MODELING THE RISK OF DCS IN EMPIRICAL DIVING TECHNIQUES

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INTRODUCTION

Empirical diving techniques used by commercial sea harvesters have largely developed through many years of trial and error. In many cases, these techniques, consisting of multiple repetitive dives, have resulted in apparently safe diving schedules even though they do not obey safe diving practices as specified by deterministic decompression models that are commonly used for developing normal diving tables or dive computers. In fact, conventional methods for calculating dive profiles or repetitive dives would make such dives not feasible since the decompression requirements would be prohibitive. In other cases, this type of diving often does results in serious cases of decompression sickness (DCS) because of inadequate decompression times.

MODELING of the dive profiles actually used by commercial sea harvesters would be valuable in developing more accurate models of decompression to determine the risk of DCS for complex dive profiles. These could then be used to develop diving procedures and schedules that would increase the health and safety of the divers. However, it is often difficult to analyze current dive practices because the actual dive profiles are not known accurately and have to be reconstructed from what the diver reports was done. In many cases, for multiple repetitive dives which result in DCS, the surface interval between dives is not accurately known. Thus these profiles are often not reliable and are not suitable for analysis.

This presentation will discuss the modeling and analysis of empirical diving techniques using the mathematical model behind the Defence and Civil Institute of Environmental Medicine (DCIEM)/Canadian Forces air decompression tables (1) and a probabilistic model of decompression based on Doppler ultrasonic bubble scores (2). The work was initially started using the DCIEM model to analyze dive profiles being carried out by the pearl divers of Western Australia (3,4) and to try to calculate safer decompression procedures by providing adequate decompression times, particularly for progressively deeper dives. The advantage of working with these dives was that accurate depth-time information was available since the dives were tested in a chamber. Several other dive profiles were also analyzed, including dive profiles resulting in DCS that were conducted by diving fishermen in Kyushu, Japan, as reported by Kawashima et al. (5).

METHODS

Two analysis methods were used to model and analyze the safety or risk of DCS of the dive profiles. The first was a conventional gas loading/supersaturation analysis using the DCIEM 1983 air decompression model. Unlike the usual Haldanian decompression models, the DCIEM model is an empirical model consisting of four compartments in a series arrangement rather than in parallel. This deterministic model is based on the original work done by Kidd and Stubbs (6) in developing a dive computer designed for random depth and multiple repetitive dives. Figure 1 shows an example of some of the dives done by Kidd and Stubbs in developing their model. The 1983 model was used to calculate the gas loading and to apply the ascent criterion based on gas supersaturation to determine the "Safe Ascent Depth (SAD)". Whenever the SAD is greater than zero, decompression is required according to the DCIEM model (Fig. 2). The aim in using this model was to first determine the adequacy or inadequacy of the dive profiles in providing sufficient decompression and then to modify the decompression requirements.

The second analysis method uses a probabilistically based gas bubble evolution model to calculate the gas loading for the dive profiles and determine the theoretical formation and growth of bubbles resulting from multiple repetitive dives. In a probabilistic model of decompression, the parameters of the model are determined by calibrating the model with a large number of real, accurately recorded dive profiles in which the outcome (DCS or no DCS) is known. The model is fitted to the data using the principle of maximum likelihood. The model can then be used to generate decompression tables or dive profiles for a given DCS risk level or to analyze the risk of DCS for any given dive profile. In the DCIEM implementation of the probabilistic model (Fig. 3), the model was fitted to real dive data in which the outcome was venous gas emboli detected by Doppler ultrasonic bubble monitors (7) rather than DCS (2). This model, consisting of only two compartments, can then be used to calculate the formation and evolution of bubbles for any given dive profile. An example of bubble evolution in the first and second compartments after a dive to 45 msw for 30 min is shown in Fig. 4. Note that the bubble is predicted to persist for a long time after a dive. A comparison of the bubble evolution model with a probabilistic model based on DCS risk shows that there is a correspondence between the maximum bubble size, R_{max}, attained and estimated DCS risk (8). Thus the bubble evolution model can be used as a measure of the risk of DCS and assist in refining the dive profiles.

RESULTS

Figure 5 shows an example of a typical multiple dive sequence for a pearl diver that consists of 10 repetitive dives to 19 msw. The bottom time for each dive is 40 min with a 20-min surface interval. The ascent rate is 3 msw/min and decompression stops are taken at 9 msw with oxygen on dives 6, 8, and 10. An analysis of this sequence of dives using the DCIEM SAD model (Fig. 6) shows that each dive after the second dive requires considerable decompression and would be unsafe. This particular sequence, tested in 1992, did result in a case of DCS.

Extensive experience with using the DCIEM model with dives done successfully at shallower depths had shown that the model might be conservative for this type of diving and that the divers might be able to surface with a SAD of 1–1.5 msw instead of at 0. The decompression requirements for the 19-msw dives were calculated from the SAD model by Dr. R. Wong by introducing O_2 decompression stops for all dives. The criterion for surfacing after each dive was the SAD value being less than 1.5 msw. Figure 7 shows the calculated SAD for the modified 19 msw dive sequence. The total number of dives was reduced to only 9 dives instead of 10. This dive sequence was tested successfully in 1996 without any incidence of DCS.

Figures 8 and 9 show the calculated bubble evolution for the 1992 and 1996 19 msw profiles. During the surface interval, the bubble growth is limited since the surface interval is so short and the pressure increase associated with the next dive causes the bubble to decrease in size. However, after the final dive, the bubble can grow considerably. For the 1992 dives, the bubble reaches a maximum radius (R_{max}) of approximately 73 μm. In the 1996 dives, the addition of oxygen stops for each dive reduces the bubble growth during the surface interval. The additional decompression and the elimination of one dive are sufficient to limit R_{max} to under 60 mm.

It should be noted that the maximum bubble radius, R_{max}, is a model output that should be viewed as an index instead of an actual physical bubble size. Previous applications and studies using the bubble evolution model have revealed that R_{max} >60 μm was associated with DCS.

Figures 10 and 11 show a comparison of similar profiles that have been described by Kawashima et al. (5). These consist of five dives to 18 msw for 40 min, with one sequence having a surface interval between dives of 10 min and the other with a surface interval of 20 min. The SAD analysis show that both sequences need considerable decompression at the end of the dives. The bubble evolution model shows that R_{max} after the dives is approximately 80 μm. Both of these dive sequences resulted in DCS.

The influence of the length of the surface interval between dives can be seen in Fig. 11 where the short 10-min surface interval keeps the bubble radius smaller than with a 20-min surface interval. Although this may imply that a short surface interval is better than a longer surface interval, contrary to normal safe decompression practices, it should be kept in mind that very short surface intervals may not be beneficial in practice. Physiologically, a longer surface interval may be better since it allows the body to off-gas for a longer period. The bubble size at the end of the surface interval should be kept below a DCS threshold.

Chamber dives from 11 to 23 msw that were done to evaluate the diving schedules and practices being used by the pearl divers were analyzed using the probabilistic bubble evolution model. The dive subjects in these dives were also monitored for decompression-generated bubbles in the circulatory system using the Doppler ultrasonic bubble detector (4). Figure 12 shows the calculated maximum bubble size for a number of different dive schedules at depths from 11 to 23 msw. For each depth, there were a number of dives with varying amounts of decompression. The results show that for those dives in which R_{max} was greater than 70 μm, DCS generally occurred. For those dives in which R_{max} was less than 70 μm but greater than about 60 μm, high Doppler bubble grades were generally observed. For R_{max} less than 60 μm, no bubbles or low Doppler bubble grades were normally observed. Although the results shown are from a limited subject database and there is some variability in the results, it is clear that dives which produce large bubble sizes should be avoided and that sufficient decompression should be given to try to keep R_{max} after the last dive to less than 60 μm.

Figure 12 also shows the results from the two dives reported by Kawashima et al. (5) (Fig. 11). Analysis of a number of other dives reported by these investigators in which the divers incurred DCS showed that R_{max} varied from 77 to 130 μm.

In these multiple repetitive dives with relatively short surface intervals, the bubble growth between dives is limited. However, there could be a potential problem if the surface interval were to be extended. For example, if some mechanical problem prevented the divers from continuing on with the next dive, there may be sufficient time for bubbles to grow large enough to cause problems. An example is shown in Fig. 13. During dive trials of these multiple repetitive dives, observable Doppler-detected bubbles are generally below bubble grades I or II during the surface interval. On several occasions when a delay was encountered or when dives had to be terminated, Doppler-detected bubbles rose to grade III levels after approximately 90 min. Thus it is important in designing dive schedules such as these that adequate decompression be given after each dive as well as after the last dive of the day.

The pearl divers dive schedules are rather well-defined and regimented consisting of a number of similar dives done at regular intervals. There may be a number of reasons why these divers seem to be able to dive safely (9). These may include the slow rate of ascent, appropriate decompression stop depth, use of oxygen, a suitable surface interval and perhaps acclimatization. Diving procedures for many other commercial seafood harvesters, on the other hand, are not as regimented, with multiple dives consisting of depths, bottom times, and surface intervals that may vary considerably and with little or no decompression on any of the dives. Figure 14 shows an example of such a dive profile where the diver incurred DCS.

The upper graph shows the profile that was actually dived (reconstructed from a description provided by the diver) and the bottom graph shows the decompression that would have been required according to the DCIEM SAD model. In the actual dives, decompression stops of a few minutes were taken at depths less than 10 fsw. The bubble evolution model shows that maximum bubble size attained is in the DCS range shown in Fig. 15.

The final profile analyzed was a series of no-decompression dives that were done using a dive computer with a data logger. The analysis was done on the actual profile that was recorded. The calculated SAD is shown in Fig. 16. According to the DCIEM SAD model, this sequence of dives would be safe. The bubble evolution model (Fig. 17) also shows that the maximum bubble size resulting from the dives would be well below the DCS or high bubble threshold levels. One concern would be that the very short dives (such as dives 4 and 5) are not sufficiently long for the gas phase to go back into solution. It would appear that the use of a dive computer, if followed properly, may be beneficial for this type of diving.

SUMMARY

MODELING of complicated dive schedules involving multiple repetitive dives as carried out by commercial seafood harvesters appears to be useful to predict the risk of DCS. Although traditional gas loading/supersaturation models, if designed for this type of diving, are useful to estimate the decompression requirements, the growth of bubbles after diving must also be taken into consideration in determining the risk of DCS. The probabilistic bubble evolution model of decompression appears to be a more accurate indicator of the risk of DCS. For multiple repetitive dives, the maximum bubble size attained after the last dive is of great importance, and it is necessary to provide enough decompression for the last dive to limit the bubble growth to a size below a DCS/high Doppler bubble grade threshold.

The surface interval between dives is also important. Short surface intervals limit bubble growth between dives and may explain why higher supersaturations may be tolerated without symptoms of DCS. On the other hand, very long surface intervals between successive dives may allow greater bubble growth and may provide some increased risk of DCS under conditions in which there is high gas loading. The probabilistic bubble growth model, combined with gas loading calculations, can provide a valuable tool for modifying complex dive profiles and reducing the risk of DCS.

With the type of diving carried out by commercial seafood harvesters, we have a valuable source of data in which decompression requirements are being pushed to the limits and there is a high outcome of DCS. MODELING these types of dives can help us to develop better decompression models, both deterministic and probabilistic, and lead us to a better understanding of the decompression process. This then would help us to develop safer diving procedures for these divers. It is important that we be able to get accurately recorded dive profile information along with DCS and high bubble grade outcomes to help us develop or further refine our models. The use of dive computers with depth time recorders or data loggers would be a step in the right direction.

The author thanks Dr. Robert Wong for providing all the information and data on the pearl divers' schedules, chamber trials, and Doppler bubble monitoring, and for his valuable collaborative effort in analyzing the dive schedules; Mr. Keith Gault and Dr. Peter Tikuisis for the development of the probabilistic bubble evolution model; and Dr. M. Lepawsky, Dr. C. Lehner, and Dr. A. Pollard for providing unpublished dive profiles

REFERENCES

1. DCIEM diving manual: Part 1, air decompression procedures and tables. DCIEM No. 86-R-35, Richmond, BC: Universal Dive Techtronics, Inc., 1992.
2. Gault KA, Tikuisis P, Nishi RY. Calibration of a bubble evolution model to observed bubble incidence in divers. Undersea Hyperbaric Med 1995; 23:249–262.
3. Wong RM. Western Australian pearl divers' drift diving. SPUMS J 1996; 26(suppl.):30–35.
4. Wong RM. Doppler studies on the dive schedules of the pearl divers of Broome. SPUMS J 1996; 26(suppl.):36–48.
5. Kawashima M, Tamura H, Noro Y. Studies of decompression sickness in Japanese divers. In: Proceedings of the 13th meeting of the United States-Japan Cooperative Program in Natural Resources Panel on Diving Physiology. Miura, Kanagawa, Japan. 1995:101–113.
6. Kidd DJ, Stubbs RA. The use of the pneumatic analog computer for divers. In: Bennett PB, Elliott DH, eds. The physiology and medicine of diving and compressed air work, 1st ed. London: Bailliere, Tindall and Cassell, 1969:386–413.
7. Nishi RY Doppler and ultrasonic bubble detection. In: Bennett PB, Elliott DH, eds. The physiology and medicine of diving, 4th ed. London: WB Saunders Company, 1993:433–453.
8. Nishi RY, Tikuisis P, Survanshi SS, Parker EC, Ball R, Weathersby PK. A comparison of probabilistic models of decompression based on DCS and VGE. Undersea Hyper Med 1997;. 24(suppl):29.
9 Wong RM. How safe is pearl diving? SPUMS J 1996; 26(suppl.):49–60.

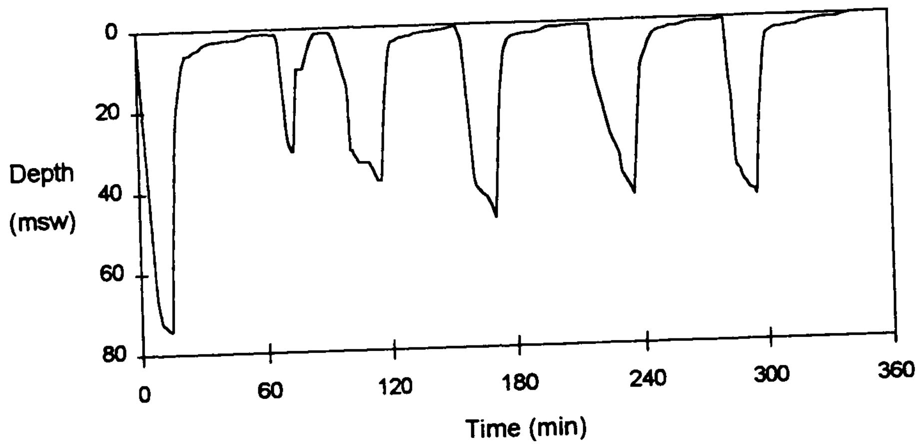

Figure 1. Example of Repetitive Dives Tested (Kidd-Stubbs model, 1964)

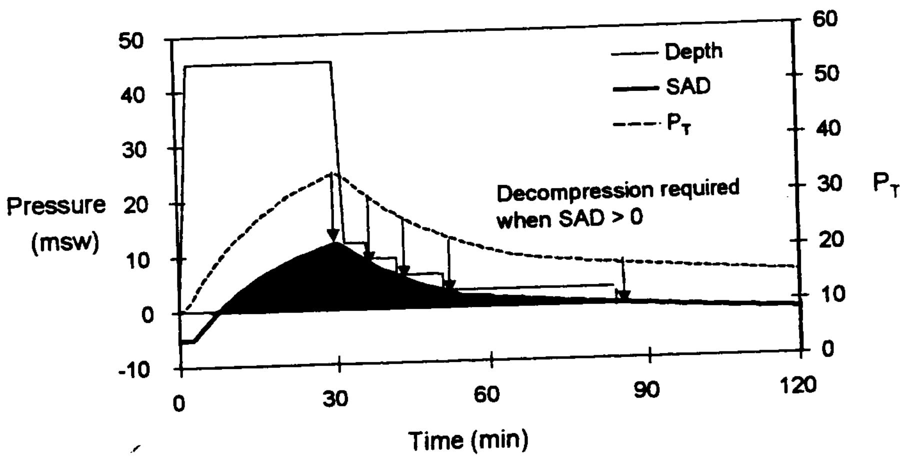

Figure 2. Example S.A.D. (Safe Ascent Depth) Calculation

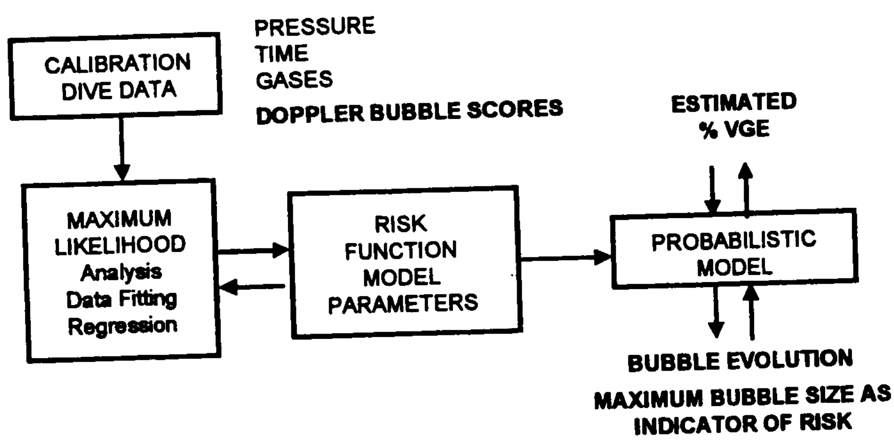

Figure 3. Probabilistic Model of Decompression Based on Venous Gas Bubbles

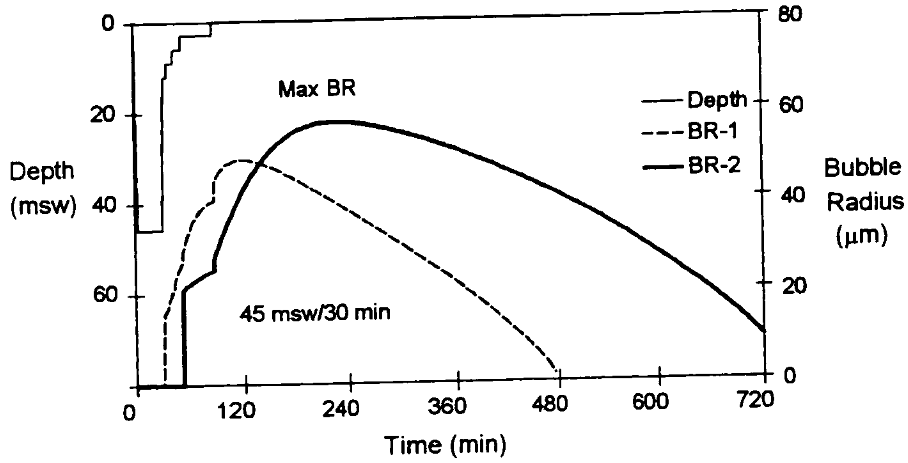

Figure 4. Example - Bubble Evolution Calculation (2 Compartment Model)

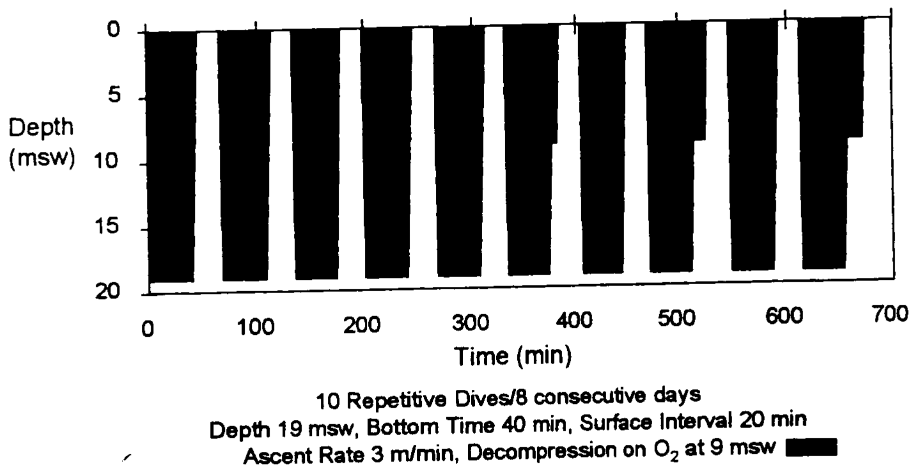

Figure 5. Pearl Divers Dive Schedule

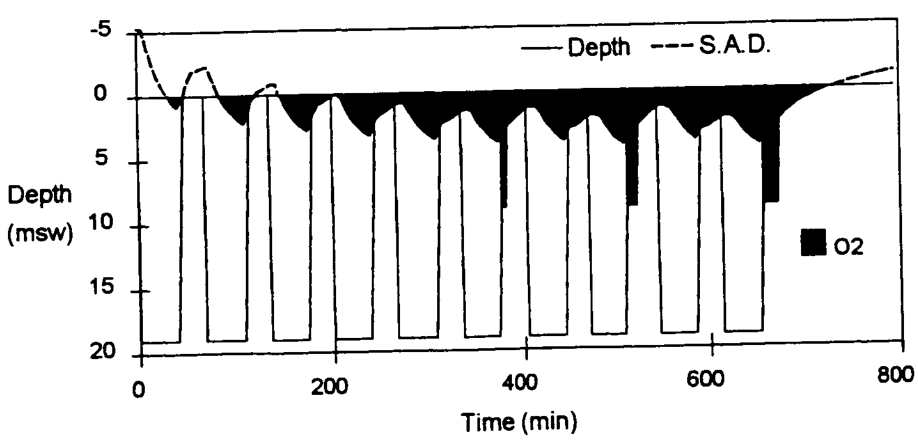

Figure 6. 1992 Dive to 19 Msw - S.A.D. Calculation (DCS)

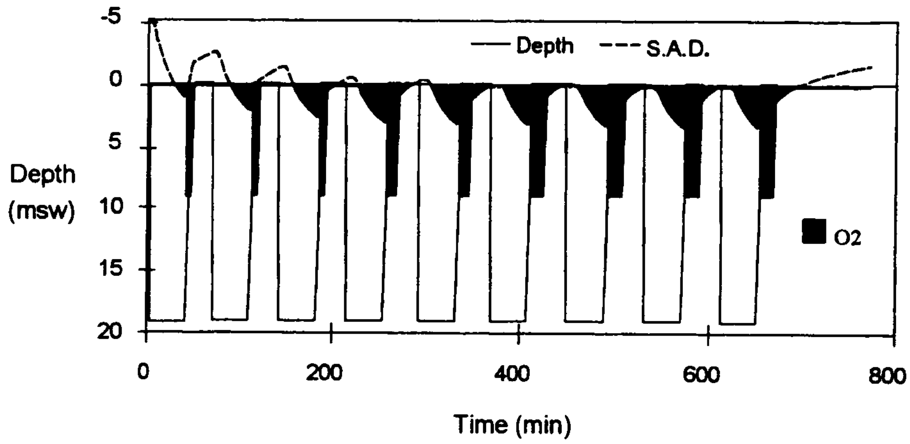

Figure 7. 1996 Dive to 19 Msw - S.A.D. Calculation

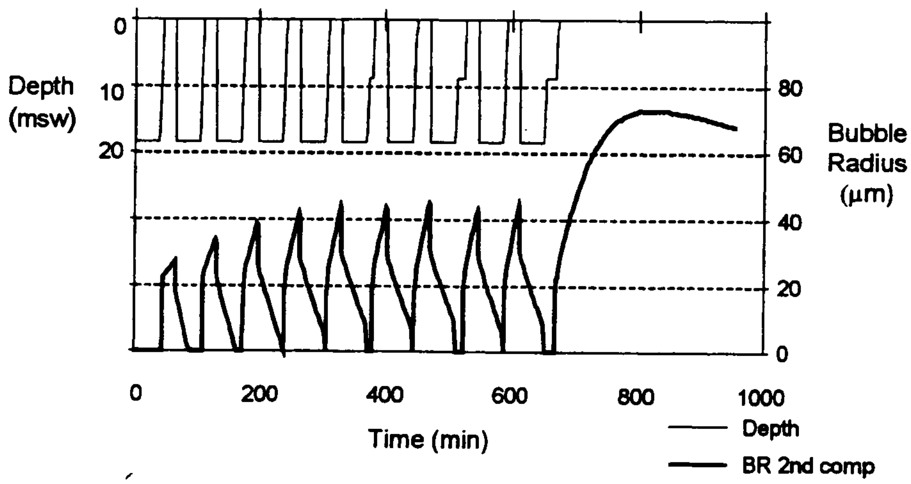

Figure 8. 1992 Pearl Divers' 19 msw Profile (10 dives)

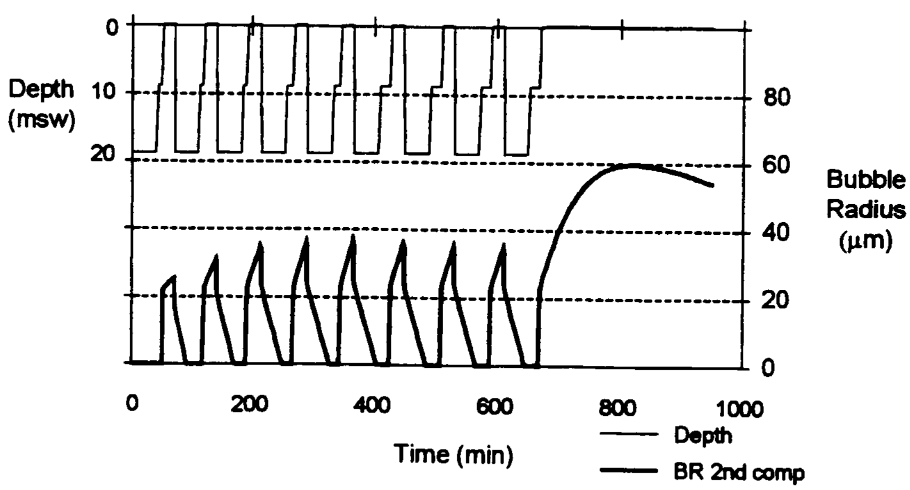

Figure 9. 1996 Pearl Divers' 19 msw Profile (9 dives)

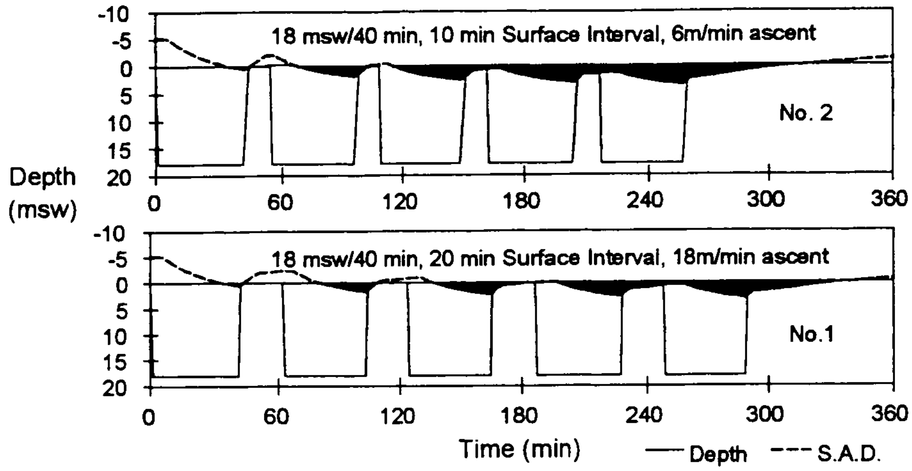

Figure 10. SAD Calculation for Kawashima et al. (UJNR 1995)

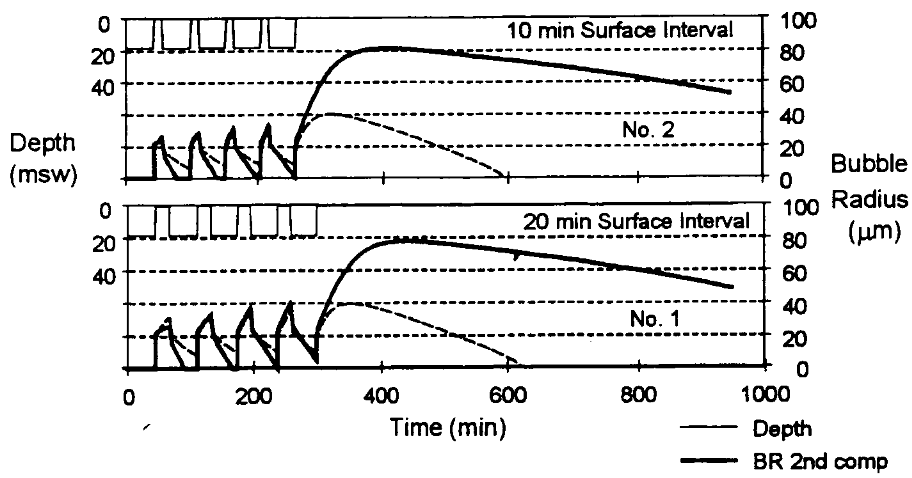

Figure 11. Bubble Evolution for Kawashima et al. (UJNR 1995)

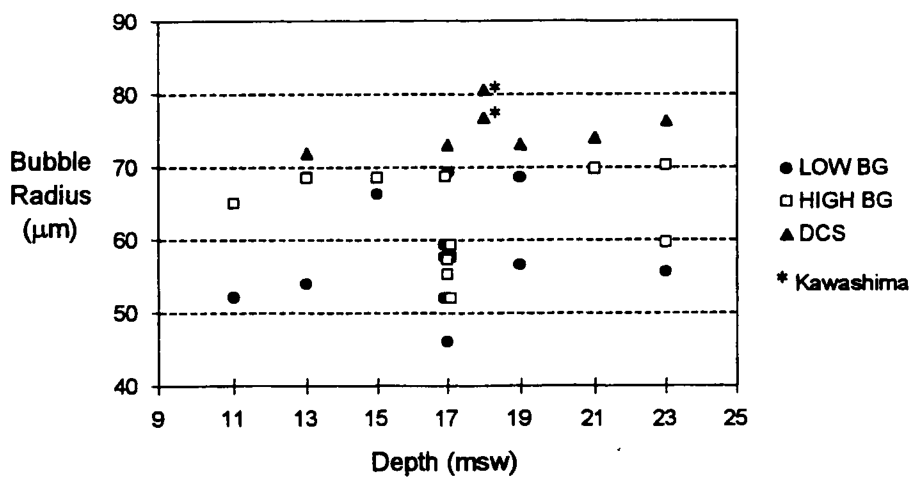

Figure 12. DCS Bubble Radius Threshold Pearl Divers Profiles (1992-97)

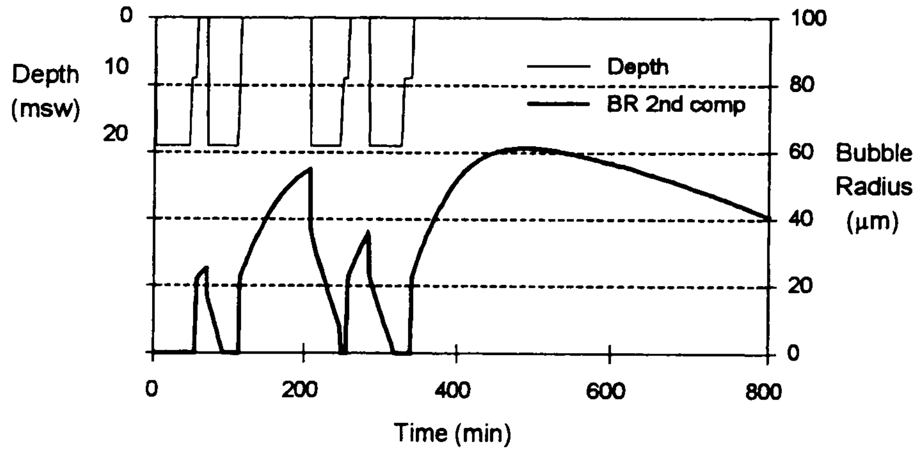

Figure 13. Effect of Long Surface Interval - Pearl Divers Profiles

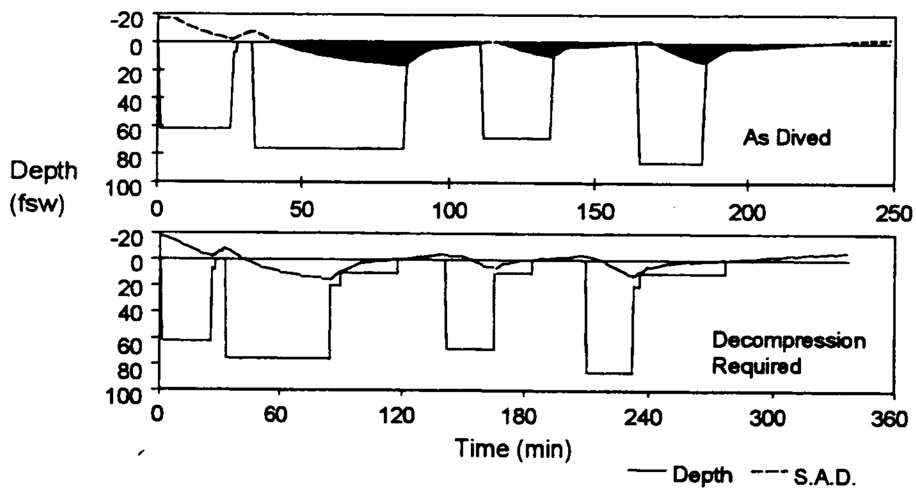

Figure 14. SAD Calculation - BC Dive Profile (DCS) (Lepawsky 1998)

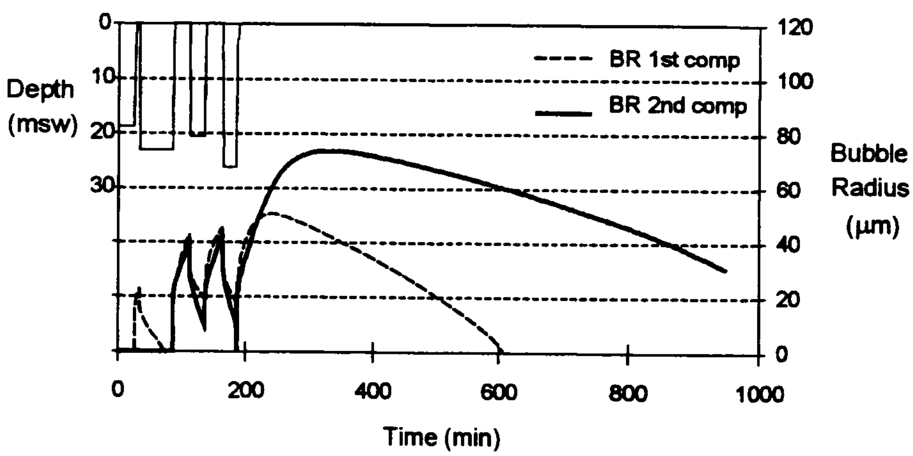

Figure 15. Bubble Evolution Calculation - BC Dive Profile (Lepawsky 1998)

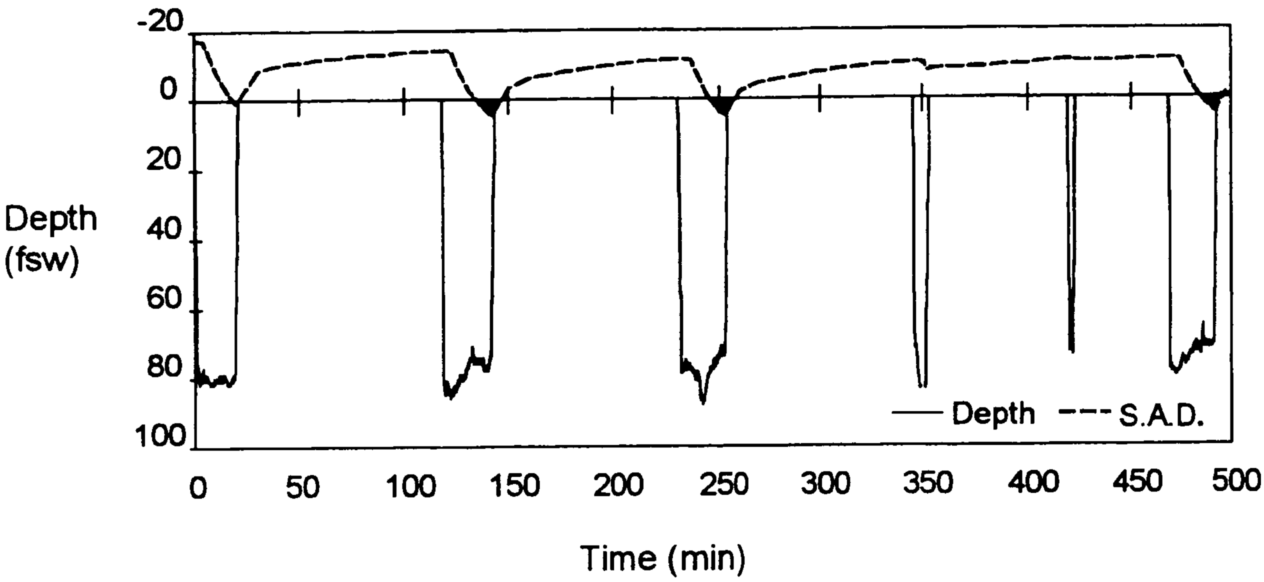

Figure 16. SAD Calculation - Maine Scallop Diver's Profile (Lehner and Pollard 1998)

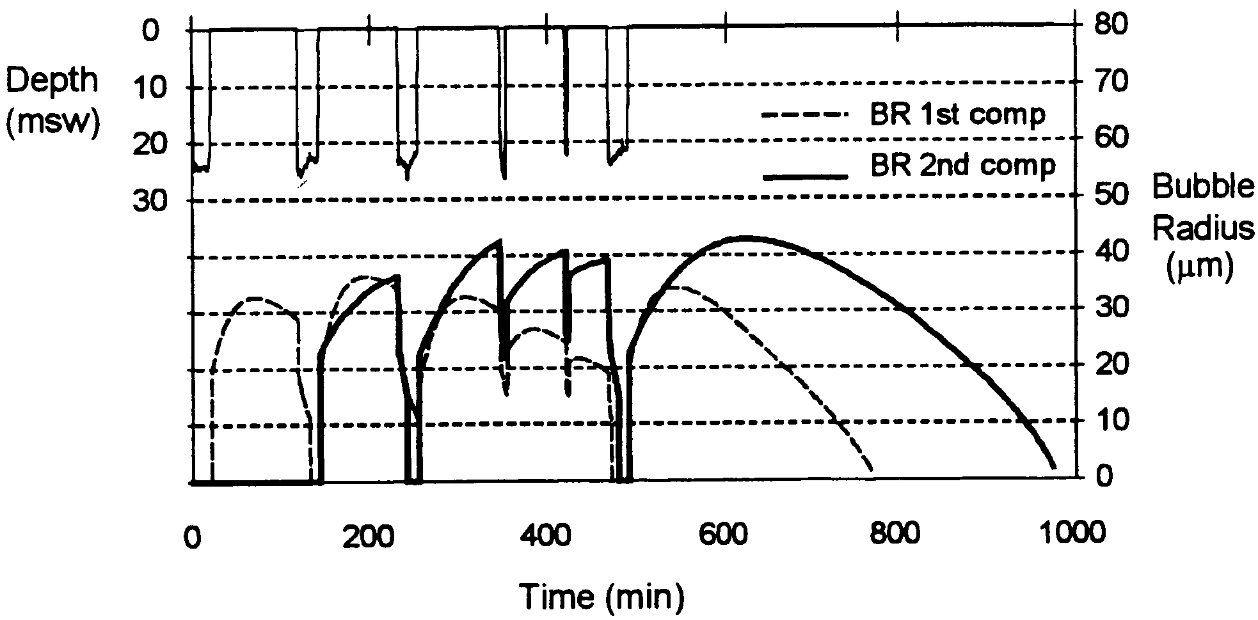

Figure 17. Bubble Evolution Calculation - Maine Scallop Diver's Profiles (Lehner and Pollard 1998)

DISCUSSION

Dr Wong: The pearl divers have learned by trial and error that they need a long decompression stop at the end of the day and they have no scientific knowledge. Now, any questions?

Unidentified Speaker: Wrong U.S. Navy tables, wrong except the 12-hour surface interval is wiping out a clean slate and starting again, do you think that's a little short now because it's usually (indiscernible) that your bubble model is still sort of residual trial and error?

Mr. Nishi: Yes, I think there's all sorts of evidence, including from Doppler, that bubbles persist for a long time after a dive. The calculation for DCEIM tables, we used 18 hours as a time that you had to wait before doing a new dive, but there are some people who are giving six hours. But I think a longer surface interval is better.

Unidentified Speaker: I just have a comment. By testing the profile on pearl divers in the chamber, the longest bubble, I think, was 19 hours your bubble evolution model is a lovely model, it matches both decompression sickness and bubbles -- Doppler bubbles. Does the time frame match the peak of the bubble size? That is, does the occurrence of the maximum bubbles and the DCS match the highest point of your calculation?

Mr. Nishi: Yes, the maximum seems to be about one or two hours after a dive and quite often people start reporting symptoms about that time after a dive. In our Doppler studies, we haven't looked at it exhaustively but we've noticed that the bubble size seems to match the Doppler bubble growth that we see.

When we monitor bubbles in the heart -- using the heart, even after a dive to, say, 150 feet for 30 minutes, sometimes we don't pick up bubbles immediately after a diver surfaces. But say 20 minutes later, we'll start picking up bubbles and an hour later the bubbles will have grown to a bit larger size.

So we do see this evolution of bubble -- Doppler bubbles that we detect going up similar to the evolution curve that is shown and sometimes, in some people, these bubbles persist for a couple of hours after a dive.

Unidentified Speaker: This is fascinating -- fascinating. I have a question but it's actually with -- we've gone over the Navy that's doing the short bounce dives, short surface intervals and now we're looking at the longer dives with longer intervals and the bubble formation.

Would it be possible for you to come up with some kind of a model or graph or chart that shows that as you get increases and bottom time decreases, as far as the relationship as to what your surface interval would be doing. So do you understand what I'm saying?

Mr. Nishi: Mm-hmm.

Unidentified Speaker: As far as what depth to tell the diver what kind of surface interval to be working with to get the utmost time and still be safe as far as not having to go to bubble formation?

Mr. Nishi: Yes, it's probably premature with our model at the moment but it's theoretically possible. The other part of the (indiscernible) model is predicting decompression sickness risk and Wayne Gerth, who's sitting in the back there, from Duke University, has a pretty good model for doing that.

I think it's a matter of working with, say, the bubble evolution model, (indiscernible) model, and even conventional gas models to see whether we can come up with optimal surface intervals and so on. But it may be a bit premature at the time. We actually need a lot of data to put into our models to make sure that we can accurately predict what's happening.

Unidentified Speaker: I think your 18 hours is more realistic (indiscernible) because since 1990, times got a lot better. There were a lot of divers going to the Caribbean and the Channel Islands doing multiple days, multiple dives and as a result, since 1990, more than half the guys that are being treated in our chamber had been (indiscernible) divers.

They come from all over northern California. They actually came over (indiscernible) dives. So I think that the bubbles are (indiscernible); they're not (indiscernible) may have accumulated while they're diving four or five days (indiscernible).

Mr. Nishi: Well, there was discussion earlier about diving, taking a day off after doing these multiple days of diving. I don't know what the optimum number of—how many dives these—how many days of diving you should do and then take a day off.

But whether they should after a day or the eighth day or whatever. I don't know what's the correct way. It's probably useful to take a day off now and then and give the body a rest.

Unidentified Speaker: (Indiscernible) and they remain the same until the (indiscernible) increases. They seem to keep the (indiscernible) long days and they keep (indiscernible) so I don't know whether (indiscernible).

Mr. Nishi: Yes, there may be acclimatization coming into effect, too and whether I said that the DCEIM, this type of diving seems to make the DCEIM model too conservative of that need because there is acclimatization attached.

Unidentified Speaker: (Indiscernible). Is there any information on how to predict a severe decompression illness perhaps if paralysis or unconsciousness (indiscernible) or toward the mild symptoms?

Mr. Nishi: Well, it's probably the larger the bubble size -- calculate the bubble size. It would probably be the worst situation. I actually don't analyze about five or six profiles that Dr. Kawashima has published in a report last year or two years ago, three years ago.

Some of them, I think, were very severe cases of decompression sickness and bubble sizes I calculated were from 77 microns to 130 microns. So I think once you're getting into that size bubbles, theoretical, you know, bubble, you're going to start getting pretty serious cases of DCS.

Unidentified Speaker: In your vast experience of monitoring divers for bubbles, looking at score of data, did you find any evidence of any (indiscernible) increased set of bubbles for (indiscernible) indicating perhaps your basic model assumption (indiscernible) for (indiscernible)? Is there any reflection that you see in the bubble scores?

Mr. Nishi: Well, in the Doppler monitoring, we're really limited to four bubble grades. You know, zero is no bubbles, one is a couple of bubbles per cardiac cycle, two is, you know, maybe a three to eight bubbles per cardiac cycle and so on, grade four is so many bubbles that you can't hear.

We don't have enough so with gradation in the bubble scores to see very sensitive changes because once it gets grade four, it's going to persist for quite a while more than grade three. So we do see bubbles going up to grade three and holding for a grade three for, say, an hour or two hours and so on before they start decreasing.

When we do experimental diving we monitor all the divers for about two hours after a dive. If they're bubbling at, say, grade three levels, we hold them until there's a clear indication that the bubbles are starting to decrease before we will let them go. So they have to be in the vicinity of the chamber until we have a very clear indication that the bubble scores are starting to go down.

Dr. Olson: We found that people that do multi-day dive, particularly within four dives on a day definitely get more severe decompression illness than the people that don't. Have you modeled multi-day diving (indiscernible) profiles (indiscernible)? In other words, you'd have a one-day model on multiple dives and then (indiscernible) after that and then (indiscernible)?

Mr. Nishi: Yes.

Dr. Olson: Then (indiscernible) bubble (indiscernible)?

Mr. Nishi: Yes, actually there was a cluster of dives in the 17-metre depths on that threshold slide I showed. Those were done for seven to eight days. I think eight days. I did analyze as a new dive every day or as one long dive sequence for eight days and there was a bit of a difference.

If you used it as one long dive sequence, the bubbles were a bit larger on the second day and on the third day and so on. So it sort of stabilized after a few days. But it takes a lot more time to do that sort of analysis so I usually stick with one-day analysis.

Unidentified Speaker: Coming back to the taking the day off or taking a day off after a serial dive -- a few days of diving, there is the risk of losing acclimatization which we found in tunnel workers, that if there was a holiday, the incidents of bends rose on the day after the holiday.

In other words, if there was a four-day weekend, it would rise in the number of cases that followed it. But I wondered if the same sort of thing could be traced in divers?

Mr. Nishi: I'm not too sure. I think we have to probably start looking at this type of diving. We're getting very heavy diving for days in a row versus the sport diver who's going out and diving daily.

For a sport diver, I mean, the gas bubbles are not going to be that great compared to this type of diving so probably a day off for a sport diver would be pretty good. In this case, it's possible that you may lose your acclimatization. Bob, do you know about the incidence is as highfor pearl divers if there is a day off for some reason?

Dr. Wong: Didn't Dennis Walder or someone report a (indiscernible) project that they (indiscernible) or something for two or three weeks and they lost the acclimatization during that period?

Mr. Nishi: I think it's been well-known in the case on compressed air work that, when they start a project, the first few days people get bent and after that there's very few bends. And yes, you can lose your acclimatization. I think somebody mentioned that in the last few days.

Unidentified Speaker: I think that one thing else that's (indiscernible) air work and (indiscernible) concerning the air tunnel worker among the divers so we might be seeing that if there were two or three divers that it takes more than 72 hours from the stop of diving to lose (indiscernible).

My question to you, Dr. Nishi. In our treatments, we see about 50 to 60 percent of the -- of the symptoms (indiscernible) worse when we were at the (indiscernible) breathing oxygen in them. For the first 20 minutes, they're very relaxed and back to normal (indiscernible).

Have you done any real time work with treatment in which you have detected the bubbles (indiscernible) during the treatment you found following the (indiscernible) for the first 20 or 30 minutes to this (indiscernible) producing immediate groups of five (indiscernible) the size of all (indiscernible) oxygen or carbon monoxide -- carbon dioxide (indiscernible)?

Mr. Nishi: I didn't get all of your question there.

Unidentified Speaker: My question is, have you followed up in real time a Doppler monitor in a diving accident in the first 20 to 30 minutes of the first period of oxygen?

Unidentified Speaker [Mr. Nishi?]: No, we haven't done any of that. No, that's—if you put that out, I think we're (indiscernible) with diving and (indiscernible). (Indiscernible) the diver reported symptoms -- took the -- well, the tendency of the diving medical officer is to get the diver into the chamber right away so (indiscernible). We haven't monitored (indiscernible).

Mr. Drummond: Yes, Rupert Drummond. I have several comments and perhaps a couple of questions. First of all, the time course of the bubbles. We have done quite a number of experiments in humans and looked at that We are able to get a number so that we can follow it. At least in the animals, we can follow its continues.

When it comes in a time course, 20 minutes makes quite a lot of sense as a time between dives because to see the maximum bubbles and if there is an extremely stressful dive, it would cost a bit. Usually the maximum of the bubbles are something between 20 to 40 minutes. So that would indicate that with 20 minutes bottom time, we're just taking the top of the interval. They'd just start the next dive.

As we come to the treatment of this whole procedure is, of course, in the end because if you omit the long decompression period in the end then you will be in trouble. So the whole trick is if this is going to be used by anybody for anything else, it's very important that one says that part of this profile is that you have a very long—on the last dive, there is a very, very long decompression in order to get rid of these bubbles.

Because what your model doesn't consider is, of course, the fact that every time when you get two dives that produce a lot of bubbles, which some of these profiles, they do, the gas accumulates in the bottle -- in the bubble and lowers case attentions, a precept with (indiscernible).

That means that the (indiscernible) is very low. It means that the bubbles should stay there for a long time and the more bubbles there are, the longer it will stay. So it means that the diver produces sequentially more bubbles or larger volumes or size or however you measure it. It means that (indiscernible) will be very, very slow.

So that means that after a series of dives like this, if you have not had a long enough loss decompression period, you need perhaps even longer than 18 hours before you can actually dive again. That -- these are theoretically but there are some data we have some experimental data showing this, that it takes a very, very long time to get rid of the gas once you have a lot of bubbles.

There are some differences to this. If you look at -- we have looked at dives where we have no super -- surface decompressions (indiscernible) where it seems that the bubbles stay much longer much higher, if you don't eliminate all the gas bubbles. I don't know the reason for this.

It could be it has (indiscernible) effects or something else. But it's striking that in all the profiles in these air dives the bubbles go like this and after these surface decompressions, they continue continuously for several hours without showing any (indiscernible).

Lastly, to the question about treatments, we've never done it in humans but we've done quite a number of experiments in animals and looked at how it falls off.

Usually when you do a treatment like that, regardless of how severe the dive is and regardless if you're using 10 minutes -- 10 minutes -- that one, sorry, 10-metre recompression, 18-metre recompression or 30-metre recompression, it seems that the bubbles are eliminated at least from the pulmonary artery with a time frame of something like -- so between 30 and 60 minutes, they're gone.

In most cases, they're really gone because when we go to the surface again, they -- in most cases, they don't reappear. But these are -- it's still much too early to say more than that but it seems you eliminate them and they go down rather rapidly after we apply pressure. Or even oxygen. Oxygen takes longer time.

Unidentified Speaker: (Indiscernible). You (indiscernible) and you compared them to (indiscernible). How can you make that comparison?

Mr. Nishi: How can I make the comparison?

Unidentified Speaker: Yes, between the (indiscernible) and (indiscernible). (Indiscernible).

Mr. Nishi: We haven't actually a direct comparison. We tried to correlate bubble grade against bubble size which is not really valid, I guess.

But I don't know whether you heard the talk by Estherdahl and Brubakk in Seattle. We haven't tried using that -- to try and correlate both sides against bubble number yet. But there are many things that we want to try yet. It's just a matter of time.

Unidentified Speaker: I'd like to tell about our experience about DCS risk (indiscernible). We had joined an excavation and they have made now (indiscernible) and we have four decompression sickness cases. Two of them was up to a day old because of the weather conditions.

So that they couldn't fly for several days and two of the decompression sickness cases up to five or more days old. I'm hopeful the decompression sickness cases now, the (indiscernible) more open at the beginning of the diving season. For example, for (indiscernible), at the beginning we see few more cases rather than (indiscernible).

Dr. Sanchez: We see the same thing in Mexico. The only problems that I have (indiscernible) of the season is where (indiscernible) related? It might be that during the off season, they don't do any exercises (indiscernible) and then once they start working they're (indiscernible) than for the physical fitness. Because the other thing, usually divers, well, if they don't work at diving, they go home and do a lot of work at home. So it might be that they were working and doing all these other physical activities before returning to the dive profiles. We should monitor the physical activities during those off days or else (indiscernible).

Mr. Nishi: That's one of the difficult things about doing table development and decompression modeling. You know, you don't really know what the divers are doing on their off days or off hours and we've had, you know, divers who go weight lifting after a dive and coming back the next morning with symptoms and so on. Now, is that your table or is that what the diver did? It's pretty hard to say.

Dr. Brubakk: I talk too much but I have some information relating to this, too. Brubakk (sic) demonstrated quite clearly in animals that animals who had better physical aerobic capacity, better physical shape, had a much, much lower incidence of central nervous decompression sickness in this model. It was statistically very significant.

There are people in our lab doing -- looking at the effect of physical fitness and (indiscernible) [inert gas? Nitrogen?] elimination and it's just preliminary but it seems quite clear that even a limited increase in physical fitness will appreciably increase the amount of (indiscernible) to get rid of. We're doing it with oxygen breathing and it seems clear that it has an effect so I think physical fitness is a very, very important factor.

Just to the similar – this paper you cited in the *Australian Journal of Medicine*, an old paper, one of the interesting things that he describes is that he feels that there were always much more decompression accidents at the late in the season. He speculated the mock write-up was so and determined that it had something to do that they didn't get fresh fruit.

So he gave them fresh fruit at the end and thinks that the incidentce of decompression sickness fell of dramatically. So he speculated maybe Vitamin C could play a role. So biochemical effects, I think, can be quite important. We don't understand much about it.

Dr. Wong: One last question for Dr. Nishi.

Unidentified Speaker: It's more of a comment and tends to do with (indiscernible) and the project. I think you were referring to the (indiscernible). (Indiscernible) workers were very upset with some of the decompression sickness. You were blaming it, I think, on the individuals (indiscernible).

Mr. Nishi: Yes, they'd lost acclimatization.

Unidentified Speaker: In our sheep model, we found (indiscernible) of decompression sickness down to about 20 percent and over the course of 40 (indiscernible), a 20 percent incidence of decompression sickness went up to 60 percent. There was a three-fold change in the incidence of decompression sickness. Presumably, serious consequences, whether it was some kind of process (indiscernible).

Unidentified Speaker: (Indiscernible) comment of the pearl divers that they do repetitive dives, multi-day dives for eight days. They'd go out for one week and (indiscernible) again. (Indiscernible) but they'd do the same thing in seven days. And they'd simply be (indiscernible).

Mr. Nishi: I think along the theory that there are micronuclei and so on and that each dive that you do gets rid of some of these micronuclei. That might be an explanation for the acclimatization. I don't know.

Dr. Lepawsky: Thank you very much, Dr. Nishi. We had a nutrition break 45 minutes ago so we're going to take it now, are penalized. You have to dive to 130 feet for six hours and come up in two seconds and no hyperbaric oxygen.

Also, Jane Dunne wanted me to mention that for those staying in the – the bus is apparently going to be ready to leave at six o'clock, I think she said, or 6:15. I'm not sure which. That's the trouble. So those of you staying in the residence here at the Compensation Board have to be ready in the lobby for the bus which would pick you up at about 6:15, no later than 6:15, 6:30, I would think.

I'm going to start now by introducing our last speaker. I do so with humility and pleasure. Bill Hamilton is well-known to the diving – to the international diving community, I would think to the galactic diving community. And he has been ubiquitous in being of help to those who wished to dive extreme protocols and technical protocols. His forté is in calculating diving profiles.

He has numerous numbers of accomplishments to his credit, not the least of which is that he piloted in Korea and has been a diving -- sorry, a medical attendant and serves on a number of committees having to do with barology.

He's a member of the Aerospace Medical Association, the Underwater -- the Undersea and Hyperbaric Medical Society and he's been an award winner within the Undersea and Hyperbaric Medical Society. He is speaking to us today on calculation of a variety of empirical, commercial dive profiles. And so Dr. Bill Hamilton.

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