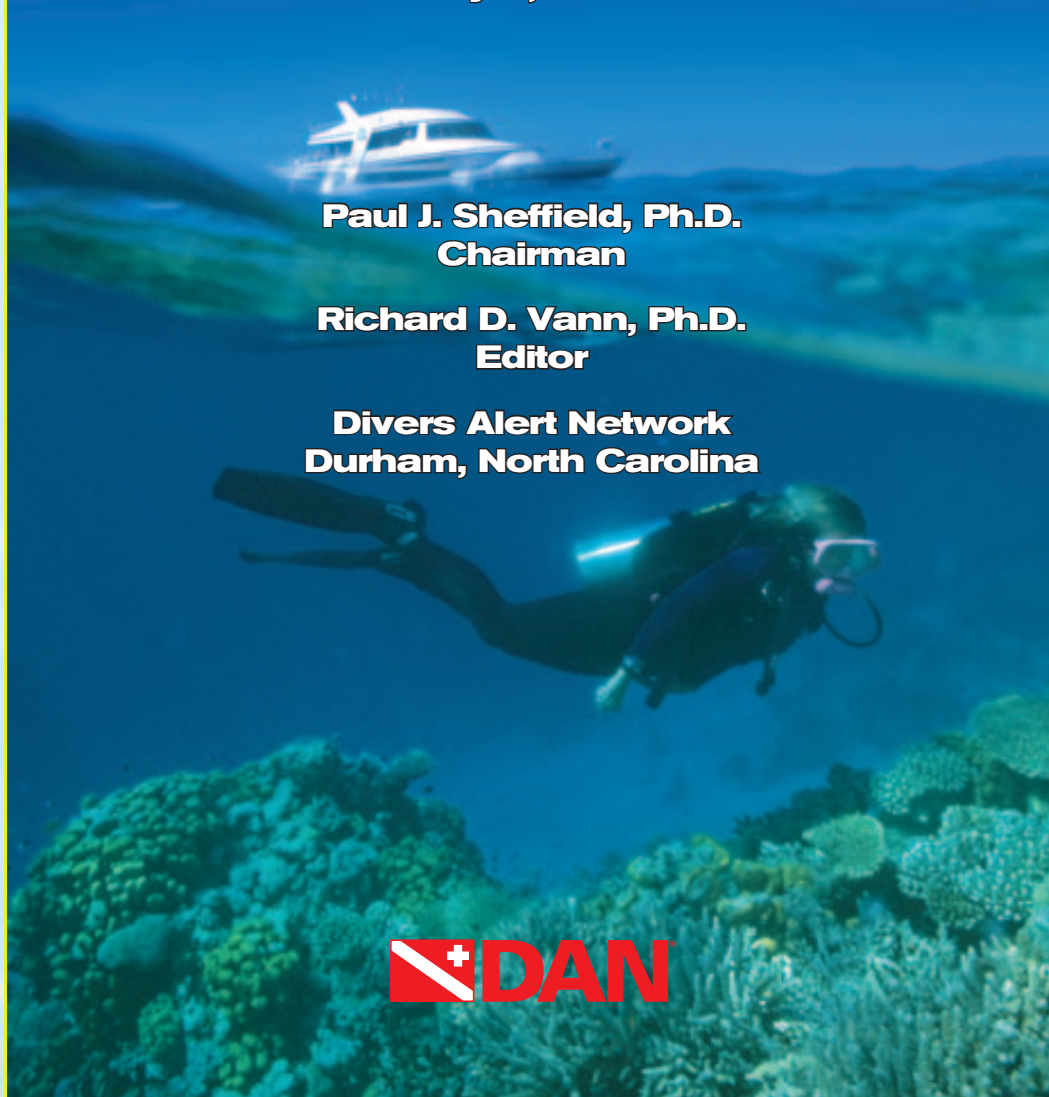




# **FLYING AFTER RECREATIONAL DIVING**

## **Workshop Proceedings**

**May 2, 2002**



**Paul J. Sheffield, Ph.D.  
Chairman**

**Richard D. Vann, Ph.D.  
Editor**

**Divers Alert Network  
Durham, North Carolina**



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## **Dedication**



**Edward D. Thalmann, CAPT, MC, USN (ret.)  
1945-2004**

We dedicate these Proceedings to Dr. Ed Thalmann. Flying after diving was among his many interests and accomplishments in diving physiology and medicine. His insights and wit are well represented in this volume. He will be missed.

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Durham, NC 27705

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## **ABOUT DIVERS ALERT NETWORK**

[www.DiversAlertNetwork.org](http://www.DiversAlertNetwork.org)

Divers Alert Network (DAN<sup>®</sup>) is a 501(c)(3) non-profit dive safety organization associated with Duke University Health Systems in Durham, N.C. Since 1980, DAN has served as a lifeline for the scuba industry by operating the industry's only 24-Hour Diving Emergency Hotline, a lifesaving service for injured scuba divers. Additionally, DAN operates a Dive Safety and Medical Information Line, conducts vital dive-related medical research and develops and provides a number of educational programs for everyone, from beginning divers to medical professionals.

DAN is supported through membership dues and donations. In return, members receive a number of important benefits, including access to emergency medical evacuation, travel and personal assistance for both diving and non-diving needs, DAN educational publications, a subscription to *Alert Diver* magazine and access to diving's premier dive accident insurance coverage.

Your Dive Safety Association, DAN currently has well more than 200,000 members worldwide.

### **The DAN Vision**

DAN's vision is to be the most recognized and trusted organization worldwide in the fields of diver safety and emergency services, health, research and education by its members, instructors, supporters and recreational diving community at large.

### **The DAN Mission Statement**

Divers Alert Network (DAN), a non-profit organization, exists to provide expert medical information and advice for the benefit of the diving public. DAN's historical and primary function is to provide emergency medical advice and assistance for underwater diving injuries and to promote diving safety.

Second, DAN promotes and supports underwater diving research and education, particularly as it relates to the improvement of diving safety, medical treatment and first aid.

Third, DAN strives to provide the most accurate, up-to-date and unbiased information on issues of common concern to the diving public, primarily, but not exclusively, for diving safety.

## **ACKNOWLEDGMENTS**

Thanks are due to all those who took time from their busy schedules to attend the workshop and, particularly, to those who made presentations and prepared written papers. The efforts of Dr. Paul Sheffield are especially appreciated for chairing this second Flying After Diving Workshop.

The experimental trials at the Center for Hyperbaric Medicine and Environmental Physiology at Duke Medical Center were initially supported by the Professional Association of Diving Instructors (PADI) and, subsequently, by Divers Alert Network (DAN), who also sponsored the workshop.

The Duke trials would have been impossible without the efforts of many people. First and foremost were the 518 volunteer divers who knew that some of them would develop decompression sickness but participated anyhow for the benefit of all divers. Another critical group was the more than 35 physicians and staff of DAN and the Hyperbaric Center. Their dedication and professionalism were unsurpassed.

Finally, I thank Cindi Easterling and Cindy Duryea for their skillful logistics management and Renee Duncan, Wesley Hyatt and Steve Mehan for their professional editing and cover art.

Richard D. Vann, Ph.D.  
Vice President for Research  
Divers Alert Network



## **2002 Consensus Guidelines for Flying After Recreational Diving**

The following guidelines are the consensus of attendees at the 2002 Flying After Diving Workshop. They apply to air dives followed by flights at cabin altitudes of 2,000 to 8,000 feet (610 to 2,438 meters) for divers who do not have symptoms of decompression sickness (DCS). The recommended preflight surface intervals do not guarantee avoidance of DCS. Longer surface intervals will reduce DCS risk further.

For a single no-decompression dive, a minimum preflight surface interval of 12 hours is suggested.

For multiple dives per day or multiple days of diving, a minimum preflight surface interval of 18 hours is suggested.

For dives requiring decompression stops, there is little evidence on which to base a recommendation, and a preflight surface interval substantially longer than 18 hours appears prudent.

*Alert Diver*, November/December 2002, page 7

## EXECUTIVE SUMMARY

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This workshop on flying after recreational diving was organized by Divers Alert Network (DAN) to bring together representatives from the recreational diving industry with experts from other diving communities. The workshop had two purposes: (a) to review the guidelines and experimental data developed since the first flying after diving workshop in 1989 (1); and (b) to debate a consensus for new flying after recreational diving guidelines.

Sheffield opened the proceedings by reviewing the history of flying after diving (2). He pointed out that the first workshop had reached the following consensus:

- (a) wait for 12 hours before flying after up to two hours of no-stop diving within the previous 48 hours;
- (b) wait for 24 hours before flying after multiday, unlimited no-stop diving;
- (c) wait for 24-48 hours before flying after dives that required decompression stops; and
- (d) do not fly with DCS symptoms unless necessary to obtain hyperbaric treatment.

Subsequently, DAN proposed a simpler 24-hour wait after any and all recreational diving. There were objections to this on the grounds that the DCS risks of flying after diving were too low to warrant such a long delay and would result in lost business for island diving resorts. The DAN guideline was changed to:

- (a) wait at least 12 hours after a single no-stop dive; and
- (b) wait more than 12 hours after repetitive dives, decompression dives, and multiple days of diving.

Because little human experimental data could be found that was relevant to flying after recreational diving, DAN funded a series of trials at the Duke University Center for Hyperbaric Medicine and Environmental Physiology that were conducted from 1992-1999 (3, 4). Dry, resting volunteers tested nine single- and repetitive dive profiles that were near the recreational diving no-decompression limits. The dives were followed by four-hour simulated flights at 8,000 feet (2,438 meters). In 802 trials, there were 40 DCS incidents during or after flight. For single no-stop dives to 60 fsw (feet of sea water; 18 msw, or meters of sea water) or deeper, there was no DCS for surface intervals of 11 hours or longer. For repetitive, no-stop dives, DCS occurred for surface intervals of less than 17 hours.

In 1999, the U.S. Navy used preliminary results from the DAN trials to revise its rules for ascent to altitude following air diving (5). In the new procedures, the required surface interval before ascent to altitude was based on the diver's repetitive group upon surfacing from a dive and on the expected post-dive altitude. The procedures were developed from a single-tissue Haldane model with a halftime of 640 minutes and a critical ratio selected to match the DAN data. While they were not formally tested in the laboratory prior to issue, no DCS cases have been reported to the Naval Safety Center to date. This safety record must be viewed as preliminary, however, since the number of times the new procedures have been used in the field is unknown.

While flying after diving guidelines can be derived empirically by matching preflight surface intervals to experimental data based on repetitive dive groups, a more desirable approach would fit a statistical model to the data so that the guidelines and empirical evidence would be in best possible agreement (6). An example of this procedure was illustrated by fitting the DAN data with a single-tissue Haldane model (as in [5]) having a 300-minute halftime. The resulting guidelines were generally consistent with the workshop consensus. With additional experimental data, a statistical model of flying after diving might be appropriate for use in dive computers.

To estimate the longest preflight surface intervals to keep DCS risk at a reasonable level, the DAN-funded trials had focused on no-decompression dives that were near the recreational exposure limits. As these surface intervals might be too long for brief dives or too short for decompression dives, a second study was proposed to the U.S. Navy to investigate exposures not previously evaluated, including some of the new Navy flying after diving procedures (7). The Navy study is currently in progress. One of its goals is to provide additional data from which a statistical model of flying after diving might be derived.

Flying after diving was also studied in divers who developed DCS during or after diving and in divers who flew without DCS (8, 9). This was a case-control study that determined the relative odds of DCS rather than the absolute DCS risk. The odds of DCS increased gradually as the preflight surface interval decreased from 48 to 12 hours. For surface intervals of less than 12 hours, the odds increased sharply. The odds of DCS were also greater for deeper dives on the last day of diving. These results, based on field data, were qualitatively similar to those of the chamber study (3, 4) but suggested greater DCS risk for deeper dives and a finite (but unknown) risk for surface intervals longer than 24 hours. An indication that flying might increase DCS severity was also found.

There were potentially important differences between field and chamber studies. Diving in the field involved immersion, exercise, and multiple days of diving, while the chamber trials occurred on a single day with dry resting divers. Thus, the chamber trials might not adequately simulate flying after diving as it actually occurs.

As more divers fly with symptoms than develop symptoms during or after flight (8), flying with symptoms may be a greater health problem than symptoms that occur during or after flight. This is an educational issue, not a scientific issue. Divers need to be taught

to seek medical advice rather than to fly if they note signs and symptoms consistent with decompression illness.

Recreational diving and Navy diving are not the only communities affected by flying. To simulate the weightlessness of extravehicular activity (EVA), NASA astronauts train in an underwater environment and, occasionally, need to fly afterwards at cabin altitudes not exceeding 10,000 feet (3,000 meters) (10). Training exposures can exceed six hours at a maximum depth of 40 ffw (feet of fresh water, or 12 meters of fresh water), during which 46% nitrox is breathed, resulting in a maximum equivalent air depth (EAD) of 24 fsw (7 msw). To allow flying after diving, NASA developed guidelines for EADs of 20-50 fsw (6-15 msw) with maximum dive durations of 100-400 minutes. These guidelines allow either air or oxygen to be breathed in the preflight surface intervals. With oxygen, surface intervals are seven to nine times shorter than with air. In a test of a single air-breathing procedure, there was one incident of transient joint awareness in 19 subjects. No further tests were conducted. The oxygen variant is reportedly used five to seven times annually, although formal records are not maintained. The air guidelines are used more frequently. No DCS has been reported.

Another military organization, the Special Operations Command (SOCOM), is concerned with high-altitude parachute operations that might occur after air diving. Flying after diving trials were conducted with dry, resting divers who breathed air while exposed for 60 minutes at 60 fsw (18 msw) (11,12). Dives were followed by simulated flights of two- or three-hour duration at an altitude of 25,000 feet (7,620 meters). The divers breathed oxygen for 30 minutes immediately preceding flight, during ascent, and while at altitude. In control experiments without diving, there was one DCS incident in 59 altitude exposures of two- or three-hour duration. When the dive was followed by a 24-hour surface interval and a three-hour flight, there was no DCS in 23 trials. With an 18-hour surface interval, one DCS incident occurred in 37 exposures, and one incident occurred in 36 exposures with a 12-hour surface interval. The study indicated that: (a) DCS risk was low for these flying after diving exposures, at least for dry resting divers; and (b) preflight oxygen might be an effective means for reducing DCS risk. For the purpose of developing a statistical model of flying after diving, these data could be combined with NASA's 10,000-foot (3,048-meter) trials and with the 8,000-foot (2,438-meter) trials conducted by DAN and by the Navy.

One generally thinks of diving guidelines as based on medical safety, but safety is not the only yardstick humans use in establishing rules for living. Economics also has a major impact, albeit one not always articulated with comfort in the medical community. Economics was a primary issue in the 1991 discussion about the impact of DAN's proposed 24-hour flying after diving guideline (1). Offshore diving operations felt they would needlessly lose business with a single 24-hour guideline. With this in mind, it was useful to approach the problem of flying after diving with an economic model in which the optimal preflight surface interval was determined by the economic interests of society as represented by divers, resorts, and insurers (13). Models of this nature depend on their assumptions, and no model can represent all situations, but economic modeling can differentiate between important and unimportant factors. In the model presented, for

example, important factors included cost of a dive, number of days diving, aggressiveness of the dive and the DCS risk due to flying after diving. Unimportant factors included the probability of evacuation, the cost of treatment, the diver's salary and the number of dives per day.

Science is a quantitative activity, while the determination of safety is a social process that considers the probability, severity and the costs of injury (14). Ultimately, the knowledgeable representatives of society make decisions about safety for society at large based on available information. Sheffield charged the workshop participants to reach consensus concerning:

- (a) whether flying after diving guidelines were needed for recreational diving;
- (b) whether the current guidelines were adequate;
- (c) what the longest needed guideline might be; and
- (d) if shorter guidelines were appropriate for short dives.

The ensuing discussion determined that guidelines were needed, and the evidence that had been presented demonstrated that existing guidelines were inadequate. After some debate (in which the writing of the Declaration of Independence was invoked as a model for the deliberations and a cockroach race was cited as an alternative process), it was decided that unless dive computers were used, written guidelines for recreational diving should be simple and unambiguous without the need for reference to tables such as the U.S. Navy procedures required.

Three groups of divers were proposed for consideration:

- (a) uncertified individuals who took part in a "resort" or introductory scuba experience;
- (b) certified divers who made an unlimited number of no-decompression air or nitrox dives over multiple days; and
- (c) technical divers who made decompression dives or used helium breathing mixes.

Based on the evidence presented, a 12-hour surface interval was recommended for the first group, an 18-hour surface interval for the second group, and substantially longer than 18 hours for the third group, as no specific evidence concerning decompression or helium diving was available.

It was stressed that as the experimental trials described in the workshop had been conducted in a dry hyperbaric chamber with resting volunteers, longer guidelines might be needed for divers who were immersed and exercising. The effects of exercise and immersion on preflight surface intervals were seen to require experimental study.

Finally, a minimum threshold altitude below which guidelines were unnecessary was discussed. Although no data were available that specifically addressed the question, a previous publication had suggested that restrictions were unnecessary below a threshold altitude of 2,300 feet (701 meters) (15). The U.S. Navy Diving Manual had followed this

recommendation without apparent problem until introduction of the 1999 procedures that reduced the threshold to 1,000 feet (305 meters) for internal consistency (5). The workshop participants agreed that 2,000 feet (610 meters) was a reasonable, if uncertain, threshold, as no problems with 2,300 feet were cited.

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## OPENING REMARKS

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Welcome, everyone, and thank you very much for coming, particularly those of you from the recreational diving industry.

This is the second workshop about flying after diving. The first workshop was organized and chaired by Dr. Paul Sheffield in 1989 (1). Our objective today is to review what has been learned since 1989 and to decide whether revisions to current flying after diving guidelines are warranted.

We are going to talk about flying after diving safety. Now, safety cannot be measured; only risk can be measured, and risk depends upon the probability and the severity of injury. Safety is the risk we judge to be acceptable. Measuring risk is a scientific endeavor, while judging safety is a political activity. We will discuss risk measurement this morning and make judgments about safety this afternoon. We will not attempt to answer all the questions or solve all the problems.

An individual may assume whatever risk he or she wishes, but for a group or organization, decisions about safety are political activities and best made by consensus. We will try to reach consensus concerning safety guidelines for flying after recreational diving. There are representatives here from many interested diving organizations – military, government and recreational – and everyone is encouraged to participate in the discussion, but when it comes to deciding on guidelines for recreational diving, the recreational diving folks will have the last word.

We begin with a historical perspective by Dr. Paul Sheffield. Paul started this discussion in 1989 and has the scars to prove it.

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## FLYING AFTER DIVING GUIDELINES: A HISTORICAL PERSPECTIVE

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Ascent to altitude after diving has become a common practice. Although the incidence is low, decompression sickness (DCS) sometimes occurs during or after ascent. During the dive, a high nitrogen partial pressure ( $pN_2$ ) in the lungs drives  $N_2$  into tissue. On ascent, tissue  $pN_2$  remains high as the ambient pressure drops. When tissue  $pN_2$  exceeds ambient pressure, supersaturation occurs. Some degree of supersaturation can be tolerated, but as a critical level is reached, gas bubbles form in blood and tissue. Continued ascent causes bubble growth to the point where the diver may become symptomatic of DCS. In some cases, divers become symptomatic at the surface, and in other cases, they become symptomatic in flight or immediately following flight. The diver can reduce the risk of DCS by extending the surface interval or by breathing oxygen during the surface interval (1, 2).

Since the 1960s, many guidelines have been proposed for flying after diving. Early military guidelines set surface intervals of zero to 24 hours (3-7). Guidelines for commercial divers were established in 1982 by the United Kingdom Diving Medicine Advisory Committee, which recommended surface intervals of two to 48 hours before exposures to 2,000 feet (610 m) and 8,000 feet (2,438 m) altitude, depending on the type of diving (8). By 1989 the literature contained over 30 recommendations for recreational divers, with surface intervals ranging from 0 to 48 hours, but few had been validated in human trials (9). Differences in diving techniques and lack of readily available hyperbaric treatment make guidelines for military and commercial divers inappropriate for recreational divers.

In 1989, the Undersea and Hyperbaric Medical Society (UHMS) held a workshop with the objective of establishing the best guidelines for recreational divers that data and expert opinion could support. The workshop reviewed the limited flying after diving research that was the basis of many of the recommendations of the day. Duffner and Kiessling reported a DCS incidence of 55% when subjects were taken to 18,000 feet (5,500 m) altitude after 90 feet (27 m) dive exposures (10). Furry, Reeves and Beckman (1967) suggested that a 12-hour surface interval was needed to protect dogs from DCS after shallow, long dives (11). Edel et al (1969) subjected experienced divers to 8,000 feet (2,400 m) altitude following dives to the no-decompression limits of the U.S. Navy Air Diving Tables and saturation exposures of 30-33 fsw (9-10 msw). Edel et al recommended a surface interval of two hours following no-decompression dives and 24 hours following dives that require decompression stops (12). Balldin (1979) detected bubbles in 60% of subjects exposed to 3,000 m (10,000 feet) after 39 msw (129 fsw) dives and concluded that divers should wait longer than three hours before making a commercial flight (13). Bassett (1982) Doppler-monitored military divers during 120 manned validation tests of various depths of the U.S. Navy Air Diving Table followed by

immediate ascent to 10,000 feet (3,000 m). He recommended a 12-hour surface interval before flying after dives with more conservative no-decompression limits, i.e., reducing the USN “no-decompression limits” by five to 10 minutes (14, 15).

The 1989 Undersea and Hyperbaric Medical Society (UHMS) Workshop on Flying After Diving formalized guidelines for recreational divers based on expert consensus concerning the limited scientific evidence at the time. The consensus was anticipated to be conservative and the surface intervals safe for the vast majority of divers. Recommendations included:

- (a) a 12-hour wait after up to two hours of no-stop diving within the previous 48 hours;
- (b) a 24-hour wait after multiday, unlimited no-stop diving;
- (c) a 24- to 48-hour wait after dives that required decompression stops; and
- (d) no flying for divers with DCS symptoms unless it is required to obtain hyperbaric treatment (9).

To simplify these guidelines and make them safer for recreational divers, DAN proposed a wait of 24 hours before flying after either single or repetitive no-stop dives. The DAN guideline was revised in 1991 in response to an appeal from the recreational diving community who argued that the low DCS incidence did not justify a 24-hour preflight surface interval for all types of diving. At the time, DAN data contained 31 cases among an estimated 2 million divers who flew during the period 1987-90, for an overall incidence of 1-2 cases per 100,000 divers. The revised (and current) DAN guideline recommended at least 12 hours after a single no-stop dive and longer than 12 hours after repetitive dives, decompression dives or multiple days of diving (16).

Under the leadership of Dr. Richard Vann, DAN conducted a human study from 1993 to 1999 with the goal of providing data upon which to base more objective guidelines. Preliminary discussion was published in *Alert Diver* (16), with definitive information published in 2004 (17). This 2002 DAN Flying After Diving Workshop has the goal of updating the flying after diving guidelines for recreational divers based on this more recent scientific evidence.

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## **DISCUSSION**

DR. SHEFFIELD: Let us discuss each morning presentation but hold our major discussion concerning flying after diving guidelines until the afternoon. Do you have any comments concerning this information that we've just talked about?

DR. THALMANN: We don't want guidelines that require judgment. We need a simple number, even though the number may have all kinds of caveats on it. We need to agree on a procedure that you either follow or don't, with no room for interpretation.

## 1999 U.S. NAVY PROCEDURES FOR ASCENT TO ALTITUDE AFTER DIVING

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### **Introduction**

Ascent to altitude after a dive increases the likelihood a diver will develop decompression sickness (DCS). The additional risk is maximal when the diver ascends immediately after surfacing; the additional risk subsequently declines as the surface interval between surfacing and ascent lengthens. Much effort has been spent to determine the “safe” surface interval before flying. A paucity of experimental data and differing organizational needs have lead to a wide variety of conflicting recommendations (1). Until 1999, the U.S. Navy recommended that air divers wait two hours on the surface after no-decompression dives and 12 hours after decompression dives before ascents to altitudes above 2,300 feet. No surface interval was required for ascents 2,300 feet and less (2). A maximum altitude was not specified, although the maximum altitude was widely considered to be the 8,000-foot altitude of commercial airliners.

While these simple rules proved easy to use and few cases of DCS were reported, the Navy elected to change the procedure in 1999 (3). There were three main drivers for the change. First, experimental studies at Duke University indicated that a two-hour surface interval after a no-decompression dive was too short. A surface interval of nine hours was not sufficient to prevent DCS following a simple 60-fsw, 55-minute no-decompression dive (Vann RD, personal communication). Second, the Navy adopted procedures for diving at altitude in 1999 based on the “Cross correction” method (4). These new altitude diving procedures required a flying-after-diving procedure that would work equally well at sea level or altitude. Third, the dichotomous “2,300 foot” rule did not capitalize on the shorter surface intervals possible with ascents above 2,300 feet, but below the full 8,000-foot cabin altitude of commercial flights. Finer gradation of the altitude would allow for earlier drives over mountain passes or earlier low level flights from the dive site.

This paper describes how we derived the 1999 U.S. Navy altitude ascent procedures mathematically, how they match the experimental data collected at Duke University, and how we modified them before publication in the U.S. Navy Diving Manual. We also provide limited feedback on their use in the field.

### **Data**

Prior to 1995, only a few human studies had been conducted to determine the safe interval before flying (5-7). We ignored these earlier studies and relied exclusively on the preliminary data available in February 1999 from a large flying-after-diving trial under way at Duke University (Vann RD, personal communication). Our goal was to develop a procedure that produced surface intervals equal to or greater than the safe surface intervals determined in the Duke study.

The Duke experiments are described in much greater detail elsewhere (8, 9). Briefly, civilian volunteers performed single or repetitive dry, resting no-stop air dives in a hyperbaric chamber, then after a prescribed interval at sea level, ascended to 8,000 feet in a hypobaric chamber where they were observed for four hours for signs and symptoms of DCS. Table 1 shows the results for a dive to 60 fsw for 55 minutes.

**Table 1. 60-fsw 55-minute No-Stop Dive Results (Feb 1999).**

Post-Dive Surface Interval (hr)	Number of Subjects	Number of DCS
3	36	3
6	6	1
9	7	1
10	24	0
11	22	0
12	27	0

DCS was observed with surface intervals of 3, 6, and 9 hours. Ten hours appeared free of DCS. (Note: later reclassification of two cases at 10 hours extended the “safe” surface interval beyond 10 hours [8]).

In total, the Duke group examined four single dive profiles and four repetitive dive profiles, each repetitive dive being separated by a one-hour surface interval. All dives were no-stop. The eight dive profiles, their final surfacing repetitive group according to the U.S. Navy Standard Air Table, and the surface interval found necessary to avoid DCS are shown in Table 2.

**Table 2. Summary of the Duke Data (Feb 1999). All repetitive dives separated by 1 hour surface interval.**

First Dive	Second Dive	Third Dive	USN Repetitive Group	Safe Surface Interval (hr)
40 fsw 60 min			G	9
40 fsw 120 min			K	13
60 fsw 55 min			I	10
100 fsw 20 min			F	10
40 fsw 60 min	40 fsw 60 min		K	>16
100 fsw 15 min	60 fsw 35 min		J	15
60 fsw 55 min	60 fsw 20 min		K	16
60 fsw 55 min	60 fsw 20 min	60 fsw 20 min	M	16

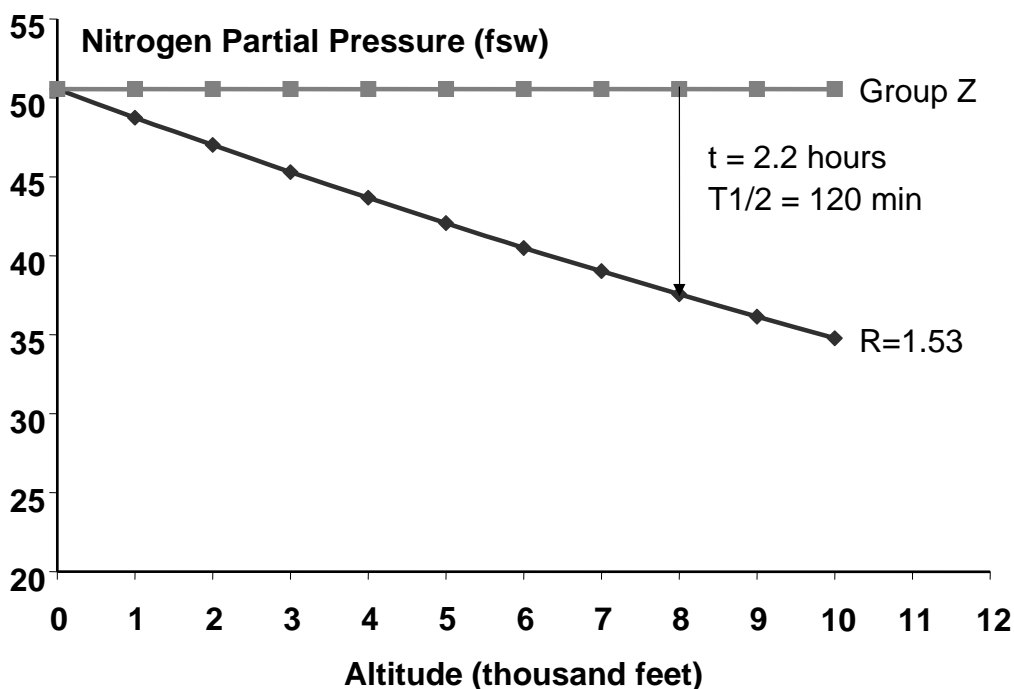
Note: The last two profiles would have required a small amount of decompression according to the U.S. Navy Standard Air Table.

In broad terms, the safe surface interval increased as the repetitive group increased. For a given repetitive group, the safe surface interval was longer after repetitive dives than after single dives. We focused on repetitive group status, because this is a quantity that Navy divers have readily available after a dive.

### Calculations

In this era, most decompression issues are examined with probabilistic modeling. We chose to revert to classical Haldanian deterministic modeling for this application for three reasons: (a) the available data were extremely limited; (b) we needed to tie the procedure to the U.S. Navy Standard Air Table and its repetitive groups; and (c) Dr. Bruce Wienke in his book, *Diving Above Sea Level* (10), had shown a practical way to achieve the longer surface intervals needed. Repetitive groups in the Standard Air Table are defined on the basis of the nitrogen tension in a 120-minute tissue upon surfacing at sea level (11). For the purposes of flying after diving, Wienke assumed that this 120-minute compartment washed out nitrogen during the surface interval with a 635-minute half-time rather than 120 minutes. We made a similar assumption. Our procedures and Wienke's are identical in concept; they differ only in the washout half-time and altitude supersaturation ratio selected.

Figure 1 (on page 23) illustrates the basic principle. Altitude is on the abscissa. Tissue nitrogen tension in the 120-minute half time compartment is on the ordinate. Group Z is the highest repetitive group and has a maximum nitrogen tension of 50.56 fsw. This maximum surfacing tension is shown at the top of the figure as a horizontal line. When the diver surfaces at sea level with a nitrogen tension of 50.56 fsw, the supersaturation ratio (nitrogen tension divided by ambient pressure) in the 120-minute compartment is  $50.56/33 = 1.53$ .



**Figure 1. Basic Approach to Calculating Required Surface Intervals.** Tissue tension in Repetitive Group Z is shown as a horizontal line at top of figure. Curvilinear line is the nitrogen tension at each altitude corresponding to a supersaturation ratio of 1.53. Group Z diver must desaturate from the Group Z line to the 1.53 ratio line before ascent. Arrow shows desaturation path and time needed for ascent to 8,000 feet with a tissue half-time of 120 minutes.

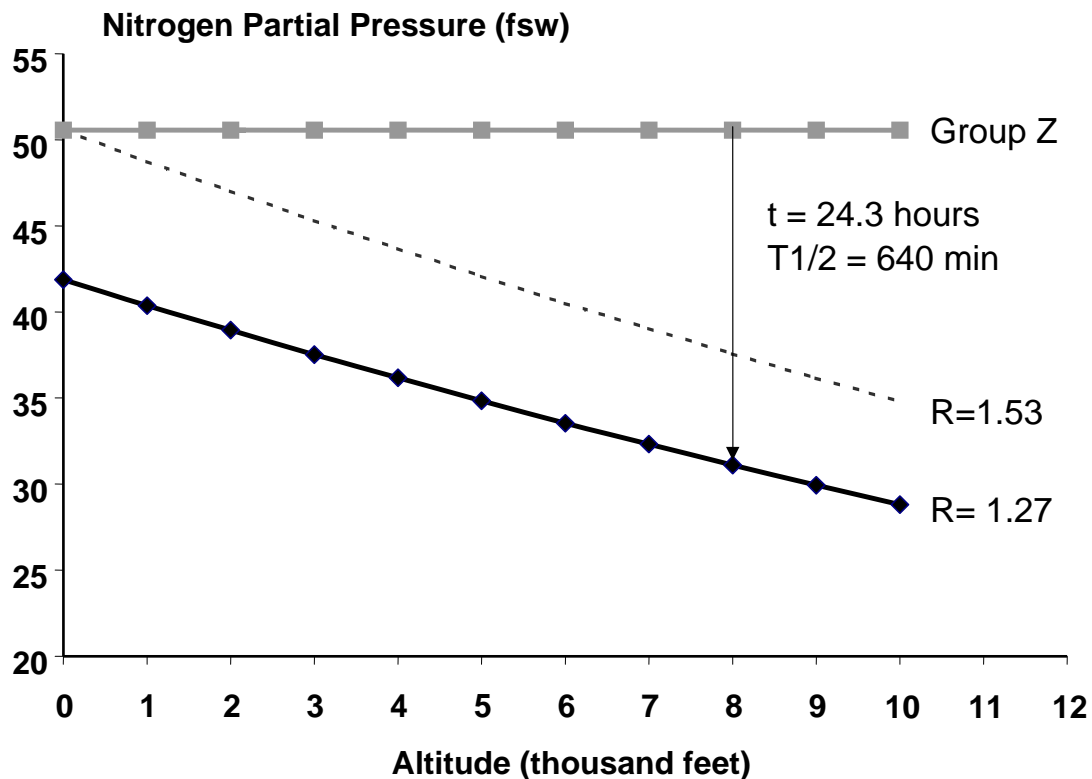
If this “safe” surfacing ratio is assumed to be the maximum allowable ratio for any subsequent exposure to altitude, the nitrogen tension would have to drop to the value indicated on the lower curvilinear line before ascent could be made. For an ascent to 8,000 feet, the maximum allowable tension is 37.56 fsw. The time to desaturate a 120-minute tissue from 50.56 fsw to 37.56 fsw breathing air at sea level is 2.2 hours. Under this scheme, a Group Z diver should be able to safely ascend to 8,000 feet after a 2.2-hour surface interval.

The Duke data clearly indicated that a Group Z diver could not ascend to 8,000 feet safely after a two-hour surface interval. Accordingly, we made two changes in the scheme outlined above. First, we lowered the allowable supersaturation ratio at altitude from 1.53 to 1.27. Second, we increased the washout half-time on surface from 120 minutes to 640 minutes. The 1.27 ratio came from our knowledge that a diver fully saturated on air at 20 fsw could safely surface without stops whereas a diver at 22-23 fsw could not (12). The nitrogen tension in air at 20 fsw is 41.87 fsw, giving a surfacing ratio of  $41.87/33 = 1.27$ . We reasoned that the allowable ratio at altitude would not be lower than this saturation-derived value. The 640-minute washout assumption came from nitrogen-oxygen saturation diving where a 640-minute half-time tissue is generally assumed to control the decompression. We reasoned that the washout time would not be longer than this saturation value. Our choices were slightly more conservative than those



made by Wienke (10). He chose 1.33 for the supersaturation ratio and 635 minutes for washout.

Figure 2 shows the result of our new calculations. To ascend to 8,000 feet, a diver must now desaturate to 31.11 fsw while on the surface. The time to desaturate a 640-minute tissue from 50.56 fsw to 31.11 fsw breathing air at sea level is 24.3 hours. In this new scheme, a Group Z diver must wait 24.3 hours at the surface before ascent to 8,000 feet.



**Figure 2. New Procedure.** Same coordinates as Figure 1. Solid curvilinear line shows allowable tensions at altitude for a supersaturation ratio of 1.27. Dotted line is previous 1.53 ratio line for reference. Group Z diver requires 24.3 hours to washout a 640-minute tissue to 1.27-ratio line at 8,000 feet.

Figure 3 is similar to Figure 2, but adds repetitive groups, A, D, and I, to the Group Z and 1.27 ratio lines. Group A lies below the 1.27 ratio line up to 10,000 feet, indicating a Group A diver can ascend to any altitude up to 10,000 feet without an intervening surface interval. Group D crosses the 1.27 line at 7,000 feet. No surface interval is required for ascents up to 7,000 feet, but higher ascents will require a surface interval in order to desaturate from the Group D line to the 1.27 line. A Group I diver can only ascend to 1,000 feet without a surface interval. A Group Z diver will always require a surface interval regardless of the altitude.

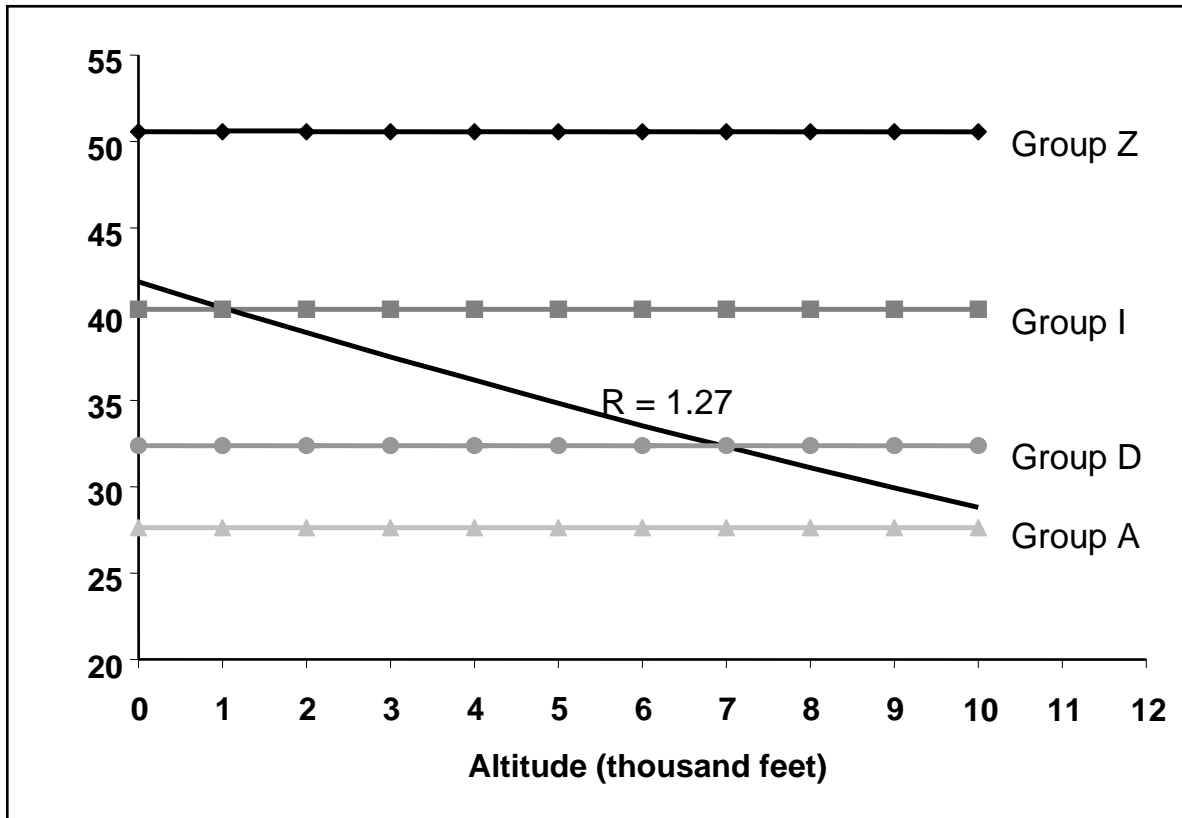


Figure 3. Effect of Repetitive Group on Requirement for a Surface Interval. See text for explanation.

Table 3 (on page 26) shows the calculated surface intervals required by the new scheme as a function of the surfacing repetitive group and expected increase in altitude post-dive. In the upper left corner of the table, zeros indicate that immediate ascent is possible without an intervening surface interval. In the lower right corner, a Group Z diver ascending to 10,000 feet requires a surface interval of 33 hours and 44 minutes. Other times in the table are intermediate between these two extremes.

Some U.S. Navy (USN) air schedules allow the diver to surface with a nitrogen tension greater than Group Z. These dives were considered outside the scope of the present analysis. To make Table 3 useful for the Fleet, an arbitrary 48-hour surface interval rule was applied to these dives.

Table 3 entries in bold highlight surface interval times greater than 24 hours. In the final implementation of these procedures, these times were fixed at 24 hours (see explanation below the table).

**Table 3. Required Surface Interval (hr:min) for Ascent to Altitude.**

Repetitive Group	Increase in Altitude (feet)									
	1000	2000	3000	4000	5000	6000	7000	8000	9000	10000
A	0:00	0:00	0:00	0:00	0:00	0:00	0:00	0:00	0:00	0:00
B	0:00	0:00	0:00	0:00	0:00	0:00	0:00	0:00	0:00	2:11
C	0:00	0:00	0:00	0:00	0:00	0:00	0:00	0:00	3:06	8:26
D	0:00	0:00	0:00	0:00	0:00	0:00	0:09	3:28	7:33	12:52
E	0:00	0:00	0:00	0:00	0:00	0:51	3:35	6:54	10:59	16:18
F	0:00	0:00	0:00	0:00	1:12	3:40	6:23	9:43	13:47	19:07
G	0:00	0:00	0:00	1:23	3:34	6:02	8:46	12:05	16:10	21:29
H	0:00	0:00	1:31	3:26	5:37	8:05	10:49	14:09	18:13	23:33
I	0:00	1:32	3:20	5:15	7:26	9:54	12:38	15:58	20:02	<b>25:21</b>
J	1:32	3:09	4:57	6:52	9:04	11:32	14:16	17:35	21:39	<b>26:59</b>
K	3:00	4:37	6:25	8:20	10:32	13:00	15:44	19:03	23:07	<b>28:27</b>
L	4:21	5:57	7:46	9:41	11:52	14:20	17:04	20:23	<b>24:28</b>	<b>29:47</b>
M	5:35	7:11	9:00	10:55	13:06	15:34	18:18	21:37	<b>25:42</b>	<b>31:01</b>
N	6:43	8:20	10:08	12:03	14:14	16:42	19:26	22:46	<b>26:50</b>	<b>32:10</b>
O	7:47	9:24	11:12	13:07	15:18	17:46	20:30	23:49	<b>27:54</b>	<b>33:13</b>
Z	8:17	9:54	11:42	13:37	15:49	18:17	21:01	<b>24:20</b>	<b>28:25</b>	<b>33:44</b>
>Z	Wait 48 hours before flying									

Table 4 shows how well these surface intervals match the Duke dataset. For Group F, the times are very close – 10 hours needed, 9 hours 43 minutes required. For higher repetitive groups, the required times are longer than the experimentally determined safe times, but not excessively so. For Group J, 15 hours was observed to be safe; the procedure calls for 17 hours 35 minutes. For Group K, safe intervals of 16 and >16 hours were observed; the procedure calls for 19 hours 3 minutes.

**Table 4. Comparison of Required Surface Interval Times to Duke Data.**

Repetitive Group	Duke Safe Surface Interval (h)		USN Surface Interval (h:min)
	Single Dive	Repetitive Dive	
F	10		9:43
G	9		12:05
I	10		15:58
J		15	17:35
K	13	16, >16	19:03
M		16	20:23

Our desire was to have a procedure that would work both at sea level and at altitude. When dives are done at altitude using “Cross-corrected” sea level tables (4), divers theoretically surface with the same tissue supersaturation ratios that they experience with a dive to the same depth and bottom time conducted at sea level. The equivalency of

ratios persists during the washout of nitrogen during the surface interval. The ratio of tissue nitrogen to ambient pressure during the washout remains the same at sea level and at altitude. A further increase in altitude at any point during the washout will increase the supersaturation ratio, but the increase in the ratio, and presumably the risk of DCS, is the same at sea level and at altitude if the increase in altitude (in feet) is the same in both cases. This follows from the fact that the ratio of the atmospheric pressure at altitude to the atmospheric pressure at the dive site is essentially the same for all equal ascents up to a ceiling of 10,000 feet. For example, consider two divers, one ascending to 5,000 feet after a sea level dive and the other ascending to 10,000 feet after a dive conducted at 5,000 feet of altitude. In both cases the increase in altitude post-dive is 5,000 feet. The ratio of the atmospheric pressure at 5,000 feet to the atmospheric pressure at sea level is 0.83. The ratio of the atmospheric pressure at 10,000 feet to the atmospheric pressure at 5,000 feet is also 0.83. Both ascents produce the same reduction in the ambient pressure ratio. The same procedure, therefore, can be applied to both.

### **Implementation**

Dr. Edward Thalmann, who consulted extensively on these procedures during their development, immediately noticed a practical problem in their implementation. Because the USN Surface Interval Credit Table is based on washout with a half-time of 120 minutes while the proposed procedure is based on washout with a half-time of 640 minutes, a diver could reduce his time to fly by simply making another shallow dive. During the surface interval before the shallow dive, washout of the nitrogen with a 120-minute rate constant would result in a lower nitrogen tension than assumed by the flying after diving procedure. The result would be a calculated shorter time-to-fly that would be little changed by the nitrogen uptake during the shallow dive. This is a problem inherent in grafting one decompression model onto another. Discontinuities can and usually do result.

The problem was discussed extensively within the Navy, and Dr. Thalmann proposed several alternative schemes, all of which involved more detailed timekeeping than Navy personnel were willing to accept. The final agreed solution was to start the flying after diving clock at the end of the last dive, but to use the highest repetitive group achieved in the previous 24 hours to determine the surface interval. Surface intervals in Table 3 greater than 24 hours were correspondingly reduced to 24 hours.

The procedure was also limited to a maximum altitude of 10,000 feet. While it was possible to calculate surface intervals for higher altitudes, it was felt that the medical problems associated with exposure to altitudes higher than 10,000 feet warranted evaluation of dive plans by NAVSEA on an individual basis.

The final procedure that appears in the U.S. Navy Diving Manual (3) is:

1. Determine the highest repetitive group achieved in the past 24 hours.

2. Determine the increase in altitude expected post-dive. (For dives conducted at altitude, the increase in altitude is the final altitude minus the altitude at the dive site). Round the increase in altitude to the next higher 1,000 feet.
3. Use Table 3 (Table 9-5 in the U.S. Navy Diving Manual) to obtain the required surface interval (3).

### **Feedback from the Fleet**

The U.S. Navy Supervisor of Diving and Salvage sponsors an annual working diver conference in which issues related to diving policy, procedures and equipment may be aired by Fleet components. To date, no component has submitted an issue paper on the new procedures. A direct email survey of Fleet Master Divers on the acceptability of the new procedures likewise produced few responses. The lack of issue papers and the lackluster Master Diver survey both indicate that either the procedures have been well received by the Fleet or, more likely, that they have had little impact on day-to-day operations.

Naval Special Warfare divers are one example of the latter situation. By and large, these divers operate from submarines or use 100% oxygen rebreathers. In the former case, no altitude exposure is planned; in the latter, the use of 100% oxygen eliminates any decompression requirement (Butler FK, personal communication).

Some anecdotal reports have been received from individual divers, mostly indicating that the procedures are too complicated. They prefer the simple two- and 12-hour rules. They do not want to track repetitive groups and perform other time-keeping functions. Others have complained that they live in the mountains and are unable to return home as soon as desired after a hard day of diving at sea level. They would like to return to the 2,300-foot rule for unlimited ascent.

The 2,300-foot rule derives from the work of Boni and Buhlmann (13), who felt that a single decompression table could adequately support dives from sea level to 700 meters (2,300-foot) altitude. The U.S. Navy adopted this position without further analysis. There is no doubt that ascent to 2,300 feet after a dive at sea level will increase the diver's risk of DCS. The question is the magnitude of the additional risk and whether it is acceptable. We may have to revisit the 2,300-foot rule for pragmatic reasons. The risks may be low enough that the inconvenience created by requiring a surface interval is unwarranted.

No reports have been received from dive expeditions at altitude where the new rules could facilitate earlier ascent over mountain passes or earlier extractions by helicopters or fixed wing aircraft. The USN only conducts one to three altitude operations per year, so it is not surprising that we do not have much information.

The decision to use the highest repetitive group achieved in the previous 24 hours is especially punitive to a diver who surfaces with a high repetitive group then within the next 24 hours makes a relatively shallow dive that leaves him in a low repetitive group.

The full surface interval penalty from the first dive is added to the end of the second dive. No complaints have been received from the Fleet about this specific scenario.

### **Summary and Conclusions**

The new U.S. Navy procedures were developed to provide surface intervals compatible with the Duke data for no-stop dives. We knew we had to make a change in the current Navy rules because the Duke data indicated that a two-hour surface interval following a no-stop dive was completely inadequate. We also wanted a procedure that would work equally well at sea level and at altitude. The available data were very limited. The main body of information from Duke was for no-stop dives at sea level followed by ascent to 8,000 for four hours. Decompression dives and ascents to altitudes other than 8,000 feet were not included in the Duke study. Also, the lowest and highest repetitive groups were not tested. We know of at least one U.S. Navy diver who suffered decompression sickness during a flight 72 hours after a decompression dive to 150 fsw for 30 minutes. Despite these limitations, the current procedure appears to map to the Duke no-stop experimental results reasonably well. No-stop diving is by far the most common form of air diving in the U.S. Navy. Some procedural problems were identified during implementation of the new procedures that resulted in using the highest repetitive group attained during the preceding 24 hours as the governing variable. Reaction from the Fleet to the new procedures has been minimal, indicating that they agree, or more likely, that the new procedures do not impose significant limits on current operations.

### **Acknowledgments**

The author wishes to acknowledge the contributions of Dr. Edward D. Thalmann, who participated in numerous discussions and worked tirelessly to achieve the desired objective. Thanks are also due to Drs. Richard Vann, Wayne Gerth, and Edward Thalmann, who unselfishly provided the data from their ongoing flying after diving study at Duke University. No restrictions were placed on the use of the data even though the study had not been completed or published. The U.S. Navy is extremely grateful for this early access to the data.

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## **DISCUSSION**

DR. THALMANN: What's the status right now? Are there plans for further changes?

DR. FLYNN: I'm not aware of any plans to change the Navy flying after diving procedures.

DR. WIENKE: The constant ratio extrapolation to altitude that you just outlined so nicely tends to break down at around 18,000-20,000 feet.

DR. FLYNN: The procedure stops at 10,000 feet. The Navy Diving Manual has a statement to call NAVSEA if you're going to dive or fly at altitudes above 10,000 feet because of the medical issues involved. But frankly, I'm not sure how prepared we are to answer any questions that might be asked. We've had a few dives at 13,000-16,000 feet, so it does come up periodically.

DR. WIENKE: Well, when you get up that high, give me a call. I can give you a suggestion.

DR. THALMANN: What altitude is the Navy looking at? Is the interest in land-based, as in dams on lakes, or is the interest in getting over mountain ranges after a dive?

DR. FLYNN: A lot of the work is on mountain dams that are fairly deep, 190-200 feet, and most of the diving is at altitudes of around 5,000-8,000 feet. We use surface decompression with the Cross corrections for the sea level equivalent depth.

Occasionally, you have to fly over the lip of a volcanic crater to get to a dive site and then fly back out. And then there are the mountain passes, of course, most of which are at 5,000-8,000 feet.



## **DIVING AT THE NO-STOP LIMITS: CHAMBER TRIALS OF FLYING AFTER DIVING**

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A review of the flying after diving literature for the Proceedings of the 1989 Flying After Diving Workshop (1) found few human trials for altitudes of less than 8,000 feet (2). A new study was clearly needed if flying after diving guidelines were to be based on empirical data. With initial support from the Professional Association of Diving Instructors (PADI), DAN conducted a flying after diving study from 1993-1999. A complete description of the study can be found in reference (3).

The study objective was to estimate preflight surface intervals (PFSI) that had little risk of decompression sickness (DCS) after no-decompression dives near the limits of the recreational diving exposures. We chose long no-stop dives, as we were interested in the maximum PFSIs that might be needed. Our volunteers were dry and at rest, as we could test up to 12 subjects per experiment under these conditions, while not more than three divers could be tested with immersion and exercise.

The experimental design was based on a dive (or dives) followed by a PFSI of three to 17 hours and a flight to 8,000 feet for four hours. We picked 8,000 feet because that was the maximum airline cabin altitude that the FAA specified (4). The flights were four hours in duration as our previous studies for NASA indicated that 92% of DCS occurred during the first three hours of four-hour flights. Recreational divers were recruited as subjects.

Our hypothesis was that the DCS incidence would increase as the PFSI decreased. We usually started with a long PFSI for which DCS did not occur and decreased the PFSI until DCS occurred too frequently or was too severe.

We defined DCS severity as Mild, Moderate, or Serious, where Mild DCS was limb pain or localized abnormal sensation, Moderate DCS was specific sensory deficit or weakness, and Serious DCS included paralysis, difficulty breathing, fainting, cerebral dysfunction, etc.

We used a sequential experimental design in which a PFSI was accepted for a given dive profile if there were only a few mild DCS incidents. When a PFSI was accepted, the next PFSI to be tested was generally one hour shorter. We rejected a PFSI if there were too many Mild incidents or if we had Moderate or Serious DCS. When a PFSI was rejected, we tested a one hour longer PFSI if we hadn't already done so. The Accept and Reject rules are listed in Table 1.

**Table 1. Accept and reject rules.**

<u>Reject</u>	<u>Accept</u>
2 Mild DCS in $\leq 10$ dives	0 DCS in 23 dives
3 Mild DCS in $\leq 26$ dives	1 DCS in 35 dives
4 Mild DCS	2 DCS in 46 dives
2 Moderate DCS	3 DCS in 56 dives
1 Serious DCS	

To choose the dive profiles, we used the Recreational Dive Planner (RDP), as it is widely accepted and since the Professional Association of Diving Instructors (PADI) provided initial project funding (5). Most of the dive profiles were at or near the limits of the RDP. We did not test the DSAT tables exactly as prescribed. These tables specify an ascent rate of 60 feet per minute, but we used an ascent rate of 30 feet per minute. In addition, for dives at the no-stop limits, the DSAT tables specify a three-minute safety stop. We did not use safety stops as they had not been used in previous flying after diving studies.

Table 2 shows the dives that were tested. We tested four single dive profiles and five repetitive dive profiles with a one-hour surface interval between dives as this short surface interval is common in recreational diving.

**Table 2. Dive profiles tested.**

Single dives	Repetitive dives
40' for 60 min	40'/60 min -1 hr SI- 40'/60 min
40' for 120 min	60'/55 min -1 hr SI- 60'/20 min
60' for 55 min	60'/55 min -1 hr SI- 60'/30 min
100' for 20 min	60'/55 min -1 hr SI- 60'/20 min -1 hr SI- 60'/20 min
	100'/15 min -1 hr SI- 60'/35 min

There were 802 exposures with 40 DCS incidents (5% DCS incidence). Twenty-one cases were Moderate, 18 were Mild, and one was Serious. The serious case was cerebral and occurred after a flight preceded by a three-hour surface interval. It resolved with hyperbaric oxygen.

Figure 1 (on page 34) shows the results of the 344 single dive exposures. DCS began to occur at approximately the same PFSI of three of the four dive profiles and increased in a similar fashion as PFSI was reduced. This was not the case for the 120-minute dive at 40 fsw, however, for which insufficient time was available to determine what PFSI would be accepted with no DCS. For this long shallow dive, the PFSI with a low DCS risk would appear to be longer than for the shorter dives, but the study terminated before the tests were completed.

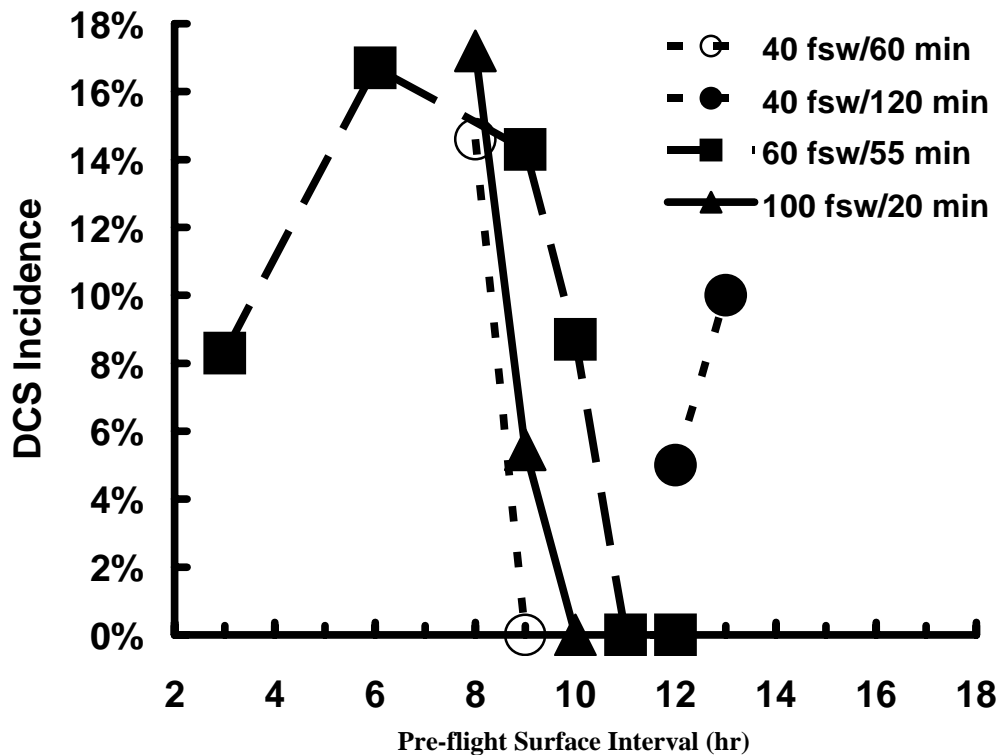
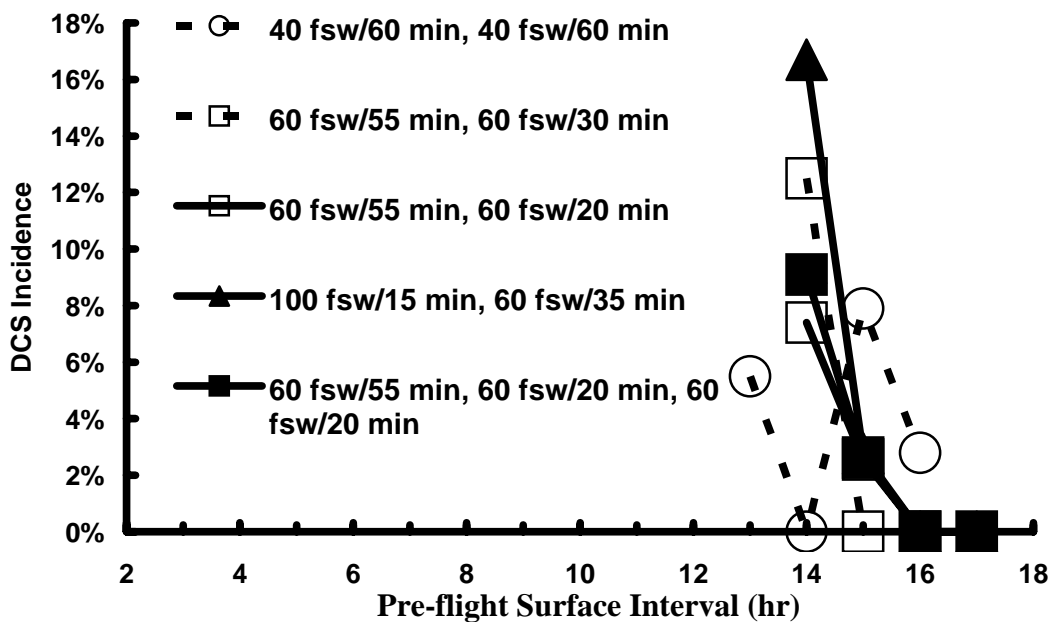


Figure 2 (on page 35) illustrates the results of the 458 repetitive dive exposures. These flying after diving profiles were similar in that the PFSIs with no DCS were 15-17 hours. At shorter PFSIs, the DCS incidence began to increase. There was a statistically significant association between PFSI and DCS incidence ( $p=0.0014$ ), and the PFSIs for single dives were significantly different from repetitive dives ( $p=0.0180$ ), but the PFSIs for single dives were indistinguishable from one another (Fig. 1) as was also the case for repetitive dives (Fig. 2).



**Figure 2. Repetitive dive results.**

In conclusion,

- (a) The diving exposures were at or near the RDP no-stop limits.
- (b) The DCS incidence increased significantly as the PFSI decreased.
- (c) Repetitive dives required significantly longer PFSIs to achieve low DCS.
- (d) No DCS occurred in a total of 52 trials of a 17-hour PFSI.
- (e) Since the experimental subjects were dry and at rest, the results may not apply to immersed exercising divers. Additional studies are needed to determine the effects of immersion and exercise.

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## DISCUSSION

DR. SHEFFIELD: You used the PADI tables for this study in which there is a six-hour surface interval before you become a fresh diver. What would have been the impact if you had used the Navy tables with a 12-hour surface interval to become a fresh diver?

DR. VANN: There would have been several repetitive dives that we would not have been allowed to do, and the U.S. Navy Tables would have required decompression stops for some of the repetitive dives.

DR. WIENKE: PADI uses 60-minute tissue compartment while the U.S. Navy uses 120 minutes. You can multiply their surface intervals of the PADI tables by roughly a factor of two to recover the Navy tables. In some sense, that carries over to any type of dissolved gas analysis such as M-values.

DR. THALMANN: The study had nothing to do with the way that any tables were calculated. Dr. Vann just picked the dive times from the Recreational Dive Planner. In essence, it was an empirical study because the surface intervals were shortened based only on observation. In fact, he could have gone to the Navy diving manual or any other tables to pick the bottom times. I doubt whether it would have made any difference.

In terms of the analysis, M-values, tissue tensions, and half-times are figments of our mathematical imagination. We can analyze it anyway we want with equal validity. The problem is that there can be big disparities in no-D limits between different dive tables. We selected the RDP limits arbitrarily with the goal of finding the longest preflight surface interval. This is independent of the way the table was computed.

DR. SHEFFIELD: We're looking at recreational flying after diving guidelines today. Is there any real difference in the application of these data for recreational dive tables as compared to the new Navy flying after diving guidelines presented by Dr. Flynn? What I think I heard you say is that it doesn't make any difference.

DR. THALMANN: The Navy views the health and well-being of its divers in the same way as recreational divers. I can think of no reason why a recommendation for

recreational divers would be any more or less conservative than a Navy recommendation. Recreational divers may need more conservative no-stop limits because they don't necessarily have the same immediate access to treatment, and recreational divers dive in very remote sites. Navy divers are required to have a plan for treatment even in remote locations. Recreational divers might get bent in the South Pacific 12, 24, 48 hours from a treatment facility.

DR. GERTH: Different tables can leave you with different gas loads on surfacing before flight. This could make a big difference for flying after diving recommendations tables.

DR. THALMANN: No-decompression limits are model-dependent and require different preflight surface intervals.

DR. SOUTHERLAND: For your 40 feet for 60 minute dive profile with a one-hour surface interval, then another 40 for 60 dive, you had three bends before the flights. Were you pretty confident about that? You know, because that – that seemed kind of different. And then you had in here that you accepted a 14-hour surface interval, but then you rejected a 15-hour surface interval, but then you accepted a 16-hour surface interval.

DR. VANN: Those are two separate issues. DCS after diving (before the flights) occurred in 1.4% of the exposures. DCS during or after flight occurred in 5% of the exposures. All cases met the Navy post hoc DCS criteria and are described in reference (3). We did a post hoc review of the data after the study was complete and found two cases for the 15-hour surface interval that met the DCS criteria but were initially missed. That is why Fig. 2 shows an increase in DCS incidence at 15 hours. The surface intervals were tested in the order 16, 15, 14, and 13 hours.

DR. FLYNN: These were all dry, resting dives? How do you think this would translate into immersed working divers?

DR. VANN: We don't have data that allows direct comparison, but the literature indicates that immersion increases nitrogen uptake and the incidence of decompression sickness. Exercise has a similar effect.

DR. FLYNN: Would it be fair to say you think that the surface interval times might actually have to be somewhat longer than you see in your current data set?

DR. VANN: We have no data on that, but I would expect so.

DR. THALMANN: My take is if the preflight surface intervals are short – say two to four hours – exercise and immersion might be important. With surface intervals of 12, 18 to 24 hours, however, I think that any incremental change due to exercise would be minimal, down into the noise and not within our ability to discriminate from rest. With surface intervals of two to four hours, that probably wouldn't be true.

DR. VANN: A study of the effects of immersion and exercise needs to be done.

## FLYING AFTER MULTIDAY REPETITIVE RECREATIONAL DIVING

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### **Preflight Surface Interval (PFSI)**

Decompression sickness (DCS) as a result of flying after diving was first reported in 1961 (1, 2). Subsequently, there have been reports of injury (3, 4) and even death (5) in both the popular press and medical literature (6). Although the American Medical Association Council on Scientific Affairs raised the topic of altitude-induced DCS in its report on medical oxygen and air travel (7), a recently published textbook of clinical aviation medicine (8) failed to comment on the subject, and only brief discussions of the topic can be found in most diving medicine texts. However, DCS resulting from flying after diving does occur, and information on how and why it happens is of great importance to the diving community.

Vann and Denoble showed that divers who flew with symptoms associated with DCS II generally experienced incomplete relief after a single recompression (9). Outside of this work, most of what is known about the risk of flying after diving comes from laboratory studies. Experimental DCS from flying after diving has been demonstrated in animals (10, 11) and humans (12, 13), but the literature is sparse. A 1989 review found 208 DCS cases out of 721 exposures (14). Furthermore, when altitudes greater than 2,438 m (8,000 feet) were removed from consideration, only 17 DCS cases in 77 exposures remained for analysis. Finally, chamber studies are distinct from field conditions where divers exercise, are immersed, and may dive for many consecutive days.

In 1987, Divers Alert Network (DAN) began collecting information on recreational divers who were treated for decompression injury. In 1997, DAN began a prospective study of DCS, Project Dive Exploration (PDE), that catalogues medical, demographic and dive outcome data on divers as well as their depth-time profiles recorded by dive computers. With 11 years of injury data and three years of PDE data in hand, case-control comparisons of safe PDE dives with dives that resulted in decompression injury have become possible. We also examined the injury data for a possible effect of flying on estimates of DCS severity.

Specifically, we addressed the following questions in the DAN injury and PDE data:

- (a) Does the pre-flight surface interval (PFSI) influence the DCS risk in divers who fly after multiday, open water recreational diving?
- (b) Does flying after diving influence the severity of DCS?

### **The Relative Risk of DCS in Flying After Diving**

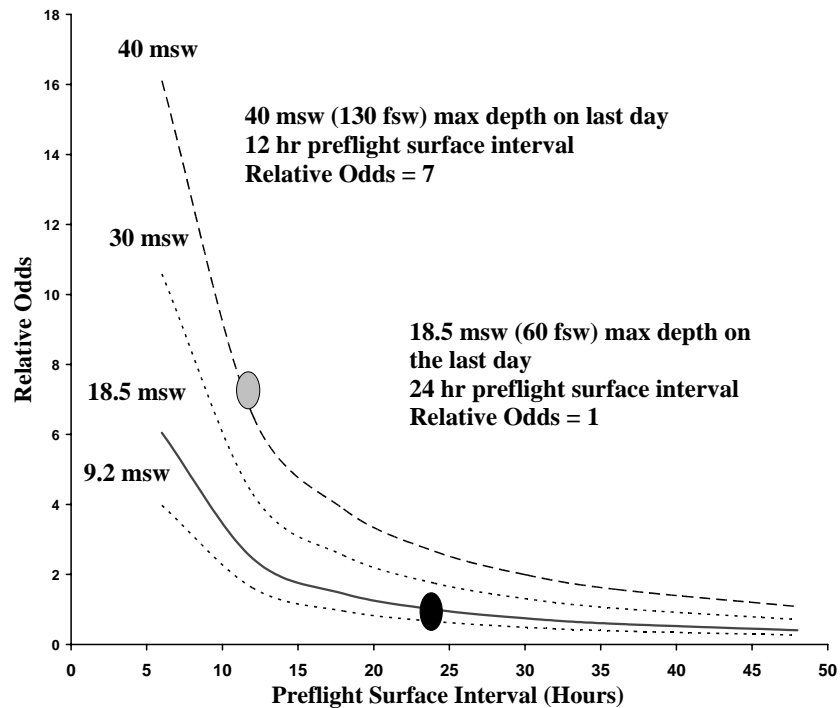
We conducted a case-control study of flying after diving that compared dives resulting in injury to uneventful dives. Our goal was to estimate how the length of the PFSI and other factors affected the relative odds of developing DCS during or after flight. A complete report of this study has been published (15).

In a case-control study, the investigator finds both cases and controls and compares the distribution of suspected predictor variables (like PFSI) between the two groups. This is an efficient technique for rare diseases because the investigator can use as many cases as he can find that meet the selection criteria. The drawback is that the incidence of the disease, the absolute risk, cannot be determined because the investigator does not have complete information about the entire population at risk. However, a case-control study can determine if a particular predictor variable that the investigator suspects might be important (like short PFSIs) is over-represented in cases as compared with controls.

For data collected from 1987-1999 that involved flying after diving, 382 divers with DCS were found in the injuries, while 245 safe control divers were found in PDE. The cases had been classified as DCS I or DCS II, not arterial gas embolism (AGE), but as they came from a retrospective review of DAN injury reports, we were unable to independently verify the diagnosis of DCS. Any patient who received recompression therapy for DCS in our sample was considered to have had DCS, and all cases of DCS were treated as equal in severity. All dives were on air, and the divers were exposed to air travel, not mountain travel, although the actual cabin altitude was unknown. Some divers may have developed symptoms from diving alone, but we assumed that the PFSIs of these non-flying related cases would be normally distributed and not affect the overall relationship of PFSI to DCS.

Figure 1 (on page 40) shows the results of comparing the length of the PFSIs in the injury cases to the length of the PFSIs in the uninjured controls. We used logistic regression to model the data and controlled for age, gender, height and weight. We also controlled for the maximum depth of the dive series, the maximum depth of the last dive, the number of dives and the number of days in the dive series.





**Figure 1. The relationship of PFSI to the relative odds of DCS.**

As in the chamber study (16), we found a significant predictive relationship between the length of the PFSI and the relative odds of DCS. Shorter PFSIs had a higher risk of DCS. There was a similar relationship for the deepest dive on the last day of diving. Deeper dives on the last day had an increased risk of DCS compared to shallower dives. Age, height, weight and gender were not predictive. Using the curves in Fig. 1, the relative odds of DCS between different PFSIs and different depths can be estimated. These data suggest that the odds increase most abruptly between 12 and 15 hours and that the depth of the last dive or last few dives is important to the risk.

### **The Effect of Flying After Diving on DCS Severity**

The next issue we examined was the effect of flying on DCS severity. We compared three groups of divers from the injury data: (a) divers who developed symptoms before they flew and proceeded to fly with symptoms; (b) divers who developed symptoms only after flying; and (c) all of the other divers with symptoms. Because some divers in the “all other group” probably did fly but were not recorded as flying, the results are biased toward the null, meaning that any demonstrable effect is probably stronger than indicated in the analysis.

As there is no accepted measure of DCS severity, we used several proxies for severity: (a) perceived symptom severity; (b) the number of treatments given; and (c) the presence or absence of residual symptoms after the first treatment and at discharge.

We ordered the cases according to our perceived order of symptom severity from most severe to least severe: serious neurological; cardiovascular; mild neurological; pain,

lymphatic / skin; and constitutional. We were unable to show any difference in perceived symptom severity between divers who did not fly, who flew with symptoms, or who developed symptoms during or after flight.

When the number of treatments received by injured divers was examined, there was a suggestion of an increase in the number of treatments for the two flying groups, but not at a statistically significant level. However, the flying groups had a significantly higher probability of post-treatment residual symptoms (Table 1), although the magnitude of the effect was small and may not be clinically relevant.

**Table 1. Residual symptoms after the first treatment and at discharge after all treatments.**

<u>Symptoms Before Flight</u>	<u>After 1<sup>st</sup> Treatment</u>	<u>At Discharge</u>
	61%	49%
<u>Symptoms After Flight</u>	66%	46%
<u>All Other Divers</u>	56%	32%

## **Conclusions**

We conclude that:

- (a) There is increased relative risk of DCS for shorter PFSIs and for deeper dives on the last day of diving.
- (b) The risk of residual symptoms after treatment is moderately increased for divers who fly with symptoms or who develop symptoms during or after flying.
- (c) There is a suggestion that divers who fly with symptoms or who develop symptoms during or after flying require more treatments than do divers who do not fly.

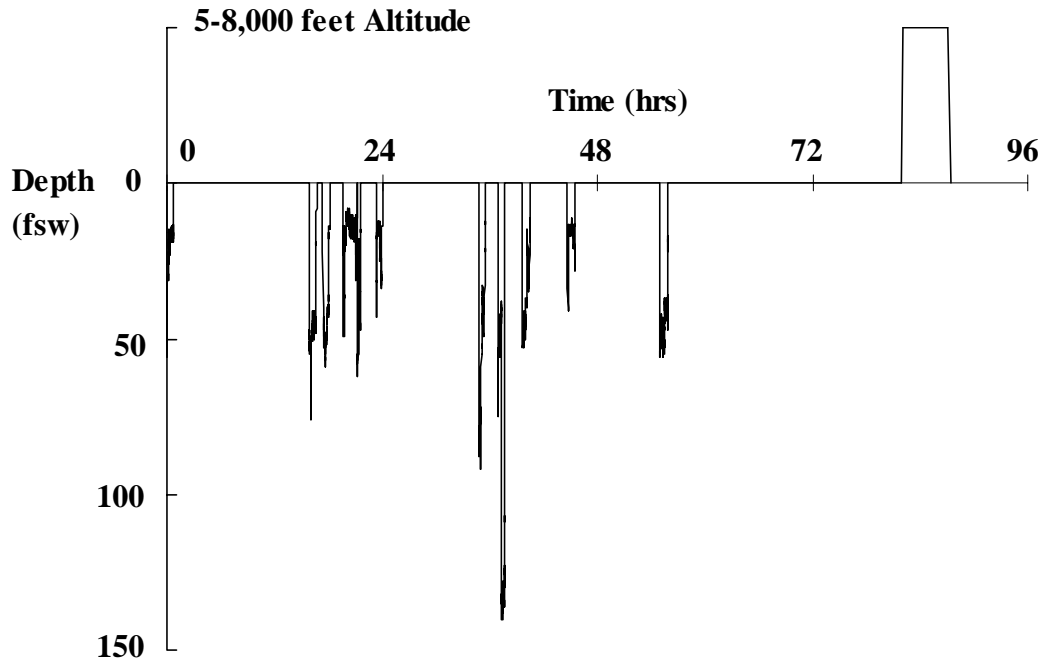
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## DISCUSSION

DR. FREIBERGER: There is one more slide. This is an individual from Project Dive Exploration (PDE) who did some relatively deep diving and then flew 26 hours later with no symptoms before flying. She was the wife of a DAN doctor and developed symptoms during a second of two flights.



DR. SHEFFIELD: There's a 150-foot dive with no-decompression stops on that dive?

DR. FREIBERGER: Her computer said she could do it.

DR. SHEFFIELD: Her computer also said she was not going to bend on that flight, right?

DR. FREIBERGER: Her computer didn't get bent either.

DR. WATENPAUGH: In the case-control study, did you try something a little more sophisticated than just the depth of the deepest dive on the last dive to address the effect of the dive profile?

DR. FREIBERGER: We had dive profiles for the PDE control divers but not for the injured divers. The best I could get for the injuries was the maximum depth of the last day. The values for the cases were self-reported, which is a justifiable criticism, because it's not hard data. For PDE, on the other hand, I had the maximum depths recorded by the dive computers.

DR. WATENPAUGH: Did you have any data on flight duration and repetitive flights?

DR. FREIBERGER: No. I just knew that they had flown and developed symptoms after they flew or during the flight. We did not know how many flights they made or what the altitude was.

DR. SOUTHERLAND: It's been reported that delay to treatment is associated with an increased likelihood of residual symptoms. Did you adjust for delay to treatment? One typically thinks that if you're flying a long time, that's going to delay your ability to get to a chamber.

DR. FREIBERGER: We don't have data of that resolution.

DR. FLYNN: How many of these 300 cases actually occurred during the flight?

DR. FREIBERGER: I knew when the symptom onset was, when they got out of the water and when they flew, but I didn't know the flight duration. I think you're asking how many of these cases would have developed the bends anyway.

DR. FLYNN: Yes.

DR. FREIBERGER: I don't know. The data set wasn't designed for this type of investigation. We are developing a new data collection instrument that will make a study like this possible.

## DEVELOPMENT OF GUIDELINES FOR FLYING AFTER DIVING

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DAN had previously conducted a Flying After Diving (FAD) study aimed at recreational divers, the results of which were presented at this conference (1) and published elsewhere (2). As noted, this study concentrated mainly on no-decompression dives. The U.S. Navy has now funded a study at Duke in conjunction with the Navy Experimental Diving Unit (NEDU) to expand the scope to better suit Navy operational needs. The project goals are as follows:

- Test selected current USN flying after diving procedures for air dives using profiles not previously tested in other studies.
- Find the minimum safe surface intervals for flying after diving breathing air with and without 100% oxygen breathing during the 1 ata pre-flight interval for selected no-decompression and decompression dives.
- Using existing data and new data, develop a decompression model capable of computing the risk of decompression sickness (DCS) for altitude exposures following air dives.
- Use the resultant decompression model to compute a comprehensive set of flying after diving guidelines for air diving, make predictions for dive / altitude exposures for nitrogen oxygen mixtures other than air, and make preliminary predictions for diving at altitude procedures.

Dr. Flynn presented the Navy's current FAD procedures pointing out they used the Cross corrections and were essentially empirical (3). This resulted in a rather complicated "look-up" procedure that did not always mesh seamlessly with the current repetitive dive procedures. In addition, some of the prescribed intervals at 1 ata before flying at 8,000 feet (the preflight surface interval, or PFSI) seemed conservative. Our ultimate goal for the study described here is to develop a mathematical model that could be used to compute a set of printed tables and would be compatible with the VVal-18 algorithm used in the current Navy decompression computer (3-6).

The technical approach addressing the first goal is shown in Table 1. We will do an air dive followed by a PFSI and a four-hour flight at 8,000 feet. The PFSI will be progressively shortened until the number of mild DCS (musculoskeletal or peripheral

paresthesias) that occurs within a certain number of person-exposures exceeds a predetermined reject limit. At that point, we move on to another dive / PFSI combination and start over.

Table 1 lists the dive profiles planned for testing. The three no-decompression dives continue the DAN study (1). We intend to sneak up on the current air no-decompression limit of 200 minutes at 40 fsw by first finding the shortest PFSI for a 40-fsw / 130-minute dive. As you can see, the VVal-18 algorithm predicts that the 40-fsw / 200-minute dive should require decompression, but we have not yet decided whether to keep the dive no-decompression or start with the VVal-18 prediction. The 60-fsw / 40-minute dive was included to see how short a PFSI was needed for a short dive. A previous study suggested that the PFSI for this dive might be relatively short (7).

**Table 1. Test Dives and Starting PFSIs.**

Depth (fsw)	Bottom Time (min)	Repetitive Group (US Navy Tables)	USN Decompression Stops (min @ fsw)	VVAL 18 Decompression Stops (min @ fsw)	Starting PFSIs (current USN procedure)	Assigned Testing Priority
40	130	K	no-d	no-d	19:03	6
40	200	N	no-d	38@10'	22:46	5
60	40	G	no-d	no-d	12:05	1
60	120	N	26@10'	123@10'	22:26	2
80	80	N	2@20', 31@10'	40@20', 92@10'	22:46	3
100	60	N	9@20', 28@10'	64@20', 93@10'	22:46	4

The last three dives in Table 1 are decompression dives. Decompression dives were not tested in the DAN study that was aimed at recreational diving, which is generally no-decompression. However, the U.S. Navy (USN) has scenarios where flying may be required after a decompression dive.

Table 1 shows two decompression schedules, one with the USN decompression stops from the current U.S. Navy Diving Manual and one with the VVal-18 stops used in the Navy decompression computer. We must decide which table to use in our tests. We know from past testing that some of the Standard Air decompression schedules have an unacceptable incidence of DCS (4). Since the object of this study is to determine the shortest PFSI after a dive, we want to avoid DCS after diving.

The next to last column of Table 1 shows the PFSIs prescribed by the current USN flying after diving procedures (3). Generally, we will start with these PFSIs and move towards progressively shorter ones as the tests allow. The last column shows the priority order in which the dives will be tested.

The study milestones are shown in Table 2. Effort 1 will breathe air during the PFSIs and will take about 15 months and involve some 360 exposures. Effort 2 will use the same test dives but will breathe 100% oxygen during the PFSI to shorten the PFSI. We will start with one hour of oxygen breathing immediately after surfacing. Our current models predict this will give the maximum effect. If we have time, we will also breathe oxygen

for one hour right before the second dive. Comparing PFSIs for oxygen breathing at the beginning or end of the surface interval should give us some clues about the proper form of the decompression model.

**Table 2. Milestones.**

Description	FY1(2002)				FY2(2003)				FY3(2004)			
	1	2	3	4	1	2	3	4	1	2	3	4
Effort 1: Pre-flight surface intervals air breathing.	S	-----	CR									
Effort 2: Pre-flight surface intervals with oxygen breathing.					S	-----	CR					
Effort 3: Minimum altitudes at which FAD guidelines must be used.									S	----	CR	
Decompression model development	S	-----	-----	-----	-----	-----	-----	-----	-----	-----	CR	
FY_ fiscal year, S-start, C- complete, R-report results												

The last experimental part of the study involves determining the maximum altitude to which one could ascend immediately after surfacing from the test dives of Table 1. This will give the altitude below which flying after diving procedures are unnecessary.

Subjects will be recruited from the general sport diving population without regard for gender. Subjects will not be screened for patent foramen ovale (PFO) because the Navy does not do these screens. We will, however, monitor subjects for venous gas emboli with Doppler ultrasound after diving and during flight. Subjects with Spencer Bubble Grades of 3 or 4 will be evaluated by transthoracic echo imaging (TTE) with a portable Sonosite acoustic imaging system to look for arterial bubbles in the left ventricle and aortic root. Past experience has shown that arterial bubbles are unlikely at low Doppler scores. Subject with arterial bubbles at altitude will be immediately returned to 1 ata whether or not symptoms are present.

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## **DISCUSSION**

DR. SOUTHERLAND: You are not going to pre-screen people for PFOs or septal defects?

DR. THALMANN: No. We're going to look for arterial bubbles after diving and at altitude. If we pre-screen and find a PFO, I don't think they would let us fly a subject with a known PFO. It's a problem. The Safety Committee of the Association of Diving Contractors has the same problem. If they screen for a PFO, find one, and tell a guy they can't dive, he sues them for taking away his profession, because there's no hard evidence that it's dangerous. If you let him dive and he ends up getting a bad cerebral hit, and he's walking around dribbling out of his mouth and can't urinate properly, he's going to sue you because, hey, you knew he had a PFO. Why did you let him dive? Right now, we don't plan on screening.

DR. VANN: We may ultimately do blinded scans and then put them aside and look at them afterwards, but we will definitely not screen.

DR. SOUTHERLAND: That's good, because you're trying to reflect the population that doesn't have screening before they go out and do recreational diving.

DR. THALMANN: Our assumption is that our study population will have roughly the same incidence of PFO as the general population. Anybody who gets bent and has neurological symptoms will get a bubble contrast scan for PFO. For the divers who don't get bent, we might also do a bubble contrast to establish what the PFO incidence is.

MR. YOUNG: What percentage of the population has a PFO?

DR. THALMANN: The total is about 25 percent, but only about 10% have a resting PFO in which bubbles just roar across the atria at rest with normal changes in intrathoracic pressure during respiration. There are other people who must do a valsalva, where you close your glottis and strain, in order to demonstrate the passage of arterial bubbles. In the latter case, the probability of a venous bubble crossing to the arterial side is less than in the former case.

## TRIALS OF FLYING AT 25,000 FEET AFTER DIVING

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### **Introduction**

Flying after compressed gas diving increases the risk of decompression sickness (DCS) if insufficient time is spent at 1 atmosphere absolute (ata) prior to flight (1-3). The time at 1 ata between dive and flight is called the preflight surface interval (PFSI). Since the majority of post-dive flights take place in pressurized, commercial aircraft with cabin altitudes no greater than 8,000 feet, the maximum limit established by the Federal Aviation Administration (4), most PFSI guidelines have been developed with pressurized, commercial flying in mind. These guidelines have been developed based on few data, most involving altitude exposures of less than 10,000 feet with fewer involving altitude exposures to 16,000 feet (5). Military Special Operations Forces (SOF) personnel have unique requirements in that they may perform missions in unpressurized aircraft at considerably higher altitudes.

SOF personnel regularly participate in both diving and flying activities. Flying frequently involves parachuting, often from high altitude. High altitude low opening (HALO) and high altitude high opening (HAHO) are designated by the aircraft exit altitude and the altitude at which the canopy is opened and freefall ends. Training activity may require jumps from aircraft at or above 25,000 feet. Operational jumps may occur above 30,000 feet. Operational diving exposures are usually conducted using oxygen, so flying after diving may not be a problem. Training and recreational diving activity, however, often employ air as a breathing mixture, so consideration of PFSI is relevant. Air breathing during diving increases the amount of residual nitrogen in the body and must be considered for flight operations.

The current operational rules prescribed by the U.S. Air Force call for a minimum of 24 hours between diving and high altitude operations and a 30- to 45-minute oxygen breathing period (prebreathe) before high altitude exposure to further denitrogenate the tissues (6). These requirements were adopted with the intention of establishing conservative practices in the absence of experimental data. While operational experience showed these procedures to be safe, it has not been determined if a shorter preflight surface interval with oxygen prebreathe would provide adequate protection against decompression sickness. The current study was conducted to address this question.

### **Methods**

The Duke University Institutional Review Board approved this study. Subjects provided written, informed consent prior to participation. Women were excluded to make the study sample consistent with current U.S. Special Operations Command combat forces.

Time and budgetary restrictions determined the scope of the study. It was decided that a single, simulated diving exposure would be employed, 60 fsw for 60 minutes, the no-decompression limit according to the U.S. Navy Standard Air Tables (7). The dive was followed by a 24-, 18- or 12-hour PFSI. The nominal altitude of Duke where the study was conducted is 398 feet above sea level. Subjects breathed medical grade oxygen via a head tent for the 30 minutes immediately preceding flight, during the 10-minute ascent and throughout the three-hour simulated flight at 25,000 feet.

The travel rate (ascent and descent) was 30 fsw per minute (fpm) ( $9.1 \text{ m} \cdot \text{min}^{-1}$ ) for dives and 2,500 feet altitude per minute ( $762 \text{ m} \cdot \text{min}^{-1}$ ) for flights. Dive time commenced when the chamber left the surface and ended when the chamber left the bottom. Flight time began when the chamber arrived at altitude. Subjects remained dry and at rest during both dive and flight.

Initial control studies employed two-hour and then three-hour flight-only exposures coupled with the prebreathe protocol described above to evaluate the DCS risk from altitude exposure alone. The dive-PFSI-flight combination profiles were then conducted with the three-hour flights following progressively shorter PFSIs. Subjects were allowed to complete a given dive-PFSI-flight profile only once, but were able to participate again in studies of different profiles.

The sequential experimental design employed was based on *a priori* accept / reject rules. Study profiles were accepted when the observed DCS incidence was lower than the one-tail upper 95% binomial confidence limit. A PFSI could be accepted with zero DCS cases in 23 trials, one mild case in 35 trials, two mild cases in 46 trials, or three mild cases in 56 trials. A PFSI would be rejected with one severe case of DCS at any time, two moderate cases at any time, two mild cases in 10 trials, three mild cases in 26 trials, or four mild cases at any time. The study design minimized the number of trials required for completion.

When a PFSI was accepted, a six-hour shorter PFSI was tested. If a PFSI was rejected, a one-hour longer surface interval was to be tested with the same dive profile.

DCS was classified as mild, moderate or severe according to the following criteria for the purposes of the study:

Mild: fatigue; joint pain or muscle aches; minor numbness or paresthesia without objective neurological findings.

Moderate: minor numbness or paresthesia with objective sensory findings. Minor motor weakness without major gait or balance disturbances.

Severe: major numbness or paresthesia with objective sensory findings; major motor weakness; gait or balance disturbance; vertigo; hearing abnormalities; visual disturbance; pulmonary involvement; disturbance of consciousness; cognitive or psychomotor change.

Doppler ultrasound (Techno Scientific Inc., Model DBM9008 with Model TSI-DPA7 2.5 mHz Continuous Wave Precordial Probe) was used to non-invasively monitor venous gas emboli (VGE, or bubbles) at 30-minute intervals post-dive for one hour or until VGE could no longer be detected. Doppler monitoring was also conducted at 30-minute intervals throughout flight and following flight when VGE were present until they were no longer observed. VGE were graded according to the Spencer 0-4 bubble grade scale (8).

Subjects were monitored precordially for VGE while in a seated position. Initial measures during motionless sitting (Rest) were followed by measures recorded during sequential limb movements (Movement). During Movement periods, the seated subject flexed each limb twice in sequence to mobilize gas bubbles presumably lodged in the venous pathway. The sequential limb measures were intended to improve the ability to localize the regional source of VGE. The highest scores, usually achieved immediately following movement, and the limb involved, if appropriate, were recorded for each monitoring cycle. VGE onset times were computed from the point of surfacing at the end of the dive and from arrival at target altitude during flight. The subsequent time to resolution (i.e., disappearance) of measurable VGE was also determined in relation to onset time. Post-flight VGE resolution was not monitored during the initial two-hour flight-only exposure.

Physicians performed pre-experiment physical and neurological examinations and monitored subjects throughout the study. Subjects were encouraged to report all symptoms, no matter how minor or fleeting. Subjects reporting signs or symptoms of DCS while at altitude were recompressed to ground level. Symptoms present at ground level were treated with ground level oxygen and 2.8-ata hyperbaric oxygen as directed by the monitoring physician.

Results are reported as means  $\pm$  standard deviation (SD). A Chi-square test for contingency tables was used to compare DCS incidence between profiles. One-way analyses of variance were used to compare differences in anthropometric measures, VGE onset time and time to maximum VGE grades as a function of post-dive PFSI. Significance was accepted at  $p < 0.05$ .

## **Results**

A total of 155 subject-exposures were completed by 102 individual male subjects. Volunteers were  $34 \pm 10$  years of age,  $1.80 \pm 0.08$  m in height,  $84.5 \pm 13.8$  kg in weight, with body mass index (BMI) of  $26.2 \pm 4.2$  kg·m<sup>-2</sup>. There were no significant differences in any of these anthropometric measures for the subset populations completing the five different profiles.

Each of the five profiles tested was accepted with either zero or only one case of DCS. The trials with symptoms are presented in Table 1. There were no reports of symptoms preceding flight for any profile tested. There were eight reports of symptoms during the flight phase. Three altitude exposures were aborted due to symptom reports. In two of these cases mild DCS was ultimately diagnosed while the third was found to be unrelated

stiffness due to prolonged sitting. The remaining five individuals with symptoms completed their flights. Only one case was ultimately diagnosed as mild DCS. The other four were classified as unrelated conditions: two cases due to seating discomfort; one due to anxiety with hyperventilation; and one due to chronic shoulder pain.

**Table 1. Symptoms reported during flight phase of the study.**

Profile	Number of Subject-Exposures	DCS Symptoms		Non-DCS Symptoms
		Cases (# [%])	95% One-Tail Confidence Interval	Cases (# [%])
2 h Flight-only	35	1 [2.9]	0.15-12.85	1 [4.1]
3 h Flight-only	24	0 [0]	0-11.73	
60'/60 min Dive + 24 h PFSI	23	0 [0]	0-12.21	
+ 3 h Flight				
60'/60 min Dive + 18 h PFSI	37	1 [2.7]	0.14-12.19	3 [8.1]
+ 3 h Flight				
60'/60 min Dive + 12 h PFSI	36	1 [2.8]	0.14-12.51	1 [2.8]
+ 3 h Flight				
TOTAL	155	3 [1.9]		5 [3.2]

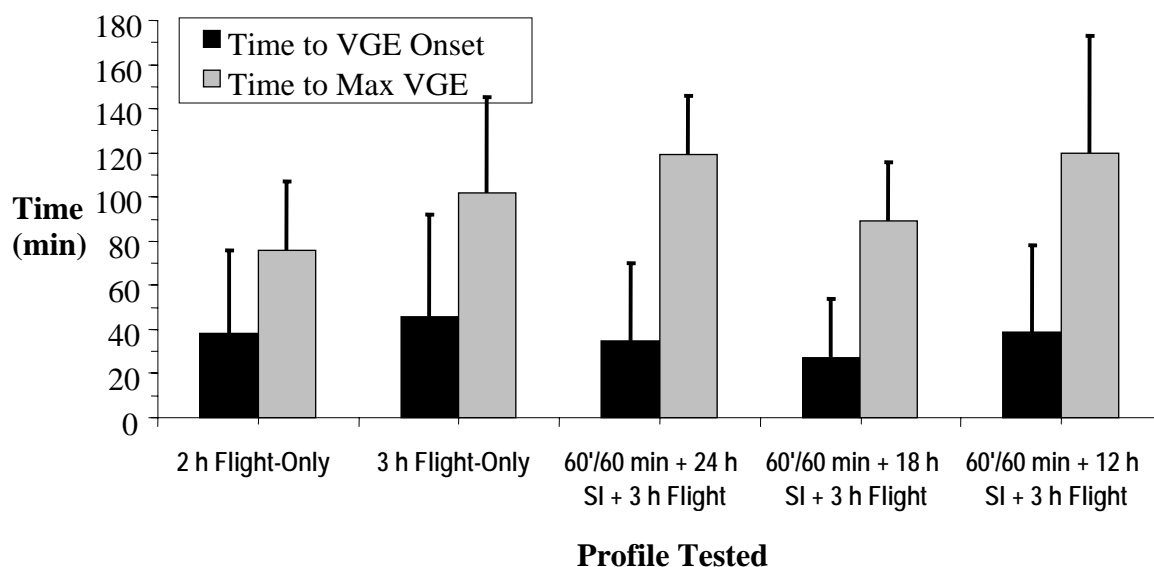
The three cases of mild DCS encountered during the study (1.9% incidence) were distributed throughout the profiles (Table 1). There was no statistically significant difference in the DCS incidence for any of the profiles tested ( $X^2[4]=1.33$ ; crit=9.49), although the 95% confidence intervals were broad (Table 1). Case 1 presented with unilateral foot pain 1h:00 into the two-hour flight-only profile (note: the symptoms were reported after completion of the study). Case 2 presented with unilateral knee pain 1h:45 into the three-hour flight following the 18-hour PFSI. Case 3 presented with bilateral elbow pain that started 0h:30 into the three-hour flight following the 12-hour PFSI. All three were completely resolved with no residua.

VGE scores are summarized in Table 2. VGE were observed post-dive in 7% (7/96) of the exposures and during flight in 20% (31/155) of the exposures. Interestingly, five of the seven subjects with post-dive VGE had no observed VGE during the subsequent flight. VGE of grades 3 or 4 were observed post-dive in 1% (1/96) of the exposures and during flight in 8% (12/155) of the exposures. All profiles with dives yielded some grade 3 or 4 VGE during flight: 13% (3/23 exposures) after a 24-hour PFSI; 5% (2/37) after an 18-hour PFSI; and 8% (3/36) after a 12-hour PFSI.

**Table 2. VGE results.**

Profile	VGE Grades (Spencer)	Max Grade Post-Dive (# [%])	Max Grade During Flight (# [%])	Onset Time, Any VGE Grade >0 (min [#])	Onset Time, Max VGE Grade >0 (min [#])	VGE Resolution from First Onset (min)
2 h Flight-only	0 1-2 3-4		27 [77] 8 [23] 0 [0]	68±38 [8]	76±31 [8]	n/a
3 h Flight-only	0 1-2 3-4		18 [75] 2 [8] 4 [17]	84±46 [6]	102±43 [6]	85±50
60'/60 min Dive + 24 h SI + 3 h Flight	0 1-2 3-4	18 [78] 4 [17] 1 [4]	18 [78] 2 [9] 3 [13]	68±35 [5]	119±27 [5]	77±55
60'/60 min Dive + 18 h SI + 3 h Flight	0 1-2 3-4	37 [100] 0 [0] 0 [0]	32 [86] 3 [8] 2 [5]	89±27 [5]	89±27 [5]	57±51
60'/60 min Dive + 12 h SI + 3 h Flight	0 1-2 3-4	34 [94] 2 [6] 0 [0]	29 [81] 4 [11] 3 [8]	100±39 [7]	120±53 [7]	71±36

Mean onset time for in-flight VGE was 82±38 minutes and mean time to maximum VGE was 100±40 minutes (Fig. 1). There were no significant differences between the profiles for onset time ( $F=0.29$ ;  $p=0.88$ ) or time to maximum VGE times ( $F=0.57$ ;  $p=0.68$ ). The mean time to resolution of VGE from the first observation of VGE was 74±46 minutes. There were no significant differences in VGE resolution time between the profiles ( $F=0.52$ ;  $p=0.73$ ), although seven cases of VGE that had not resolved by the end of the flight in the two-hour flight-only profile had to be excluded from the analysis.



**Figure 1. Time to VGE onset and time to maximum VGE grade for five profiles tested - two flight-only profiles and three dive-PFSI-flight profiles with PFSIs of 24, 18 and 12 h following a single 60'/60 minute dive. All flights to 25,000 feet.**

Two of the three subjects who experienced DCS had no in-flight VGE (Case 1: flight-only and Case 2: 18-hour PFSI). Symptom onset in these cases was at 1h:00 and 1h:30 into flight, respectively. The third subject (Case 3: 12-hour PFSI) had a maximum in-flight VGE grade of 2. VGE onset time and peak score, in this case, coincided at 0h:38 into flight. His VGE onset time was observed eight minutes after symptom onset.

VGE were observed in only one of the five individuals presenting with symptoms that were ultimately classified as not being DCS. This case occurred during the three-hour, flight-only profile and started 1h:51 into the flight with a peak VGE grade of 1. Symptoms had developed 1h:00 into the flight.

## Discussion

Current U.S. Air Force regulations require a minimum 24-hour PFSI between diving and high altitude parachuting (1). The goal of the study was to determine if the 24-hour PFSI could be reduced while still maintaining a low DCS risk. We did not find evidence of a significant increase in DCS risk for PFSIs of 18 or 12 hours after dry, resting dives to 60 fsw for 60 minutes. The 30 minute oxygen prebreathe undoubtedly contributes to the low DCS incidence (9).

Doppler-detected VGE are a commonly used measure of decompression stress for both diving and altitude exposure, where the DCS incidence has been significantly associated with higher VGE grades (10-12). For the three DCS incidents in our study, two had Grade 0 VGE and one had Grade 2 VGE. While there were too few DCS incidents to draw strong conclusions concerning the relationship of VGE to DCS, the available data do not support an association of Doppler-detected VGE with DCS for flying after diving.

Of the in-flight scores, 6.5% were Grade 4, none of which were associated with DCS symptoms.

The three-hour altitude exposure used in the current study was substantially longer than most military parachute operations. U.S. Air Force regulations limit exposure time to two hours (1). Operationally, most exposures do not exceed 45 minutes at altitude (personal communication, COL Warner D. Farr, USASOC). We chose a three-hour flight time since our previous experience with 30,000-foot exposures (with continuous oxygen breathing following a ground-level oxygen prebreathe) indicated that ~90% of the DCS incidents will occur within the first three hours (unpublished data). The long exposures provide a conservative test of profile safety. As two of the DCS incidents appeared after more than 30 minutes at altitude and responded to recompression to ground level, these might not even have been observed during a typical operation. Additionally, while our subjects ascended from a ground-level pressure of 0.999 ata directly to 25,000 feet in 10 minutes, operational personnel may spend additional time at cabin altitudes of less than 10,000 feet while en route to drop zones. Such staged ascent would provide additional time for a reduction in nitrogen dissolved in tissues and, subsequently, a reduction in DCS risk.

Our study was conducted with subjects who were dry and at rest during both the dive and flight, whereas SOF personnel would be immersed during diving and exercising during diving and possibly during flight. Immersion and exercise will affect nitrogen uptake and elimination and may increase DCS risk at altitude (13). The decision to conduct the tests under dry, resting conditions allowed a greater number of person-exposures than would have been possible if immersion and exercise were included. A lower bound estimate of DCS risk was deemed preferable to a weaker estimate due to fewer trials.

This study was designed to evaluate the safety of flying after diving following a single air dive to the U.S. Navy no-decompression limit and a single exposure altitude. Our results indicate that the current requirement for a 24-hour PFSI may be longer than necessary for a 25,000-foot exposure following a 30-minute oxygen prebreathe and that the PFSI could be safely shortened. While additional trials could not be completed as part of the current project, future studies could: 1) evaluate the safety of shorter PFSIs; 2) quantify the effect of the oxygen prebreathe on DCS risk; 3) evaluate the influence of immersion and exercise during the dive and exercise during oxygen prebreathe and / or flight; and 4) test other dive profiles and exposure altitudes. Such data would be useful in the future review of existing regulations and would support the construction of generalized decompression algorithms for flying after diving.

### **Acknowledgments**

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## DISCUSSION

DR. SHEFFIELD: What did the Army decide to do about their preflight surface interval?

DR. POLLOCK: SOCOM has not yet decided.

DR. SHEFFIELD: So, right now it is still a 24-hour limit?

DR. POLLOCK: Yes, right now it is still 24 hours.

DR. SHEFFIELD: Let me comment on that 30-minute oxygen breathing period, in case some of you are not familiar with what that is all about. When aviators are taken for an exposure to 25,000 feet or higher in an altitude chamber, they're required to breathe oxygen to wash out tissue nitrogen before ascent to altitude. Without this nitrogen washout, there have been a sizable number of cases of decompression sickness during exposure to 25,000 feet. Preoxygenation is fairly common for all altitude chamber exposures.

The exception has been for high altitude reconnaissance missions in the U2 and SR71 aircraft where the aircrew are in a pressure suit, perhaps at above 25,000-foot cabin pressure for as long as five to 13 hours. In that case, the recommended denitrogenation period was four hours, to which the operations community has said, "No way. We will give you 30 minutes on the ground and 30 minutes during the ascent. That's all."

The U2 program bought into an hour of oxygen prebreathe, but the SR71 program only has a 30-minute denitrogenation period. What was presented here is an operational requirement based on the altitude chamber exposure to 25,000 feet.

DR. WATENPAUGH: Webb and Pilmanis did a study in which the DCS incidence was 70 percent at around 22,000 feet. They did not do 30 minutes of oxygen pre-breathing. Is that the main difference between your study and theirs or were there other differences?

DR. VANN: This was an anonymous review of U2 pilots that found 75% of the pilots had symptoms consistent with DCS at least once in their careers.\* This was not a DCS incidence, and the pilots were exposed to cabin altitudes of 29,500 feet.

DR. THALMANN: Based on the anonymous study, Paul, and your having been in the Air Force and done all this stuff, is it your opinion that the incidence of bends in SR71 pilots is reflected in the chamber studies you did, or were the bends not reported because of fear of losing flight status? Didn't the anonymous survey by Andy Pilmanis find an incredibly high incidence when the pilots didn't have to fess up to who they were?

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\* Bendrick GA, Ainscough MJ, Pilmanis AA, Bisson RU. Prevalence of decompression sickness among U-2 pilots. *Aviat Space Environ Med* 1996; 67(3):199-206.

DR. SHEFFIELD: I think we're getting into an area of speculation. Crewmembers report things when it's convenient for them, and they don't report when it threatens their career. I'll give you a couple of examples.

I was with the U2 program for about four years. During that period, we had a few pilots who reported decompression sickness and were treated in the hyperbaric chamber. That was the time when Pilmanis did his anonymous study and found unreported cases.

Prior to this time, I was involved with the Army HALO program for about four years at Langley Air Force Base. This was the program that Neal just described. No case of decompression sickness was reported by these high altitude Army parachutists despite very stringent exposures, some of which occurred at above 40,000 feet for three to six minutes followed by 25,000 feet for a hypoxia demonstration and then free fall to ground level. After training was over, and I had handed out the certificates, I would get on the bus and ask, "Did any of you guys have any problems you did not tell me about?" Probably 50 percent would fess up to some sort of problem, but they would not tell you if they felt their careers were threatened.

I think that's the issue right here. If it's career-threatening, no pilot is going to report unless it's causing a serious problem or unless they want to get out of the program and are using the problem as an excuse. The same is probably true in recreational diving. A person will report if it's convenient to do so and not report if it is not convenient.

DR. THALMANN: My experience in the Navy is that most divers will report bends because it's not career-threatening. Divers are usually not disqualified or threatened in any way if they get bent. It's never been that way. Thus, the Navy probably has a better idea of what their "bends incidence" is.

Didn't the Air Force recently change the rules about altitude bends so that it's not as career-threatening as it used to be?

DR. VANN: Yes, that is correct. The Air Force more or less decriminalized decompression sickness.

## NASA FLYING AFTER DIVING PROCEDURES

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### **Introduction**

Flying after diving creates a recognized but poorly quantified risk of decompression sickness (DCS). Most of the available guidelines are based on limited experimental data. Some of these were produced as contingency procedures to address potential operational concerns, not intended for general use or public release. The U.S. National Aeronautics and Space Administration (NASA) flying after diving procedures fit into this category.

### **Use of Diving in Training for the U.S. Space Program**

NASA uses underwater training to prepare astronauts for extravehicular activity (EVA) in space. Astronauts wear a modified version of the extravehicular mobility unit (EMU or spacesuit) during pool training. The suit is pressurized to 4.0 lbs-in<sup>2</sup> differential over ambient pressure (psid). The suit overpressure applies an additional 0.27 atm to the astronaut. This is equivalent to an additional 10 feet of depth.

A number of pool training facilities have been available, including those at Marshall Space Flight Center and Johnson Space Center (JSC). The Marshall pool was 40 feet in depth and the training required back-to-back training sessions that were six to seven hours in duration. The current standard training dive in the newer JSC Neutral Buoyancy Lab [NBL], Houston, is in 40 feet for 240-390 minutes. The combination of long training dives and suit over-pressurization generates a substantial decompression stress. The option to use nitrox to reduce the risk of DCS was considered in the late 1980s (1). A programmatic switch from air to nitrox was made in August of 1993 (M. Fox, personal communication).

The standard breathing gas used for pool training dives is 46% nitrox (46% oxygen, 54% nitrogen). The reduction in the partial pressure of nitrogen results in an equivalent air depth (EAD) of 24 feet of seawater (fsw) for a 40 fsw actual depth (2).

### **Development of NASA Flying After Diving Procedures**

A space shuttle mission was planned for December 1993 to service the Hubble telescope (STS-61; Hubble mission). The flight plan allowed for up to seven extravehicular activity (EVA) sorties. A total of five EVAs were completed in the almost 11-day flight, a record

for the space program. Extensive underwater training time was required at the Marshall Space Flight Center to prepare for the mission.

A complication that existed during preparation for the Hubble mission was that several of the EVA astronauts were maintaining flight currency while the mission training was underway. The Northrop T-38 aircraft was used for this purpose. The T-38 is capable of maintaining cabin pressurization of approximately 5.0 psid. This means, for example, that at an actual altitude of 25,000 feet, the cabin altitude can be maintained at less than 10,000 feet (3).

The existing NASA standards for flying after diving were fairly conservative (Table 1), arbitrarily established through the review of the recommendations by a range of other organizations. Effectively, the long required preflight surface intervals (PFSI) were restrictive with the long pool training sessions.

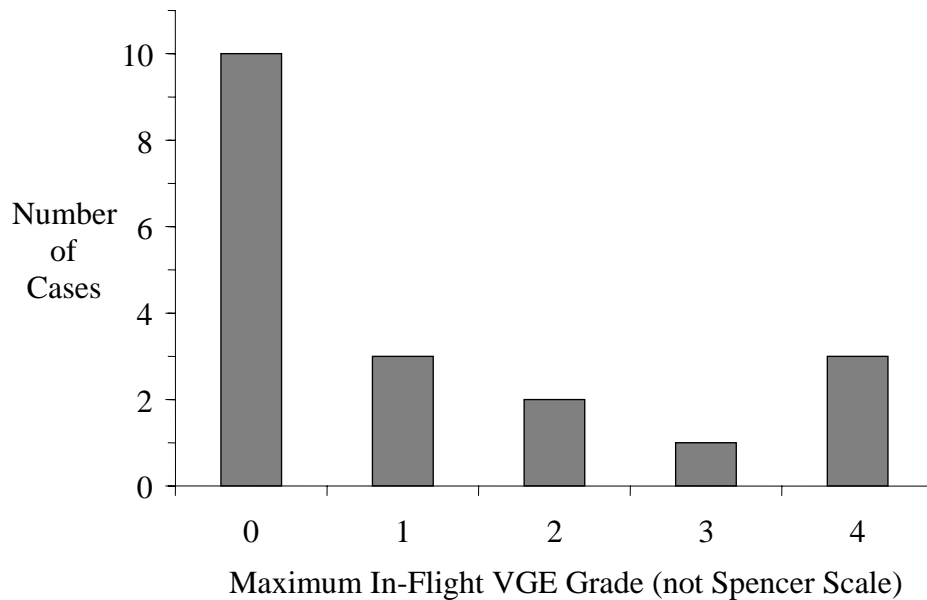
**Table 1. NASA 1980s Regulations for Flying After Diving (1).**

Depth of Dive (ffw)	Type of Dive	Duration (h)	PFSI (h)	Flight Altitude (ft)
<20	No decompression	<4	(no restrictions)	(no restrictions)
20-62	No decompression	<4	12 h air or 2 h oxygen	>8000
20-62	Decompression or >4 h or multiple dives	>4	24 h air	Any
All Other Diving			24 h air	Any

Table Notes: ffw = feet of freshwater; PFSI = preflight surface interval

Responding to the requests of astronaut-pilots, Dr. William Norfleet was tasked with developing flying after diving procedures that could accommodate mission-essential flight operations. He computed them mathematically, using a 720-minute half-time tissue, to allow a maximum tissue ratio of 1.22 at 10,000 feet. A single study was conducted to evaluate the safety of the procedures. Nineteen volunteers (14 men, five women) participated ( $31.7 \pm 6.9$  [SD] years of age,  $24.5 \pm 2.6$  kg·m<sup>-2</sup> body mass index). Subjects first carried out intermittent, light exercise (metabolic rate during exercise was  $160 \pm 35$  kcal·h<sup>-1</sup>; approximately two times resting metabolic rate) in a dry hyperbaric chamber at a pressure equivalent of 20 feet of freshwater (ffw) for 400 minutes while breathing normoxic air. This was followed by a 14-hour PFSI on air and a subsequent three-hour, seated, resting hypobaric chamber flight at 10,000 feet on air. One individual reported mild joint awareness in the left elbow after 158 minutes at altitude. The duration of symptoms was unclear, but the subject completed the altitude exposure and was asymptomatic upon return to ground level.

Precordial Doppler was used as a secondary measure of decompression stress. Venous gas emboli (VGE or bubbles) were graded in the following manner: 0=no bubbles; 1=occasional bubble sounds with majority of cardiac cycles free of bubbles; 2=frequent bubble sounds detected in more than half of the cardiac cycles; 3=bubble sounds heard in all cardiac cycles; 4=continuous bubble sounds which obscure the heart sounds. (Note: this grading scheme differs from the more standard Spencer Scale [4] in the definition of grades 2 and 3.) Scores were recorded after movement of each limb, in sequence. Maximum VGE grades measured during flight are found in Figure 1 (5). All maximum grades were observed following movement of one of the lower limbs.



**Figure 1. Maximum in-flight VGE grades during three hour seated, resting exposure at 10,000 feet after 400 minute dive to 20 ffw and 14 hour preflight surface interval (n=19)**

A management instruction was developed following the completion of this work (6). The intent of the document was to use the described tables for mission-essential exposures only. Flights were restricted to 10,000 feet cabin altitudes (a 25,000-foot flight altitude in the T-38). These limits are shown in Table 2.

**Table 2. NASA JMI 1830.3G No-Decompression Limits for Diving and Surface Intervals for Flying After Diving (6).**

Facility Depth @ 4.0 psid (feet)	Physiologic Depth or Equivalent Air Depth (feet)	No-Decompression Limit (min)	Dive Duration (min)	Air Surface Interval (h)	Oxygen Surface Interval (min)
10	20	no limit	1-60	3	20
			61-100	5	40
			101-400	14	120
			>400	24	180
15	25	400	1-45	3	20
			46-80	5	40
			81-290	14	120
			291-400	24	180
20	30	240	1-35	3	20
			36-60	5	40
			61-240	14	120
25	35	190	1-30	3	20
			31-50	5	40
			51-190	14	120
30	40	150	1-25	3	20
			26-45	5	40
			46-150	14	120
40	50	100	1-20	3	20
			21-35	5	40
			36-100	14	120

Table Notes:

- **Facility Depth at 4.0 psid** - The location, in feet, beneath the surface of the water of the gas regulator which controls suit inflation pressure for a diver enclosed in a suit pressurized at 4.0 psid.
- **Physiologic Depth** - The facility depth plus any depth equivalent imposed by pressurization of a suit (1 psi = 2.3 feet of depth; fractions should be rounded to next larger whole foot).
- **Equivalent Air Depth** - Used with nitrox diving.
- **No-Decompression Limit** - [Note: Table not specified.]
- **Surface Interval** - Surface interval at surface pressure prior to flight at cabin altitudes between 1,000 and 10,000 feet.
- To determine the appropriate depth in this table, enter with the greatest depth achieved during the dive and select the row which is greater than or equal to that depth.

Following a short dive at an EAD or physiologic depth of 25 fsw – between one and 30 minutes – the required PFSI is three hours if air is breathed or 20 minutes if oxygen is breathed. The short oxygen breathing duration is desirable in that it could be finished while diver-pilots are in the T-38 aircraft waiting for clearance.

Longer diving exposures incur substantially longer obligatory PFSIs; much more moderate with oxygen breathing. A five-hour PFSI on air is equated to a 40-minute PFSI on oxygen. A 14-hour PFSI on air is equated to a two-hour PFSI on oxygen. A 24-hour PFSI correlated to a three-hour oxygen-breathing period. All flight restrictions are lifted

for PFSIs in excess of 24 hours at cabin altitudes less than 10,000 feet and actual altitudes less than 25,000 feet. There are no flight restrictions following diving for cabin altitudes of less than 1,000 feet. A 24-hour PFSI is required for any flight with a cabin altitude exceeding 10,000 feet or with an actual altitude exceeding 25,000 feet.

### **Operational Use of NASA FAD Flight Rules**

This intent to use the procedures for mission-critical exposures only was not stated in the “scope and applicability” section of the released JMI 1830.3G document. The procedures were subsequently accepted for more general use. The air PFSIs protocols are commonly used, and the oxygen PFSI protocols are used by approximately five to seven individuals annually. NASA does not maintain a formal database of the use of these guidelines. No cases of DCS have been reported.

### **Conclusions**

Anecdotal evidence supports the great utility of relatively modest oxygen breathing periods following diving exposure. Further studies are required to document the use and safety of these procedures.

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## **DISCUSSION**

DR. MULLER: I'm Matt Muller, formerly with NASA, now with the Navy. The T-38 checklist actually has a different table in it right now. I just saw it a couple of days ago. It's a much more complicated table and has a lot more groups in it.

DR. POLLOCK: I have the complete tables that were printed in the NASA publication. They will be published in the proceedings of this workshop.

DR. WIENKE: Not to steal Ed Flynn's thunder, but the procedure you described is similar to what Ed Flynn described for the Navy, but they use slightly different tissue compartments and ratios.

DR. POLLOCK: Yes, 1.29 versus 1.22.

DR. WIENKE: Right.

## ECONOMIC IMPACT OF FLYING AFTER DIVING

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### **Introduction**

Every activity, even the very safest, involves some degree of risk, and each individual has a different level of risk tolerance. Flying too early after diving increases the risk of developing DCS (1-3), but that risk is small. When a risk is intrinsically small, it becomes very difficult to develop guidelines that are universally accepted and applicable. However, because the value of money is well understood by most people, risk expressed in monetary terms can be a useful and accessible concept.

For a large enough population, a change in the risk of contracting DCS has an identifiable cost associated with it. It is possible to put a monetary value on the worth of each dive. If a diver must not dive before he flies, he is losing some of the benefit of that period of his vacation. Depending on how much he has paid for travel, equipment, food and lodging, and depending on how much he values his sport, forgoing diving before flying may involve considerable cost to a diver. It is also possible to estimate the costs associated with a case of decompression sickness. If divers increase their risk DCS by diving up until the last few hours before flying, then ultimately more cases of DCS will occur than would have otherwise leading to increased costs to society as a whole. Although we do not know the absolute risk of flying after diving, we do know how much the odds of DCS decrease with each hour a diver waits before flying (1). Therefore, a time must exist where the benefit to cost ratio is most favorable. This paper attempts to model the potential costs associated with preflight surface intervals (PFSIs) from six to 36 hours.

### **Methods**

#### *A-priori Assumptions*

The model assigned cost to the increased risk of DCS caused by flying after diving. The earlier a diver flies after diving, the higher his risk of DCS (1). The per dive risk of DCS was calculated at PFSIs ranging from six to 36 hours. This risk was then translated into costs based on the estimated expense of evacuation, medical treatment, time lost and long-term disability. These costs were contrasted with the per dive benefits accrued to the diver from shorter PFSIs. Shorter PFSIs allow the diver to make additional dives before his departure flight.

#### *Benefits and Opportunity Costs*

In this model, benefits accrue to both the diver and the resort. Each dive benefits the diver. The diver's total benefit can be calculated based on the total number of dives made and the value placed on each dive. The value placed on each dive can be estimated by taking into account what the diver is willing to pay for the entire diving vacation. For example, a low-cost, weeklong trip to the South Pacific may cost \$3,000 inclusive. The

diver may make 30 dives. That would give a value to the diver of \$100 per dive. A more or a less upscale resort or less intensive diving would change this per dive figure. The value of the dive for the resort would be an estimate of the resort's profit per dive. Each additional dive the diver makes is an economic benefit to both the diver and the resort in this model. Any dive the diver has the opportunity to make but chooses not to make is counted as a missed opportunity or an "opportunity cost." Opportunity costs are based on the premise that time has value both to the diver and the resort. For example, if the diver has a value of \$100 per dive, and he misses a dive because he is waiting to fly, it's like taking \$100 out of his pocket. The same applies to the resort. The resort makes a certain amount of money on each dive that the diver makes. If the diver doesn't dive, the resort loses money. However, the diver may choose to forego the opportunity to dive in an attempt to avoid DCS.

#### *DCS Costs*

The above benefit figures are contrasted with the estimated costs of a case of DCS. The figure for DCS costs is based on a conservative estimate of the costs of evacuation, treatment and rehabilitation after a case of DCS. The value of the diver's time also applies to the computation of DCS expenses. If the diver is injured and loses wages, these lost wages must be considered as part of the cost of the injury. There is also the cost of a long-term injury. The diver may sustain both rehabilitation costs as well as basic annoyance costs. An annoyance cost may be explained as a cost associated with an injury that bothers the diver's ability to perform tasks of daily living and annoys or even impairs him in the same way a sports injury might impair a professional athlete. It is difficult to put a monetary value on this type of outcome.

#### *An Excel Spreadsheet Model*

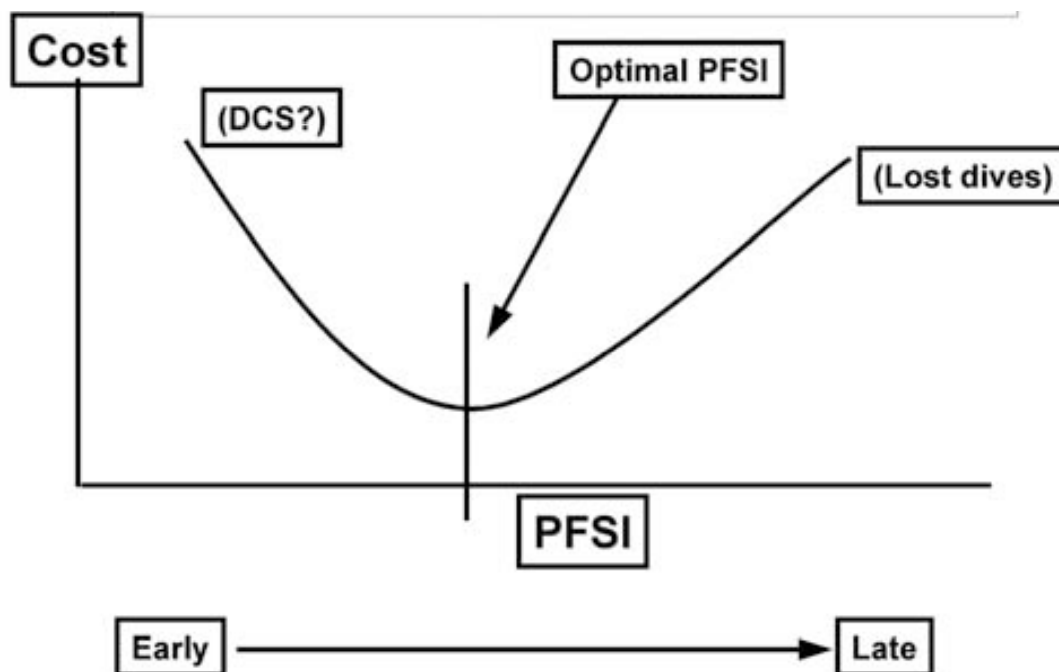
Costs were calculated on a "per case of DCS" basis. The regression equation obtained from the previously mentioned FAD case control study (1) was used to determine the relative odds of DCS at different PFSIs ranging from six to 36 hours. Because depth of the last dive also influences DCS odds, it was entered into the regression as well. Flying at 24 hours after the last dive was arbitrarily set to have an odds ratio of one, therefore, PFSIs shorter than 24 hours had higher risks of DCS and PFSIs longer than 24 hours had lower risks of DCS. The spreadsheet allowed input for the estimated non-flying incidence of DCS. Reasonable input values for DCS were from four cases per 10,000 dives for warm-water recreational diving to 30 cases per 10,000 dives for cold-water wreck diving exposures (4, 5).

The estimated incidence of DCS at the differing values for depth and PFSI were calculated using the regression coefficients from (1). Entries for the number of days diving times the number of dives per day allowed the calculation of the total dives made. The total number of dives made times the incidence yielded the estimated probability of DCS for the values entered. If DCS occurred, treatment was assumed. To estimate medical expenses, the cost per treatment, number of treatments, cost of evacuation and percentage of cases requiring evacuation were input into the spreadsheet. To compare the impact on the diver, the spreadsheet input the diver's wages per day, the total amount a diver would be willing to pay per dive (including travel, food, equipment and lodging),

the estimated probability of having a residual symptom after DCS therapy and the cost of pain and suffering from that residual. To calculate the cost or benefit to society as a whole, the above terms were summed in an Excel spreadsheet, and the total was reported at the different PFSI time points as an x-y graph.

#### *Model's Graphical Summary*

All inputs were combined in one inclusive model. A sample output is shown in Fig. 1. Cost to society is on the y-axis. The preflight surface interval is on the x-axis. The cost increases the earlier the diver flies because of the increased DCS risk. If he flies later, the cost increases due to the opportunity cost of the lost dives to both the diver and the resort. Where the curve bottoms out is an optimal cost PFSI. This PFSI represents the best combination of waiting to reduce the risk of DCS while still getting in as many dives as is safely possible.



**Figure 1.** Conceptual representation of cost minimization relative to PFSI.

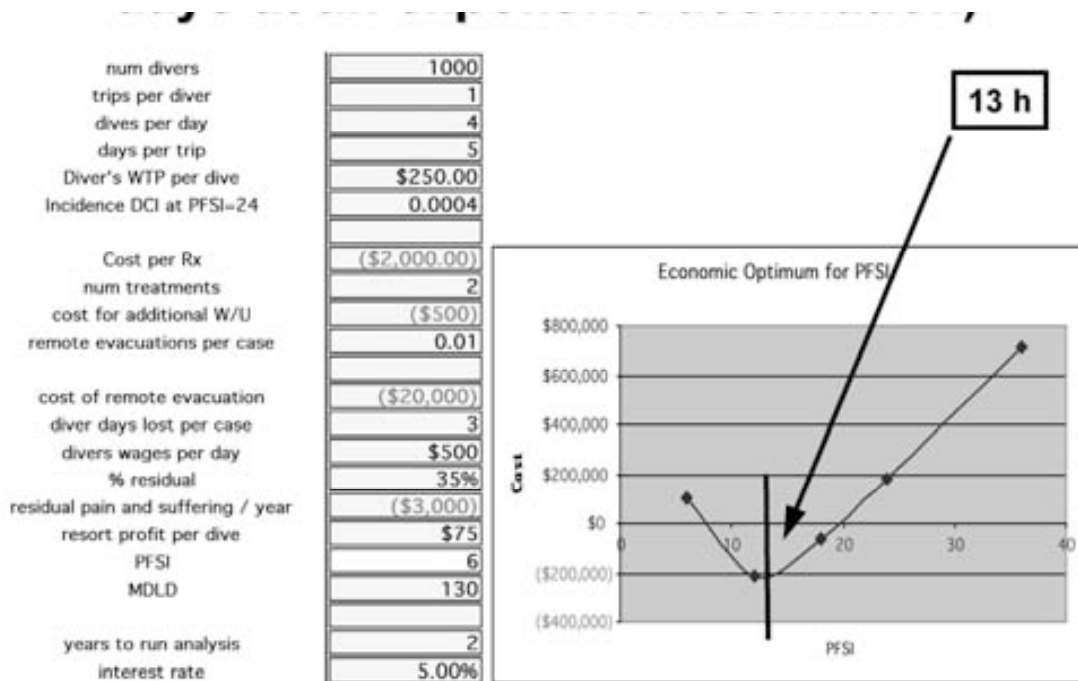
## **Results**

#### *Model Examples*

Three scenarios are provided to illustrate the model. These scenarios represent a crude sensitivity analysis of the inputs into the model. In a sensitivity analysis, the model's user is free to change a particular input throughout the range of all reasonable values. This allows the relative importance of the different model inputs to be identified. A sensitivity analysis also allows the user to estimate and experience, in a virtual sense, how one variable affects another. This exercise often uncovers relationships between inputs that were previously unrecognized. The three scenarios considered here compare low- and high-cost dives and short and long dive trips. Any other reasonable inputs are possible, but these will sufficiently illustrate the process.

### Scenario 1

Scenario 1 in Fig. 2 is a moderate case of DCS after five days at an expensive destination. The overall risk of DCS from Project Dive Exploration is four DCS cases per 10,000 dives, a figure that is used here (4, 5). The diver makes four dives a day for five days. His maximum depth on the last day is 130 feet. If he were to contract DCS, he would have a 35 percent risk of a residual after treatment (6), but for this example, we assume he would only be mildly bothered from that residual, with an estimated annoyance or impairment value of \$3,000 for residual impairment for two years. Note that a more serious residual could be valued at much more.

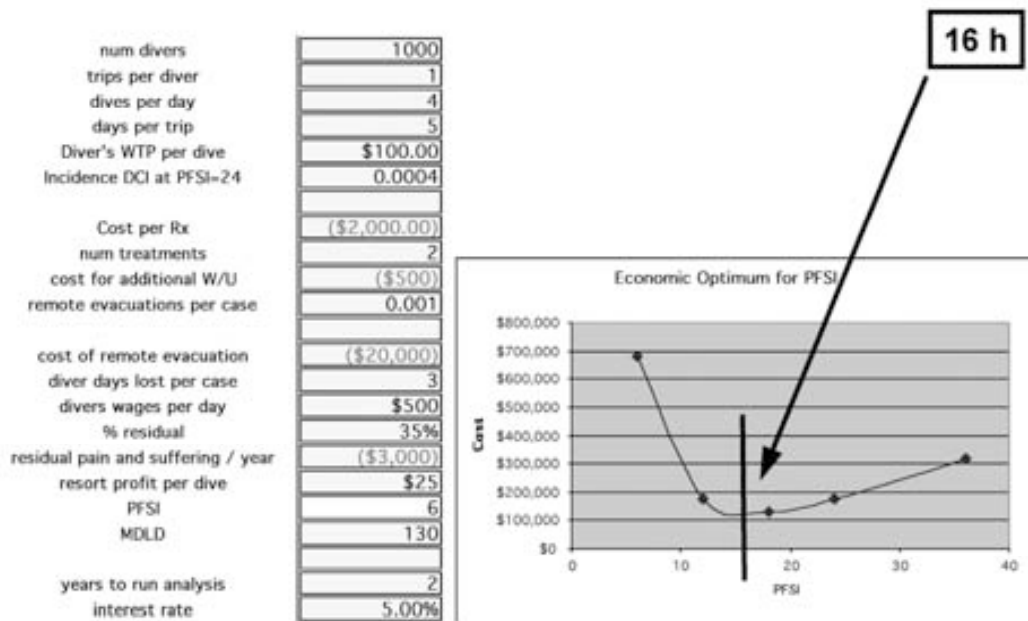


**Figure 2. Scenario 1: a moderately severe DCS case after 5 days at an expensive location.**

For Scenario 1, the model expresses an economic optimum of about 13 hours. That is the lowest dollar point when the diver's wasted time and the potential cost of a mild case of DCS are factored in.

### Scenario 2

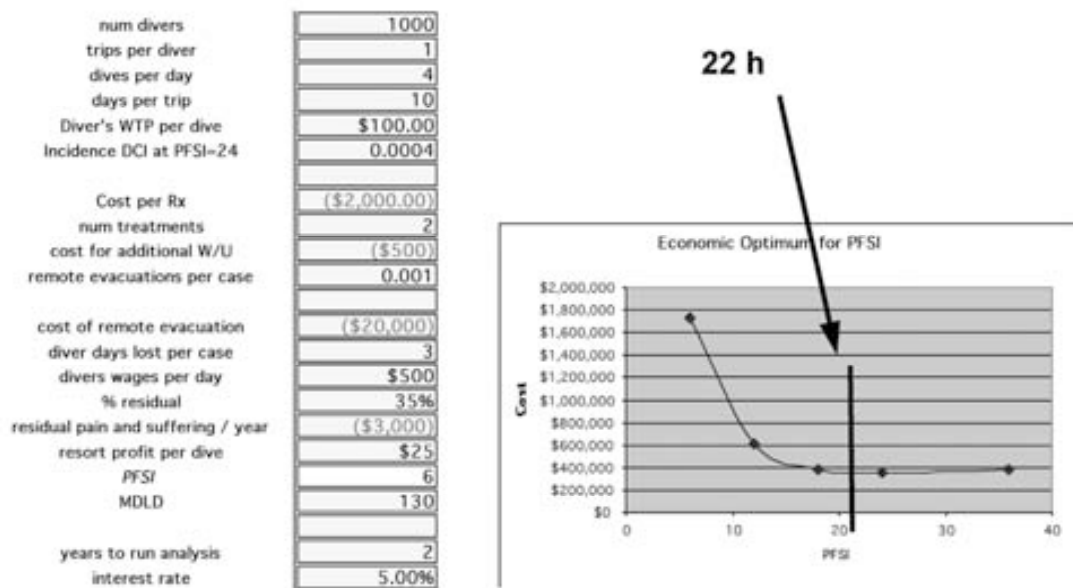
Scenario 2 in Fig. 3 models a moderate case of DCS from flying after diving following a five-day dive vacation at a moderately priced resort. The only difference from Scenario 1 is that the diver's cost per dive is \$100 instead of \$250. This increases his economic optimum from 13 hours in Scenario 1 (Fig. 2) to 16 hours in Scenario 2 (Fig. 3). As the diver values his dives less, he is less inclined to risk DCS by diving until the last moment, and more willing to wait longer to fly.



**Figure 3. Scenario 2: a moderately severe DCS case after 5 days at a moderately priced destination.**

### *Scenario 3*

Scenario 3 (Fig. 4) shows a moderate DCS case after 10 days at a mid-priced destination. The diver's cost per dive is still \$100, but this time he has been diving for 10 days. Because the limitations of flying after diving only affect the last dive, it is less of a concern after the longer 10-day trip. DCS risk and safety dominate, and the economic optimum for flying after diving is 22 hours. DCS is of higher relative concern to this diver, and it is not worth the risk of getting ill to dive one more time after 10 days of diving.



**Figure 4. Scenario 3: a moderately severe DCS case after 10 days at a moderately priced destination.**

### *Sensitivity analysis*

Any model can be perturbed to reveal the relative importance of its inputs by using the techniques of sensitivity analysis (Table 1). A sensitivity analysis for this model indicated that the most important inputs were: (a) the incidence of decompression sickness; (b) the value of the dive; (c) the length of the dive vacation; and (d) the aggressiveness of the diving. Unimportant factors were: (a) the probability of evacuation; (b) the cost of treatment; (c) the diver's salary; and (d) the number of dives performed per day.

**Table 1. Sensitivity analysis of economic model inputs.**

<u>Important</u>	<u>Not Important</u>
DCS incidence	Probability of evacuation
Value of dive	Cost of treatment
Days of trip	Diver's salary
Aggressiveness of diving	Dives per day

### **Discussion**

Economic analysis attempts to simplify extremely complex behavior. Economic models do not include goodwill, morals, or other intangibles, and money is used as a surrogate for more complex motivation. This is sometimes a difficult concept to grasp, because it is very difficult to put a monetary value on good health or quality of life.

The model described here predicts that for most divers, the economically optimal preflight surface interval would be between 12 and 24 hours. This depends on other factors, including the expressed risk of decompression sickness, the aggressiveness of diving, the duration of the trip and the value of the dive. It should also be understood that absolute dollar amounts are less meaningful than relative comparisons. Much of the usefulness of these models comes from the sensitivity analysis. A sensitivity analysis for

the example presented here revealed the important factors to be the incidence of decompression sickness, the aggressiveness of diving, the value of each dive and the length of the trip. Unimportant factors were the probability of evacuation, the cost of treatment, the diver's salary and the dives per day. Further study using economic markers to track a diver's risk tolerance may be useful in improving diving safety in a practical and sustainable manner.

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## **DISCUSSION**

DR. WATENPAUGH: In the spirit of cost-benefit analysis, I wonder if resorts should consider providing oxygen to their patrons at the end of trips.

DR. FREIBERGER: If oxygen reduces the risk of decompression sickness, that would have a huge effect on the economic optimum for the preflight surface interval.

DR. THALMANN: Jake put a dollar amount on the cost of getting bends in order to do the economic analysis. The problem is that it is a very individual thing. Somebody who really loves to dive might not mind walking around with a little residual elbow pain for the rest of his life. It wouldn't bother him at all. On the other hand, if the guy were a semipro tennis player, it'd make a big difference.

So when you look at the minimum on the curve, you have to realize that even though the economic cost is minimum, the risk of getting bent is still falling. The reason the cost is going up has more to do with spending extra time at the resort. When Jake said the diver was wasting his time, what he meant was that the risk approaches zero asymptotically. But there comes a point where the curve is so flat that you must ask if it is worthwhile plunking down six or 800 bucks to stay three more days when the change in risk of getting bent is essentially zero.

Now, what's an acceptable DCS risk? Well, Ed Flynn and I had a little shootout over the acceptable risk of a dive to 40 fsw for 200 minutes where there were, I think, three bends in a hundred experimental Navy dives. Is that too high? We had a very spirited debate. Here's three bends in a hundred dives that by most accounts would be perfectly safe for experimental dives. And yet, in the end, the Navy divers decided it was too high.

## FLYING AFTER DIVING WITHIN THE NO-DECOMPRESSION LIMITS

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This morning, I discussed the longest time that one might have to wait before flying after diving at the no-decompression limits of recreational diving (1). This was the question addressed by the experimental study. What about shorter dives, those to less than the no-decompression limits? There is little experimental data concerning these dives.

An Air Force study by Bassett in 1982 addressed this question with dives that were short enough to allow direct ascent to altitude (2). Table 1 summarizes Bassett's data.

**Table 1. Experimental results from the Bassett study of direct ascent to altitude after diving (2).**

<u>D (fsw)</u>	<u>T (min)</u>	<u>DCS</u>	<u>Exposures</u>	<u>USN RG</u>
11	1440	1*	20	H
40	34	1*	20	E
60	20	1*,1 <sup>@</sup>	36	D
80	14	1 <sup>+</sup>	35	D
100	10	1*	38	D
130	7	0	20	D

Altitude: 8,500-10,000 for 4 hr, then 14,000-16,000 ft for 1 hr

<sup>+</sup> - DCS at 10,000 ft

<sup>@</sup> - DCS at 14,000 ft

\* - DCS at 16,000 ft

The study had two phases. Phase I investigated dives to 11 fsw for 24 hours, 40 fsw for 34 minutes, 60 fsw for 20 minutes, 80 fsw for 14 minutes, 100 fsw for 10 minutes and 130 fsw for seven minutes. These dives were followed by one minute on the surface, direct ascent to 10,000 feet, four hours at 10,000 feet, and one hour at 16,000 feet. In Phase II, the altitude exposures were reduced to 8,500 and 14,000 feet. The asterisks in Table 1 reflect bends at 16,000 feet. The ampersand represents a bend at 14,000 feet, and the plus sign is a bend at 10,000 feet.

Most of the bends occurred at either 16,000 or 14,000 feet and only one at 10,000 feet. Thus, for these dives, flights to 8,500 feet appeared to be safe. This is the most definitive study that exists of direct ascent to near 8,000 feet with low risk of decompression sickness.

Figure 1 shows data from the Duke and Bassett studies (1, 2) with the 1999 U.S. Navy (USN) flying after diving guidelines published in the 1999 USN Diving Manual (3) and presented in this workshop by Dr. Flynn (Table 3; [4]). The x-axis of Figure 1 shows the Repetitive Group Designator from Table 3 of Reference (4) while the y-axis is the

preflight surface interval in hours. Bassett's data are represented by squares. The circles represent the Duke chamber studies for which decompression sickness did not occur while the triangles are the studies for which decompression sickness did occur. The line through the diamonds represents the USN guidelines. As Dr. Flynn pointed out, the USN guidelines were more conservative than the experimental data, including the Bassett results for direct ascent.

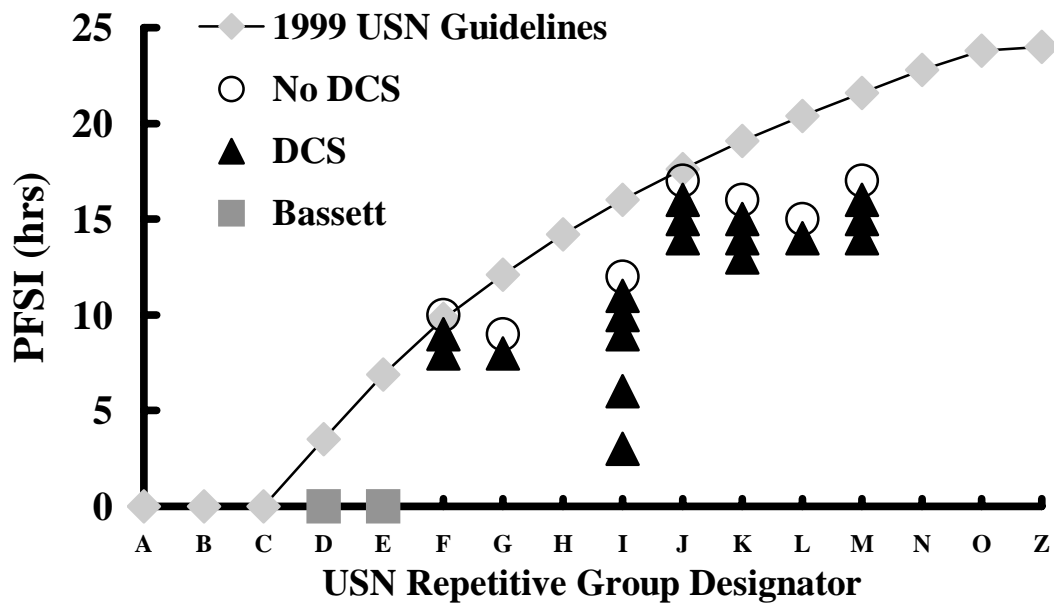
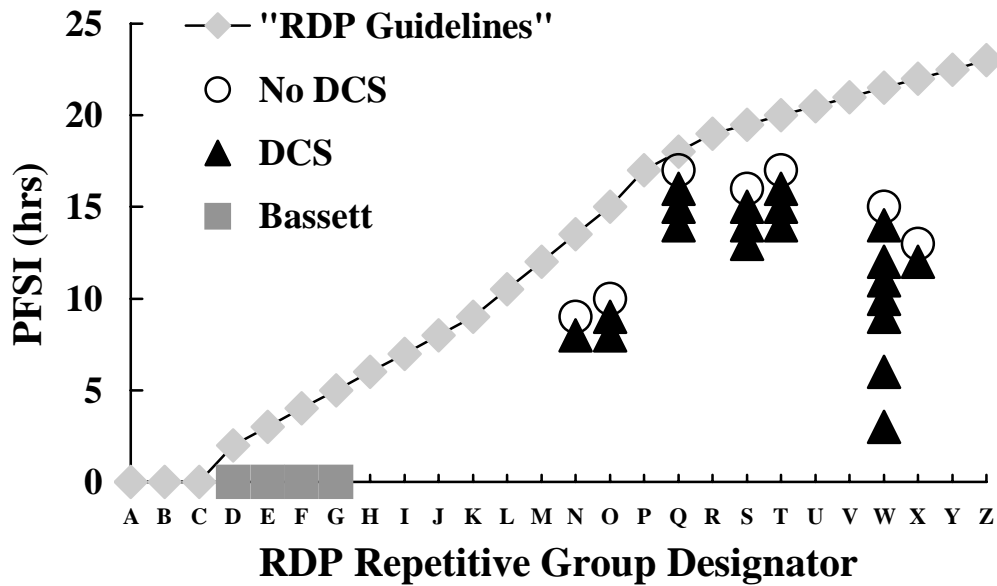


Figure 1. The US Navy Flying After Diving Guidelines (4) and the relevant experimental data (1,2).

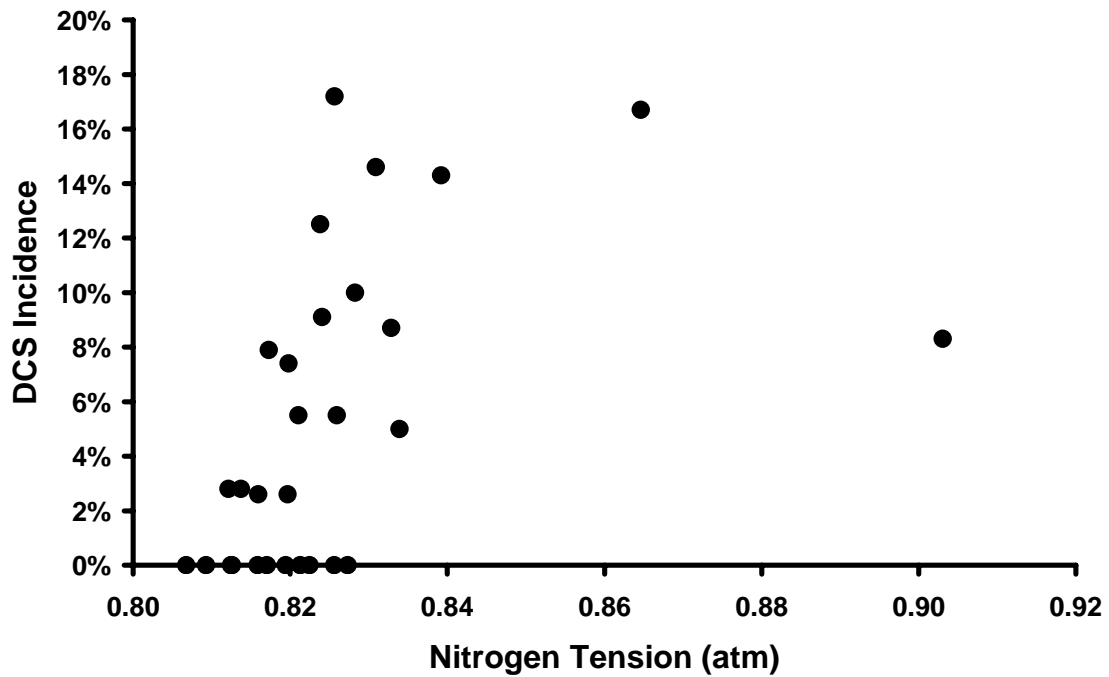
We could take a similar approach as used by the Navy to the DSAT Repetitive Dive Planner (RDP [5]). Figure 2 represents the repetitive dive groups for the RDP with empirical PFSIs that were chosen by eye to avoid DCS in the experimental data. This empirical approach is completely model independent.



**Figure 2. Empirical Flying After Diving Guidelines for the DSAT Recreational Dive Planner (RDP [5]) and the relevant experimental data (1,2).**

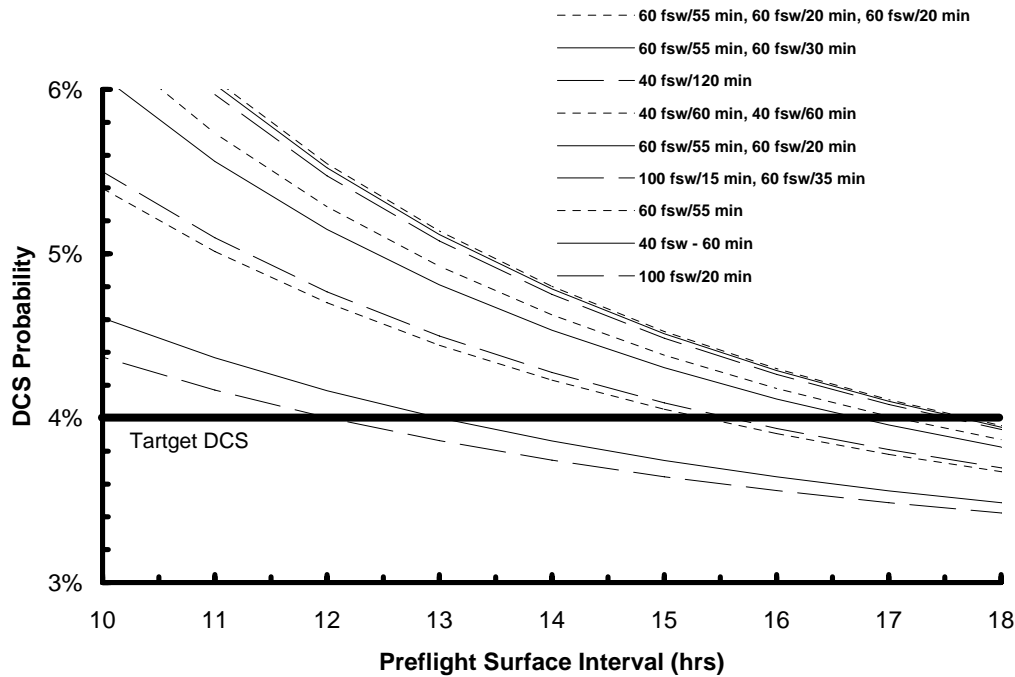
In a more general approach, we applied a simple statistical model to our data that would allow estimations for untested dives. The model computed the nitrogen tension ( $PN_2$ ) in a single perfusion-limited Haldane tissue compartment having a half-time of 300 minutes at the end of the surface interval just before ascent to altitude.

Figure 3 (on page 76) shows how the DCS incidence for each dive profile and preflight surface interval we tested varied with the compartmental nitrogen tension. Except for the two highest nitrogen tensions (for the three- and six-hour surface intervals after the 55-minute dive to 60 fsw), the relationship of % DCS to  $PN_2$  appears linear.



**Figure 3. Nitrogen tension in a 300-minute half-time tissue at the end of the surface interval.**

With the tissue nitrogen tension as the independent variable in logistic regression, an estimated DCS probability may be computed as a function of PFSI for any dive. Figure 4 shows how the estimated DCS probability varies with PFSI for each dive profile we tested.



**Figure 4. The relationship of PFSI to DCS probability for the dives tested (1).**

If an “acceptable” or target DCS probability is selected, the PFSI needed to achieve this target is readily determined. For example, if 4% DCS is the target in Figure 4, the PFSIs shown in Table 2 are found for the dives that we tested. These estimates are generally consistent with the experimental results shown in Figs. 1 and 2 of the earlier report (1). By using the supersaturation at altitude in the logistic model, computations of this nature could be made for any dive and ascent to any altitude.

**Table 2. PFSIs for the tested flying after diving exposures with a target 4% DCS.**

<u>PFSI (hrs)</u>	<u>Dive</u>
12	100 fsw/20 min
13	40 fsw/60 min
15	60 fsw/55 min
16	100 fsw/15 min – 60 fsw/35 min
17	40 fsw/60 min – 40 fsw/60 min 60 fsw/55 min – 60 fsw/20 min
18	40 fsw/120 min 60 fsw/55 min – 60 fsw/30 min 60 fsw/55 min – 60 fsw/20 min – 60 fsw/20 min

While the logistic model used to generate Figs. 3 and 4 was statistically significant ( $p=0.021$ ), we concluded that there were insufficient data to justify this approach at present. We elected to publish the experimental data that emphasized the long recreational no-decompression dives (6). When additional data are available for other dives, we will attempt a more general statistical model.

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## DISCUSSION

DR. BENNETT: The concept is very good, but I come back to what we heard earlier. The complexities of all this are not what the instructors want. Quite often, and I'm sure the same is true for Drew, I talk to the divers and instructors at resorts, and as we heard earlier, they want a simple rule. "Is it 12 hours or 24 hours? What do I do?" If you tell them, "Well, go back and do the calculations," they're not going to do them.

Either we have to have a computer do it for them – Mr. Cochran can design one – or we have some other method that gives the instructor the ability to deal with this issue easily.

Another problem that locations such as Turks and Caicos and Australia have is what to do after treatment for an incident of decompression sickness. Planes now fly directly from Heathrow to Turks and Caicos or to Sydney from L.A. And after treatment, they're finding that 72 hours is not long enough to wait before returning home. In Australia, they

are recommending three weeks. In one case, a girl was required to sign a piece of paper saying she accepted the risk of flying after treatment.

Flying and diving is a broader problem than not flying when you have no injury. Unfortunately, we can't solve every problem at once.

DR. VANN: I agree. Our goal this morning has been simply to focus on data concerning flying after diving when you have no symptoms. What we know, and what we don't know. This afternoon, we're going to discuss how these data might be formulated as safety guidelines.

Ed Flynn makes a good point: the Fleet thinks that the new Navy flying after diving guidelines are too complicated. They want something simple. Can we come up with something simple that the recreational community feels is not unreasonable?

I don't think we can yet come up with a computer model that automatically calculates the surface interval for us. Sometime in the future we may be able to do so, and a workshop like this may need to be convened in the future to address further revisions of flying after diving guidelines based on new data.

DR. THALMANN: Let me address the complexity issue. How many of you remember repetitive group computations? This was part and parcel of most scuba courses. Most divers didn't object to it because if you did the repetitive group calculation, you got to do two or three dives a day. I wonder if the problem with complexity is that we've gotten so far into the decompression computer mode, many divers no longer know how to use tables.

It is the same for the Navy. I didn't think those flying after diving guidelines were certainly any more complicated than computing repet group. But the problem is, is there a cost-benefit? The benefit of computing repet groups is very high for repet diving because you get more time on that second dive.

The perceived benefit of the flying after diving regulations is low at least in the Navy, as it's not a problem. The Fleet perceives it, "Hey, we don't see a problem. Therefore, we don't see any benefit in doing this complicated calculation."

I'm going to guess that recreational divers are going to look at the benefit of doing a complicated calculation and wonder, "What's the evidence that I have to do this complicated calculation? Why can't they just tell me either yes or no to dive?"

But that's not to say that we shouldn't offer them a tabular method of slicing the bologna a little thinner if we can along with some global rules. Well, you can either obey these global rules in which you only got to remember two numbers, 12 and 24 or 10 and 18 or something. Or if you want to get more accurate and feel better about getting the early morning flight rather than the late afternoon flight, you can go to this table and work it



out from your repetitive groups. So it may be that we need to work on both procedures and let the divers choose.

DR. WIENKE: This isn't a setup, but those issues have been addressed by NAUI. NAUI has released a new set of recreational dive tables with a no-group, no-calculation, no-fuss approach to repetitive diving. All successive dives have to be shallower, and we have three simple rules for flying after diving depending on the number of reps you made.

DR. THALMANN: Tom Hennessey's BSAC tables were the same way. It really cut down the complexity, and there was no calculation. It was all look-up. Oddly enough, the Navy came out with a set of tables that were 6 inches thick but worked the same way. Rather than doing a calculation, you simply pick the appropriate table and followed it.

The Fleet actually didn't mind the thickness so much, but they had other objections. The Master Divers didn't seem to mind the thickness because they knew how many errors were made in computing repetitive groups.

Now, of course, you can put it all in a bloody computer, and even if you use a model, the computer will do table look-ups for you in a microsecond.

DR. RICHARDSON: The comments being made are bang on, but it's overly simplistic to say the recreational industry is just one type of diver. Three categories may be more realistic. In the first category, each year, 2 to 3 million people who are not certified go to a resort with no plans to dive and make a short exposure to 10 meters or less. They've had a dive in the morning. They've played golf in the afternoon, and they're not going to slog through tables or look at groups. They may not even know what a group is.

The next category of divers is certified and might include people on liveaboards and so on. These people are certainly trained in repetitive diving procedures but are virtually all computer users. They follow their computer algorithms when it comes to flying after diving.

The third category would be the so-called technical community who I think would be quite happy to have a stack of tables including oxygen breathing to accelerate nitrogen washout. They're a much more disciplined group and use stacks of tables now. So before we get into discussions about guidelines, keep in mind that one size fits all wouldn't necessarily be the best approach.

DR. THALMANN: Drew, do you see decompression tables as a thing of the past for most recreational divers? Do they just strap their computer on and do whatever it says if they do want to multiple dives?

DR. RICHARDSON: During training, no, but in practice, it's definitely gone that way, except for the technical community, which is much more disciplined. For the casual diver, you don't see tables too often whether at a resort or in domestic locations, even though most agencies still train with tables.

DR. THALMANN: For the technical community, is it fair to say the main reason they use complicated tables is that there are very few decompression computers that handle the complicated diving they do?

DR. RICHARDSON: There are a few computers that will handle technical dives.

DR. THALMANN: But by and large, I guess they're expensive, so for the average recreational diver, he's happy with the computer he can buy in the scuba shop that will meet his needs. For the technical guy, it probably won't, so there's still this need out there for something more complicated until one day we get to the point where these guys can use their laptops to dive however they want.

DR. RICHARDSON: Well, they're doing that now. They're smart enough to have figured that out.

DR. WIENKE: What Drew just said is true for NAUI, too. It's going to be a long time before training regimens for divers or instructors throw tables out the window, but as soon as someone is diving on his own, he pretty much dives on a computer.

On the technical side, NAUI has compiled probably 600 pages of tables for mixed gas diving – trimix, heliox, nitrox with oxygen breathing at 20 feet. These tables are invaluable to instructors because they're not readily available unless you buy software like Decoplanner or Abyss.

As Drew and Ed suggested, technical diving methods are likely to spill over into recreational diving. People with PCs will be able to get software and know enough to get hurt. That's something to be concerned about.

DR. FLYNN: How do the various computer algorithms predict the time to fly compared to experimental data from Duke and elsewhere? Are the times to fly compatible or incompatible with the data?

DR. WIENKE: I'll speak for Los Alamos. In computing time to fly, most dive computers use an M-value for the slowest tissue compartment in about the same way. Probably 95 percent of the computers on the market rely on the conventional approach to doing decompression calculations.

Some new dive computers do not use dissolved gas models. They try to do bubbles along with the dissolved gas buildup. For recreational diving, the times to fly are pretty close because there's not much separated gas, we think. But as you go to deeper and longer exposures, there are some radical deviations, but in general, from the data that Dick sent me ahead of time, I think that most dive computers and tables are roughly consistent.

MR. COCHRAN: The way Cochran dive computers forecast time to fly is to take all the tissue compartments down to ambient, whatever that may be, and arbitrarily add 12 hours. We make no secret about adding 12 hours, so you can do what you want.

Cochran dive computers operate on barometric pressure rather than sea level pressure. They record and compute the nitrogen loadings according to what your actual altitude whether you're diving or not. The pressure transducer detects and records barometric pressure changes equivalent to 500 feet of altitude with the date and time of the change. On the flight we took to get here, for example, the computer recorded the entire altitude profile with a maximum altitude of 6,500 feet.

Which brings me to another point. We made a commercial flight about two years ago and happened to have O<sub>2</sub> and CO<sub>2</sub> detectors with us. In the middle of the flight, we found that the O<sub>2</sub> partial pressure was 0.15 atm while the CO<sub>2</sub> level was at least 1%. So there may be issues other than altitude that have to do with flying after diving. The difference between a chamber and a commercial flight could be very significant. These issues might need to be addressed.

DR. THALMANN: I think that a PO<sub>2</sub> of 0.15 atm is about what you would have at 8,000 feet, since the barometric pressure is around 0.72 atmosphere, and the plane's full of air, not oxygen. That's what it is in all the experiments.

It's a fact that your computers measure pressure, but the issue is how the model works with ambient barometric pressure. The classic example is the Haldane two-to-one ratio, which worked reasonably well, but we know you can't saturate at a thousand feet and come to 500 feet. So rules that work in one pressure range may not work under another. We have to keep that in mind. Just because the computer measures barometric pressure doesn't mean you can automatically trust it when you're at altitude. You need data to back up your algorithms that, of course, are based on dives on dives from one atmosphere, not at altitude. You can't automatically assume an algorithm will work at altitude just because it works well for diving.

## NATURE OF SAFETY DECISIONS

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Safety is the judgment of acceptable risk where risk is measured by the probability and severity of harm. Safety is defined as the degree to which risks are judged acceptable (1). Decisions about safety must consider the risk, benefit and cost involved. When establishing a safety guideline, the degree of safety that a client desires must be kept in mind.

The level of risk can be measured scientifically by determining the probability and the severity of harm caused by an untoward event. Safety is the personal and social judgment of acceptable risk, however, and cannot be measured. No activity is absolutely risk-free. An activity is considered safe if society judges its risks to be acceptable. As there are varying degrees of risk, there are varying degrees of safety.

Making a decision about safety is a two-step process. The first step is to measure the degree of risk scientifically. Gauging risk is a matter of probabilities. What is the probability that an undesirable event will occur? One can assess the chance that an untoward event will occur, but it is not possible to predict a specific event on a specific day. For example, one can determine the likelihood that an automobile tire will fail and cause an accident, but one cannot predict which automobile will have the defective tire. Vann (2) conducted a risk assessment for flying after diving exposures that are typical for recreational divers. He reported the probability that divers who fly after a specific dive / fly profile would develop decompression illness (DCI), but could not predict a specific diver who will get DCI.

The second step in the safety decision process is to judge the acceptability of the measured risk. This is a personal or social value judgment that can be politically charged with values that differ between groups. To establish a flying after diving guideline, we must ascertain the level of risk that would be acceptable to the group to whom the guideline will apply. There are five factors to consider when judging acceptable risk:

- (a) Is it reasonable?
- (b) Is it customary usage?
- (c) Is it the prevailing professional practice?
- (d) Is it the best available practice with highest practicable protection, and lowest practicable exposure?
- (e) Does it provide a degree of necessity and benefit?

Examples of acceptable risk might be a higher probability of mild joint pain at altitude that resolves on descent to ground level after a flight, or a low probability of muscular weakness after diving that resolves with recompression.

Any decision about safety includes value judgments about: the adverse effects (risk); the beneficial effects (efficacy); the financial, time and social effect (costs); and the political effects (distribution of risk, benefit and cost). Safety is the degree to which risks are judged to be acceptable. Benefit is the degree to which efficacies are judged socially useful. Equity of distribution of risks, benefits, and costs is a judgment of fairness and social justice. The Revised Flying After Diving (FAD) Guidelines will impact several groups: divers, diver operators / resorts, certifying agencies, insurance carriers, professional societies, and the legal profession. Each group has its own interpretation of what is acceptable risk. On a given day, a diver might take more risk, but when an injury occurs, might seek assistance of the legal profession. It is important that any new safety guideline be considered fair and just.

Before recommending new FAD guidelines, the following questions must be answered:

- (a) Are any FAD guidelines needed at all?
- (b) Is the current DAN FAD guideline acceptable?
- (c) What is the longest preflight surface interval needed after multiday, repetitive diving at the limits of the recreational dive tables?
- (d) What guidelines are appropriate for diving well within the no-decompression limits of recreational dive tables?

## **References**

1. Lowrence WW. Of Acceptable Risk: Science and the Determination of Safety, Los Altos, CA: Kaufman, 1976.
2. Vann RD. Diving at the No-Stop Limits: Chamber trials of flying after diving. In: Flying After Diving Workshop. Vann RD, ed. 2004. Durham: Divers Alert Network. ISBN 0-9673066-4-7. 32-37.

## **CONSENSUS DISCUSSION**

DR. SHEFFIELD: During my early years in the Air Force, I had the good fortune to be stationed with Jeff Davis. Jeff had a tremendous reputation for supporting the diving community as well as aviation, and he was a strong enforcer of the rules. One of our Air Force rules was that any hyperbaric exposure required you to wait 24 hours before flying. One day, a nurse was unable to clear her ears after reaching 5 feet in the hyperbaric chamber. She was washed out of the training program and needed to fly home that evening. Jeff refused to allow her to until her surface interval was 24 hours. I suggested to him that it was not fair to force her to spend the night when she could go home that afternoon. He said, "The rule is the rule, and this is a military person in a military setting." She spent the night and flew out the next morning. I asked Jeff how long he waited to fly after diving in the Caribbean before flying. "Twelve hours," he said. "But that is a different rule that applies to the civilian setting."

So when we discuss flying after diving recommendations this afternoon, let's keep in mind who we're talking about. Do we want to consider the three groups Drew mentioned: uncertified divers, certified divers, and technical divers? What would be best for each of these groups?

DR. THALMANN: Another question is should FAD guidelines be enforced? Not necessarily like a law by the police, but should resort operators post them and point them out aggressively?

DR. BENNETT: I wouldn't want to use the word "enforce." DAN enforces nothing. DAN provides information. These are guidelines. If you enforce them, you will enforce the lawyers' fortune.

DR. THALMANN: I'm asking if the resort operators should be proactive rather than passive? Being passive means you assume people know the guidelines and follow them. Being proactive means reminding people they should remember the guidelines.

DR. SHEFFIELD: Why don't we use the word "encourage" instead of "enforce"?

DR. WATENPAUGH: This is an education issue, isn't it, for the resorts and the divers?

DR. GERTH: If guidelines are needed, what form should they take? Should they be simple rules or more complex but flexible like Navy guidelines? Do we need both?

DR. SHEFFIELD: The first question is, "Are any flying after diving guidelines needed at all?" Is there anyone in the room who feels that we should abolish all flying after diving guidelines?

**THE ATTENDEES AGREED THAT FLYING AFTER DIVING GUIDELINES WERE NEEDED.**

DR. SHEFFIELD: The second question is, “Are the current guidelines that were published by DAN acceptable, or do they require modification based on what we heard this morning?”

DR. FLYNN: Could you state exactly what the guideline is?

DR. VANN: The current flying after diving guidelines recommends waiting at least 12 hours after any diving before flying and longer than 12 hours after extensive multiday diving.

DR. BENNETT: It doesn’t say how long because the 24-hour guideline was unacceptable to various entities within the recreational diving industry. The solution was to let the divers decide how close to 24 hours they should wait based on how much diving they had done.

DR. THALMANN: If we agree that flying after diving guidelines are needed, and we believe the data that we’ve seen today, then 12 hours is inadequate. The issue is, where between 12 and 24 should we be?

DR. SHEFFIELD: If you have more than a single dive?

DR. THALMANN: Twelve hours is not enough, period.

DR. GERTH: If you dived no-decompression dives to the limits.

DR. THALMANN: You’re right, Wayne. It applies only if you’re diving to the no-D limits. It’s not true if you’re only diving 60 feet for 30 minutes, but we don’t have any data for 60 for 30, or 60 for 20, or 40 for 30. All we have are the longest surface intervals if you were diving at the limits of the Recreational Dive Planner (RDP). If you do that, 12 hours is obviously inadequate.

DR. VANN: We have Bassett’s data that defines the times at which you can fly immediately.

DR. THALMANN: Yeah, but we’re talking about guidelines that don’t specify the kind of dive. It just says if you’re doing a no-D dive, 12 hours. Bang. If you’re doing a no-D dive by the PADI Recreational Dive Planner, 12 hours is not adequate. To me, that’s pretty clear.

DR. RICHARDSON: Let me read the current guidelines that have been adopted by the educational institutions. The first guideline says, “A minimum surface interval of 12 hours is required to be reasonably assured you remain symptom-free from decompression sickness upon ascent to altitude in a commercial airliner.” In parentheses, it states the altitude as up to 2,400 meters or 8,000 feet.

The second guideline says, “If you plan to make daily multiple dives for several days or make a dive requiring decompression stops, you should take special precautions and wait for an extended surface interval beyond 12 hours before flight. The greater the duration before the flight, the less likely decompression sickness will occur.” That is what was released after the discussion in 1990.

DR. GERTH: What constitutes special precautions other than spending a longer time?

DR. RICHARDSON: Stay hydrated.

DR. THALMANN: I’ll restate my first statement even though you’ve embellished it with all kinds of stuff. The data says 12 hours is not adequate for many dives. A 12-hour PFSI was not adequate. So that first guideline is out the window. The second guideline does what Paul said we didn’t want to do. It requires judgment. What are special precautions? It’s argle-bargle. Let’s get down to what they want – a number. If you say 12 and greater than 12, well, 12 hours and one minute is greater than 12 hours. Is a special precaution 15 minutes more? Is a special precaution taking a hot shower? These are judgments. I think the second statement is political, because you can’t tell what special precautions to take to minimize your risk except a longer surface interval. Twelve hours is not adequate if you’re diving the RDP at the limits, and I’ll be willing to bet you could show it’s not adequate for a lot of no-D dives on decompression computers.

DR. RICHARDSON: It has nothing to do with politics. There’s no black and white in physiology. I don’t think anybody in this room is prepared to say that there’s a magic number that’s going to eliminate decompression sickness. There’s a probabilistic element to it as well. We’re trying to come up with general guidance that the great masses of the world can follow. That was the goal in 1991 when this overly verbose statement was released and is out there in 175 countries. Is it working now? Does it need to be amended?

DR. THALMANN: Is 12 hours a magic number?

DR. SHEFFIELD: Let’s don’t dwell on that. Is it working now? Is the number of events of decompression sickness for flying after diving sufficient to warrant changing the guidelines? That’s the big question. Refresh our memories as to what was the DCS incidence in flying after diving.

DR. VANN: We don’t know. We know about some of the divers who were injured during flying after diving, but we have no idea how many divers flew safely.

DR. FREIBERGER: The data do not allow us to compute an incidence, but if I can make a suggestion, look at the relative risk graph of Figure 1.<sup>\*</sup> At around 12 hours, the relative risk of DCS begins to increase geometrically as the surface interval becomes shorter. The

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<sup>\*</sup> Freiburger JJ. Flying after multiday repetitive recreational diving. In: Flying After Diving Workshop. Vann RD, ed. 2004. Durham: Divers Alert Network. ISBN 0-9673066-4-7. 38-44.



line is relatively flat at more than 12 hours and becomes steep at less than 12 hours. So whatever your risk at less than 12 hours, it increases rapidly the sooner you fly. Your risk is going to increase at least several-fold from shorter to longer times. Your risk will be higher if you fly sooner. The breakpoint at the knee of the curve is around 10 to 12 hours.

DR. FLYNN: The distribution of cases indicated that the majority of cases are at 12 hours or greater.

DR. FREIBERGER: That distribution is not representative of all cases. In fact, there were more cases than controls. The incidence of decompression sickness, apparently 60 percent here, cannot be computed in a case control study.

DR. SHEFFIELD: We faced that problem when we met in 1989. The 12-hour guideline was not based on the DCS incidence – even a relative DCS incidence as shown here – but on the preflight surface intervals reported by the patients. The 12-hour guideline was based on the distribution of cases.

DR. THALMANN: The number of decompression sickness cases we get per year is about 700. If 30 per year are due to flying after diving, roughly 5 percent of the DCS cases are due to flying after diving. We surveyed a thousand divers and got data from about 500 from which we estimated the overall incidence of bends for recreational diving to be about three per 10,000 dives. That said nothing about severity, of course. Is flying after diving a public health hazard? Not when we're dealing with incidences in the range one-and-a-half cases per 100,000 dives. My guess is that most public health departments wouldn't throw any money at that, but it is important to the individual who gets DCS.

Global rules based on Figures 1 and 2<sup>+</sup> for single and repetitive dives at the limits of the Recreational Dive Planner would say that you're probably safe if you wait for 12 hours after single dives. For repetitive dives, you're probably safe if you wait 18 hours.

Let me ask the group if dive computers give you more bottom time or less bottom time for repetitive dives than does the RDP? In other words, would guidelines based on testing the limits of the RDP extrapolate to decompression computers?

MR. COCHRAN: I'm not that familiar with the RDP, so it's difficult for me to say whether Cochran computers give you more or less repetitive dive time.

DR. WIENKE: In general, the dive computers we work with are a little more aggressive than the RDP, but there will be cases where that's not true.

DR. THALMANN: Can we reasonably conclude that FAD recommendations based on the dives done according to the RDP might be a minimum recommendation for most dive

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<sup>+</sup> Vann RD. Diving at the no-stop limits: chamber trials of flying after diving. In: Flying After Diving Workshop. Vann RD, ed. 2004. Durham: Divers Alert Network. ISBN 0-9673066-4-7. 32-37.

computers. If that is the case, Figure 2<sup>+</sup> suggests that 17 or 18 hours probably would get you out of the woods for RDP dives, but this might not apply to a decompression computer.

DR. WIENKE: In the new tables we're releasing at NAUI where the maximum depths decreases for repetitive dives, we're advocating a 12-hour preflight surface interval after one dive, 15 hours after two dives, and 18 hours after three dives. The NAUI instructor-trainers have done 600 or 700 dives at the no-D limits including repetitive dives on these rules for the last two or three years without problem.

In my activities on the Los Alamos countermeasures dive team, we do a lot of deco diving and frequently use trimix with two deco dives a day, separated by a minimum three-hour surface interval. We dive in four-man teams, so there may be 16 of us in the water. Our decompression model computes how long we have to wait to fly at any given altitude whether in a pressurized or unpressurized plane.

If I were to estimate the minimum surface interval before flying after a single deco dive, it's 18 hours. This is based on our experience of about 400 dives, a mixture of single deco dive and two deco dive profiles. These dives are as deep as 200 feet with the second dive shallower than the first. If we do two deco dives, we don't fly for 24 hours.

DR. THALMANN: We don't need a guideline if we don't think divers get bent on airplanes often enough to worry about, and we can't change diver behavior anyhow. Flying after diving is not a public health problem, and it sounds like everybody's saying, "We have a 12-hour guideline, and it's working," but it's based on diver behavior. It's probably working because most divers don't push the limits of the tables or computers. They just say, "I'll wait 12 hours," and don't ask, "If I change my dive behavior, should I change the 12 hours I usually wait?" Our flying after diving trials suggest if you wait 18 hours after your last dive, chances are no matter what you did, your DCS risk will probably be relatively low. A global rule is simple but restrictive. A more flexible rule is more complicated. How much complexity are you willing to accept for flexibility? Should we provide divers with guidelines that, by our research, would ensure that they had a very low DCS probability if every dive that they did was at the limit?

DR. SHEFFIELD: Let's address the three groups Drew mentioned. The first is people who are not certified, make a very minor single exposure at a dive resort, and fly back to the States. The second group is certified divers who dive within the limits of the no-decompression tables. The third group is technical divers who use fairly complex decompression procedures and fly afterwards.

DR. THALMANN: We haven't answered the question, "Are the current guidelines acceptable?"

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+ Vann RD. Diving at the no-stop limits: chamber trials of flying after diving. In: Flying After Diving Workshop. Vann RD, ed. 2004. Durham: Divers Alert Network. ISBN 0-9673066-4-7. 32-37.

DR. SHEFFIELD: I think the three groups will help to answer that question. Are the current guidelines OK for these three groups?

DR. GARNER: Do we exclude any group from the guidance? Would guidance be more advanced for technical divers? If current guideline is fine for resort divers, do you say, "That's good for resort divers. Technical divers, go elsewhere?" Or should the guidelines be applicable to all groups?

DR. SHEFFIELD: Let me restate the question. Are the guidelines good for all three groups? If not, what would be an appropriate guideline for each group?

DR. THALMANN: Resort course divers are not educated divers and rely totally on whoever runs the course. How are they going to make a decision if they are uneducated?

DR. SHEFFIELD: I think that's Drew's point. I was an expert witness in a case involving a resort diver. The son of a lawyer was flying from a resort hotel in Hawaii to the States and got bent during flight. He had flown about four hours after diving based on the PADI guideline at the time. The lawsuit claimed the resort should have known that the rule was 12 hours because NAUI and others used 12 hours. The suit was frivolous and was dismissed, but the point is that a suit was brought because the guideline of one agency was different from another agency's guideline. We hope to formulate guidelines today that will avoid such situations in the future for all three groups of divers. Would the current guideline be appropriate for the resort diver who only has a single exposure?

MR. YOUNG: What is the typical profile of the resort diver?

DR. RICHARDSON: Thirty feet for an hour or less limited by air consumption.

MR. YOUNG: One dive? Two dives?

DR. RICHARDSON: Usually one, but "resort course" is a misnomer. It's just an "experience," often in the morning, for somebody who goes on a tour, plays golf, or goes on the banana boat in the afternoon.

DR. SHEFFIELD: Would a minimum of 12 hours be acceptable for the resort course diver?

DR. WIENKE: Sure.

DR. THALMANN: As long as the resort course didn't exceed the RDP single no-D dive limits.

DR. SHEFFIELD: Would that apply to a single dive within the no-D limits of table or computer they choose?

DR. THALMANN: Right.

DR. SHEFFIELD: Would everyone agree they should wait a minimum of 12 hours?

DR. THALMANN: I would agree, yes.

DR. SHEFFIELD: Let's write that down as one of our possible recommendations.

DR. SOUTHERLAND: I come from Panama City where we don't have resorts but have a lot of people who do that kind of diving. Is it necessary to say "resort course" diver?

DR. SHEFFIELD: OK, let's say for a single dive within the no-D limits of whatever table or computer they choose, they should wait a minimum of 12 hours before flying. That would certainly meet the current guidelines for the Navy tables. It would certainly meet the PADI and NAUI tables, right? How about the second group, certified divers – not tech divers – who may use computers or tables? This is the group, Ed Thalmann, for who the 12-hour guideline alarms you.

DR. VANN: Not exactly, Paul. The first no-D dives for the Navy tables are longer than for the RDP while the repetitive Navy dives are shorter than for the RDP.

DR. THALMANN: I think saying "greater than 12 hours" is a cop-out. I'm in the military. I'm used to rules. But you said it and others said it: put a number out there. We can footnote the number and let people make their own judgment, but if we just put out the footnote, we're copping out.

DR. SHEFFIELD: You've made your point, Ed. Let's go to the recreational diving attendees to whom this applies. Alex, what's your view?

MR. BRYLSKE: I agree with Dr. Thalmann. Having taught the flying after diving guidelines to quite a few instructors, it would be a copout to just say more than 12 hours. I would encourage us to come out with something definitive. That number is for the group to decide, but from an instructional standpoint, simply saying greater than 12 hours is inadequate.

MR. CAPPS: I teach open water scuba for PDIC. I also teach instructors. We need a uniform guideline for all agencies, it doesn't matter if you're PADI, PDIC, NAUI, YMCA, or whatever. We need a guideline that says, "If you dive to 20 feet for 40 minutes, you need to wait X hours before flying." We need to protect the diver, not the agency. That's what counts.

DR. SHEFFIELD: Mike Cochran, what's your view?

MR. COCHRAN: I need to think about this a while.

DR. SHEFFIELD: Larry Elsevier, what's your view?

MR. ELSEVIER: My experience in the last few years is with Cochran computers because that's whom I work for. We add 12 hours to the time after the tissue compartments in the decompression algorithm get down to a certain level after a dive. This gives times to fly of 17, 18 hours, or 21 hours.

DR. SHEFFIELD: So your computer program doesn't use the 12-hour rule? You add 12 hours to whenever surface time it takes the tissues to desaturate. You're really looking at 17 or 18 hours.

MR. ELSEVIER: Yeah, and sometimes more. If somebody's been on a liveaboard for a week, it can be up to 20 hours or even 24 hours.

DR. WIENKE: I can speak to computers other than those made by Cochran. For a single recreational dive, say to 50 feet to the no-D limit, other computers will typically register less than 12 hours, somewhere in the vicinity of eight to 11. They are even more aggressive than the 12-hour rule. But I think computer divers generally use the 12-hour rule even if the computers do not.

DR. SHEFFIELD: So dive computers have different algorithms which makes some of them less than 12 hours and some 12 hours plus the desaturation time?

DR. WIENKE: We tested a bunch of dive computers a few years ago – more than a few years. Most had the same generic algorithm but used slightly different tissue half-times and M-values. The difference in time to fly between most computers was an hour or an hour and a half. That seems to be changing in newer computers that do more extensive calculations.

DR. SHEFFIELD: Let me make sure I understood what you said: most of the computer models allow you to fly in less than 12 hours?

DR. WIENKE: For a single dive by a nominal recreational diver pushing 40, 50 feet out to the no-D limits, but most divers don't push the limits, and they're going to show seven to 11 hours. Mike Cochran's dive computer is the only one that I've ever seen to add 12 hours. The other side of the coin is that recreational divers generally wait 12 hours. Photographers who are trying to go from one site to another don't follow the 12-hour guideline. They dive on computers and are getting away with it.

DR. THALMANN: Look at Figure 1<sup>+</sup> and make your own determination of whether you would follow the advice of a computer that told you to wait six, seven, or eight hours.

DR. SOUTHERLAND: I did some work with dive computers from different manufacturers a few years ago, and at least two had 24-hour timers that counted down when you reached the surface.

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<sup>+</sup> Vann RD. Diving at the no-stop limits: chamber trials of flying after diving. In: Flying After Diving Workshop. Vann RD, ed. 2004. Durham: Divers Alert Network. ISBN 0-9673066-4-7.32-37.

DR. SHEFFIELD: Drew, what's your view?

DR. RICHARDSON: For single dives, I think 12 hours is working. For repetitive dives, I think we've learned two things since 1989-91 from Dr. Vann and associates. One is that some people fly with symptoms. That's a side topic, but we might want to make a statement about it. Two, if you look at Figure 2<sup>+</sup>, you're looking at a threshold of 17-plus hours that might be justifiable for repetitive dives. Based upon the data, a minimum of 17 hours may be appropriate.

DR. SHEFFIELD: Brad Smith, would you like to comment?

MR. SMITH: I think we need to provide the average diver with information to make an informed decision. The decision rests with them. Even if they wait for 18 or 24 hours, they need to know that there is no magic rule that frees them from DCS risk. The current guidelines say that. I concur that the recent studies reflect 17 hours as needed to be reasonably sure of avoiding decompression sickness.

DR. THALMANN: Are you saying that you would like some hard numbers, but with those numbers, you want a footnote saying where they came from? Or do you just want the footnote to say, "This is what the data shows. You pick your surface interval based on however you want to interpret the data."? Do you want a hard number with an explanation of where it came from, or do you want general guidance and allow the diver to pick his own number?

MR. SMITH: It's a good question. Some people go up into the mountains or drive over a pass without any problems. These people will say, "I appreciate your study, but it isn't really applicable to our situation." This allows them to weigh out the information. We've done our duty to the individuals by informing them of what the recent studies have shown.

DR. THALMANN: Even for these individuals, would you recommend 18 hours after repetitive diving but point out the study on which the recommendation is based? They can still make their own decision. It would be bad to make guidelines based on observations for a particular group of self-selected divers. I agree they're going to make their own decision no matter what, but is it better to say, "Here's the guidance: 12 hours for a single no-D dive, 18 hours for any kind of repetitive diving or multiple-day diving," and add a little thingy saying, "This was based on this kind of research," and let them make their minds up? Or just not even give them the 12 or 18-hour number?

MR. SMITH: In the second part of the rule, let's say if you plan to make multiple daily dives for several days or make dives requiring decompression, recent studies indicate that 18 hours is appropriate.

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DR. THALMANN: You saved yourself in that last statement. That sounds relatively reasonable, and leave out, “take special precautions,” that’s in the present guideline. The last sentence, “Studies have shown that 18 hours seems to be the minimum surface interval for repetitive diving,” provides a benchmark. He’s not totally out of the woods but can say, “For me, 16 hours is OK, 14 hours is OK.”

DR. SHEFFIELD: Should it be 17 hours or 18 hours?

DR. BENNETT: Eighteen’s better. It’s one up.

DR. SHEFFIELD: Drew, which one serves your purpose?

DR. RICHARDSON: If I recall the data, it was zero DCS out of 52 exposures at 17 hours.

DR. GERTH: With this observation, you can only be 95 percent confident that that the real risk is less than 6 percent.

DR. THALMANN: Rule number one: never use a prime number in a recommendation.

DR. GERTH: That’s right. Don’t get hung up on 17 versus 18. There are still substantial error bars on the observations.

DR. RICHARDSON: Right. There are caveats on all our tables, computers, or guidelines. Nothing is guaranteed. As soon as you become concrete, you’ve given a lawyer something to compare. Nothing is rock solid. It has to be reasonable based on what we’ve seen here that’s new. You guys tell us whether 17 or 18 is better, but from what you’ve collected since we got together in 1991, 17 or 18 might a better place to land than 12. We’ll interpret what you give us through the educational systems.

DR. SHEFFIELD: Let’s change “required” to “recommended” in the proposed guideline. We have a couple other people from the diving community we need to hear.

DR. WIENKE: Before I came here, I asked NAUI headquarters to look up reports of DCI in our training files. They average about five a year in maybe 100,000 dives. Over the last eight years, none were associated with flying under NAUI’s present 12-hour rule. There were only two problems with altitude excursions, both after ocean diving and driving in mountains. That’s two out of a million dives in the last 10 years. It’s not hard science, but it tells you something about the real world.

DR. THALMANN: I refer you back to Figure 1.<sup>+</sup> These were sandbox dives, not provocative dives where the divers were immersed and exercising in cold water. Look at the data. There are people getting bent. If the real incidence was as low as you say, all those points should be close to zero, and they’re not. There’s a big disconnect.

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DR. WIENKE: That's not what I said. They were using a 12-hour guideline.

DR. THALMANN: Oh, I'm sorry. Were the training dives single or repetitive?

DR. WIENKE: The training dives can be repetitive.

DR. THALMANN: You said you only saw two cases of flying after diving problems for repetitive training dives in 100,000 dives. Figure 2<sup>+</sup> shows the repetitive dives that were tested in which decompression sickness was observed with preflight surface intervals of 14 and 16 hours after diving. If you look at the 100-foot and 60-foot, 60 and 60, 40 and 40, they're only double dives that I assume are quite common in training. Maybe a triple dive isn't. If your statistics are correct, this would suggest your population is different from the population we used, unless there's some other reason for the big disconnect between your very low DCS incidence and the incidence in Figure 2.<sup>+</sup>

MR. COCHRAN: I think a training agency's experience with the number of DCS incidents is going to be radically different from the diving population as a whole. It's my understanding NAUI doesn't teach resort courses, and how many students fly after taking a class? I think almost none. I think the population is radically different.

DR. WIENKE: The population is different, and the chamber tests were at the exposure limits. Most recreational divers don't dive to the limits. I'm just pointing out a field fact. We're going to make recommendations, so maybe we should go back to 12 hours because it seems to be operationally OK. I'm not arguing from a science point of view that we don't have this problem, but out in the field, we don't. We tested the NAUI tables to the no-D limits, so we are looking at stuff like science here. We did 600 dives with instructors who are qualified and well able to handle themselves in the water and didn't see any DCS.

DR. POLLOCK: Bruce, you said you have a very low DCS incidence with a 12-hour guideline, but you don't know the actual time before they flew. They might have waited longer than 12 hours.

DR. WIENKE: That's true, but the only two incidents I knew of were from driving up from the coast of California to Tahoe and the mountains. They were probably at about 8,000-9,000 feet at six or seven hours after they got out of the water after repetitive diving.

DR. THALMANN: You said the magic words – “habits and behavior.” If we want to rely on behavior and nothing else, you could say the current diver behavior is such that flying after diving is not a problem, and FAD guidelines are not needed. But if we're going to have guidelines, I think three of the recreational diver representatives have said they

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don't want wishy-washy, mushy recommendations. They say, "Give us a number and we'll work it from there."

DR. SHEFFIELD: Bruce, as I understand your new guidance, you're going to make a 12-hour minimum FAD guideline after a single exposure, 15 hours after two exposures and 18 hours after three exposures?

DR. WIENKE: Yes.

DR. SHEFFIELD: Then he's done exactly what you said, Ed. With their new guidelines, they are already changing.

DR. THALMANN: No, he's done what you just said. What he was saying before, I think ...

DR. WIENKE: Stop putting words in my mouth. The guidelines I just suggested are only for recreational air diving to 120 feet maximum, and each successive repetitive dive has to be at least 30 feet shallower than the last. You wind up in the shallow zone on the third dive. These are dives we tested over the last three years with instructors.

DR. SHEFFIELD: We need to hear from Mark Young of the diving community.

MR. YOUNG: I agree that there should be recommendations, and they should be more definite than at present. What we had on the screen with 12 and 18 or 17 hours sounds pretty good. I know we can't put a denominator to it, but can you remind me how many FAD bends are reported to DAN each year?

DR. VANN: A rough estimate is 30 flying after diving incidents out of a total of 800 DCI cases per year.

DR. FREIBERGER: The incidence can't be determined from those numbers. Some people may have flown but didn't tell us.

MR. YOUNG: I understand. However you break the numbers down, it's a small incidence as the number of people flying and diving is probably incredibly large. Having said that, you don't want to make it too strict, because if it's such a low incidence, you could fall off a curb and do worse. I'm thinking through this myself because I'm a little bit like Mike Cochran. I'd like to withhold my judgment, but having heard what I've heard today, I guess I kind of agree with what has been suggested.

DR. VANN: This gets us back to where we started: what is acceptable risk, recognizing that risk depends upon probability and severity? The probability is very low, and the severity does not appear to be major, and the evidence doesn't indicate a large component of residual symptoms. So we're saying, "Well, we're going to accept a certain small incidence, albeit we don't know exactly what it is."

DR. THALMANN: DAN doesn't get all safe dives, so there's no way to compute an incidence, but with 30 cases of flying after diving bends in 800, that's about 5 percent. Maybe it's 10 percent, but we're not talking 20 or 30 percent. If the DCS incidence is somewhere between three and four events per 10,000 dives and reckoning on 400 to 500 injuries that make the DAN database per year, this represents about a million recreational dives per year. Is that way out of spec?

DR. RICHARDSON: That's way out of spec. Entry-level certification requires four dives. PADI alone certifies about 600,000 entry-level divers annually. Four dives times 600,000 divers equals 2.4 million certification dives per year alone. The resort diver population of one-off dives is estimated to be about 2.3 million. One million recreational dives per year is a gross underestimate.

DR. FREIBERGER: If you look at the DAN injuries and the DAN membership, we estimate about 2.8 million dives per year. There are probably more than 400 injuries per year, probably around a thousand injuries reported to DAN each year. We don't know what percentage of all the injuries we get, perhaps 75 or 80 percent.

DR. THALMANN: I used the number of the divers that made it in the DAN injury database. If we look at all injuries, we just double it. So we're talking in the neighborhood of 2 to 3 million dives per year. But you were just talking about certification dives, not recreational dives.

DR. RICHARDSON: Right. There's no way to measure how many recreational dives take place, but we can measure certification dives, because we have those data. We also have a pretty good idea of the resort dives from surveys we've done of people who have tried diving. That's a huge number. So there's a lot of diving going on.

DR. THALMANN: People tend not to get bent on certification dives. Our diving population reported recreational dives, not certification dives.

MR. YOUNG: Did I understand you estimated 2.8 million dives a year, and 30 people that get bent on airplanes?

DR. FREIBERGER: No, you did not hear that. The first part was correct, 2.8 million dives per year estimated, and Drew says there may be more than our estimate, which is imputed from the percentage of injured people and the size of the DAN membership. The number of flying after diving bends is probably at least 30. As we do not know the percentage of divers who report, I cannot tell you exactly. I can tell you that if we have 300 cases over 10 years, that means an average of 30 cases a year were reported, but not all cases were necessarily reported. It could be 10 times that.

DR. REED: On the basis of DAN emergency call volume, 30 cases a year is a gross underestimation, probably by an order of magnitude. I talked to five people this year who had definite to questionable DCI symptoms as a result of flying after diving. So saying "Thirty flying after diving bends a year is not a problem" is probably an illusion.

DR. SHEFFIELD: Unless I'm really misinterpreting everything that has been said, there is a need for flying after diving guidelines, and 30 FAD bends per year is not the number to focus on. We're working toward a guideline for the people who get bent when they fly after diving. Whatever the size of that population, the guideline is important to those who get bent. During the break, I'd like you to discuss this among yourselves to iron out any disagreement. Remember, our focus is the recreational diver who does multiple dives during the week.

DR. FLYNN: Let me ask about risk being the product of the probability of the occurrence times the severity. We haven't talked much about the severity. In the DAN study, did the severity of bends fall off as the surface interval increased?

DR. VANN: The most serious case, cerebral symptoms, occurred after the three-hour surface interval, but the mild and moderate cases were evenly distributed throughout all surface intervals. Other than the most serious case being at the shortest surface interval, there didn't appear to be a correlation of severity with surface interval.

## **BREAK IN DISCUSSION**

DR. SHEFFIELD: Let's continue our discussion. Do the guidelines need to be in terms of number of dives? Maybe the first group should be divers who make a single dive? This would apply to both resort divers and recreational divers. How about multiple days of diving and multiple dive exposures?

DR. THALMANN: Multiple repetitive, multiple day dive exposures.

DR. SHEFFIELD: OK. You all want that? Repetitive dives or multiple dives?

DR. BENNETT: Keep it simple.

DR. WIENKE: If you say repetitive dives for the second group, I think that would mean a single day to most divers. It should be differentiated from multiday diving with repetitive dives over many days.

DR. SHEFFIELD: Do we need both of those in the title?

DR. THALMANN: I would recommend repetitive / multiday. Because I think you need to cover both. It's not just multiday, and it's not just repetitive. It's either type.

DR. SHEFFIELD: Drew, what works best for you?

DR. RICHARDSON: I think that would work, repetitive and / or multiday diving.

MR. COCHRAN: I think you should take out the words "plan to."

DR. WATENPAUGH: I'd like to suggest oxygen breathing as a special precaution in parentheses.

DR. SHEFFIELD: No, that's not what the original guidelines meant as special precautions. Unless I'm badly mistaken, a special precaution meant that you just should extend your time. It didn't have any other meaning.

DR. WATENPAUGH: That's why I'm suggesting that oxygen breathing be added to that.

DR. VANN: We should not say anything about oxygen breathing without data on its effectiveness. We will be testing oxygen breathing in the lab, and it may ultimately be good, but we don't know how good it is right now, and that's putting ourselves out on a limb. I recommend taking "special precautions" out because it doesn't have any meaning.

DR. SHEFFIELD: One should wait for an extended surface period?

DR. GERTH: I suggest the paragraph be simplified to, "Repetitive dives and / or daily multiple dives over several days should be followed by a minimum surface interval of 18 hours before flight."

DR. POLLOCK: Make that "multiple daily dives," not "daily multiple dives."

DR. SHEFFIELD: Does anyone disagree?

DR. RICHARDSON: No, but there's a risk in the last sentence about letting people take responsibility for themselves. It's not failsafe. When we say the greater the duration, the less likely, if that is true, they decide for themselves instead of taking a specific number that some lawyer will compare to some other rule, as you said, Dr. Sheffield.

DR. GERTH: Fine, then keep the sentence, but keep the other stuff simple so it can't be misinterpreted. "Repetitive dives and / or daily multiple dives should be followed by a minimum surface interval of 18 hours before flight." Let's get this down first and then trim it, because it's still very wordy.

DR. SHEFFIELD: Get rid of the "and / or."

DR. GERTH: All right. "Should be followed by a minimum surface interval of 18 hours before flight." You might want to add that last sentence, "The longer the surface interval, the less likely DCS will be." We're missing the decompression stop issue. "Repetitive dives, daily multiple dives or decompression dives should be followed by a minimum ..."

DR. SHEFFIELD: Are you going to include decompression dives in 18 hours? That's 24 hours in the current guideline, isn't it?

DR. BENNETT: We didn't get that far in the previous guidelines.

DR. WIENKE: If this is being directed at the recreational dive community, the decompression stop has to be considered. If it's going to be a short stop, 18 hours is probably OK, but if the stops are long, as in technical diving, the 18-hour rule certainly isn't going to be true for repetitive deco dives.

DR. SHEFFIELD: Would any of you object if we took out the words "decompression dives," as this group is discouraged from making decompression stop dives?

DR. WIENKE: That's right.

DR. SHEFFIELD: Right? So we shouldn't make it one of our recommendations, should we?

DR. BENNETT: No.

DR. SHEFFIELD: "Repetitive dives and / or daily multiple dives should be followed by a minimum surface interval of 18 hours before flight. Recent studies indicate a period of at least 18 hours before flight may be needed." We need to address what the cost and compliance impact is going to be.

DR. THALMANN: We have no data on decompression dives. I want to make that clear.

DR. SHEFFIELD: We've taken it out.

DR. THALMANN: I understand that, but we know that there is a group of divers doing decompression dives. So when you get to the third group, let's see if this workshop wants to make a recommendation for divers who decompress.

DR. SHEFFIELD: Good point. Let's look at the impact of 17 versus 18 hours if we should go to a recreational resort and make a dive Friday morning and fly out Saturday morning. If we get out of the water by noon, we can fly out at 6 o'clock the next morning with an 18-hour surface interval. But we don't always get out of the water by noon. Sometimes we get out of the water by 1 or 2 o'clock.

DR. BENNETT: One o'clock sometimes, yeah, 1:30.

DR. SHEFFIELD: OK. Let's round it off to 2 o'clock. Two's the latest. If you get out of the water by two, an 18-hour rule allows you to fly by 8 o'clock the next morning. A 17-hour rule allows you to fly at 7 o'clock the next morning. So what's the practical number to use? Is it 17 because the data shows 17 hours, or is it practical to round up to 18?

DR. GERTH: The data doesn't show 17 hours as distinguishable from 18. Remember, there are error bars on those observations. With zero incidents at 17 hours, we're only 95 percent confident that real incidence is less than about, what, 8 percent? Don't look at 17 as a hard number.

DR. SHEFFIELD: You're saying the number should be 18 or 17?

DR. GERTH: I'm saying we do not know the difference between 17 or 18. If you want to be a little conservative, and that's the way you'd have to go with data, use 18.

DR. BENNETT: We have 70 divers on each of two DAN courses per year. Since we changed the last dive to the morning rather than the afternoon, we fly after 18 hours and have not had any problems. Before the change, I'd come into my office and hear, "Hey, you've had two bends on your course." That's stopped. While the experience is small, I would vote for 18 instead of 17. It seems to work.

DR. GERTH: That's my point.

DR. SHEFFIELD: Remember, this is the politics, not the science. Selecting a number, 17 versus 18, is a subjective judgment. In addition to being more conservative, there's another advantage to picking 18: you've got 12, 18, and 24. This gives three increments of six hours, which seems to be a logical way of handling the numbers.

DR. GERTH: That's really about our level of our resolution right now, so I advocate 18.

DR. THALMANN: We could vote on 17 or 18, we could have a cockroach race, or we could flip a coin. What Wayne is saying is that you can't defend the choice statistically. Let me just tell about statistically indefensible choices. I wrote an article for the *Alert Diver* about oxygen toxicity. I put in 1.3 atmospheres as the maximum oxygen partial pressure. We got feedback from one of group that was using 1.4 atmospheres who felt that they might get in trouble if DAN put out 1.3. I discussed it with Dan Orr. "Dan, there's no difference in the data between 1.3 and 1.4." So in my manuscript, I simply put 1.3-1.4 and everybody was happy. In this case, you could probably put 17-18, and it would work fine.

DR. SHEFFIELD: No, no. Got to give them a number. What works for you?

DR. WIENKE: Eighteen is fine.

DR. RICHARDSON: Yes.

DR. SHEFFIELD: Eighteen works for you? OK. Put in 18. Does anyone object to the recommendation since the recreational diving community will be making multiple dives during the week or repetitive dives during the day?

DR. MULLER: In the title, you say "multiday diving," and then you say "daily multiple dives." Would you want to flip those two around?

DR. SHEFFIELD: OK.

DR. POLLOCK: Actually, it should be multiple daily diving.

DR. SHEFFIELD: OK. Let's punt. Repetitive dives and / or multiple days of diving?

DR. POLLOCK: It's fine now.

DR. SHEFFIELD: Is there anyone who objects to this statement for the recreational community?

DR. VANN: Do we want "should" or do we want "recommend?"

DR. SHEFFIELD: Instead of "should," it should be "are recommended for?"

MR. YOUNG: How about, "It's recommended that repetitive dives and / or multiple days of diving be followed by...?"

DR. SHEFFIELD: That's a good. Start with the first sentence saying it is recommended that ...

DR. THALMANN: Before "repetitive," put "after" and put "it is recommended that..."

MR. YOUNG: "It is recommended that after repetitive dives and / or multiple days of diving..."

DR. SHEFFIELD: Take "it is recommended" and put it before "repetitive dives." "It is recommended that after repetitive and / or multiple day diving."

MR. YOUNG: Take out the word "that" after "recommended and" it will work. "It is recommended after repetitive dives and / or multiple days of diving that a minimum ..."

DR. SHEFFIELD: How about this? "A minimum surface interval of 18 hours before flight is recommended after repetitive dives or multiple days of diving."

DR. THALMANN: If anybody's frustrated, this is exactly how they wrote the Declaration of Independence. We talk about multiple days of diving and multiday diving. To me, multiday diving implies what DAN calls a continuous series, diving one day after another, whereas multiday diving could imply any sort of interval between subsequent dives. So I'll ask Dick. Which is more appropriate, multiday diving or multiple days of diving?

DR. VANN: In my mind, they are synonymous.

DR. SHEFFIELD: OK. If that becomes a semantic problem, we'll clear that up later.

DR. RICHARDSON: Previously, someone suggested, "recent studies have shown that a minimum surface interval of 17, 18 ..." We may want to start with that. You know, that's

really what we've learned. If we say "multiday" up there, then change to it to "multiday" in the body, too. Either way, if it's synonymous, but we do use multiday diving for much of the literature. So anyway, I would put "recent studies have shown..." as a roll into this recommendation.

DR. SHEFFIELD: How about changing it to, "Recent studies have shown that a surface interval of greater than 18 hours duration before flight is less likely to cause decompression sickness to occur."?

DR. GERTH: That's not what the data shows. That wasn't tested.

DR. THALMANN: Why don't you say, "The above recommendation is based on recent experimental dives?"

DR. RICHARDSON: Well, I guess the point is going to be, who are we making these for? They're going to say, "Why did you change them?"

DR. SHEFFIELD: Right, exactly.

DR. RICHARDSON: They were changed on evidence that it was probably a wise thing to do.

DR. WIENKE: We can give a reference in the introduction, but not as part of the guidance. It's got to be flat-out simple. This is our recommendation. See reference so and so for details.

DR. RICHARDSON: People who are locked into what's been out there since '91 probably won't take the effort to look at that study, but it's available to satisfy their interest. "OK, there's been some new evidence, so we've got to change our operational protocols."

DR. SHEFFIELD: We need to be able to say that a recent study that has come up with this 18-hour interval.

DR. RICHARDSON: The simpler the better, because I've got to translate it into 24 languages.

DR. THALMANN: Do we want to publish the study as part of the recommendation?

DR. POLLOCK: Can we have a footnote saying, "This is based on recent studies?" That way, it's not part of the formal recommendation, but it's on the same page.

DR. SHEFFIELD: Will that work for you, Drew?

DR. RICHARDSON: I think that's reasonable without having people fish around for it.



DR. SHEFFIELD: Should we say, “recent DAN studies”?

DR. THALMANN: Put “recent studies” and with the reference.

DR. VANN: “Recent studies” is fine.

DR. SHEFFIELD: Here’s what we’ll do. “Recent studies have shown that a surface interval of 18 hours is needed to limit the risk of decompression sickness.” If any of you have specific thoughts of how we should modify that, write it down so that we can put it into the text.

DR. GERTH: Keep it simple. “Recent studies motivate a recommendation of a minimum surface interval of 18 hours.”

DR. THALMANN: Why else would you need 18 hours? To turn in your rental car?

DR. SHEFFIELD: Remember the definition of safety. It has a political arm as well as the scientific arm.

DR. GERTH: It really doesn’t mean what we know. We know that a six-hour surface interval reduces your risk of decompression sickness compared to three hours. We know that a surface interval of 12 reduces your risk of decompression sickness compared to a surface interval of six. So, adding that phrase is argle-bargle. A minimum surface interval of 18 hours is recommended, period.

DR. THALMANN: If you want to leave that in, you’re going to have to add, “to a level which is probably acceptable to most divers.” Let’s come out with a recommendation instead of political mush.

DR. SHEFFIELD: I’m trying to solve an issue with the recreational diving community.

DR. SHEFFIELD: Drew, do you want to take that sentence out or leave it in?

DR. RICHARDSON: To further reduce the risk, increase the duration. That appeals to the person’s choice. Individuals have to choose for themselves, and they should know the longer the better. We knew in ’89 that a greater duration before flight made bends less likely. That’s not rocket science. It’s accepted doctrine. In fact, it was stated. The recent studies are what we learned since ’89. The new data changed it from something nebulously greater than 12 to 18 hours. That’s what’s influenced our thinking. Otherwise, we would have left this alone. I don’t see a problem with saying, “That’s where 18 came from. And by the way, the longer you wait, the greater is the reduction.” Take the whole last day off. Go shopping or whatever. Let people know they have a choice. You can’t enforce their behavior. All you can do is appeal to their intellect and hope that they make a good decision.

DR. WIENKE: I’m for making it as short as possible to jump out at everybody.

DR. BENNETT: Take “recent studies” out and start, “The greater the duration before flight, the less likely decompression sickness will occur.”

DR. MULLER: Is this an update to the current recommendations or is the new guideline? The guideline stood for 10 years. Do you want a temporal relationship in the guideline? Ten years from now, the recent studies are no longer recent. A guideline doesn’t need a temporal relationship. If it stands for another decade, should it say recent studies?

DR. SHEFFIELD: Certainly a good point. Let us take this as an editorial comment. We’ll work it after the conference is over. As long as I know you agree that this is the kind of text that you want. Now, do you from the recreational community agree with this text?

MR. COCHRAN: Yes.

MR. ELSEVIER: Yes.

MR. BRYLSKE: Yes.

MR. YOUNG: Yes.

DR. RICHARDSON: It’ll work. And actually for the proceedings, that’s wonderful.

DR. SHEFFIELD: Let’s then go the next dive group, which will take some discussion.

DR. VANN: I vote we make no recommendations for technical divers. They can read the literature. They’re smart enough and they can draw their own conclusions.

DR. WIENKE: I second that motion.

DR. RICHARDSON: I third that.

DR. SHEFFIELD: Well, any other thoughts about technical divers? Is there anyone who disagrees with the view that we should not make recommendations for technical divers?

DR. GARNER: Would you want to at least provide a guideline telling them you should look for guidance based upon your specific dive requirement? “You’re responsible for advanced applications.”

DR. SHEFFIELD: Unless you all have some real serious objection to it, I would think we ought to leave that entirely alone, because the lawyers will come to DAN and the certifying agencies.

MR. COCHRAN: I wouldn’t touch it.

MR. ORR: Technical divers are a very savvy group. They're going to read all the literature and make their own decisions.

MR. YOUNG: Could the definition we spelled out apply to technical divers? Should we just exclude them? Just say that this does not apply to technical diving.

DR. WIENKE: I wouldn't say anything.

DR. SHEFFIELD: The recommendation would be to add a sentence in the guidance that this does not apply to technical diving.

DR. RICHARDSON: We've gotten rid of the old 24-hour decompression recommendation that we had. Maybe it's separate from technical. I agree with Dan that most of them are quite savvy and disciplined in their dive planning. Do we need to consider 24 hours after stage decompression as a minimum back in the recommendation?

DR. SHEFFIELD: Even though you may not have data, a minimum of 24 hours after decompression stops is a pretty well industry-accepted recommendation, isn't it?

DR. WIENKE: Yeah, generally.

DR. RICHARDSON: Yes, and I think recreational divers need to know what to do if they had to make an emergency decompression.

DR. SHEFFIELD: A new page for emergency decompression diving. The first sentence should be that decompression diving is discouraged, but in the event of emergency decompression, a minimum of 24 hours before flying is recommended. Anybody want to come up with a better bit of text?

MR. CAPPS: Why not just say "decompression stop?"

DR. WIENKE: I think that you're getting in a can of worms here. The technical diving community will probably look at this as a fluff-over approach because there's a lot more going on.

DR. VANN: Maybe we should say this is not based on any data.

DR. THALMANN: Then nobody will follow it, so why even go forward?

DR. WIENKE: My suggestion is if you're going to put in a emergency decompression stop, add it to the previous slide where you had repetitive dives and / or multiple days of diving.

DR. SHEFFIELD: I think we need to stay away from that because we're trying to discourage decompression diving.

DR. WIENKE: If this is for recreational diving, I feel uncomfortable with having a third category for emergency decompression, which is something you're not supposed to do.

DR. THALMANN: Not only is this the way the Declaration of Independence was written, but this is the way the two revisions of the diving manual were written that I worked on. You guys are getting too far down in the weeds here. We're trying to come up with every possibility. It's a black hole. Make simple recommendations. Emergency is an emergency that you can't predict. We don't have any data on emergency stops. You don't have any data on decompression dives. If we were recommending 18 hours for repetitive multiday exposures, that ought to be the minimum for decompression dives.

DR. WIENKE: This is Alexander Hamilton, Ed, and I agree with you.

DR. SHEFFIELD: So you're saying we shouldn't make any recommendation on decompression diving?

DR. WIENKE: My recommendation is not to have any recommendations about decompression stops in this very short language.

MR. YOUNG: Is there a recommendation in the current procedure?

DR. RICHARDSON: Yes. Surface intervals for dives requiring decompression stops should be longer than 12 hours. We took it out of the recommendation under consideration here.

DR. WIENKE: If you're going to put it back in, keep it really short and sweet.

DR. SHEFFIELD: Do you use it for PADI?

DR. RICHARDSON: There's definitely a point there. I don't like the emergency decompression category. However, people do make decompression stops intentionally and unintentionally. Right now, a recommendation exists, and we're not being responsive to that. Sophisticated guys in Bikini Atoll are going to accelerate their time to flight with oxygen breathing, but that's not what we're dealing with. A lot of recreational divers routinely make decompression stops even though they're advised not to. What should they do? Eighteen hours? If we're happy with that, don't say anything about it. But we did say something about it for the last 12 years. It will be noticeable by its absence if we don't say anything today.

MR. YOUNG: What if we did the same thing and recommend an interval longer than 18 hours for decompression stops?

DR. SHEFFIELD: Would you buy that?

MR. YOUNG: If it's up to me.

DR. SHEFFIELD: Take that sentence from the previous side and bring it in as a third point.

DR. THALMANN: Hey, Paul, do you remember I asked you to make the third category separate? Then why not make it separate?

DR. SHEFFIELD: We voted not to make any recommendations for tech divers.

DR. THALMANN: Does that include safety stops that everybody makes, even on no-D dives?

DR. SHEFFIELD: No, it doesn't. Let's proceed.

DR. RICHARDSON: Right now, the guidelines say wait longer than 12 hours for a dive requiring a decompression stop. Are the scientists here comfortable with saying wait longer than 18 hours or should we say 24 hours?

DR. THALMANN: If we're publishing truth about where these guidelines came from, you need to say, "We don't know how long, because we don't have any data."

MR. CAPPS: Why put the decompression stop in the first sentence?

DR. WIENKE: That's what I said. I think 24 hours for a short emergency decompression stop is a little excessive.

DR. SHEFFIELD: Do we want a separate category with an interval longer than 18 hours, or do we want the same category with 18 hours? The problem is that there are no data to support a decompression dive for any number. What satisfies the recreational community?

MR. CAPPS: Leave it at 24 hours if you do an emergency or mandatory decompression stop. The only thing you're changing is the recommendation on flying after multilevel dives. You're just moving from 12 hours to 18 hours.

DR. THALMANN: Wasn't the original recommendation 24 hours for decompression diving? Does anybody have any heartburn with that? That's what the Navy said. There is no evidence suggesting that the current 24-hour recommendation should not be followed for decompression diving.

DR. SHEFFIELD: When you state that there is no evidence to support your recommendation, the lawyers will have a heyday.

DR. THALMANN: Hey, there isn't any evidence.

DR. SHEFFIELD: You don't tell your wife you've been cheating on her.

DR. WIENKE: NAUI can live with 24 hours, even though we've been teaching 18 hours. So you're being a little safer than that. That's cool.

DR. SHEFFIELD: PADI, how does this satisfy your requirement?

DR. RICHARDSON: Well, 18 is better than where it was.

MR. YOUNG: Take out the word "minimum."

DR. SHEFFIELD: Good point.

DR. SHEFFIELD: Is there anybody who objects to this sentence?

DR. THALMANN: Eighteen hours and one minute is longer than 18 hours.

DR. SHEFFIELD: The issue is that a diver needs a choice rather than the certifying agency giving him a number. If I have a choice, I can make it 18 hours and one minute or I can make it 30 hours.

DR. RICHARDSON: That's true. At present, they can make it 12 hours and one minute, so it just depends on how happy we are with it.

DR. SHEFFIELD: Does it satisfy your need at DAN, Peter?

DR. BENNETT: Sure. As far as the data we have in hand, that's fine.

DR. SHEFFIELD: From the military, is that going to be a problem for any of your tables?

DR. FLYNN: No.

DR. SHEFFIELD: Is the terminology correct? "Repetitive multiday diving"? Anyone object to this? OK, it's done. Let's go back to the first recommendation for single dives.

DR. THALMANN: Do the words "significantly greater" have a different connotation than "greater?" Eighteen hours and one minute is greater than 18 hours, but not significantly greater. Is there utility in saying significantly greater than 18 hours?

DR. SHEFFIELD: I think it will give the lawyers a chance to draw in a number of consultants to help define what "significantly greater" is. Anyone want to comment on that?

DR. THALMANN: We're writing it for divers, not for the lawyers.

DR. BENNETT: No, we're not.

DR. SHEFFIELD: Mark my word.

DR. THALMANN: We're supposed to be writing it for divers.

DR. SHEFFIELD: "For a single dive within no-decompression limits, a minimum surface interval of 12 hours is recommended ..." Do we need commercial airliner? .... "Is recommended before flight in a commercial airliner."

DR. VANN: At altitudes of up to 8,000 feet.

DR. SHEFFIELD: Take out "commercial." "Is recommended before flight to cabin altitudes up to 8,000 feet."

DR. THALMANN: Guys, how does somebody on an airplane know if he's above 8,000 feet? It's recommended before commercial flight, period. The 8,000 feet is an FAA recommendation. The diver has no way of knowing whether he's going to be at 8,000 feet.

DR. SHEFFIELD: Ed's point was that the recreational diver has no idea of what the cabin altitude is going to be. They will know whether it's commercial flight or private aircraft. It is probably appropriate to leave commercial aircraft in there. Anyone have objection to that?

MR. YOUNG: Private and up to 8,000 feet? That means 5 feet, 100 feet, 30 feet. What if you're in a private airplane? When you say up to 8,000 feet, that means every altitude from sea level up to 8,000 feet.

DR. VANN: I think the question is should there be a minimum altitude.

DR. THALMANN: What about "is recommended for a commercial flight in a pressurized aircraft or in an unpressurized aircraft at 8,000 feet or lower if it's unpressurized?"

MR. YOUNG: It says that you have to wait 12 hours for any flight up to 8,000 feet. Does that apply to a flight at 500 feet?

DR. SHEFFIELD: Yes. I see what you mean.

MR. YOUNG: We do a lot of private airplane flying and hop around between islands and you're perfectly fine. That definition says any flight.

DR. SHEFFIELD: Do we want a minimum altitude of 2,300 feet such as the Navy used?

DR. BENNETT: There needs to be a minimum. I was asked recently in Cayman about people flying from Little Cayman to Grand Cayman. They said, "We want somebody to tell us if we can do it. We're going to go a thousand feet or below. Can we do it?" I said,

“Well, I think you can.” There’s enough evidence in the past, but we haven’t put it in there. Should say something like “from 1,000 to 8,000 feet?”

DR. VANN: I know of no evidence. I think it’s certainly reasonable, but there’s no evidence.

MR. COCHRAN: The barometric pressure can change in a given location 1,200 feet.

DR. THALMANN: The experimental evidence is not there.

DR. SHEFFIELD: You’re not going to put that in the recommendation?

DR. THALMANN: No, but we’re debating how to phrase it. It’s not going to be based on hard experimental evidence.

DR. RICHARDSON: The problem is a real one. The Maldives has air shuttles going all over the place. So do the Caymans. Blue Hole, Belize – people do low altitude flights rather than two-day boat rides in and out. It happens every day. Must they wait for 12 hours? They’ve been flying without waiting for 12 hours. Is Buehlmann’s work with altitude exposures at 700 meters of any use here?

DR. SHEFFIELD: The Buehlmann data<sup>#</sup> has been the basis for the 2,300-foot exclusion limit in the Navy tables since the seventies. Some in the hyperbaric medicine community have used 2,000 feet for flying after diving tables. What is the point at which the Cross Corrections are applied in the Navy tables, Ed?

DR. FLYNN: We start them at 1,000 feet, but only for dives greater than 150 feet.

DR. SHEFFIELD: So it doesn’t apply to this group then, because they’re not going to be diving deeper than 150 feet.

DR. VANN: Could I suggest a minimum altitude at which flying after guidelines should begin to be observed, with the caveat that there’s no data? We’re covering it as a separate issue to clarify it’s based on the past usage.

DR. THALMANN: Is there utility in using the current Navy flying after diving recommendations for unpressurized aircraft flying at low altitudes? Everybody appears to agree that you probably don’t need to worry below a thousand feet. The question is, what happens above a thousand feet? Maybe the best recommendations at present for flying in unpressurized aircraft are in the Navy Diving Manual.

DR. VANN: I think that’s reasonable. Citing the U.S. Navy guidelines is a good idea to cover other situations. It will take the recreational community off the hook, and it allows people who want to be more sophisticated in their calculations to fly at lower altitudes.

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<sup>#</sup> Boni M, Schibli R, Nussberger P, Buehlmann AA. Diving at diminished atmospheric pressure: Air decompression tables for different altitudes. Undersea Biomed Res 1976; 3(3):189-204.



DR. BENNETT: Good.

DR. FLYNN: The only problem I see is this is based on Navy Repetitive Groups. Where would these individuals get that information if they're diving other kinds of tables?

DR. VANN: They're going to have to estimate the maximum depth and bottom time.

DR. GERTH: They'll have to have a set of Navy tables to do it. They'll have to transcribe their dive history into a square dive, go to the tables, get the surfacing Repet Group, and work from there.

DR. WIENKE: Paul, you asked about the Cross Correction. You increase your depth by roughly 3 percent for every thousand feet of altitude. So if you're diving at 8,000 feet, you multiply your depth by 1.24 to go into the Navy tables for altitude diving.

DR. SHEFFIELD: What I was driving at was that if we come up with that minimum altitude of a 1,000 feet, 2,000 feet, or 3,000 feet based on the Cross Corrections, what level should it be? Right now, Ed, the Navy correction starts at 1,000 feet, and the Buehlmann correction starts at 2,300 feet.

DR. FLYNN: Right. We correct at 1,000 feet. In the Navy flying after diving procedure, you can fly immediately to 1,000 feet if your repetitive group is Group I or lower, to 2,000 feet if your repetitive group is Group H or lower, and to 3,000 feet if your repetitive group is Group G or lower. These limits are not based on Cross Corrections.

DR. SHEFFIELD: We have a couple of approaches. One is to refer to the Navy tables. Another is that to agree on a minimum altitude – 1,000 feet, 1,500 feet, 2,300 feet – and put this into the recommendation so that Peter won't have to field these questions individually. Looking at the numbers, 1,000 feet would be a non-problem, because you don't do any correction up to 1,000 feet, but 2,300 feet has been used for many years. Maybe it's some value between 1,000 and 2,300 feet. What do you think?

DR. POLLOCK: One thousand feet may not be realistic, because many terrestrial altitudes are 1,000 feet above ground level. It should start at 1,500 or 2,000 feet if you want to be practical.

DR. SHEFFIELD: Probably the best number to start with is 2,300 feet, since it has been used since the 1970s. Does that make sense?

DR. WIENKE: Yes.

DR. BENNETT: Yes.

DR. SHEFFIELD: It's an operational issue with the precedent of being in the U.S. Navy Diving Manual for all these years.

DR. THALMANN: Ed can chime in, but I don't believe the Navy would have a problem with that recommendation, but how much experience is there with dives at 2,300 feet?

DR. FLYNN: The question is one of ascending to 2,300 feet following a dive. It's clearly more risky than just staying on the surface. It's only a matter of how much more risky? We don't know because we've never studied it, and we don't know how many times Navy people have actually done it. Almost all Navy dives stay at sea level.

DR. THALMANN: True, and Buehlmann's tables are not the same as Navy tables and apply to people living at 2,300 feet. That's a big difference.

DR. SHEFFIELD: Much different. Other guidance that's fairly common is for a clinical hyperbaric facility at above 2,000 feet. You have to use special diving and altitude tables.

DR. THALMANN: Is there experience to show that it works?

DR. SHEFFIELD: We've had no bends cases reported, so how would we know? There are not very many facilities at elevations of 1,000 to 2,000 feet: Colorado Springs, Denver, and some locations in California are considerably higher.

DR. THALMANN: Is that good enough that you are willing to say experience at an altitude up to 2,000 feet requires no particular precaution?

DR. SHEFFIELD: If we're consulting with some special group, I would say 2,000 foot would be acceptable based on the fact that the Navy allows 2,300 feet.

DR. THALMANN: You're consulting with a special group. You're the chairman of that group. As the chairman, if you feel comfortable and nobody objects, we can make that recommendation, but we want to be clear from where it comes. At least we could say, "Based on this experience..." which we cite. If everybody's comfortable with that, it is not unreasonable.

DR. VANN: Let's stay as simple as possible for recreational divers and refer to the Navy Diving Manual for more complicated situations. Otherwise, we'll say things we have no basis to say. That's not a problem for the Navy as they are masters of their own ship.

DR. SHEFFIELD: You don't want to put a minimum altitude here?

DR. VANN: I would refer to the U.S. Navy Diving Manual for other situations.

DR. GERTH: If you're going to do that, you don't need to say both commercial and 8,000 feet because commercial flight covers the cabin altitude range.

MR. YOUNG: Not necessarily. There are a lot of unpressurized commercial shuttles, as Drew said, that go between islands.

DR. GERTH: We're back to the issue of how do the passengers know their cabin altitude?

DR. SHEFFIELD: I've flown to Little Cayman a number of times unpressurized. I have no idea what altitude we were flying.

DR. MULLER: The airline may call you if you put this number out and want to know why they can't fly above 2,300 or below 2,300.

DR. VANN: That's right. Citing the Navy is the cleanest way to do it. The Navy gives you a procedure. You have to work a little harder, but you can get it.

DR. SHEFFIELD: Will you agree with, "For other flight circumstances, consult the U.S. Navy Diving Manual?" Would that be an appropriate from this group as a DAN recommendation?

DR. BENNETT: This is not a DAN recommendation. DAN has held this workshop to have an industry-DAN consortium. DAN must work as a part of the group to reach a consensus recommendation.

MR. ORR: Why do we say commercial flight? There's also a lot of general aviation out there.

DR. GARNER: It obviously applies to generally aviation. You have tied into the FAA reference of 8,000 feet, but the experience is totally different above 8,000 feet. Below 8,000 feet, as uncomfortable as it may be to specify an altitude, if it's really important that they get guidance, give them some.

DR. SHEFFIELD: Cabin altitudes of 2,000 to 8,000 feet, which means that a flight below 2,000 feet would be acceptable without delay. Above that altitude, we'd say, "Go to the Navy Diving Manual to figure out what to do."

MR. BRYLSKE: This will be a worldwide guideline. Will there be implications referencing the U.S. Navy Dive Manual?

DR. SHEFFIELD: It's possible many divers wouldn't have access to that.

DR. SOUTHERLAND: If you're going to quote the Navy Diving Manual, you need to quote the correct revision, as many people have older revisions without the new FAD procedures, and you can expect that will change again. Moreover, the new procedures are not man-tested, either. Everybody needs to understand that up front. The Navy is willing to use them, but we're willing to do lots of things.

DR. GERTH: The Navy has different acceptable risks for its operations, and the manual provides guidance in accord with those risks.

DR. SHEFFIELD: "Altitudes between 2,000- and 8,000-feet cabin pressure." Do you any of you object to this? I know the objection is to setting a minimum number where you don't have specific data, but 2,300 feet has been accepted for a number of years.

DR. GERTH: Why don't you say, "flight to cabin altitudes between 2,000 and 8,000 feet?"

DR. THALMANN: Could we say the U.S. Navy Diving Manual has procedures that are more flexible? We're not recommending them; we're just saying they exist.

DR. SOUTHERLAND: How about just taking it out? You've already got a minimum, and you're only concerned about between 2,000 and 8,000 feet. So I mean, if they can't wait 12 hours, then --

DR. SHEFFIELD: The question is what should be the minimum altitude, 2,000 or 2,300 feet? 2,300 has been used for many years.

DR. VANN: Can we cite that?

DR. SHEFFIELD: The Navy guidance.

DR. VANN: It's not in there now.

DR. SOUTHERLAND: There wasn't a problem when it was changed, it was just changed to try and make things meld in more.

DR. FLYNN: As I said before, it's just a matter of how much risk you want to take. Where you draw the line is arbitrary. The problem with the proposed recommendation is that you don't tell them specifically that you don't have to wait at all below 2,000 feet. This one says that you have to wait 12 hours between 2,000 and 8,000, but it doesn't say if you're less than 2,000 how long you have to wait. You need say if you're less than 2,000, you don't have to wait at all, no matter what kind of diving you're doing.

DR. SHEFFIELD: OK, but are you comfortable with a minimum altitude, because there's not data in the current database to support it?

DR. POLLOCK: Since we don't have the data, could we say a functional altitude for the inter-island flights of, say 1,500 feet? You need more than 1,000 feet, but if you want to be conservative, 1,500 feet would probably get the job done.

DR. SHEFFIELD: Will 1,500 feet work with the island travel?

DR. VANN: I would still suggest referring to the Navy manual for situations other than the simple ones we've already discussed.

DR. SHEFFIELD: So what are you telling me? Don't put in a minimum altitude?

DR. VANN: Given that we don't have any hard numbers to base it on, we're getting away from where we started. The Navy Diving Manual is a widely recognized standard and gives you flexibility.

DR. THALMANN: Part of the new FAD research study I presented will be to look for the minimum altitude. Right now, it's a best guess. My best guess was 2,300 feet, which I put in the Navy Diving Manual based on Buehlmann's tables. When we did that, Buehlmann was the only game in town. We had guys asking, "Hey, what's the minimum altitude we need to worry about?" We had to have something, but we didn't want anything complicated, since there was so little to base it on. What's happened now is 2,300 feet is out because of Ed's new procedures. Otherwise, there would be two different standards, one 2,300 and the other 1,000. Is there enough expertise in this group to make a recommendation for a minimum altitude, which is practical? You can't put an altitude in at which the planes won't fly.

DR. SHEFFIELD: Maybe we should go back to the recreational diving certifying agencies. Do you need a minimum altitude in there, Drew? Bruce, do you need a minimum altitude?

DR. WIENKE: No, we don't.

DR. VANN: Would the recreational community be satisfied with a reference to the Navy manual for other situations?

DR. WIENKE: That's fine.

DR. VANN: Do you want to poll them?

DR. RICHARDSON: I'm torn because right now we don't have one, so we don't need one, but it's making a contribution if we can substantiate that contribution. The anecdotes that have been presented describe what's really happening between islands. They're sorting it out themselves, I guess, is another way to look at it, but it would be a contribution if we were comfortable saying, "Don't worry about waiting to fly at less than this threshold." You know, I'm torn.

MR. YOUNG: You'd be surprised how many people fly privately, to the Bahamas, to the Cayman Islands. There's the big Cayman caravan every year where a couple hundred planes fly down with their scuba gear. They're all confused.

DR. SHEFFIELD: Do you know the flight altitude?

MR. YOUNG: In the case of the Cayman caravan, they're up over Cuba, so they're at about 5,000-8,000 feet. When you go to the Bahamas, and I've been to the Bahamas many times in my airplane, I've come back at 800 feet because of being scared to go

higher. I just didn't know. If I followed this 8,000-foot recommendation, I'd stay on the ground.

DR. GARNER: For unpressurized general aviation, they could choose to fly continuously at 12,500 feet or up to 14,000 feet for as much as 30 minutes.

DR. SHEFFIELD: How many of you would like a minimum altitude? Give me a show of hands. OK, it's 11. How many of you do not think we should specify a minimum altitude? Only one person.

DR. VANN: Do we need to justify what altitude we put in there?

DR. SHEFFIELD: How many of you are comfortable with 1,000 foot as it now in the Navy Diving Manual? With a 1,000-foot limit, the aircraft can't fly, it's not very useful. How many of you would accept 1,500 feet? Ten. How many of you would accept 2,000 feet? Fifteen. How many of you would accept 2,300 feet? Five. Unless I am really off base, the number's 2,000 feet. Are you comfortable with that?

MR. ORR: Does that mean that somebody can come directly out of the water after a 60-foot dive for 55 minutes and go directly to 2,000 feet?

DR. SHEFFIELD: That's what it would mean.

MR. ORR: We're comfortable with that?

DR. VANN: Are we comfortable that we don't know if it's true?

DR. SHEFFIELD: Any of you object to this statement?

DR. THALMANN: I told the Navy that 2,300 feet was OK based on the Buehlmann data. We've got to go on what's available. We can't keep getting down to, "There's no data." You've made a case for 2,000 feet, which sounds reasonable. Why don't we just come out and say in the proceedings, 2,000 feet, and this is how we got it?

DR. SHEFFIELD: If we use 2,300 feet, it's been an operational guideline for many years. If we use 2,000 feet, that's a generally accepted practice in clinical hyperbaric medicine facilities that have to use special diving and altitude tables above 2,000 feet, but it's not published or easily defensible.

DR. THALMANN: That's right.

DR. SHEFFIELD: And 2,300 feet has been published.

DR. THALMANN: Well, published for one set of circumstances and rationalized to another. But if you want to argue between 2,000 and 2,300, let's go out back and have a cockroach race because there's no difference.

MR. YOUNG: If the Navy's been using 2,300 feet, 2,000 is arbitrary. Put a footnote at the bottom, "based on U.S. Navy protocols."

DR. SHEFFIELD: "Based on U.S. Navy operational experience."

DR. FLYNN: I have to say that we couldn't quantify that in any way, shape or form. All we can say is that when the 2,300-foot guideline was in the manual, nothing obviously bad happened. But we couldn't say that's acceptable. It's not in there now.

DR. SHEFFIELD: A lawyer would see the 2,300-foot guideline, and as a consultant, I would dig the old Navy Diving Manuals that listed 2,300 feet. The lawyer would bring out the new Diving Manual where 1,000 feet is the guideline and say, "There was a reason the Navy took it out." What's my defense?

DR. THALMANN: It came from a study published by Dr. Buehlmann<sup>#</sup>. Is it a reasonable limit? When you ask the Navy expert if there is evidence of problems, the answer is no, but it depends on the question is asked. The Navy can't say, "I can show you a ton of statistics that it works." The Navy can only say that a problem has never been reported. The Navy took 2,300 feet out of the Diving Manual to be consistent with a new FAD procedure that was more conservative. To be globally consistent, minimize paperwork, and avoid 10 volumes of exceptions, we simply removed it. I don't see any problem with that argument. I think it would hold up legally just fine.

DR. POLLOCK: There's no purpose in going to that 2,300 feet. The last 300 feet won't buy us anything, and we're a little bit more conservative at 2,000 feet.

DR. FLYNN: I support that. We have been talking about altitudes in feet. When we say 2,300 feet, that sounds very specific, whereas 2,000 feet sounds more general. The only reason we used 2,300 feet was because it is a round number, 700, in meters. If we were flying with a meter-denominated altimeter, we'd want to use meters, but 2,000 feet is a nice, even increment.

DR. SHEFFIELD: We could discuss the issue for days. To move forward, how many of you agree with the recommendation? Seventeen. How many of you want to change this recommendation? No one wants to change it?

DR. VANN: Does it apply just to single dives?

DR. SHEFFIELD: This is for single dives and cabin altitudes of 2,000 to 8,000 feet. Do we want to use the same guidance for multiple dives?

DR. FLYNN: Paul, would you like me to read out the depths and times from the current Navy manual that would allow flying at 2,000 feet with no preflight surface interval?

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<sup>#</sup> Boni M, Schibli R, Nussberger P, Buehlmann AA. Diving at diminished atmospheric pressure: Air decompression tables for different altitudes. Undersea Biomed Res 1976; 3(3):189-204.

DR. SHEFFIELD: Thank you, yes.

DR. FLYNN: For an H diver, it would be 20 feet for 325 minutes, 25 for 195, 30 for 146, 35 for 100, 40 for 80, 50 for 60, 60 for 50, 70 for 40, 80 for 35, 90 for 30, and 100 for 25. Would that cover the waterfront?

DR. SHEFFIELD: Will that work for all of you? OK. Great. Thank you, Ed. Makes me feel more comfortable.

DR. POLLOCK: Paul, before leaving that point, shouldn't it be changed from "single dive" to "single no-D dive?"

DR. SHEFFIELD: Good point, single no-decompression dive. Next, we're looking at repetitive multiple day diving. "Based on recent studies, a minimum of 18 hours before flight is recommended."

DR. THALMANN: Are we getting redundant? Can you just say the recommendations apply to altitudes between 2,000-8,000 feet? You'll save a lot of words.

DR. SHEFFIELD: Good point. And we've already decided not to mention tech diving.

DR. RICHARDSON: Should we make a statement about divers who fly with symptoms?

DR. THALMANN: No.

DR. RICHARDSON: Is it worth saying they shouldn't fly? It seems like common sense, but ...

DR. THALMANN: Yeah, they shouldn't.

DR. RICHARDSON: Don't do it. Exactly. It's occurring for a lot of reasons. Is it worth saying, "Please, don't?" It complicates the treatment and increases residuals.

DR. SHEFFIELD: From some of the patients we've treated in San Antonio, you wonder how they got their dive certification because their level of knowledge was so bad. It probably is worth a comment about seeing a doctor or calling DAN if they have symptoms rather than flying.

DR. VANN: We'll make sure to address the issue of the problem of flying with symptoms in the proceedings. Hopefully, that might encourage more training about symptom recognition.

DR. SHEFFIELD: Should we make a statement about aircrew members?



DR. THALMANN: Our FAA rep says there is no global FAA recommendation. It's up to each airline.

DR. GARNER: There's a difference in the FAA between regulations and recommendations. Yes, FAA would like to have a recommendation.

DR. THALMANN: For flying after diving? What is it right now?

DR. GARNER: Twenty-four hours.

DR. SHEFFIELD: At one time it was 12 hours, but it may be 24 hours.

DR. THALMANN: Can the airlines have something less than 24 hours if they choose?

DR. GARNER: I don't specifically recall the FAA regulation. All the airlines that I know of have a 24-hour minimum requirement. There may be some that don't have a requirement. I'd be happy to get back with you on that, but I don't specifically know of any that don't have a regulation.

DR. THALMANN: But they have to follow the recommendations of their airline?

DR. GARNER: Yes.

DR. THALMANN: Does this workshop need to address the aircrew members because they already have a rule? It's whomever they're flying for. How do we get the results of this workshop out to the airlines so they can look at their rule and decide what they want to do? But the bottom line is they are responsible for setting rules for their pilots. We have no business telling them what to do. Let's just get the workshop into their hands.

DR. SHEFFIELD: It might be done by giving the workshop proceedings to Dr. Garner at CAMI if he can put it into their system.

DR. GARNER: Yes, we can disseminate information through education programs, advisories, and other means, but there's a difference between disseminating information and dictating compliance.

DR. VANN: Why don't you see if everybody agrees to the proposed guidelines?

DR. SHEFFIELD: Let's go around the table and make sure we've not omitted an important topic.

DR. VANN: No.

MR. COCHRAN: No.

MR. CAPPS: No.

DR. FLYNN: Do the training agencies have guidelines for recreational diving at altitude or travel through mountain passes as this is definitely like flying after diving?

DR. WIENKE: I'll speak for NAUI. Diving at altitude is a separate course, but students are told they can ascend to 2,000 feet without worrying about altitude.

DR. RICHARDSON: PADI has a specialty course as well, but some entry-level divers are trained at altitude if that's their environment. We use the Cross Conversions. Driving to altitude is a different. What do you do when driving to and from Caracas and the sea or in Hawaii or in many other places? We tell them to treat it as an altitude dive.

DR. FLYNN: Altitude diving and driving over a pass are different. Would it be correct to say that any altitude excursion up to 2,000 feet above your current diving depth would be OK? For anything greater, would you have to wait 12 hours or 18 hours as the case may be? Can we export the guidelines to altitude on the basis of a change in altitude?

DR. WIENKE: That's exactly what NAUI does.

DR. SHEFFIELD: Do you want the recommendation to include flights between 2,000-8,000 feet or excursions to altitude? Do you put such a statement in the recommendation or handle it elsewhere?

DR. WIENKE: It's handled elsewhere, but maybe we don't want to get into it here, as there are many ways of handling the problem.

MR. SMITH: I agree. Divers have gone through an 8,000-foot pass at the Blue Hole in Colorado for years. Without data indicating it's a problem, I recommend we leave it alone.

DR. WIENKE: Yes. I live at 5,000 feet and often dive at 6,000 or 7,000 feet. In classes there, instructors from all agencies use the Cross Corrections. That's explained in a high-altitude diving class where you dive at altitude and go over mountain passes.

MR. CAPPS: Why not just say this: "These recommendations apply for all altitudes between 2,000 and 8,000 feet."? That will cover pressurized and unpressurized aircraft and altitude diving.

DR. THALMANN: The proposed recommendation covers dives and excursions to 2,000 feet or less. If you're going over a pass, you may be at altitude for only an hour. Our experiments simulated four-hour commercial flights, but flights can be much longer. Flight duration is important. If divers feel they've been going over a pass to a lake for years without trouble, they're going to ignore a 12-hour guideline. We'd best leave it as is.

DR. SHEFFIELD: Any other comments? No? Anything further? No? Drew, are you happy?

DR. RICHARDSON: Absolutely. My compliments.

DR. REED: Let's make it clear that the recommendations are for people flying as passengers, not aircrew, specifically commercial airline pilots.

DR. GARNER: His point is very real. If I'm flying for a major carrier whose rule is 48 hours before flying, I have to wait 48 hours regardless any other recommendation.

DR. SHEFFIELD: Any other thing?

DR. SOUTHERLAND: According to the DAN data, about 18 percent of the flying after diving DCS cases flew after waiting for less than 12 hours. Those people didn't follow the existing guidelines. If divers don't observe the new guidelines, we can expect the same outcomes. This is an education issue.

DR. RICHARDSON: I agree it's an education problem, but people also make choices even when they've been well informed. A doctoral thesis at Berkeley was titled something like, "Are Divers Choosing To Die?" The author demonstrated that divers who die ignore the safe diving practices they had been taught. We'll certainly put the word out. All of the educational community, including DAN, will get the word out. It'll be in the computers, it'll be at the resorts, but people still might choose to ignore the guidelines, just as they choose dehydration and excessive alcohol use.

DR. WATENPAUGH: For future consideration, how about oxygen breathing to mitigate DCS risk?

DR. SHEFFIELD: Good point. Anything else? Meet your needs?

MR. YOUNG: Yes, sir.

DR. BENNETT: Yes, it does.

DR. RICHARDSON: Having been through acrimony of '89 and the '91 meeting in San Diego, I'd like applaud the way this community came together to review what we've learned since then and to build some sensible recommendations that, hopefully, will influence diver health and safety. I think we've come up with a good result in a harmonious manner. Thank you.

DR. SHEFFIELD: Let me summarize the consensus FAD recommendations for Recreational Diving that will be sent out for coordination:

1. For a single no-decompression dive, a minimum preflight surface interval of 12 hours is suggested.

2. For multiple dives per day or multiple days of diving, a minimum preflight surface interval of 18 hours is suggested.

3. For dives requiring decompression stops, there is little evidence on which to base a recommendation, but a preflight surface interval substantially longer than 18 hours appears prudent.

4. These recommendations apply to air dives followed by flights at cabin altitudes of 2,000 to 8,000 feet (610 to 2,438 meters).

5. These recommendations are for recreational divers who do not have symptoms of decompression sickness (DCS).

Thank all of you for your participation in this important workshop.

## **APPENDIX A. Workshop Attendees**

### Recreational Diving Industry

Alex Brylske  
Senior Editor, Diving Training Magazine  
Cape Coral, FL

Andrew P. Capps  
PDIC - IT  
Tatum, SC

Mike Cochran  
CEO, Cochran Consulting  
Richardson, TX

Larry Elsevier  
Sales Manager, Cochran Consulting  
Richardson, TX

Drew Richardson, MBA, Ed.D.  
Sr. VP, PADI Worldwide  
Rancho Santa Margarita, CA

Paul Sheffield, Ph.D.  
International ATMO  
San Antonio, TX

G. Brad Smith  
Man Training & Quality Mgmt, PADI  
Rancho Santa Margarita, CA

Bruce Wienke, Ph.D.  
NAUI  
LANL, MS-D413  
Los Alamos, NM

Mark Young  
Publisher, Dive Training Magazine  
Parkville, MO

### U.S. Government

Edward T. Flynn, M.D.  
Naval Sea Systems Command (SEA OOCM)  
Washington Navy Yard, DC

Robert P. Garner, Ph.D.  
AAM-630, FAA-CAMI  
Oklahoma City, OK

Wayne A. Gerth, Ph.D.  
Navy Experimental Diving Unit  
Panama City, FL

Matthew S. Muller, ENS, MC, USNR  
Navy Experimental Diving Unit  
Panama City, FL

Warner D. Farr, M.D., Ph.D., CHT  
Command Surg, US Army Spec Ops Command  
Fort Bragg, NC

David Southerland, M.D.  
Navy Experimental Diving Unit  
Panama City, FL

Don Watenpugh, Ph.D.  
Navy Submarine Medical Res Lab  
Groton, CT

Divers Alert Network and Duke University

Peter Bennett, Ph.D., D.Sc.  
Petar Denoble, Ph.D., M.D.  
Eric Douglas  
Renée Duncan  
Celia Evesque  
Jake Freiburger, M.D., MPH  
Dan Leigh  
Dan Nord, EMT-P, CHT  
Dan Orr, M.S.  
Neal Pollock, Ph.D.  
Ward Reed, M.D.  
Eric Schnazi  
Ed Thalmann, M.D.  
Donna Ugucioni, M.S.  
Richard Vann, Ph.D.  
Brett Boyle, M.D.  
Bob Long, M.D.

Carl Pieper, DPH  
Department of Biometry and Bio-Informatics  
Duke University Medical Center  
Durham, NC

## APPENDIX B. Workshop Agenda

Divers Alert Network  
**Flying After Diving Workshop**  
Thursday, May 2, 2002

<u>Time</u>	<u>Speaker</u>	<u>Topic</u>
8:30 AM	Vann	Introduction
8:35 AM	Sheffield	Flying After Diving History
8:50 AM	Sheffield	Discussion
9:00 AM	Flynn	1999 U. S. Navy Flying After Diving Guidelines
9:15 AM	Sheffield	Discussion
9:25 AM	Vann	Diving at the No-Stop Limits: Chamber Trials of Flying After
9:40 AM	Sheffield	Discussion
9:50 AM		Coffee
10:05 AM	Freiberger	Flying After Multiday Repetitive Recreational Diving
10:25 AM	Sheffield	Discussion
10:40 AM	Thalmann	Development of Guidelines for Flying After Diving
10:50 AM	Sheffield	Discussion
11:00 AM	Pollock	Trials of Flying at 25,000 Feet After Diving
11:10 AM	Sheffield	Discussion
11:20 AM	Pollock	NASA Flying After Diving Procedures
11:30 AM	Sheffield	Discussion
11:40 AM	Vann	Flying After Diving Within the No-Decompression Limits
11:50 AM	Sheffield	Discussion
12:00 PM		Lunch
1:20 PM	Sheffield	Nature of Safety Decisions
1:35 PM	All	Consensus Discussion
3:15 PM		Coffee
3:30 PM	All	Consensus Discussion
5:00 PM	Sheffield	Consensus Summary
5:15 PM	Vann	Adjourn