TABLES OR COMPUTERS; HOW BEST TO CONTROL DECOMPRESSION

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Decompression

Every dive is a decompression dive involving on-gassing and off-gassing from the blood and tissues. There is no such thing as a no-decompression, or more properly a no- stop, dive. We use that term to describe dives from which direct return to the surface is usually safe. The rate at which we on- and off-gas the tissues is a function of the pressure gradient, solubility and diffusion characteristics of the gases and of the blood flow in various tissues. Multi-day multi-level diving may result in residual nitrogen levels that accumulate over a period of days which may not be reflected in the tables or in diving computers which are not kept operational for the duration of multi-day diving excursions.

All tables and dive computers are based upon assumptions. The assumptions may reflect interpretations of research findings, attitudes of the designer, consistencies of human behaviour, environmental constants, consistent rates of change in pressure, and other factors which are not readily quantifiable. It should be clearly understood that the assumptions are largely unavoidable since the state of the art is still under development. Tables and computers are different because the people behind them have used different assumptions, different techniques, different kinds of modelling formula and unsurprisingly, they come up with different answers to basically the same problem. The purpose of table and dive computer technology is to provide criteria and monitoring capability that will enable a diver to plan, and execute, a reasonably safe dive profile, one with a low probability of a decompression accident. They are tools that can help us minimize risks. We must accept their limitations when we plan and execute our dives and to do that the diver must develop the understanding and skill to be able to use them effectively. The old saying that only a poor carpenter blames his tools applies to divers.

The current emphasis on safe decompression procedures has led to considerable confusion. Much of the confusion appears to be related to a fundamental misunderstanding. Many people buy a decompression table or dive computer with the belief that it is going to protect them from decompression sickness. Allegations that a particular table or dive computer “bent” someone should be viewed with extreme caution since tables as well as dive computers are simply tools used to reduce the risks associated with decompression in diving. There is not and never has been a set of tables, or a dive computer, that can eliminate 100% of the risk of a decompression accident 100% of the time. One of the reasons for that is pretty obvious, we are all different physiologically. There is wide inter- and intra-individual variability in the response to a given diving profile. At best, we take a calculated risk each and every time we dive. The best we can hope for is that the table or dive computer we are using on a given dive profile will be compatible with our individual response and result in a problem free ascent.

Divers, decompression tables and computers

There are many divers who still have not got the foggiest clue as to what decompression really means. They simply want to be told what to do and when. Probably the most common decompression routine is where the divemaster says 24 m for 30 minutes. One comes up at the end of the dive, sits out for 45 minutes to an hour and then is told to go back to 18 m for 40 minutes. Everyone dutifully goes about their business. Fifteen to 20% ignore the instructor completely. They go as deep as they want and stay as long they want and, if they come back up to the surface without any difficulty, they write down depths and times using the “Woolworth Effect” (everything finishes in 5s and 10s).

The current situation with regard to tables and dive computers reminds me of a remark by Poul Anderson, many years ago, when he observed, “I have never encountered a problem, however complicated which when viewed in the proper perspective did not become more complicated”.

Individuals should know and appreciate their own limitations in relation to each dive. Neither the table nor the dive computer has a clue regarding ones physiological and mental state. To reduce decompression sickness risk in divers we have to look at other things as well as depth and time. A few of these are age, obesity, physical exertion, hangovers, state of health, physical condition, post-dive exercise and dehydration. We dump an awful lot of water while diving. Immersion decreases central blood volume and negative pressure breathing also inhibits antidiuretic hormone. Dry gas is saturated during respiration. You are exercising, you sweat underwater at a high rate. All these mechanisms take water out of the blood and put it in other places, including the open sea. A diver working for an hour at 45 m will lose about a litre and a half from his circulating blood volume. One does not have to go that deep to be losing roughly equivalent to the amount of fluid that an athlete loses when running a marathon. You can lose about a litre to a litre and a half an hour, and you should be replacing that fluid or you are going to end up in a dehydrated state. This can be cumulative over a number of days. It is also important to recognize that individual susceptibility to decompression illness can change during the dive and between dives on the same day as well as between days.

Regular exposure to increased pressure appears to reduce individual susceptibility to decompression sickness. Thissuggests that a progressive increase in exposure to greater depths is a good idea and that deep dives following long periods of inactivity are a bad idea.

The past

When I started diving there was only way to do the job. You went in, followed the instructions, did the dive the way you were supposed to and a certain number of people got hurt and that was of the way the ball bounced. In fact, when we dive we are still taking a calculated risk each and every time we put our heads under the water.

My first depth gauge was a capillary depth gauge. It was amazingly simple and extremely accurate in shallow water. But it gets a little less accurate as one goes deeper and finally the lines get so close together that one cannot be sure of the exact depth.

Later bottom timers and depth gauges that are accurate over a wider range were produced because it is important to monitor depth and time. We really have not come very far since then. We now pay $US 400 to $US 600 for devices that are very good time and depth recorders. But they also do calculations that may, or may not, be in our best interest 100% of the time. A computer does not do any more than we have been able to do from the time since we first had waterproof watches and some kind of depth gauge.

Divers get into the water and look down. The water is clear and everything is wonderful. Someone in the group sees something in the distance We wander down. As we go down we notice that light does not penetrate as well as it did. That does not stop us and probably never will. At around 36 m we find something that is truly wonderful. We now have a focus of interest. Unfortunately humans, when we start to narrow our focus, tend to forget about peripheral things like time and depth. We lose interest in having to leave this depth before doing all the things we want to do. Finally someone probably notices that we have been down quite a while, looks at the depth gauge and at the watch. If they can remember what time they left the surface, they may have a clue as to how long they have been on the bottom. Then we start to round up the troops and go up to towards the surface.

Even in the good old days, if we knew that we had over stayed our welcome in the deep we took it upon ourselves to do some kind of hang off somewhere in the water column. Most of us were trained that one must hold the depth gauge level with the centre of the chest and it must read precisely 3 m (10 ft). This proved difficult, because occasionally swells came through and one went from 3 to 6 m (10 to 20) ft very rapidly.

Tables

We had the much maligned US Navy (USN) decompression tables of 1958, where 18 m for 60 minutes is a no-stop dive and at 36 m 15 minutes is a no-stop dive. These tables have the largest database and smallest incidence of accidents of probably anything we have with a comparable number of exposures. I get a little annoyed when people say the USN tables are bad. There are some areas in the USN tables that we know are not what they should be and it took many, many years find that out. Thousands of dives have been done safely on these tables, primarily because very few people, including the old USN Chiefs that run USN diving, ever operated the tables as they appear on the page. Most of the dives were done at shallower depths. They were not done as square dives, they were done as some kind of variation of a square dive. The tables accepted a particular incidence of decompression sickness. Rumour has that it one time it started off with a model of 5%. As the tables were refined it came down. The last time I heard it was 0.6%, less than one in a hundred. One in a hundred is still a pretty high incidence when one thinks of the kind of damage that can be done. But the bottom line is that these tables are still widely used today. Many people reject some of the other tables because they do not really understand what advantages they would get from them.

There are a number of tables available that are literally the USN tables, rearranged in layout and how to read them. The numbers and the assumptions underlying these tables are the same. Some tables were rearranged because the producers thought that divers were not bright enough to learn how to use the tables. So they gave them something to put a finger on and run it around three or four places to give better accuracy and so better protection. Unfortunately the protection available does not change with the format.

The recreational divers now using the USN tables are not young, healthy, male, athletic individuals who are under military discipline. So diving organisations reduced times. There are tables with shorter no-stop times, 50 minutes at 18 m instead of 60. There are minor modifications in terms of how these tables predict on- and off-gassing. This is an interesting approach because logic says if we cut the times down we are making these tables safer. But, in fact, making the times shorter does not eliminate the possibility nor the probability of decompression sickness. There are too many other variables.

The DCIEM tables are very popular because they are very conservative. They have a database and an experimental background. It is interesting that when doing the Doppler studies there were bubbles on about 70% of the dives to the limits of depth and time. They were only grade one or grade two bubbles and sometimes a few grade three bubbles. The DCIEM team were not really concerned unless there were grade three bubbles or higher.

Then there is the Recreational Dive Planner or the PADI Wheel. The PADI wheel is accumulating a good database. It has received a great deal of marketing acceptance. It is probably as good as anything that is about. It uses the 60 minute tissue to control the repetitive interval because that fits better with typical recreational dives than the 120 minute tissue used by the USN tables. It is based on certain assumptions that differ from the other tables. The tables are being tested and a database is being accumulated. However, it is not going to be a bends free table as there is no such thing. As long as we understand these facts and make the decision that we want to use it and agree that we will take the calculated risk that this particular device puts on us, then everything is fine.

If people are bubbling on the most conservative dive tables that we currently have, we have a problem. After your dive today probably more than 60% of you would have Doppler detectable bubbles, for one reason or another. If you get on a bicycle ergometer and pedal up to a maximum VO2 level wearing a Doppler, you start throwing some bubbles at 1 ATA whether you had been diving or not ! Bubbling may not be the best criteria that we have for safety. But it bothered me as, to me, bubbles have been the problem. Even though the bubbles are on the venous side, and the lung is a wonderful filter, we now know that bubbles can pass through a patent foramen ovale or other shunts to the arterial side. So any bubbles seem to be something that we should be concerned about as there are circumstances under which the lung does not filter as well as it does at other times. We do not really know much about that and none of that is built into the tables.

All tables have the same basic problem. They are concerned with depth and time and certain figments of the imagination. The figments are the assumptions that tissues fall into compartments that have different half times. There are a number of things that interfere with those assumptions, but using half times is still the way that tables are derived and we have data that says that they work really quite well. There have been thousands, perhaps hundreds of thousands , perhaps millions, of dives on virtually all the tables and we have a relatively low incidence of decompression sickness. Perhaps not as low as it should be but it still relatively low.

Shrinking bottom times

The USN tables no-stop time of 25 minutes at 30 m was accepted for a long time. Then NAUI, PADI, Huggins and the BS-AC reduced the no-stop limit by 5 minutes, in order to make it more compatible with the recreational population. The Suunto dive computer cut it to 18 minutes, the Germans came down to 17 minutes, the DCIEM tables came down to 15 minutes, the MicroBrain and MicroBrain Pro Plus went to 12 and 11 minutes respectively. Incidentally, the algorithms in these two are done by the same man.

There is the new terminology of risk assessment. It perhaps is not new in epidemiology, but for diving it is new. What would you have as bottom time at 30 m if you wanted to have a maximum risk likelihood of 1% ? The current wisdom says that is going to be 8 minutes. Now there is a considerable difference between diving 8 minutes at 30 m (to get that kind of protection, but notice it is not perfect, and spending 25 minutes at that same place with a risk that is still less than 1%, statistically 0.6%. I just want to know who is right. I want someone to tell me what I should do so that I can get maximum protection.

Each dive computer that comes onto the market gives less bottom time than the one before it. I think the logic behind it is “I have an algorithm that is safer than their algorithm, how can I be criticised?”. So each one in turn came out with less. There is a serious problem. If my understanding of human nature is correct, no one wants to buy a computer that only gives 9 minutes when his peers are buying ones that give 18 or 20 minutes. That would be like saying I am not as good or not as fit as they are. So divers go out shopping for the set of tables or dive computer that is going to give the most time. Divers want to be able to stay down as long as possible.

The old SOS decompression meter, rather rudely called the “bendomatic”, when tested against a set of tables would often allow the same no-stop dive on every dive of a repetitive series. The tables however would start stacking up decompression time so at the end of the four dives the SOS meter would be about a half hour of decompression time short. Some got and some did not get decompression sickness.

Dive computers

The next step was when a group of people put together an electronic device. We entered the computer age. Orca Industries, in conjunction with Carl Huggins, put together some algorithms and some computer technology. The Edge is a very fine watch and depth gauge with some assumptions in terms of what depth and time mean relative to tissue compartments. A dive computer has a pressure transducer, an internal clock, a microprocessor unit, a read only memory, access memory, power supply and some way to display the results. Within this basic construct we put the infinitely variable human mind to work. We all have ideas about how and what kind of information should be displayed.

Once an individual was found to be wearing a Edge with the five holes that let water get to the pressure transducer firmly against his forearm. When asked why he said that it was the physiological monitoring area and he assumed that it was monitoring his physiology. He would occasionally make sure that it was in position so that the monitor would work. When it was suggested that for it work properly he should have put the openings away from the skin he was outraged because he thought that for around $695, he was getting something that was monitoring his decompression status. He was angry when he found out that all it is monitoring is the Edge’s decompression status. If you have the same characteristics as the program inside the Edge you will be in good shape. If not you have a level of risk associated with decompression that is a function of how different you are to what is going on inside the machine.

The American Academy of Underwater Sciences (AAUS) recently brought together 50 people from all over the world, representing medicine, physiology, physics, engineering, highly experienced divers and instructional agencies. At Catalina Island we went through a lot of the concerns associated with the question of "Do we use computers or do we use tables?".

The basic problem is that using five computers, as I did, to track the same series of dives it became obvious that there are variations that ranged from owing decompression to having hours of remaining dive time. This is really unfortunate. The reason is that the algorithms developed for the different dive computers are different. Also each meter, not only had a personality that differed from its counterparts in the industry, but in many instances they have little idiosyncrasies that provide subtle differences between instruments, such as variations in pressure transducer sensitivity.

Part of the difference is the way they treat multi-level dives. We want to keep track of on-and off-gassing as we progressively move towards the surface during our dives. This is generally the way that recreational dives are done and there is a lot of heartburn associated with getting a square dive calculated risk when making a multi-level dive which should be getting safer.

Because of the differences between computers each diver relying on a dive computer to plan dives and indicate or determine decompression status must have his own unit. AAUS had to make that rule when setting guidelines for scientific divers because a number of folks involved thought that one per buddy pair, like a dive watch, was entirely adequate. But if you have on any given dive two dive computers, you must follow the more conservative dive computer. My dive buddy today, I think would have been a little more than reluctant to dive with me had he known that on virtually every first dive this week, on one of my computers I went into decompression. On the other one I had not. That is part of the risk that I take as an individual.

Once a dive computer is in use it must not be switched off until it has indicated that complete out-gassing has occurred or 18 hours has elapsed, whichever comes first. If one leaves an Edge on all week usually by the second or third day it is saying that you still have some nitrogen left over from yesterday and the pixels start building along the slow tissue compartment side of its face. That is probably reflecting real life.

The notion that we can dive for infinitely long periods in shallow water for multiple days is now recognised as more hazardous than previously thought. We are now more concerned about the potential damage of long multi-day and multi-level diving than we have ever been in the past. The dive computer does enable us to dive multi-level because it says you pay for what you are using at any given time. When using an Edge watch the pixels fill in. Notice that the fast tissues go in really quickly. But when you come up a bit the pixels empty almost instantaneously. The ones to be concerned about are those of the slow tissues that tell you how much nitrogen you are retaining.

Ascent rate equals the rate of change of the pressure gradient for decompression purposes. Rapid gradient changes have been identified as a potential trouble-maker in the case of decompression problems. Years ago Campbell showed that divers come up much faster than they USN tables require. A group 20 or so sport divers were taken to the bottom where they were at at 18 m (60 ft). They were given some nonsense arithmetic to do. The observers were ostensibly studying the effects of shallow water narcosis. They were, however, studying ascent rates. They had a signalling device to the surface. When the person left bottom, the signal started a stop watch, which was stopped when the person broke the surface. The time was recorded. The divers were asked "Did you come up at your normal ascent rate?" The answer was almost always "Yes". "How fast did you come up?" Those who could answer this usually said "I came up at no faster than 60 ft per minute with my small bubbles". However when we analysed the data, the average ascent rate for the group was about 51 m per minute.

At this time there is confusion regarding the safe rate of ascent. Tables and dive computers are based upon rates of ascent ranging from 9-18 m per minute. The Edge has three different ascent rates depending upon where you are in the water column. The majority opinion is that ascending at 12 m per minute is better than ascending at 18 m (60 ft) per minute. Slower ascent rates are probably less likely to produce problems for divers.So the AAUS has said that its people will not ascend faster than 12 m per minute in the last 18 m of the water column.

Most people ascend much more rapidly than they think they do because none of us have a really good way of being able to monitor ascent rates. Some of the dive computers today have little lights or messages that will come on and if you are watching, the computer will tell you when you are exceeding the ascent rate. Some of them even have audible alarms.

A couple of computers, that are no longer manufactured, simply shut down if you ascended too fast. It would not give any more information. That was supposed to be a clue that you should not dive again until the computer turned itself on some time later. An ingenious idea but it left the diver without advice during the over-rapid ascent.

Taking a stop between 3 and 9 m for 3 to 5 minutes, whenever practicable, is really cheap insurance. The advantages of taking safety stops at depths of 5-6 m rather than 3 m include better control of depth and position and possibly more stable off-gassing. This advice is tailored primarily for those people using dive computers.

The majority of the computers will let you go back to 30 or 45 m just about any time you want to. This is based on the assumption that if the controlling tissue is a fast tissue, it has off gassed. There was an Edge Club, which was going to do a 39 m dive until the pixels filled the no-stop area then come up and sit until those tissues cleared, then back down to 39 m and repeat the process all afternoon. They had some problems.

One of the first rules one learns about repetitive diving is "Always make your deep dive first and every dive following that in a 24 hour period, shallower". That is pretty good advice. Even if the mathematics in the dive computer says that you can make these deep repetitive dives, humans really cannot. You have to be smart enough not to make that kind of a mistake.

One day, perhaps, we will have a dive computer that may be able to factor in a few of the other variables. When you are facing into a current, your work rate is much higher than when you are making a nice easy drift. This sort of thing has not been factored into any of the computers or any of the tables that we currently have. The closest thing is a statement in USN tables that said, if the dive is cold or arduous, you must take that into consideration by going to the next gradient on the time/depth scale.

Deep diving

We have a deep dive mania developing in the United States. People want to go deeper, they want to stay longer and they do not want to have to pay the price in decompression time They have gone into this "recognising that we can use air a lot deeper than we thought". A man claims to have done a 452 ft dive on air. I think the only people to witness that dive was the man and his girl friend. That dive is clearly beyond the bounds of what we would consider reasonable. However there are some dive computers that are designed to accommodate this quest for depth.

We also have computer generated designer tables. Cave divers produce one off tables for a particular penetration using a PC fed with the depth profile and the gas mix (which may be or may not have been obtained by gas analysis). These tables are used completely untested. They also do not take into consideration any of the other variables.

Conclusions

One's risk of bends is unpredictable on any given day or any given dive. The best thing you can do is dive conservatively. Diving conservatively is not going to prevent decompression sickness. We have to understand that it is one of the calculated risks we take as a diver. If we do get decompression sickness, we should not run around screaming for someone's head to roll, because the bottom line is that each individual who uses a table or dive computer does, in fact, elect an informed consent to all of the risks in diving. That requires education. In most instances the manuals that come with tables or computers discuss the nature of that risk and in doing so put the burden squarely on the diver. If you do not know what you are doing perhaps you ought not to be doing it.

The limits of the tables and the dive computers are arbitrary as are the designations of tissue half-times and other concepts used in modelling the decompression schedules. These devices provide guidelines. Those divers who press the devices to their limits are working in the vicinity of the cutting edge and should not be surprised if they are injured.

This is an edited transcript of a lecture given by Dr Egstrom when he was the guest speaker at the SPUMS 1991 Annual Scientific Meeting.

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