training and equipment.

Safety Planning

Having defined the hazards which require detailed safety planning (scoring 3+) it is important to review the environment's affect on those hazards, after which a safety plan may be generated.
The world's diving environments are not only varied across the globe but may vary from day to day and even hour to hour at any one site. Each type of dive has its own specific environment due to its location. Especially in open water, dives that require extended decompressions or long submerged durations may be affected by a range of changing environments. It is important to plan for these changes and include them as part of a risk assessment.

Type Of Dive	Scenario	Hazard
Shore -> Reef	Enter / Exit Point	Physical Injury
	Current	Swept Away From Safe Egress
	Marine Life	Physical Injury
	Boat Traffic	Physical Injury
	Sea State	Physical Injury, Inability To Safely Egress
	Weather	Changing Sea State, Reduced Visability
	Gas Failure	Drowning
	Underwater Visability	Loss Of Dive Partner
Shore -> Wreck	All Of The Above	All Of The Above
	Entrapment	Drowning Or Other Physical Injury
Boat -> Reef or Wreck	All Of The Above	All Of The Above
	Underwater Visability	Loss Of Line To Surface
Cave or Wreck Penetration	Line Loss	Inability To Find Exit
	Silt Out	Inability To Find LIne Or Partner

Figure 13-1: General Hazards
This table shows some of the general hazards (both physical & environmental) which might occur. These should be assesed for each specific dive being planned. Where necessary, corrective action should be implemented for any high rish scenario.

Scenario / Hazard	Probability	Life Threatening Factor	Overall Risk
Loss of Gas	1	3	4
Loss of Boat	1	2	3
LossofPartner	1	0	1

Figure 13-2: Example Of A Probability Table

As the dives' environment and any physical hazards affect our overall safety, let's now include both of these in our safety plan and define possible corrective action to reduce any risk. This will be completed for a range of dives.

Shore Diving

Shore diving generally requires that a diver has good navigational skills especially when ocean diving along cliffs, where specific access/egress points are limited. Where drift dives are to be performed with an extensive floating decompression, ensure boat cover is adequately equipped.

With all diving, but especially where land is to be crossed, remember: always respect the environment and landowners' wishes.

Boat Diving

Boat diving presents a number of unique challenges. See Figure 13-4 for some examples of boat diving risk.

Cave Diving

We have looked at a range of dives and their possible hazards. We have defined the probability of a hazard occurring and the life threatening potential if it happens. As well as defining the risk we have looked at how the environment may produce its own problems and how to plan safely to reduce those problems. **It is worth noting at this point that the three most common causes of diving fatalities can be defined as:**

1. Not planning for proper gas reserves (***Rule of Thirds***) especially on penetration dives.
2. Not carrying a truly redundant gas source.
3. Not using a continuous guide line to the exit on penetration dives.

Hazard	Safety Procedure
DIFFICULT ACCESS/ EGRESS TO SITE	Carry kit in stages - employ sherpas - Use ropes & slings
OCEAN SWELLS	Submerge ASAP to identify U/W hazards - Deploy exit line & floats - Use shore cover personnel
ICE	Always use a line to the surface and shore personnel - with thick ice, ensure surface cover has safety cutting equipment
POOR SURFACE VISIBILITY	Carry surface signalling equipment - Sonic Alerts or EPIRB'S work in most instances
POOR U/W VISIBILITY	Use buddy lines and compasses
BOAT TRAFFIC	Use surface marker buoy
NETS & LINES	Carry cutting equipment
CURRENT	Where long dives are planned in a tidal area, tidal planning to predict an egress point is vital - Shore and probably boat cover will be needed - Drifing divers should always use a surface marker

FIGURE 13-3: EXAMPLES OF SHORE DIVING HAZARDS

Hazard	Safety Procedure
ROUGH SEAS	Deploy diver pick-up and kit drop lines with buoys tethered to the boat - Do not attempt to egress in full kit
CURRENT	In the event of being swept away carry signalling equipmentsuch as flares, EPIRB, Sonic Alert, etc. - Plan for a Lost Diver Drill and Search Pattern at a predetermined time/ point where the divers should surface
OTHER BOATS	Never surface without a marker or being on your boats shot line
ENTRAPMENT	Avoid penetration - Check structures for safety before entering - Dive with a partner who may be able to assist
NETS & LINES	Carry cutting equipment
POOR U/W VISIBILITY	Use strobes or reels on the down line to ensure a safe return

FIGURE 13-4: EXAMPLES OF BOAT DIVING HAZARDS

Hazard	Safety Procedure
CURRENT	In extreme cases work against the flow going in - Test for changes in current and tidal effects before entering - Lay strong lines - Correct & strategic planning should prevent tidal problems
LOW IN-WATER VISABILITY	Always use continuous exit lines - Remain in touch contact
COLLAPSE / ENTRAPMENT	Dive as part of a team - Do not enter unsafe structures

FIGURE 13-5: EXAMPLES OF CAVE DIVING HAZARDS

Surface Dive Support Platforms

Dive platforms can be subdivided into those that remain on the surface and those that stay submerged during the dive. In the simplest form these range from shore safety personnel, the boat, through to decompression stations and habitats. Shore personnel must be aware of the team plan, carry safety equipment such as oxygen and ropes and slings and have good communications (phone/radio).

Boats

Let us first define the functions of a boat in a technical diving operation. **Briefly, these can be listed:**

- Safe transport to and from site
- Protection from the elements
- Accommodation
- A dive-support platform
- A rescue platform

The first three categories of the above list are almost always defined by the physical size of the boat. Boats as operational platforms tend to fall in four size-related categories. These categories will also define the range of the vessel and possibly its suitability for a specific operation.

Whilst each of the above may be suitable for technical operations, each has its own problems. Because weather will often decide the range and type of diving undertaken on the smaller vessels, larger boats also generate problems in strong weather particularly ith diver egress. Even though larger vessels may take divers comfortably to site in strong weather, diver safety may still be compromised during the entry and exit phase because of poor ladders/ high sides, etc. In short, anything much above a force 5 on the Beaufort scale will preclude safe diving. Extended decompressions in strong seas also become uncomfortable unless precautions are taken[4].

Accommodation will only normally be found on the larger live on board/expedition size of vessels. Find out as much about the boat as possible prior to chartering. Three things that can make a trip miserable above all others are poor or inadequate food, inability to rest comfortably and poor sanitation. All of these also affect team safety.

SURFACE SUPPLIED OXYGEN BEING USED WITH A FIXED MOORING. THE LARGE SLED IS A DIVER TOWED UNDERWATER METAL DETECTOR. PILAR PROJECT 1998

Boats as Dive Support Platforms

The boat is used to deliver the divers to and retrieve them from the water, to allow an area for kiting and de-kiting, to provide protection while they are submerged and to transport equipment specific to an operation. The following is a list of practical suggestions to overcome some of the associated problems.

Entry & Exit

Smaller vessels allow the diver to roll backwards to enter the water and once in, clip on additional equipment and cylinders (if boat space is limited). Exit at worst will involve removing the equipment prior to returning into the boat. This is especially true of the inherently stable inflatable technology. Larger vessels may have a similar entry method although stern entry doors are becoming more popular and do provide more safety and less potential for physical injury with multiple cylinder set-ups. With larger vessels, re-entry to the boat will often be via some form of ladder. Whilst side ladders are extensively used in some countries, on non-cathedral hull boats (where the pitching of the vessel can be extreme) this type of exit can be hazardous. In general, stern platforms provide for a much more stable base for entering and exiting the boat. In any event one of the safest ways to re-enter any vessel is to remove excess equipment prior to so doing. **Two proposed methods for achieving this are:**

1. Use a small support boat (inflatable) to retrieve heavy equipment (side mounts, etc.)
2. Deploy a kit retrieval line. This is a long line of 15-33 ft (5-10 m) with brass rings positioned along it and a large float at one end. The other end is tied to the stern of the boat, preferably at a high point away from the propeller using floating line. If surface conditions are slight, simply return to the line, remove one side mount clip at a time and clip it to the line. (This stops accidental dropping and loss of the cylinder)

If conditions are severe, undo the rear side mount clip whilst still submerged (at the last stop) rather than in the surface swell. Attach one clip at a time to the line to prevent loss. Pull yourself back to the boat using the line, allowing the skipper/support crew to retrieve the cylinders. If twin sets are to be removed, provide a firm anchor point on the set by which it can be lifted (not the manifold). Some boats may have winches to assist with this.

Kiting & De-kiting

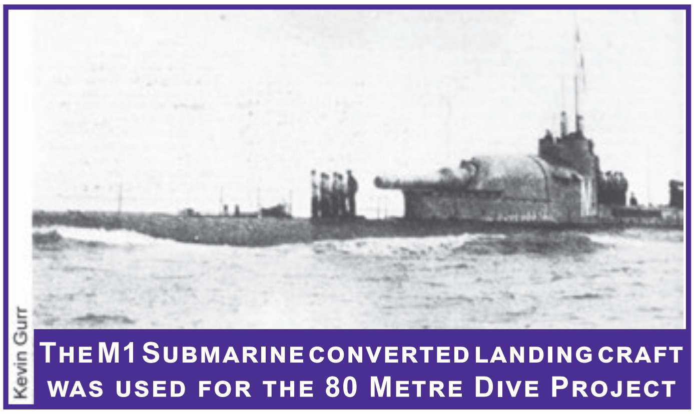
Whilst kiting areas on smaller boats may be limited, on larger vessels there can often be too much space leading to confusion on the boat. Boat loading plays a crucial role especially if an emergency occurs.

In Summary:

- Ensure personnel team equipment is accessible in the order of which it is to be used. The first pair of divers in the water should have their kit nearest the kiting area or exit point

Type	Construction	Size	Suitability
Dory / BostonWhaler	GRP or Aluminum	Up to 20 ft (6 m)	In-Shore Open Boat Work Can Be Used For Small Team Technical Operations
Inflatable	Rigid or Soft Hull Inflatable	Up to 30 ft (9 m)	In-Shore & Off-Shore Work - All Levels of Technical Ops
Day Boat	GRP, Wood or Steel	Up to 50 ft (15 m)	As Above
Live Aboard	As Above	Up to 80 ft (24 m)	As Above + Expeditions

FIGURE 13-6: TYPES OF MARINE DIVING PLATFORMS



THE M1 SUBMARINE CONVERTED LANDING CRAFT WAS USED FOR THE 80 METRE DIVE PROJECT

- Ensure that all safety equipment is easily accessible and make space to treat a casualty
- Where possible, make a separate kiting up to travel area for equipment. In rough seas equipment tends to move around and should be firmly locked in a stowage area to prevent damage. It is often far safer to fully rig equipment on land prior to loading and then firmly secure it in the boat rather than trying to assemble and test it in a pitching sea. This also reduces the number of kit bags required (freeing valuable space). Simple benches or a central table make good kiting areas once on site, empty bags being stowed underneath
- If support divers can be used, employ them to kit team members. If they are not available, educate your boat skipper!
- When re-entring the boat, de-kit as quickly as possible and stow equipment
- Employ team planning to reduce pre-dive stress. Each member has an assigned task and each pair helps the previous pair to dress in and out

Operational Check Lists

A vital part of operational safety is ensuring that all equipment is loaded prior to leaving base. In order to achieve this it is prudent to generate checklists. Figure 13-7, is offered as a typical checklist that might be employed.

Similar checklists can be generated for shore and cave-diving activities.

Protection Whilst Submerged

Whilst the dive is being conducted, it is the boat's function to protect the dive team. The vessel its self can offer physical protection from other sea users by employing such things as radar and communications equipment. Its ability to do this for the whole team relies on the divers acting as a unit. In tidal areas it is just not acceptable that extended decompressions be carried out on an individual basis where there is a possibility that the group will become fragmented. **Separation of the team is hazardous for the following reasons:**

- The boat cannot offer protection from other vessels for all team members
- If weather and sea states change, divers may become lost at sea

M1 PROJECT TEAM & FILM CREW ~ DIVERS: PHIL SHORT, RICH & IGGY LUNDGREN & KEVIN GURR; HISTORICAL EXPERT RICHARD IARN; CHAMBER OPERATOR RUSSEL CATELY

Personal Equipment	Boat Equipment	Emergency Equipment
Cylinders	Shot Lines	Surface Oxygen
Regulators	Navigation Gear	First Aid Kit
Suit Inflation System	Decompression Station	Casualty Recovery Equipment
Harness and Wings	Emergency Deco Gas	Fluids/Hydration Supplies
Primary Light	Radio and Cell Phone	
Primary & Back-up Reel(s)	Anchor	
Lift Bags	Tools and Spares	
Dive Computer	Kit Recovery Lines	
Back-up Dive Timer/Guages		
Dive & Run Time Tables		
Communications Slate		
Emergency Buoys		
Marker Strobe		
EPIRBS/Flares/Sonic Alert		
Knife and Net/Line Cutter		
Tools/Spares		
Suit and Underwear		
Fluids/Hydration		
Mask/Fins/Gloves/Hood		
Compass		
DPV		

Figure 13-7: Sample Operational Checklist

- If a pair of divers or an individual has a problem, the boat may not be in the right place at the right time
- If separated pairs of divers or individuals have problems, the boat cannot be in two places at once
- In emergencies, organised team help is more efficient than buddy assistance

The only real answer to this problem is the use of decompression stations or habitats as described in a previous chapter.

Whichever boat platform is used there are several golden rules which should not be broken:

- Never leave the boat unattended
- Carry a 100% oxygen supply system
- Carry a medical kit
- Carry communications equipment (radio, phone, flares, etc.)
- As a minimum carry a compass and/or more suitable electronic navigational aids

Helicopter Rescues

Important points to remember are:

- Remove all obstructions (aerials, etc.) from pickup point
- Always follow the pilot's instructions
- Never touch the winch man, lines or stretcher until a ground wire has touched the boat or sea. There is a risk of electric shock
- Do not attach any lines from the helicopter to the vessel

Deep Research Submarine on Grand Cayman with underwater photographer/technical divers

- Do not haul on the winch line
- Attach detailed written information about the incident to the casualty
- Position the boat into the wind at an angle of 30 degrees off the port bow. You may be asked to slowly motor (5 knots)

In the event of a lost diver scenario the dive boat should mark the last known position prior to leaving the incident site.

Insurance

International medical insurance to cover diving incidents and any subsequent treatment can be covered by taking out Divers Alert Network (DAN) insurance or Dive Assure. DAN can also advise on chamber locations and rescue facilities.

Conclusions

The safety planning of any single dive or series of dives may range from the simple to the extremely complex. Remember, define the hazards, assess the risks, plan for the specific scenarios and stay in practice.

One of the best weapons in your arsenal is you, provided that you are a prepared and practised, logical, thinking diver.

Notes & References

1. 30 minutes maximum
2. Dr William C Stone. *The Wakulla Springs Project*
3. *The Wakulla Springs Project* book is an excellent reference for would be habitat designers. See Bibliography.
4. P. 155

Chapter Seventeen
The Diver's Mind

Joseph Dituri M.S.

Generally speaking, divers are not risk adverse people; they simply have a certain zest for life. A smaller and still more extreme group of divers are technical divers. As Psychologist Frank Farley of the University of Wisconsin notes, many of the world's ***daredevils, doers and delinquents*** share a common personality, ***Type T*** (for thrill seeking). Whether scientists or criminals, mountain climbers or extreme skiers, says Farley, they are all driven by temperament, and perhaps biology, to a life of constant stimulation and risk taking. These people are ***pursuing the unknown, the uncertain***. It is my contention that the most valuable piece of equipment these thrill seekers take with them on each diver is their brain. Potential superfluities and detractors to the health and welfare of your ***brain power*** include, but are not limited to: diet, sleep, memorization techniques, and the physiological changes that occur in stressful situations. This chapter is an exploration of Type T people as well as a hypothesis of how they can improve their brain function and consequently chances of survival in a high stress situation.

Diet

For years Tom Mount and IANTD have been extolling the virtues of proper diet and nutrition for these extreme series of dives. Recently, a Cambridge study confirmed Dr. Mount's opinion. The study indicates good eating habits have proven to increase productivity and aid in memorization ability. Most importantly, Omega 3 makes it easier for your brain to ***jump*** gaps between brain cells. These ***gaps*** will be described in greater detail below. Many other memory aids, in the form of pharmaceuticals, have been developed and show great efficacy of improving memories in laboratory rats. However, most of these drugs have side effects ranging from headaches to death. As we were all told in our open water classes, it appears that drugs and diving do not mix, but eating well is a good way to get a solid head start.

Memory aid substances have flooded the supermarket and television info-commercials and have been marketed as drugs that assist the brain in its paramount function. The efficacy of these drugs remains questionable and for the most part, should be avoided unless a compatibility test for diving has been conducted. Before choosing one of these memory aid substances, it is important to understand what happens within your brain with respect to the memorization process.

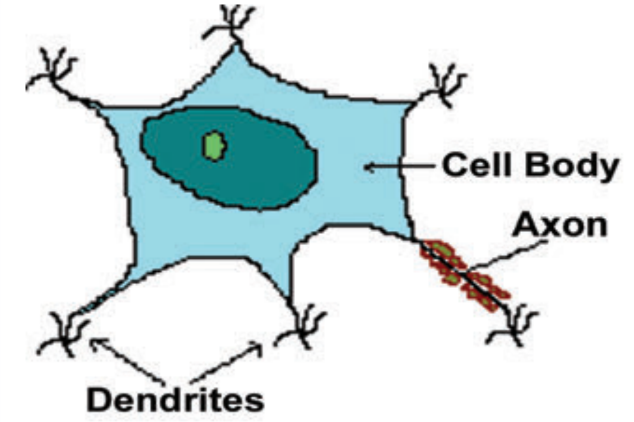
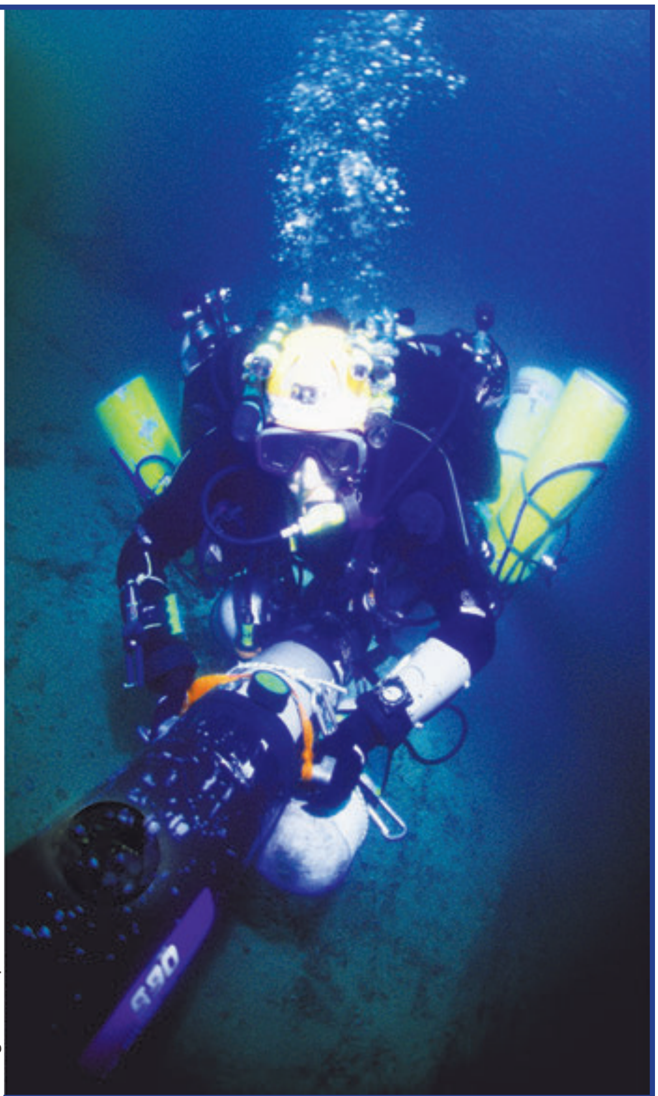


Figure 17-1: Basic Neuron Design

The brain is made of approximately 100-billion nerve cells called neurons. These neurons have the ability to gather and transmit electrochemical signals. They are like the wires in a computer along which signals are transmitted. Neurons have similar characteristics and parts to other cells, but the electrochemical feature lets them transmit signals over long distances and pass messages. The neurons in the brain have axons (cable-like projection of the cell that carries the electrochemical message along the length of the cell) that are very short because of the relative closeness of the other neurons. The neurons make links that connect the sensory inputs and motor outputs with centers in the various lobes of the cortex. There are also connections between these cortical centers and other parts of the brain.

Sleep

Most people have heard the axiom that a good night's sleep aids in concentration. It is assumed that a good night's sleep allows the diver to be clear in the morning and gives him or her the maximum advantage when performing these technical dives. Moreover sleep aids in memory formation. A Harvard study suggests memory accuracy increases as much as 30% with a good night's sleep. This increase is due to the fact that when we sleep, our minds deconstruct the day's events. In an assiduous manner, our



Leigh Bishop

Leading Cave Diver Rick Stanton sets out on an epic cave dive in France

brains spend the "***down time***" during sleep attempting to associate the events encountered in the day to those with which the brain is familiar. Sleep allows the brain time to catalog the learned events of the day. Cutting short the sleep cycle shortchanges the body's ability to strengthen the connections between brain cells.

Memorization Techniques

There are several techniques individuals can use to train their minds to recall items. For instance in order to recall the order of a deck of 52 playing cards in three minutes some people use a technique called "***association***." These memory experts break up the stream of information and put it in smaller packets. Then they associate the smaller memory with something they have already cataloged and remember easily. They build a story with those easily remembered associations to recollect the stream of information.

An example of this is the number seven. While seven is a rather innocuous number, James Bond is a particularly memorable figure and modern icon. To remember the number seven, one merely has to associate it with James Bond's agent number 007. By correlating the number requiring memorization with your favorite Bond, one would easily recall the number seven. By stringing together several of these associations, one could build a story and, for instance, easily recount that it takes seven turns of a knob to turn the bottle from open to closed. This is the method by which some Type T people perform progressive penetration into wrecks. They continue to look back and make a mental picture of the retreat while associating it to some other memorable situation.

Most divers already make similar types of associations. ***ConVENTID*** is a mnemonic device using letter association. It remains a group of unrelated letters that do not form an intelligible word. However, divers know it stands for: Convulsions, Visual disturbances, Hearing disturbances, Nausea, Twitching/Tingling, Irritability, and Dizziness. Our brains have formed the association between this seemingly meaningless word and its alternative significance.

Stress

Stress hormones have been shown to have a marked increase in solidification of learned events. The memory gained from the stress of surviving the traumatic event is well engrained enough that the traumatic event is not repeated. This is why people generally only make significant mistakes once. A recent study showed people could duplicate this effect by voluntarily exposing themselves to a traumatic event after a point of erudition. Something as subtle as immersing your arm in ice-cold water for as long as you can stand was enough to solidify events and provide a 25% increase in recollection of facts.

Before we utilize this extreme methodology with our students or ourselves a disclaimer for the Type T individuals is appropriate. You need not subject yourselves or your students to extreme measures to solidify your salient points.

When you are at the point of information saturation, you could, for instance, take a very cold shower. As seems evident, this should be in a controlled environment to ensure safety.

The mind is a powerful tool. It can be used to promote safety. Although much of the focus in technical diving is gear-related association, there are many other concerns of equal or greater value. Most injured divers have received proper training and knew the way to avoid their unfortunate situation. The supposition that the brain is the determining factor in technical diving injuries is not the primary focus of this article. The fact remains that most divers who suffer injuries were properly trained at one time and ***failed to respond or prepare*** for the stressful situation.

Physiological Changes That Occur During Stressful Situations

When a diver goes through times of significant stress, myriad physical changes occur within the body and the mind that help the person overcome the situation. Physical power is increased with the release of adrenaline among other changes in physical ratios, but physiologically, the flow of information in-and-out of the prefrontal cortex is reduced. This abridged mental acuity seems contradictory to the initial premise that the brain is the most important piece of equipment a diver has, but it is the reality of our physiological being. The prefrontal cortex controls the willed actions as well as higher thinking functions. Willed actions can be interpreted as the survival skills that divers should be working towards during high stress situations such as regulator recovery or valve shutdown during a catastrophic tank neck o-ring failure.

The prefrontal cortex control allows divers to prevent the flight part of the ***fight or flight*** syndrome. While fear and stress can account for a decreased flow to and from the prefrontal cortex, an increase in parasympathetic systems activity can account for an increase in flow to the prefrontal cortex. There are many ways to stimulate the parasympathetic systems, but the ***most profound*** results seem to be correlated with yoga and meditation.[1] Many of these mind control methods have been empirically tested at great length. During transcendent states of consciousness as have been found during meditation and yoga exercises, the brain activity shows a marked increase in prefrontal cortex activity.

This indicates some of these meditation and yoga exercises may actually increase people's ability to remain cool and calm in a situation. Before learning yoga or seeking the console of a meditation guru, temper this information with some balance. Many busy people may not have the time or desire to absorb yoga or adopt the philosophy behind meditation in order to perform these actions correctly. While meditation and yoga yield the best results, a compromise is breathing slowly and deeply and gazing off into the distance while not focusing on any particular object. This action can achieve a portion of the benefits of meditation and yoga. The supposition around this premise is that the mind becomes confused with no change in visual input and turns its recuperative power elsewhere. This results in a stimulation of the body's recovery systems, one of which is to restore normal brain function. Obviously a diver cannot break into a meditative trance during a high-pressure situation. However, evidence suggests that repeated exposure to this transcendental state increases an individual's ability to remain calm in a highly stressful situation. The diver can effectively train the involuntary response. ***What was once considered an unchanging set of neural pathways is now believed to be pliable and modifiable.***[2] As discussed earlier, if Type T people can improve their neural pathways, they will increase their intellect and consequently their safety.

As suggested meditative practice or similar return to this state can ***re-wire*** the brain during high stress situations. This re-wiring could facilitate retention of higher brain function throughout the experience, which would benefit the diver and allow him/her to think and reason. This meditation can potentially change a person from someone who merely reacts to someone who is proactive.

The average divers spend 30 minutes prepping their technical diving gear and upward of 60 minutes prepping a rebreather for a mid-range technical dive. Spending 15-30 minutes each day in a deep state of relaxation will aid you psychologically to ease daily life stressors as well as reduce the magnitude of your physiological response to a dangerous or stressful situation. This seems like an easy decision. If the brain is the most important piece of equipment on a dive, divers would be spending the same amount of time working on it as would be spent prepping other gear; 15-30 minutes could amplify your level of safety.

At this point in a diver's continuing education, a diver can dive in many different environments. In his book, ***Caverns***

Measureless to Man, Sheck Exley discusses hazards of diving, which seem apropos. **A relevant passage is recounted below:**

> "When asked how I have survived so many years of diving I replied, controlled paranoia. This forces me to take the time to examine all of the potential hazards of each dive, and devise ways to surmount them as well as conjure up backup procedures in case those ways don't work. Lots of divers have the self-discipline to go through that process, and have the ability to perceive the hazards and weigh the risks so they can decide whether or not they can dive with an acceptable degree of safety. But to survive a long-term career of diving, you can't afford to stop at that. You have to convince yourself that the ocean is a fickle friend, harboring malevolent thoughts. If you leave any danger un-addressed, no matter how remote, the ocean will definitely and gleefully kill you."

Sheck confirms that divers need to think and be proactive with their safety and well-being.

What Sun Tzu, the author of ***The Art of War,*** said in his book has direct application to the mind of our Type T individuals: ***Warfare is the greatest affair of state, the basis for life and death, the way to survival or extinction.***

It must be thoroughly pondered and analyzed. This is true for technical divers as well; they must concentrate, visualize and analyze the situation at hand. Add an adequate night of sleep, good diet and proper training of your mind to maximize memory of the training you have received and a well-equipped diving warrior emerges. Treat the extreme sport of technical diving like warfare and prepare yourself with all possible tools to ensure your survival. If you know both yourself and your ***enemy***, you will come out of one hundred ***battles*** (with the ocean) with one hundred victories.[3]

Footnotes

[1] Brian Germain, "Skydiving and the Mind," *Parachuting*, (Jan 2007): 42.
[2] Brian Germain,"Skydiving and the Mind," *Parachuting*, (Jan 2007): 43.
[3] Sun Tzu, Translated Into English by Samuel B. Griffith, USMC (Ret), *The Art of War*, (1963): 38.

Tom & Patti Mount

Patti Mount & a smiley friend in the Bahamas in the 1980's. During this trip Patti and Jan Weeks had been hand feeding the sharks until Patti got adventuresome and made the sharks perform for her before giving them food (Bally Hoo). One of the sharks went behind her and bumped her three times with adequate force to move her. Until we played back the tape that night Patti did not believe that she had been nudged & bumped three times as it was so gentle!

Chapter Twenty
Response Training & Failure Points ~ The Importance Of Developing Response

Tom Mount D.Sc., Ph.D., N.D.

In the majority of cases, it is seldom a single event that causes a diving accident, but rather a chain of escalating incidents and reactions. Moreover, there is the actual event and the diver's subjective view of the event. The diver's mental reaction is often based on his or her perception of the initial incident, which in turn leads to a behavioral response. This response is based partly on objective fact and partly on subjective experience. In many cases, it is the diver's reaction to the immediate situation that causes the accident, rather than the actual event. If a diver has a basic fear of darkness, in the diver's mind, the loss of an underwater light may be considered a serious emergency. This scenario leads to fear, and in some, to full-fledged physical and mental panic. In the same situation, another diver might simply switch to a backup light and exit the dive.

Sadly, most diving accidents are avoidable. Analyses indicate that most accidents would either not occur or be significantly minimized if the diver had followed certain simple steps designed to prevent minor mishaps from escalating into life-threatening situations. "*Response Training*" is the term used to identify the type of teaching that helps prevent relatively innocuous problems from developing into catastrophic events, as well as potentially controlling negative outcomes in true emergencies. Response training should be an integral part of every diver's education, as it is a key to safe diving practices. Response training begins with the identifying and understanding the causes of dive-related stress. Through discussion and practice, the diver is encouraged to develop an analytical attitude to adversity or unexpected events. Response training culminates with mental conditioning and physical drills designed to develop virtually instinctive mental and physical reactions to potentially threatening circumstances.

Through research supported by the University of California (*UCLA*), Glen Egstrom, Ph. D., determined that humans require repetitive practice in order to retain and recall learned skills while under duress. For example, it is not very likely that a person shown a single demonstration of CPR technique will remember the necessary skill in the chaos of an automobile accident. On the other hand, a person who has practiced CPR drills repeatedly will typically remember the correct skill sequence, even in a moment of stress. Just as CPR training involves multiple repetitions of the chained skills comprising CPR coupled with ongoing CPR practice sessions and refresher courses, technical diving programs should provide the repetitive practice needed to develop emergency response skills. Ideally, divers rehearse the skills most important to survival using a variety of methods and under a variety of conditions. In addition, divers should practice such skills both during and outside of formal training sessions.

The old adage "*use it or lose it*" definitely applies to emergency response capabilities. A single demonstration, practice, or explanation of a skill provides the diver with a general idea as to how the skill is performed; it does not create the over-learned response necessary for using, or possibly even remembering, the skill itself. Unfortunately, some instructors do not provide needed practice in response training, and few students realize they are not receiving necessary skills practice.


Mel Clark

JOHN ROE & JO CRIBLEY CAVE DIVING IN MADISON BLUE SPRINGS

Emergency Response Skills to Master

Over the years, IANTD identified certain emergency response training skills that should be a necessary component of a comprehensive training program. Emergency response training and practice should be in effect for each of the following areas: Valve manipulation, out of gas and gas sharing procedures, stage and decompression tank management. Moreover, based on the diving environment, skills such as guideline and lift bag use may be highly valuable.

One cause of underwater accidents is the diver's reaction to gas supply emergencies. This includes true gas failures, perceived failures, and accidental valve shutdown. As simple as the emergency drills for such situations appear, each of the above situations has produced a number of accidents. Regarding perceived or true catastrophic gas loss, the first response skill that must be overlearned is the ability to open and to shut down valves during a dive. A dual valve manifold has little advantage if the diver cannot reach the valves to shut them down in event of a regulator failure. In addition, most dual valve outlet manifolds have a design dysfunction enabling the valve on the left post to shut down if it makes contact with the roof in an overhead environment, or in some instances, even a descent line. Training divers to recognize and appropriately respond to this situation by immediately reopening the valve effectively stops the "snowball effect," in which a minor emergency becomes a major catastrophe.

In IANTD courses, manipulating valves and practicing in-water regulator switches begins in confined water and continues in each open water training session thereafter. This skill is practiced until the diver is able to shut down the primary regulator, switch to the secondary, open the primary, and shut the secondary while switching back to the primary quickly and efficiently. Upon completion of the drill, the diver is responsible to ensure that both valves are on. Divers practice this drill, in one form or another, on almost all dives in the applicable courses. One may ask, "Why so much emphasis on valve manipulation?" The answer is that your life could depend on a quick, correct, valve shutdown. ***Valve shutdown is the proper response to a number of common gas delivery or gas failure problems, and experience has proven that divers who do not practice this skill fail to make appropriate corrective action in real life occurrences.*** In addition, many divers with limited shoulder flexibility find this skill quite difficult to perform, and should therefore take every available opportunity to gain proficiency at reaching and manipulating the valves.

In Closed Circuit Rebreather (***CCR***) diving, the ability to open and close valves is also important. This skill may be required in the event of an oxygen solenoid failure or issues with diluent addition. CCR divers must rehearse and overlearn responses to hyperoxia, hypoxia, hypercapnia, canister floods, solenoid failures, and gas loss events. The CCR diver must practice each of these at regular intervals to remain competent in each of these situations. The CCR diver must also be highly skilled in bailout and in switching cylinders with a dive partner at critical gas pressures.

The correct out-of-gas response is a multi-task skill divers should practice until it becomes second nature. To understand the importance of this skill in real-world diving situations, remember that divers typically are not within touch contact of each other, and when an out-of-gas emergency occurs, both divers are usually swimming. This means that under the duress of an out-of-gas situation, the distressed diver must develop the ability to maintain composure while swimming to his dive partner, get his or her partner's attention, and then commence gas sharing in an orderly fashion.

The actual physical actions involved in gas sharing are straightforward, as are the training exercises. What is considerably more difficult than mastering the physical actions is training the mind to react to the stress of an unplanned, unexpected gas emergency during an actual dive. This is why it is so important to provide the diver with a conditioned response in the event of a real emergency, and why conventional training, which does not emphasize overlearning through continuous practice often fails the diver in the most critical of situations. In conventional recreational dive training programs, divers simply start gas sharing while positioned side-by-side. This procedure, while teaching the basic physical technique of gas sharing, does not simulate the stress of being out of gas. In addition, recreational courses frequently teach divers to escape to the surface in a gas sharing situation.

In technical diving, where there is typically an overhead environment and/or a multi-stop decompression ceiling to contend with, escape to the surface is not a valid option. Thus, the technical diver's training must include developing deeply embedded responses to out-of-gas emergencies, and conditioning the diver's ability to control emotional responses in possibly life-threatening situations. One drill used by IANTD to promote such skills is to have divers swim 60 to 75 ft (18 to 22.5 m) without gas. (***Note:*** The regulator should remain in the ***out-of gas*** diver's mouth, as it is better to breathe and repeat the exercise than to drown.) When the "out-of-gas' diver reaches his or her partner, the divers commence sharing gas, with the "***distressed***" or "***out-of-gas***" diver taking the second stage with the long hose. The divers remain at rest for a minimum of three breaths to simulate regaining their composure, and then the divers swim a specified distance while sharing gas within a given time limit.

When we analyze this training skill, we find that the out-of-air swim simulates the distance an out-of-gas diver typically swims in order to reach his partner, taking into account the extra distance created by the continued movement of the partner, who does not yet know of the emergency. The timed swim that follows is at the divers' average swim pace. The reasoning here is that if the divers swim too fast, they will increase both stress and gas consumption. On the other hand, if they swim too slowly, they run the risk of running out of gas before they reach the surface.

With CCR divers, the emphasis is on switching to the "distressed" diver's bailout stage breathing from it. In addition, they are also taught how to exchange stages with the dive partner, in a manner that allows for close to normal swim pace and body posture. The importance of trying to maintain normal swim pace and posture is to avoid the creation of additional emergencies due to situations such as silt, disorientation, and changes in exit speed that may affect duration of the gas supply. In an actual CCR gas emergency, the divers make the exchange when the "distressed" diver's bailout gas is at the half-way point. This practice ensures that each team member exits with remaining bailout gas.

Stage and decompression tank management is another area that calls for response training. These drills develop the diver's ability to remove and replace the tanks quickly, and to position them on the body for minimum drag. For deep diving, at least one of the stage bottles usually contains a decompression gas. In these applications, it is important to develop a consistent order for tank placement, along with a profound awareness as to the location and identity of each tank within the arrangement. In addition to learning standardized stage bottle placement, the diver must practice the physical act of removing and replacing the stage tanks, with special attention given to positioning. A slow recovery of a stage tank increases the dive's bottom or stop time, creates confusion, and may add to the chance of entanglement. This is even more important for the CCR diver, as part of the gas management procedures in a bailout situation depends on proficiency in stage exchanges between divers. Moreover, tank placement for minimal drag is important on any dive, but especially so on swimming dives, such as cave and wreck penetration dives. Another area that requires practice is learning how to deal with malfunctions in gas delivery systems such as:

1. **Non-return valve leaking, thus allowing water into the divers breathing medium:** Lightly "ride" the purge immediately before and after inhalation resolves this issue. However, a diver who is not educated in this technique may not be able to identify and problem-solve this issue while under duress
2. **Leaking O-rings at the regulator or cylinder interface**: Divers can manage leaking regulator or cylinder o-rings by repeatedly opening the cylinder valve when inhaling, and closing the valve when exhaling. This technique ensures that the duration of gas will be similar to that of a normal functioning gas supply
3. **Loss of a decompression gas:** Divers should be taught how to modify their decompression schedules and how to switch to a dive partner's decompression cylinder once the dive partner's decompression obligation is complete. In this instance, emphasizing teamwork and team safety is critical
4. **CCR divers must be proficient at managing open solenoid failures and free flowing or leaky Auto Diluent Addition Valves (*ADV*).** If the diver is controlling the CCR unit manually, the diver must be able to deal with and, if possible, correct ADV failures. Such ADV failures result in diluent being added at such a rate that the dive becomes overly buoyant. Moreover, If the solenoid (or shrader valve is adding oxygen, the PO_2 level will be getting continioously higher. In sum, the diver must be able to handle ***both explosive*** and "***creeping gasses***" from either the oxygen or the diluent side of the breathing loop.
5. **CCR divers must be proficient in manually controlling their gas supply when solenoids fail**

in the closed position. Failed closed solenoids prevent the automatic injection of oxygen into the breathing mix when the PO_2 level drops below the diver's setpoint. CCR divers should likewise be able to handle failed orifices in manual CCR units. In addition, CCR divers should be capable of plugging in off-board gas given gas loss occurring in either the on-board diluent or oxygen supply.

6. **Experienced CCR divers should learn how to dive their units as if they were "passive" Semi-Closed Rebreathers (*SCR*).** Although the appropriate drills and techniques may be introduced in the CCR diver course, it is imperative that such drills be practiced in Normoxic or overhead CCR programs provided the CCR unit can be dived in SCR mode.

Additional areas that require response training would include the use of guidelines within overhead environments and the deployment of lift bags in open water scenarios. A full discussion of these and other related drills and techniques is beyond the scope of this chapter. At this point, the reader should be aware of the importance of response training, as it relates to one's survival as a diver, and to the survivability of a dive team. The reader should also understand the need to seek out responsible, competent technical or CCR instructors who practice emergency response skills, and who are certified by reputable agencies such as IANTD.

Once the diver attains the appropriate degree of response training, the second phase of response training begins; training the diver to keep the emergency response integrated into the dive. In many situations, the diver focuses on the emergency response to the point of removing themselves from the dive. This is actually an unwanted effect of response training and other survival skills; the distressed diver becomes hyper-focused on overcoming the current emergency that he or she ignores or forgets the safety objectives built into the dive itself. When this occurs, even though the distressed diver may react correctly to his or her situation, other emergencies involving the diver and or the team itself may arise due to the diver's, and possibly the teams', tendency to ignore critical components of the dive itself, such as orientation, buoyancy control, silting and simple dive performance. ***The ability to perform a correct emergency response yet remain focused and attuned to the dive performance is one of the major challenges in response training.***

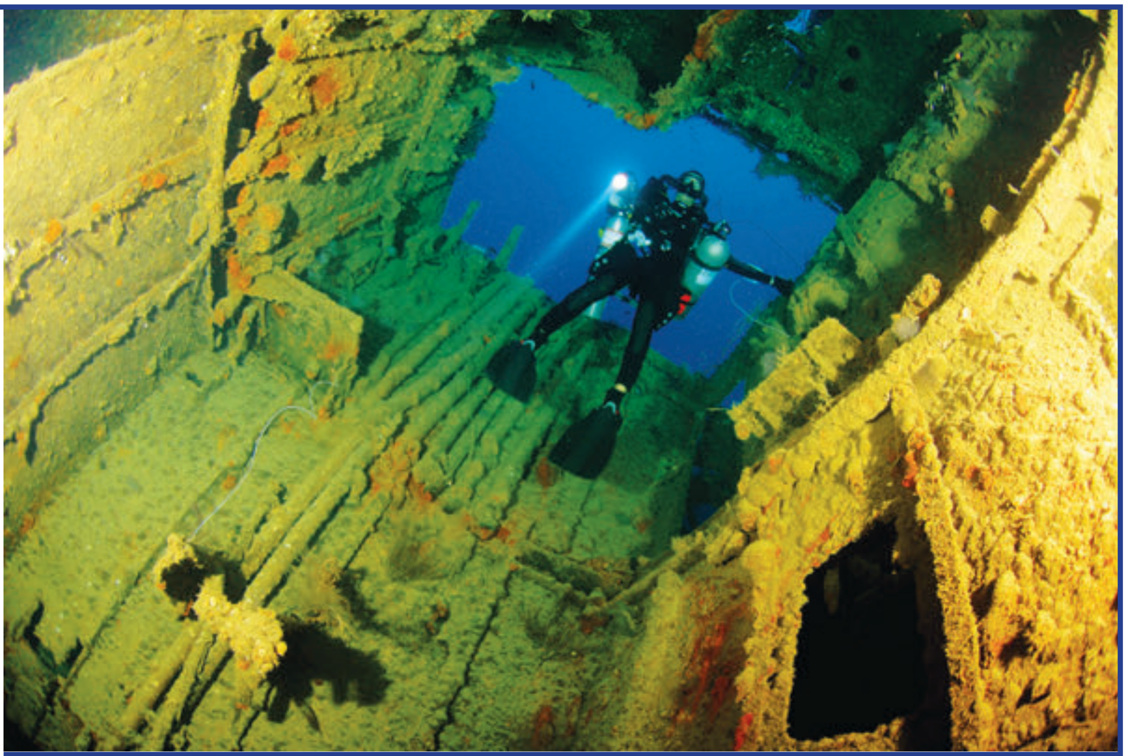
The purposes of response training:

- Provide recognition of emergency situations
- Develop conditioned responses to specific emergencies
- Rehearse responses to the point that they become reflexive
- Develop recognition of risk benefit for all dives
- Train the diver to focus and block negative thinking
- Produce a survival-oriented diver
- Develop skill levels to the point of constant exemplary performance
- Instill an "***I can do***" attitude
- Train a diver to be self-reliant
- Produce a diver who recognizes self-defined limits, is responsible, and who fully appreciates and enjoys all dives due to self-confidence, mature judgment, enhanced skill levels and an awareness of his or her surroundings

Failure Points in Life Support Systems

The key point of equipment is that it functions as a safe and reliable life support system. The equipment we wear supports our very lives when underwater. It is imperative that we are sure a breathing gas is available, we have the ability to perform self-and-partner rescue, and are capable of surfacing safely. It is evident that the equipment we elect to use is our life insurance, so we must use the best equipment we can find. Do not shortcut your safety by using inferior equipment. The old saying "the right tool for the right job" is "right on" for SCUBA diving. The more sophisticated the diving, the more profound this statement becomes.

First, we must choose the correct equipment for the type of dive we are making. Be careful to be neither over nor under equipped. Further, equipment needs vary according to depth and possible overhead conditions. Being in open water versus overhead environments significantly affects equipment choices, and the extent of a dive also contributes to what type of gear is necessary. Obviously, on a 60 ft (18 m) open water dive in relatively calm seas, the equipment requirements are minimal. A mask, fins, buoyancy compensation device (*BC*), regulator with an octopus, exposure suit, depth gauge and timer or computer is adequate. At 100 ft (30 m), or in an overhead environment, a prudent diver will look at failure points and realize that unless they are quite experienced, a completely safe emergency swimming ascent is difficult. They will realize that while the octopus is a good safety device for shallow water it can be a diver's worst enemy on deeper dives.


MEL CLARK

STEVEN GUTIERREZ IN THE ENGINE ROOM OF THE *RB JOHNSON*, SOUTH FLORIDA

The octopus is for your dive partner's use; it is not a self-rescue device. If you develop a free-flow on an octopus, you are losing your gas supply. This may lead to a rapid ascent, and even prevent a safety stop, or if diving beyond no-stop limits, cause a diver to omit a decompression stop. On the other hand, the aware diver will elect to use a dual outlet valve (***H-valve***) instead of the common "***K***" valve on the cylinder. With an H-valve, the diver is able to connect two regulators with shut-off valves to his or her cylinder. This allows the diver to shut down the free-flowing regulator and switch to the remaining operative regulator.

An alternate and much safer procedure would be to use a pony or stage cylinder in lieu of the H-valve; a pony bottle usually mounts on the tank, while a stage bottle connects to the backpack or backplate with clips. Open water divers using a pony or stage cylinder, as a safety gas supply should configure the bottle so it can be easily removed in situations such as entanglement or the need to hand the cylinder off to an out-of-air diver.

A dual outlet manifold, which is used with "doubles," is a third option. Doubles is the term used for two tanks banded together. The manifold connects the two tanks; however, each tank has its' own original shut-off valve. Either tank can be shut down if the regulator connected to it free-flows, or in any other situation that causes a loss of gas in one of the two tanks. Many manifolds also have a third shut-off (isolation) valve in the center of the manifold, allowing the diver to shut off gas exchange between tanks. The options discussed in the last few paragraphs serve as examples of risk management and avoidance of failure points in the life support system. The paragraphs also emphasize a main theme; considering the diver, and the diver's situation, location, dive plan, and needs are all part of risk management and response training.

If diving in current or in areas where it is possible to become lost, the thinking diver will add a lift bag and reel. In technical diving, a lift bag and reel is required when diving in open water environments. This practice allows the diver to have a stable ascent platform and, more importantly, may prevent the diver from being lost at sea. If the diver increases depth or explores overhead environments such as wrecks and caves, the diver's equipment needs again change. Be responsible enough to accept this and ensure the right tools are used. Failure points may vary in an open water environment versus an overhead environment. For instance, let's look at quick release devices (***QD***) on a backpack or harness.

If a cave penetration is the dive objective, quick releases may not have an in-water need. However if the unusual chance a diver is required to remove equipment it may expedite this process. In an open water (***OW***) environment, the quick release may also make the difference between life and death during a rescue attempt.

In our rescue programs, we teach that regardless of how carefully the diver configures is or her equipment, there is a significant difference in the time it takes to remove dive gear from a "victim" on the surface who does not have a QD compared to one who does. In the author's opinion, QD's are one of the greatest safety assets in open water diving offered in modern day diving. Even the old navy harnesses and early backpacks used QDs. The history of diving and diving accidents bears out the importance of QDs in open water rescue situations. With quick-disconnect failures being as rare as they are (one manufacturer states once in 5000 dives, and most often due to other divers damaging them by placing heavy equipment on top of them), it is worth considering using QDs in both open water and overhead environments. The QD's value in open water as a safety factor for rescue and for ease of removal on the surface or a boat is well recognized. However, many cave divers view it as a failure point; however, this author does not agree with this analysis. In contrast, this author, who has seen the inside of many a cave and wreck, believes a single QD is an advantage in all diving environments.

The equipment a diver chooses and the configuration of said equipment may easily be an accident in the making if incorrect equipment and poor equipment configuration rules the day. The following discussion will not address overall configuration: it will identify and discuss potential failure points in the type of equipment and the configuration of the equipment used. With this in mind, the diver should snap consoles or pressure gauges to the BC or waist strap so they do not dangle and remain easy to access. Moreover, a diver should carry a depth gauge, bottom timer, and dive tables as their primary or back-up decompression guide. Although many dive computers have integrated bottom timers and depth gauges, divers may wish to consider wearing an independent bottom timer and depth gauge as a "back-up" in case of computer failure. Some technical divers opt to carry two dive computers, thereby affording them a computerized decompression profile given a primary dive computer failure.

In recreational open water diving, the alternate second stage should not to dangle loosely beside the diver. Instead, the diver should stow or clip off the alternate in a safe and efficient manner. Avoid Velcro enclosed octopus pockets, as they often bond quite tightly, and may be hard to open. In an emergency, any difficulty releasing the alternate may become a life threatening failure point. The spare second stage, be it an octopus or alternate regulator, should be stored in an easy-to-access method. Ideal set-ups have the primary with a four-to-five foot hose wrapped around the neck; in this configuration, the diver hands off his or her primary regulator. The diver secures his or her alternate second stage in a "necklace" often made of bungee cord below the neck, so that he or she can easily switch to the secondary when handing off the primary. This method insures, among other issues, that the distressed diver will receive a functioning secondary stage.

An additional method adopted by some divers is using an integrated second stage. An integrated second stage usually consists of a usable regulator mouthpiece attached to the BC's low-pressure power inflator. In this configuration, equipment keeps to a minimum by eliminating the octopus' hose. If a diver chooses this system, the non-distressed diver hands off his or her primary regulator's second stage to the distressed diver and switches to the integrated alternate. If a diver chooses to use an integrated alternate octopus, I personally recommend that his or her primary regulator's mouthpiece be attached to a four-to-five ft (1.2 to 1.5 m) long second stage hose. A diver configures a primary regulator attached to a long hose in a certain way; the hose routs under the shoulder to avoid entanglement. If the diver chooses a five ft (1.5 m) length, the diver should also make a ¼ turn around the neck with the long hose.

It is considered good practice to have low pressure cutoff valves "up line" from the alternate air source second stage. Many divers attach low pressure cutoff valves on all second stages. If the diver incorporates such valves into their configuration, the diver must train on opening and closing the valves, and to be certain they are open if handed off or switched to during a dive. Dive partners must be aware of such modifications, so that if the diver who passes them a second stage fails to have it in the open position, the receiving diver is capable of adjusting the valve to get gas.

Another important point concerns surface self-rescue. A common behavioral failure point is that divers frequently forget to drop their weight belts when in trouble on the surface. All BC's on the market will allow a diver who becomes unconscious to float with the face partially or wholly submerged. To offset this situation, which could lead to a diver drowning, some recommend steel cylinders or attaching a weight to the back of the cylinder. In theory, these techniques will force the diver who is unconscious at the surface to roll over on his/her back, provided the BC be fully inflated. If either of these methods is to be used, care should be taken not to overweight the diver.

In technical diving, hose configuration is a major decision; a long hose on one of the diver's second stages is required in technical diving as a dive partner assist option. Generally, the long hose is between 5 and 7 ft (1.5 and 2 m) long. The chosen length depends on the type of dive and the local community standard. Keep in mind that some divers overuse the longer hoses. As the length becomes excessive, there is an increase in entanglement potential and difficulty in storage. Most of us view a hose over 5 ft (1.5 m) as a potential failure point.

Where the long hose is stored can also create a failure point. Hoses wrapped along the outside side of a cylinder can and do become entangled with wiring, fishing lines, lures, and other obstacles in wreck diving. This in itself may become a threat to the diver's safety. In addition, hoses configured in this manner create "hose chaffing," which shortens the life of the hose. If you must store your hose on the cylinder, place it in close proximity to your back, rather than on the outer side of the cylinder. Wrapping a hose across the back of the tanks below the manifold is another potential failure point. It may cause confusion when you reach for the valves, or if the manifold itself is entangled with the hose, the initial problem may easily escalate into two or more problems.

The hose configuration IANTD recommends, and is the most popular with IANTD instructors and divers, is to simply run it down diver's side (usually behind the wings), across the divers body, and then wrap the hose ¼ around the diver's neck. This particular hose storage system prevents entanglement and chaffing potential. Further, all hoses leading off the regulators should be routed as straight down as possible. Avoid hoses that stick out from the sides of the diver, especially those that actually go beyond the width of the tank valves. This creates a failure point in that it increases the entanglement potential when diving on wrecks or in caves. Two common means of hose routing are the "criss-cross" method advocated by a supposed *do-it-right* (***DIR***) methodology and the original Holgarthian DIR approach, which consists of running the hoses straight from point to point, thereby extending the hoses downward and avoiding criss-crossing the hoses. Please note that the diver should decide which approach suits his or her needs best and adopt that hose configuration.

Back-plates and harness/backpacks is another area where potential failure points can and do occur. This is also an area where strong opinions exist. There are two issues offering the most debate and that is the choice of a back-plate or a technical backpack. In this discussion, we will leave this debate to the individuals, as both are safe and efficient. However, the design of either may produce failure points.

The quick release is where points of contention exist. In the cave community, many consider a quick release a failure point. The argument is the quick release creates unnecessary risks during a penetration dive, as QDs occasionally break or disengage. In actual practice, most divers find that should a quick release unhook, the cylinders still tend to remain stable. When one analyzes the history of quick release failures, it becomes obvious that such occurrences are extremely rare and tend to occur on land rather than in the water. The advantages of a quick release include an ease of equipment removal either on land or in the water. Although this is normally considered simple convenience, in emergencies the quick release can make a tremendous difference in the time it takes to remove the disabled diver from the water.

A harness or backpack without a quick release usually has to be cut from the distressed diver on the surface. In choppy seas, this can become a complex situation and the extra time either cutting the webbing to free the diver or the time spent wrestling the diver out of the gear may very well complicate the rescue. While the distressed diver is in the water, it is likely, especially in choppy seas, that he or she may aspirate seawater or become more anxious and panicked. A diver can readily open a quick release, and remove equipment from the distressed diver in seconds.

The time saved by using a quick release speeds up and simplifies the rescue, which may make a critical difference in whether the distressed diver survives. Moreover, the quick release also decreases the chance of creating another victim: the diver desperately trying to cut an entire rig off

Patti Mount geared up for her first OC Trimix dive in Bikini Atoll

backup light placement, reels, and other accoutrements. The goal is simplicity and functionality. To produce an ideal system, combine simplicity and functionality with the concepts of minimizing failure points while still providing rescue capability.

Redundant flotation devices and air cells, also known as wings, are worth review. Given the weight and complexity of technical gear, a bladder failure within a wing or air cell poses a potential problem. Divers who use drysuits may have the dry suit provide the necessary redundancy. CCR divers can use their counter lungs as redundant flotation devices. When wetsuit diving,

his or her partner. Given the difficulty involved in cutting through webbing, possible poor sea conditions, and fighting to control a panic-stricken diver, the rescue diver may reach a point of exhaustion, become entangled with the distressed diver or float lines, and at worst create a double drowning.

Rigging the back-plate or backpack is also an important consideration. In general, the more simple the configuration, the better the configuration. The back-plate or back-pack system should have an adequate number of D-rings placed appropriately, as well as whatever other accessories are needed for the dive. However, "more" is not necessarily "better." Some recreational manufacturers, who are not overly familiar with technical diving yet are interested in gaining market shares, as well as certain "technical" manufacturers, appear to be following the trend of "the greater number of bells and whistles, the better." Such companies are promoting systems that are overly bulky and quite confusing.

Remember the back-plate and backpack is the foundation of a technical diving system. If the foundation starts as a simple apparatus then the remainder of the system is easy to keep simple and clean. Either a back-plate or backpack can fulfill the needs of the diver. Beyond that, the diver should put a great deal of thought into the number and way to rig

if the diver cannot swim in and/or ascend safely in his or her gear given a wing failure, the diver may wish to consider a redundant wing. Some feel using a single-bladder BC when diving wet on open circuit (*OC*) is a potential failure point. However, it is the diver's obligation to weigh the risk of the failure point and the corrective action necessary to survive a BC bladder failure and make his or her decision based on an objective assessment of available information. With this information, the diver can then decide whether to offset the failure point by using a redundant BC.

Reel storage and backup lights often present failure points. A misplaced light or reel can lead to entanglement or be lost without the diver being aware of it. In this author's opinion, the greatest failure potential exists when divers place safety lights and reels on tank D-rings. This configuration increases the likelihood of entanglement and essential gear loss more than any other configuration. Other failure points occur due to swivels, which result in more O-rings in the diver's configuration. When setting up equipment, the diver should take the time and effort necessary to analyze the failure potential of each portion of his or her life support system.

Once the diver has completed the evaluative step outlined above, the diver should return to the configuration and determine methods for reducing all failure points. Bear in mind those items critical to survival rate additional redundancy, and the diver minimizes all other items. In other words, the diver uses what is necessary and reduces what is unnecessary. Unneeded items increase the number of failure points within the system.

The very number of items causes an increase in failure points, and unnecessary complexity may over-task a diver's reactions in critical situations.

Deciding how to store stage cylinders is also an important part of the diver's configuration. Two common methods are the "standard" way of attaching the stages to a top shoulder D-ring and a waist D-ring. Another method that is becoming increasingly popular is to place the stages in a "***side mount***" configuration. Whatever the choice, the diver must become proficient in removing and replacing the stage bottles, as well as in exchanging the stage bottles with other team members. often side mount systems incorporate a butt plate. However, many technical divers prefer to eliminate the butt plate, as it is awkward to store on boats. A set of side mounted D-rings attached to the crotch strap works extremely well in lieu of a butt plate. These side mounted crotch strap D-rings also serve as excellent places to store reels. For CCR diving, this type of configuration seems to be ideal.

GILBERTO MENEZES DE OLIVEIRA PREPARES FOR AN IN-THE-WATER RECOMPRESSION TREATMENT FOR A 600 FT (180 M) DIVE IN BRAZIL.

AFTER SURFACING, GILBERTO DEVELOPED NEUROLOGICAL DECOMPRESSION SICKNESS SYMPTOMS. SINCE A RECOMPRESSION CHAMBER WAS NOT CLOSE AT HAND, HE ELECTED TO PERFORM A SUCCESSFUL IN-THE-WATER RECOMPRESSION PROFILE.

Regarding stages and CCR diving, the CCR diver secures the stages so they can easily be handed off to a CCR diver who is "off the loop" for the duration and has used a specific portion of their own bailout gas. Moreover, the stages may also serve as an alternate gas supply for a distressed OC diver. Practicing removing and securing stages, handing off stages, and related drills is necessary to ensure that regulators are easily accessed, and a quick hand off is possible. Some CCR divers opt to use 40 inch (1.25 m) to 5 ft (1.5 m) hoses on their bailout cylinders' second stage. This configuration mandates that the diver accomplish a regulator handoff before the bailout cylinder is passed to the distressed diver.

Dive planning and team responsibilities are the core of a safe dive. The dive plan does not need to be an elaborate and complex deed. A dive plan, though, must ensure that the divers are aware of individual responsibilities. In addition, in order to become responsible as a team member, the diver must be proficient and self sufficient in the type of dive conducted. At this point, he or she can be a responsible team diver. A team should support and assist one another; they should be efficient in rescue technique and skilled in the needs of a particular dive.

Failure points in a dive team exist when one or more divers are dependent upon the abilities of the other divers instead of being working partners. In complex exploration dives, each team member has to depend on the fulfillment of each individual's assigned task. This is not a place for the dependent diver. ***A failure point in team responsibility can lead to disaster.*** To avoid failure points in a dive plan, be sure to understand the objectives of the dive and have confidence in your ability to perform your task on that dive.

Potential failure points on a dive plan and team effort include:

- The team or team leader does not define dive objectives
- The team members cannot meet the dive objectives
- One or more divers do not understand objectives of the dive
- Dive objectives are beyond one or more team member's ability; therefore, the divers' missions cannot be completed
- Dive objectives are too stressful for one or more team members
- Dive objectives are not completed by a team member
- Dive objectives are modified during the dive by a team member, thereby placing the team's safety in jeopardy
- The dive plan does not call for sufficient back-up support such as safety gases on a penetration dive or adequate decompression gas
- Dive objectives are not verbalized or do not exist; both situations lead to confusion and mistakes
- The dive plan does not insure that each individual is functioning within their limits, which may prevent the divers from being confident in their ability to swim, think or breathe for themselves

The solution for all of the above failure points is team communication and comprehension. Most accidents occur due to failure points in dive systems, diver behavior, and a lack of diver education. By reviewing dive-related failure points, incorporating response training, and insuring the capability of the team's members, divers will enjoy safer dives by minimizing the potential for accidents.

Courtesy of DiveTech, Grand Cayman

REGARDLESS OF TASK LOADING WITH EXTRA PHOTO EQUIPMENT, *DIVE YOUR PLAN*

Chapter Twenty Nine ~ Modeling ~ Reduced Gradient Bubble Model

Gene Melton

Overview

Many decompression theories and algorithms have been developed over the last century. The classical Haldanian approach developed by Dr. Bühlmann was the first break though to permit the use of multi-gas mixes by recreational divers. Dr. Bühlmann's equations were a step in the right direction. Along the same time frame the Variable Permeability Model (***VPM***) was developed. VPM is discussed elsewhere. The Reduced Gradient Bubble Model (***RGBM***) roots started with VPM but swiftly evolved into a different method for the calculation of decompression requirements. At the time of this writing, all of the current decompression models use the same method to determine gas absorption and release. The method of determining where decompression must begin and the stop time requirements is the critical difference between the different algorithms. The number of tissues a model uses may vary but the general outcome of the model is essentially the same as long as there is some reasonable number of tissues considered. There is little to be gained using 32 tissues rather than 16 tissues for the decompression calculation other than a smoothing the transitions between the tissues. The fastest and slowest tissues along with an reasonable distribution in between are important for a reasonable stepped decompression profile.

Bubbles

Although not generally recognized as such, the decompression tables developed by Dr. Haldane, Dr. Bühlmann and the military permit bubble development with the goal of keeping the quantity of bubbles to a sub-clinical level where the diver remains asymptomatic. This approach allows the diver to develop bubbles during the decompression phase of the dive with the goal being no symptoms. The ***treatment*** phase of the dive is in the shallow ranges 30 fsw (9 msw) and less where the diver remains until sufficient time has passed so as to allow the bubbles to be eliminated before ascending to the next stop. The success of this approach has allowed millions of dives to be performed without clinical decompression symptoms. However, there were a number of cases where the dive developed symptoms for no apparent reason.

The RGBM was developed by Dr. Bruce Wienke. The

Curt Bowen & DiveTech

CCR diver at the "Sponge Belt" Grand Cayman, BWI mathematics of RGBM is steeped in statistics and is best explained by Dr. Wienke in the books he has published on the subject. The website, www.rbgmdiving.com, has more detail and history about RGBM development as well as the titles of the books. The basic premise of RGBM is that the diver is much better off when the bubbles are never formed. With no bubbles produced, the need for the long shallow stops is reduced. Ideally the deep stops allow the elimination of sufficient dissolved gas to preclude bubble formation. This process is continued throughout the decompression process until the diver reaches the surface with no bubble production or growth.

RGBM takes into account many factors in the calculations: ascent rates 30 fsw per min (9 msw per min) or less, multi-day and multi-dive schedules, reverse profiles and bounce diving, helium-rich mixtures with recommended limited isobaric gas switches (the shallower the better) and the use of 100% in the shallow decompression stops.

RGBM Benefits & Considerations

The benefit of no bubble growth is seen in decompression profiles where the total decompression time of a RGBM profile is less than a Bühlmann profile. In any case the shorter shallow stops are important considerations in open ocean diving. The less time spent in the zone where the pressure changes caused by wave action the better. In the following example, 41 minutes at 10 fsw (3 msw) versus 61 minutes is significant. In a high sea conditions, the shorter time means less time trying to control depth and hang onto the decompression line.

The use of RGBM in cave diving can present decompression considerations. The nature of many caves may require the diver to ascend to depths requiring decompression in order to return to the surface. Gas planning in systems requiring deep in cave decompression is critical to the safe outcome of the dive. Failure to properly prepare can result in omitted decompression and the potential for DCS deep within the cave or a shortage of breathing mix at the end of the dive. Tables are not adequate for this type of diving. Real-time monitoring is mandatory for accurate decompression calculations. Tables will either be inaccurate or require (or not) decompression when the computational depth and times are guessed at beforehand.

RGBM Implementation

To date, pure RGBM schedules have been implemented in 3 ways: tables, software and a dive computer. There are approximately 500 schedules available for many depth and mix configurations including open and closed circuit.

Pure RGBM software packages available include ***GAP*** and the HydroSpace ***HS Explorer Simulator***. The GAP software is a graphical interface which displays both RGBM and Bühlmann schedules at the same time for the planned dive profile. The HydroSpace Explorer Simulator has limited RGBM output in the form of tables which may be used for planning and backup.

The only pure RGBM dive computer is HydroSpace Engineering's ***HS Explorer***. The HS Explorer provides real-time RGBM decompression calculations.

RGBM Testing

For any decompression algorithm to be useful it must be tested. The RGBM algorithm was tested by LANL with over 2000 uneventful dives. Additionally, thousands of dives have been performed using GAP software RGBM profiles. The HS Explorer adds thousands of real-time RGBM profiles to the list.

With potentially 25,000 technical dives, RGBM may be safer than any other decompression algorithm currently available.

Tom Mount

Friends like these at deco stops along the wall in Grand Cayman cause one to keep a watchful eye, especially when deco'ing in mid-water.

```
*** Explorer Calculation Formula (CF) Comparison Table ***
*** HS Explorer Dive Computer Simulator - v5.0.0.4 - RGBM/Bühlmann ***
*** Copyright 2000-2008  HydroSpace Engineering Inc. ***
===========================================================================
Alt = 0, Mode = Open Circuit
Start Mix = 2, N2 = 0.26, He = 0.62, O2 = 0.12, PPO2 1.8 Depth = 461 fsw
Descent Mixes [(#) O2\He\N2, Switch Depth]:
             (2) 0.12\0.62\0.26,    0 fsw;  No descending mix changes
Bottom Mix = (2) 0.12\0.62\0.26, PPO2 1.8 Depth = 461 fsw, END = 98 fsw
Deco Mixes   [(#) O2\He\N2, Switch Depth]:
             (3) 0.32\0.40\0.28, 110 fsw;
             (4) 0.80\0.10\0.10,  30 fsw;
Decompression Stops in Feet Sea Water
```

D	BT	AT	230	220	210	200	190	180	170	160	150	140	130	120	110	100	90	80	70	60	50	40	30	20	10	TTS	(BT)	[D]	OTU
CF = 0, Algorithm: RGBM, F=100																													
300	30	3	1	0	1	1	2	1	3	3	3	4	6	5	4	3	6	6	7	12	12	19	13	20	31	172	(30)	[300]	197
CF = 5, Algorithm: ZH-L16C Bühlmann, Asymmetrical 100, F=100																													
300	30	5										1	1	2	2	4	3	4	8	6	15	13	17	24	47	156	(30)	[300]	205

```
D = Depth, BT = Bottom Time, AT = Ascent Time, TTS = Time To Surface
TTS includes Ascent Time, Decompression Time and Ascent Time between Stops
Equivalent Nitrogen Depth (END) is calculated on deepest depth
```

Figure 29-1: Comparison of decompression profiles for a 300 fsw dive

A note of caution: No decompression algorithm is a 100% guarantee against DCS. There are many variables and no two divers have the same physiology and physical makeup. The only 100% guarantee is to ***not*** dive.

RGBM Profile Data Bank

An extension of the aforementioned testing is the continuous gathering of RGBM dive data. Divers are encouraged to report their RGBM profiles so they may be forwarded to LANL. **The requested information includes:**

- Location
- Surface Interval
- Open/Closed Circuit
- Bottom mix
- Depth and time
- Descent/Ascent rate
- Decompression mixes and change depths
- Decompression stage depths and times
- Divers age, weight and gender
- Outcome

The more information that is gathered will provide more detailed data for RGBM statistical and risk analysis. Please send in your dive histories.

Figures 29-1 and 29-2, present a hypothetical open circuit dive to 300 fsw (90 msw) for 30 minutes. The bottom mix is 12% O_2, 62% He and 12% N_2. The down the (surface hypoxic) gas switch was ignored because it presents a trivial

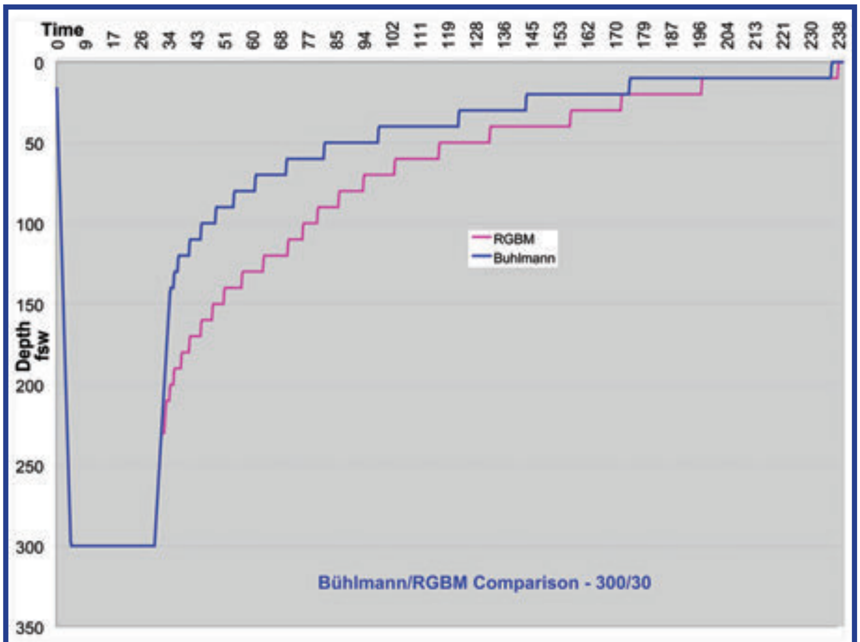


Figure 29-2: Comparison of decompression profiles for a 300 fsw dive

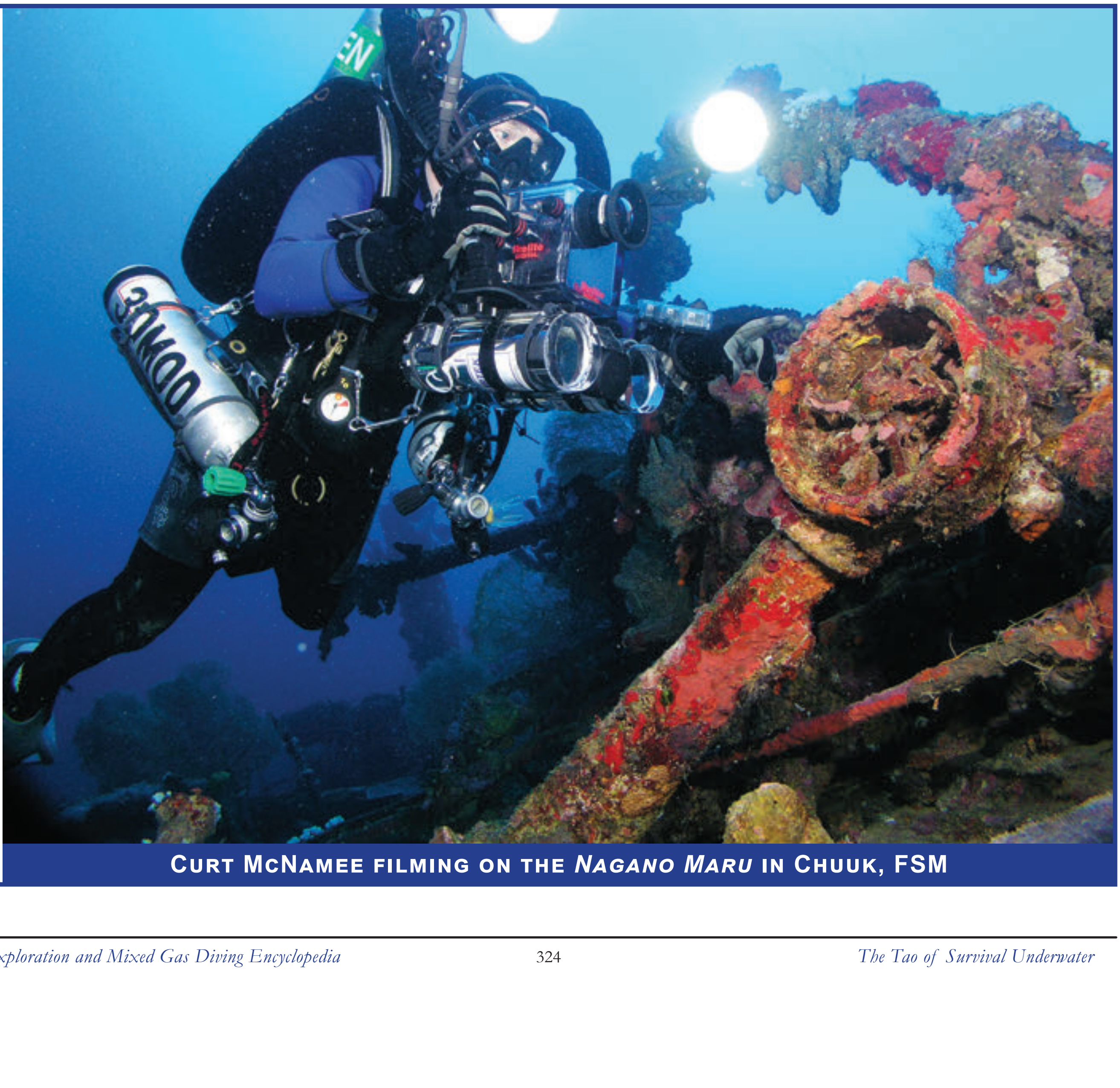
factor in the decompression calculation. In both RGBM and Bühlmann algorithm profiles the upward gas switches to 32/40/28 at 110 fsw (33 msw) and 80/0/20 at 30 fsw (9 msw). In the overall scheme of things the important information is the initiation of the decompression stops and the length of the shallow stops.

Note that the RGBM algorithm requires the initial stop at 230 fsw (34.5 msw) while the Bühlmann algorithm's first stop is at 140 fsw (42 msw). The difference being 90 ft (27 m) or 2.7 atmospheres. Inspection of the following graph of the two profiles reveals the ascent to the first stop in the Bühlmann algorithm. The RGBM profile is 15 minutes into the decompression schedule at the same depth the Bühlmann algorithm starts. The two schedules briefly touch at the 20 fsw (6 msw) stop then finally converge for the last 2/3's of the 10 fsw (3 msw) stop.

Observe also that RGBM has a much more gradual in the ascent profile. The Bühlmann schedule arrives at the 50 fsw (15 msw) stop in 43 minutes where as the RGBM takes 77 minutes to reach the same depth. It is easy to see that RGBM decompression schedules are more gradual and have lower tissue pressure gradients when compared to Bühlmann schedules.

Conclusion

RGBM presents an advanced decompression algorithm for technical diver. The deep stops prevent bubble generation and subsequent growth as is allowed by single phase mechanic algorithms. The methods for implementation are no different than other algorithms. Testing results and diver reports provide for the safety of RGBM profiles.



Mel Clark

Curt McNamee filming on the *Nagano Maru* in Chuuk, FSM

Chapter Thirty ~ Modeling ~ Varying Permeability Model

Simon Pridmore and JP Imbert

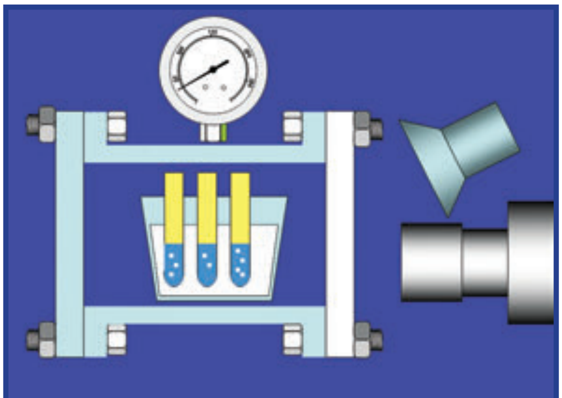
Overview

The original study of Varying Permeability Models (*VPM*) was carried out during the 1970's and 1980's by a team of researchers at the University of Hawaii led by Dr. David Yount (see ***History of VPM*** sidebar on next page).

Their initial purpose was to observe and describe bubble formation and growth during depressurization of tubes of gelatin that were compressed in a small chamber. Through a plexi-glass viewing port in the chamber, using a microscope, the researchers could see, count and measure growing bubble populations.

He established a relationship between the number of bubbles and the supersaturation gradient and this he defined as the difference between saturation pressure and decompression pressure, essentially Haldane's theory adapted to gelatine and quantified in terms of the number of bubbles. He expected to find a nice linear relationship but discovered a line that was far from straight.

So he reviewed his protocol. First he filtered the gelatin



THE YOUNT EXPERIMENT

Leigh Bishop

MARK BULLEN EXAMINES THE GUNS ON THE *HMS LIMBOURNE* DEEP IN THE ENGLISH CHANNEL

and used distilled water to remove all impurities. The bubbles almost disappeared. Then he added impurities and the number of bubbles dramatically increased. He concluded therefore that the bubbles were generated because of the impurities and that there were pre-existing seed-nuclei, ***93% of …*** (which were...) ***already present in the water in which the gelatin is prepared.***

He speculated that if the nuclei were there from the start, it might be possible to eliminate them by compressing them. He therefore changed the experiment and subjected the gelatine tubes first to a ***crush*** pressure.

He found that the bubbles were more durable than he had thought. By increasing the pressure he managed to make the bubbles smaller but could not make them disappear. He tried a variety of methods.

Yount wanted to explain the bubbles' surprising stability during compression. He knew surface tension tended to

The History of the Varying Permeability Model

1974 – 1984: Series of Research Papers released by Yount, Hoffman and others on:

- Bubble formation
- Bubble nucleation in supersaturated fluids
- Isobaric bubble growth
- Skins of varying permeability
- Determination of the radii of gas cavitation nuclei
- Application of a bubble formation model to decompression sickness
- Evolution, generation, and regeneration of gas cavitation nuclei
- Use of a cavitation model to calculate diving tables
- Microbubble fission in surfactant solutions
- Microscopic investigation of bubble formation nuclei

1986: Varying Permeability Model (VPM) dive tables published by Yount and Hoffman

1994: Eric Maiken distributes his BASIC VPM program to divers and researchers

1995: The Yount and Hoffman (1986) VPM algorithm is made freely available to programmers and researchers at the teK95 Diving Technology Conference

1995: Eric Maiken releases his VPM program code reporting his experiences with non-Bühlmann based decompression.

1999: VPM development progresses with David Yount, Eric Maiken and Erik Baker working on repetitive diving and a paper for the Smithsonian conference on reverse dive profiles

2000: David Yount dies, aged 64

The core VPM algorithm is finalized. The algorithm has advanced beyond Yount/Hoffman's original 1986 paper to include, among other things, multiple inert gases and switches and the effects of multiple consecutive dives

Erik Baker's Fortan VPM program codes are finalized. This becomes the standard implementation of VPM

2001: Ross Hemingway adapts the VPM Fortan code by Erik Baker from DOS into a full Windows program. The new program is named V Planner

2002: VPM is adapted for use with CCR planning. As a result of diver feedback and documented experiences grow a revised model is released and named VPM-B

2004: IANTD includes VPM-B tables into all new training courses

2005 to Present:

- V Planner program is further developed to include many of the current tech diving planning features and practices
- VPM-B/E model option introduced
- Delta P Technology announces an optional VPM/BE based alternative algorithm for its range of VR dive computers

shrink bubbles and he introduced surfactants to prevent the bubbles from shrinking too much. Modern views on surfactants would challenge his findings but nevertheless he started using his model to trace the growth of an entire bubble population during a decompression. **Yount's conclusions were:**

- Seed nuclei exists in tissues
- Any gas bubble beyond a certain size, depending on the depth of a dive will increase in size during decompression
- During ascent the aim is to keep the volume of bubbles below a certain critical volume at the end of the decompression

With the help of Hoffman, in 1986 Yount computed decompression tables with extremely deep stops which were never tested and would have been forgotten by history if it had not been for Technical Diving.

Many years later in the mid-nineties technical divers were looking for decompression tables for deep Trimix dives and two key individuals picked up on the pioneeering work of Yount and Hoffman. The first, Bruce Wienke, developed an adaptation which he called the Reduced Gradient Bubble Model (***RGBM***). The second, Erik Baker, who had worked with Yount, was a cave diver who developed a number of versions of the VPM for his own use and generously announced these on the Internet, along with a number of excellent articles on the VPM (from which this article draws).

Then as part of the continuing quest of the technical diving community into deep stops, Ross Hemingway implemented the VPM into a well designed piece of software named ***V-Planner***. Via V-Planner the VPM algorithm became well-known and widely used by divers at the more extreme and exploratory end of the sport. This empirical testing led V-Planner to undergo a series of modifications to replace the original dramatically short shallow stops by stops of a more ***Bühlmann-like*** duration, more akin to what divers were used to.

What is the VPM?

The VPM presumes that microscopic voids and gas nuclei exist in water, and tissues that contain water, before the start of a dive. Any nuclei larger than a specific ***critical*** size, which is related to the maximum dive depth (***exposure pressure***), will grow upon decompression. The VPM aims to minimize the total volume of these growing bubbles by keeping the external pressure high, and the inspired inert gas partial pressures low, during decompression.

The term ***Varying Permeability*** refers to the different responses of bubble nuclei to pressurizations encountered on dives deeper than approximately 9 ATA, compared to shallower dives. On deep dives, nuclei are thought to become impermeable to the flow of gas, and the VPM generates more conservative tables for these deeper dives.

The first and last schedules produced for a short dive are often quite different. This results from the contribution of both the magnitude of the growth gradient and the time that the gradient acts to drive bubble growth. After a short dive, the tissues will off-gas rapidly to the circulation. Hence, because the time that the gradient acts is small, the magnitude of growth gradient can be increased by allowing shorter and shallower stops.

VPM tables handle the in- and out-gassing of dissolved gas in tissues the same way as conventional neo-Haldane calculations do. That is, parallel compartments with exponential half-times ranging from minutes to hours are used to model the uptake and elimination of inert gas by the body.

The VPM postulates that as a diver ascends, nuclei larger than a specific ***critical*** size, which is related to the maximum dive depth, descent rate, and breathing mix, will grow upon decompression.

The VPM aims to minimize the total volume of these growing bubbles by keeping the external pressure large (through deep stops), and by keeping the inspired inert gas partial pressures low during decompression.

Michael Dudas

Evelyn Dudas, member of the Women Diver's Hall Of Fame, is the 1st woman to dive the *Andria Doria*, and one of the 1st female cave divers certified by IANTD.

The VPM uses a step-by-step procedure to refine decompression schedules. In each step, a new ascent schedule is calculated. The total decompression time is fed back into the calculation to revise the critical gradients, and a more liberal schedule is produced at each step. This process is repeated until the decompression time converges to a length that corresponds to the formation of the maximal allowable amount of free gas bubbles. The total decompression time depends on the contributions of the magnitude of the growth gradient and the time that the gradient acts to drive bubble growth. After a short dive, the tissues will off-gas rapidly to circulation.

A divergence of the VPM from conventional calculations is in how a diver's ascent is controlled. Rather than setting pre-defined limits (like M-values) on the maximum pressure ratio between gas dissolved in tissues and ambient pressure, ascents are limited by gradients that depend on specific details of a particular dive, which include factors such as depth, gas mix, and descent rate. The objective is to control the volume of gas that evolves in the body due to the inevitable formation of bubbles. As long as this volume is kept smaller than a certain "***critical volume***," it is presumed that a diver's body has the ability to tolerate the bubbles. If the volume of bubbles exceeds the critical volume, then the diver is at risk of developing DCI.

VPM decompression computations handle the in- and out-gassing of dissolved gas in a set of compartments the same way as standard dissolved gas algorithms. However, the VPM does not associate individual compartments with specific organs or tissues in the body. Parallel compartments with exponential half-times ranging from minutes to hours are used to model the body's range of time scales governing the uptake and elimination of dissolved inert gas.

The volume of the gas in bubbles is related to the product: (N***umber of Bubbles***) ***x*** (***Gradient***) ***x*** (***Growth Time***). The number of growing bubbles is set by the maximum compression encountered on a dive. This crushing pressure is related to the deepest depth of the dive as well as the descent rate and gas mixture.

The gradients and bubble growth time are controlled by the ascent schedule, with the surface as the last decompression stop.

For the Neophyte: Questions Regarding VPM

What works, works. If you are a diver who engages in decompression diving and you have been using a decompression model for years that works for you and with which you are satisfied then why change it? If however you are dissatisfied in some way with the profiles your current computer or desktop decompression software is giving you or you have heard and read the many glowing reports on the benefits of the VPM model, then by all means see for yourself what the fuss is all about. Many divers around the world are using VPM and other bubble models in their diving, and feeling better post dive than they did on the models they were using before.

But bear in mind that VPM is a theory. There is a growing database of proven dives but this is still smaller than the database for competing models and there are few scientific results to review. Much reporting is subjective and anecdotal.

Note that VPM does require specific control of depth and time during decompression.

If you're getting started and unsure about VPM, try planning with conservatism of +4 and padding out the last two or three stops to look like any M-value deco model.

The VPM-B/E model variation introduced by Ross Hemingway is for exceptional, extreme, or extra long dives and exposures. It gives a more relaxed version of a plan for dives when extra safety is prudent. With bigger dives (typically more than 100 mins deco), a B/E model plan will diverge from the VPM-B, and produce something similar to a combined VPM-B and Haldane plan.

Divers who carry out very long deco dives often prefer this "best of both worlds," or combining theories approach to dive planning.

This is the sort of conservative approach applied in the IANTD VPM-B based waterproof decompression tables and to the new optional alternative VPM-based algorithm introduced for the Delta P VR range of decompression computers.

Then, if you are happy with the profiles generated and feel that you are being overly conservative, then over a series of dives work your way cautiously closer to a +3 or +2 setting, eliminating the additional padding, until you find a solution that best suits your needs.

Be aware that with the VPM:

1. Safe ascent criteria just boil down to a certain volume of gas not to exceed after surfacing;
2. There is no physiological analysis of possible different bubble sites and scenarios; and
3. There is no attempt to explain the fact that different profiles result in different symptoms.

Therefore it is not a universal panacea, nor is it a one-stop solution to the mysteries of decompression. It is only a theory that describes a part of the arterial bubble scenario. In the field of decompression science we have no answers as such, we still have only competing theories and, as JP Imbert describes so eloquently in his piece in Chapter 27 in this ***Encyclopedia***, combining theories is probably the best route available to today's divers. ~ ***Simon***

Further Reading

http://www.hhssoftware.com/v-planner/index.html
http://www.decompression.org/maiken/VPM/VPM_Algorithm.htm
http://www.gue.com/Research/Exercise/q3_1l.htm

Chapter Thirty One ~ Modeling ~ Gradient Factors

Matti Anttila Ph.D.

Remember your first diving classes and the lesson about a bubbling soda bottle as it relates to a too rapid ascent? No matter how deeply you study the decompression theory, this soda bubble analogy is still valid. However, it's time to introduce some more fundamentals of the issue. But let's start from the history.

History

Decompression theory is a relatively old science. Already in late 1800's, French physiologist Paul Bert (1833-1886) discovered decompression sickness and the need for decompression stops and slow ascend speed. Bert also studied the effects of oxygen to the humans, as he was more interested in the physiological effects of mountaineering and hot air ballooning. He also extended his studies to cover high pressure environments, and found out later about oxygen toxicity. Bert made a conclusion that high oxygen partial pressures affect humans chemically, not mechanically, as he described the causes of Central Nervous System (***CNS***) oxygen toxicity. When Bert studied air and nitrogen, he correctly determined the cause of the Decompression Sickness (***DCS***) to be caused by the nitrogen bubbles in the blood and other tissues (mechanical effects). Bert also did experiments on recompression therapy and oxygen administration in DCS cases. The most famous of Bert's books is "***La Pression barometrique***"[1], published in 1878, which dealt with the human physiology in low and high air-pressures.

While Bert laid the fundamentals to the decompression studies, it was John Scott Haldane (1860-1936), a Scottish physiologist who approached the problem of decompression theory with more scientific approach. In 1905, Haldane was appointed by the Royal Navy to perform research about Navy's diving operations. His focus was to study the decompression sickness and how it could be avoided. Haldane performed several tests and studied the effects of compressed air at depth, and in 1908 he published the results of his tests in the Journal of Medicine [2]. This article also contained his diving tables.

Haldane is considered to be the father of modern decompression theory. In his research, he made an important conclusion that a diver could surface from an indefinitely long 33 ft (10 m) dive without DCS. From this result, he determined that human body could tolerate pressure change with a factor of 2:1 (the pressure at 33 ft [10 m] is 2 ATA, while on the surface it is 1 ATA). Later this number was refined to be 1.58:1 by Robert Workman. Workman was an M.D. and decompression researcher in U.S. Navy during 1960's. He studied systematically the decompression model that was used in the U.S. Navy and which was then based on Haldane's research. In addition to refining the tissue pressure ratio, Workman found out that the ratio varied by tissue type (hence the term "tissue compartment" (***TC***), representing different half-times, e.g. speed of gas dissolving) and depth.

Dr. Albert A. Bühlmann (1923-1994) from Zürich developed decompression theory further. During his long research career, he extended the number of tissue compartments to 16, which was the basis of his ZH-L16 decompression model (***"ZH" as Zürich, "L" as Linear and "16" for the number of TCs***). The first set of ZH-L16 tables was published in 1990 (previous tables[3], published earlier, contained smaller amount of TCs).

Decompression Basics

Let's start from basics: A diver goes down and breathes compressed air from his/her cylinder. Air contains nitrogen, which, as an inert gas, dissolves into the diver's tissues. When the diver starts ascending, the ambient pressure decreases and dissolved nitrogen transfers from other tissues to the blood, from there to the lungs and finally leaves the body with each exhale cycle. Simple as that, is it?


James Rozzi

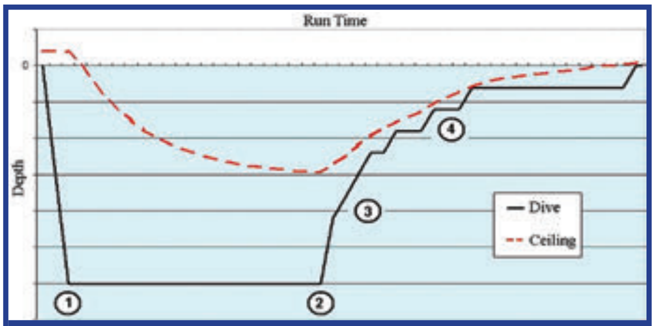


Fig.31-1: A typical decompression dive profile with ceiling line visible. The numbers represent different phases (See Phases in Fig. 31-2)

In recreational diving, no decompression dives are being conducted. Divers are told to stay within their no-decompression limits (*NDL*) of bottom time. This NDL is shown in diving tables, and besides that, divers must stay within certain ascent speed. This information is generally enough for most divers, but what happens when we exceed the NDL and start accumulating decompression time?

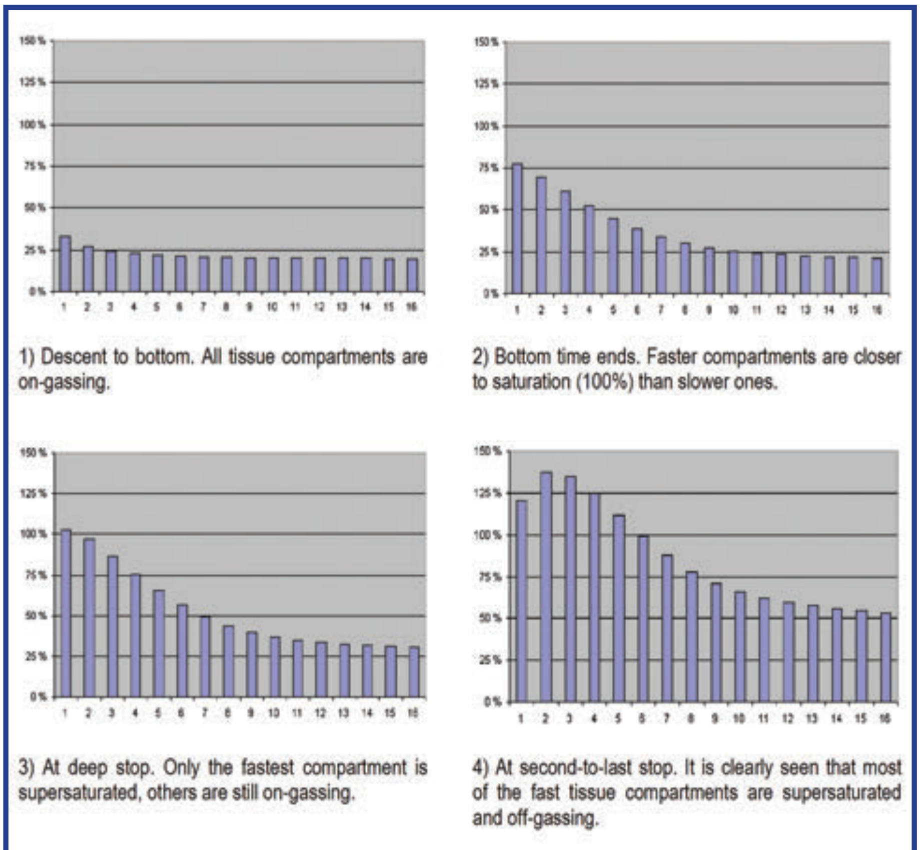


Figure 31-2: An example of inert gas loading in tissues. Pressure in tissue compartment is indicated as percents, 100% being ambient pressure.

Tissue Saturation & Ascent Ceiling

When we dive, we always have an invisible ceiling above us. This ceiling is a depth, which we can ascend to without getting DCS symptoms (generally speaking). The ceiling is based on the amount of dissolved inert gas in our tissues.

Figure 31-1 represents a typical decompression dive profile with multiple decompression stops. Before the dive, your "ceiling" is in fact ***negative*** depth (above surface), meaning that your tissues could tolerate certain overpressure gradient. As the run time increases and diver spends time at the bottom, the ceiling depth goes down and starts limiting the ascent possibilities, generating the need for decompression. In fact, some decompression software indicates the ceiling depth when user types in the desired dive levels. Diving computers indicate the ceiling as the deepest required decompression depth.

When the ascent starts, the diver can not ascend above the ceiling without risking the possibility of decompression sickness. The decompression stops are clearly visible in the dive profile in Figure 31-1. The closer one goes to the ceiling, the less margin of safety remains. The ceiling depth does not yet indicate on-gassing or off-gassing. Bühlmann used 16 tissue compartments to model inert gas dissolving in our body. These compartments either take more dissolved gas in (***on-gassing***) or expel dissolved gas out (***off-gassing***). The ceiling depth indicates the pressure change from current depth, in which the leading compartment off-gasses so fast, that further increased pressure drop would risk the possibility of DCS.

Figure 31-2 illustrates these 16 tissue compartments during the dive, presented in Figure 31-1. A tissue compartment (***TC***) has reached its saturation point when it is 100% full. During the ascent phase, a TC can go supersaturated (exceed 100%). The key of the decompression is to be supersaturated, but not so much that the dissolved gas would form excess bubbles to our tissues and blood.

As shown, the amount of dissolved gas, or specifically the partial pressure of the dissolved inert gas in our tissues, tends to follow the ambient pressure in which we are during the dive. The bigger the pressure difference (i.e. ***pressure gradient***), the faster the gas dissolves, in both directions. This leads to an obvious question: Why not just come up? What are the limits of supersaturation, and how are they defined?

JAMES ROZZI

DIVERS TOURING CARGO DECK OF *KT12* OFF THE EAST COAST OF SARDINIA

M-VALUES

Back to the history: Robert Workman introduced the term ***M-value***, which means ***Maximum*** inert gas pressure in a hypothetical tissue compartment which it can tolerate without DCS. As mentioned, Haldane found out in his research that M-value is 2, and Workman refined it to be 1.58. (This number comes from pressure change from 2 ATA to 1 ATA, and taking into account that air has 79% inert gases, mainly nitrogen.)

Workman determined the M-values using depths (pressure values) instead of ratios of pressure, which he then used to form a linear projection as a function of depth. The slope of the M-value line is called ΔM (***delta-M***) and it represents the change of M-value with a change in depth (***depth pressure)***.

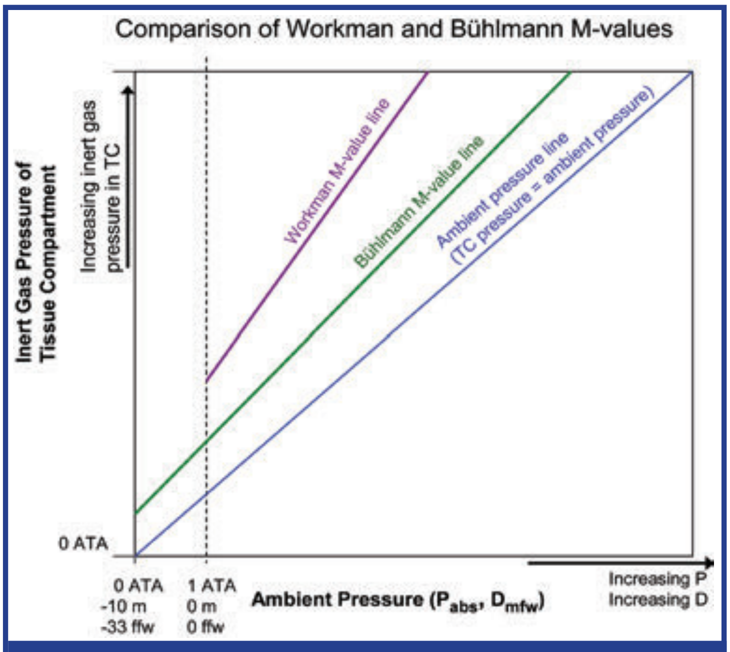


FIG. 31-3: COMPARISON OF DIFFERENT M-VALUE LINES

Bühlmann used the same method than Workman to express the M-values, but instead of using the depth pressure (relative pressure), he used absolute pressure, which is 1 ATA higher at depth. This difference is shown in Figure 31-3, where Workman's M-value line goes above Bühlmann's M-value line.

Figure 31-3 shows a comparison between Workman and Bühlmann M-value lines. A more detailed explanation can be found in literature[4], but it is easy to spot the greatest differences: while Workman M-value line is steeper than Bühlmann M-value line, there is also less margin for safety. Workman M-values also allow higher supersaturation than Bühlmann's.

To make things a bit more complex, it should be noted that while the M-values vary by tissue compartment, also two sets of M-values are used for each TC; M_0-values (of ***depth pressure, indicating surfacing pressure. M_0 is pronounced "M naught"***) and M-values of pressure ratio (*ΔM, "**delta-M**"* values). Workman defined the relationship of these different M-values as:

$$M = M_0 \, x \, \Delta M \cdot d$$

where:

M = partial pressure limit for each TC (in ATA units)
M_0 = partial pressure limit at sea level for each TC (ATA)
ΔM = increase of M per depth, defined for each TC (ATA/m)
d = depth (m)

These sets of values are listed in literature [4]. However, they concern the same thing: maximum allowed overpressure of the tissue compartments. It is also important to know, that decompression illness does not exactly follow the M-values. More sickness occurs at and above the pressures represented by the M-values, and less sickness occurs when divers stay well below the M-values.

Gradient Factors

Gradient Factors (*GF*) are meant to offer conservatism settings for Bühlmann's decompression model. As mentioned in the previous chapter, M-value line sets a limit which is not supposed to be exceeded during ascent and decompression. However, as no decompression model can positively prevent all DCS cases, and because both dives and divers are individual, additional safety margin should be applied.

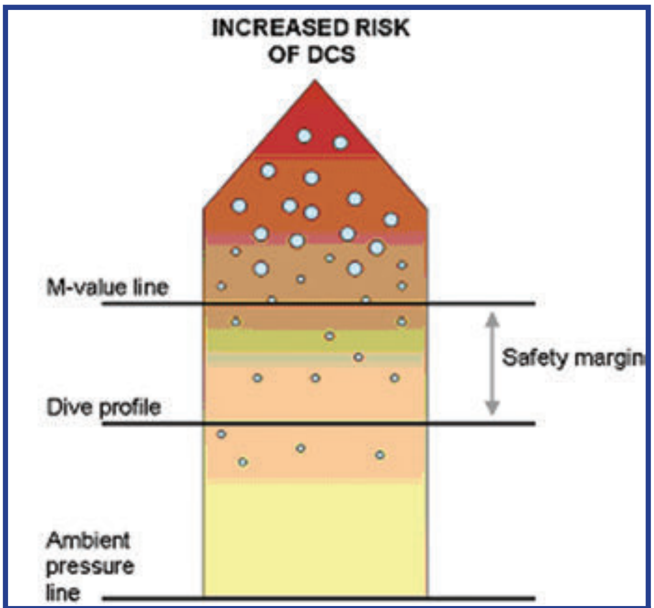


Figure 31-5: Silent bubbles are present in our tissues even when no DCS symptoms are present. It is important to know one's personal safety margin and individual susceptability to DCS.

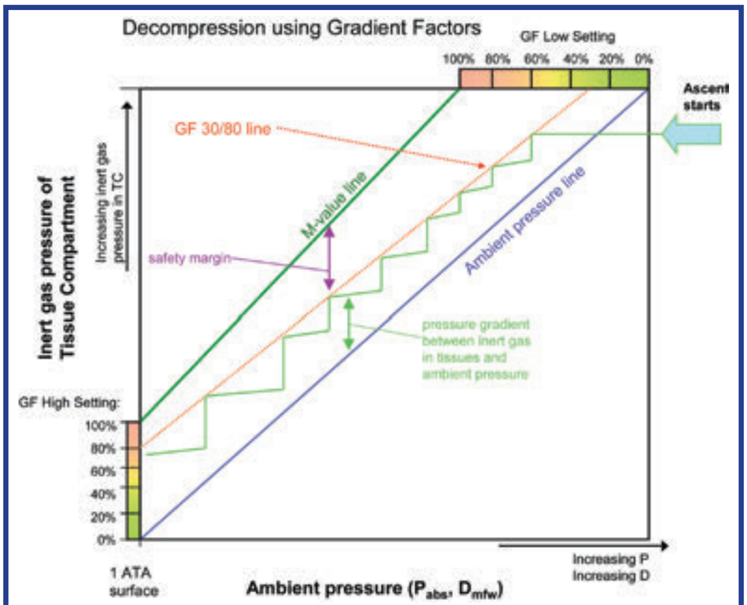


Figure 31-4: The one-tissue model of decompression graph starts from top right and slants down to the left, between the ambient pressure and gradient factor (GF) lines. The GF line stays below the M-value line and forms the safety margin for decompression. Pure Bühlmann decompression follows the M-value line (GF 100/100).

As shown in Figure 31-3, ascent and decompression occurs between the M-value line and Ambient Pressure line. Inert gas pressure in tissue compartments must exceed the ambient pressure to enable off-gassing. On the other hand, we do not want to go too close to the M-value line for safety reasons. Gradient Factors define the conservatism here.

The GF defines the amount of inert gas supersaturation in leading tissue compartment. Thus, GF 0% means that there is no supersaturation occurring and inert gas partial pressure equals ambient pressure in leading compartment (*Note: The leading TC is not necessarily the fastest TC!*) GF 100% means that decompression is being done in a situation where the leading TC is at its Bühlmann's M-value line and risk for DCS is far greater than using lower GF. *(Note: Sometimes, especially in equations and calculations, GF's may be numbered as 0.00 ... 1.00 instead of percentage. However, these are effectively the same thing as 100% = 1.)*

Some diver's did not like the idea of using the same conservatism factor throughout the ascent. Instead of having one GF, there was need to change the safety margin during the ascent. This led to two GF values;

"***GF Low***" and "***GF High.***" Low Gradient Factor defines the first decompression stop, while High Gradient Factor defines the surfacing value. Using this method, the GF actually changes throughout the ascent. This is illustrated in Figure 31-4, where GF Low and GF High form start and end points to a ***Gradient Factor Line***. In this line graph, decompression starts when the inert gas partial pressure in diver's TC's reaches 30% of the of the way between the Ambient Pressure line and the M-value line. Then the diver spends time at that stop until partial pressure drops low enough in the TC's for enabling ascent to the next stop, which again has a bit higher GF. These two GF values are often written as "***GF Low-% / High-%,***" e.g. GF 30/80, where 30% is GF Low value and 80% is GF High value.

Practical Applications & Safe Diving Habits

No decompression model can positively prevent divers getting hit. M-values do not represent any hard line between ***no DCS symptoms*** and ***getting hit***. In fact, modern decompression science has proven that there might be bubbles present in our tissues even when there are no DCS symptoms after a dive. Therefore, M-values neither represent a bubble-free situation, but ***tolerable*** amount of "***silent***" bubbles in tissues.

It is important to understand that certain dives and different people may need different safety margins. Therefore it is good to know the practical differences between dive plans where different Gradient Factors are used. **Let's take another example:**

A diver goes to 165 ft (50 m) for 20 minutes bottom time, using Trimix 18 45 (18% oxygen, 45% helium) as back gas, and oxygen for decompression from 20 ft (6 m) on. Descent rate is 50 ft/min (15 m/min) and ascent rate is 33 ft/min (10 m/min). Decompression algorithm is based on Bühlmann ZH-L16B and the different decompression tables, based on five different GFs, are shown in Figure 31-6.

These GF parameters are commonly used for different types of dives (e.g. rebreather, deep/cold dives, default values in some decompression SW) and GF 100/100 is shown here as a reference, since it is pure Bühlmann table (containing no margin, so it is also not very safe!) As clearly shown in Figure 31-6, low GF Low numbers generate deeper stops. In fact, some divers use GF Low value of 10% to generate "deep stops"[5]. Deep stops, also called "***Pyle Stops,***" are a means to reduce micro-bubbles during deeper phase of ascent. However, during deep stops, many slower tissues are still on-gassing and thus total decompression time will increase. (But again, safety is worth some added hang-time!) Small ***GF High*** values generate longer shallow stops, as also seen in Figure 31-6.

It is easy to modify the dive plan even drastically by using different gradient factors. Most modern decompression software provides either conservatism settings (in verbal terms or numbers) or gradient factors. A diver can modify the total dive time easily by even tens of minutes with these settings, not to mention also the decompression gas needed. But this is also a pitfall; consider a situation where decompression software indicates that you need an

BÜHLMANN ZH-L16

Depth: 165 ft (50 m)
BT: 20 min
Back gas: Trimix 18 45
Deco gas: O2

Depth ft (m):	Time At Depth With Different Gradient Factors:					Gas:	Note:
	GF 10/90	GF 20/70	GF 30/85	GF 36/95	GF 100/100		
165 ft (50 m)	20	20	20	20	20	Trimix 18 45	Run time: 3...20min
100 ft (30 m)	1					Trimix 18 45	
90 ft (27 m)	1	1				Trimix 18 45	
80 ft (24 m)	1	1	1			Trimix 18 45	
70 ft (21 m)	1	2	1	1		Trimix 18 45	
60 ft (18 m)	1	3	2	2		Trimix 18 45	
50 ft (15 m)	3	3	3	2		Trimix 18 45	
40 ft (12 m)	3	5	3	3	2	Trimix 18 45	
30 ft (9 m)	7	10	7	5	3	Trimix 18 45	
20 ft (6 m)	5	6	5	4	4	O2	PPO2 1.6 ATA
10 ft (3 m)	8	13	9	7	7	O2	PPO2 1.3 ATA
Total Dive Time:	**54**	**67**	**54**	**48**	**40**		

Figure 31-6: Decompression tables for 165 ft (50 m) / 20 minutes BT using various Gradient Factors

FUNDAMENTAL KNOWLEDGE ABOUT THE GRADIENT FACTORS IS ESSENTIAL FOR YOUR SAFE DIVING. ON LONG DECOMPRESSION DIVES, SAFETY MARGINS NOT ONLY CONTRIBUTE TO PREVENT DCS, BUT ALSO TO GAS PLANNING, LOGISTICS AND EQUIPMENT CONSIDERATIONS. A GOOD DIVER ADAPTS HIS/HER PERSONAL GRADIENT FACTORS ACCODING TO PERSONAL FITNESS, ENVIRONMENT AND DIVE TYPE. NO MATTER WHICH DIVING GEAR YOU USE, DECOMPRESSION AND THE NEED FOR CONSERVATISM ALWAYS FOLLOWS YOUR PLAN!

intermediate decompression mix fill pressure which is just above your cylinder capacity (including margins). Now, an easy but dangerous choice would be altering the gradient factors so that the decompression time decreases, leading to lower decompression gas need.

Divers using computers, which have user-configurable gradient factors, should understand how modifying their GF's will affect to their decompression profiles. Too many divers simply use the default settings or copy their GF parameters from other divers or even from the Internet, no matter what kind of a dive they are doing. Some divers have higher susceptibility to DCS and some dives are physically more demanding than others. Although the gradient factor method provides substantial flexibility in controlling the decompression profiles and thus the dive plan and gas logistics, it just might be worth to hang there a bit longer sometimes.

As always in diving, it remains ***YOUR*** responsibility to choose the gradient factors and conservatism appropriate for you!

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3. Bühlmann, Albert A.: *Decompression - Decompression Sickness*. Berlin: Springer-Verlag, 1984
4. Baker, Erik C.: *Understanding M-values*
5. Baker, Erik C.: *Clearing Up The Confusion About "Deep Stops"*

PHOTOS COURTESY R. TODD SMITH

...AND WE ARE STILL WORKING THE ICE FROM ALL ANGLES

Photo Courtesy DiveTech, Grand Cayman

Section Six

Authors & Contributors

Tom Mount has a master's degree in Health Sciences, a D.Sc. in Martial Sciences, a Ph.D. in Natural Health Science and a N.D. as a Naturopathic Doctor and is currently studying Integral Energy medicine at the famed Holus Graduate School and Seminary. Tom is a certified Master Past Lives Therapist in Clinical Hypnotherapy, practices and teaches Qi Gong and is certified in numerous energy healing modalities. He is on the Board of Directors of the Society for Vitalistic Health (SFVH).

At age 9 Tom made two major decisions about his life; the first was after reading a book about a sponge diver creating a desire to become a diver. The second was to become a martial arts devotee and at age nine he commenced boxing and later began studying Asian martial arts. After honorable discharge from the US Navy, Tom became a true diving pioneer in cave diving, deep diving, mixed gas diving, and was instrumental in formulation of original concepts accepted in CCR diving.

Tom Mount, D.Sc., Ph.D., N.D.

Tom received the NOGI for Sports Education, Beneath the Sea's Diver of the Year award, Rebreather Worlds Lifetime Achievement Award and multiple certificates of recognition. He is a three-time inductee to the United States Martial Arts Association Hall of Fame. A Grand Master in martial arts he was appointed to the USMA Grand Masters Council.

Tom is a saturation diver and was the Saturation Diver Supervisor on the NOAA FLARE program. He was a founding member of NACD and for many years was the Diving Officer at the University of Miami Rosensteil School of Marine and Atmospheric Sciences and then Tom became the YMCA SCUBA program Training Director in Key West, Florida. Tom is the Founder of Ki Survival Systems, and is currently Chairperson of the IANTD Board of Directors.

Continued on page 338

Tom Mount, D.Sc., Ph.D., N.D. continued from page 337

Tom's experiences in survival led to studying the process of survival and then sharing his experiences and knowledge with others. He feels our primary strengths lie in the ability to use intuition and our use of Chi.

He is married to Reverend Patti Mount, M.A., current CEO of IANTD; Patti is a CCR Trimix and technical cave/wreck diver, Women Divers Hall of Fame inaugural member, PlatinumPro 5000 inaugural member, homeopathic practitioner and she is in Who's Who in Business and Who's Who in Diving.

Tom considers his Three Elements of Survival and Existence to be the key to life. These are:

> "Knowledge is Essential, Survival is Practical."
> "Always remain in life itself, and not on the problems that exist in the path."
> "We all die thus, it is the Quality of Life, not quantity that defines having lived."

Tom has written numerous books plus published papers on diving, photography, martial arts, etc. As well, he has worked on film productions with Bruno Valletti, John Stoneman, Jacques and Phillippe Cousteau.

A partial list of diving text authored by Tom Mount includes:

- The Cave Diving Manual (NACD 1971)
- UM RSMAS Diving Manual (UM RSMAS 1972)
- Practical Diving (University of Miami Press 1975)
- Safe Cave Diving (NACD 1974)
- Army Corps of Engineers Training Manual (YMCA 1979)
- Greatest Adventure Photography (SeaMount Publishing 1985)
- New Practical Diving (University of Miami Press 1978)
- Mixed Gas Diving (Watersports Publishing 1993)
- Technical Diver / Normoxic Trimix Manual & Workbook (IANTD 1991)
- Trimix Manual & Workbook (IANTD 1991)
- Advanced Deep Diving Manual & Workbook (IANTD 1991)
- Cave Diving Manual & Workbook (IANTD 1993)
- Technical Diver Encyclopedia (IANTD 1998 & 2nd Ed. 2000)
- Revised Technical Diver Encyclopedia (IANTD 2003)
- Tek CCR Manual (IANTD 2004)
- Tek Lite Manual (IANTD 2005)
- Open Water Diver Manual (IANTD 2000)
- Revised Open Water Diver Manual (IANTD 2007)

Joseph Dituri, M.S.

LCDR Joseph Dituri enlisted in the U.S. Navy due to his desire to be a Navy diver and later was commissioned into the Special Operations Officer pipeline. Currently he is a U. S. Navy Saturation Diving Officer with 23 years of service and holds a commercial saturation diving supervisor rating from the Association of Diving Contractors.

Joseph earned a Bachelor's Degree in Computer Science from the University of South Carolina and a Master's Degree in Astronautical Engineering from Naval Postgraduate School. His current assignment for the Navy is Officer-in-Charge of Deep Submergence Unit's Diving Systems Detachment in San Diego, where he is responsible for all tethered submarine rescue. He is one of only 23 qualified 2000 fsw (600 msw) "Hardsuit" pilots and has worked in every facet of diving within the U.S. Navy. A few of his former duties in the USN include: Diving Officer at Mobile Diving and Salvage Unit One and the Operations / Salvage Officer onboard *USS Salvor*. Following a change of designator to Engineering Duty Officer (Diving Officer), he served at Pearl Harbor Naval Shipyard as a Nuclear Project Superintendent, SUPSHIP Project Manager, and Business Operations Officer. LCDR Dituri is a member of the Acquisition Professional community and is a Level III Program Manager capable of managing programs of $4 Billion. His personal awards include three Navy Achievement Medals, an Army Commendation Medal, and two Navy Commendation Medals.

Joseph is an avid technical / rebreather diver who owns part of the International Association of Nitrox and Technical Divers while serving as their Training Director. He is also an Instructor Trainer for Diver's Alert Network and a Hyperbaric Physician Instructor for the International Board of Undersea Medicine (IBUM). In a civilian capacity Joseph has trained hundreds of technical divers to dive and physicians in the use of hyperbaric

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medicine. He is a contributing author to the Navy Diving Manual and has been published in several journals and magazines including those produced by the American Society of Naval Engineers and American Institute of Aeronautics and Astronautics. Joe is a veteran of numerous deep diving expeditions and has an affinity to explore the undersea environment.

A sample listing of training materials Joseph has developed include IANTD Rescue Diver, IANTD Dolphin and Ray Training manuals, IBUM & IANTD Diving Medical Technician Manual as well as the revolutionary series of IANTD “FUNdamentals” DVDs for Rescue Diver, Divemaster and Rebreather Diver. He has assisted in production of IANTD Standards and Procedures, numerous training slides used in IANTD programs as well as the IANTD Nitrox Diver Manual, IANTD Public Safety Diver Manual, IANTD Azimuth Rebreather Diver Manual and IANTD Overhead Diving Manual.

Joseph is married to the former Amy M. Entress. Together they have three children. He enjoys skydiving, martial arts and has a long-term goal of being an astronaut upon retirement from military service.

The opinions expressed herein are possessed solely by the author and do not necessarily reflect those of any organization with which the author may be affiliated. Joe’s commitment to this publication is completely separate from his military duties.

Matti Anttila has an M.Sc. in Technical Physics and a Ph.D. in Space Flight Instrumentation, so diving science is close to his heart. He was trained as a minehunter diver in the Finnish Navy in 1995 using semi-closed rebreathers, and later Matti pursued them for recreational and then technical diving. In the late 1990’s he began teaching IANTD technical diving in Finland. Currently he is on the IANTD International Board of Advisors and is an IANTD Trimix Instructor Trainer. Matti is interested in diving technology, experimental diving and cave diving, but still finds it equally nice to teach open water diving class for beginners or Trimix diving for more advanced divers.

Matti Anttila, Ph.D.

Dr. Peri M. Blum offers training and certification through IANTD in open circuit (OC) and closed circuit rebreather (CCR) SCUBA diving. Thanks to this unique combination of skills, students are trained by a professional who understands and works with divers in building on strengths and overcoming weaknesses, while recognizing individual needs, goals, and lifestyles.

Peri Blum, Psy.D.

Dr. Blum, who is in independent private practice, specializes in a number of areas, including medical and sports psychology. Dr. Blum also works extensively with children, adolescents, and at-risk youth and their families.

Dr. Blum has over 30 years diving experience and more than 15 years studying and practicing psychology. Dr. Blum's technical and instructor training is under the IANTD programs. Dr. Blum's dive career includes assisting in training divers from all over the world, working on the Looe Key Artificial Reef Project, preparing for toxic oil spills, and field-testing dive equipment. Dr. Blum is also involved in writing and editing across numerous topics and fields.

Joe Citelli did his first free dives as a teenager in the waters off City Island, NYC and became an avid diver when he moved to Florida. During the 1980's Joe used the Navy Dive Manual to learn decompression diving and cobbled together a set of doubles to pursue diving deeper wrecks. Recognizing the need for formal training he became Cave certified and later participated in the first IANTD Trimix course ever offered. With no books or texts, this class was the one in which students and teacher collaborated to derive and perfect some of the formulas and methods in use today. Joe can usually be found diving deep wrecks all over the Southeastern US, the Gulf Coast of Florida and occasionally in the Northeastern US.

Joe Citelli

David Doolette, Ph.D.

David Doolette is currently working at the USN EDU in Panama City specializing in projects involved with Diving Physiology. Formerly he was a research fellow in the department of Anesthesia and Intensive Care in the University of Adelaide Royal Hospital, Australia. He has been trained in neurophysiology and neuropharmacology. This background and his diving pursuits led to his interest in diving physiology. David's current works involve decompression illness, decompression modeling, and health management for divers. David has been diving since 1979 and is devoted to cave exploration.

Jeff Gourley

Jeff Gourley was born in Arizona in 1967. At the age of six he designed and built an underwater habitat in his pool and consequently discovered the dangers of hypercapnia, and as they say, the rest is history. Jeff learned to SCUBA dive in 1985 and has achieved practically every rating or certification related to Underwater Exploration: CCR Trimix Instructor Trainer-IANTD ITT #403, CCR Cave, Instructor and user ratings on the Optima, Inspiration, Megalodon, Evolution, KISS, Azimuth, Dolphin, LarV, Mark 15, Cis-Lunar to name a few. He is a certified Chamber Operator, Gas Blender, Side Scan Sonar Tec, and ROV Operator. He also holds the following medical ratings: Military Medic, IEMT - State of Arizona, DMT - Undersea and Hyperbaric Medical Society, Chamber Operator - International Board of Undersea Medicine. Jeff's work experiences include the design of various CCR's and components, marketing, publishing, diving safety/stunt work, underwater film and photography. His other interests include surfing, mixed martial arts, repelling, and he is a gourmet chef.

Kevin Gurr

Kevin Gurr was the first certified Technical Diving Instructor outside of the USA and is an IANTD IT at all levels and has been instrumental in expanding Technical and mixed gas CCR diving globally. A Marine engineer and professional diver, Kevin developed an EANx dive computer in the late 1980's, he is the co-author of Proplanner Decompression software, the designer of the VR3 mixed gas dive computer, the Ouroboros and Sentinel Rebreathers.

He led the first sport diving expedition to the *HMHS Britannic*, has dived the *Lusitania*, the *USS Monitor*, and made a MIR submersible dive on the *Titanic* plus several archaeological and filming expeditions.

Kevin is an active Caver/Cave diver and Instructor and given the choice between fast women and fast motorcycles would probably choose the motorcycle.

Jean-Pierre "JP" Imbert

Jean-Pierre (JP) IMBERT spent 20 year in the offshore industry as Diving and Safety Manager of Comex, a major offshore diving contractor in the North Sea. He was involved in research programs such as hydrogen diving and deep projects in Norway.

As an engineer, JP developed a special skill for decompression modeling and he is the producer of a long list of tables and procedures for the diving industry. He has published widely on decompression modeling including a chapter in the IANTD Technical Diver Encyclopedia (1998, 2000 & Revised 2003).

He is presently deeply involved with work on solving the tiny bubbles equations in an attempt to design the ultimate bubble growth decompression tables. JP is highly respected worldwide as one of most knowledgeable decompression modeling researchers.

Jean-Pierre is proud to be a Technical Diving Instructor and Instructor Trainer in IANTD. He is the former IANTD Licensee for France, and currently is on the IANTD Board of Advisors.

Gene Melton

Gene Melton is a graduate of the University of Florida. He developed repetitive group designations and surface interval credit tables for the USN Exceptional Exposure tables. This work was published in "Practical Diving" by Tom Mount. Later he wrote the "Nitrox Blender's Handbook" which is published by IANTD. Gene was in the initial group of cave instructors certified by the NSS-CDS and is a Life Member and Fellow of the NSS and a Life Member of NSS-CDS. As a submersible pilot/electronics engineer/diver, Gene performed submersible lockout dives to 600'. After 15 years in the Space Shuttle Solid Rocket Booster Retrieval program he left the Kennedy Space Center to work on the Super-Conducting Super Collider project. When the SSCL project was closed, Gene moved back to Florida and started development of the HS Explorer dive computer. To date, the HS Explorer is the only dive computer to fully implement the RGBM deep stop algorithm. Further developments include the Explorer PPO_2 monitors and the Neptune Closed Circuit Rebreather. Gene's instructor credentials include IANTD, NSS-CDS CCR Cave and FAA Airplane, Single and Multi-engine.

Simon Mitchell, M.B. ChB., Ph.D.

Dr. Simon Mitchell's 30 year diving career has included more than 6000 dives spanning many disciplines including sport, scientific, commercial, and military diving. In recent years his diving interests have focused on photography and technical diving. He is an avid deep mixed gas diver and uses an Mk15.5 closed circuit rebreather. Simon is a diving physician and anaesthesiologist and has more than 40 papers in international medical literature. He recently co-authored the second edition of "Deeper into Diving" with John Lippmann, and authored 2 chapters on decompression sickness in the most recent edition of Bennett and Elliott. He is currently Vice President of the Undersea and Hyperbaric Medicine Society, and Chairman of the Society's Diving Committee.

Simon Pridmore

Simon Pridmore - Simon Pridmore is a former Hong Kong Police Officer and Assistant Political Adviser to the Governor of Hong Kong. He was one of the pioneers who introduced technical diving to Asia in the mid-1990s, has been a member of the IANTD Board of Advisors since 1995 and ran a dive centre in Guam for 7 years while holding the IANTD License for Micronesia. Since 2003 Simon has been the IANTD Licensee in the United Kingdom, is an IANTD Instructor Trainer Trainer and works with VR Technology, developers of the VR3, the Ouroboros and Sentinel Closed Circuit Rebreathers.

Martin Robson

Martin Robson is an IANTD Open Circuit and CCR Trimix Cave Instructor Trainer Trainer. He specializes in overhead environment and closed circuit rebreather training and was the first ever IANTD CCR Cave Instructor Trainer. Martin regularly contributes to training manuals on all aspects of technical diving and has been published in magazines in the UK, USA, Scandinavia and Russia. He is an experienced cave explorer having conducted substantial expeditions with major penetration to depths over 600 ft (180 m) in the caves of Europe. Martin enjoys diving in extreme environments and has taught and dived in caves, wrecks, flooded mines and under ice from the arctic circle to the equator.

David Sawatzky, M.D.

David Sawatzky is currently a physician with the Canadian Armed Forces in Halifax, Nova Scotia, Canada. He was a Diving Medical Specialist on contract at Defence Research and Development Toronto (formerly DCIEM) from 1998 to 2005. Previously he was the Canadian Forces Staff Officer in Hyperbaric Medicine at DCIEM (1986-1993) and later the Senior Medical Officer at Garrison Support Unit Toronto (1993-1998). He writes a diving medicine column for Canada's Diver Magazine and Australia's Sport Diver Magazine, is on the Board of Advisors for IANTD, and is an active Cave, Trimix and Closed Circuit Rebreather Diver / Instructor / Instructor Trainer. David has done over 600 cave dives, most of them original exploration/survey dives in Canada's cold, remote and challenging caves.

R. Todd Smith

R. Todd Smith began diving in 1981 in Lake Superior and ice diving there in 1983. Combining extensive experience in cold weather back country travel, mountaineering and ice and technical diving he authored the PADI Ice Diving course in 1989, followed by "Beneath A Crystal Ceiling, the Complete Guide to Ice Diving" (available through IANTD). He has trained hundreds of ice divers and police, military and public safety divers across the U.S. and more people learn ice diving through his materials and procedures that any other. His ice diving pursuits extend throughout New England, the Great Lakes and both polar regions, in addition to extensive deep wreck and cave diving world wide. Todd is an IANTD Instructor Trainer Trainer and PADI Course Director. He and his wife Anita, a USCG licensed Captain and technical diver, plan their next adventures from their base camp on Cape Cod.

Roberto Trindade, M.S.

Roberto Trindade, M.S. - Roberto holds a MS in Psychology and is specialized in pscicomotricity, psicopedagogy and marine archeology. Roberto holds Instructor Trainer credentials with IANTD, DAN and PDIC. He has also earned instructor certifications with PADI, NAUI, CMAS, SSI, TDI and HSA. He is also certified to teach First Aid / CPR / AED with many agencies, including the National Safety Council and the International Federation of Red Cross and Crescent Societies. He is also a certified Water Rescue Instructor with the National Pool and Waterpark Lifeguard. Roberto is a member of the Historical Diving Society, the Brazilian Speleological Society, the Undersea and Hyperbaric Medical Society, among other societies.

John Zumrick, M.D.

John Zumrick, M.D., Capt., MC USN (Ret.), is a former Medical Research officer and Senior Medical officer at the US Navy Experiential Diving Unit. While there, he was responsible for major investigations on CCR diving apparatus, thermal protection, and deep saturation diving experiments. He has been the subject of numerous diving physiological experiments and was a dive subject on many saturations, one lasting 37 days which reached 1,500 fsw (458.7 msw). In his off-duty time John, an IANTD Trimix Diver, can be found cave diving in Florida, the Bahamas, and Mexico. John started cave diving in 1971 and has been responsible for original exploration of numerous springs and caves. He is a fellow of the National Speleological Society and of the New York Explorers Club.

Lamar Hires

Lamar Hires is a modern day explorer and dive pioneer. A legend among cave divers, Lamar is known for his expertise in sidemount diving. He developed the very first training guidelines for sidemounting and has taught many well-known sidemount divers.

Underwater exploration, education and conservation are a passion that has led Lamar all over the world. He has mapped and explored cave systems from the rugged mountains of Japan to the remote jungles of the Dominican Republic. Not a stranger to the ocean, Lamar's curiosity for exploration has taken him to the rarely dived icy waters of the Antarctic as well as countless wreck dives off the coasts of Florida and the eastern United States.

When Lamar began diving in 1979, exploration-quality dive equipment was not commercially available. In 1984, Lamar joined a start-up dive equipment company called "Dive Rite" and there he helped bring to market the first buoyancy compensator for double tanks known as the "Classic Wing." Dive Rite also mass produced the first metal backplate and invented the "Bridge," which was the industry's first Nitrox-compatible dive computer. In 1997, Lamar purchased Dive Rite and has grown the company into a worldwide dive manufacturer with distribution in over sixty countries.

Affiliations & Awards

IANTD Board of Advisors (current)

National Speleological Society, Chairman (1992-1994)

National Speleological Society, Training Chairman (1987-1992)

International Underwater Cave Rescue and Recovery (IUCRR) Training Coordinator (current)

National Speleological Society, Lifetime Fellow Award

Florida Springs Exploration Award, 2000

Contributing writer for *Advanced Diver Magazine, Divers Magazine, Scuba Times and Sport Diver Magazine*

Contributing author NSS-CDS Cave Diving Manual

Contributing author IANTD Technical Diver Encyclopedia (1998, 2000 & 2003)

IANTD Instructor Trainer: NSS-CDS instructor and former Training Director

INTERNATIONAL ASSOCIATION OF NITROX & TECHNICAL DIVERS

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