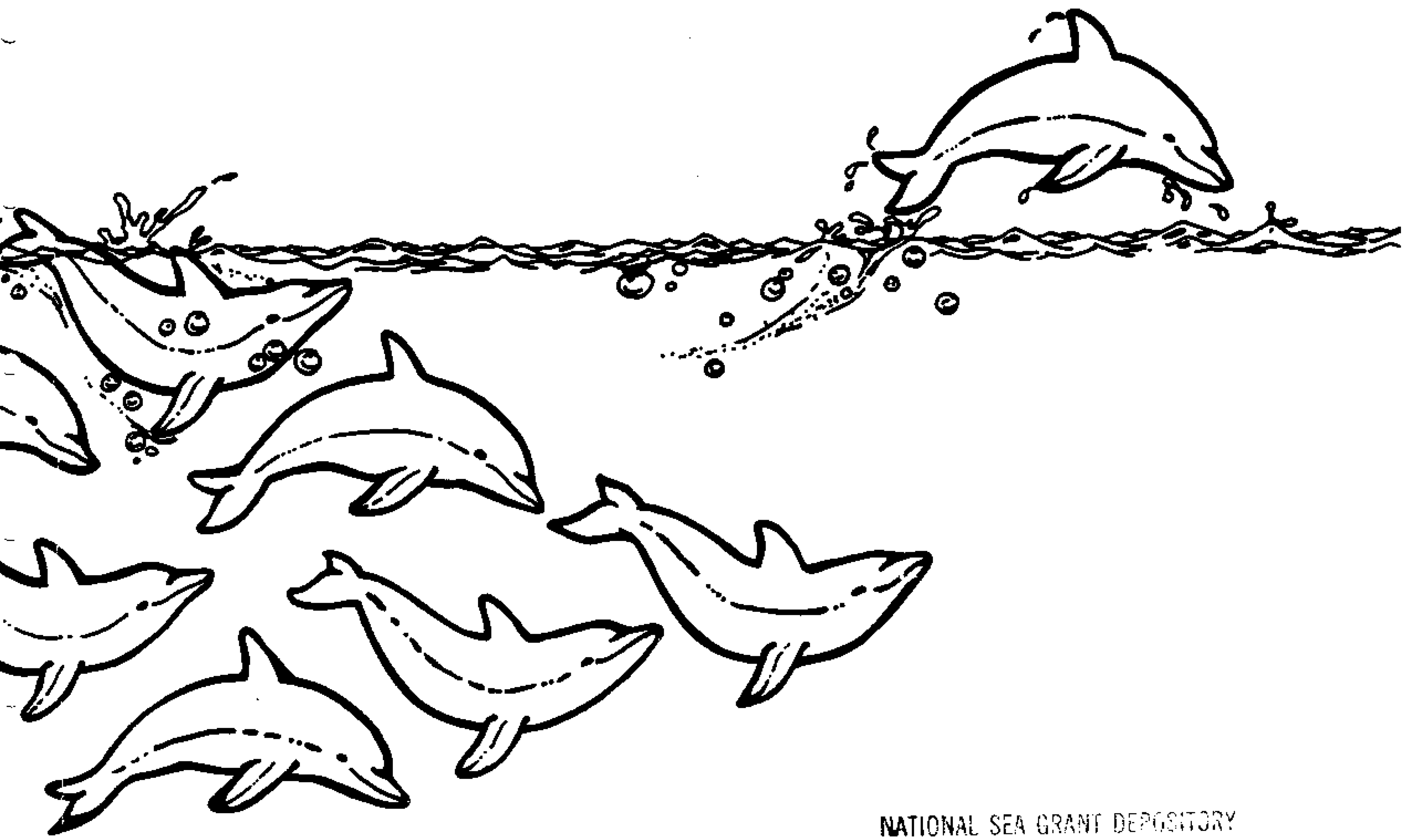
HAWAU-T-86-001 C3

LOAN COPY ONLY

Sea Grant Technical Paper

DIVING AND DECOMPRESSION SICKNESS TREATMENT PRACTICES AMONG HAWAII'S DIVING FISHERMEN



NATIONAL SEA GRANT DEPOSITORY
PELL LIBRARY BUILDING
URI, NARRAGANSETT BAY CAMPUS
NARRAGANSETT, RI 02882

HAWAU-T-86-001 C3 $1.00

DIVING AND DECOMPRESSION SICKNESS TREATMENT PRACTICES AMONG HAWAII'S DIVING FISHERMEN

by

CIRCULATING COPY
Sea Grant Depository

Frank P. Farm, Jr.
Edwin M. Hayashi
Edward L. Beckman

Sea Grant Technical Paper
UNIHI-SEAGRANT-TP-86-01

February 1986

UH Sea Grant College Program
Honolulu, Hawaii

This technical paper is the result of research ("Investigation of Methods to Improve the Treatment of Decompression Sickness Based Upon the Physics of Dissolution of Gas Bubbles in Gelatin" project, HP/R-3) sponsored in part by the University of Hawaii Sea Grant College Program under Institutional Grant No. NA81AA-D-00070 from NOAA Office of Sea Grant, Department of Commerce. The U.S. Government is authorized to produce and distribute reprints for governmental purposes notwithstanding any copyright notation that may appear hereon.

<u>About the Authors</u>

Frank P. Farm, Jr. is Director of the Hyperbaric Treatment Center, University of Hawaii John A. Burns School of Medicine, 42 Ahui Street, Honolulu, HI 96813.

Edwin M. Hayashi is Diving Safety Officer, University of Hawaii, and Chief Engineer of the Hyperbaric Treatment Center, University of Hawaii John A. Burns School of Medicine, 42 Ahui Street, Honolulu, HI 96813.

Edward L. Beckman is Medical Director of the Hyperbaric Treatment Center, University of Hawaii John A. Burns School of Medicine, 42 Ahui Street, Honolulu, HI 96813.

The views expressed in this technical paper do not necessarily reflect those of the University of Hawaii or the University of Hawaii Sea Grant College Program. Any errors are the sole responsibility of the authors. Any commercial product or tradename mentioned herein is not to be construed as an endorsement.

ABSTRACT

In 1981-82, a survey was conducted of Hawaii's diving fishermen, 24 of whom were selected for this study. Up to the date of the interviews, these active diving fisherman had collectively made over 250,000 dives, with each averaging over 500 dives per year. On an average day they made from 5 to 8 dives, which ranged in depth from 140 to 350 feet salt water (fsw). Many made a last dive at depths of from 60 fsw to 10 fsw to catch whatever fish they could while decompressing from deeper dives made earlier in the day. All divers interviewed had experienced one or more incidents of decompression sickness (DCS), which they treated by immediate in-water recompression. Some divers reported experiencing DCS symptoms as often as one out of three diving days. Immediate in-water recompression was utilized 527 times for the treatment of early signs of DCS or of overt disease. The divers reported that when in-water recompression was utilized, it relieved or cured the disease in all but 65 incidents. Of this number, follow-up treatment in a recompression chamber was sought 14 times. In the remaining 51 incidents, the divers had improved to the point where they elected to endure the remaining pain until it disappeared -- usually in a day or two. Refinements of the practice of in-water recompression on air have been recommended for use by Hawaii's diving fisherman, i.e., the use of the Australian in-water oxygen treatment or the Hawaiian in-water recompression schedule using a combination of air and oxygen.

TABLE OF CONTENTS

LIST OF FIGURES

INTRODUCTION

A spear was probably the only equipment used by Hawaii's early diving fishermen. Around the early 1900s, divers learned to make and use goggles (K. Masaki, 1979: personal communication). Then in the 1940s they began to use rubber fins. The aqua-lung (U.S. Divers Co., Cousteau-Gagnan process), or scuba, was first commercially available in Hawaii around 1948. Usually only one tank and regulator were purchased due to their high cost and limited supply. The diving regulators were of the twin hose style, with one hose for inhaling and the other for exhaling. Each regulator came with an air tank and nylon harness. Neither instructions for its use nor any literature relating to dive tables was issued with the equipment. Thus, the early users of scuba in Hawaii had to rely on hearsay to gain knowledge pertinent to diving with this equipment inasmuch as it was not until February 1957 that the U.S. Navy opened a school to train scuba divers at Pearl Harbor.

The introduction of the aqua-lung resulted in a dramatic change in the diving methods of Hawaii's fishermen in that they no longer made short breath hold dives and could now breath comfortably while swimming at depth for 15 to 30 minutes. For some of the more experienced skin or free divers, use of scuba included changes to some basic equipment, e.g., from the bamboo or hau wood eyefitting goggles to a full face mask and from bare feet or "tabi-style" shoes to rubberized fins.

Typically for the early Hawaiian scuba diver, the first tank dive was done in about 40 ft of water and with a buddy acting as a safety person on the surface. The safety diver could free dive to the scuba diver to provide assistance if required. The scuba diver, rigged with tank and regulator, first swam to the anchor rope and then slowly pulled himself down the rope. Usually before reaching the bottom, the diver would break away from the rope and "free swim" with the fish and other marine life. To ascend, the scuba diver would return to the anchor rope and slowly pull himself to the surface, being careful not to pass any exhaled bubbles. Most early diving fishermen believed that this was the only requirement for proper decompression.

Hawaii's warm, clear waters provide a natural setting for extensive use of scuba, both recreationally and commercially. The introduction of scuba enabled Hawaii's diving fishermen to increase their daily catch so as to make fishing a profitable occupation. An enterprising group of divers engaging in this profession operate with small trailerable boats that offer a number of advantages, i.e., reduced operating costs, speed, and the capability of carrying a relatively large load of air tanks, nets, fish, ice, fuel, and other gear for a dive crew of two to four people. Besides fishes, some divers harvest black coral, a precious coral found in very deep water that at times is sold by the ounce. The time-depth profiles used by some of Hawaii's diving fishermen have been measured and reported by Kanwisher et al. (1974) and Spencer et al. (1974).

Large amounts of fish were caught with a minimum of equipment but this required making repeat dives throughout the day. The profit incentive made divers take risks relative to bottom times. It took about three repetitive dives for each of several divers to net a school of fish. These dives were often made with little or no interval between dives other than that required to change air tanks. Since these dive profiles were prone to produce decompression sickness (DCS), they were modified by trial and error so as to lessen the frequency of DCS. The profiles were also designed so that the divers could get the greatest possible fishing time out of each workday. They would make a deep dive for fish or black coral and then follow with several shallower decompression dives while doing a netting operation or, if the netting was done in the deeper water, they would follow with shallower fish spearing dives. These typical dive series designed to prevent DCS were, for example, 1 very deep dive (170 to 220 fsw), followed by 1 or 2 shallow dives (to 60 fsw or less); or, 2 or 3 dives (90 to 120 fsw), followed by 2, 3, or 4 shallow dives.

The purposes of our survey were (1) to chronicle the diving habits of Hawaii's diving fishermen and coral collectors from the time of the introduction of the aqua-lung to the present day; (2) to investigate dive profiles which were developed; and (3) to study the methods of treating decompression sickness which were empirically evolved.

METHODS

Fishermen who dove commercially on a full- or part-time basis in Hawaii were surveyed. The survey, started in late 1981 and completed in December 1982, included divers from each of the major islands of the state. More than 40 divers were interviewed. These were the hardcore scuba users who dove for either a primary or a secondary source of income and were exposed to the most severe decompression stress.

Data obtained from the interviews show that the divers represented two different generations: (1) older divers who were self-taught, had been diving for more than 10 years, and had made over 5,000 dives in their lifetime; and (2) younger divers who had not had such extensive experience, had been taught to dive through conventional NAUI or PADI courses, and had made far fewer dives. The younger group, for the most part, were not full-time commercial divers and did not rely on fishing for their primary source of income because the continued depletion of the fish population had made fishing less profitable. On the basis of this dichotomy in diving practice and experience, we chose to limit this analysis to the older group of 24 self-taught divers.

RESULTS

Initial interview/questionnaire

The oldest diver of the group was 61 and the youngest was 31, with the average age at the time of the interview being 42.5 years.

The average number of dives that had been made by each diver at the time of the interview was 11,475. The range was from a low of 5,200 to a high number estimated to be in excess of 23,000 for the most experienced diver who had been diving since the late 1940s. (Prior to this survey, this latter diver had been treated 11 times at the U.S. Navy's recompression facility at Pearl Harbor.)

These divers harvested the ocean's resources for food and profit, using spearing, trapping, and netting methods. The average number of scuba tanks (72 cu ft capacity) used in a day of fishing varied from a high of 8 tanks to a minimum of 2 tanks, with a mean value of 5 tanks. The maximum number of scuba tanks used by a single diver in a day was 12, which equated to 12 dives.

Of the group studied, the "deepest air dive" reported was 350 fsw. However, a group of black coral divers had worked a coral bed at deeper than 300 fsw for a month. The mean value for depth of "deepest air dive" was 228 fsw.

The maximum number of years of scuba experience reported was 32 and the minimum was 10, with an average experience factor at the time of the survey of 23 years.

Follow-up interview of divers with in-water recompression experience

During the initial part of the survey, the successful use of underwater treatment for decompression sickness was frequently mentioned. Attempts were therefore made to recontact the divers interviewed. The questionnaire was modified to include specific questions about in-water recompression with respect to their experiences. These divers reported in excess of 527 incidents of underwater DCS treatment, or an average of 22 per diver. The most remarkable finding was that in-water treatment was successful in 462 incidents (87.7 percent). In another 51 incidents (9.7 percent), divers had improvement but still suffered from some form of residual after effect, usually a mild pain or ache that lasted anywhere from hours to several days. These divers reported that they chose to wait it out -- "bite the bullet" -- and used home remedies such as beer and aspirin or took hot or cold showers. In some cases, tenderness of the affected limb or fatigue still existed, but relief from pain was satisfactory. In-water treatment provided incomplete recovery and was deemed unsatisfactory in only 14 reported incidents (2.7 percent). The divers involved in these incidents sought relief at the Navy recompression chamber at Pearl Harbor.

In-water recompression depths that proved successful ranged from the deepest estimated depth of 85 fsw to the shallowest estimated depth of 25 fsw, with an average treatment depth of 41.3 fsw. In-water recompression times showed a high of 200 minutes and a low of 20 minutes, with an average time of 63.7 minutes.

The signs and symptoms which were relieved varied from the mild or suspected DCS (primarily pain and aches around the shoulders and arms) to the more serious CNS conditions that included paralysis, loss of vision, loss of movement, and loss of sensation. However, it should be noted that this type of DCS treatment does not necessarily protect divers against the chronic form of decompression sickness of the bone, i.e., dysbaric osteonecrosis, a disease which many of Hawaii's diving fishermen have developed (Wade et al., 1978).

<u>Case histories</u>

One of the authors, Frank Farm, has personally treated others several times and, likewise, has been treated himself by in-water recompression on two occasions. His personal treatments were for pain in the shoulder and arms. On one occasion after the onset of symptoms, he was rapidly taken to shallower water and two dives were made spearing fish in 45 to 55 fsw. Most of the pain disappeared immediately upon reaching depth, and relief continued while diving. He was very comfortable after the "treatment" dives.

In another incident, he initiated the in-water recompression of another diver who had made three dives ranging from 120 to 160 fsw with approximately 45-minute rest periods between dives. Shortly after the third dive, the diver developed uncontrollable movements of the muscles of his legs. The boat was already underway so Farm piloted it toward shallower water. Within a few minutes the diver was paralyzed and had no feeling from the nipple line down and could not stand or move his lower extremities. A full tank of air was strapped to the victim who was able to breathe through the mouthpiece of the regulator. He was then lifted over the side of the boat and rolled into the water. Farm was waiting in the water and, after checking the victim's breathing, commenced pulling the disabled diver toward the bottom. No immediate benefit occurred in 35 to 40 fsw so Farm towed the victim toward deeper water. In approximately 50 fsw, the victim started tugging and made noises and gave an "OK" hand signal. He further demonstrated that he had regained movement of his legs and feet.

The victim was instructed by hand signals to remain at the bottom holding onto or swimming around a large boulder. The boat was anchored in close proximity and a safety diver hung from a rope attached to the boat and watched from the surface as the victim recompressed. When the recompressing diver engaged his reserve valve (indicating low air pressure in his tank), the observing diver went to the bottom and exchanged tanks, thereby letting the victim have another full tank. The victim later ascended to 25 fsw and then to 15 fsw, where he stayed until the air supply was almost gone, and then he surfaced. He felt a little tired that evening, but he appeared to be walking normally and had good return of strength in his legs and arms, as well as good sensation throughout his body.

Another incident, which was reported by one of the divers interviewed, may explain why immediate in-water recompression for the treatment of decompression sickness is practiced in Hawaii. This incident was subsequently verified by other divers involved and by the county Coroner's Office. On this day of fishing, four divers were working in pairs at a site in about 165 to 180 fsw. Each pair alternated diving and made two dives each. Upon surfacing from the second dive, both divers of the second pair rapidly developed signs and symptoms of severe CNS decompression sickness. The driver of the boat and the other diver decided to take both victims to the U.S. Navy recompression chamber, so they headed for the dock some 30 minutes away. However, one diver refused to go and elected to undergo in-water recompression. He took two full scuba tanks and told the boat driver to come back and pick him up after they got the other diver to the chamber. He was then rolled over the side of the boat. The boat crew returned after 2 hours to pick him up. He was asymptomatic and apparently cured of the disease. The other diver died of severe decompression sickness in the Med-Evac helicopter on the way to the recompression chamber.

DISCUSSION

Recent research has provided a scientific basis for the empirical practices of Hawaii's diving fishermen not only in diving but also in the treatment of decompression sickness. On the basis of the personal interviews with these diving fishermen, it can be inferred that they have empirically learned a very efficient and relatively safe diving method. The number of dives made by these fishermen exceed the number made by most commercial or military divers manyfold. These divers have, for the most part, learned to dive at great depths by trial and error, and they plan their underwater work to be as efficient as possible because the quantity of their harvest depends upon how efficiently they work. In the beginning they had no guidelines in the way of dive tables so they used their subjective feelings to determine their diving depth limit. They all have had decompression sickness of varying degrees of severity and by experience learned to recognize their subjective DCS end points. When they recognized early signs or symptoms, they usually terminated their diving "work" for the day and took a shallower (less than 60 fsw) dive to decompress and relieve the signs or symptoms. This shallow dive was not just for decompressing, but also for spearing fish or octopus.

In addition to learning their subjective "bends" end point, these divers have empirically developed diving procedures which we now recognize as being compatible with sound scientific principles. The frequently quoted but previously undocumented statement that Hawaii's diving fishermen make deeper and more dives per day than would be permitted by U.S. Navy air diving tables has been established by this survey.

The scientific explanation as to why these fishermen can make such deep dives and so many dives per day with relative safety can be explained on the basis of the micronuclei theory of gas bubble formation expounded by Yount and Strauss (1976) and by Kunkle (1979). According to the gas micronuclei theory, a diver could significantly increase his tolerance against bubble formation (and therefore against incurring decompression sickness) by following three simple diving practices:

1. Make the first dive of the day a deep, short (crush) dive. This "crushes" the micronuclei down to a smaller, safer size.
2. Make succeeding dives of the day progressively more shallow, thus diving within the crush limit of the first dive.
3. Make frequent dives, i.e., at least every other day, which depletes the gas micronuclei pool of the body, thus depleting the number of micronuclei available to form bubbles.

The effectiveness of these practices has been substantiated by in-vivo testing (Beckman et al., 1984). Hawaii's diving fishermen have empirically learned to utilize these physical principles to their own advantage, as the results of this survey demonstrate.

Not only have Hawaii's diving fishermen empirically developed more efficient diving techniques, but they have also empirically learned more efficient techniques for treating DCS if it occurs. They have learned the advantage of immediate treatment for decompression sickness by in-water recompression using scuba.

The U.S. Navy early recognized the advantage of immediate recompression in water for hard-hat divers, but pointed out the difficulties which would have to be overcome -- i.e., cold, prolonged immersion, and difficulties in communication -- if this treatment were to be used by scuba divers (U.S. Navy Department, 1963).

Hawaii's diving fishermen also recognized these problems. They usually took extra scuba tanks in case treatment of a stricken diver would be required. They knew from experience that the waters around Hawaii are warm enough to permit long in-water recompressions, and that communication can be maintained both visually from the surface through the clear water and by the attendant diver swimming down, at regular intervals, to check the victim.

In the early stages, the treatment of decompression sickness is basically the treatment of gas bubbles. Beckman (1980) and Kunkle and Beckman (1983) demonstrated that the rapid dissolution of bubbles in gelatin, as in the body, requires immediate adequate repressurization. As shown in Figure 1, the length of time required to dissolve bubbles with a given overpressure is directly proportional to the size of the bubble. Therefore, the smaller the bubble, the shorter the time needed to dissolve that bubble at any given overpressure.

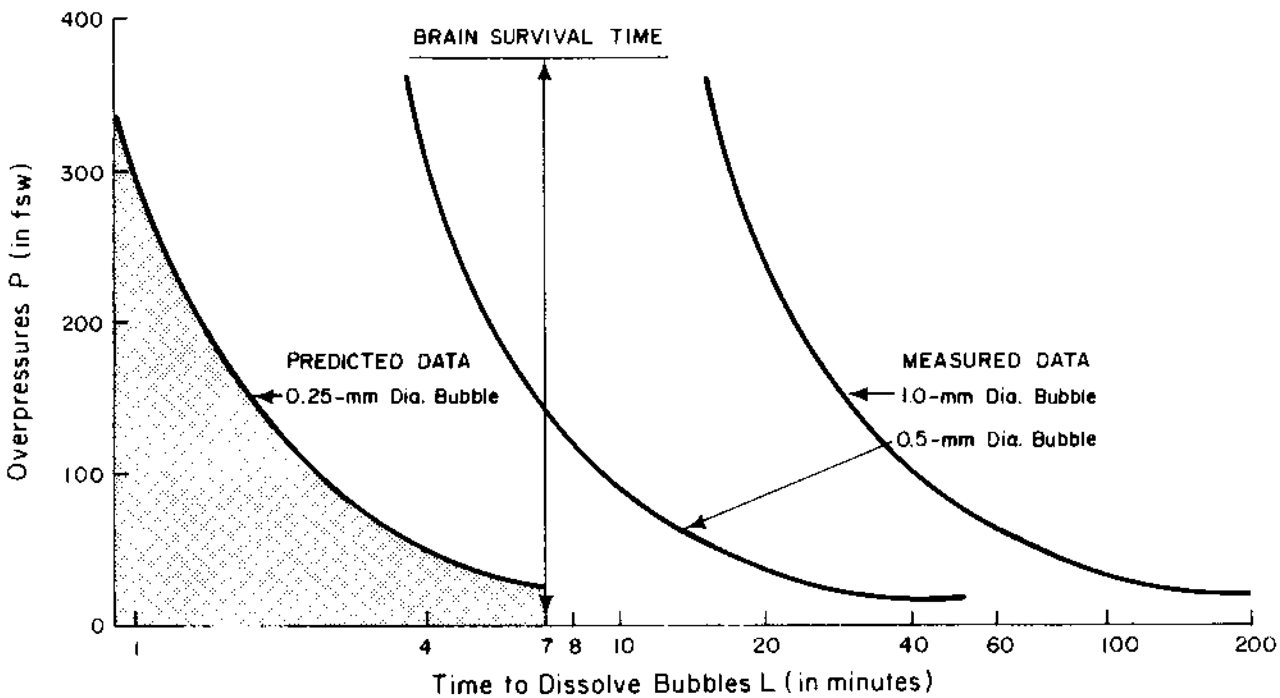


Figure 1. Curves to show time (L) required to dissolve bubles of graded size after application of different overpressures

The bubbles studied by Kunkle and Beckman (1983) in both agarose gel and body fluids grew to approximately 1 mm in diameter in 5 hours (Figure 2). Hills and Butler (1981) measured the size of bubbles which were collected from the right heart of dogs which had been exposed to a simulated air dive. The bubbles increased in size from 30 micrometers 5 minutes after the dive, to greater than 100 micrometers in 30 minutes, and to a maximum diameter of 700 micrometers -- a bubble growth rate comparable with that observed in gelatin. Figure 1 shows that, with any

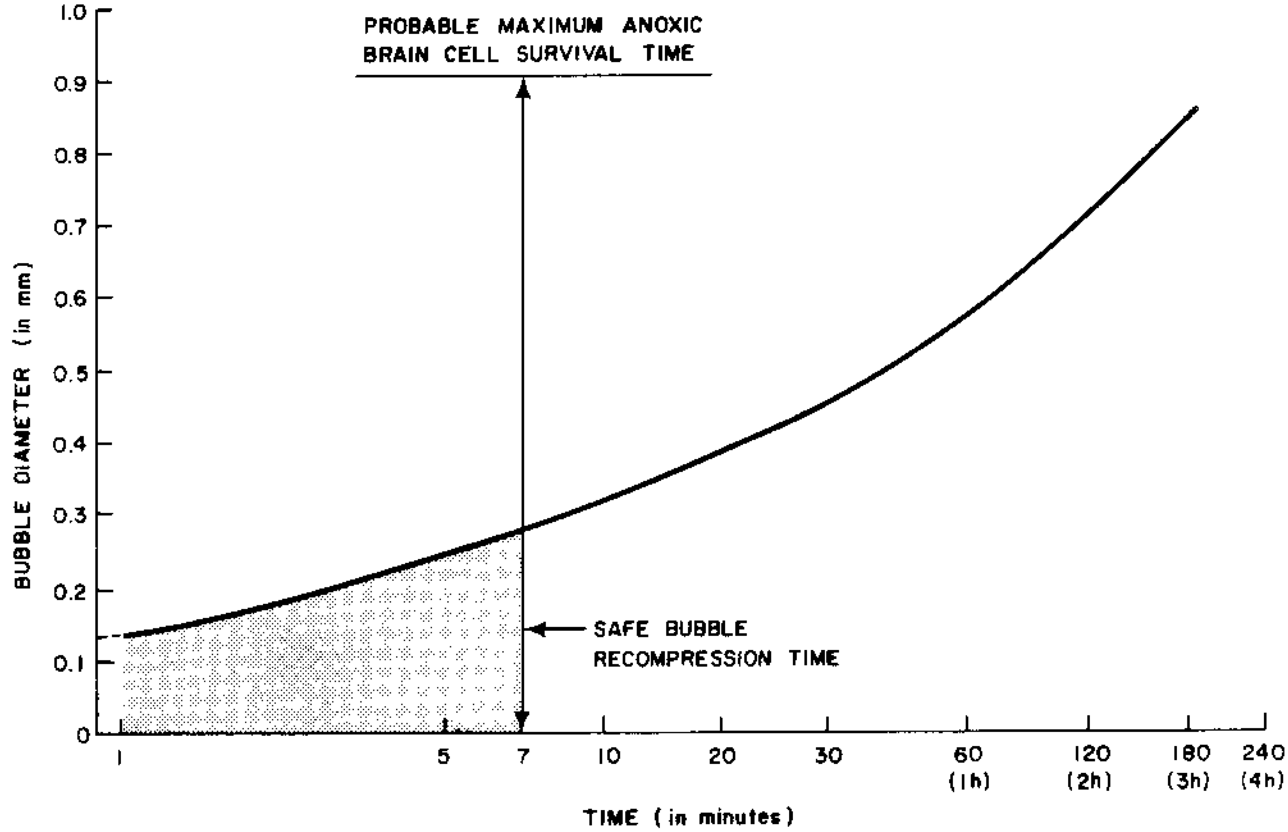


Figure 2. Rate of growth of bubbles in agarose gel formed at 1 ATA ambient pressure following decompression from saturation at 20 fsw

given overpressure, the length of time required to dissolve bubbles of 250 micrometers in diameter would be significantly shorter (i.e., more than 10 times shorter) than that required to dissolve large bubbles (1 mm in diameter) allowed to grow for 5 hours.

Immediate recompression within less than 5 minutes (i.e., when the bubbles are less than 100 micrometers in diameter) is therefore essential if rapid bubble dissolution is to be achieved. Hawaii's diving fishermen have recognized the urgency of immediate recompression if treatment is to be successful and have opted to return to the depths immediately. The data reported above bear out the wisdom of their decision. Only when treatment in water is unsuccessful do they seek help from the recompression treatment facilities on the islands.

More recently Hawaii's diving fishermen have been encouraged to carry a tank of oxygen (of 120 cu ft or more capacity) in their boat for use in treating decompression sickness in water. They have been instructed in the use of the Australian emergency underwater oxygen treatment (Edmonds et al., 1976; Appendix A) and the Hawaiian emergency in-water, air-oxygen recompression treatment (Beckman, 1981; Appendix B). They have been encouraged to carry the necessary equipment (tank of oxygen and regulator with 30-ft tether) with them on their boat and to initiate treatment by either method immediately if any crew member develops signs or symptoms which could be related to decompression sickness. The recompression profiles to be used for these treatments are shown in Figures 3 and 4.

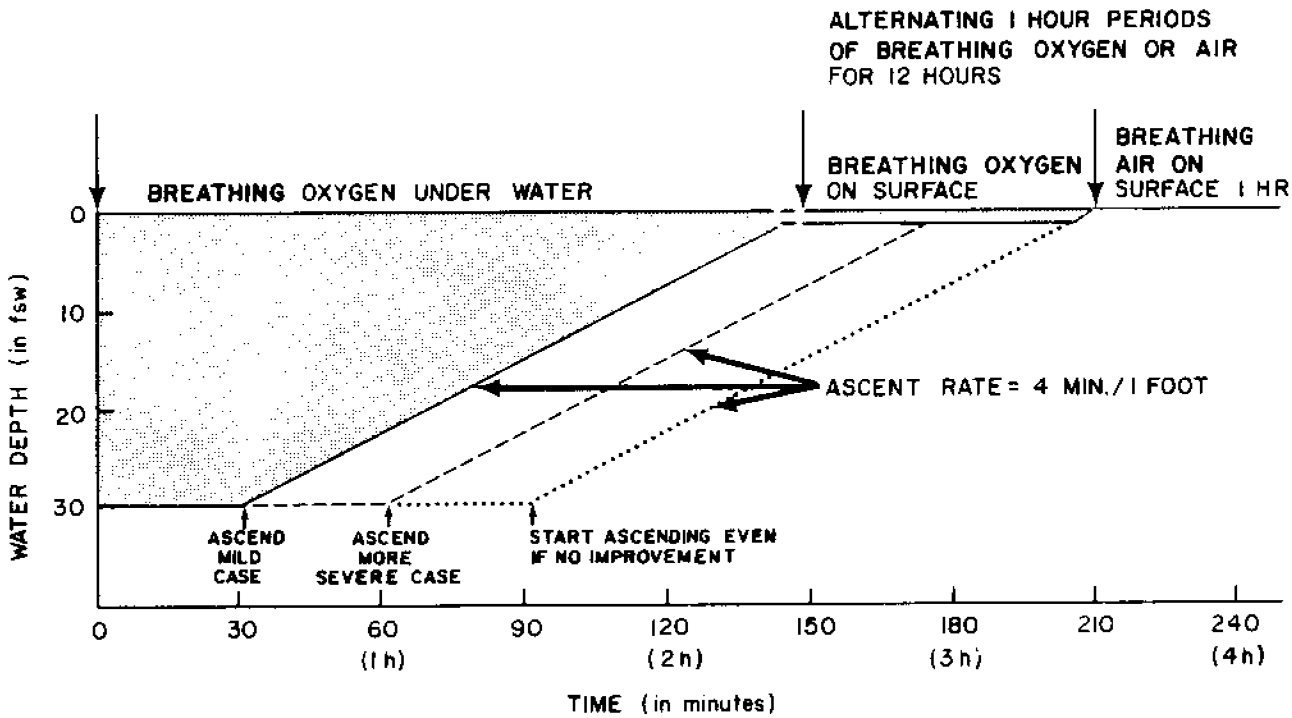


Figure 3. Australian emergency in-water recompression treatment tables using oxygen

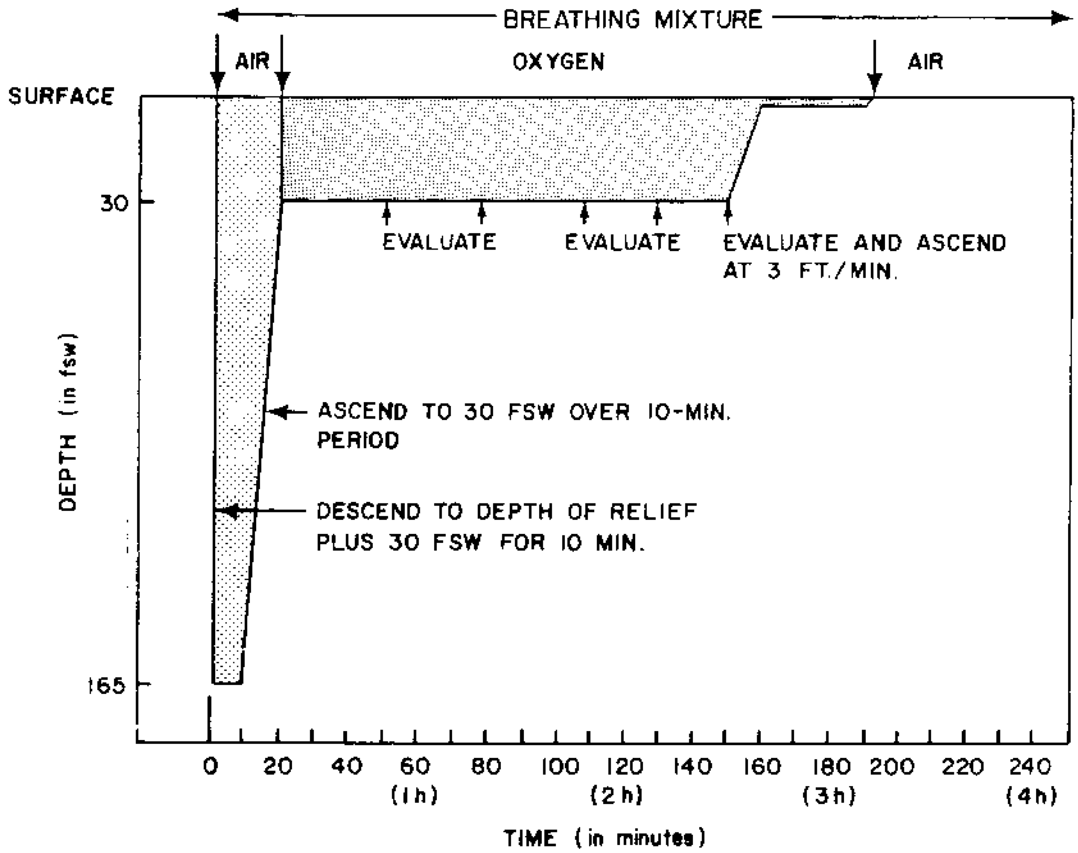


Figure 4. Hawaiian emergency in-water decompression treatment schedule using air and oxygen

CONCLUSIONS

The results of this survey establish that many of Hawaii's diving fishermen:

1. Make more dives during their diving career than most commercial or military divers
2. Make more and deeper dives in a day than would be permitted by the U.S. Navy Standard Air Decompression Tables
3. Have experienced the onset of decompression sickness while diving from a boat
4. Have learned to initiate immediate treatment for their decompression sickness by in-water recompression using scuba
5. Have treated DCS of all types (i.e., bone pain, vertigo, loss of sensation, and/or loss of ability to move limbs) by immediate in-water recompression
6. Have established that the efficacy of immediate in-water recompression using air as a breathing gas is equal to or better than results from later treatment by recompression and oxygen in recompression chambers using standard treatment procedures (87.7 percent had

complete recovery, 9.7 percent had moderate residuals for which further treatment was refused, and 2.7 percent failed to obtain satisfactory relief and sought further treatment)

Several factors should be considered before making a decision to use in-water recompression. Such factors include: (1) on board supply of air and other breathing gases; (2) ability of the patient to accept treatment; (3) personnel available to help; (4) the signs and symptoms, indicating the severity of the disease and the urgency of treatment; (5) time, usually measured as distance from the dive site to land support; (6) ocean conditions; and (7) availability of transportation to get patient to the treatment facility. If an evaluation of these factors indicates the need for and the support to undertake in-water recompression, this survey indicates that the stricken diver would generally benefit from such treatment.

RECOMMENDATIONS

If Hawaii's diving fishermen were to add the use of oxygen breathing to their in-water recompression treatment, the effectiveness of the treatment would be increased even more. It is therefore recommended that Hawaii's diving fishermen, when afflicted with signs or symptoms of decompression sickness while diving, utilize either the Australian emergency in-water recompression table using oxygen, or the Hawaiian emergency in-water decompression sickness treatment schedule using air and oxygen.

REFERENCES CITED

Beckman, E.L. 1980. Treatment of decompression sickness based upon bubble dissolution physics. In Proceedings of the Second Japanese Commercial Diving Symposium, Tokyo, Japan.

Beckman, E.L. 1981. An emergency method for immediate in-water treatment of decompression sickness. Presented at Alii Holo Kai Dive Club, June 30, 1981.

Beckman, E.L., T.D. Kunkle, B. Porter, and A. Morita. 1984. Gas bubble disease in dogs. II. Effect of rapid compression. Undersea Medical Society, Annual Meeting, May 30, 1984, San Antonio, Texas.

Edmonds, C., C.F. Lowry, and J. Pennefather. 1976. Diving and Subaquatic Medicine. 1st ed. New South Wales, Australia: Diving Medical Centre Publication.

Hills, B.A., and B.D. Butler. 1981. Size distribution of air emboli produced by decompression. Undersea Biomedical Research 8:163-170.

Kanwisher, J., K. Lawson, and R. Strauss. 1974. Acoustic telemetry from human divers. Undersea Biomedical Research 1:99-109.

Kunkle, T.D. 1979. Bubble nucleation in supersaturated fluids. UNIHI-SEAGRANT-TR-80-01, University of Hawaii Sea Grant College Program, Honolulu.

Kunkle, T.D., and E.L. Beckman. 1983. Bubble dissolution physics and the treatment of decompression sickness. Medical Physics 10:184-190.

Spencer, M.P., S.K. Hong, and R.H. Strauss. 1974. Venous gas emboli in Hawaiian divers. Undersea Biomedical Research 1-A-18.

U.S. Navy Department, Section 3. 1963. U.S. Navy Diving Manual (NAVSHIPS 250-538). Washington, D.C.: U.S. Government Printing Office.

Wade C.E., E.M. Hayashi, T.M. Cashman, and E.L. Beckman. 1978. Incidence of dysbaric osteonecrosis in Hawaii's diving fishermen. Undersea Biomedical Research 5:2.

Yount, D.E., and R.H. Strauss. 1976. Bubble formation in gelatin: A model for decompression sickness. J. Appl. Physiol. 47:5081-5089.

APPENDICES

(3) ***AUSTRALIAN TABLES***

(a) Emergency recompression treatment in the water, using oxygen

Notes:

1. This technique may be useful in treating cases of decompression sickness in localities remote from recompression facilities. It may also be of use while suitable transport to such a centre is being arranged.
2. In planning, it should be realised that the therapy may take up to 3 hours. The risks of cold, immersion and other environmental factors should be balanced against the beneficial effects. The diver must be accompanied by an attendant.

Equipment:

The following equipment is essential before attempting this form of treatment.

1. Full face mask with demand valve and surface supply system OR helmet with free flow.
2. Adequate supply of 100% oxygen for patient, and air for attendant.
3. Wet suit for thermal protection.
4. Shot with at least 10 metres of rope (a seat or harness may be rigged to the shot).
5. Some form of communication system between patient, attendant and surface.

Method:

1. The patient is lowered on the shot rope to 9 metres, breathing 100% oxygen.
2. Ascent is commenced after 30 minutes in mild cases, or 60 minutes in severe cases, if improvement has occurred. These times may be extended to 60 minutes and 90 minutes respectively if there is no improvement.
3. Ascent is at the rate of 1 metre every 12 minutes.
4. If symptoms recur remain at depth a further 30 minutes before continuing ascent.
5. If oxygen supply is exhausted, return to the surface, rather than breathe air.
6. After surfacing the patient should be given one hour on oxygen, one hour off, for a further 12 hours.

Table Aust 9 (RAN 82), ***short oxygen table***

DEPTH (metres)	ELAPSED TIME		RATE OF ASCENT
	Mild	Serious	
9	0030-0100	0100-0130	12 minutes per metre (4 min/ft)
8	0042-0112	0112-0142	
7	0054-0124	0124-0154	
6	0106-0136	0136-0206	
5	0118-0148	0148-0218	
4	0130-0200	0200-0230	
3	0142-0212	0212-0242	
2	0154-0224	0224-0254	
1	0206-0236	0236-0306	

Total table time 2 hours 6 min — 2 hours 36 min for mild cases
2 hours 36 min — 3 hours 6 min for serious cases

(b) ***Treatment of delayed or complicated cases of decompression sickness.***

1. Recompress to a depth which produces an acceptable clinical result.
2. Administer oxygen mixture by mask. Percentage of inspired oxygen is determined by the absolute pressure. The aim is to achieve an oxygen partial pressure of 2 ATA e.g. at 30 metres a 50% oxygen mixture could be used.
3. Higher partial pressures of oxygen may be used if depth of recompression is shallow e.g. if an acceptable clinical result is produced at 18 metres, 100% oxygen

Reproduced from Diving and Subaquatic Medicine, p. 558, with permission from the authors and the publisher, Biomedical Marine Services Pty. Ltd.

Appendix B. Hawaiian Emergency Air-Oxygen Treatment for Decompression Sickness

This decompression sickness treatment table is designed for use by Hawaii's diving fishermen when afflicted with decompression sickness while diving and when more than 30 minutes away from a regular recompression treatment facility.

In such an event, treatment must be initiated as soon as the signs or symptoms of decompression sickness are recognized. The urgent nature of the treatment must be recognized and acted upon immediately, inasmuch as nervous tissue of the brain or spinal cord can only be completely revived within the first 7 to 8 minutes after its oxygen supply has been stopped by the intravascular bubble emboli of decompression sickness.

Because of the urgency to initiate adequate recompression therapy, this treatment regime is designed to utilize (1) immediate recompression in water while breathing air using standard scuba gear to a depth 33 fsw greater than that required to relieve the signs and symptoms of the disease, and (2) oxygen breathing at 30 fsw to wash out the excess nitrogen and permit a safe ascent to the surface. An oxygen supply bottle (120 cu ft capacity) is provided in the boat connected with a 40-ft long diving hose and a scuba regulator. The victim and the attendant diver, both using scuba, should descend to 30 ft past the depth of relief of the signs and symptoms of the disease, but not to exceed 165 fsw. The victim should stay at that depth for 10 minutes, and then start a gradual ascent with stops every minute to check to see whether signs and symptoms of the disease have returned. The rate of ascent should be no faster than 30 ft/minute for the first 2 minutes, with decreasing rates so that at 40 fsw the rate is 5 ft/minute. If no return of symptoms is noted, then slow ascent should be continued with total ascent time to 30 fsw being not less than 10 minutes.

Upon reaching 30 fsw, the patient should switch to 100 percent oxygen breathing, using the regulator and hose supplied from an oxygen bottle in the boat. Oxygen breathing must be continued at 30 fsw for a minimum of 1 hour, so as to wash out the excess nitrogen which caused the disease, plus the additional nitrogen excess accumulated during the deep descent required to crush the bubbles producing the disease. The victim should be checked regularly (i.e., every 15 minutes) by an attending diver descending from the surface. After 1 hour of oxygen breathing at 30 fsw, consideration can be given to starting the ascent if the symptom was "pain only." However, if the disease presented brain or spinal cord manifestations, the victim should stay at 30 fsw for another hour and carry out a "scrape" dive if desired. Regardless of the length of time spent breathing oxygen at 30 fsw, the ascent to the surface should be slow (i.e., 10 minutes), and the victim should continue to breath oxygen in the boat for another hour, or until the supply of oxygen is exhausted.

The safety of the attending diver must be taken into account at all times, inasmuch as the attending diver most probably had also been fishing and exposed to increased air pressure. Therefore, the attending diver may also need to decompress after taking the victim to depth, particularly if it was necessary to descend to 100 fsw or greater. In such an event the attendant diver should transfer responsibility for the victim to another diver as soon as the patient has relief of symptoms at depth and should himself ascend to 30 fsw and breath oxygen for 10 minutes before returning to the surface.

These emergency air-oxygen treatment tables, like all decompression sickness treatment tables, must be used with judgment based upon diving experience. Most experienced divers have learned that the disappearance of the signs and symptoms of the disease at depth does not mean that the disease is cured and that the diver can ascend and go home. After relief of symptoms, the tedium of preventing the disease from returning upon surfacing begins. This is the purpose of the oxygen breathing.

Even after a safe, symptom-free ascent to the surface has been accomplished, a diving medical officer should be consulted upon return to shore, and the possibility that the symptoms might return should be considered and planned for.

Although oxygen breathing is used in the treatment of DCS at depths to 60 fsw in a dry chamber, the possible occurrence of oxygen toxicity makes the use of oxygen breathing in water below 30 fsw unwise.

Equipment Required

1. An adequate supply of oxygen on board boat, i.e., a 120 cu ft capacity or greater bottle, an oxygen-clean hose at least 40-ft long plus fittings, and an oxygen-clean scuba regulator and mouth piece
2. A length of line marked to 30 ft from the waterline with seat attached upon which the victim can sit during decompression (the seat should be weighted so as to make victim and seat negatively bouyant)
3. Extra air tanks for victim and attending diver (minimum of two)
4. Anchor rope or sounding float line marked at 165 ft
5. Depth gauge and watch for use by attending diver
6. Wet suit jacket for use by victim with appropriate weights

Method

1. Upon recognizing symptoms or signs of decompression sickness, immediately --

    a. Stop the engines

b. Throw over anchor line and let out to 165 fsw or to bottom
c. Rig one full air tank for victim and another for attendant diver
d. Put victim in water with one attendant diver (or two if required) to take victim down anchor line
e. Descend to depth of relief plus 30 fsw
f. Keep victim at that depth for 10 minutes
g. Attending diver and victim start slow ascent with initial rate of 30 ft/minute with stops every minute for assessment of patient's condition
h. Ascent from maximum depth to oxygen breathing depth of 30 fsw should not take less than 10 minutes. Suggested rates of ascents from 165 fsw are: 30 ft/minute x 2 minute; 15 ft/minute x 2 minute; 10 ft/minute x 3 minute; 5 ft/minute x 3 minute
i. If patient starts to experience recurrence of any signs or symptoms, return to 10-ft deeper stop for 5 minutes, then resume ascent
j. During deep air breathing period, crew in boat rigs oxygen breathing equipment with regulator attached to hose and line with seat at 30 fsw
k. Upon reaching 30 fsw victim switches to oxygen breathing
l. Victim breathes oxygen at 30 fsw for a minimum of 1 hour
m. If victim had initial symptoms of pain only, and if signs and symptoms are relieved after 1 hour of breathing oxygen, start slow ascent. If victim had signs and symptoms of CNS disease, keep victim at 30 fsw on oxygen for one or two additional 30-minute periods. When victim is completely relieved, start slow ascent to surface while breathing oxygen.
n. If the in-water recompression is not effective and the supply of oxygen is apparently inadequate, emergency transport to the on-shore recompression chamber should be arranged. Recompression on oxygen at 30 fsw should be continued until the oxygen supply is exhausted or transport arrives.
o. Even if victim is asymptomatic when reaching surface, have victim breath oxygen in boat on surface until supply is exhausted. Consult with diving medical officer upon return to shore.