EMPIRICAL DIVING TECHNIQUES OF COMMERCIAL SEA HARVESTERS

Fiftieth Workshop of the Undersea and Hyperbaric Medical Society

Co-Chairs and Editors

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INTRODUCTION

R. W. McGinn

The Workers' Compensation Board is glad to host and support this workshop and to provide facilities for it. The Workers' Compensation Board is the supremely fitting venue for this event, as the mission of the Workers' Compensation Board of British Columbia is quite compatible with the goals and objectives of the Workshop.

The Workshop is well designed to provide a forum to develop an international consensus for safe guidelines to protect the safety and health of commercial sea harvesters and the commercial sea harvesting work place.

In *The British Columbia Gazette* of 9 October 1933, the workmen's Compensation Board of British Columbia announced that "Pursuant to the "Workmen's Compensation Act", being Chapter 278 of the "Revised Statutes of British Columbia, 1924," the Workmen's Compensation Board has adopted the following regulations for the prevention of accidents and industrial diseases in submarine diving. Interestingly, 34 regulations were promulgated including "Table 1", entitled 34. "Time-limits under Water, Stoppages during ascent, Rest Intervals, and Approximate Air-supply needed during Work." These "Time-limits under Water..." included, for example, "Stoppage in Minutes" at 54–60 ft for 5 min at 10 ft after "20 to 45 mins." (sic).

This profile is more conservative at 60 feet of seawater than that in practice today. Perhaps, then, criteria for The British Columbia Table 1 should be reassessed with a view to whether it may have some merit for re-application to institution today.

As this clearly demonstrates, for at least 64½ yr, The British Columbia Workers' Compensation Board has been proactive for, and deeply concerned with, "the prevention of accidents and industrial diseases in submarine diving."

In April 1998, The Workers' Compensation Board of British Columbia promulgated new regulations. These regulations are the result of consensus discussions held during 1½ yr between diving industry, working divers, diving and hyperbaric medical and Workers' Compensation Board of British Columbia representatives who closely conferred, advised and consented to the resulting consensus derived from these exhaustive, carefully coordinated deliberations. These Regulations, now in effect for the Province of British Columbia and closely observed by the Canadian commercial diving community, stand a strong probability of becoming a working model for other jurisdictions.

In recent years, it was gratifying that the last diving seafood harvester fatality had been in 1994. Accounting for this, there is, in fact, a generally perceived change in the character and abilities of commercial divers suggesting a more capable, better-trained, and increasingly sophisticated group of individuals. This results from advances in, accessibility to, and affordability of commercial diving training. Employers, moreover, have become increasingly demanding in their acceptance criteria for applicant commercial divers. The new Workers' Compensation Board of British Columbia Regulations, furthermore, require demonstration of at least minimal established competence levels and medical standards to be accepted for Workers' Compensation Board certification to pursue a career in commercial diving in British Columbia. These required levels and standards result from the consensus discussions and deliberations that led to the new Regulations mentioned a moment ago.

Having said all this, we should be absolutely clear that regulations are just and only that. Such deliberate and well-conceived attempts to establish guidelines based on sound and proven fundamental principles of accident prevention, safety, and health can only be as successful as the practice of those activities for which such codes are established and written.

As we speak just now, the sad fact is that on 13 May 1998, a commercial diving sea harvester lost his life in pursuit of sea urchins off the coast of British Columbia. This was the 13th such fatality since 1975. Little is known of the details regarding this unfortunate accident at the present time and it is under investigation by The Workers Compensation Board of British Columbia and The British Columbia Coroners' Service. As details become available those will be duly communicated to the diving industry and the larger community. Our commitment must be that, to the extent we can, we shall practice our individual and collective work in such a way that a similar event will never again occur.

This tragic episode dramatizes the fact that we must never lapse into complacency regarding the general philosophy that to preserve and enhance the health and safety of workers, the work place must itself be designed and maintained as a healthy and safe environment. We must not allow ourselves to become lax in attention to the details of exercising the safe and healthy practice of the crafts and procedures upon which our increasingly technologically based societal and economic yields depend for producing their domestic, national, continental, and global outcomes. In fact, the very result of what our civilization becomes is contingent upon exactly that. Our survival, our quality of life, our art, our science, our measure of humanness, our legacy, and our birthright will be written in large part by how we practice our work. For inherent in this is reflected what we have been and how we became what we are. It is what will determine what we shall become.

Let us comport ourselves now and later so that those who entrust us with their present and future will feel secure that we do so with the absolute intent to create a safe, healthy, and perceivable workplace, habitat, and ecology for them, their children, and all our generations to come.

Again, The Workers' Compensation Board of British Columbia welcomes you all. We wish you well with this historic workshop. We shall observe the proceedings and the outcome with interest, concern, and hope.

The last time he Undersea and Hyperbaric Medical Society held a function at the Workers' Compensation Board of British Columbia was in 1992. That one was a resounding success. May that outcome also follow your efforts here for the next two days.

We hope you enjoy your stay in the Greater Vancouver Regional District and invite you to return frequently.

Thank you for your kind attention and may you all be well and do well in your endeavors.

DECOMPRESSION SICKNESS AND ARTERIAL GAS EMBOLISM IN MISKITO INDIAN DIVERS: A REVIEW OF 229 CASES

Diana Marie Barratt, Humberto Castro Olayo, Gerard Rudy, Norvelle Goff-Rudy, Armando Palacios, and Keith Van Meter

BACKGROUND

The Miskitos are an indigenous population numbering 250,000 (Nietschmann 1997). They participate in subsistence farming, fishing, and hunting. Since the 1600s, when the Miskitos first came into contact with Europeans, they have also participated as wage laborers in industries such as the rubber, gum, lumber, gold, coconut, and most recently, the lobster industry (Dodds 1998). Geographically, the Mosquito Coast is 400 miles long, encompassing portions of the Atlantic Coast of what is now Honduras and Nicaragua. The population density is approximately two persons per square kilometer, with small communities clustered around major rivers or lagoons. Access and communications between this region and the capital cities of Honduras and Nicaragua can be very difficult.

Harvesting of Lobster in Central America

In Central America, lobster are harvested with traps or by divers. A variety of boats are employed, ranging from simple cayucos (canoes) launched from the shore, to privately owned sailboats to sophisticated commercial dive or trap boats. Free diving is performed in some locations, in addition to scuba diving.

Typical industrial diving boats measure 17-21 meters in length, and transport approximately 20 cayucos, 60 scuba tanks, and 40 workers to the lobster fields (USAID 1996). The divers work from the cayucos, collecting lobster with a hook and bag, while a canoe handler remains above the surface. Divers may also collect conch in addition to lobster. Throughout the day, the diver returns to the big boat for lunch and to obtain more tanks. Dive trips typically last about 12 days.

Lobster Industry

Due to the illegal, unreported fishing activity it is difficult to determine the quantity of lobster harvested in Central America. However, according to the U.S. Department of Commerce, the value of Honduran lobster imported to the United States in 1996 was $25.8 million USD. Nevertheless, how much of this is diver- vs. trap-caught lobster is unknown.

In 1995, approximately 500,000 pounds of diver-caught lobster tails were landed in Puerto Cabezas, Nicaragua, as a result of the industrial diving fleet. The artisanal diving fleet harvested approximately 210,000 pounds of tails the same year. This does not include lobster landed in other Nicaraguan ports (USAID 1996).

Demographics

A large survey (n = 334) indicated that 92% of divers had a primary school education; only 7% of divers had received formal diver training. (Proyecto Nautilo 1993). The average diver is close to 30 yr of age with approximately 10 yr of diving experience. However, divers' ages range from 17 to 60, and diving careers may last anywhere from less than 1 yr to 24 yr. (Comite Pro Desarrollo 1986, Miller and Dagen 1990, Proyecto Nautilo 1993).

Alcohol and drug use among divers is very common. Thirty-six percent (n = 334) of active divers reported smoking marijuana, 78% reported drinking alcohol, and 2% reported using other drugs. Fifty-three percent reported drinking excessively, and 10% reported drinking habits consistent with alcoholism (Proyecto Nautilo 1993). Many divers use drugs and alcohol while diving (*see* Dunford and others, this workshop).

Dive Equipment and Dive Profiles

Virtually all divers on industrial lobster boats (n = 334) reported using masks, fins, tanks, regulators, and gloves. However, watches were only used by 2% of divers, air pressure gauges by 0.3%, and depth gauges by 0% (Proyecto Nautilo 1993).

Lobster diving takes place near the continental shelf of Honduras and Nicaragua. In July 1996, aerial transects were conducted near the coast of Puerto Cabezas, Nicaragua. Clusters of lobster boats were present within the 20-m depth contour line near the Cayos Miskitos, and between the 20-m depth contour and the 100-m depth contour, where the continental shelf drops off sharply (USAID 1993). Divers have reported variable depths; however, mean reported diving depth in a number of studies was between 100 and 115 feet with a range of 48 to 180 feet (Comite Pro Desarrollo 1986, Miller and Dagen 1990, Proyecto Nautilo 1993).

Survey data shows that 88% (n = 334) reported bottom times of 20 to greater than 30 min. The mean number of tanks used per day is greater than 12, with a maximum of 24. Reported surface interval had a bimodal distribution. Sixty percent reported a surface interval of 1–5 min, while 21% reported a surface interval of 60 min or more (Proyecto Nautilo 1993). This bimodal distribution is thought to be one of practicality. If divers locate lobster, they will ask for another tank and descend immediately. If they don't see lobster, they may move the boat to a more favorable location. (*See* Dunford and others, this workshop for actual recorded dive profiles.) Dive trips typically last 12 days; the mean number of dive trips per month (n = 51) was 1.5 with a range 1–3 trips (Comite Pro Desarrollo 1986).

Microeconomics

In 1993, divers were paid approximately $2 USD for each pound of lobster tails and $0.30 USD for each pound of conch that they harvest. Divers (n = 334) reported harvesting 5–50 pounds of lobster tails per day, in addition to 60–200 pounds of conch per day (Proyecto Nautilo 1993). As such, they have the potential to earn in excess of $1000 USD per month. (In comparison, a government-employed physician earns a salary of approximately $200 USD per month.)

Seventy-eight percent of divers (n = 334) have four or more dependents. Divers (n = 334) reported spending their most recent earnings in the following ways: 95% purchased food, 89% purchased clothing, 66% purchased alcohol, 62% invested in the home, 54% invested in agriculture, 49% purchased medicine, 43% invested in education, 5% invested in livestock, and 3% saved (Proyecto Nautilo 1993).

Health Problems of Divers

In a cross-sectional study that took place in two Miskito villages, divers and former divers were evaluated by history, physical, and laboratory analysis. Although inclusion and exclusion criteria were not clearly defined, all divers had one or more signs and symptoms of decompression illness (Table 1). In addition, infectious diseases such as syphilis, gonorrhea, scabies, and tuberculosis were also present (Comite Pro-Desarrollo Integral de la Moskitia 1986).

Diving-Related Fatalities

Between 1975 and 1990 there were at least 56 diving-related fatalities in la Mosquitia, as determined by community interviews (Miller and Dagen 1990). Another study reported 18 fatalities between 1990 and 1991 (Kawaguchi 1991), but the method of obtaining the data is unknown. By sampling half of the Honduran villages in la Mosquitia, another group estimated that between 1990 and 1992 there were 28 fatalities among 4,570 divers. Therefore the incidence of diving-related fatalities during that period was approximately two fatalities per one thousand divers per year (Proyecto Nautilo 1993).

Table 1: *Health Problems of Divers and Former Divers*[a]

Signs or Symptoms	n = 60, %
Lumbar pain	52
Arthralgia	50
Chest pain	35
Headache	28
RPR +	22
Otalgia	18
Dizziness	17
Conductive hearing loss	12
Neurologic hearing loss	8
Otitis media	7
Paresis/Paralysis	5
Bronchitis	5
Sinusitis	3
Scabies	3
Tuberculosis	2
Gonorrhea	2

[a]By history, physical exam, and laboratory analysis of divers and former divers who had complaints. Many patients had more than one sign or symptom.

Diving Accident Management

Lobster boats in La Mosquitia are not equipped with deck decompression chambers or oxygen. However, some of the lobster boats in Nicaragua employ an on-board health care worker who is able to give massages, injections, and start Foley catheters. When a diver is injured, he may be transported to a medical or hyperbaric facility, or treated with in-water recompression on air.

Supernatural Beliefs

Miller and Dagen (personal communication) first began teaching dive classes in the 1980s. They distributed a pre-test that asked if divers knew the cause of decompression illness. Universally, divers responded that the cause of decompression illness was the mermaid's curse. They believed that the mermaid ruled the underwater world and allowed divers to take lobster. If a diver took too much, she became angry and put a curse on him.

Because divers believed that the etiology of decompression illness was supernatural, rather than physical, they did not know of any way to prevent its occurrence. In addition, they did not feel any sense of urgency to go to a hyperbaric treatment facility, or to a hospital. Instead, they sought out local shaman healers, who specialize in removing curses.

Over the years, numerous local and foreign groups have taught dive classes in the region. Although classes have not been accessible to all, the knowledge of the physical cause of decompression illness is spreading. In addition, many divers have personally seen the results of hyperbaric treatment of decompression illness. More and more, divers are willing to receive hyperbaric treatment.

Treatment Facilities in the Region

Before 1991 there were no hyperbaric chambers in La Mosquitia. At that time, some of the more severely injured patients were transported to Roatan, one of the Bay Islands of Honduras, for recompression therapy. However, many divers with neurologic decompression illness simply did not receive hyperbaric oxygen therapy. Instead, they were treated by local physicians with normobaric oxygen (when available), intravenous fluids, systemic steroids, and physical therapy. Divers also sought assistance from shaman healers or took home remedies. The first hyperbaric chamber in the region arrived in 1991 in Ahuas, Honduras. In 1997, hyperbaric chambers arrived in Puerto Cabezas, Nicaragua and Cauquira, Honduras. In addition, the existing hyperbaric chamber in Trujillo, Honduras, again became operational in 1997.

Liability of the Industry

Now that hyperbaric chambers are available in the region, boat owners frequently pay for the divers' transportation to the treatment facilities. Certain individuals in the diving industry refuse to pay their employee's medical bills, but the problem is with individual boat owners, rather than industry as a whole. While some Honduran boat owners consistently pay hospital bills for their employees, others do not. Geography can work against Honduran divers, as many of the boat owners live in the Bay Islands and have never met the divers, or the treating physicians.

In contrast, boat captains, boat owners, and divers are part of the community in the Puerto Cabezas, Nicaragua. Boat owners frequently bring their divers to the hospital for treatment of not only decompression sickness, but other minor illnesses. At least one of the boat owners there has health insurance policies for his employees. The treating physician brings a bill for the patients' medical care directly to the owners' office; therefore, collection of fees in Puerto Cabezas is not as difficult as it can be in Ahuas.

Divers that are not cleared to return to diving are sometimes offered non-diving positions within the industry. These individuals become frustrated with the significant drop in income. They disappear, and are later found to be employed as divers for other companies. Disabled divers may be offered severance pay, and fatalities can result in a significant payment to the family.

SETTINGS

Clinica Evangelica Morava

Clinica Evangelica Morava is a clinic/hospital in Ahuas, Honduras. Due to its remote inland location, it is accessible only by plane, or by boat from the river. Hyperbaric facilities include a Vicker's monoplace chamber that delivers oxygen with a demand regulator. Oxygen, which must be transported by boat, is always in short supply.

Hospital Nuevo Amanecer

The Hospital Nuevo Amanecer is a regional hospital in Puerto Cabezas, Nicaragua. A port city, it is accessible by ship from the sea, and by air. Hyperbaric facilities include a Perry Submarine Builders (1971) multiplace chamber. Oxygen, which must transported by road from the capital city, is always in short supply.

METHODS

Louisiana State University IRB Identification Number 3701 was issued before beginning the study. Data on patient demographics, dive profiles, presenting signs and symptoms, treatment, and outcomes were collected from medical records at the two institutions. Using a database in Version 6 of Epi-Info (Centers for Disease Control), descriptive statistics were calculated.

When calculating means, missing data were disregarded. When calculating percentages in terms of presence or absence of a condition, in most cases, the denominator was 229, the total number of cases in the database. However, when outcome data are presented, the denominator used for ambulation and motor deficits is 182—the number of patients who presented with motor deficits.

RESULTS

Patient Numbers

The chamber at Clinica Evangelica Morava arrived in 1991. Once established, the number of patients admitted for decompression illness rose to approximately one per week. (Table 2) Due to its remote location, the majority of patients were admitted for treatment, rather than be treated as outpatients.

At Hospital Nuevo Amanecer, many of the local divers were treated as outpatients. The hospital does not keep records on outpatients; therefore, a significant proportion of the data is not available. The number of patients admitted for decompression illness by year is listed in Table 3.

Divers and Dive Profiles

Seventy-one percent (n = 229) of divers in this database were treated at Clinica Morava Evangelica and 29% at Hospital Nuevo Amanecer. Only 4% of patients treated at Clinica Evangelica Morava (n = 162) lived in Ahuas, while the remainder originated from 32 different villages in the region. Fifty-one percent of divers treated at Hospital Nuevo Amanecer (n = 67) lived locally, while the remainder were from 17 other villages.

All patients (n = 229) were male. The average age of divers in this study was 29, with a range of 16 to 67. Divers had relatively long diving careers, despite participating in extreme diving practices, including long dive trips with multiple bounce dives to approximately 100 feet (Table 4).

Clinical Presentation

Mean number of hours to presentation (n = 197) was 116, and median was 48 with a range of 4 to 1056. When analyzed separately, mean time to presentation for patients at Clinica Evangelica Morava (n=138) was 124 hours, and median was 72 with a range of 18 to 816. Mean time to presentation at Hospital Nuevo Amanecer (n=59) was 98 hours, and median was 24 with a range of 4 to 1056. Twenty-four percent of patients (n=229) reported at least one prior episode of decompression illness. The vast majority of patients presented with neurologic deficits, including motor and sensory deficits. Urinary deficits and reflex abnormalities were also common (Table 5).

Table 2: *Number of Patients Admitted[a] for Decompression Illness to Clinica Evangelica Morava, Ahuas, Honduras*

Year	Number of Patients
1989	12
1990	14
1991	21
1992	48
1993	41
1994	39
1995	51

[a]Due to the clinic's remote location, the vast majority of patients were admitted for treatment, rather than to receive treatment as outpatients.

Table 3: *Number of Patients Admitted[a] for Decompression Illness to Hopsital Nuevo Amanecer, Puerto Cabezas, Nicaragua*

Year	Number of Patients
1996	30
1997	46

[a]Due to the large population of divers in Puerto Cabezas, about half of the patients were treated as outpatients. The above numbers do not reflect the large number of outpatients.

See Table 6 Co-morbidity included many infectious complications (Table 7).

In patients with motor deficits (n = 182), more than half presented with injuries involving the lumbar spine. Only 6% were quadriparetic or quadriplegic. Approximately one quarter had unilateral motor deficits (Table 8), In patients with sensory deficits (n = 138), the distributions often did not conform to the motor deficits. Although some of the sensory deficits were difficult to categorize, more than half involved lumbar spine distributions.

Treatment

Almost all patients (n = 229) who presented after the arrival of chambers received at least one hyperbaric oxygen treatment (Table 9). However, if the patient presented many weeks after the injury, or at a time during which there was no oxygen, he did not receive a hyperbaric treatment. More than half of patients received systemic steroid administration. There were no instances in which steroids were discontinued due to complications.

Outcome

Patients were noted to have some spontaneous recovery before reaching the treatment facilities. For example, most of the patients with loss of consciousness had regained consciousness by the time they arrived. In addition, some patients had partial resolution of motor deficits before arrival. In general, patients that did not receive hyperbaric oxygen experienced a gradual improvement in neurologic function. Many patients that received hyperbaric oxygen had immediate improvement in neurologic function on recompression. The data did not allow comparison of long-term outcomes between treatment groups; therefore, all of the data were combined and presented below.

Table 4: *Divers and Dive Profiles*

	Mean	Median	Range
Age, n = 228	29	28	16–67 yr
Years diving, n = 169	11	10	0–35 yr
Days diving, n = 45	5	4	1–12 days
Tanks per day, n = 140	7	7	1–18 tanks
Depth of dive, n = 141	102	102	14–192 ft
Time of presentation n = 197	116	48	4–1,056 h

Of patients presenting with motor deficits (n = 182), almost one third were normal on discharge. Another third had motor deficits of one or both lower extremities. Only 2% were quadriparetic, and only 3% had complete paralysis (Table 10).

Approximately two thirds of patients were walking on discharge, either unassisted or with crutches. Only 5% were not ambulatory (Table 11).

DISCUSSION

The injured Miskito Indian lobster divers in this series were relatively young (mean age 29), and had worked as divers for an average of 11 yr. Their dive profiles were extreme, consisting of long dive trips lasting up to 12 days. They participated in multiple bounce dives to approximately 100 feet, using an average of seven tanks per day. Twenty-four percent reported prior decompression illness. Data collected in this series are consistent with other studies of this population, in terms of age, number of years of diving experience, diving depth, and prevalence of prior decompression illness. Number of days diving and number of tanks used per day were slightly lower, but this may be because their normal activities were interrupted by an accident.

Time to presentation was very long, even when taking into account the distances between the treatment facilities and the fishing areas. This may be due to a number of the following factors: in water recompression on air; delay in diagnosis; difficulties with travel; and supernatural beliefs such as the mermaid's curse.

The vast majority of patients presented with neurologic deficits; more than half presented with motor deficits consistent with lumbar spine injury. Sensory deficits, urinary deficits, and reflex abnormalities were common. As a result of the severe neurologic deficits, relatively minor symptoms, such as pain, dizziness or vertigo, and mild sensory abnormalities, may have been underreported. In addition, it is thought that the majority of patients with relatively mild cases of decompression illness do not even present for treatment. Infectious co-morbid conditions, such as scabies, malaria, PPD+, tuberculosis, and parasites are common diseases in the region. However, the presence of UTI, pyelonephritis, decubitus ulcers, and pneumonia were direct complications of neurologic injury.

Before the arrival of hyperbaric chambers in the region, divers were treated with normobaric oxygen (when available), intravenous fluids, systemic steroid administration, and physical therapy. When chambers became available, most physicians continued to use systemic steroids. The majority of patients in this series received hyperbaric oxygen therapy and systemic steroids. Those that did not generally presented at a time during which these were not available, or presented weeks after the injury. There were no instances in which steroids were discontinued due to complications.

Of patients presenting with motor deficits, almost one third were normal on discharge. Approximately two thirds of patients were walking, either unassisted or with crutches. Only 5% were not ambulatory.

There are many possible ways in which to reduce the

Table 5: *Clinical Findings in Divers With Decompression Illness*[a], *n* = 229

Type of Deficit	Positive, %	Negative, %	Missing Data, %
Any neurologic deficit	94	3	3
Motor deficits	70	17	4
Sensory deficits	60	6	34
Urinary deficits	48	12	40
Reflex abnormalities	45	1	54

[a]Less serious signs and symptoms were not always documented. In the majority of cases, only the presence of symptoms were documented, not the absence.

Table 6: *Presenting Signs and Symptoms*[a], *n* = 229

Pain	37%
Dizziness	32%
Loss of consciousness	20%
Chest pain	12%
Headaches	8%
Nausea	7%
Auditory abnormalities	4%
Sinus and otologic barotrauma	3%
Aphasia	1%
Visual disturbances	1%

[a]Some patients had more than one sign or symptpom.

Table 7: *Co-Morbidity*, *n* = 229

Urinary tract infection	27%
Parasites	25%
PPD+	6%
Malaria	5%
Decubitus ulcer	3%
Otitis media/externa	2%
Pneumonia	1%
Tuberculosis	1%
Depression	1%
Pyelonephritis	1%

Table 8: *Clinical Presentation of Divers With Decompression Illness*

Motor deficits	*n* = 182
Paraparesis	27%
Paraplegia	26%
Lower ext. monoparesis	14%
Lower ext. mnoplegia	6%
Quadriparesis	4%
Hemiparesis	4%
Hemiplegia	3%
Quadriplegia	2%
Missing data/other	14%
Sensory deficits	*n* = 138
L1-L5	60%
T7-T12	12%
T1-T6	10%
Hemi	9%
C4-C6	2%

Table 9: *Medical Treatment Received by Divers at Both Clinica Evangelica Morava and Hospital Nuevo Amanecer (n = 229)*

	Received, %	Did Not Receive, %	Missing, %
Hyperbaric oxygen therapy[a]	63	31	6
Systemic steroid administration	61	13	26

[a]When resources became available, all divers with neurologic deficits were given at least one hyperbaric oxygen treatment.

incidence of decompression illness in the region. A number of groups, past and present, have instructed divers in safe diving practices and the use of decompression tables. One of the articles of the 1997 Nicaraguan Regulations calls for more equipment, including watches, gauges, snorkels, fins, and routine inspection of tanks. Certainly, the knowledge that decompression illness is a physical, rather than supernatural phenomenon, empowers the diver. He knows that there is something that can be done to prevent the disease, and should he become ill, medical treatment is available. However, more instruction and better equipment may not reduce the incidence of decompression illness if divers continue to practice the same extreme dive profiles.

Divers can do a number of things to decrease their risk of decompression illness. They can refrain from using drugs or alcohol on dive trips and voluntarily reduce the number of tanks used per day. Once an injury has occurred, divers should follow their doctor's advice regarding whether or not they can return to diving. Commercial boat owners could help to reinforce this by prohibiting the use of drugs and alcohol on board their vessels, restricting the number of tanks used per day, and preventing disabled divers from returning to diving. However, safe diving practices would severely impact productivity, increase the amount of time spent at sea, and decrease the incomes of the divers and the industry as a whole.

Efforts to improve treatment could include minimizing the time to presentation, and improving availability of oxygen in remote areas.

Table 10: *Motor Function on Discharge Compared to Presentation*, *n* = 182

	Presentation	Outcome
Normal	0%	30%
Paraparesis	27%	15%
Paraplegia	26%	3%
Lower extremity monoparesis	14%	15%
Lower extremity monplegia	6%	0%
Quadriparesis	4%	2%
Hemiparesis	4%	2%
Hemiplegia	3%	0%
Quadriplegia	2%	0%
Missing data/other	14%	33%

Table 11: *Ambulation on Discharge*, *n* = 182

Normal gait	19%
Abnormal gait	19%
Requires one crutch	10%
Requires two crutches	16%
Not ambulatory	5%
Missing data	31%

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REFERENCES

Comite Pro-Desarrollo Integral de la Moskitia, Informe Narrativo Jornada De Trabajo Con Buzos Miskitos Para Diagnostico De Salud, Tegucigalpa, Honduras, 1986

Dodds, David J. 1998. Lobster in the Rain Forest: The Political Ecology of Miskito Wage Labor and Agricultural Deforestation. Journal of Political Ecology 5:83-108.

Kawaguchi, Shigeru, Encuestas: Investigacion de los buzos enfermados en la Mosquitia, 1991

Miller, Walsted and Dagen, Miriam King, Encuesta: Buzos Afectados Por La "Enfermedad del Buzo" PROMEBUZ/MOPAW1,1990

Nietschmann, Bernard, Chapter 7, Protecting indigenous coral reefs and sea territories, Miskito Coast, RAAN , Nicaragua, in Conservation Through Cultural Survival, Ed. by Stan Stevens, Washington, DC: Island Press, 1997

USAID. Environmental Initiative of the Americas Fisheries Project, Cayos Miskitos, 1996.

DISCUSSION

Mr. Gold: First of all, I'd like to congratulate you on an excellent presentation.

Dr. Barratt: Thank you.

Mr. Gold: It was very interesting. Are they all diving with tanks or are some using surface-supplied air at this time?

Dr. Barratt: I don't believe there's any surface-supplied air. There are all different types of divers. There are the ones that work for commercial boat owners. There are also people, especially down in the southern region of Nicaragua, that are diving from little canoes.

They rent tanks and go out in a canoe. And there is some free diving, also. But the ones that I reported on were mainly commercial divers diving with scuba tanks from industrial lobster boats.

Mr. Hubert: (California) You actually answered one question a little bit. Who owns the boats? To my knowledge, about 6 years ago, a lot of American buyers went down to this area and starting buying lobster. That's why they see so much coming up through the United States.

And I think we might find that that answer is why it takes it so long to get into the chamber. The boat owners don't want us to take the boat in before the day is through diving. So anyway, as to the question I was asking, who owns the boats and how are they run?

Dr. Barratt: I'm more involved in Nicaragua at this time and in Nicaragua I met a number of the boat owners. A lot of them live locally. They're involved in the community and they are held accountable for what happens because the divers come home and they're in the same community.

So I think that they do want them to get treated and they want them to get better because there is severance pay involved. If a diver dies, there's a big payment to the family. Now, in Honduras it might be a little different and perhaps Richard could talk about this.

Mr. Dunford: My understanding is they're responsible in Honduras, also. They have payments to be made if there's a fatality.

Dr. Barratt: He said that they're also responsible in Honduras. I understand from some of the physicians in Honduras that they have a group of boat owners that continuously pay their bills without any problems, they cover all the cost of treatment, and some that continually ignore the bills and all communications. In Nicaragua, it's a little more difficult because you can walk down to the boat owner's house and knock on his door and hand him the bill.

Dr. Brubakk: You want us to have a similar system. I have a question about your incidence rates. As far as I understood it, you said that 27% of the divers had prior decompression illness.

That is a surprisingly low number. We did a study on Norwegian commercial divers and they had nearly exactly the same number of prior incidents. So I was first very surprised on that.

The question would then be, does this mean that these divers, once they've had one incident of decompression sickness, stop the dive? Because I'm surprised at the low number.

Following up on that, you may have gone a bit quickly for me but did you show that actually there was no difference between the outcome of treatment as opposed to those who had no treatment?

You ended up with approximately 30% having no clinical symptoms after the episode even if they were not treated. So actually, that's frequent. Are these groups comparable, in other words?

Dr. Barratt: For the first question about number of decompression events, out of the 229, 17% reported having one prior episode, 3% reported having two prior episodes, and 0.4% reported three or four episodes. I think that they're just not reporting minor things like minor weakness but they can still walk. It seems like if the diver can walk, he thinks he's okay, but maybe severe pain would bring him in.

For the second question, that's what I really wanted to learn, what is the impact of hyperbarics on outcomes. But the numbers start to get very small. Before they had hyperbaric chambers, there wasn't a lot they could do. They gave steroids, they gave i.v. fluids and physical therapy.

So there was less interest in collecting data on it because there wasn't a lot they had to offer. I find that once they got the chamber, their records were a lot more accurate, much more detailed, much more interest in diving histories, better documented.

Also, the two groups were not comparable. I tried to look at that, but without a continuous variable, it's difficult to say. But there was more paralysis in the hyperbaric-treated group and there was a lot more weakness in the no hyperbaric group.

So you're starting out at different points. But if you look at it that way, it looks like the outcomes are all about the same. If you look at the hyperbaric group, they had more paralysis. So it's a stretch on retrospective data.

Dr. Mitchell: Dr. Barratt, this is a marine biological question rather than a medical one, although it has long-term medical implications. How sustainable is this industry?

It seems to me there's an incredible pressure on the lobster population here although it's been there for a long time from the data that you've seen. Is this an industry that is going to continue on or are we just going to over-fish this population and it will die out?

Dr. Barratt: I'm going to kind of sidetrack that because I don't have a good answer for you. There's an anthropologist named David Dodds out of Indiana who's been studying this population. He actually looked at the impact of diving on deforestation in Honduras.

He found that families who had income from diving did less deforestation. So I mean, his conclusions were—I'm paraphrasing now—but that there was a difference in deforestation and that the lobster income, although it had adverse effects on the Caribbean lobster population that it did save some of the forest. I don't know how sustainable the lobster is out there.

Dr. Kawashima: How many percentage has dysbaric osteonecrosis? Is this always 5%?

Dr. Barratt: I don't know. I saw, I think, two cases of avascular (dysbaric osteo-) necrosis of the femoral head and I'd wondered if they were due to steroids. I'm sidetracking again. The cases that I reviewed came in with severe hip pain so I think that they had a hip there to begin with.

It would be hard to say because x-ray is a more expensive technology. They don't use it as much as we do. And there are a lot of people walking around with extremity pain that probably never presents. That's a potential area for study.

Mr. Freebaum: (USA) You mentioned in-water treatment. Is that catching on and what percentage of the people are treated that way?

Dr. Barratt: I know there's a North American person down there who's got some diving background. I haven't met him yet. He's teaching in-water recompression and using air as an option. I don't know how many people are using it and I know the physicians are a little uncertain about it.

They don't have a lot of information about it and they seem kind of concerned about it. I mean, I've had reports from boat owners saying that they really think it works, that they send a guy down who's paraplegic and he comes back up walking. There are a few reports in the medical records that I've seen. But I couldn't give you the incidence of it.

DIVE PROFILES AND RESULTS OF TREATMENT

R. G. Dunford, G. W. Salbador, E. B. Mejia, and N. B. Hampson

In 1994 we presented data on the diving conditions of the Miskito Indian lobster harvesters of Honduras (1). At that time we reported that they were untrained in standard diving techniques, had a poor understanding of the risks and causes of decompression sickness (DCI), and dove profiles that carried a high risk of DCI. In 1998 we again observed field diving conditions to verify our earlier findings.

Divers are recruited from local villages by an intermediary known as a "sacabuzo" (diver puller) who will pay a 700-lempiras (approximately $53 US) advance to a diver and 150-lempiras advance to the cayuguero (a diver assistant). For this trip, 30 divers and their cayugueros were recruited, but six failed to board the vessel before departure due to heavy drinking by all divers the evening before.

Only divers dive for product. A productive diver will earn approximately 4,500 lempiras per trip and take five such trips per year (observatioon by EBM). Diving represents the only form of dependable income for the Miskito Indians. The cayuguero follows the diver by observing his bubbles while manning a cayuco, a small hand-carved wood craft. Cayugueros are between 12 and 17 yr old and usually accompany a relative or have been sent by the family to work. It is from these ranks that future divers are chosen.

During the month of January 1998, an observer skilled in the examination treatment of DCI was placed aboard a local harvest vessel *Harmac I*. The observer obtained consents, randomly selected eight divers to be followed, examined each for signs and symptoms of DCI before the first dive, and collected all diving data during the voyage.

Divers averaged 31 yr of age and had been diving an average of 12.4 yr. Although only one of eight divers admitted to using marijuana on the predive demographic form, all divers were seen by the observer smoking marijuana frequently, before, during, and after diving as well as late into the night.

Before the first dive of the trip, Cochran Commander dive computers were affixed to the divers' regulator hoses near the first stage. These computers log the deepest depth attained within a preset interval. They are capable of retaining 80 h of data when the sampling interval is set to 15 s. The computers were fashioned to the regulator hose in such a manner that the computer could not be removed without visible disruption to the mounting system and were checked each day before diving and after the last dive. Profile data were up-loaded from the computers using software supplied by the Divers Alert Network.

While en route to the fishing grounds, each diver received diving equipment from the ship's captain. The inventory included one mask; a pair of fins; a regulator some of which had depth gauges; one glove, a net, bag for product, a harpoon for hooking lobster, a hammer (for breaking conch shells underwater as only the meat is recovered in the product bag), and a tank backpack without buoyancy compensator.

The initial diving occurred at Gorda Bank. During the first day, divers found little product so the boat relocated to Rosalind Bank for the remainder of the trip. During all days of diving the observer noted that in addition to lobster, large amounts of conch and an occasional sea turtle were brought aboard.

The captain of this diving vessel was also the owner and expressed a desire to avoid excessive depth to reduce risk of DCI because he is liable for expenses for medical treatment of an injured diver. The captain also indicated that he was sensitive to publicity surrounding the Miskito diving and wanted to be conservative in his choice of depth because of the presence of an observer.

Due to technical error, only five of the eight divers selected have computer data available and only for the first 7 days of the 11-day trip. Information on tanks used and DCI symptoms was collected for all 11 days.

A total of 378 separate exposures were recorded for dive times in excess of 1.25 min and greater than 22 feet of sea water (fsw). Mean depth and mean maximum depth for all dives was 62.1 ± 6.7 fsw and 69.0 ± 6.8 fsw, respectively. Dive time averaged 23.6 ± 6.3 min on 10.8 dives per day. The 11-day tank count averaged 10. 7 tanks with a maximum of 15 tanks a day. The average number of tanks used and the percent of reported DCI symptoms was 11.5 and 35.7%, respectively, on Days 2–7 where computer data are available, and 11.6 and 37.5% on Days 8–11 where it is not. Since the *Harmac I* remained in the same area from Day 2 onward, it is likely that the aggressive diving style seen in Days 2–7 continued for Days 8–11 where computer data are unavailable.

Compared to the five divers whose data were retained, the three divers whose data were lost used more tanks per day at 11.6 vs. 10.1 over the 11 days and reported 53.1% of the DCI symptoms, suggesting that they were among the most aggressive of the group.

To carry out these dives, the diver conducted up to three

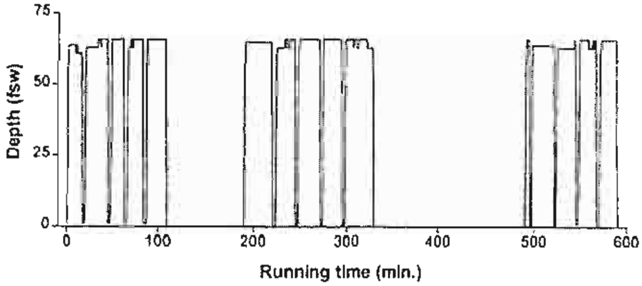

Figure 1: A triple excursion profile. The time depth data logged by Cochran Commander dive computers for deepest depth per 15-s interval for one triple excursion profile. Total time underwater per excursion is 100.0, 134.75, and 94.5 min, respectively. Surface interval time is 81 min between excursion 1, to 2 and 161 min between 2 and 3. Maximum depth per excursions is 66 fsw for the three excursions. Mean depth is 60.1 ± 3.2, 61.7 ± 2.2, and 58.6 ± 3.8 min, respectively.

(average = 2.5 ± 0.6) excursions per day. During excursions they dove one to eight dives (× = 4.3 ± 1.36) using as many as five tanks previously loaded into cayuco. Figure 1 depicts one triple excursion profile recorded on Day 6. Maximum depths for these three excursions in Fig. 1 are 66, 66, and 67 fsw, respectively. The first two dives are generally completed before noon and the third by 1500–1600 h.

Figure 2 shows the data from the first excursion shown in Fig. 1 and is characteristic of the profile management recorded for all dives. Ascent to the surface was accomplished in less than 2 min in 94.4% of all dives. Ascent time represents the interval from mean depth minus 10 fsw to a depth of 5 fsw or less. The descent required less than 2 min in 85.2% of all dives and is similarly calculated from 5 fsw to a depth 10 fsw less than mean depth. Fluctuations in depth while at the bottom is calculated from the standard deviation of depth after ascent and descent data have been dropped. The standard deviation for depth is less than 4.0 fsw in 74.6% of all dives.

Figure 3 displays the time underwater for all triple excursion profiles. Over the 7 days of observation, the five divers carried out 57 triple excursion profiles averaging 4.4 ± 1.0 dives per excursion. The mean total time underwater per excursion was 111.8 ± 17.2, 98.6 ± 26.3, and 91.8 ± 23.4 min, respectively. .

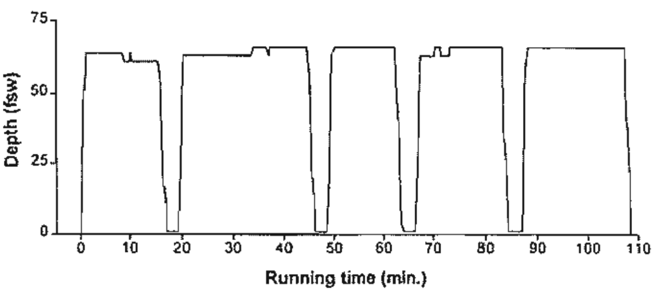

Figure 2: First excursion of the triple excursion profile. Table shows the time depth data as described in Fig. 1 for a single excursion by one diver. Maximum depth is 66 fsw and total time underwater = 100.4 min.

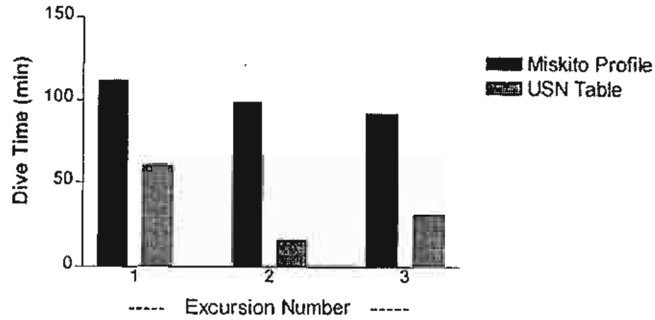

Figure 3: Time allowed by USN tables compared to the time taken underwater by the Miskito Indian harvesters for all 19 triple excursion profiles. Mean dive time undertaken is 111.8 ± 17.2, 98.6 ± 26.3, and 91.8 ± 23.4 min, respectively. Mean surface interval time between excursions 1 and 2 is 99.5 ± 21.6 min and between excursions 2 and 3 is 122.9 ± 34.3 min. Mean depth for the three excursions is 60.8 ±2.5, 59. 7 ± 2.9, and 59.9 ± 5.0 fsw, respectively. Maximum bottom time allowed by USN tables for a no-stop profile at 60 fsw with surface intervals undertaken as indicated is 60, 14, and 30 min, respectively. The comparison indicates that the Miskito Indian divers undertook dive times 2.8-fold greater than that allowed by the USN tables for a no-stop dive of similar depth and surface intervals

The average depth for all triple excursion dives was 60.1 ± 3.6 fsw. Surface intervals averaged 99.4 ± 21.6 and 122.8 ± 34.3 min, respectively, between excursions. In comparing these profiles to the time allowed by the U.S. Navy (USN) air tables for a depth of 60 fsw with surface interval times undertaken by the Miskito divers, the Miskito divers exceeded the USN table no-decompression times by a factor of 2.8.

Decompression illness symptoms were obtained by interview from each diver after the last dive of the day. There were 32 reports of DCI symptoms following 88 interviews (36.3%). A total of 24 occurrences of joint pain were reported by six of the eight divers with 18 occurrences (75.0%) of pain reported in the upper extremities. All but one of the six reported occurrences of joint pain on multiple occasions. Of these same divers, four also reported additional occurrences of fatigue, dizziness complicated by ear barotrauma, low back pain, and generalized pain. Of the two divers not reporting joint pain, each reported a single occurrence of a headache and one reported two instances of low back pain. Acetaminophen 500 mg is the standard pain medication used by these divers. Use of pain medication closely followed reported incidence of DCI and was reported in 35% of the interviews. In no case was recompression or oxygen therapy administered.

In this survey, seven of eight divers attributed DCI to the depth and time under water. However, five of eight of these same divers also attributed DCI to superstitious dreams of a mermaid that they believe would cause serious DCI on a subsequent dive. Joint pain is often attributed to water temperature or to heavy use of the conch hammer.

While the incidence of DCI is high at 36.3%, it may be underreported. The observer noted that these divers were often reluctant to talk about symptoms because to do so is a sign of weakness. Further, he noted that at least one diver's reports were notably affected by marijuana intoxication. Diarrhea was reported by two divers and was a common ailment during the trip. Diarrhea may have adversely affected fluid balance and thus altered the susceptibly of these divers to DCI.

A second objective of this presentation is to report on a retrospective chart review of DCI among Miskito Indian underwater harvesters treated at the St. Luke Medical Mission in Roatan, Honduras. The facility was the primary DCI treatment facility in Honduras from 1989 until the Mission closed in 1997. The Mission operated a 10 foot by 54 inch, double-lock, decompression chamber. In its 9 yr of operation, the facility treated over 700 cases of DCI, including both recreational divers and underwater harvesters.

Included in the present study are 302 identified lobster or conch divers who underwent hyperbaric treatment at the St. Luke Medical Mission from September 1991 to November 1996 and received both pre- and posttreatment neurologic examinations. All cases were examined by medical staff at the Mission using consistently applied neurologic evaluation criteria. All cases of DCI were treated with at least one USN standard treatment table 5 or 6 (2), and 81% received more than one treatment.

Delay to treatment is recorded in days, as reported by the diver from onset of symptoms to treatment in the chamber. Median delay to treatment was 3 days with a mean delay of 8.5 days and a maximum delay of 265 days. Because of the potentially negative repercussions within the local community of denying treatment to a Miskito Indian and in an effort to encourage them to use the chamber, the St. Luke Medical Mission maintained a policy of treating all divers despite long delays. Of the 23 cases treated with delays exceeding 30 days, 11 failed their initial neurologic examination; of these, four improved to passing.

This delay cannot be explained by evacuation distances alone. The Mission's hyperbaric facility maintained a medically equipped, fixed wing aircraft and was situated approximately 2.5 h flying time from the nearest point of land to the fishing grounds located approximately 200–600 nautical miles off coast. Under these conditions, the maximum potential delay to the hyperbaric chamber would be expected to be 70 h. The excessive delay reported in this review may represent efforts by the Miskito Indians to seek traditional (bush medicine) therapies elsewhere, to ignore or refuse treatment for some length of time, or to continue to dive with neurologic symptoms (observation by GWS).

The pre- and posttreatment neurologic examination given to all cases comprised a total of 79 focal neurologic tests. Included in this analysis are a subgroup of 58 focal tests of spinal cord function that were measured in ordinal scale. These were categorized into 10 groupings of neurologic function. Not every focal test was completed for each pre- and posttreatment examination. For example, if a particular site tested normal before the initial treatment, it was not necessarily tested again after hyperbaric treatment.

Examination data for the first 257 cases analyzed were recorded in Quatro Pro spreadsheet format with one case per spreadsheet. The remaining 45 cases were input into a FoxPro database using input and formatting criteria consistent with the original Quatro Pro format, with one record for each examination. The original 257 cases were transformed to database record format and joined to the 45 cases to form the 302-case data set containing results from 1,727 diver examinations.

All 10 neurologic functions were reduced to an initial and final result based on the lowest value contained in the focal tests comprising that function. The lowest initial value was selected from the focal neurologic test administered before the first treatment. The lowest final value was selected from the final value reported for each the focal tests. Missing values and results between the initial evaluation and last reported values were ignored. Except for those test sites that were initially normal, a posttreatment value was required for a test site to be included in the analysis. Even if the initial examination value was missing, final values were included if available. Results of the initial and final analysis were then dichotomized to a pass or fail score for each neurologic function.

Strength was measured bilaterally in the shoulders, elbows, hips, and knees, with both extension and flexion. Ankles were evaluated for dorsal and plantar flexion. Grip strength was evaluated for flexion, long toes for extension, and small toes for flexion.

A passing score for strength was defined as active movement against full resistance or active movement against some resistance. A failed score resulted where strength was limited to active movement against gravity, active movement with gravity eliminated, palpable or visible muscle contraction, or total paralysis.

Sensation was evaluated at the medial and lateral aspects of the upper arm, fore arm, thigh and calf, and at the top of the hand and foot. Initial screening for areas of reduced sensation was performed by the examiner passing his hands over the patient's skin. Detailed evaluation of areas identified as abnormal was then performed with two point discrimination testing, with points set 5 cm apart for the upper and lower extremities. Those unable to discriminate two points were evaluated for detection of light touch by passing cotton or fingers lightly over the skin. Failing that, they were evaluated for detection of a light pressure applied by a finger to the affected area. Those unable to discriminate light pressure were evaluated for heavy pressure. A final test for deep pain sensation by pinch was performed on those failing all previous tests. For this analysis, failure to detect light or heavy pressure or deep pain was considered failing.

Reflexes were ranked from normal to most abnormal in the following progression: normal, hyporeflexia, absent reflexes, hyperreflexia, and sustained hyperreflexia. Passing score included normal, hyporeflexia, and absent reflexes.

Vibration sense was evaluated at the elbow, patella, and medial malleolus. Values for vibration sense, clonus, Rhomberg test, and micturation were recorded on a three-point ranked scale that included normal, equivocal, and abnormal. Equivocal values were equated to normal during analysis. Tandem gait and Babinski were similarly ranked on a three-point scale in the first 257 cases, however, equivocal values were later equated to normal when merged with the final 45 cases, as those cases were evaluated by the examiner as normal and abnormal only.

Profound lower extremity dysfunction precludes performance of tests for gait, tandem gait, and Rhomberg. To more accurately describe the condition of affected cases, missing values for gait were replaced with failed when the results of hip or knee extension or flexion for one or both sides indicated an inability to move against gravity. The Rhomberg test was replaced with missing if the hip and knee strength values were at that level. The St. Luke Mission did not test for tandem gait in the first 84 cases in this series. As such, data replacement for tandem gait in those cases was not performed, but was done where indicated in subsequent cases.

Figure 4 shows the initial and final results for failed examinations for each of the 10 neurologic functions.

Strength and sensation showed highest initial failure rates at 39.1% and 37.4%, respectively. They also demonstrated high improvement rates (67.8 and 66.4%, respectively). Strength, sensation, and vibration sense dysfunction limited to the lower extremity occurred in 82.4% of the examinations that were initially failed. This finding is consistent with other reports on this type of diving population (3). However it is inconsistent with the 75% upper extremity joint pain symptoms reported by the field divers given earlier in this report.

Clonus and Babinski are the least sensitive tests in this data set, however they represent a more profound level of neurologic involvement than either strength or sensation. They also showed the lowest improvement rates of the 10 neurologic functions examined.

Severe gait disturbances were common, with an initial failure rate of 35.1%. Gait is affected by clonus, reflexes, sensation, and in particular, strength and proprioception and would be expected to show a high level of dysfunction because of the high levels of those neurologic functions that affect it. After adjusting for cases not tested, gait showed high levels of initial dysfunction at 36.9%.

The Rhomberg test results included a high number of missing values, the majority of which reflect a diver's inability to attempt the test. Where testing was completed, the Rhomberg test showed the highest improvement rate of any neurologic function with treatment.

The first 86 cases in this review were not tested for ability to perform tandem gait. This test emerged as the most commonly failed neurologic function at 42.6% after adjusting for missing values. Tandem gait is affected by all those neurologic functions affecting gait as well as balance as represented by the Rhomberg test. Given the high number of failed examinations in many of the prior neurologic functions, it is not unexpected that tandem gait would also show a high level of failure.

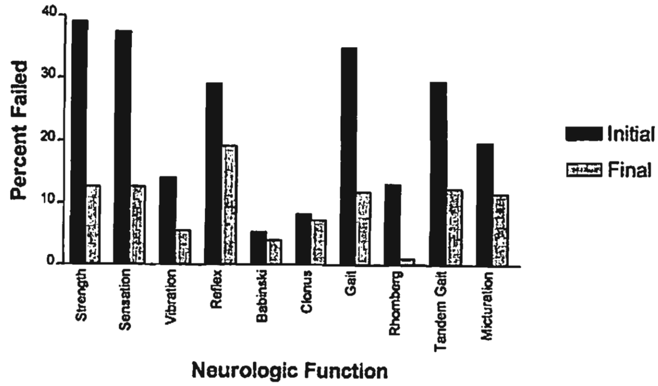

Figure 4: Initial and final results for failed examinations for 10 neurologic functions assessed. Bars indicate percent of cases failing to achieve a passing score for the initial (*black bars*) and final (*gray bars*) examinations on each of the 10 neurologic function assessed.

Micturation dysfunction, as defined by requiring a urinary catheter, exhibited a low initial failure rate at 19.9%. Micturation is clinically remote from the other neurologic functions in this analysis but also represents the most profound neurologic level of involvement of the 10 neurologic functions tested.

These results do not reflect qualitative reports that suggested high levels of micturation dysfunction in this type of indigenous diver (3,4). Micturation has also been reported to be the most difficult to reverse completely (5). In this series, micturation showed a moderate 41.7% improvement rate when the criteria for a passing score included difficulty urinating without need of a catheter.

Gait, sensation, strength, vibration sense, tandem gait, and Rhomberg showed a high level of improvement. Babinski and clonus showed substantially less improvement with treatment. All neurologic functions showed al least some improvement with treatment. Adjusting for missing values did not substantially alter these results.

Overall, at least one neurologic function failed in the initial examination in 69.2% of the cases evaluated. Following final hyperbaric treatment, 35.1% of cases failed at least one neurologic function. Table 1 shows the percent of failed examinations for delays ≤3 days and for several groupings of delay beyond 3 days. For delays 6 days and beyond, the proportion of improvement is similar to that seen in delays less than 6 days

Reports suggest that delays in treatment reduce the effectiveness of recompression therapy (6). These reports however, involved delays of generally less than 24 h, involve military

Tbele 1: *Initial and Final Results by Delay to Treatment for 302 Cases*[a]

	Failed, %			
Delay, days	Initial	Final	Improved, %	*n*
≤3	78.2	42.5	45.5	174
>3	57.0	25.0	56.2	128
>6	55.7	30.0	46.2	70
>9	63.5	34.6	45.5	52
>12	63.6	36.4	42.9	44

[a]Medial is 3-days delay with a mean 8.6 ± 20.3 days and maximum delay of 265 days. Results are expressed as a percent of cases failing to achieve a passing score on at least 1 of the 10 neurologic functions assessed after all treatments were completed. Delays ≤3 and >3 days comprise all cases in the study. Delays >6, >9, and >12 days comprise results for decreasing numbers of cases as delay increases.

divers, and concern primarily type I DCI. Other authors have noted that it is not uncommon to observe symptoms improve by recompression after delays of 24 h in open-water, civilian divers (5,7). In one case, neurologic symptoms improved after a 4-day delay (7).

While the 35.1% overall failure rate seen in this study following treatment is high, the data also indicate that even after extended delays, improvement in neuroloogic function to passing score is achievable in a portion of the population.

Results from the 1998 field study confirm our earlier observations that the Miskito Indians dive highly stressful profiles with dive times far in excess of that allowed by USN tables. We also observed a high level of DCI symptoms in those for whom no recompression therapy is given in the field. The results of treatment at the St. Luke chamber indicate a high level of presenting neurologic dysfunction. After treatment a high level of dysfunction persisted. Nevertheless, despite long delays to recompression, nearly half of the cases improved from failed to passing under the criteria imposed on the analysis. These results suggest that DCI treatment may be effective in improving serious neurologic DCI in cases where delay to treatment exceeds 12 days.

REFERENCES

1. Dunford RG, Arrazola FL, Salbadr GW, Hampson NB. Mosquito Indian lobster harvesters. Undersea Hyper Med 1994; 21(suppl):99.
2. U.S. Navy diving manual, vol 1 (air diving), Navsea 0994-LP-001-9010. Washington DC: Supervisor of Diving, Navy Department, 1993.
3. Blick G, Durth MD, Lond LRCP. Notes on divers paralysis. Br J Med 1909; 1796–1798, Reprinted in SPUMS J 1996; 26:1–4.
4. Bassett-Smith PW. Divers paralysis. Lancet 1892; 1(Feb 6):309–310. Reprinted in SPUMS J 1996; 26:1.
5. Erde AE, Edmonds CE. Decompression sickness: a clinical series. J Occup Med 1975; 5:324–328.
6. Rivera JC. Decompression sickness among divers: an analysis of 935 cases. Mil Med 1964; 129:314–334.
7. Kizer KW. Delayed treatment of dysbarism: a retrospective review of 50 cases. JAMA 1982; 247:2555–2558.

DISCUSSION

Mr. Dawson: Your observations about the use of alcohol by the divers is reflected very much in our study in the Philippines. Tell me, do you think that the use of alcohol by the divers actually reduces the incidence of some of the worst symptoms or increases them?

Mr. Dunford: Well, that's a very interesting idea and my answer to that is I have absolutely no idea. I have to leave it there. I mean, it's something that we should look at. But I could not make any comment. The data that we have doesn't approach that question at all.

Dr. Brubakk: One of the most interesting aspects of these studies is, of course, the baffling protean causes of the disease. We can learn a lot about what happens in decompression sickness and treatment of it by looking at this.

I was wondering about you're saying here in abstract that many different treatment procedures were used. Have you looked at the difference between the different people that received it? Did it really matter what kind of treatment you gave them or were the results equal for all of them?

Mr. Dunford: Not at this time. That's, I think, the next phase. We didn't take into account the type of treatment or even the number of treatments in this analysis. I think that's the very next step here.

Dr. Hamilton: Do you attach any physiological significance to the use of marijuana?

Mr. Dunford: No, I do not.

Unidentified speaker: Some of these profiles seem rather close together. Do you consider this to be yo-yo profiles?

Mr. Dunford: Yes, I think that the yo-yo concept of decompression stress is probably inherent in here because they're spending time at surface of less than 10 minutes on the majority of these dives and that, I think, has to be considered here as an additional stress factor.

Somebody did once mention that it would be a better idea just to drop these tanks down on a rope to keep those guys on the bottom. More bottom time but perhaps it would reduce the yo-yo stress. No, I actually do not. I personally think that yo-yo diving is a stressful type of profile, I don't have any data to support that.

Mr. Hurdle: (Victoria) You mentioned that they're not using any type of pressure gauge. Do they run out of air and then just come shooting to the surface when it's time to change their tanks?

Mr. Dunford: Yes, they have a very strong indicator to surface and that's there's no breath left and when that happens, they have approximately three breaths on that tank and that's what they use to get to the surface. So that's the gauge they use.

Dr. Wong: Richard, you may or may not be able to answer this question. It's about the mode of presentation for treatment. Why was table 5 used? Do you not consider table 6 more appropriate? And also why were so many patients treated with steroids?

Mr. Dunford: In our case study, there were no patients treated with steroids that I'm aware of. All right, it's not reported. Why table 5 was used in lieu of table 6 on these pretty long delays was a decision made by the Roatan chamber.

I had no part in it and I don't know the explanation for it and you might have to direct that question to Gus. He may have the explanation. I don't.

Dr Lepawsky: Dr. Barratt, have you got any comment on that?

Dr. Barratt: Yes, I think that the reason why they're using steroids is they didn't have hyperbaric chambers and they were treating decompression illness just with steroids and physical therapy. Then at the time the chambers came about, they got used to using steroids.

Apparently the steroids worked so they continued to use them. As far as table 5 versus table 6, the chamber has been in operation since 1981.They've got a pretty standardized system where everyone who comes in either gets a table 5 or a table 6 and I think it depends on oxygen. It's so severely limited. If a guy is very severely injured, they'll try to give them a table 6 but a lot of them will just get a table 5.

Mr. Dunford: Gus, do you want to add to that?

Dr. Salbador: (Honduras) We normally treated most patients right after with a table 6 because most of the patients were presenting with a neurological condition. Now, some can—and again staying on oxygen—we treat with table 5. Sometimes we'd follow up with a table 5 and then later on we'd do what we called a "two-by-two step." [2 ATA × 2 hours × 2 per day, editor]. Sometimes we give 15 treatments.

Mr. Dunford: "Two-by-twos" are 45 minutes for 45 feet for 90 minutes.

Dr. Salbador: No, 33 feet.

Mr. Dunford: Oh, sorry, 33, okay.

Dr. Mitchell: I thought I had one question here. A comment here. While I definitely agree that in your delayed treatment, you're almost certainly affecting processes that are not probably related at the time, I would be reluctant to draw the conclusion that you aren't affecting bubbles because if the system's bubbles are there for that long it doesn't fit the models.

There is very good evidence that the bubbles do exist for that long, both in the cardiothoracic surgical literature and in the diving medicine literature, also. So I think it would be incorrect to draw that conclusion.

Mr. Dunford: I think that's a good comment. While there is no existing model to predict how long or how large the bubble would remain. We also have no data to show that it wouldn't persist.

Dr. Mitchell: In fact, there are.

Mr. Dunford: Alf has something to say about that. You'll have to talk to him.

Mr. Roy: I was wondering, do you know how long this fishery has been fairly active to do this as far as the exploration of a large number of long term leading up to this? Was it shallow water or can you anticipate the 60-foot area that might be going deeper and deeper?

Mr. Dunford: Well, let me answer that in two parts. One, I believe the scuba was introduced into the Miskito population in the 60s or 70s or so. There's no clear records for that.

On the other hand, on the question of depth, the presentation here is to adapt at the 60 feet because that's where the captain went because he had his observer on board. He wasn't about to go to 120-foot depth. But they go out there.

Our other 1994 data shows a 100-foot depth and I think they have been diving deep to get a lot of product because the lobsters that come—you find more deep than shallow even in a non-depleted area, I would think. Maybe I'm wrong there, I'm not a fisherman ichthyologist. But I get the impression that the depth is not being driven by product depletion to a large degree, although it may be a factor in what occurs as we continue to see them diving. There certainly is product depletion. They will find it deeper. They're going to go after it.

Dr. Barratt: Just a comment about the depth. The earliest information I have is from 1986 and they were going as deep as 100 feet in 1986.

DIVING-RELATED ACCIDENTS IN COMMERCIAL SEA HARVESTERS OF THE STATE OF YUCATAN, MEXICO

E. Cuanhtemoc Sanchez and Humberto Paredes

INTRODUCTION

The State of Yucatan is located in southeastern Mexico on the northern part of the Yucatan Peninsula. To the north and west lies the Gulf of Mexico, it shares its eastern and south-eastern borders with the State of Quintana Roo and its western and southwestern borders with the State of Campeche.

The State is located between parallels 19°29' and 21°37' North latitude and 89°32' and 90°24' West longitude. Yucatan has an area of 39,340 square kilometers. With 2.0% of Mexico's total territory, :it is the country's 20th largest state. Its 378-km coastline comprises 3.8% of Mexico's total coast, and it ranks 11th in terms of coastline.

Average annual temperature ranges between 25.4° and 26.3°C. May is the hottest month and January the coldest. Average relative humidity ranges from 66% in March to 89% in December. Mean annual rainfall along the coast is 469 mm and 1,200 mm in the southern part of the State.

The State of Yucatan is divided into 106 municipalities, Mexico's equivalent to U.S. counties. The capital city, Merida, is the administrative center for regional federal offices, and the state has a number of other smaller cities.

According to the 1995 Mexican Census figures, Yucatan had a population of 1,555,733 inhabitants of which 772,950 (49.6%) were males and 782,783 (50.4%) females. Of the total population, 38% are under 15 yr old and 56% between 15 and 64 yr old. Population density is 39.54 inhabitants per square kilometer.

Merida is the Yucatan Peninsula's major health center. It has an excellent system of public and private hospitals staffed by graduate specialists in all areas of medicine. Government-operated hospitals and clinics provide medical care to approximately 960,721 people. These facilities are staffed by 2,132 doctors, 3,193 paramedics, and 4,346 employees in different areas of medical care. The government operates 243 medical units, of which 222 are for outpatient care and 21 provide hospitalization facilities. Government facilities include 1,347 hospital beds, 612 doctors offices, 69 laboratories, 5 blood banks, and other services.

Of the total number of men, 69.05% (366,304) are employed, whereas 17.93% percent of the women (98,999) are employed. This accounts for 42.94% of the EAP, totaling 465,303 persons.

THE SEA FISHERIES

The fish and seafood catch totaled 40,130 metric tons in 1995. Together, grouper and octopus (caught by divers) accounted for 75.2% of the State's total catch. Fisheries infrastructure is distributed along the entire coast of the state. There are currently 11 fishing shelters, the most important of which is the Yukalpeten facility. The fishing harbor there has facilities for mooring a large number of vessels and has the largest facility in the State for processing fish and seafood.

Other smaller-scale fishing harbor facilities are located at Celestun, Sisal, Chuburna, Chabihau, Telchac Puerto, Dzilam de Bravo, Rio Lagartos, San Felipe, and El Cuyo. In 1995, the fisheries sector generated revenue of 329,258,779 pesos. The more than 20,000 persons engaged in this activity are involved in the catch, processing, marketing, researching, and training. The fleet of larger vessels increased to 539 in 1995, which represents 50% of this industry. The fleet of smaller vessels expanded to 3,013 in the same period.

There are 13 different commercial diving sea harvesting companies in the State incorporated to the National Department of Fishery: San Felipe (SF), Rio Lagartos (RLm), El Cuyo (Cuy), Dzilam Bravo (DB), Progreso (Pgm), Progreso (Pgj), Rio Lagartos (RL3, Sisal (SGG), Sisal (Spp), Progreso (Ptp), Chixchulub (Cnc), Chixchulub (Ckk), and Progreso (Pps), with a total of 671 divers (Fig. 1). Ten of them (77%) were created in the 1970s and 1980s, two in the 1960s (15%), and one in the 1950s (8%). The percentage of divers in the personnel of these diving sea harvesting companies is an average of 74% (range 31–100).

DIVING PRACTICE

This group dive for lobsters and octopus. The equipment used by the divers is hookah with a gasoline-driven compressor from a boat, with one top-side assistant. The dive profile generally is a saw-like profile bringing to topside the net with the product and then resuming the dive. Usually a diver will remain inside the water up to 6–8 h without coming out unless they need a change of diving site. Thus they do not usually incorporate a surface interval. They dive with a wet suit and a face mask. The hose of the hookah runs free (no tender) and is tied to the weight belt of the diver. They do not usually use a life line. In the event that the top-side assistant considers that the boat is in jeopardy, he will cut the hose of the diver and save the boat, the diver will be left to his own luck. The line pulls are not accustomed in this group of divers. Refueling of the compressor is done with the motor on during the long hours of underwater work, and sometimes the fumes of the gasoline itself will contaminate the intake of the compressor. Preventive maintenance of the compressors is not usual, and the filters used for the intake are generally improvised. In some diving boats there is a small volume tank that would allow the air to cool and as a water trap. Routine drainage of the tank is not usual until the divers report water in the mouthpiece.

Since the divers are owners of their boats, they do not allow fellow divers to accompany them. Also, they are very jealous of their "own" diving areas and do not want to share them. Thus, they practice solo diving and have no help underwater and depend solely on their topside assistant

The diving season starts in July and ends in April. Divers dive 6 days a week during the diving season unless the weather does not allow them to do so. During hurricane season, which starts in November and ends in March, they may stop diving for varying lengths of time. Once the weather settles down, they try to recapture the lost working time by making more aggressive dives with longer bottom times.

DIVERS GENERAL INFORMATION

Divers live in small fishing villages. Normally, their homes are made of wood. They have a local general practitioner who will examine them in the event of a diving-related accident and will refer them to the chamber if needed. This general practitioner has received training from the Mexican Undersea and Hyperbaric Medical Society (AMHS).

All divers are grouped in small "cooperatives" (from 15 to 200 divers). They have several special programs to assist the families or members in case of a personal or group disaster. Nevertheless, the cooperatives are normally "ruled" by the middle man that would pay very low prices for the kilogram of lobster and will resell it later at 3–4 times the price paid to the divers. The divers are usually uninsured and the cooperatives have looked for medical assistance for the divers through the Mexican Institute of Social Security, which is the owner of the hyperbaric chamber based at Tizimin. In the event the diver develops a permanent lesion, he will only have support from the Social Security and not from the cooperative.

The average age of the divers (Fig. 2) is 30.2 yr (range, 18–58). Twenty-three percent of the divers have a diving experience of less than 5 yr, 50% have between 6 and 10 yr, 25% have between 11 and 16 yr, and 2% have more than 10 yr experience (Fig. 3). Thirteen percent are illiterate, 22% did not complete elementary school, 35% completed elementary school, 22% completed middle school, and only 5% completed high school (Fig. 4). Nevertheless, if we joined illiteracy and incomplete elementary school the average rises to 33% (range 0–100%) (Fig. 5). Diving is learned by practice and there are no tables to follow.

Many of them still are accustomed to heavy alcohol use around the dive site. Only a very small number used recreational drugs before diving, usually marijuana. The older divers try to promote healthier ways of living for the younger divers, although it is not necessarily followed by the young divers until they have their first accident.

DIVING ACCIDENTS

From 1988 to 1993, before the inauguration of the hyperbaric chamber at Tizimin in 1993, there was a total of 88 reported accidents, although it is believed that they were under reported. These diving accidents were managed at the naval hyperbaric unit at Isla Mujeres, Quintana Roo (5–6 h boat ride from the Yucatan diving areas). The information available from these accidents is scarce. We know that there were 88 accidents (90% received treatment) and 7 deaths. A total of 68 divers abandoned the activity for unknown reasons.

From December 1993 to April 1996, there were a total of 175 accidents (Fig. 6). The accidents happened most frequently during September (26%) and November (26%), that is when the temperature of the water gets colder and in the middle of the hurricane season, respectively. The months distribution is shown in Fig. 7. Seventy percent of the divers come from the Rio Lagartos and San Felipe areas, which are the two closest towns to the chamber at Tizimin (Fig. 8).

Only 2.6% of the divers developed symptoms while doing a no-decompression (no-D) dive. The rest of the divers dove an average bottom time of 4.5 times (range 0.6–8 times) above the no-D limits. Nevertheless, under 70 fsw the average bottom time was 2.5 times above the no-D limits, and above 70 fsw it is 6.5 times above the no-D limits. This means that the deeper they dive the longer they stay at depth, probably due to availability of the product they are diving for. Also, the divers report that they are now diving deeper because there is less product at lower depth, in part due to a non-rational exploitation of the natural resources. The average depth was 83 fsw (range 30–150 fsw). The average bottom time in all the dives was 223.3 min (range 15–480 min).

Fifty-two percent of the diving accidents were considered decompression sickness (DCS) type I and 48% had DCS type II. The most frequently affected area was the upper extremities (49.3%) followed by the lower extremities (20%).

Symptoms in 78% of the patients resolved with one or two treatments and those that required more than two treatments, accounted for 65% of the total treatments; the average number of treatments was 3.5 (range 1–58) (Fig. 9). Thirty-nine percent of the patients received treatment within 6 h, 43% between 6 and 24 h, and 18% after 24 h (Fig. 10). The number of treatments in the <6-h group was an average of 1.6 (range 1–4), in the <24 h was 2.25 (range 1–10), and in the >24 h group was 7 (range 1–58) (Fig. 11).

The US Navy treatment tables used were: TT5 in 65 (11.5%), TT5 :ext in 1 (0.2%), TT6 in 77 (16.6%), TT6 ext in 85 (15%), TT6A in 12 (2.1%), 45/90 in 115 (20.4%), and 33/90 in 210 times (37.2%) (Fig. 12). After several patients developed recurrence of symptoms after the initial treatment (TT5 or TT6) and due to the great gas load of residual inert gas that these divers have, we decided to modify the initial treatment. Regardless of their symptoms; we always started with a TT6 ext and the incidence of recurrence was reduced to 0.2%. The results of the treatments were satisfactory in 94% of the cases, 3% had no modification of their conditions, and 3% required further treatment after the first series.

CONCLUSIONS

There is a high incidence of diving accidents (39%) in the commercial diving sea harvesters of the State of Yucatan. This high number of accidents (175 from 1993 to 1996) is due in part to the inadequate diving practice of this diver population who has never received adequate training, and the little training they get is learned by word of mouth. Also, the use of hookahs allows them to have an extreme bottom time. Although they have been exposed several times to the US Navy diving tables, they have been taught by sport divers who try to teach them the use within the no-D limits, practice that does not allow them enough bottom time to do their recollection of sea products.

We have tried to introduce a two-diver system in one diving boat. Meaning that one diver would dive for 90 min and the other would then dive for the same time, each diver making two dives a day. This system would allow us to incorporate a 90-min surface interval between dives, reducing the excess of inert gas that they normally have in their diving profiles. Thus, two divers would do their 3-h dives divided into two dives with 90-min surface intervals, both completing their work shift in 6 h. This way they do not have to learn the diving tables and still would be closer to the no-D limits. Moreover, the topside tender would help to pull up the full net without the diver having to make saw-like profile and eliminating this risk factor.

We are confronted with other problems not related to their diving practice that hinder this practice. For example, the social, political, and economic organization of their diving companies. There is no limit of product that they can extract in a given day, so in a good one, they can dive up to 8 h without coming to the surface. In the northern part of the country, Baja California, the abalone divers can only extract 150 abalone per day, this limits their bottom time and helps to preserve their precious ocean product. If that system were incorporated into the octopus and lobster divers of the Yucatan Peninsula, we would be able to limit their bottom time and reduce the incidence of DCS.

Another important factor is that the companies sell their product to an intermediary who resells the product in the tourist areas (i.e., Cancun) and obtains the greatest part of the profit, without any risks. If the economic practice of the company changes, they would be able to commercialize their product directly without using an intermediary. Efforts have been made in the past to accomplish this, but they stall when one of the group making the proposal for a change dies mysteriously.

Furthermore, it would be expected that by raising the general education of divers we would be able to lower the number of diving accidents, although in this group of divers there is a higher incidence in a population that is 100% literate (Rio Lagartos) instead of that community that is illiterate (Progreso). We believe that the accidents are more related to the training than to general education.

The number of divers in a sea-harvesting company (in relation to fishermen) is also important because in certain companies (Rio Lagartos and Chixchulub) the diving members are 30% of the total members and they do not have enough votes to make changes within their company, although they might be responsible of 80% of the total income of the company.

In contrast to what is expected in commercial divers, the incidence of neurologic DCS is higher in this group, probably due to the length of their dives, saw-like profiles, and quick ascents without safety or decompression stops. Nevertheless, with thus type of profile, we would expect to have a higher incidence of DCS, permanent disability, or death.

The US Navy tables used as indicated in the Navy Manual were not as efficient as shown by the US Navy, probably due to the high inert gas load (average of 6 times above the no-D limits) that these divers have. When we started treating patients with TT5 or TT6, we had a 15% of recurrences of symptoms after the first treatment. By doing a TT6 ext as the first treatment we reduced the incidence of recurrences to less than 2%. Our trailing treatments after the TT6 ext were either 45/90 or 33/90, twice a day. We continue the treatment until there is no neurologic improvement in two consecutive treatments after treatment no. 10.

The reality of these divers, their lack of training, inadequate equipment, lack of government support, and the social, political, and economic foundation of their diving companies, promotes the high incidence of diving accidents. The donation of the hyperbaric chamber (1993) has allowed the accidents to be managed more adequately without the long delays of treatments due to the distance they had to travel before (6 h). During 2 yr we were able to provide training, lectures, and general support to the communities, reducing the number of accidents. Once we had to stop these efforts due to lack of support, the number increased 3 times over the year before. To be able to reduce this number, we need to have permanent participation in these communities, to truly modify the reality of this sea-harvesting diving experiences.

REFERENCES

1. Anuario Estadistico del Estado de Yucatan, INEG,I 1994.
2. Manual de Medicina Ocupacional-Enfermedad Aguda por Descompresion-adecuada. Ministerio de Salud de Republicade Chile, 1986.
3. US Navy Diving Manual. Washington, DC: Government Printing Office, 1985.

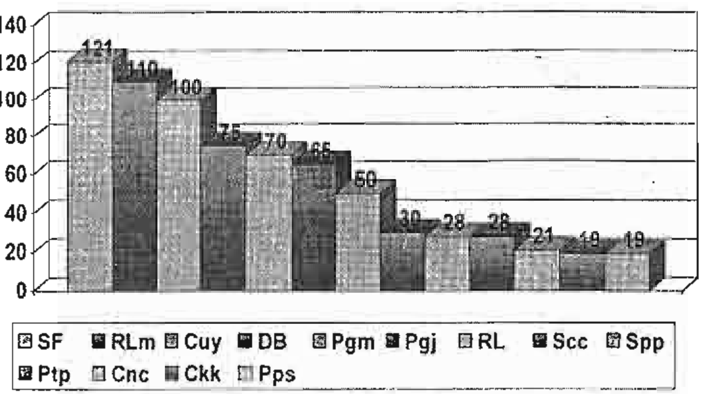

Figure 1: Number of divers per commercial sea-harvesting company.

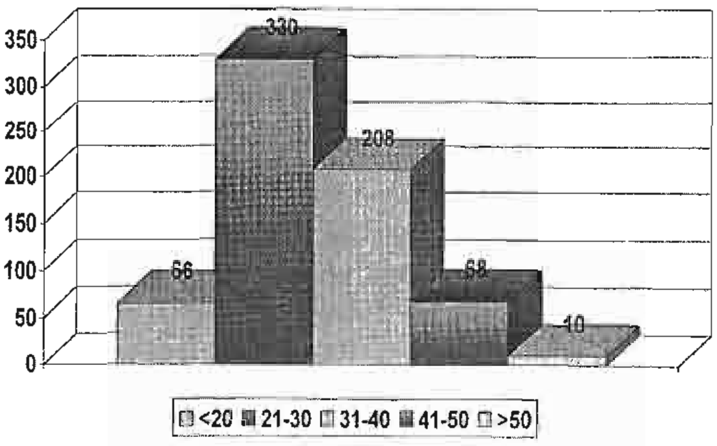

Figure 2: Histogram (years).

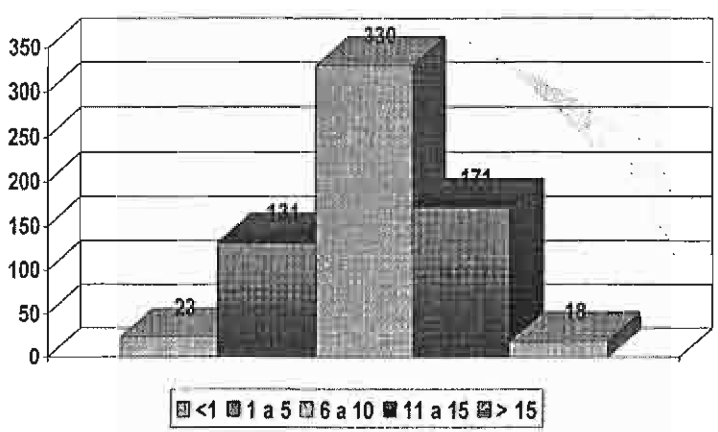

Figure 3: Experience (years).

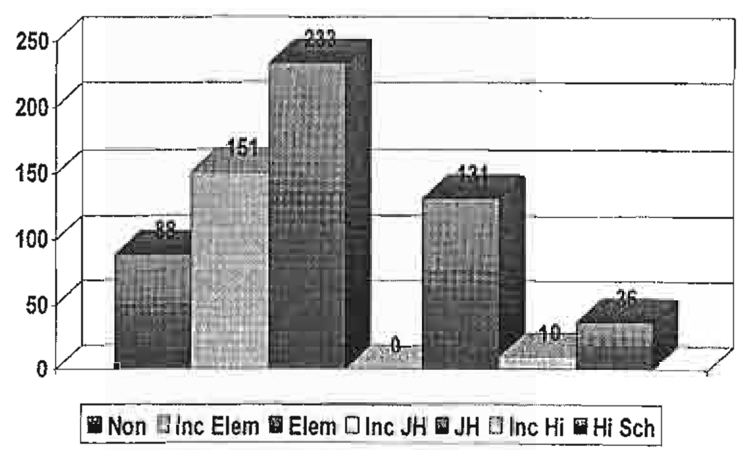

Figure 4: Schooling among divers.

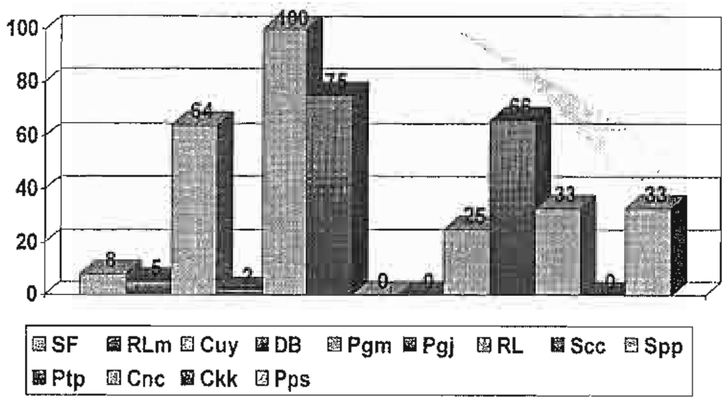

Figure 5: Incomplete elementary school/no schooling.

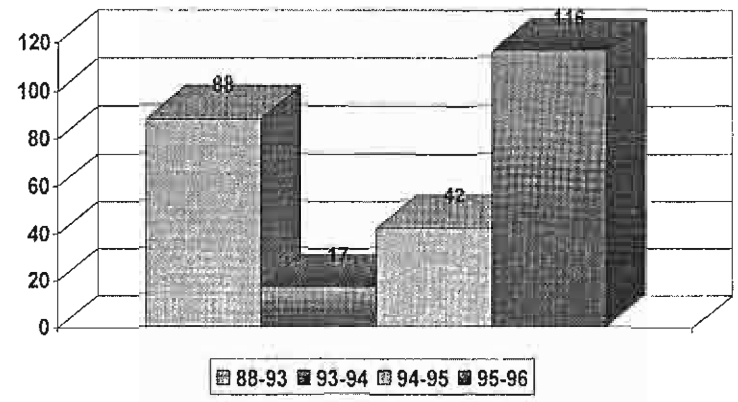

Figure 6: Number of accidents form 1988 to 1996.

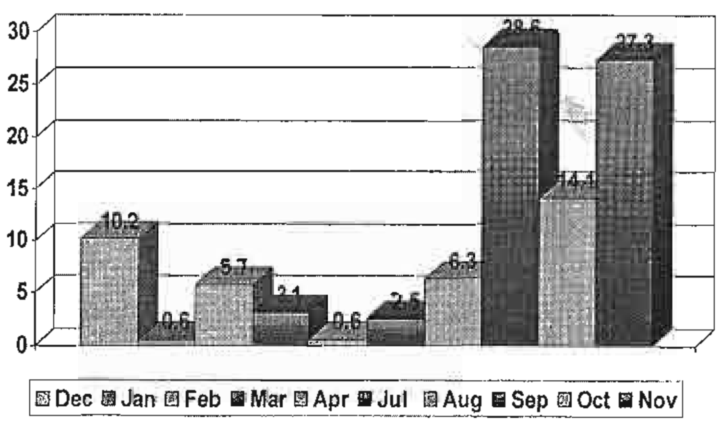

Figure 7: Distribution of accidents by months (percentages).

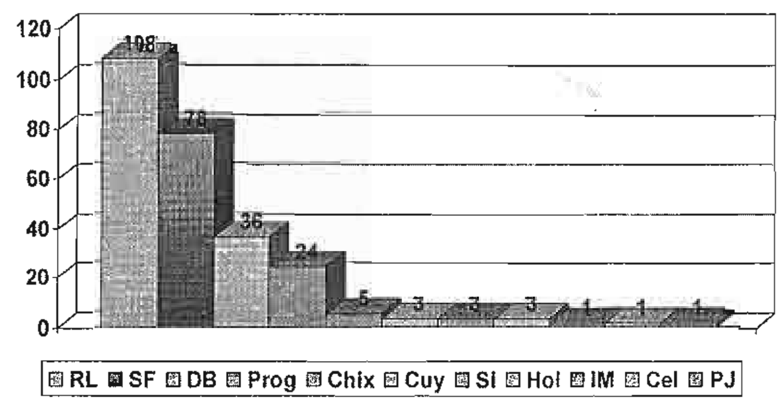

Figure 8: Diving accidents per diving cooperative.

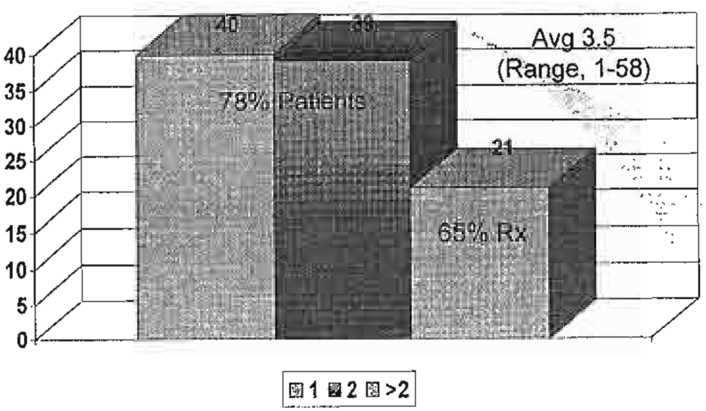

Figure 9: Number of treatments.

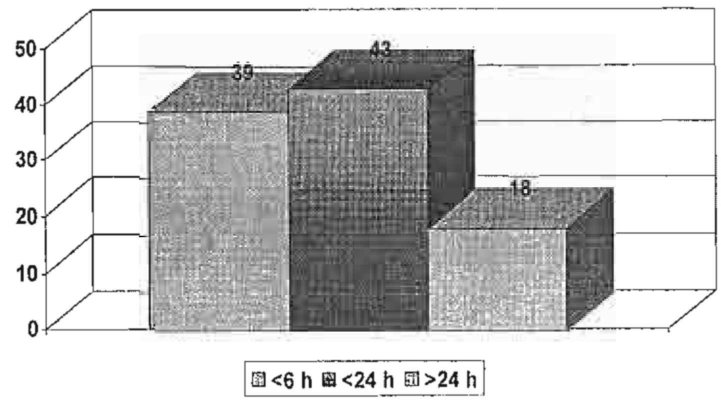

Figure 10: Number of treatments by hours delay to treatment.

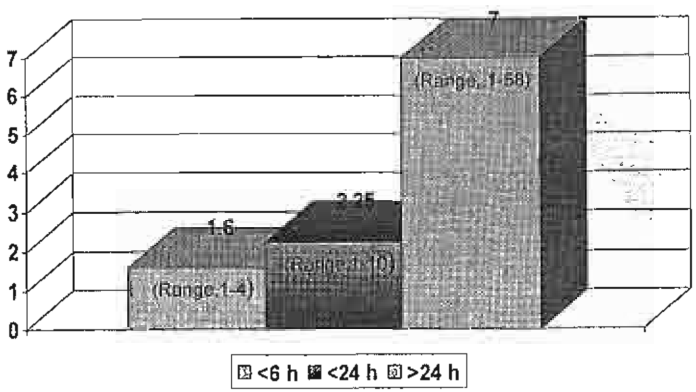

Figure 11: Number of treatments in function of the time to treatment (average).

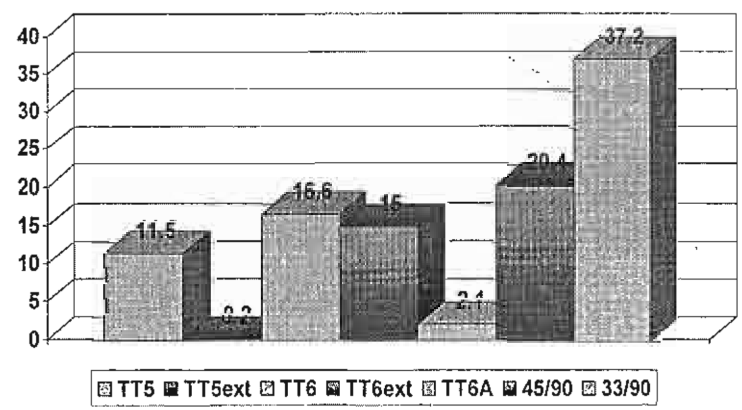

Figure 12: Treatment tables used (percentages).

DISCUSSION

Mr. Tabu: I wonder if they carry oxygen for divers?

Dr. Sánchez: No, they don't have oxygen. That's the next step. We are involved in many projects in Mexico. But the first thing that we did was for sports divers, we made a law that they must have oxygen available all the way from the dive area to the treatment area, regardless of where they are diving.

The next step is for the commercial divers to do the same from the diving area to the treatment area. The problem here is that the boats are not big enough to accommodate the big tanks. They don't have the economy for the big tanks. We might get the smaller tanks.

Fortunately, it's not such a long ride; it's between 30 minutes to 4 hours. So although it's very important to have oxygen, we might be able to accommodate smaller tanks.

What we try to do is to reduce the number of boats by keeping the same number of divers, then we will have to buy just one tank for two divers if we have this "two divers per boat system". That would be cheaper and easier for us so we might go to that. But if you enforce the law then all the boat owners will have to buy the tanks. It's a good idea and the second question was how many of them – ?

Mr. Tabu: They don't have any in-water recompression?

Dr. Sánchez: No, no, they don't do in-water recompression.

Mr. Gold: Have you found that there is an advantage with the hookah diver, the surface supply diver, precipitates decompression sickness? Is decompression sickness a normal part of everyday diving or is there an event on the surface that leads these people to emergency ascents?

Dr. Sánchez: In this part of the country, there's very little problems with trauma. I mean, there are sharks and all those things but there are not as many sharks as in the Pacific coast because of the temperature of the water. This is warm water, while the Pacific is very cold water.

The major event that they have is loss of air supply. Either the compressors stopped, their line got cut or whatever. So that's the major precipitating factor for them to make a quick ascent. But the problem is they don't stop, they go up as fast as they can. There is no way you can make them understand. Well, there are ways to make them understand but their normal practice is that they haven't incorporated that part into their dive.

We change a little bit at a time. They started with a.shallow dive and when they couldn't find the produce, they went deeper. What we have asked them to do is to go deep first and then come shallow for the produce for a natural decompression process. But remember they have huge gas loads.

The most frequent precipitating factor that they refer when they come and say, "I started to have a limb pain." "What were you doing"? They were either carrying something into the boat, cleaning the produce, or doing a physical activity before developing pains or paresthesia in the upper limb.

Dr. Gill: I'm interested in your comment that the divers incurred much more decompression than if they dove deeper and I think that in the Miskito divers we saw much the same thing. They tended to dive—the triplets that were shown and they'd dive, three of them.

I think what they determined in their dive was based on their continuing diving, they were higher. Depth was kind of secondary, whether it was 60 feet, 100 feet, 110 feet, they didn't say.

They didn't really pay attention to depth so much as how long they would actually be in the water to get the product. So when they get the stress load way up, and I think they sort of ignore that or minimize it.

Dr. Sánchez: I think that if you generalize, yes. But the thing that we see is that at the beginning of the season, they dive very shallow and it's very productive because they don't have to dive more than twice to reach the limits. But as the season goes on and progresses, they have to go deeper. When we include the hurricane season, they not only have to go deeper, but also longer because they have to make up for the days of lost work.

So that's why I think we are seeing a difference in the deeper dives, that they are longer because of the logistics of the diving itself and they have really made an impact on the product. The conch used to be one of the main resources, it's not anymore because there is not any more conch there. So they are diving for octopus and lobster.

This is totally different from the abalone divers of the Pacific. It's a different story. Just to make a very short comment on the differences, the good and the bad. The abalone divers in Porto Totoogus and Biye [?Baille] Totoogus in the Baja Peninsula, they contracted five biologists to study abalone. They have a huge factory. They can their product. They sell their product directly to Japan and they bought their own chamber and got their own physician trained. They have two airplanes to do the quick retrieval of patients and to deliver food and goods.

So it's totally different. It can be done but you have to organize that company. To get into that company, you have to wait 10 years. But once you're in and you dive, your family is cared for by that company. So it's like a big family. It's very difficult to get in. But then once you're in, you're in for good. So it can be done, it's just that you have to really change the whole attitude.

Mr. Kadis: (Queensland, Australia) I'm very interested in the outcomes of your treatments.

Dr. Sánchez: Good.

Mr. Kadis: The thing that interests me is the difference in technology (indiscernible) with very little return, 0.2 percent.

Dr. Sánchez: Now.

Mr. Kadis: Is that because you're able to follow them and here is the case or because they have that one treatment and they go away and don't come back? Could you give me the numbers again? The second point up for the T5? You said the T5 you had are much larger return --

Dr. Sánchez: Sixteen percent.

Mr. Kadis: Sixteen?

Dr. Sánchez: Of recurring symptoms. T5 and T6, both of them. The favorable results are 93 percent. There are 3 percent that don't get better and 3 percent that improve but don't come to a good outcome. Good outcome means that they have a normal neurological exam.

There are certain things I haven't mentioned that are very important. There is a group of divers that has recurring accidents. There is a group that has residuals from before. They are very difficult to identify.

Remember we just started to work in '93 with them butthey have been diving for more than 10 years. Once they get to the chamber, then we have our base line but it's difficult to have a base line before they have their first accident that we're managing.

INDIGENOUS FISHERMEN DIVERS OF THAILAND: HARVESTER-GATHERERS OF THE ANDAMAN SEA

David Gold

INTRODUCTION

Four hundred men between the ages of 11 and 50 are diving and using compressors to gather fish, seashells, and other marine products on Thailand's west coast. A research project, in partnership with the Ministry of Public Health, has been active for the past 2 yr addressing diving practices, the attitudes and awareness of divers toward the risks they face while diving, mortality and morbidity of the diving population, the extent of carbon monoxide in the breathing air, and informational and educational interventions to reduce the risks of diving-related injuries and illnesses. Many of the divers engage in diving practices that put the diver at considerable risk. These practices include diving without adherence to diving tables, diving without regard to decompression, diving without alternative air sources, and making multiple dives with little or no surface intervals. Several methods have been used to gather data, including field observation; specific questionnaires for heads of villages, active divers, disabled divers, and the family of deceased divers; physical examination; and the determination of presence of carbon monoxide in the breathing air. These divers suffer a high mortality and considerable disability compared to other high-risk occupations in Thailand. Of 108 divers physically examined, 46.3% had joint pain in one or more joints at rest or with movement (1). When questioned as to whether pain is considered part of the job, 83.7% (267/319) indicated yes (2 and Gold unpublished data).

PROJECT DESCRIPTION

In Thailand, in full concert with the Ministry of Public Health and three provincial medical offices, a special project was set up with a view to examining the diving practices of an indigenous group of divers and to provide assistance when and as appropriate. The project implementation team includes two occupational physicians, one environmental health specialist, one epidemiologist, the Chief Provincial Medical Officer of Phuket Province, four public health workers, and myself as project leader. The goal of the project is to explore diving practices, identify the risks the divers face, determine the attitudes of the divers toward those risks, determine the morbidity and mortality among the population, and develop and implement informational and educational strategies to reduce those risks.

The population at risk: The target population was a group of indigenous fishermen divers known as the Urak Lawoi (Gold, unpublished data). The Urak Lawoi, along with another group of indigenous people living to the north of Phuket, are known as the sea gypsies. The Urak Lawoi live in nine villages in three provinces between Phuket Island and the border with Malaysia. As some of the villages are quite small, that is less than 10 divers, the project has created six geographical groupings, three in Phuket Province, one in Krabi Province, and two in Satun Province. There are approximately 400 active divers at any one time. Only males dive. Virtually all of the divers speak Thai, and almost all of the younger generation is literate having completed Thai compulsory education. They normally start diving when they finish compulsory education and will dive until the age of 50 unless they are unable to continue (3 and Gold unpublished data). The distribution of divers by age is shown in Fig. 1.

The target catch: The divers hunt and gather fish and seashells for the tourist industry. They hunt shellfish for human consumption, including lobsters and crabs. They trap fish for both food and aquariums. They also seek pearls and sea cucumber. The target catch as well as distances to dive sites will vary during different seasons and weather patterns (3 and Gold unpublished data).

METHODS

The project was divided into several stages. The first stage is information gathering. It comprises of direct observation, questionnaire administration, physical examination, and measuring the presence of carbon monoxide in the breathing air. The second stage was designed to allow for interventions on several levels. Education is being provided for physicians, nurses, public health care workers, and divers. Information sheets have been designed for the divers. Since the project is ongoing and several informational and educational activities are currently underway, this paper will address only the information-gathering stage.

INFORMATION GATHERING

Direct observation: During the first year of the project, time was devoted to traveling to the villages on Thailand's west coast where divers could possibly reside. Interviews were held in Thai language with village chiefs, dive leaders, and divers and their families. This information became the basis for the

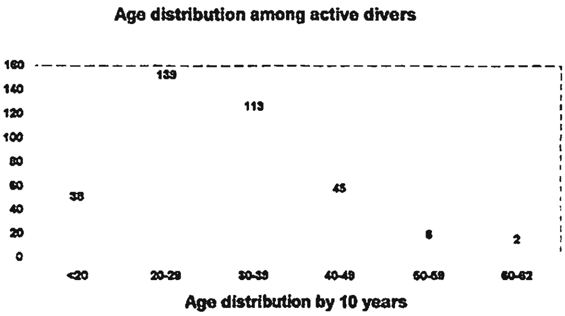

Figure 1: Age distribution of the diving population.

questionnaires described below. Members of the project team also accompanied divers on their boats and observed both surface activities and diving techniques. Field observations were recorded.

Questionnaires: Based on field observations, four questionnaires were designed, translated, and piloted, following a World Health Organization (WHO) methodology (5). Questionnaire 1 addressed the chiefs of villages; questionnaire 2, the active diver; questionnaire 3, the disabled diver; and questionnaire 4, the family or coworkers of deceased divers. In all four questionnaires, most of the questions were closed; that is the responses were restricted to a given set of answers that the interviewer checks off. Some questions were open where the interviewer recorded the answer as stated. And some questions were both open and closed where the interviewer would have the ability to fill in a response that was not covered by the given responses. Sixteen health care workers from the provincial medical offices and the sub-districts and villages where the Urak Lawoi reside were trained in implementing the questionnaire. All interviews were conducted in Thai and the results were analyzed using EPI-Info 6 Software (3 and Gold unpublished data). The questionnaires addressed some basic demographic information, diving practices, awareness of risk and attitudes toward risk, and the morbidity of decompression illness, which is defined as decompression sickness and pressure-related injuries or barotrauma.

Diving practices: Several diving practices were covered by the questionnaire. For the purposes of this paper, responses regarding four practices will be examined. These include the measurement of depth and time, the deepest dive recalled, adherence to diving profiles, and conducting decompression and/or safety stops on ascent. Divers were asked in the questionnaire how they measured depth and time. They were also asked to recall their deepest dive in their career.

The U.S. Navy (USN) tables for non-decompression diving have been developed with a view to reducing the risk of decompression sickness (6). As a proxy to diving practices, divers were asked to recall their depths, times bottom times, and surface intervals of the first five dives of their last day of diving. This information was entered into the USN table to ascertain whether the divers were within the limits set by this table. Divers were also asked whether they would make a stop, being a decompression stop or a safety stop (3 min at 5 m) on a 40-m dive for 30 min (3 and Gold unpublished data).

Mortality: Within the villages of the Urak Lawoi, neither registries of divers nor registries of death are maintained. Therefore, to ascertain a history of diving and death within this population, it was necessary to first determine who died, whether they were a diver and whether the death was diving related. Using the WHO methodology mentioned above, a questionnaire on deceased divers was developed, piloted, and finalized. Sixteen village and sub-district health care workers were trained in administration of this questionnaire. With information ascertained from the chief of the village, the health care workers interviewed the family or work colleagues of any male over the age of 11 that died within the 5 yr before the survey. This selection was made as only males dive and they start diving after they complete compulsory education (age 11). The village health care worker was selected to administer the questionnaire, as this individual is normally well aware of the health patterns within the village. As the Urak Lawoi are indigenous people living in rural villages, postmortem examination is uncommon. In defining diving-related deaths, certain clinical signs and symptoms that are directly related to diving practices and not normally found in the population were used. The project team considered each death according to causes or reported signs and symptoms likely to be diving related. These included paralysis and sudden death (2 and Gold unpublished data).

Morbidity: Questionnaire—As part of questionnaire 2, divers were asked several questions about selected signs and symptoms relative to diving-related illness. For this paper, the following were addressed: whether the diver believed that pain was part of his work; whether the diver often experienced joint pain, tingling, loss of sensation or the inability to move as a result of his diving; and whether the diver ever experienced and recovered from decompression sickness (DCS). (Within this population, DCS refers to a situation leading to paralysis, unconsciousness, or more severe signs and symptoms (2).

Physical examination: Two senior medical students from the United Kingdom worked with the project for just over a month as part of their senior project. A neurologic assessment tool was developed and they conducted neurologic examinations in four villages. The results of their assessment were later verified by a follow-up examination of a number of selected divers in two villages by an experienced medical practitioner. The physical examination included the tympanic membrane, an examination of joints for pain, crepitus and restricted movement, lower limb neurology, clonus, lower limb power, reflexes, sensation, coordination, and incontinence of urine or feces. The divers were examined for joints that may have been damaged by long-term exposure to diving. The shoulder, hip, knee, and ankle were examined for pain, crepitus, and restricted movement (2).

RESULTS

The trained public health care workers interviewed nine heads of village, 340 active divers, 26 disabled divers, and the family or colleagues of 29 males who died over the past 5 yr.

Diving practices: From questionnaire 1, it was learned that diving is done from open boats ranging from 7 to 11 m in length. There are approximately 86 dive boats in active use. Four boats have gasoline-driven compressors and 82 have diesel-driven compressors. Normally two to four divers are working underwater at any given tim (3)e.

Breathing air is supplied from a very basic compressor on the boat. Unfiltered air passes through approximately 100 m of plastic hose to the diver. A hose from the compressor is secured by a rope to the diver's waist and is attached to a tire valve pierced through the skirt of the diving mask. The diver inhales and exhales through his nose, the exhaled air escaping through the skirt of the mask. The diver has no alternative air source (2 and Gold unpublished data).

Regarding the measurement of depth and time underwater, as the divers are fishermen they were well aware of depth based on their knowledge of the bottom or the length of anchor lines or air hoses. On the other hand, regarding the measurement of the amount of time spent underwater, over half of the divers either guessed or stated they did not measure time (3 and Gold unpublished data).

Regarding the deepest dive recalled in the diver's career, 27% responded in depths of less than 40 m. An additional 58% had dived to depths between 40 and 59 m. And 14% had dived to depths 60 m and below (3 and Gold unpublished data).

Concerning the questions relating to the dive profile and comparison of these profiles to USN tables for non-decompression diving, of the 275 divers who responded only 26.9% (74/275) of the divers were within the limits of these tables (3 and Gold unpublished data).

Concerning a safety stop or decompression stop on a 40-m dive for 30 minutes, the USN tables call for a 5-min decompression stop at 6 m and an additional 21-min stop at 3 m before surfacing, with a total of 28 min 20 s of decompression (4). Of the 318 divers that responded to the question, 45.9% (146/318) indicated that they would not make a stop (3 and Gold unpublished data).

Mortality: Through the Chief of Village Survey, it was estimated that there are approximately 400 indigenous divers at any one time among the Urak Lawoi. All are male and between the ages of 13 and 62. Results of the survey for deceased divers indicated that there were 29 deaths of males over the age of 11 within the whole Urak Lawoi population and that of these 29 deaths, 13 had dived using a compressor (Table 1). Therefore the mortality rate for the population of divers was 13/400 for the 5-yr period. Six of the deaths were directly attributable to diving, leading to an occupational death rate of six deaths per 400 divers over 5 yr or 1.2 deaths per year (2).

Morbidity: When asked if the divers believed that pain was part of their work, 83.7% (267/319) indicated that they did (2 and Gold unpublished data).

Regarding selected symptoms of DCS divers were questioned if as a result of their diving they often experienced joint pain, 79.2% (270/341) responded yes; tingling 75.7% (181/239) responded yes; loss of sensation 70.7% (169/240) responded yes; and inability to move 8.7% (18/207) responded yes (2 and Gold unpublished data) (Table 2).

Divers were asked if they ever had experienced and recovered from DCS. Within this population, DCS most often refers to a situation leading to paralysis, unconsciousness, or other more severe signs and symptoms; 33.5% (113/337) responded that they had (2).

Physical examination: All of the 109 divers that were examined were active divers. Pain in one or more joints at rest

Table 1: *Deaths Among the Diving Population Over a Five-Year Period (1992–1996)*

Reference Number	Age at Death	Year of Death	Cause of Death	Diving Related Y/N	Profile of Last Dive, min/depth
01	65	1994	semi-paralyzed, hemoptysis	N	
02	61	1996	diabetes, hypertension, TB	N	
03	70	1993	fell into water drunk while securing boat to dock	N	
04	22	1994	complications of diving-related paralysis and amputations	Y	30/50
05	40	1992	paralysis after diving	Y	20/40
06	53	1993	paralysis after diving	Y	60/40
07	36	1994	acute onset of chest pain and hemotysis after diving	Y	30/50
08	18	1996	death within 5 min of surfacing	Y	10/60
09	30	1993	death in the water during a dive	Y	60/60
10	23	1995	seizure after drinking	N	
11	26	1995	drug-related death	N	
12	55	1994	acute asthma attack	?	
13	25	1995	murdered in a discotheque	N	

Table 2: *Signs and Symptoms by Village*

Name of Village	Joint Pain	Tingling	Loss of Sensation	Inability to Move
Rawai, Phuket	86.7% (85/98)	80.0% (56/70)	64.3% (63/98)	4.2% (4/95)
Koh Serat, Phuket	91.8% (78/85)	81.8% (36/44)	76.2% (64/84)	9.3% (7/75)
Sampam, Phuket	88.9% (16/18)	75.0% (6/8)	75.0% (12/16)	5.9% (1/17)
Koh Lanta	67.3% (33/49)	75.5% (37/49)	65.3% (32/49)	4.5% (5/49)
Koh Le Peh	66.7% (44/66)	77.1% (37/48)	63.6% (42/66)	7.9% (5/63)
Koh Boulon	58.8% (10/17)	47.1% (8/17)	47.1% (8/17)	0/0
Total	79.9% (266/333)	76.3% (180/236)	67% (221/330)	6.9% (22/317)

or with manipulation was present in 46.3% (50/108) of the divers examined. Crepitus in one or more joint was found in 18.5% (20/108) of the divers examined, and restricted movement was observed in one or more joint among 5.5% (6/108) of those examined (2).

Clonus was present in 14.8% (16/108) divers examined, 12% (13/108) of which had bilateral clonus. Raised muscle tone in the lower limbs was found in 11.1% (12/108 divers), 5.5% (6/108) bilateral. Reflexes were graded on a scale of 0 to +3. Those patients exhibiting reflexes of +3 were considered heightened. Heightened reflexes were found in the knee of 1.9% (2/108) divers both being bilateral and in the ankle 3.7% (4/108) divers 2.8% (3/108) bilateral. 9.3% (10/108) divers showed a Babinski sign, 6.5% (7/108) bilateral (2).

DISCUSSION

Although information is still under analysis, it appears that certain diving practices among the indigenous fisherman divers of Thailand, as compared to the diving practices of commercial and recreational divers, suggests that these divers may have more exposure to diving-related illness. These acute and chronic exposures have the potential for injury, illness, disability, and death. Future work will need to focus on logging depths and times on randomly selected divers to have a more objective view of diving practices.

The International Labour Office uses deaths per 100,000 workers per year as a rate of occupational fatalities. In Thailand, one of the more visible dangerous occupations is construction work. According to informal communications with the Workmen's Compensation Office in Thailand, in 1992 there were 92 deaths per 100,000 workers. As a result of data from this study it can be estimated that the annual rate of occupational fatalities among the Urak Lawoi is 300 deaths per 100,000 workers per year (2).

Interruption of air supply through compressor failure, loss of diving mask, or a cut or ruptured air hose is frequently the precipitating event leading to sudden death or disability, especially among younger divers. Working at depths for long periods point to more chronic effects such as damage to the joints and the central nervous system. Another possible future activity for the project could be to encourage the Ministry of Public Health to do a radiographic study to determine the degree of dysbaric osteonecrosis among the divers.

The problems cited above are compounded by limited access to medical care. Considerable effort is currently being devoted to the education and training of physicians, nurses, and public health workers on the prevention, diagnosis, and treatment of diving-related diseases.

A most important activity now underway is to develop knowledge and skills of the public health worker so that they can work with boat owners and divers to increase awareness to reduce the risks of diving-related problems (4 and Gold unpublished dadta).

As a glimpse toward the future of this occupation, one question in the survey asked if the diver could earn the same amount of money doing a job other than diving, would they change jobs; 66.7% (228/342) indicated that they would (1 and Gold unpublished data).

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REFERENCES

1. Gold D, et al. The indigenous fishermen divers of Thailand: attitudes toward and awareness of the hazards. J Safety Res 2000; 31:13–28.
2. Gold D, et al. The indigenous fishermen divers of Thailand: diving-related mortality. Int J Occup Safety 2000; 6:147–167.
3. Gold D, et al. The indigenous fishermen divers of Thailand: diving practices. Int J Occup Safety Ergonomics 2000; 6:89–112.
4. Gold D, et al. The indigenous fishermen divers of Thailand: Strengthening knowledge through education and information. J Safety Res 2000; 31:159–168.
5. U.S. Department of Health, Communicable Diseases Control Center, Division of Surveillance and Epidemiology. EPI Info 6. Atlanta (GA): Communicable Disease Control Center. 1996.
6. U.S. Navy, Sea Systems Command. US Navy Diving Manual, vol 1 (air diving). Washington, DC: US Navy, 1993:7-35 - 7-36.

DISCUSSION

Dr. Brodaki: Is the air free flow that supplies mask? There's no regulator at all?

Mr. Gold: Absolutely no regulator. They have a mask—and what happens if the compressor's a truck compressor. The mask is a diving mask and there is a tire valve where a hose is simply attached to it. So it just simply flows right through the mask all the time.

Dr. Brodaki: So the mask is enough breath?

Mr. Gold: They breathe through their nose. Well, in 10 metros for 10 minutes, I had a difficult time. I was able to breathe. I was able to stay down there but I wouldn't have wanted to have gone much deeper.

Richard just handed me a T-shirt that we provided the divers. I don't know if anybody reads Thai. It says, "Come up slowly from every dive", both in Thai and in Passa Chow Lay. It's very rewarding to go through the villages today, to just go onto a dive boat without them knowing you're coming and finding that 75 percent of the divers are actually wearing these shirts. It's a good mechanism at least because every time they come up, they have to read it just as a reminder that they should be coming up slowly.

Dr. Brodaki: How slowly?

Mr. Gold: Well, we simply say "slowly" to them. We ask them to come up slowly. We tell them slower than their bubbles. They have nothing else to gauge by. Most of the divers are in pain most of the time. So we have some difficulty trying to figure out whether or not change in the practice is good enough. But we can't gauge the speed.

Unidentified Speaker: Yes. I was just wondering. You mentioned a lost mask or a rupture of the hoses as causes of accidents. Is there any frequency to this, can you identify this frequency?

Mr. Gold: We are still analyzing a lot of the data. The project is young and it will go on for at least three or four more years. Hopefully, it will go on forever. I don't have an accurate answer for you on this today. We probably will in the future. But informally, when we interview divers that have had a disability, and our disability survey is under analysis right now. when we asked, "What was the precipitating factor that caused the accident?", it's either "Engine failure or the compressor, separation of air hose from mask, cut air hose, ruptured air hose or lost mask." I would say probably – and this is a guess – that 80 percent of the cases that we're dealing with where we have type two DCS or we have neurological DCS, we're dealing with this.

One other caveat, if I may. I realize I'm infringing on time here. We are also looking at the issue of in-water recompression. Now, I've told you that we've had six diving-related deaths in five years. We've also asked the question and we're in the process of analyzing the issue of in-water recompression amongst our cohort.

But my guess would be that if these guys did not practice in-water recompression—I don't know where they learned it—but if they did not practice in-water recompression, we'd probably look at 20 to 30 fatalities rather than six fatalities over the five-year period of time.

Any one of the divers will tell you if someone comes up unconscious, if someone comes up paralyzed, if someone comes up in trouble, we stick them back in the water, we go down to 10 meters and we stay there until they improve. They go down with two divers, they hold the mask in place, they're on air. So it's 10 meters until paralysis shows improvement.

Many of the people that are walking around the villages today have been either paralyzed or unconscious when they've come up to the surface. They've been brought down to depth by their colleagues and they have shown signs of improvement.

Unidentified Speaker: Why 10 meters of air?

Mr. Gold: I don't know. I don't know why -- where they got the criteria for 10 meters. But somewhere someone along the line -- it may have been the Royal Thai Navy but I have asked them and they have said, "Not us". But someone somewhere along the way has told them 10 meters until there's improvement and they practice it with a high degree of regularity.

Mr. Aguarda: How often is the chamber used for treatment of DCS?

Mr. Gold: We had a bit of difficulty initially. The chamber is a commercial chamber. It's been put in by an American organization.... The chamber operator at that time, one of the partners in this organization, agreed that if there was a certain amount of money put forward by the Ministry of Public Health, we could put sea gypsies in the chamber. There was a high degree of reluctance amongst the sea gypsies to go into the chamber.

Like was reported earlier, they're not afraid of mermaids; they're afraid of what they call the "Pry Nam". The Pry Nam is the ghost in the sea that would pull you back into the sea and kill you if you don't treat him properly. There is a very strong distrust for modern medicine.

But through the education efforts that we're putting forward and through the local person in the village who's responsible for health care—it's a long answer to a short question—we managed to have eight divers treated, all with successful outcomes. Usually the delay is quite significant. I don't have data for you like my colleagues do on the treatments and the delays at this point.

The problem with carbon monoxide and diesel emission is quite significant, in my mind.

TUNA FARM DIVERS OF SOUTH AUSTRALIA

Christopher J. Acott

INTRODUCTION

Tuna fish are one of South Australia's natural resource. A majority of the tuna fishing is conducted in the Southern Ocean. Fisherman divers (the abalone divers of south and southeastern Australia, salmon divers of Tasmania, and the pearl divers of the tropical north) are part of the "fishing culture" of Australia. Communities of some Australian coastal towns depend on fishing for their livelihood. Port Lincoln, a southern coastal town, is the center for the South Australian tuna industry. It has a population of 12,000. It was first settled in 1834 and was to be the capital of the new colony of South Australia because of its deep natural harbor. However, a lack of an adequate fresh water supply and the barren land interior prevented this. Its main industries now are fishing (tuna and abalone), grain exporting, tourism, and wine production. The community is "governed" in part by the "fishing families", who have powerful political contacts.

FISHING

Until the 1990s the tuna industry used traditional fishing methods. Now, however, tuna schools are netted in the open sea and brought back to Port Lincoln in large nets, where they are kept in netted enclosures near the shore for fattening before harvesting. The main export market for the tuna is Japan. The divers are employed for net maintenance, clearing the dead tuna from these enclosures, and initially in the tuna harvest by swimming the fish to the surface [this involved many extremely rapid ascents "per dive" from depths of up to 18 meters of sea water (msw), this practice was stopped by the regulations introduced in 1995]. Two nets are used in the netted enclosures; the inside net houses the fish and an outside net prevents any intrusion by sharks. Sharks have been found between these nets but to date no diver has been attacked by a shark However, this may reflect a lack of reporting of any such attack. Government marine biologists have expressed concern about the impact the nets are having on the environment. All the debris from feeding and fish excrement are deposited below the nets, no attempt has been made to clear this. (One storm has already stirred up this debris and suffocated millions of dollars worth of fish.) The presence of the tuna has encouraged sharks (particularly the Great White) to the area where the nets are. These areas are near the local beaches.

THE DIVERS

Between August 1993 and January 1995, 17 divers employed in the tuna industry were treated for decompression illness by the Royal Adelaide Hospital's Diving/Hyperbaric Unit (RAH D/HMU). Many of these 17 divers continued to dive while symptomatic. In all but one case there was a delay before medical treatment was obtained. From January 1995 a further four divers were treated, making a total thus far of 21 divers. Two deaths have occurred: an untrained diver failed to surface (despite regulations being in place from 1995) after running out of air, the other death was a suicide related to the death of the other diver. These two cases are under police investigation at present and so will not be discussed any further. The initial response by the South Australian Government and Medicare to this cohort of 17 divers was that the RAH D/HMU's medical practitioners were "overservicing" these divers and so were guilty of fraud, despite the RAH D/HMU's attempts to alert the appropriate regulatory body, divers, and their employers to the dangers of their diving practices (an investigation into the treatment practice of the RAH D/HMU was carried out secretly by Medicare). By the end of 1994, the bureaucrats recognized that a significant problem existed, and regulations were put in place despite considerable opposition by both the tuna farm owners and the divers' employers. From 1995, these regulations produced by the Department of Industrial Affairs and Workcover have resulted in a decrease in the incidence of reported cases of decompression illness. The incidence of decompression illness in this diving population is unknown. Many divers elect not to seek treatment or report their symptoms for various reasons, the main one being a fear of losing their employment.

DIVING PRACTICE

The initial working environment was undisciplined and unregulated. Their diving profiles involved multiple rapid ascents, multiple dives per day, and multiple days diving with only 1 day off per week. After their daily diving duties the divers were involved in hard manual labor. A majority of divers used surface supply, which was frequently left unattended. Compressor malfunction (usually running out of petrol) inevitably caused an out-of-air ascent. Communication systems and "bail out" bottles were not used. The 1995 regulations have altered their diving practice (when adhered to and enforced). However, there are still many instances where divers have ran out of air due to compressor malfunction (bail out bottles and an attendant are only present when a "secret inspection" is known about). The tuna industry's diving practice will always substantially differ from other commercial, recreational, or abalone diving practice, and indeed by its nature may be provocative for decompression illness but safe diving practice should never be discarded because of cost or convenience. The divers' diving experience ranged from ex-Royal Australian Naval divers to those who had recently obtained a recreational "open water" diving certificate. Frequently, Port Lincoln's unemployed youth were sent by the local government unemployment agency to the local diving shop to obtain a recreational diving qualification to enable them to be employed as a tuna farm diver; this not only decreased the area's unemployment figures but also gave the tuna farmers a cheap labor force. Since 1995, all divers must be commercially trained, but in 1996 an untrained diver died while diving in the nets.

TREATMENT

The divers were initially treated with a RN 62 with daily follow-up treatments. The follow-up treatment tables used were at the discretion of the physician in charge; usually a 60-min soak at 18 meters of sea water followed by a 30-min ascent (the RAH D/HMU's 18:60:30 treatment table). These daily "soaks" were continued until the diver's symptoms plateaued. Initially the treatment response was good but subsequent follow-up showed an emerging pattern or syndrome in nine divers.

Posttreatment syndrome: Nine divers (three have been lost to follow-up) have a posttreatment syndrome, which has not been previously described. This syndrome is characterized by generalized arthralgia, muscle and bone pain which is worse in the winter; fatigue, weakness, agitated depression, mood swings, poor libido, breakdown of personal relationships, and cognitive dysfunction (poor short-term memory and concentration problems). All of these symptoms and signs have been exhibited by the majority of these nine divers at some stage posttreatment. The muscle and joint pain is crippling at some stages during the winter. In four of the divers there have been degenerative changes to their right acromio-clavicular and in two symptoms of prostatism. All investigations and specialist consultations have been inconclusive. Bone scans, plain x-rays and magnetic resonance imaging have been negative for osteonecrosis (although some bone scans have been positive, the follow-up magnetic resonance imaging (MRI) has been negative). In one diver, the MRI scan was positive for osteonecrosis but subsequent screening was negative. Rheumatological investigations have all been negative for any arthritic conditions. Two divers have undergone arthroscopies, synovial fluid analysis, and synovial biopsies of their worst-effected joint, these have all been negative. The RAH's Chronic Pain Unit has had little success in the control of their pain. Psychiatric consultation has helped in diminishing their depression and anger. Urological consultation has not shown an enlarged prostate but has demonstrated poor bladder capacity. Their rehabilitation has been hampered by an inability to move fluently, feelings of anger and resentment (particularly toward their employers and Workcover), a lack of insight into their problems, an inability to accept that their injury did not respond well to treatment, and a lack of understanding and support by their local community and peers.

SUMMARY

These divers suffering from this post-decompression syndrome present a management problem which does not seem to have a solution. A majority are seeking compensation, and once this has been settled it will be interesting to see if these symptoms persist (my personal opinion is that in all but one of these divers are genuine). A study entitled "The Longitudinal Survey of the Health of Tuna Farm Divers in South Australia", funded by Workcover and the Department of Industrial Affairs, is being conducted at present. The principal researcher is David Doolette. The study aims to define the true risk of decompression illness in the tuna farm divers and the risk factors associated with diving in the aquiculture industry; in an endeavor to improve the health of these divers and to prevent a similar scenario being repeated in other aspects of the emerging aquiculture industry of South Australia.

DISCUSSION

Dr. Wong: Before I introduce the next speaker, I'd like to get a consensus—with all this unconventional type of diving there are a lot of bounce diving or yo-yo diving. I'd like the audience to participate and tell us what yo-yo diving is.

Well, what is yo-yo diving? Has everybody got a definition of yo-yo diving? I'd just like people to think about it. Is it a special type of repetitive diving?

I mean, if you use the U.S. Navy table, if you have a surface interval of more than 10 minutes within the 12 hour dive, it's a repetitive dive. If you use the DCIEM table, with a surface interval of 15 minutes, but less than 18 hours, it's a repetitive dive.

So yo-yo diving, what does that mean? Does it depend on the depth-time limits of the dive?

Do we think yo-yo diving is dangerous? If so, is it due to the depth of a dive or the number of ascents, the rate of ascent, surface intervals, all of the above or none of the above?

I'm quoting a few papers here. Parker et al. in 1994 UHMS Meeting says:

> The risks increase if a large number of these ascents are made, greater than 10 and if the surface interval was about five minutes, it gives the highest estimated probability of DCS.
>
> If a surface interval [is] of zero minute, in other words, if you come up and go straight down again, [then there] is the lowest incidence of probability of DCS. Whereas if you have a surface interval of 10 to 120 minutes, it

gives you intermediate estimates.

Now, using that kind of surface interval, is that repetitive diving or is that yo-yo diving? Some years ago, Tom Shields and others made a report of decompression sickness arising from diving at fish farms in Scotland.

Some of you might know that report. Perhaps John Ross might be able to comment on that. The number of ascents made were less than 10 and this report refuted the allegations that yo-yo diving is dangerous.

The pearl divers, they do a bit of "dump diving". This is sort of yo-yo diving. After they have collected the wild oysters, they put them in panels. There are six shells in a panel and they are tied up in ropes and then placed in a holding ground and dumped them in the seabed at a depth of about 15 meters of water. Then they dive down there to inspect the panels. The bottom time is between 20 and 30 minutes. They dive down there to examine the panels and then they come up and look for the next lot of panels that are attached to a buoy and they swim over to the buoy and dive down again.

The surface interval is anything between one to five minutes and they do about eight dives like that per day. As far as I understand, they haven't had one single incident of decompression sickness from that kind of diving.

Because a lot of our dive profiles involve repetitive yo-yo diving, I just wanted people to think about yo-yo diving. Perhaps during discussion later today or tomorrow, we can come to a consensus what yo-yo diving is, how dangerous is it, and what should we do about it? I'm not sure whether the speaker will be able to answer the questions since he's not the author of the paper.

Mr. Long: (Colorado) I was just wondering, the patients that had the post-traumatic syndrome, is it a standard procedure that they lose their job or their occupation if they have to go through treatment?

Dr. Griffiths: Not at all. No, they are treated and unless they're advised by a diving medical practitioner that they should not dive again, they are entitled to return to their place of work and continue working and it's only those people who have a poor response in the conventional term that would normally be told not to go back to work.

Now, in some of these instances where they've obviously got problems that make them dysfunctional, I suspect that they will lose their job for reasons other than being told that they cannot dive again.

However, I'm sure that the more seriously affected individuals would have been told not to dive again. But I can't give you a complete answer in that regard because I'm not sure of the statistics in South Australia.

Dr. Brubakk: In addition to that, we did a survey of Norwegian divers some years back by an anonymous questionnaire. We found exactly the same thing, that a large statistically significant portion of all of those who had been treated and also those who had symptoms of decompression sickness and who had not been treated, it was a very large proportion of them, they had similar type of symptoms, although not as severe as this. They had signs of mild head injury. We used a standard questionnaire for that. But they were all working and all functioning normally. But they had that type of symptoms so I guess this fits perfectly with what we found.

Mr. Sutherland: (Oregon) Didn't hear it in your talk but were there any divers that had not been treated and had some of these same symptoms?

Dr. Griffiths: I can't answer that because I suspect that there may well be some, but of course, if they don't come forward and offer themselves for evaluation, this will not be known.

In Tasmania, from my own experience, it's often the wives of the divers that push their husbands into being assessed medically because they find that they become aggressive, they exhibit a number of the signs and symptoms that were identified here. It's often their wives that encourage them to seek medical advice, rather than the individuals themselves appreciating that they have a problem.

Mr. Sutherland: Right. Are there any heavy metal or other toxins detected?

Dr. Griffiths: To my knowledge, there's no particular heavy metal problem in the Port Lincoln area. In Hobart, the area that I used to be in, there was certainly a very serious heavy metal problem in the Derwent River by virtue of the fact that there was an electrolytic zinc company just up river from the main city.

Further north still, was, on the river itself, a papermaking factory and the paper-making process made all the inorganic heavy metals soluble. Now, that created a problem in the mouth of the Derwent River. But the fish farms, of course, have been established in Tasmania well away from that area because that's well recognized and I assume the same will have been done in Port Lincoln. Can you answer that, Bob? I presume it would not be a heavy metal problem but that's an interesting point. I take your reason.

Mr. Cervenko: (Richmond) Some of these features that you've described are shared by other people who are injured in automobile accidents and industrial accidents. Is there any thought that some of these features might be non-specific reaction to injury?

Dr. Griffiths: Well, brain damage may be caused by a whole host of different possible alternative pathways. I suspect that the two may well be related. But other than that comment, I can't help in that regard.

Dr. Ladd: (Vancouver) What you're describing is consistent in part with the psychological post-traumatic stress response. It would be very interesting to see. You mentioned that that was the first time that this post-traumatic syndrome had been documented with divers.

It would be interesting to see if a more detailed, post-traumatic assessment was done, if they come out positive for PTSD and I think that in part addresses the earlier question about other accident victims from industrial and motor vehicle accidents, coming up with the same kinds of profiles.

Dr. Griffiths: A new field for research?

Dr. Ladd: Yes. Well, the psychological domain of injury is something that is frequently ignored. As a psychologist, I'm sensitive to that.

Dr. Griffiths: Sure, but I don't think it's been applied to the fish farm industry at this stage.

Mr. Maine: Just a couple of questions. One is, what was the end point of treatment for these divers?

Dr. Griffiths: When the divers plateaued, that is, when they ceased improving, they had to have two consecutive days of treatment demonstrating no objective sign or subjective sign of further improvement in their signs and symptoms.

Mr. Maine: The second comment was, were any of these divers tested for carbon monoxide poisoning?

Dr. Griffiths: I am not aware that they were tested for carbon monoxide poisoning but their presentation, as you probably saw, was relatively late. Even if they were tested for carbon monoxide poisoning, I suspect that since they didn't have any overt symptoms initially, probably would have missed the boat.

If they were going to be tested for CO, then that should have been done on-site at the time of the problem. If they were tested later in Adelaide, a couple of days after the event, you'd probably get false, low numbers

SALMON-FARM DIVERS AT STEWART ISLAND, NEW ZEALAND: FROM THE RIDICULOUS TO THE SUBLIME

S. J. Mitchell and B. D. P Murphy

INTRODUCTION

New Zealand's clean, temperate coastal waters have proved an ideal environment for salmon farming. Several highly productive units now operate at various locations. One of these is at Stewart Island, the smallest and southernmost of New Zealand's three main islands. This farm was gradually established over 10 yr, with activity peaking in 1994–1995. Over a 4-mo period in 1995, the Royal New Zealand Navy Hospital at Auckland treated four cases of decompression illness (DCI) in divers working at this farm. These events prompted a series of significant changes in diving philosophy and techniques. There have been no further cases of DCI over the last 2 yr.

This paper briefly describes the diving practices in vogue during early 1995, and the circumstances that fostered any weaknesses in these practices. The steps taken by management to improve safety are also described.

STEWART ISLAND

Stewart Island lies at latitude 47°S, 21 miles to the south of New Zealand's South Island. The climate is unaffected by large land masses and is considered harsh. Sea water temperatures average 16°C in summer and 7°C in winter. The prevailing winds come from the westerly quarter, and the east side of the island is both relatively sheltered and has many inlets. The terrain is broken, difficult, heavily bushed, and there are essentially no roads other than in the single small "town".

The island's population is approximately 350 and consists mainly of fishing families, although a number work in the tourist industry, which exploits the islands rugged beauty. There is no secondary schooling, and consequently most children leave the island during their teenage years. Links with the mainland are by small ferry (daily) and 10-seat aircraft (daily). The population encourages a culture of "independence" and a reputation for hardiness. The typical rural New Zealand "can do" attitude is very strong. There is no doctor on the island and primary medical care is provided by a district nurse.

SALMON FARM OPERATION

The salmon farm is located in one of the east-facing inlets close to the only town. The farm is based on a series of 20–30 "pens" constructed from nets, whose walls extend from the surface to the sea floor some 15–18 m below; there is no underwater communication between the nets. Operational tasks include removal of dead salmon ("morts") from the bottom of the net, net cleaning; and net maintenance and repair. Initially, diving was the most convenient means of achieving these aims, and the operation was consequently very diving intensive.

The "evolution" of the salmon farm dive team is relevant to the subsequent problems The team of approximately 14 developed out of the pool of workers involved in development of the farm as the emphasis shifted from development to operation between 1993 and 1995. These were young men from the local population whose primary interest was earning a living rather than diving per se. None was a professional diver, and all held recreational diving qualifications only. Some members of this team were neither technically good nor well-motivated divers, but they became de facto "professionals" simply because the farm's operation involved diving. Although no data support the contention, it has been suggested retrospectively that the life style of some individuals in this team was not ideally suited to professional diving.

This environment fostered evolution of certain idiosyncratic diving practices that more closely reflected recreational rather than commercial diving techniques. Divers wore wet suits even in mid winter, when water temperatures fell below 8°C, and used scuba equipment. They operated alone underwater with no surface communication such as lifelines. The tasks often involved a short period of work in multiple pens necessitating an ascent to the surface between each pen. The Defense and Civil Institute of Environmental Medicine (DCIEM) air diving table (1) was adopted to control the time and depth exposure, but the application of the table was unconventional. For example, the 50-min, no-decompression limit for 18 m was interpreted as allowing as many bounces into different pens as could be achieved within that time. The divers invariably worked hard to complete the planned number of pens. In addition, the pattern often adopted in net-cleaning dives was to move up and down the net wall, rather than to work horizontal sweeps from the bottom up. An individual diver would commonly work 5–7 days in succession. It is notable that no legislated standard or code determines diving practice in the aquiculture industry, and none of these practices breached any laws.

CASES OF DECOMPRESSION ILLNESS

Between March and July 1995, four divers from the salmon farm were evacuated to the RNZN Hospital at Auckland for treatment of decompression illness. Brief summaries of these four cases are presented below. A fifth case was also evacuated, although it was unclear whether that diver's illness was related to his occupational diving or concomitant recreational dives.

Case 1: Male aged 28 yr. Five consecutive days diving, 15 m for 50 min each day, and 10 bounces within each 50-min period. Presented 2 days after last dive with marked fatigue, multifocal pain, and abnormalities in both balance and deep tendon reflexes. He was treated with a U.S. Navy (USN) table 6 (2) and three 18:60:30 follow-up treatments (3), making a full recovery,

Case 2: Male aged 22 yr. First diving for 5 days consisting of 18 m for 40 min with four bounces in the 40-min period. Presented 2 days later with right hand paresthesia, multifocal pain and abnormal balance. He was treated with a RNZN2A (30-m heliox table) (3) and four 18:60:30 follow-up treatments, making a full recovery.

Case 3: Male aged 31 yr. First diving for 5 days consisting of 15 m for 39 min with four bounces in the 39-min period. A fifth dive to 12 m for 36 min followed 2 min after the fourth 15-m bounce. He presented on the day of the dives with fatigue, headache, multifocal pain, objective sensory changes, and grossly abnormal balance. He was treated with a RNZN2A (30-m heliox table) (3) and 10, 18:60:30 follow-up treatments. Unfortunately he was left with residual pain and impaired balance and was advised never to dive again.

Case 4: Male aged 24 yr. First diving for 7 days consisting of 17 m for 43 min with four bounces in the 43-min period. Presented 6 days later with multifocal paresthesia. multifocal pain, and abnormal balance. He was treated with a USN table 6 and four 18:60:30 follow-up treatments, making a full recovery.

REMEDIAL ACTION

This rapid sequence of DCI cases indicated the need for remedial action and the farm management was well motivated and supportive of problem rectification. Remedial strategies involved elimination of the need for diving wherever possible, and modification of diving practice.

ELIMINATION OF DIVING

Two important modifications to the operation significantly reduced the need for diving. First, a static airlift system was introduced to the pens to remove dead fish. An airlift was placed in a strategic position in the pen, usually at the deepest point where the dead fish tended to gather. This system proved successful in removing the bulk of dead fish, thus reducing the frequency of diving for this purpose.

Second, a mechanical device, that used a spinning disc (cleaning head) and could be operated from the surface, was introduced for net cleaning. This not only reduced numbers and duration of dives, but eliminated a particularly disadvantageous type of diving. Net cleaning by divers is hard work, and as previously mentioned, some divers had completed this task using vertical rather than horizontal sweeps.

Data describing the precise changes in numbers and duration of dives effected by these changes are not available. However, the magnitude of change is indicated by the current employment of a four-man dive team (*see* below) who are required to dive approximately as often as the individuals in the previous 14-man team.

MODIFICATION TO DIVING PRACTICE

Diving could not be eliminated completely. Some dead fish were not removed by the airlift system. Maintenance on the nets forming the pens still needed to be done by divers. However, the philosophy of diving was substantially changed. Most significantly, a clear distinction was drawn between working at the farm and diving at the farm. No longer were all farm employees expected to be divers. Indeed, the company employed a diving supervisor and three other career professional divers, thus ensuring that diving staff were appropriately trained and motivated The diving staff became responsible for no duties other than diving.

The equipment configuration was also changed. Diving in wet suits was stopped and high quality dry suits were purchased, These are used in conjunction with scuba equipment for work that involves moving around the pens. In addition, a surface supply breathing apparatus system with hot water wet suits was procured for use in more static work, such as the maintenance or establishment of moorings.

It is notable that some bounce diving (to a maximum of four bounces) is still performed "within" the no-decompression limits of the DCIEM tables as described above. Despite this, there have been no cases of DCI in the 2 yr since the new team and equipment were introduced

DISCUSSION

The problems at Stewart Island arose in a new unregulated industry lacking a Code of Practice, which drew upon an isolated, independent, self-reliant fishing community for its workforce. We contend that this is a "blueprint" for the development of substandard diving practices. In such a setting, scrutiny by experts is unlikely, and what knowledge is available may be applied dangerously. This is illustrated by the application of no-decompression limits to bounce diving as described here. In another unrelated but relevant example, an operator of dive tours to an isolated site sought our opinion on his protocol which purported to account for an ascent to 2,000 ft during the road trip out of the site. He planned the sea-level dives as though they were conducted at 2,000 ft, and therefore assumed freedom from ill effects on the subsequent drive to that altitude. While there was a degree of superficial logic in this reasoning, we felt unable to endorse the practice for reasons that were explained. Although this operator had the initiative to seek advice, there are almost certainly many undiscovered examples of similar empirical practices, especially in isolated settings

This case history also illustrates the marked improvement in safety that can be achieved by relatively simple modifications to an operation. It is difficult to isolate the most important changes made here, Individual divers still perform up to four-bounce dives in one sequence over multiple days, so far without incident. It follows that a significant advantage has been accrued by the use of a small, dedicated team of career commercial divers and improvements in thermal protection.

REFERENCES

1. Canadian Forces decompression tables. Canada: Defense and Civil Institute of Environmental Medicine, 1992.
2. United States Navy diving manual, vol. I. Arizona: Best Publishing Company, 1993.
3. Stark Hyperbaric Unit Operating Procedures. Auckland: Royal New Zealand Navy, 1991

DISCUSSION

Mr. Sandford: (Seattle) I have a question. I want to know what your feel for this situation is. You came with professional divers and you got a reduction in the decompression sickness recorded and you imply it's because of their stated technique. Do you have any feel for the fact that they may not be reporting decompression sickness because they don't want to lose their jobs?

Dr. Mitchell: No, there's no question about that. That's always a possibility and it's one of the big problems that the sort of data that we're all collecting, I think. You know, Dr. Sanchez presented some very interesting data that it seems to be the educated divers with a bit of training that were getting more decompression illness.

Now, is that because they're more educated and better trained and therefore they're reported? Or is it because the uneducated people don't report it because they don't recognize it? I mean, attribution of cause in these situations is always very difficult. I quite agree and I don't know the answer.

Having said that, I think that most professional divers operating in New Zealand recognize that the diagnosis of decompression illness doesn't mean that your commercial diving career is over. Lots of professional divers have decompression illness treated and go back to their careers and carry on. I think most people are aware of that.

Unknown Speaker: Do you know if professional divers have changed their ascent versus the original divers we had?

Dr. Mitchell: No, I don't. What I do know is that when they do net cleaning work, for example, they don't do the up and down stuff which was causing terrible problems with more rapid assent rates because they were jumping up and down through the work column all the time as did the original team. But no, I don't know. My understanding is that, what they report to me is that they operate within the guidelines implicit in the Canadian Navy (DCIEM) tables. That's all I know. No one's mentioned that.

Mr. Sutherland: (Oregon) For the amount of professional dive rates, were they generally their own boss? Were they running their own compressors? If so, if a person was out there, I take it that that gas is then bottled and all of a sudden they had this big increase of problems?

Dr. Mitchell: That's an interesting point. I mean, I glibly said that it was the first winter when the farm reached its full activities and hoped that you'd all accept that. But you've picked up on one of the things that puzzled us, too. Why did we suddenly have this big increase? I mean, we have attributed it to that.

They did have their own compressors. They were filling their own bottles. I don't know whether they had had the compressor examined in accordance with the rules that do govern the compressor operation in New Zealand. I suspect they probably did. But they were doing that. But I wouldn't expect to see the sort of compressor problems that we've already had demonstrated to us down there, even in that isolated setting.

DIVING ACTIVITY ON COMMERCIAL FISH FARMS IN NORWAY

Alf O. Brubakk

INTRODUCTION

Fish farming is a very large and important industry in Norway. The main product is Atlantic salmon where Norway in 1997 farmed 52% of the world's total production (I). The total export value was about 8 billion NOK or about 1.2 billion US dollars, making it the third largest export industry after fisheries and the oil activity. Norway is also one of the main producers of equipment for fish farming in the ocean, and sells these systems all over the world. The two main competitors in fish farming are Chile and Scotland.

While the main product is Atlantic salmon, trout is also farmed and there are experimental farms for halibut. Farming and harvesting of different kinds of sea shell is a growing activity.

The farms are located around the coast, employing about 5,000 people, with an additional 15,000 working in connected businesses. The activity is closely regulated, with permits given by the government. Each permit is limited to 14,000 m^3, but the calculations are made based on the assumption that each net is 5 m deep. As the salmon is very temperature sensitive, it is useful to have deep nets to allow the fish to migrate up and down, and a deeper net will also allow more fish to be kept. Therefore, the cages can be 35–40 m deep. Each individual cage is usually round, with diameters up to 30–40 m. Seven hundred and eighty-six permits given m 1997. There were 266 companies having less than 5 permits, these together had a total of 520 permits. Only two companies had more than 20 permits, these had a total of 108 permits (Norwegian Association of Fish Farmers, personal communication). Thus the majority of the companies are quite small, usually with about four or five employees. The tendency is toward larger and larger units. The number of companies engaged in this activity was reduced from 1,050 in 1991 to 280 in 1997. The fish farms are usually located in remote areas and are of vital importance to local economics and habitation around the coast. There is ongoing research to develop systems that can be used in the open sea and even totally open systems where the fish are controlled by electronic means.

DIVING ACTIVITY

Diving activity is absolutely necessary for the industry. The cages have to be inspected regularly for holes (which is quite common) and they have to be cleaned at regular intervals. Inspection is usually performed once a month, cleaning at longer intervals, the intervals being determined by factors like temperature, organic material in the sea, algae growth, and so on. Divers are also needed for performing inspection of anchors, mooring, and cables; retrieving equipment; and various other tasks.

Many of the tasks at the larger units have been taken over by automatic systems, like video cameras for inspection and automatic cleaning devices. Still, the majority of the activity is still based on divers.

The majority of the diving is done inside the cages and is by nature repetitive, with considerable variation in depth.

Up until some years ago, many of the employees at the fish farms had diving certificates, usually sport diver qualifications, and performed the dives. Although this was illegal according to Norwegian regulations, it was widely done. Some companies even paid for the diving course! This has apparently changed significantly over the last few years and now most operators have agreements with certified divers or diving companies. This was probably largely brought about by an accident in 1994, where an employee with a sports-diving certificate tried to replace a filter on an intake line. The diver was dragged into the line by the suction, was unable to come free and drowned. The owner of the company was given a jail sentence, this being the harshest sentence ever brought against any violator of these work regulations.

NORWEGIAN DIVING REGULATIONS

Assuming that each concession is using an average of at least four cages, this will mean that there are about 3,000 cages for fish farming in Norway. If these are inspected every month, this will imply that there is at least 35,000 dives/year on fish farms in Norway. There are no official statistics.

Norwegian regulations require that the diver has a working diver's certificate. When working dives are performed, one diver and a standby diver are required as well as a supervisor. There are no particular rules about diving tables, but most Norwegian diving companies use the official Norwegian tables (2). These tables are a more conservative version of the Royal Navy diving tables. At a depth of 30 m on air, this table will allow a no-decompression bottom time of 20 min. At a depth of 24 m, these tables require 30 min for decompression after a dive lasting 75 min.

Most of the diving is performed on air, although some companies use nitrox. Surface decompression using oxygen is also used by some of the larger companies. The divers are required to have oxygen and access to a decompression chamber if the dives are deeper than 24 m or require more than 35 min of in-water decompression (3). However, as there is a clause in the regulations that says that short inspection dives do not require a decompression chamber, many dives may be falsely classified as inspection dives. There is no definition of how long a short can last.

Scientific diving is not covered by these regulations. This is of importance as some of the activity is claimed to be sampling and collecting specimens for scientific use. This is particularly the case when collecting shells, which is not done in farms but at depths down to 25 m in the open sea. This activity is very intense and may involve diving at the limit of existing tables. They also use considerable quantities of oxygen, both during decompression and between dives. About 10 divers in one region in Norway buy nearly as much oxygen as the neighboring university hospital!

DIVING PROBLEMS

Obtaining information about such problems is not easy. There are no official statistics on the diving practices and diving accidents. Over the last 15 yr there have been two deaths related to this activity, one mentioned above; the other was a professional saturation diver with little air diving experience who performed an inspection dive alone. He was found drowned, tangled in the net. The number of treatments for decompression illness (DCI) is also not known, but none has been reported from the diving companies for the last 5 yr. At the central treatment facility in Bergen, approximately six professional divers have been treated each year; on average, one of these has dived on fish farms. There are no reports of permanent injury to any divers from this kind of diving.

DISCUSSION

It is not unreasonable to believe that there is considerable underreporting of problems related to diving on fish farms. Based on a survey done in 1993, we found that approximately 50% of the divers with air diving certificates had experienced symptoms of DCI without ever reporting it (4). The nature of the diving, in particular as the nets have a considerable depth, indicates that one would expect some decompression problems. However, these are probably minor as serious DCI would have been reported. The Norwegian Labor Directorate and its inspectors around the coast consider that most diving is now done safely and that few if any problems exist today.

There have been no studies performed on diving practices on fish farms in Norway. A study from Scotland concluded that the incidence of decompression sickness was no higher than that seen in the rest of the diving industry (5).

It is not satisfactory that no official statistics exist on diving activity on fish forms in Norway. However, based on the information I have been able to obtain, I conclude that this activity generally is performed in a safe way.

REFERENCES

1. Anonymous. Akvakultur i Norge (Aquaculture in Norway). 1997; Trondheim, Norway. Norske fiskeoppdretteres forening
2. Amtzen A, Eidsvik S. Norske Dykke-og behandlingstabeller. (Norwegian diving and treatment tables). ed. Bjoemdalstrae, Norway: X-dykk, 1991.
3. Kronprinsregentens resolusjon av 30. november 1990. 1990; pp. 1-30. Forskrift om dykkig AT-511. (Norwegian Diving Regulations).
4. Brubakk A, Bolstad G, Jacobsen G. Helseeffekter av luftdykking Yrkes og sportsdykkere. (Health effects of air diving) 1993; Trondheim: SINTEF Uniroed. STF23 A93053:1 p
5. Willcock SE, Cattanach S, DuftPM, Shields TG. In: Proc. EUBS. Schmutz J, editor. The incidence of decompression sickness arising from diving at fish farms. Basel: 1992:191–195

DISCUSSION

Dr. Greenbaum: (USA) They picked this surface D technique for decompression, you put them into cold water?

Dr. Brubakk: No, the point with the surface D is that it gives you somewhat longer bottom time, and in particular, it gives you less time in the water. So it is more comfortable to sit in the chamber when divers are dry and reading a newspaper. They have to have a chamber on-site in any case, so that's why they do it. I mean, they have the chamber so why not use it? It's simply a matter of convenience.

Dr Lepawsky: While more people are formulating their questions, I think that perceived post-traumatic stress disorder diving. That is, yes or no, they would return to diving? Do you have experience with that, Dr. Brubakk?

Dr. Brubakk: Well, most of these individuals go back to diving after one treatment. But usually the problem we have is that a lot of the divers stop diving for whatever reason but there are a few old divers.

There is a population that's dying out from the old hard-hat divers in Norway who are still going around and some of them are still diving. I remember one guy who came to a shop and wanted to get his oxygen bottle filled. I said to him, "What are you going to use this for?" "Well, I'm going to use it for diving." I said, "Well, oxygen?" So it appeared that this was a very old guy who had been doing this for years but he's had problems clearing his ears so he never went deeper than five or six meters. He only took jobs where he couldn't go deeper. So that's why he got away with diving with oxygen.

But no, I don't know much about that. Most of them return after one single decompression incident. But now we have so few cases. We have treated cases. I think we have much more of the cases who had some symptoms and do not report them and those are actually the interesting group.

But there actually are quite a number of individuals out there who have symptoms that normally would have brought them to treatment but they did not do it. It seems, at least from our study, that some of them end up with symptoms compatible with slight head injury.

Although, I must add that in Norway, the Norwegian population that we looked at, there were no signs that they didn't function. They were all working. They were all functioning. We have a very large control group of both firemen and office workers that did not dive, so an incidence of these kind of problems is approximately 15%, which you will find in a survey here in the so-called normal population.

Dr Lepawsky: In some of the cases that I've seen, I have been concerned with residuals, disabilities and impaired attention deficits.

Mr. Hubert: (California) You just made a statement regarding being warm but in the chamber and my question is some of the research evidence seen on a bubble formation, do you know what the time is they have from getting out of the water and getting in the chamber? What's your opinion on that and why.

Dr. Brubakk: Well, we have done quite a lot of work on that. At the time, the regulations are quite clear. It's from five minutes from the time you leave bottom until you are under pressure at 12 meters in the chamber. That's the regulations. As someone who's used to this, you usually do not spend more than 3 minutes. It goes very quickly. So it's a very effective way of doing it.

You can easily demonstrate that in that interval that you have—if you have a particularly stressful dive—that your gas loading and bubble count goes up very rapidly. But you get them before anything starts to happen and all the statistics seems to indicate that this is a safe method.

There are no indications that this gives rise to any more late sequelae. It seems to be a safe way of doing it. Although, of course, you can't try to give someone decompression sickness by treating it.

But it has been shown at least that in the North Sea where there are a lot of bad weather conditions that this is a very effective way of decompressing the individual. What can be discussed is if the procedures are optimal. But they seem to function pretty well.

Mr. Hubert: What's the ascent rate?

Dr. Brubakk: The ascent rate is 10 meters a minute, the standard U.S. Navy assent rate.[*Ed: the standard rate was 18 m/min; the new rate is 9 m/min*].

Mr. Hubert: But that's included from when they leave the bottom to when they reach the--

Dr. Brubakk: Yes, but some of the procedures have stops in the water. But our studies seem to indicate that on the theoretical basis, that is not very good, and it's probably better to get them as fast as possible to the surface and get them into the chamber because they pick up gas when they stop.

So many of these stops are actually not beneficial, they do not do what you think they do, namely, to reduce the risks. You have to be very careful about exactly how long you've stopped.

Some model doesn't take account of what's really going on. So my theoretical position and based on all our experience, it's better to get them to the surface and get them into a chamber if you're going to use that technique.

Mr. Evans: (Toronto) We're dealing with a lot of cold water there. I just wonder if there's any thoughts about thermal regulation.

Dr. Brubakk: Not usually for these guys. All these guys dive in dry suits. There is even one company who have their guys on hot water suits which is the standard diving technique in the North Sea, to use a tube suit or a suit that's filled with hot water. But most of them dive in dry suits and that functions very well. But of course, at the end of a longer dive if it's in winter, for instance, you can get quite cold. But usually the bulk of that time we're talking about here, it usually is no big problem. It's more of a problem like icing of the regulator and things like that, that's a bigger problem.

Hands, of course, that's always a problem in all these conditions to get enough flexibility in your hands because unless you have an actively heated glove, which doesn't exist as far as I know, for diving yet—but unless you have something like that, then you'll get cold fingers which will impair your dexterity.

PATTERNS OF DIVING IN SPORTS DIVERS COMMERCIAL DIVERS AND SCALLOP DIVERS IN SCOTLAND PRESENTING WITH DECOMPRESSION ILLNESS

John A. S. Ross and Ruth N. Stephenson

INTRODUCTION

King scallops (*Pecten maximus*) are fished all round the coast of Scotland, the largest percentage being caught by dredging along the sea bed. In certain areas, they are also hand caught by divers. Diving for scallops or "clams" is performed from all the Scottish islands and from the west coast. In these areas, the diver competes with the dredgers for the market in these shellfish. Thus divers are under strong commercial pressures to maximize bottom time and to dive as often during the day as possible. These pressures are not experienced by the sport divers who constitute the majority of people treated for decompression illness (DCI). This study was done to determine whether scallop divers who sustained DCI used diving practices that differed from those of sport divers. The Hyperbaric Unit at Aberdeen Royal Infirmary serves as the national medical advice line and tertiary referral center for the treatment of DCI in Scotland. Most of the cases of DCI occurring in Scotland are reported to this unit with copies of the local case records being filed at Aberdeen. The majority of cases are treated either at Aberdeen on the east coast or at the Dunstaffinage Marine Laboratory on the west coast.

METHODS

Copies of all the patient treatment notes from January 1992 to December 1997 which were available to the Aberdeen unit were reviewed. In addition patient audit forms were filled out prospectively from January 1996 onward and returned to the Hyperbaric Medicine Unit at Aberdeen from throughout Scotland. Details on the timing of the onset of symptoms in relation to diving were recorded and the subsequent time of presentation to medical services and of treatment. Details of each patient's diving practice were recorded and the patient's clinical progress and response to treatment were noted.

Diving practice: Dive profiles for the 3 days before the decompression incidents were analyzed. The expected decompression for these profiles was then calculated from the 1974 BSAC/RNPL tables, assuming a square wave profile. This was compared to the amount of decompression actually performed by the diver. The result gave the individual a decompression penalty (if there was calculated omitted decompression) or a calculated excess decompression, measured in minutes. A measure of compression stress was also calculated by using the equation $P\sqrt{t}$, i.e. absolute pressure (P) multiplied by the square root of time (t) (1). Both indices were calculated for all dives performed in the period up to 72 h before the decompression incident. The incidence of rapid ascent or buoyancy problems, the number of dives, and the maximum depth achieved during the day of the incident were also noted.

Decompression penalty was calculated for two time periods before the onset of symptoms. The period of up to 24 h before the onset of symptoms, i.e., the same day, and the period 24–72 h, before the onset of symptoms, i.e., the previous 2 days. Compression stress was similarly measured and in addition was calculated for the incident dive. Both indices were added from each dive to give the totals for each time period.

Decompression penalty—calculation assumptions: Assumptions were made in cases where it had not been possible to get data to allow the surface interval to be calculated. If no surface interval was stated, it was assumed to be between 4 and 6 h for dives on the same day. Repeated days diving were assumed to be independent, i.e., a surface interval between 1 day's diving and the next of over 16 h was assumed.

Some dives were out of the range of the tables used. A few divers had exceeded the maximum exposure for their dive depth and a fair calculation needed to be made so that these divers were not eliminated from the data set. To calculate decompression penalty for the periods 0–24 and 24–72 h before the onset of symptoms, where divers had exceeded a maximum exposure for a given depth, they were given the figure of the maximum decompression penalty at that depth from the table. The 1974 BS-AC/RNPL table allows only two dives per day, and for those who had performed three or more dives on a particular day, the third dive, which usually presented the shortest and shallowest exposure, was ignored and not entered into the calculation. Both these assumptions would underestimate the decompression penalty.

Clinical progress: Clinical progress was scored according to the presenting symptoms and signs on the onset of illness, the clinical presentation on admission, and the patient's condition on discharge from hospital. Complexity of treatment was assessed by noting whether the patient relapsed after initial treatment so that further recompression therapy was required. Scores were allocated as shown in Table 1.

Table 1: *Scoring System for Clinical Presentation and Condition on Discharge From the Hospital*

Initial Symptoms and Signs		Condition on Admission		Condition on Discharge	
None	0	none	0	complete resolution	0
Pain	1	pain	1	mild pain or sensory residue thought to be short term	1
Sensory	2	sensory involvement	2	mild residual motor involvement or ataxia	2
Motor	3	motor involvement	3	more severe residual motor involvement or ataxia or urinary catheter in place	3
Ataxia	4	ataxic	4	cerebral residue	
Nausea/vertigo	5	bladder/rectal involvement	5		4
Cerebral	6	nausea/vertigo cerebral involvement	6		

Initial symptoms or signs These were defined as the first symptoms and/or signs that caused referral to the medical services. A history of no symptoms and no signs indicated patients presenting with omitted decompression. Ataxic symptoms or signs included both upper and lower limbs and gait and were regarded as a more severe indicator than motor symptoms or signs alone. Nausea or vertigo was regarded as an indicator of possible vestibular or cerebral involvement and cerebral symptoms or signs were disorders of consciousness, memory, concentration but not headache or eyesight. Loss of bladder or rectal control was not scored at this stage since it is not identifiable early in the disease progression.

Condition on admission: The same scoring system was used as for presenting symptoms or signs up to the level of identifiable ataxia. Loss of bladder or rectal control was identifiable at this stage and was scored as higher than motor involvement alone. Nausea and vertigo were classified as having the same score as cerebral involvement. Absence of signs or symptoms indicated either someone presenting with omitted decompression or a condition which had spontaneously resolved.

Condition on discharge: Each patient was assessed before discharge from hospital. People with no symptoms or signs were assessed as having complete resolution. Motor residua were classified as mild if function was largely unaffected and severe if there was functional impairment. Cerebral impairment was identified by neuropsychological assessment.

Analysis: The data were entered into the computer program SPSS 7.5 and assessed using the appropriate statistical technique.

RESULTS

The study population: Two hundred cases were audited. In this population, three categories of diver were recognized. Amateur divers diving recreationally (157), divers with a professional training either diving professionally or recreationally (21), and divers gathering scallops (22).

Diving practice: Table 2 shows the deepest dive on the day of the incident in meters and the number of dive on the incident day. These data are expressed as median and the interquartile range. The frequency of multiday diving and buoyancy problems are also detailed.

Professionally trained divers dived to significantly shallower depths than either sport or scallop divers ($P < 0.04$). Scallop divers dived more frequently on the day of the incident than either of the other two groups ($P < 0.001$), and both professionally trained and scallop divers performed multiday diving less frequently than sport divers ($P = 0.05$). Professional divers admitted to fewer buoyancy control problems than did amateur divers, and clam divers in particular had a much lower incidence than expected ($P = 0.03$).

Compression stress: Compression stress ($P\sqrt{t}$) was calculated for the incident dive, the day of the incident, and for the 2 days before the incident. Data are quoted as median and interquartile range (Table 3).

Table 2: *Deepest Dive on the Day of the Incident and the Number of Dives on the Incident Day*[a]

	Maximum Depth, m	Number of Dives	Multiday Diving	Buoyancy Problems
Amateur	34.00 (27–52)	1 (1–3)	98 (63%)	58 (37.2%)
Professional	23.00 (17–48)	1 (1–4)	7 (37%)	6 (28.6%)
Scallop	31.50 (25–86)	2 (2–4)	10 (48%)	2 (9.1)

[a]These data are expressed as median and the interquartile range. The frequency of multiday diving and buoyancy problems are also detailed.

Table 3: *Compressed Stress (P$\sqrt{t}$) Calculated for the Incident Dive, the Day of the Incident, and for the 2 Days Before the Incident*[a]

	Compression Stress Incident	24 h	24–72 h
Amateurs	21.4 (18–24.9) n = 154	28.2 (21.5–41.9) n = 154	57.6 (35.9–82.7) n = 81
Professionals	19.9 (16.8–22.8) n = 18	28.2 (19.6–31.8) n = 18	38.5 (18.8–45.4) n = 5
Scallop divers	17.1 (12.5–20.6) 17.2 n = 20	43.3 (32.8–51.9) n = 20	52.3 (48.6–76.2) n = 5

[a]Data are quoted as median and interquartile range.

For the dive preceding the clinical presentation of the diver with decompression illness, the clam divers had significantly less compression stress than amateur divers (P = 0.002) although there were no significant differences in this parameter between amateur and professionally trained divers or between clam divers and professionally trained divers (Table 3). For the 24-h period before presentation, however, the compression stress for clam divers was significantly greater than for either of the other two groups (P = 0.002). There were no significant differences between the groups for the 24- to 72-h period

Decompression Penalty: (Fig. 1)

There were significant differences between the three groups over the 24-h period before the incident (P = 0.028). While there was no difference between the amount of decompression omitted in the amateur and clam diver groups, the professionally trained group had significantly less omitted decompression than either the amateur group (P = 0.009) or the clam divers (P = 0.014). There were also significant differences between the three groups over the 24 to 72-h period before the incident (P = 0.002). Although there was no difference between the amount of decompression omitted in the professionally trained and clam diver groups, the amateur group had significantly more omitted decompression than either the professionally trained group (P = 0.03) or the clam divers (P = 0.014).

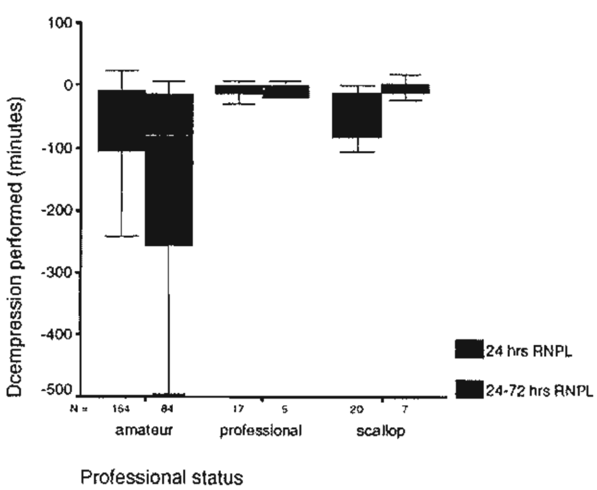

Figure 1: Decompression penalty calculated as the amount of decompression actually preformed subtracted from that calculated from 1974 BS-AC/RNPL table. The median (*bar*) and interquartile range (*box*) are shown. Whiskers run to the nearest value that is less than 1.5 box lengths from the quartile. The figure includes data from all the divers studied.

Timing of Clinical Progress: Data for the time taken for patients to get to initial recompression treatment was available for 189 cases and for the time for the patient to present to the medical services in 147 cases. Total delay to treatment ranged from 6 min to 135 h (median 5.53 h, interquartile range 2.98–13.28). The 6-min period was for a diver that was treated initially in the offshore oil industry but who presented with a relapse of his condition to the Aberdeen unit. The time taken for the diver to present to the medical services represented a substantial portion of this delay and ranged from − 19 to 109 h. Negative values for this parameter represent people who developed their first symptoms after presentation due to a problem of rapid ascent or omitted decompression. There was no difference between the three groups studied.

Clinical Progress: There were no differences between the groups in the presenting symptoms or signs or in the condition of patients on admission to the hospital.

Clinical Presentation: The commonest type of presentation was neurologic with cerebral symptoms being almost as common as sensory. It was common for patients to have a complete resolution of their symptoms during the time taken for them to get to a treatment facility (Table 4). In particular, it was common for people with cerebrally related symptomatology to have recovered before admission.

Clinical Outcome: Although there were no differences in outcome between professionally trained and sport divers, decompression illness in scallop divers was associated with a poorer outcome (P = 0.001 Pearsons Chi^2) with 27.2% of those injured in this category being left with a relatively severe residual condition as opposed to 7% of sport divers and no professional divers.

Table 4: *Clinical Presentation*

Initial Symptoms or Signs	Number (%)	Condition on Admission	Number (%)
None	6 (3)	none	33 (16.7)
Pain	48 (24.4)	pain	45 (22.7)
Sensory	47 (23.9)	sensory involvement	32 (16.2)
Motor	29 (14.7)	motor involvement	38 (19.2)
Ataxia	14 (7.1)	ataxic	19 (9.6)
Nausea/vertigo	12 (6.1)	bladder/rectal involvement	7 (3.5)
Cerebral	41 (20.8)	nausea/vertigo cerebral involvement	24 (12.1)

Although the numbers are too small for tests of statistical significance, it is interesting to note that of the scallop divers who were left with a poor outcome of treatment, four out of six had been multiday diving.

The incidence of relapse after initial treatment was 13% overall and there was a significant relationship between the occurrence of relapse and the practice of multiday diving ($P = 0.05$). Of the 26 divers who experienced a relapse, 20 had been multiday diving and these divers also went to greater depths than people who had dived on one day only. Again, although numbers are too small for statistical evaluation, of the five scallop divers who relapsed (23%), four had been multiday diving.

There was no relationship between time to treatment and outcome of treatment although there was a strong negative correlation between severity of presenting symptoms and this measure.

DISCUSSION AND CONCLUSIONS

The standard practice adopted by scallop divers is to position the dive-boat over the area to be fished and then to perform several dives to the seabed during which the diver's buoyancy becomes increasingly negative as scallops are collected. Return to the surface is by means of a shot rope, and these are often fixtures on the scallop bed. The surface intervals used vary greatly, but increasingly computers are being used rather than instinct or tables. The data gathered by this audit study reflect this practice with a low incidence of buoyancy problems or rapid ascent but with a relatively high number of dives per day.

In comparison with sports divers with decompression illness, scallop divers dive more frequently on the day of the incident, have fewer buoyancy problems and have a poorer clinical outcome. Identifiable risk factors for both groups are the depth of diving, little diving was performed at less than 25 m depth, omitted decompression and frequent diving. Risk due to frequency of diving was reflected both in the number of dives on the day of the incident and in terms of the practice of multiday diving.

Scallop divers do not dive deeper or perform less decompression stops than do sport divers and so any difference between the two groups is unlikely to be related to these factors. The major difference between the two groups is that, on the day of the incident, scallop divers dive more frequently. It seems likely that the decompression practices being followed may not adequately cover this form of diving. However, poor outcome after treatment may relate to the previous condition of the patients and, while it was unusual for a sport diver to admit to previous episodes of decompression illness, previous episodes of decompression illness were common in the scallop diving group.

Given that computers are being increasingly adopted by both sport and professional divers, the great majority of the patients reported in this study were using them, it is of concern that using a conventional, albeit conservative, decompression table it was possible to calculate a large amount of omitted decompression for most divers. The 1974 BSAC/RNPL tables used are particularly conservative with

Table 5: *Clinical Outcome in Relation to Professional Status*

Condition on Discharge	Number of Divers (%)			Total
	amateur	professional	scallop	
Complete resolution	98 (62.4)	13 (61.9)	10 (45.5)	121 (60.5)
Pain or sensory residua thought to be short term	41 (26.1)	3 (14.3)	6 (27.3)	50 (25.0)
Mild residual motor involvement	7 (4.5)	5 (23.8)		12 (6.0)
More severe residual motor involvement or urinary catheter in place	5 (3.2)		2 (9.1)	7 (3.5)
Cerebral residua	6 (3.8)		3 (13.6)	9 (4.5)
Dead			1 (4.5)	1 (0.5)

regard to repetitive diving and with this observation, together with the importance of dive frequency as a risk factor in this study, it seems relevant to consider whether currently adopted residual nitrogen times are correct or whether more conservative values should be adopted.

This audit study was done with the collaboration of our colleagues in hyperbaric medicine in Scotland and we thank them for this. The Aberdeen Royal Hospitals Hyperbaric Medicine Unit is funded by the National Health Service via the National Services Division of the Scottish Home and Health Department.

REFERENCE

1. Giles R. Decompression sickness from commercial offshore air-diving operations on the UK Continental shelf during 1982 to 1988. Department of Energy Report.

DISCUSSION

Mr. Heywood: (Vancouver) You just finished saying scallop divers seem to have the greater problems with decompression sickness. Might that be because they're always doing the square profiling? They're doing square dive profiles where the recreational divers might go down together and they work in a shallower depth?

Dr. Ross: Yes, we don't know the prevalence of decompression illness because we don't know how many of these people there are. In Scapa Flow, everybody's doing square way of diving. All right? They do it less so, across on the West Coast. But we don't really pick up much of a difference in respect to omitted decompression between these two lots and you'd expect to, if you were looking at that kind of data, I suspect.

The other problem we've got is with regards the denominator, if I can go back, is that on the slide which showed maximum depth, in the slide that showed frequency of diving in the professional group, there was a group of professionals who were diving more often than their colleagues. These were probably people that had been clam diving. And because they're diving in an unregu-lated way, they don't really want you to find out whether they've been clam diving or not.

Following on from that, we think that there are people who train professionally who go clam diving. On one day, they'll dive professionally within professional requirements. Following day, they will go clam diving and they will go clam diving according to the usual clam diving practice. In other words, they will leave their professional training home on the pier and they'll do the four deep dives of a clam diver when they're out on the boat.

Dr Wong: I have some questions. The decompression techniques that you used, the RNPL tables, they only permit two dives?

Dr. Ross: Yes.

Dr Wong: Would that not give misleading results ?

Dr. Ross: Yes. I mean, it will be misleading if you consider only the RNPL table. And most of our population are not clam divers so it's an entirely reasonable thing to do overall. USN tables, however, do allow you to do multiple dives and you can model that. We've had to miss out very few divers on the USN tables.

So what you miss out on the RNPL tables, you pick up on the USN ones. The RNPL ones are really quite prescriptive as regards repetitive dives and if you are repetitive diving, you pick up a maximum penalty really quite rapidly. So your point's correct and that's why we use the USN tables as well.

Unidentified Speaker: A point of clarification for USN tables. You used USN 93, those are the USN tables you're talking about?

Dr. Ross: Yes.

Unidentified Speaker:(Wayne Gerth?) USN 93 is a set of tables probably list of tables developed by memory that are not in use within the United States Navy, except by one group, Special Operations Forces.

One of the things that came out with these while they dove out multiday dives, is that in certain regions, mainly shallow, they seemed to be too conservative to be accepted by the ship's divers.

So for some profiles, we had several hundred minutes of differences in decompression time between current air chambers. So I just wanted to point that out.

Dr. Ross: Yes. I mean, we're not really interested in these as things you do to stop you from getting decompression illness. We're just trying to get some handle on how much omitted decompression these guys have had.

The interesting thing to my mind is that most of these people are using computers. Certainly, the amateurs are all using computers and increasingly more of the clam divers are using computers, which is a considerable increase in their safety.

They say a lot of the time that they're staying within the tables and the question that's posing itself in my mind is, do computers lead you to do a lot less decompression than your conventional square rate table, and does that have a safety implication?

Unidentified Speaker: Why don't you get those computers and download them and see what they're actually doing?

Dr. Ross: We do as much as we can because they can give you the quite important information that divers can't. Recently a chap came in and said, "I can't understand why I've bent. I've been within the tables". We downloaded his computer. Out of a series of five dives to 30 to 40 m, he'd had an ascent alarm on each dive. So that they're extremely useful in that respect.

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

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

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 aqualung (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. 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 aqualung 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 15–30 min. 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. (1) and Spencer et al. (2).

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, one very deep dive [170–220 feet of sea water (fsw)], followed by one or two shallow dives (to 60 fsw or less); or two or three dives (90–120 fsw), followed by two, three, or four shallow dives.

The purposes of our survey were a) to chronicle the diving habits of Hawaii's diving fishermen and coral collectors from the time of the introduction of the aqualung to the present day; b) to investigate dive profiles that were developed; and c) to study the methods of treating DCS 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: a) older divers who were self-taught, had been diving for more than 10 yr, 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 National Association of Underwater Instructors or Professional Association of Diving Instructors 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 yr.

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. (Before 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 eight tanks to a minimum of two tanks, with a mean value of five 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 were 32 and the minimum was 10, with an average experience factor at the time of the survey of 23 yr.

Follow-up interview of divers with in-water recompression experience: During the initial part of the survey, the successful use of underwater treatment for DCS was frequently mentioned. Attempts were therefore made to recontact 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%). In another 51 incidents (9.7%), divers had improvement but still suffered from some form of residual aftereffect, 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%). 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 min and a low of 20 min, with an average time of 63.7 min.

Signs and symptoms that were relieved varied from the mild or suspected DCS (primarily pain and aches around the shoulders and arms) to the more serious central nervous system (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 DCS of the bone, i.e., dysbaric osteonecrosis, a disease which many of Hawaii's diving fishermen have developed (3).

Case histories: 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 45–55 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-min 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 so the victim 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 35–40 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 DCS 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 min 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 h to pick him up. He was asymptomatic and apparently cured of the disease. The other diver died of severe DCS 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 DCS. 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 manyfold the number made by most commercial or military divers. 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 on 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 DCS 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 (4) and by Kunkle (5). According to the gas micronuclei theory, a diver could significantly increase his tolerance against bubble formation (and therefore against incurring DCS) 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 (6). 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 DCS 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 that would have to be overcome, i.e., cold, prolonged immersion, and difficulties in communication, if this treatment were to be used by scuba divers (7).

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 recompression, 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 DCS is basically the treatment of gas bubbles. Beckman (8) and Kunkle and Beckman (9) demonstrated that the rapid dissolution of bubbles in gelatin, as in the body, requires immediate adequate repressurization. As shown in Fig. 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.

The bubbles studied by Kunkle and Beckman (9) in both agarose gel and body fluids grew to approximately 1 mm in

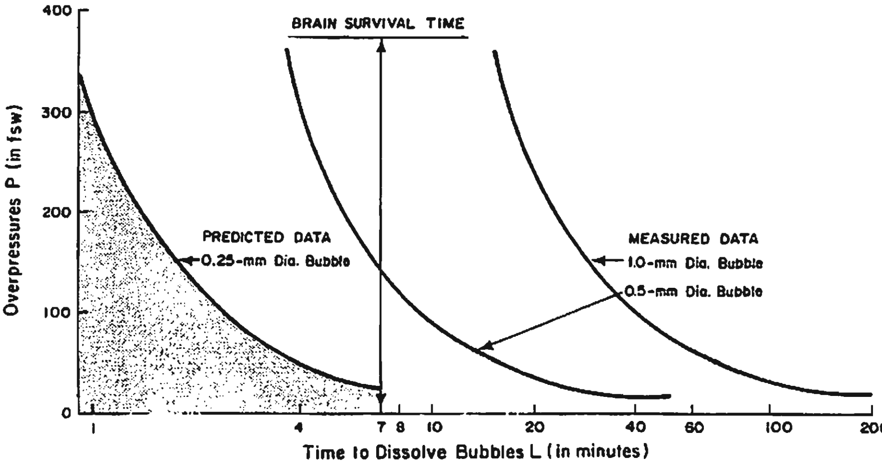

Figure 1: Curves to show time (L) required to dissolve bubbles of graded size after application of different overexposures.

diameter in 5 h (Fig. 2). Hills and Butler (10) measured the size of bubbles, which were collected from the right heart of dogs that had been exposed to a simulated air dive. The bubbles increased in size from 30 μm 5 min after the dive, to greater than 100 μm in 30 min, and to a maximum diameter of 700 μm—a bubble growth rate comparable with that observed in gelatin. Figure 1 shows that, with any given overpressure, the length of time required to dissolve bubbles of 250 μm 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 h.

Immediate recompression within less than 5 min (i.e., when the bubbles are less than 100 μm 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 DCS in water. They have been instructed in the use of the Australian emergency underwater oxygen treatment (11) and the Hawaiian emergency in-water, air-oxygen recompression treatment (12). 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 that could be related to DCS. The recompression profiles to be used for these treatments are shown in Figs. 3 and 4.

CONCLUSIONS

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

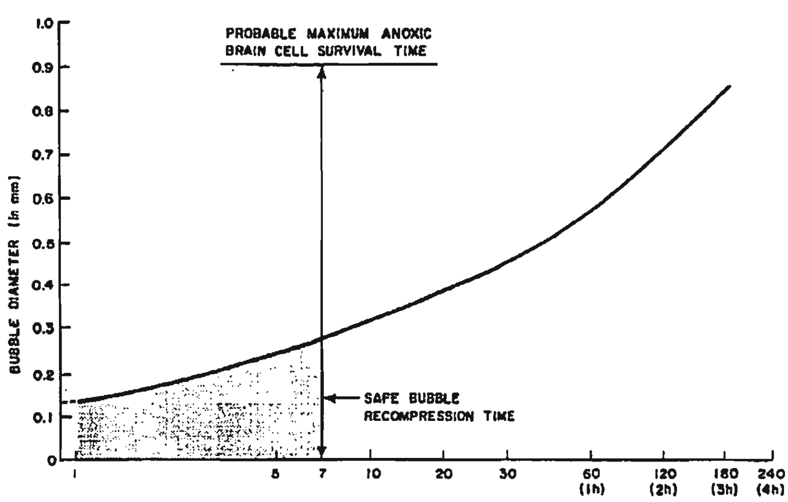

Figure 2: Rate of growth of bubbles in agarose gel formed at 1 atm abs ambient pressure after decompression from saturation at 20fsw.

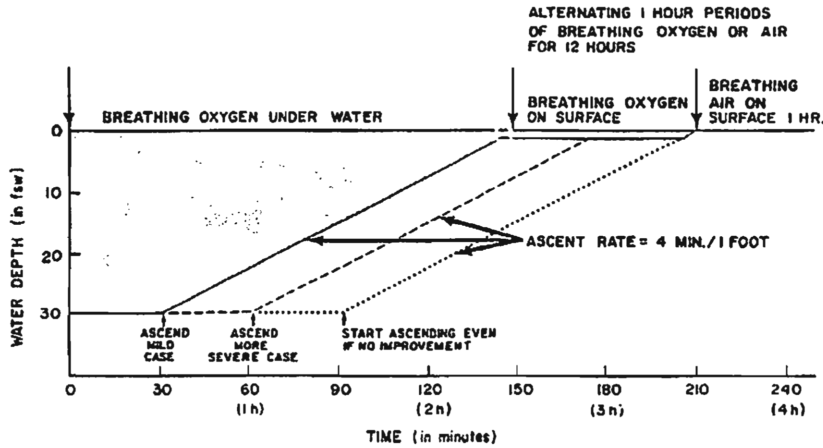

Figure 3: Australian emergency in-water recompression treatment tables using oxygen.

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 DCS while diving from a boat
4. Have learned to initiate immediate treatment for their DCS 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% had complete recovery, 9.7% had moderate residuals for which further treatment was refused, and 2.7% failed to obtain satisfactory relief and sought further treatment).

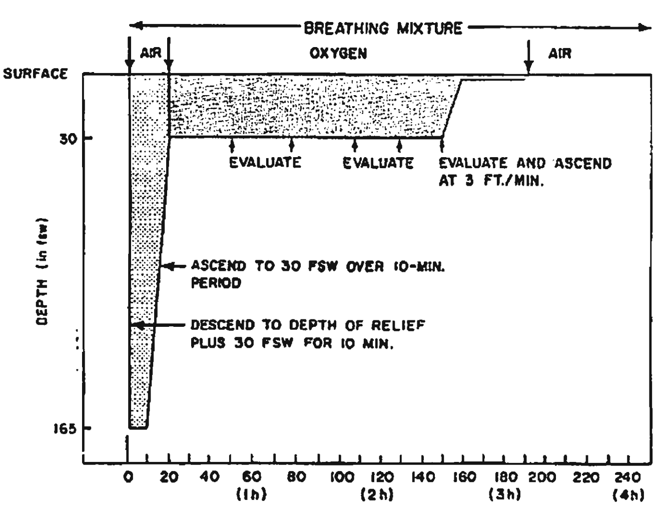

Figure 4: Hawaiian emergency in-water decompression treatment schedule using air and oxygen.

Several factors should be considered before making a decision to use in-water recompression. Such factors include: a) on board supply of air and other breathing gases; b) ability of the patient to accept treatment; c) personnel available to help; d) the signs and symptoms, indicating the severity of the disease and the urgency of treatment; e) time, usually measured as distance from the dive site to land support; f) ocean conditions; and g) 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 DCS while diving, use either the Australian emergency in-water recompression table using oxygen, or the Hawaiian emergency in-water DCS treatment schedule using air and oxygen.

REFERENCES

1. Kanwisher J, Lawson K, Strauss R. Acoustic telemetry from human divers. Undersea Biomed Res 1974; 1:99–109.
2. Spencer MP, Hong SK, Strauss RH. Venous gas emboli in Hawaiian divers. Undersea Biomedical Research 1974; 1-A-18.
3. Wade CE, Hayashi EM, Cashman TM,. Beckman EL. . Incidence of dysbaric osteonecrosis in Hawaii's diving fishermen. Undersea Biomed Res 1978; 5:2.
4. Yount DE, Strauss RH. Bubble formation in gelatin: a model for decompression sickness. J Appl Physiol 1978; 47: 5081–5089.
5. Kunkle TD. Bubble nucleation in supersaturated fluids. UNIHI-SEAGRANT-TR-80-01, University of Hawaii Sea Grant College Program, Honolulu, 1979.
6. Beckman EL, Kunkle TD, Porter B, Morita A. Gas bubble disease in dogs. II. Effect of rapid compression. Undersea Medical Society Annual Scientific Meeting,, San Antonio, TX,

1984..
7. U.S. Navy Department, Section 3. U.S. Navy Diving Manual (NAVSHIPS 250-538). Washington, D.C.: U.S. Government Printing Office, 1963.
8. Beckman EL. Treatment of decompression sickness based upon bubble dissolution physics. In: Proceedings of the Second Japanese Commercial Diving Symposium. Tokyo. Japan, 1980.
9. Kunkle TD, Beckman EL. Bubble dissolution physics and the treatment of decompression sickness. Med Physics 1983; 10:184–190.
10. Hills BA, Butler BD. Size distribution of air emboli produced by decompression. Undersea Biomed Res 1981; 8:163–170.
11. Edmonds C, Lowry CF, Pennefather J. Diving and Subaquatic Medicine, 1st ed. New South Wales, Australia: Diving Medical Centre Publication, 1976.
12. Beckman EL. An emergency method for immediate in-water treatment of decompression sickness. Presented at Alii Holo Kal Dive Club, 30 June 1981.

Appendix A: Australian Recompression Tables

(3) AUSTRALIAN TABLES

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

Notes:

1. This technique may be useful in treating cases of DCS in localities remote from recompression facilities. It may also be of use while suitable transport to such a center is being arranged.
2. In planning, it should be realized that the therapy may take up to 3 h. 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 meters 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 m, breathing 100% oxygen.
2. Ascent is commenced after 30 min in mild cases, or 60 min in severe cases, if improvement has occurred. These times may be extended to 60 min and 90 min, respectively, if there is no improvement.
3. Ascent is at the rate of 1 m every 12 min.
4. If symptoms recur, remain at depth a further 30 min 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 1 h on oxygen, 1 h off, for a further 12 h.

b) Treatment of delayed or complicated cases of DCS.

1. Recompression to a depth that produced 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 atm abs, e.g., at 30 m 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 m, 100% oxygen.

Table 1: *August 9 (RAN 82) Short Oxygen Table*

	Elapsed Time		
Depth, m	mild	serious	Rate of Ascent
9	0030–0100	0100–0130	
8	0042–0112	0112–0142	
7	0054–0124	0124–0154	12 min · m^{-1}
6	0106–0136	0136–0206	(min · ft^{-1})
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 h 6 min—2 h 36 min for mild cases
2 h 36 min—3 h 6 min for serious cases

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

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

In such an event, treatment must be initiated as soon as the signs or symptoms of DCS 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 7–8 min after its oxygen supply has been stopped by the intravascular bubble emboli of DCS.

Because of the urgency to initiate adequate recompression therapy, this treatment regimen is designed to utilize a) 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 b) 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 min, 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/min for the first 2 min, with decreasing rates so that at 40 fsw the rate is 5 ft/min. 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 min.

Upon reaching 30 fsw, the patient should switch to 100% 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 h 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 min) by an attending diver descending from the surface. After 1 h 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 min), 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 min before returning to the surface.

These emergency air-oxygen treatment tables, like all DCS treatment tables, must be used with judgment based on 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

- 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
- 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 buoyant)
- Extra air tanks for victim and attending diver (minimum of two)
- Anchor rope or sounding float line marked at 165 ft 5. Depth gauge and watch for use by attending diver
- Wet suit jacket for use by victim with appropriate weights

Method

Upon recognizing symptoms or signs of decompression DCS, immediately—

- Stop the engines
- Throw over anchor line and let out to 165 fsw or to bottom
- Rig one full air tank for victim and another for attendant diver
- Put victim in water with one attendant diver (or two if required) to take victim down anchor line
- Descend to depth of relief plus 30 fsw.
- Keep victim at that depth for 10 min
- Attending diver and victim start slow ascent with initial rate of 30 ft/min with stops every minute for assessment of patient's condition
- Ascent from maximum depth to oxygen breathing depth of 30 fsw should not take less than 10 min. Suggested

rates of ascents from 165 fsw are: 30 ft/min × 2 min; 15 ft/min × 2 min; 10 ft/min × 3 min; 5 ft/min × 3 min

- If patient starts to experience recurrence of any signs or symptoms, return to 10-ft deeper stop for 5 min, then resume ascent
- During deep air breathing period, crew in boat rigs oxygen breathing equipment with regulator attached to hose and line with seat at 30 fsw
- Upon reaching 30 fsw victim switches to oxygen breathing
- Victim breathes oxygen at 30 fsw for a minimum of 1 h
- If victim had initial symptoms of pain only, and if signs and symptoms are relieved after 1 h 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-min periods. When victim is completely relieved, start slow ascent to surface while breathing oxygen.
- If the in-water recompression is not effective and the supply Recompression on oxygen at 30 fsw should be continued unit of oxygen is apparently inadequate, emergency transport to the .on-shore recompression chamber should be arranged. l the oxygen supply is exhausted or transport arrives.
- 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.

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.

DISCUSSION

Mr. Hubert: I find it curious that the Hawaiian divers seem to be the deepest of all the other divers as far as what your depth is when they're going back down to do the recompression.

Do you think that has any correlation to the fact that they seem to be diving deeper than anybody except for Richard Pyle, who broke all records? Uniquely, Richard also used pretty deep depths, going down as far as for his first stop. You know, this dive was at 165, I think it was.

Unidentified Speaker: 165, 125.

Mr. Hubert: 125.

Mr. Farm: I think initially, you know, if you want to say it was empirically developed, the fact is that I know what influenced me when we did it and I know when we're diving and we're doing all the deep dives now and for some reason if there was a problem with some of the DCS, and the boat's in motion full throttle, what you're thinking about is where's the nearest fish grounds that I know that might still produce something?

The depth line would be, oh, I take it to be 80. That usually has a basis and then our buddy is really hurting and the time. You know, we were really wasting time. What's the closest area? They got him rigged up and they got another tank ready to go.

If we hadn't gotten real close to the spot where we could be productive, you know, we didn't stop, especially if it's a CNS type thing. Pain, we can wait three or four or five more minutes trying to go some place.

I think this influenced the depth in the initial years when the fishermen were doing this. Did that answer your question?

Mr. Hubert: Really, in most of their recompression they were looking for relief of pain or relief of paralysis.

It just seems like let's say the Australian divers, they seemed to be diving a little bit shallower, to my knowledge, and then the California divers they do pretty much the same thing, to my knowledge, except for they do it at about 20 feet.

So it just seems there's a correlation here amongst the different areas as far as how deep initially we're diving and at what depth we're noticing the relief of the symptoms.

Mr. Farm: There's not too many coral divers—black coral divers—precious coral divers in Hawaii anymore. There are a few. In fact, about 2 years ago, we had a sudden fatality diving just a little over 200 feet. It was very sad because the dad came up and found out that his son wasn't there on the boat.

So he knew what he was doing. He was an experienced diver. He often would go with his son and dive. You can't be unbiased and unemotional at the time. We told him that he shouldn't go down. He went down and found his son at the bottom. We brought him from the bottom to the top.

But black coral and precious coral are not being harvested too much now. I think as the marketplace changes and the incentive is given back by people. There's not a lot of people. The diving fishermen like I showed, you know, they go where the fish are. It could be 20 feet, 30 feet, 80 feet, 100 feet, and they just do their operation and get out of there.

Mr. Gold: Thank you for a very interesting presentation. I enjoyed that. To what extent or what are the numbers today as far as diving fishermen in Hawaii? Are there still the same sort of numbers?

Mr. Farm: You mean diving for profit?

Mr. Gold: Number of divers, not number of fishermen.

Mr. Farm: I think they're still out there and I would say over 500 —between 5 and 1,500 would be my guess. Lots. There's different levels of diving. There's people that do it on a part-time basis.

They can go to work and when they have 2 days off, that group or that little crew will go out and they make good use of their operations. Doesn't cost them anything. The boat is free and everything else they do is free. But as far as the full-fledged, full-time, probably about 8 or 10 boats with about three- or four-man crew statewide.

Dr. Sanchez: Yeah, you presented a group that is very experienced. They have the knowledge of 20 years diving. So it seems to me that you present a different type of diver who's natural selection but is selected and conserved outside. What is the turnaround of this group of divers? How many years do you expect to see them diving?

Mr. Farm: Can you say that again?

Dr. Sanchez: You see, you have very experienced divers, for how long do they dive? Because that's the other question. How long do we keep our divers diving?

Mr. Farm: You mean, how many out of the old group is still diving?

Dr. Sanchez: Well, how many years of productive diving do you have in this group of Hawaii divers?

Mr. Farm: I know some of them in that initial group and they are still diving. There are not too many.

Dr. Sanchez: That is exactly what I need. Our number of divers have not changed in the last 20 years. But the problem is the turnaround of these divers.

We started to see very young divers because they were finishing the old divers. So it's not the total numbers but the number of years that they are diving.

Mr. Gold: While people are coming in, I have a request, if I may. I would like to propose -- I don't how many of you that are dealing with indigenous divers have web sites or know of web sites that deal specifically with indigenous divers. Personally, I've put together a web site for a project on the Sea Gypsies. I know the DDRC has done the same. I know that Izdepski of SOS has done the same thing with the Indians.

What I would propose perhaps is using, if the good Chair agrees, I will put down the URL for web site that we've developed. If you could do the same it would be very helpful. I would like to link in to your web sites. In other words, put cross-linkages so that other people can access it and perhaps those of you that wish to could do the same.

Chairperson: So we'll look for the URL and we'll all link up when we get back to our home computers or office computers, whatever the case may be.

Mr. Gold: Thank you.

DIVING TECHNIQUES OF THE CENTRAL COAST ABALONE DIVERS

Takashi Hattori

Commercial diving for abalone along the central California coast started in the late 1890s with the arrival of Gennosuke Kodani, a trained marine biologist, sent to the Monterey Peninsula by the Japanese government to check out a report of an abundant supply of large abalone in the area.

Initially, dried abalone was the main product, but Mr. Kodani in partnership with Mr. Alien, who owned the land around Pt. Lobos, started canning abalone for sale both in Japan and the United States. In 1913, California passed a law prohibiting the export of abalone products out of the state. Commercial processing of abalone was about to dry up, but in 1920, a restaurateur named "Pop" Ernest Doelter started offering fried abalone steak, which had been pounded to tenderness. This soon became so popular that by the 1930s the supply could hardly keep up with the demand.

Before 1920, a single work dive boat was used. However, as the abalone around the Pt. Lobos area started to thin out, it became necessary to go farther and farther away from the processing plant. Mr. Kodani acquired a larger boat about 50 ft in length, which was used to sleep in on arriving at the harvesting area. In the thirties, they generally stayed anchored in one area for 4–5 days before coming home. Each night, the day's harvest was stored in wooden boxes, which were floated in the water.

The dive work boat was about 25 ft in length and was powered by a gasoline engine which also operated the air compression pump that stored air under pressure good for about 15–20 min after the engine stopped.

The crew consisted of the diver, a lifeline tender, an air hose tender, and a driver. The lifeline tender also brought up the full basket of abalone. Three quick pulls on the lifeline by the diver meant "send down an empty basket". After the basket was sent down, the diver would tie on the full basket, and give the line a single jerk as a signal to haul up the basket. Five quick jerks by the diver meant that he was going to surface. A series of quick jerks meant an emergency, and the diver should be hauled up quickly. The man handling the air hose also cut the seaweed free of the air hose. The driver of the boat followed the diver around using the sculling oar most of the time. The engine was rarely used except when reverse was needed.

Hard-hat diving was the only commercially feasible way of harvesting abalone along the central coast because of the frigid waters—usually between 50°–55° year around. Most of the harvesting was done at depths between 20 and 50 ft. No commercial harvesting was allowed shallower than 20 feet. Diving started at sun-up and lasted till sundown. The diver usually surfaced about every three hours mainly because his bladder was full.

Decompression sickness was rare for two main reasons. First, most diving was done between 20 to 50 feet. Second, diving usually started at the deepest site and went to progressively shallower sites during the work day. When signs of decompression sickness (DCS) occurred, treatment was by "in-water recompression", as we know it today. The diver was dumped back down to the depth he was working and allowed to walk back toward shore over a couple of hours time. If symptoms occurred at night, the diver was suited up, placed in a sling and lowered to about 30 ft, then brought up about 3–4 ft at a time every 15–20 min to the surface.

In 1939, we had gone down to Santa Barbara to see what kind of abalone and how much was available in the area. Because of the swift current in the afternoon, and because the abalone were found in deeper waters (50–80 ft). The amount of air hose was almost double the working depth, and the diver had to exert himself much more to keep from being swept away. About 1400 h one day, my brother developed shoulder pain, so in-water treatment was started in about 50 ft of water. Over the next 5 h, he worked toward the shore. He was at about 15 ft depth when he signaled for a basket. When we pulled up the basket, it contained the largest lobster I had ever seen. It was over 4 ft in length. Its antenna was so large I could not get my hands around them and probably weighed about 40 pounds. His DCS was resolved. Another time he developed symptoms at night and had to be lowered into the water. He said it was a most terrifying experience to be bumped by something he couldn't see or vaguely see a dark unidentifiable shadow pass by. I can think of only one old Japanese diver who limped around on land most probably due to aseptic necrosis of the hip. He always felt better when he was at the "bottom".

There were no fatalities among the Japanese divers, although I know of at least one near fatality when a diver got entangled in kelp for 30 min or so after the engine stalled and could not be started. There were several fatalities among the divers in the San Simeon area. The main reason was that they did not use a sculling oar to maneuver among the rocks in following the diver. They used the engine for all the maneuvering with the result that the air hose was severed by the propeller.

DISCUSSION

Dr. Lepawsky: Any questions for Dr. Hattori? I would ask, did they decompress by walking back home under the boat as well as treating themselves under the boat as they walked back?

Dr. Hattori: No, the bubble in the hose always stayed in front of the boat to stay away from the propeller. But you know, they usually walked in the daylight, it would take -- he would always go down around 30 feet —30 or 40 feet and then walk back towards shore.

Dr. Lepawsky: Any cases of aseptic necrosis?

Dr. Hattori: Yes, I think that one old diver that I told you that limped around on his hip, who always felt better in the water, was a case of aseptic necrosis.

Unidentified Speaker: They're still trying to find a few abalone out there now. Can you tell us how they're doing it now?

Dr. Hattori: Well, in the Monterey area, there is none. No abalone diving at all. There is some diving down in the Santa Cruz Islands. They're just talking about opening up some of the Channel Islands to commercial abalone. And those have been going on around San Diego but I think that's died off. They're all using the scuba or hookah gear now. There aren't any hard-hat divers.

Unidentified Speaker: If they're going to a hundred feet.

Dr. Hattori: Yes, they're going much deeper, too.

Unidentified Speaker: Is it legal to harvest abalone?

Dr. Hattori: Yes, you know, there are areas open for commercial abalone harvesting in southern California and as I said, I think some of the Santa Cruz Island areas are being opened up to commercial diving.

Unidentified Speaker: At today's prices, you would have gotten rich with one of those boatloads.

Dr. Hattori: Yeah, well, even in the 30s, you know, when the filet mignon was 50 cents a pound, abalone brought $1.50 a pound. So it wasn't cheap even in those days.

Unidentified Speaker: No, it's just a statement. In the State of California now, all commercial abalone is prohibited.

Chairperson: British Columbia stripped its abalone that had evolved for some four-and-a-half billion years, they stripped their abalone in about a decade-and-a-half and we've been shut down for abalone for the last roughly 10 years or more. I can't remember how long and we're not opening up.

Unidentified speaker: Abalone we're expecting to be wiped out by the sea otters in this area. The otters haven't quite gotten south of San Francisco. But they'll be all gone, I think, up there, too.

Unidentified speaker: Do we know if abalone diving still takes place in Mexico?

Dr. Lepawsky: There is abalone diving in the Baja and other areas.

Dr. Sanchez: Baja basically. All around the Baja.

Chairperson: In the Baja, yes.. So our next speaker is Colonel William Patrick Butler from San Antonio, Texas. He's at the Davis Hyperbaric Facility. I think it's at Brooks Air Force Base.

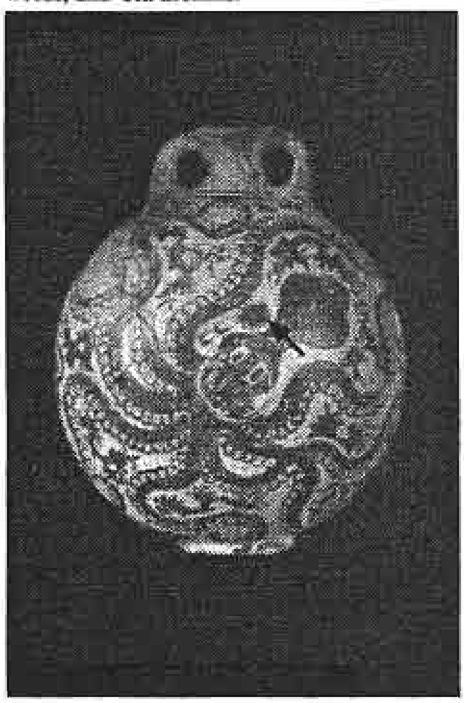
Dr. Butler has numerous citations and honors. I can't go through them all. It's too long. Just to say that we're about to hear from a very accomplished and intellectually nimble individual. So here is Dr. Butler to tell us about Maine sea urchin divers.

URCHIN DIVING IN MAINE
The Urchin Diver and Urchin Spine Injuries

William P. Butler

Background

Sea urchins have been used by man since ancient times. Variously, they have been medicines, art objects, and foodstuffs. The Greek writer, Dioscorides, describes medicinal urchins. Here, the sea urchin treated burns, gastrointestinal complaints, and bladder problems. Another ancient use for the sea urchin was art. The Minoan civilization of Crete regularly incorporated urchin motifs. On arguably the most famous Minoan flask/vase (circa 15th century BC), placed among the octopus' legs are seashells, sea weeds, and sea urchins.

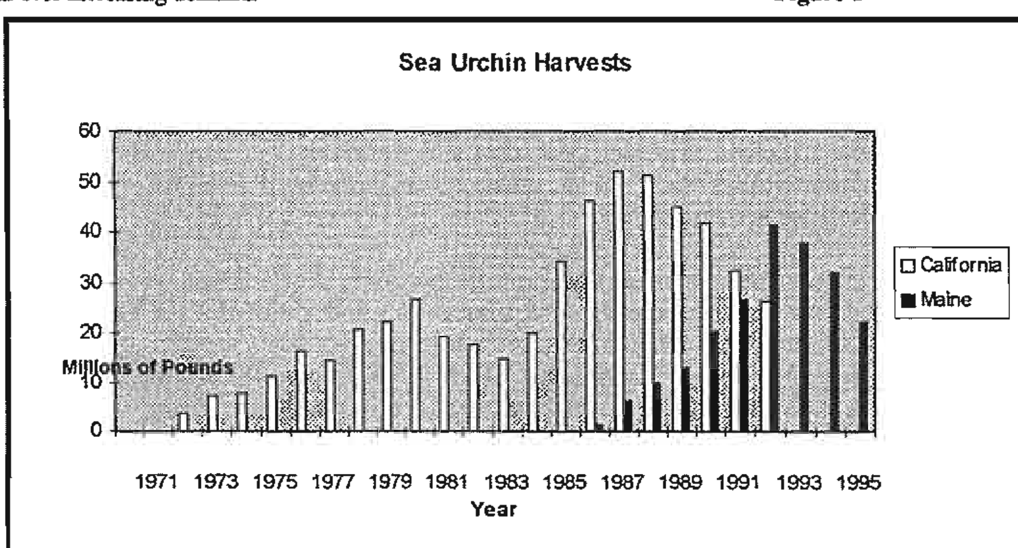


Clearly, however, man most commonly eats the sea urchin. Pacific coast Native Americans have enjoyed the urchin for thousands of years. More recently, this delicacy was popular not only in the Mediterranean region, but also in Victorian England. In fact, post-World War II Paris was a hotbed of urchin fanciers. The Left Bank Existential movement was particularly fond of devouring urchin roe.

Indeed, it is the urchin roe that is sought. The modern urchin fishery is not based on Western demand, it is based on Eastern demand. In Japan, "uni," urchin roe, is a delightful gastronomic treat. For this reason, uni has been harvested in Japanese waters for centuries. Eventually, the demand exceeded the local supply. Importation became important. Incidentally, today, uni sells for about $100 per pound.

In the early 1970's, North America's Pacific coast filled the uni void. In particular, California and British Columbia became major suppliers. Although, the red sea urchin was the primary cash crop, the purple and green sea urchin were also harvested. Over the ensuing ten years excessive fishing took its toll. From a high harvest of 26 million pounds in 1981, the take plummeted to 14 million pounds in 1984. (Figure 1) Despite the subsequent rebound, concerned Japanese buyers were forced to look for new markets to supply an ever increasing demand.

Figure 1



The New England coast of the United States was examined. For many years, New York City and Boston had provided specialty markets for a small, relatively insignificant urchin fishery. The Downeast coast of Maine was a primary source. Here, the green sea urchin grew prolifically. Not infrequently, urchins carpeted the many coves and inlets. However, until the late 1980's this fishery accounted for less than $50,000 of Maine's annual multi-million dollar sea harvest industry. In fact, from 1947-1977 the average annual value of Maine's urchin harvest was under $4000.

All that changed in 1987. Despite the West Coast harvest collapse, the demand for uni was unabated. It was rising. Although the California harvest rebounded over the next several years, Japanese suppliers wanted alternative sources. The Maine urchin fishery was discovered. Now, urchin harvesters had volume buyers and easily collected product. Almost overnight 1.4 million pounds were harvested valued at $236,000. Sea urchins had become Maine's newest "cash cow." This minor fishery was now 29th in annual revenue. By 1993, the harvest had grown to 41 million pounds worth over $26 million dollars. Only lobster and salmon brought greater moneys. This once minor fishery was now a major fishery. (Table A & Table B)

Table A

Maine Sea Urchin Harvest			
year	million lbs	million $'s	ranking
1987	1.4	0.2	29
1992	26.4	15.2	2
1993	41.6	26.8	3
1994	38	33	3
1995	32	33.2	3
1996	22.1	23.9	3

Word spread of $500 to $1000 work days. Harvesting by hand (scuba diving) or by dragging (lightweight bottom bags towed by a boat) was commonly employed. However, scuba required less investment, less training, and less skill. Scuba harvesters appeared from nowhere. The "gold rush" had begun.

Table B

Maine Sea Harvest Value—million $'s (ranking)	1987	1992	1993	1994	1995	1996
lobster	55 (1)	72 (1)	74 (1)	101 (1)	102 (1)	106 (1)
salmon			43 (2)	36 (2)	57 (2)	46 (2)
urchin	.2 (29)	15 (2)	27 (3)	33 (3)	33 (3)	24 (3)

In 1992, when urchin harvesting licensure began only 807 divers were licensed. By the end of 1993, there were 1439 licensed urchin harvesters. (Figure 2) With this tremendous surge in harvesters the easy-to-collect coves and inlets were soon exhausted. The search for quarry no longer concentrated in calm waters. Open ocean coastline was targeted. Again, many green sea urchin carpets were discovered; however, the diving conditions were different.

Here, tidal surges and accompanying currents are unfettered. Swift, powerful flows with unexpected directional changes are common. Factoring in the tidal shifts of 20-30 feet produces very narrow windows of safe diving. In addition, the famous rugged coast has few beaches and many sharp, rocky outcrops. Many a diver knows first hand the variety of injury suffered when flung against them. Winter harvest—the best time for uni—is frequented by rapid weather change. What looks to be a calm blue-skied day often becomes blustery, cloud-covered, and rain-soaked/snow-flaked. Outright poor weather is frequent. And, the water itself is exceedingly cold. In short, urchin harvesting had graduated from a low energy to high energy environment. The danger had risen exponentially.

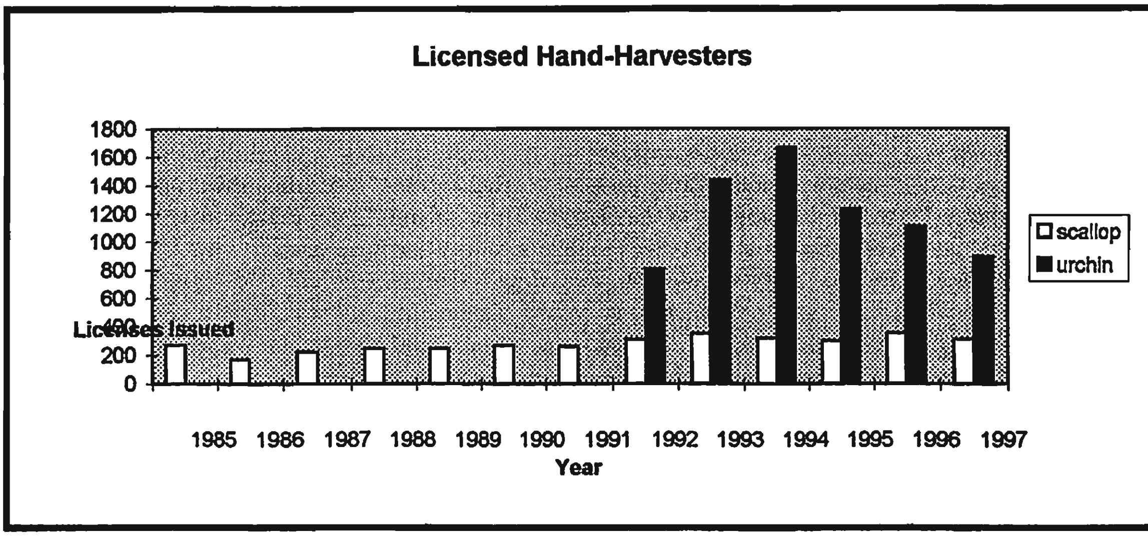


Figure 2

The "new" danger was swift to manifest itself. Almost a quarter of Maine's 34 reported injuries in 1993 involved urchin harvesters. (Table C) And, just over a quarter of marine casualty incidents associated with commercial vessels involved urchin harvesters. However, death brought dramatic focus upon the urchin fishery. In 1992, three urchin divers died. This was followed by four fatalities and five near-fatalities in 1993. (Table D) All but one of these deaths were considered "industry specific." These tragedies and near-tragedies produced a legislative impetus to reform the urchin industry. Regulating legislation passed muster in late 1993.

Table C

Urchin Related Injuries (1993)	
hypothermia	3
DCS	2
fractures	1
urchin spine reactions	1
partial hand amputation	1

A licensure moratorium was enacted. Unless the diver already possessed a hand-fishing urchin license, no new license could be purchased. This moratorium would last until 1999. However, 1998 legislation made this limitation permanent. To obtain a "new" license, a diver must win a lottery. The licenses eligible for lottery distribution are based on the previous year's non-renewed licenses. For every five licenses not renewed, one license is placed in the lottery. In this way, a gradual attrition of divers occurs. The goal is to reduce the harvesting cadre to below 1000 divers.

Table D

Urchin Related Fatalities				
1992				**3**
	DD	AGE	1st dive	
	BM	AGE		
	?	?		
1993				**4**
	DM	drowned	experienced	
	AS	drowned	not diving	
	MR	drowned	1st dive	
	DM	drowned	2 weeks	
1994				**0**
1995				**1**
	CW	MI		
1996				**0**
1997				**1**
	JS	drowned	6th tank; 0.32% Etoh	
1998				**1**
	?	drowned	6th tank; under ice	

In addition, diver participation in a competency training course was mandated. Valid open water diving certification was a prerequisite. The Department of Marine Resources (DMR) Diver Safety Program was the result. By September 1994, divers and tenders began taking the 3-day course developed by Jamestown Marine, Inc. of Rhode Island. Cardiopulmonary resuscitation and first aid were taught during Day 1. Topics discussed on Day 2 included equipment, operational procedures, dive accident management, rescue/emergency procedures, boating safety, laws and regulations, and industry review. On Day 3 dive physiology, dive tables, decompression, and environment were presented.

Needless to say, there was initial diver resistance. Ron Henkle, a certified diver and experienced commercial harvester, distilled the protests to the *Quoddy Tides* saying, "I got to take three days off work, plus spend $170, and travel to Eastport or Bangor to take a course that's not going to teach me anything I don't already know." Indeed, early enrollment was slow. Only 50 divers had signed on by mid-September. Seeing this resistance prompted very public statements by both DMR and the US Coast Guard. This law would be strictly enforced. In fact, inspections would be common in port and at sea. As expected, enrollment rose. Today, those taking the course are mostly tenders (3 tenders:1 diver) awaiting their opportunity in the license lottery.

The legislature also addressed the sea urchin as a commodity. A legal size was declared. Taking urchins less than 2 inches in diameter became illegal. Night harvesting was prohibited. And, a nine month harvesting season was created---16 August to 14 May---replacing year round fishing. However, divers continued to ramble unrestricted along the coast focusing their efforts where the urchin was most populous.

In 1994, this was remedied. Limited access zones were established. Using Rockland as a centerpoint, from Kittery to Rockland was designated Zone 1 and from Rockland to Calais was designated Zone 2. A diver could acquire a license for only one zone. Harvesting was allowed solely within that zone. No cross-over was permitted. No change in zone was allowed until the following year's license was purchased. In 1996, the Sea Urchin Zone Council was created by the legislature. Its only purpose was to advise the DMR commissioner "... on the selection of open fishing days." Today, this council has nineteen members---three divers from Zone 1 and three divers from Zone 2, three draggers from Zone 1 and three draggers from Zone 2, one urchin processor from Zone 1 and one urchin processor from Zone 2, one urchin buyer from Zone 1 and one urchin buyer from Zone 2, two scientists with marine resource management experience, and one diver with a boat handler's license. A split season now exists. A diver may harvest up to 170 days between 1 August and 30 March *or* 1 November and 30 April. But, only certain days designated by the Council are open for harvesting. For instance, during the 1997-1998 season, the Council limited Zone 1 to 119 days and Zone 2 to 120 days. (Chart 1 and Chart 2)

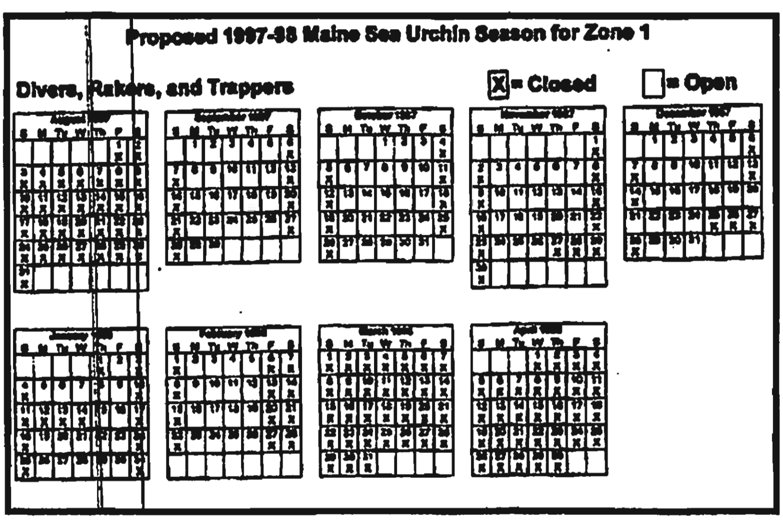
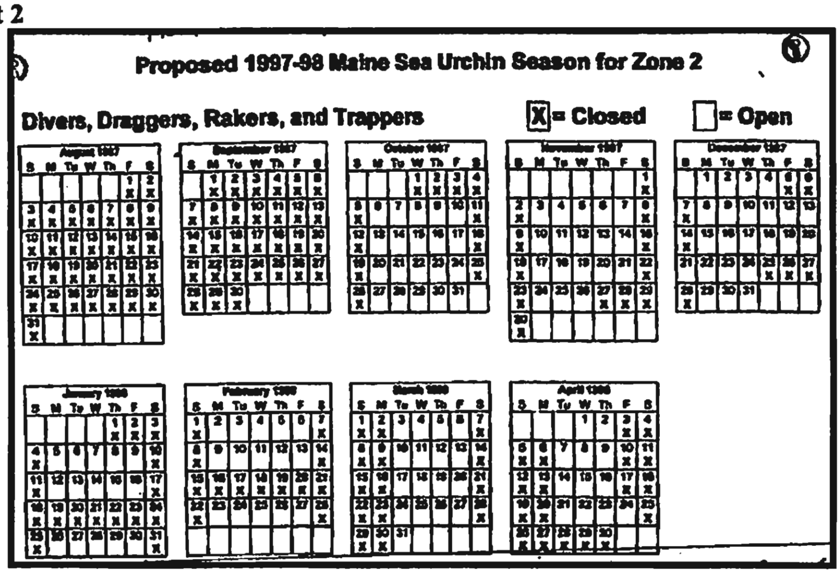
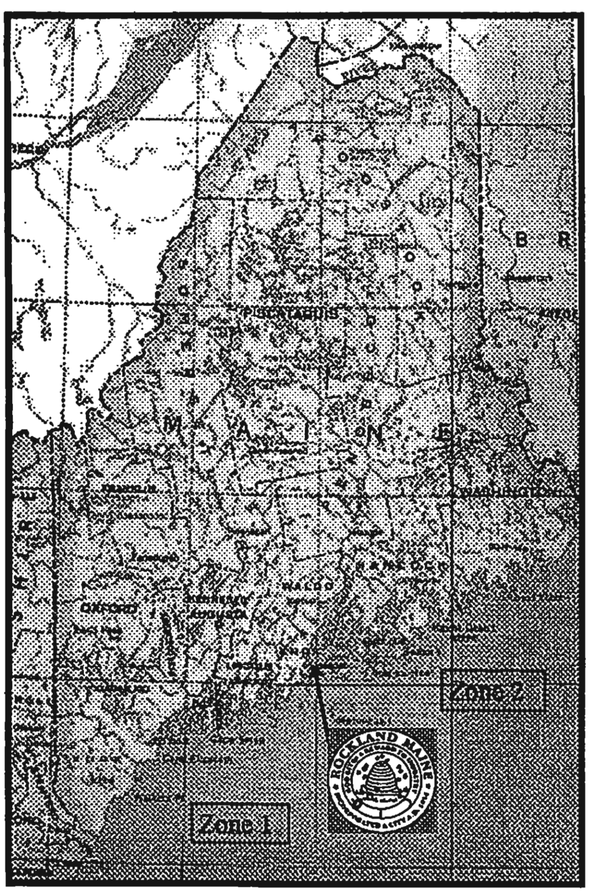


Chart 1

Chart 2



Use the map of Maine to appreciate the coastal zones. Use Rockland as centerpoint.



Since 1993, there has been a gradual attrition of urchin divers from a high of 1670 licenses (1994) to 898 licenses (1997). (Figure 2) As expected, the harvest peak of 1993 (41+ million pounds) has not been revisited. In fact, landings have gradually dropped since the legislative reforms. Despite the reduced harvest, the urchin industry persists as Maine's #3 sea product producing $20-30 million annually. (Table A and Table B)

As for the individual harvester, urchins remain profitable. The price per pound has stabilized over the past three years at about $1.00. Although the $1000 days are gone, a very good day consistently brings in $400. And, finally, there have been only three urchin-related fatalities. One involved alcohol (1997), one was from a heart attack (1995), and one resulted from improperly diving under ice (1998). (Table D)

Thus, it would seem that the legislative actions have been successful. Industry access has been limited. Harvest volume has been modulated without significant revenue loss. Diver safety training has been mandated and maintained. And, deaths have been reduced. In short, it appears the urchin fishery of Maine has become a renewable resource with a consistent annual worth.

Other Urchin Markets

It is interesting to briefly look at other urchin fisheries. In California, the red sea urchin is harvested. Here, a limited entry permit in conjunction with a commercial fishing license is required. There are 550 licensed divers. Every other year they must accumulate at least 20 landings totaling over 300 pounds. Otherwise, the permit is sacrificed. There is a lottery for new permits. To offer a new permit ten must be lost by attrition. Most harvesters have over 10,000 diving hours. Most dives are from 40-60 feet deep. And, most commonly, diving is by hooka gear. In addition, there is an urchin size limitation. In Southern California the urchin must be larger than 3.25 inches. In Northern California the urchin must be larger than 3.5 inches. The peak harvest season extends from Thanksgiving to New Year's Day. Furthermore, the California urchin industry is worth $75-80 million annually. Amazingly, urchins have headed California's sea harvest revenue list from 1989-1995.

Eastern Canada harvests the green sea urchin. Again, Japanese demand severely affected a hitherto minor fishery. To avoid the problems seen in California and Maine, the provinces of New Brunswick (1994-1995) and Nova Scotia (1996-1997) developed formal "Green Sea Urchin Conservation Harvesting Plan(s)." Addressed were harvesting seasons, urchin size, sorting at sea, harvest reporting, gear restrictions, area restrictions, and licensure requirements. Of note, during the years 1992-1995, there were two waves of urchin deaths off the Nova Scotia coast. The cause was "paramoebiasis" which results from an infection by the marine amoeba, *Paramoeba invadens*. When the water temperature drops below 10 degrees Centigrade, the infection ceases.

The Urchin Diver---1993/1994

Maine's legislative intrusion into the urchin fishery began in late 1993. During the controversial days preceding action, there were often heated discussions. Many of these revolved around the urchin diver and his diving practices. Only anecdotal observations were available. Thus, a survey was undertaken to better characterize the urchin diver.

Using the list of 1993 hand-harvesting license holders (provided by the Department of Marine Resources), each diver was mailed a one-page survey consisting of 21 questions. Topics included basic census information, diving certification and experience, diving habits, medical problems, diving environment, and symptoms attributable to diving. It was designed to be anonymous if the respondent desired. The mailings began in early December 1993, and returns ceased by mid-June 1994.

Of the 1545 surveys mailed, forty-six were returned unopened and 323 were returned answered. The overall return rate was 22% (323/1499). Many included detailed commentary on the industry itself.

The respondents described the 1993/1994 diver. The Maine hand-harvester was usually a young male of medium build who viewed himself physically fit and in "good" to "excellent" health. Few were over 41 years (17%) and only a small number admitted they were unfit (4%). (Table 1) Most divers had more than one occupation. Often, it was a land-based job. (Table 2) The majority were open water scuba certified; however, 2% admitted no formal training. (Table 3) In addition, there was a trimodal distribution of experience. Those divers with the most experience had over 10 years diving (27%) or over 1000 dives (23%). Those with intermediate experience had 4-10 years diving (33%) or 101-1000 dives (38%). Those with the least experience had 3 years or less diving (37%) or less than 100 dives (14%). In fact, 17% had no more than one year's experience. (Table 3) Over half the divers made 2-5 dives daily in less than 60 feet of water. Most did "bounce" dives without using decompression stops. Most used a safety schedule (ie, computer or dive table) and a majority regularly dove solo. (Table 4)

Table 1: Divers' Profile, n = 323

Sex	No. Divers	Age, yr	No. Divers
Male	314	15–20	12
Female	9	21–30	124
		31–40	133
		41–50	47
		>50	7

Build	No. Divers	Physical Condition	No. Divers
Slight/slim	27	out of shape	13
Medium	217	inshape	228
Heavy	70	in top shape	82
Overweight	5		
Not answered	4		

Health Status	No. Divers
Poor	1
Fair	11
Good	151
Excellent	160

Table 2: Usual Occupation, n = 323*

Sea related	285
Construction related	54
Service related	43
Public service related	19
Miscellaneous	25
Not answered	13
Sea related includes	urchin diver, "diver", commercial fishing, lobsterman, commercial diver, scallop diver, clam digger, boat builder, aquaculture, boat captain, seasonal, harvester, seafood processor, merchant marine, marine biologist
Construction related includes	carpenter, construction, mechanic, pipefitter/welder, electrician, laborer, tinsmith, equipment operator, machinist, masonry, paper mill, manufacturer, mill wright, refrigeration, brick layer, supervisor, asbestos worker, sheet metalist, floor installer, contractor
Service related includes	dive instructor, chef/cook, printer, telephone technician, retail seafood, photographer, caretaker, property manager, technical planner, waste vacuumer, surveyor, real estate, estimator, martial arts instructor, flight attendant, landscaper, artist, architect, transportation, bar manager, consultant, truck driver, car salesman, athletic trainer
Public service related includes	firefighter, police, game warden, Coast Guard, teacher, nurse, counselor, emergency medical technician, waste water treatment plant, vocational rehabilitation counselor
Miscellaneous includes	student, self-employed, retired, engineer, disabled, farmer, dog trainer

*Many divers described more than one occupation (1.36/diver).

Table 3: Certification and Experience, $n = 323$

Organization	No.[a]	Diving Time, yr	No. Divers	No. Dives	No. Divers
YMCA	51	≤1	55	1–50	21
NAUI	62	<1	25	51–100	24
PADI	182	1–3	96	101–150	21
IDEA	12	4–5	43	151–200	16
SSI	9	6–10	64	201–500	55
Other	31	11–15	39'	501–1,000	26
None	6	16–20	28	1,001–2,000	43
		>20	21	2,001–5,000	19
				>5,000	12
Not answered	10	not answered	7	not quantified	59
				not answered	27

Key: YMCA, Young Men's Christian Association; NAUI, National Association of Underwater Instructors; PADI, Professional Association of Diving Instructors; IDEA, International Diving Educators Association; SSI, Scuba Schools International.

[a]A number of divers had earned more than one certification (1.12/diver).

Table 4: Diving Habits, $n = 323$

Number Daily Dives	No. Divers	Usual Diving Depth, ft	No. Divers
1	3	<30	128
2–3	59	<60	125
4–5	129	<80	35
6–10	18	<100	25
11–15	1	>100	4
Not specified	11		
Not answered	102	not answered	6
Bounce Diving	**No. Divers**	**Decompression Stop**	**No. Divers**
Yes	195	yes	63
No	118	no	256
Not answered	10	not answered	4
Safety Schedule	**No. Divers**	**Solo Diving**	**No. Divers**
Computer	46	never	37
Dive tables	146	rarely	49
Both	47	sometimes	65
None	56	often	91
		always	78
Not answered	28	not answered	3

A small cadre of these divers (18%) had medical problems. (Table 5) Also, medications were used chronically by an even smaller group of divers (11%). (Table 6) Since the majority of harvesters dove from boats into cold ocean water and worked vigorously often during inclement weather, symptoms were expected. (Table 7) In fact, 78% reported symptoms compatible with decompression illness, pulmonary overpressurization, barotrauma, and nitrogen narcosis. (Table 8) Of note, less than 2% admitted recompression therapy.

Table 5: Medical Problems, *n* = 58

Musculoskeletal	No. Divers	Eye, Ear, Nose, Throat	No. Divers
Back problem	13	Sinus problem	5
Obesity	1	Allergies	3
Arthritis	4	Inner ear infection	1
Chronic shoulder/knee injury	5	Hearing loss	1
Reduced arm use	1	Eustacian tube disorder	1
Osteomyelitis	1	Meneier's disease	1
Tendonitis	2	Left eye blindness	1
Cardiovascular	**No. Divers**	**Endocrine**	**No. Divers**
Hypertension	9	Diabetes mellitus	3
Aortic regurgitation	1	Hypothyroidism	1
High cholesterol	2	Thyroid cancer	1
Gastrointestinal	**No. Divers**	**Genitourinary**	**No. Divers**
Liver problem	1	Hydrocele	1
Gastroesophageal reflux	1	Kidney stones	1
Excess acid	1		
Celiac sprue	1		
Pulmonary	**No. Divers**	**Miscellaneous**	**No. Divers**
Difficulty breathing	1	Migraine	1
Lung scar tissue	1	Low platelets	1
		TB exposure	1

Table 6: Medication Used, *n* = 35

	No. Divers
Decongestants	11
Anti-seasickness	2
Birth control pills	2
Prednisone	2
Benazepril	2
Lisinopril	2
Enalapril maleate	1
Hydrochlorthiazide	1
Verapamil	1
Insulin	1
Glyburide	1
Cromolyn inhaler	1
Propoxyphene maleate	1
Oxycodone	1
Anti-inflammatory drug	1
Ibuprofen	1
Aspirin	1
Fluriprofen	1
Famotidine	1
Cimetidine	1
Omeprazole	1
Hydroxyurea	1
Azathioprine	1
Tetracycline	1
Isoniazid	1
Gemfibrozil	1
Conjugated estrogens	1

Table 7: Diving Environment, *n* = 323

Percent Diving Time	Commercial Diving	Boat Diving	Cold-Water Diving	Salt-Water Diving	Vigorous Diving	Poor-Weather Diving
1–20	18	10	5	3	25	76
21–40	6	7	4	1	9	62
41–60	17	17	13	8	30	76
61–80	32	18	47	12	38	16
81–100	225	224	215	272	123	17
Not answered	29	47	39	27	98	76

Table 8: Symptoms Experienced, $n = 323^{a,b,c}$

Symptom	No. Divers	Symptom	No. Divers
Fatigue	151	Mottled skin	4
Headache	111	Abnormal speech	4
Ear pain	49	Confusion	4
Ear/nose bleeding	49	"Swollen face/eyes"	4
Weakness	43	Seasickness	4
Joint pain	42	Double vision	3
Ringing ears	35	Unconsciousness	3
Dizziness	34	Temporary paralysis	2
Feeling of spinning	25	"Leg cramps/leg pain"	2
Rash	22	"Back pain"	2
"Cold"	19	"Blocked sinus"	2
Numbness/tingling	18	"Nausea"	2
Hearing loss	17	Blindness	1
Cough	16	Abdominal pain	1
Itching	15	Difficulty urinating	1
Crackling skin	13	"Swollen hands"	1
Hoarseness	13	"Ruptured sinus"	1
Disorientation	12	"Air embolism"	1
Blurred vision	10	"External otitis"	1
Rapid/pounding heart	10	"Burning airway"	1
Tender cheek	8	"Poor thinking"	1
Joint swelling	8	"Sinusitis"	1
"Bends"	8	"Reverse squeeze"	1
Difficulty swallowing	7	"Hand pain"	1
Chest pain	7	"Intoxicated feeling"	1
Rapid breathing	7	"Grade 4 ear barotrauma"	1
Shortness of breath	7	"Vomiting"	1
Loss of coordination	7	"Tooth pain"	1
Near drowning	7	"Nitrogen narcosis"	1
"Bad air"	6		
Tender forehead	5	No symptoms experienced	72

[a] Many divers described more than one symptom (2.59/diver). [b] Those items in "quotes" represent problems volunteered to the symptom list by the divers themselves. [c] Five divers related six instances of "chamber rides."

The Divers' Comments

Many of the responding divers had stories to tell, complaints to make, and opinions to voice. A generalized sampling of these comments highlight many of the observations already described. Related in a logical sequence, these divers paint a dramatic picture.

Disclaimer

"I am not trying to absolve myself from criticism, but show how rampant poor diving practices are in the urchin industry."

Solo Diving

"(I) go out on my own boat solo."

"Everyone knows that when you urchin dive with other divers you're still diving alone."

"Maintaining eye contact with another diver is not a real possibility due to current and mud/sediment clouds."

"The question is: when is a buddy a buddy and when is a buddy a project in itself."

Equipment

"I have seen people go out in boats that should only be used as large planters or decorations in front of seafood restaurants."

"Some of the gear I've seen in the water, boat, diving gear, etc. is far below standards."

"I was using junk gear and my tank got tore off in kelp and mud and couldn't find the regulator...I drank a bunch of water, but turned out fine."

"(I) pull up urchins in 100 pound bags using my BC and dry suit to float it up."

"The common shortcuts are: no knife, no BC, too much weight, draining tanks to unsafe levels, diving alone."

Weights

"(I) use 55 pounds lead weight."

"(I have) back pain---little (pain) with suspenders (on to support the weight belt), more (pain) without (suspenders)."

"(I) nearly drowned when I ran out of air and was too heavy with lead...had to ditch the weight belt."

Dive Profiles

"I do believe some of my symptoms may be from pushing my bottom time."

"Does anyone know the effects of diving five tanks a day?"

"Five or more (tanks) make me tired."

"(I do) 18-20 ascents at 100 feet daily for five tanks."

"(I) have been known to dive five tanks per day at 100 feet for two weeks to a month at times."

"The last bad diving I had was last summer with three 70 foot dives in one afternoon."

"The symptoms of fatigue and weakness are occasioned by back to back diving in very cold conditions, usually having dived up to 6-7 tanks. Headache and ear bleeding is usually a result of repetitive dives while scalloping (or urchining) in 40-80 feet of water, up to 6 or 7 tanks of air."

"I personally have done 7 tanks at 70 feet with no problems. Leave enough air to come up slow and stop at 10 feet with about twenty minutes in between tanks. This is my post-bends typical operating procedure. Pre-bends was not to worry how deep you are, just run out of air and bolt for the surface. Duh!!"

"(I) got a mild case of bends diving four 125 foot dives a little too close together."

Dive Experiences

"I experienced fatigue and weakness once after...getting back on board the boat after the weather took a sudden turn for the worst and went from 1-2 foot seas to 4-6 foot seas."

"(I have been) slammed up against ledges."

"(I had a) compound fracture of the humerus, boat struck a ledge."

"(My) foot got stuck in a rock crevice and ran out of air."

"(I) got tangled in urchin bag lines...and was out of air. Stern man saw there was trouble and stuck a gaff down and hooked into my BC and hauled me up."

"Some of my near misses are being caught in bags and ropes."

"I have been shot at, dragged over, run over---all by lobstermen."

Drug Use

"Headache, fatigue (occurs) if I stayed out late and drank the night before."

"Headache, confusion (comes) from either coming up too fast or maybe a little hung-over or maybe a combination."

"(I) smoke cigarettes---2 packs/day...(I smoke) pot---daily to weekly."

"From 1979 until 1992, I saw an incredible level of cocaine, marijuana, and alcohol use and abuse among divers...heroin is now popular..."

"Anyone possessing a harvester's license (should) be subject to random drug testing and should be required to pass a (drug) test upon renewal of their license. This would eliminate a good half of the urchin divers and a quarter of the lobstermen."

Divers' Opinions

"A lot of fatality are from "inexperienced" divers, who think it's easy and fast money. The money is good, but the work is hard."

"Many new divers that have been lured into this business with the promise of big money lack the experience to make wise choices concerning dive conditions and natural elements...extremely harsh, sometimes possibly life-threatening conditions."

"New divers should not be urchining or scalloping as they are still learning to use their primary equipment with little reserve ability. Anything wrong could lead to a panic and dysfunction. They don't have the reserve attention span to also harvest, manage bags and buoys, handle surf and surge and current and watch gauges and navigate."

<u>The Urchin Diver—1997/1998</u>

Today's urchin divers have not been polled. But, telephone interviews with knowledgeable sources suggest the following. The diver remains relatively young and male. All are scuba certified and have taken the mandatory 3-day DMR Diver Safety Program. All have significant diving experience. No longer is a raft of novice divers rampant. Diving depths continue at 30-50 feet; however, 60-70 feet is not infrequent. Bounce diving continues with 5-7 tanks daily. This seems to confirm biologist notions that the green sea urchin has not fully rebounded from the earlier profligate harvesting of the "gold rush" days.

Marijuana and cocaine remain present. And, alcohol overuse is frequent. Sometimes, "(alcohol is the) only way to rid the pain." This statement certainly suggests that symptoms from urchin diving continue. Of note, the one death in 1997 was alcohol related.

The urchin industry is stabilizing. No longer do controversy and high emotion rule the day. With a stable diving population based on a stable revenue source, further investigation is warranted. A detailed diver survey and characterization of today's diving practices should begin the process. Once accomplished and analyzed, future research could be intelligently planned.

Urchin Spine Injuries

"Don't forget: urchin spines are a leading cause of urchin diver injuries."
---Kevin Kimball, urchin diver

Introduction

When Maine's urchin boom arrived in 1987, few could have predicted its massive economic impact. Certainly, the fishery was unprepared for the problems that arose. While fatalities and near-fatalities attracted the most attention, a quiet epidemic of urchin spine injuries arose. Most divers suffered through them; however, a small cadre of divers became patients. This particular discussion will report a series of urchin spine injuries treated over a two year period (1992-1994). In addition, this series will form the centerpoint for a literature review. Thus, an accumulated experience with 40 urchin spine injuries will be presented.

Urchin Biology

The green sea urchin is an invertebrate within the Phylum Echinodermata. This phylum has four classes that include over 6000 species. Only about 85 of these many species are known to be venomous or poisonous. Urchins are in the Class Echinoidea. And, *Strongylocentrotus drobachiensis* (green sea urchin), is in the Family Strongylocentrotidae. This valuable species of sea urchin is most at home in cold subtidal waters at 30-50 feet deep. Maine's rugged, rocky coastline is an ideal environment for this urchin.

The 750+ species of urchin have many similar characteristics. Its calcareous shell of interlocking plates, or "test," is flattened at the poles. The anus is centrally placed on the dorsum, while its mouth is centrally placed on its ventral surface. The mouth, "Aristotle's lantern," has five very strong teeth leading to an extensive gut system. There, brown kelp (*Laminaria*), a particularly favorite foodstuff, is digested along with an assortment of marine algae including *Chondrus*, *Corallina*, *Ascophyllum*, and *Agarum*. The energy obtained is used for day-to-day activities and for the all important gonadal storage cells.

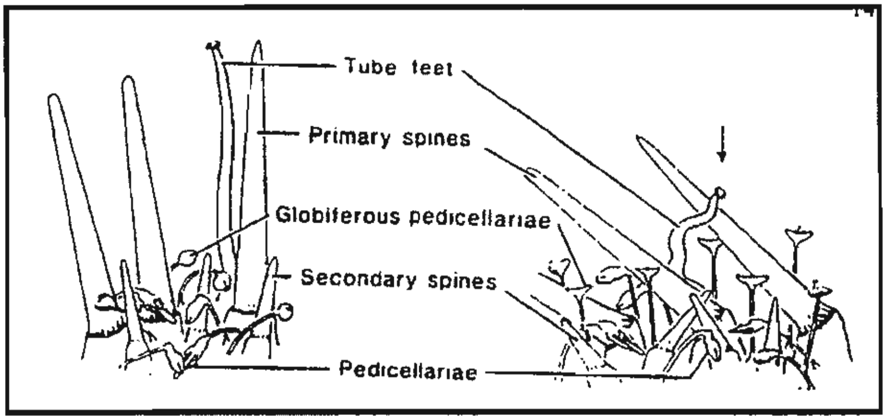
The palatal delicacy known as "uni" is the urchin gonad. It is distributed within the test in a pattern reminiscent of starfish legs. These gonadal storage cells reach their prime commercial value during the months November through March. At that time, the gonad can reach up to 25% of the urchin's body weight. Such heavy gonads are the result of abundant food sources. Because of this, there is little cellular water content making the gonad extremely valuable. Light yellow to light orange coloration denotes this state. Finding a field of such urchins is extraordinarily fortuitous. Most commonly, however, gonads reach 10-20% body weight. This means that 1000 pounds of urchin will garner 100-200 pounds of product. Incidentally, fresh specimens and proper preparation are absolute "musts" to ensure top dollar.

Urchins unharvested by March convert the storage cells to reproductive cells. Thus, spawning begins. Lasting from April to the summer, spawning rapidly depletes the gonad. Thus, its commercial value is very limited in late summer. However, the cycle once again begins with the inception of voracious feeding which will eventually replete the gonadal storage cells.

During spawning, the female eggs and male sperm are shed into the water. Leaking sex hormones seem to coordinate this activity. In fact, over 2 million eggs can be released by one female alone. Once fertilized, the eggs become larvae. These "pluteus" are particularly sensitive to temperature (prefer < 10 C), pollutants, and bacteria (ie, paramoebiasis). After 4-6 weeks they attach to an agreeable bottom. Here, they metamorphosize into juvenile sea urchins. Many predators search out these delicate juveniles---lobster, crabs, birds, and bottom-feeding fish. Survival for 2-3 years is marked by graduation into the adult urchin body. The test is now about 2 inches in diameter. It is just large enough to be harvested by man. Notably, in Maine the minimal size for harvest is 2 inches.

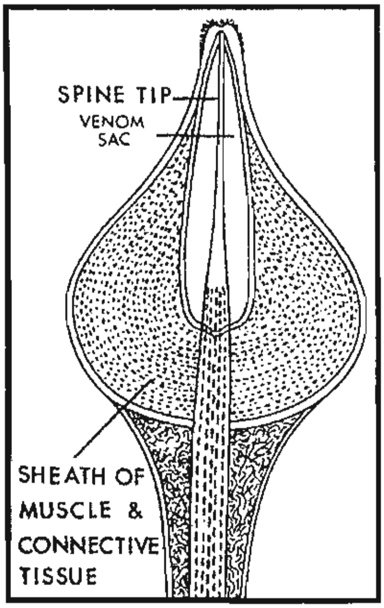
Looking at the external urchin reveals several interesting structures. Tube feet are soft tissue tentacles extending in a five-fold star-like pattern. These highly mobile limbs operate hydraulically. Important functions include locomotion, chemical/touch sensing, oxygen absorption, shell cleansing, and food collection. Distributed around the tube feet are myriads of primary spines, secondary spines, and pedicellariae. (Picture 1)

Picture 1



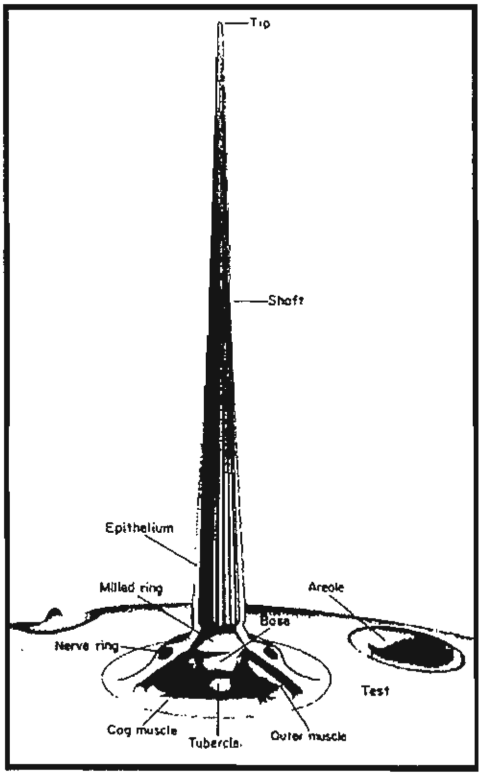
There are several types of mobile pedicellariae; however, all grasp prey, groom the shell, and provide self defense. In addition, poison glands are frequently housed within these structures. Venoms from the various urchins have been studied. Unfortunately, they have been incompletely characterized. Among the active components are acid mucopolysaccharides, kinin-like compounds (ie, bradykinin), histamine, serotonin, chymotrypsin-like compounds (from *Tripneustes gratilla*), and primin (2-pentyl-6-methoxy-1,4 benzoquinone). In fact, the venom of *Toxopneustes pileolus* has been know to paralyze people.

Picture 2



The secondary spines are rigid and small. Some genera (ie, *Areosoma* and *Asthenosoma*) have specialized bulbous distal tips that release venom when penetrating tissue. (Picture 2)

Picture 3



Most important for this discussion are the primary spines. These are large and rigid with an investing layer of epithelium. This organic material is only 6% of the spine. The rest of the spine is mineral. The vast majority is calcium carbonate (94.9%). Magnesium carbonate is about 5%. Silica oxide, calcium sulfate, and phosphates are present in very small amounts. No beryllium or zirconium has ever been described.

The primary spines, when cross-sectioned, display species specific patterns. In addition, they are often fluted and hollow. The spine rests on a ball-and-socket joint. This joint is innervated by a nerve ring and inserted with muscle attachments. (Picture 3) Such an anatomic arrangement explains the urchin's ability to coordinate spine motion. Thus, urchins are able to use primary spines for locomotion, digging, and self-defense.

Urchin Spine Injury Data

From 1992-1995, eight patients sought treatment. This series was analyzed in conjunction with a series of 32 patients found in a broad literature review.

Most victims were men in their 30's. While the literature revealed an almost even upper versus lower extremity distribution, my series clearly favored upper extremity injuries. (Table 1A) This certainly correlates with the hand-harvesting nature of the urchin industry. In fact, only one individual in my series was injured outside of Maine. While on vacation, a lady stepped on an urchin during a beach walk in the Bahamas. In contrast, the literature described spine injuries worldwide; there was no predominant locale.

Table 1A

Urchin Spine Injuries Demographics	
Literature	Series
32 pts (9 females)	8 pts (1 female)
age 34 (21-53)	age 30 (17-44)
LE > UE (19:17)	UE >> LE (9:4)

Symptoms most commonly found among these 40 patients were tenderness/pain/ache (28), swelling (27), erythema (17), lump (17), and decreased range of motion (11). Despite these symptoms most patients delayed 2-6 months prior to seeking definitive medical care. (Table 2A) Furthermore, systemic symptoms were seen exclusively in the literature (3 patients). Malaise, agitation, fever, nausea, myalgia, muscle cramping, and lymphadenopathy were described.

Table 2A

Urchin Spine Injuries Symptoms			
Literature		Series	
tenderness/pain	23	swelling	8
swelling	19	erythema	7
erythema	10	lump	7
lump	10	reduced ROM	5
discoloration	6	pain/ache	5
reduced ROM	6	purulence	2
paresthesia	3	drainage	2
cystic lesion	1	draining sinus	1
systemic rxn	3	bleeding	1
SXMS: 5-6 months		SXMS: 2-4 months	
x-rays			
FB + (10/20)		FB + (5/8)	
+ bone (1)		+ bone (1)	

Although the history and physical exam are most useful diagnostic tools, x-rays can be extremely helpful. Over half of the reported x-rays revealed foreign bodies (15:28). And, two showed bony injury. (Table 2A) Of note, one report successfully employed ultrasound to locate the offending urchin spines. In fact, the authors described a punctiform or linear hypoechoic area with acoustic shadowing.

In the literature, 19 patients received medical therapy. Medical care was variously local care, steroids, non-steroidal anti-inflammatory drugs (NSAID's), aspiration, splinting, and radiation therapy. Nine fully resolved, two failed with persistent pain, and eight went to surgery. Overall, 19 patients had surgery. Ten fully resolved, two failed with persistent pain, and one had a digit amputated. The outcome in the remaining six could not be determined. Looking more closely at the surgery, relatively minor procedures (surgical details undescribed) were by and large successful. Foreign body removal (4 of 6 cases), local excision (3 of 5 cases), and biopsy (2 of 2 cases) remedied the patient's problem 69% of the time. Only 8% failed (1of 13 cases). And, results were unknown in 23% (3 of 13 cases). The more radical aggressive exploration had two successes, one failure, and one unknown. (Table 3A)

In contrast, three received medical therapy in my series. This consisted of heat, elevation, soap and water, and antibiotics. Overall, 7 had surgery; all completely resolved. To detail, six local excisions and one aggressive exploration were successful. Local excision in my series described an en bloc resection of the offending granuloma and its overlying skin (not unlike a sebaceous cyst excision). On the other hand, aggressive exploration described a wide exploration of the affected digit removing all granulomatous material, any foreign body, and any devitalized bone. It was reserved for those most severely affected digits. (Table 3A)

Table 3A

Urchin Spine Injuries Treatment			
Literature		Series	
medical	(19/32)	medical	(3/8)
local care, steroids, NSAID's, aspiration, splint, Rad Rx		heat, elevation, antibiotics, soap and water	
results: resolved	(9)	*results:* resolved	(1)
surgery	(8)	surgery	(2)
persisting pain	(2)		
surgery	(19/32)	surgery	(7/8)
foreign body removal	(6)		
local excision	(5)	local excision	(6)
aggressive exploration	(4)	aggressive exploration	(1)
biopsy	(2)		
amputation	(1)		
unknown	(1)		
results: resolved	(10)	*results:* resolved	(7/7)
persisting pain	(2)		
amputation	(1)		
unknown	(6)		

As expected, microscopic foreign bodies (urchin spines) were occasionally seen. However, a histologic foreign body reaction was the more common finding. Acid fast staining was described in 9 patients. One was positive; but, culture proved negative. (Table 4A)

Table 4A

Urchin Spine Injuries Pathology			
Literature		Series	
c/w FB	(11/12)	c/w FB	(7/7)
FB +	(1)	FB +	(3)
acid fast neg	(5/6)	acid fast neg	(3/3)
+ acid fast was neg for culture			

Discussion

Urchin spine injuries have generated a multitude of medical and indigenous therapies. Some have proven effective (hot water immersion), while others seem to have little merit (crush spine in situ with a rock). Since there have been no recent examinations of the subject, this review seems timely.

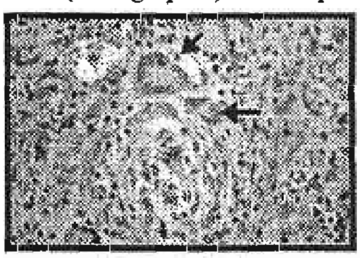
Remedies for Urchin Spine Injuries	
soap & water	thick mud immersion
lather area & shave	hot candle wax to wound
methylated spirit bath	urinate onto wound
salicylic acid paste	dilute ammonia soaking
poultices	open wound & vinegar soak
intralesional steroids	crush spine in wound
immediate surgical excision	hot water bath

Perusing the literature reveals four potential clinical scenarios. The simple puncture is characterized by severe pain within a few minutes. This lasts about 24 hours and is without sequelae. An accompanying venom/toxin reaction lasts for about 3-4 days having local redness, swelling, and pain. Systemic presentation, though unusual, can include malaise, fever, nausea, syncope, ataxia, paresthesia, weakness, myalgia, and respiratory distress. Another local phenomenon is pyogenic infection. Often, uncommon bacteria predominate (ie, *Erysipelothrix*, *Vibrio*). In fact, *Mycobacterium* frequents the marine environment infecting many fish species. Although it has never been isolated from human spine injuries, the *Mycobacterium* etiology has generated a goodly amount of discussion. Appropriate antibiotic therapy for these infections is essential. Lastly, a foreign body reaction may ensue. Both inorganic and organic etiologies have been suggested; however, no definitive determination has yet been obtained. The ultimate truth probably rests with a combination of the two. Of course, it is this presentation that accounts for most physician appointments. And, it is this presentation that has prompted this report.

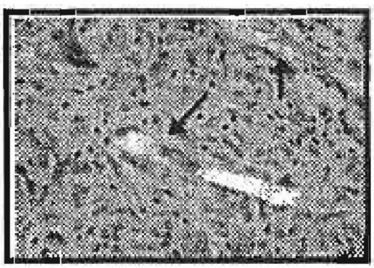
The foreign body reaction should be considered a three-staged clinical continuum. **Stage I** consists of a transient local reaction. It is essentially a simple puncture. A venom/toxin reaction may be occur. This reaction may be local or systemic, but is generally self-limited. Subsequent pyogenic infection may occur, but is readily treated with appropriate antibiotics. There is no granulomatous process. And, there are no sequelae. Standard care consists of hot water immersion, gentle spine extraction, pain control, tetanus prophylaxis, and serial observation with supportive care.

Stage II consists of foreign body granuloma formation. Within 1-2 months of the injury a painless nodule forms. It is characterized by pink to blue discoloration, central umbilication, and a hyperkeratotic surface. This nodule will often impair the range of motion in nearby joints. Fingers are particularly susceptible. X-rays frequently display the residual urchin spine. And, local excision of the nodule will remedy this process and reverse the mild to moderate disability commonly seen.

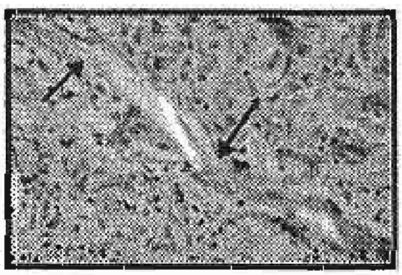
Finally, **Stage III** consists of granuloma growth with accompanying bone and/or joint destruction. This causes severe disability. A finger, so affected, will suffer fusiform swelling, little range of motion, and constant discomfort. In fact, the literature relates a case requiring amputation of such a digit. Microscopically, lymphocytes, histiocytes, and multinucleated giant cells abound. Sometimes, the multinucleated giant cells will form "Teuton giant cells." Here, nuclei are arranged in a ring pattern. Incidentally, this phenomenon has been seen in tuberculosis. (Histograph 1) The spine itself may be seen. (Histograph 2) Under polarized light, it is characteristically double refractile. (Histograph 3) The



Histograph 1



Histograph 2



Histograph 3

mechanism for this process has been variously attributed to an accelerated foreign body reaction (beryllium and/or zirconium particles have been suggested, but never found), an excessive immunologic or autoimmunologic reaction (spine epithelium etiology), and mycobacterial infection (*Mycobacterium* has never been isolated). In short, why a given spine will generate this excessive response is unknown. However, it is known that spines migrate. Not infrequently, the very mobile areas around joints attract these foreign bodies. It has been suggested that any spine found near a joint or lodged in a bone be removed. This is an excellent recommendation that can not be too strongly supported. The severe disability associated with this destructive process definitely corroborates that logic. Once the process is established, aggressive surgical exploration with vigorous debridement of granulomatous tissue (gray, friable, almost gelatinous material) and any spine remnants is essential. Here, fluoroscopy and/or ultrasound may be necessary to ferret out the offending foreign tissue. Recovery and return to function usually proceeds over the ensuing three months.

In summary, it is clear that most urchin injuries are self-limited requiring only local and supportive measures. (Stage I) However, occasionally granulomas appear causing mild to moderate disability. Local excision remedies this problem. (Stage II) Rarely, bone and/or joints are affected. To salvage this situation an aggressive exploration and debridement is essential. Even then, failure can follow. Ultimately, even amputation can result. (Stage III)

ACKNOWLEGEMENTS

Much help was provided by Ms. Ann Tarr and Dr. Ted Creaser (Maine Department of Marine Resources; Augusta and Boothbay Harbor, Maine), Mr. Jeff Ciampa (US Coast Guard; Portland, Maine), and Mr. Rick Benoit (Kissing Fish Dive Shack; Calais, Maine). I gratefully thank all these individuals.

In addition, several of the pictures, diagrams, and charts were borrowed. The sources are listed below. Needless to say, no pecuniary gain has resulted from their use; only clarity of academic presentation has been achieved. I gratefully thank all these resources:

Page 1: picture of the Atlantic green sea urchin; internet = British Columbia Creature Page: www.clever.net/kerry/creature/gurch.htm---copyright Kerry L. Werry (use permitted for nonprofit purposes without charge)
Page 2: picture of the Minoan vase; internet = John Boroughs School Department of Classics: www.jboroughs.org/index.html
Page 5-6: Charts 1-2; Maine Department of Marine Resources; Courtesy of Mr. Rick Benoit (Kissing Fish Dive Shack) of Calais, Maine.
Page 6: map of Maine; internet = The Perry-Castaneda Library Map Collection of the University of Texas at Austin: www.lib.utexas.edu/Libs/PCL/Map_collection/maine.html
Pages 7-10: Tables 1-8; reference #6---Butler, W---pages 308-312.
Page 14: Picture 1; reference #39---Russell, F---page 149.
Pictures 2-3; reference #23---Halstead, B---pages 200, 202.
Page 17: Histographs 1-3; Courtesy of Dahl-Chase Pathology of Bangor, Maine.
Page 20: picture of California red sea urchin; internet = California Sea Urchin Harvesters Association: www.seaurchin.org/

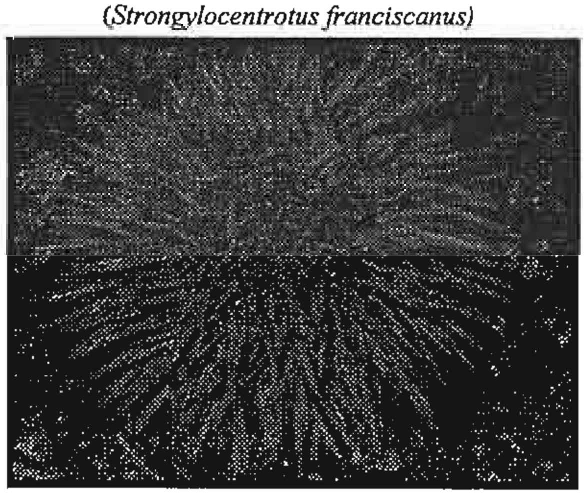
REFERENCES

1. Asada, M et al. A case of delayed hypersensitivity reaction following a sea urchin sting. *Dermatologica*. 180:99-101, 1990.**
2. Baden, H. Injuries from sea urchins. *Clinical Dermatology*. 5:112-117, 1987.
3. Baden, H and Burnett, J. Injuries from sea urchins. *Southern Medical Journal*. 70:459-460, 1977.**
4. Benoit, R. Mandated dive safety courses scheduled in area next month. *The Quoddy Tides*. Eastport, Maine. August, 1994.
5. Benoit, R. Personal communication. Kissing Fish Dive Shack; Calais, Maine. 1998.
6. Butler, W. Maine's urchin diver: a survey of diving experience, medical problems, and diving-related symptoms. *Undersea & Hyperbaric Medicine*. 22(3):307-313, 1995.
7. Chenoweth, S. The green sea urchin in Maine fishery and biology. Maine Department of Marine Resources (Augusta, Maine); Marine Sciences Laboratory (Boothbay Harbor, Maine); 1994.
8. Ciampa, J. Personal communication. US Coast Guard Marine Safety Office; Portland, Maine. 1998.
9. Ciampa, J. Summary of fatal injuries experienced within the commercial fishing industry of Maine, 1993 through 1997. US Coast Guard Marine Safety Office; Portland, Maine. 1998.
10. --------. Commercial fishing industry mortality summary: 1993 through present. US Coast Guard Marine Safety Office; Portland, Maine. 1998.
11. Cooper, P and Wakefield, M. A sarcoid reaction to injury by sea urchin spines. *Journal of Pathology*. 112:33-36, 1974.**
12. Cracchiolo, A and Goldberg, L. Local and systemic reactions to puncture injuries by the sea urchin spine and the date palm thorn. *Arthritis and Rheumatology*. 20:1206-1212, 1977.**
13. Creaser, T. Personal communication. Department of Marine Resources/Marine Sciences Laboratory; Boothbay Harbor, Maine. 1998.
14. Doose, P. The $4000 sea urchin spine. *Skin Diver*. 39:174, 1990.**
15. Earle, K. Echinoderm injuries in Nauru. *Medical Journal of Australia*. 2:255-266,1941.**
16. Falkenberg, P. Sea urchin spines as foreign bodies—an alternative treatment. *Injury*. 16:419-420, 1985.**
17. Feigen, G et al. Studies on the mode of attack of sea urchin toxin on natural and synthetic substrates. II. Physical properties, substrate specificity, and reaction kinetics of purified fractions. *Physiology, Chemistry, and Physics*. 2:427-444, 1970.
18. Fisher, A. <u>Atlas of Aquatic Dermatology</u>. Grune & Stratton; New York; pp. 27-34, 1978.
19. Frey, D. The use of sea cucumbers in poisoning fish. *Copeia*. 2:175-176, 1951.
20. --------. Green sea urchin conservation harvesting plan. New Brunswick, Canada; 1994-1995.
21. --------. Green sea urchin conservation harvesting plan. Nova Scotia, Canada; 1996-1997.
22. Groleau, S et al. Ultrasonography of foreign body tenosynovitis. *Canadian Association of Radiology Journal*. 43:454-456, 1992.**
23. Halstead, B. <u>Poisonous and Venomous Marine Animals of the World</u>. Darwin Press, Inc; Princeton, NJ; pp. 187-212, 1988.
24. Hausen, B et al. Primin as the source of sea urchin hypersensitivity? *Contact Dermatitis*. 17:319-321, 1987.
25. Heino, C. "Your Guide." *The Lincoln County News*. Damariscotta, Maine. September, 1994.
26. Kane, H. Clinical curio: hypersensitivity after a sea urchin sting. *British Medical Journal*. 285:950, 1982.**
27. Killpack, W. Injury from spines of sea urchins. *Lancet*. 1:1342, 1974.
28. Kinmont, P. Sea urchin sarcoidal granuloma. *British Journal of Dermatology*. 77:335-343, 1965.**
29. Lewis, R. Fatalities associated with harvesting of sea urchins---Maine 1993. *Morbidity, Mortality Weekly Report*. 43:235-242, 1994.

30. Lewis, R and Tarr, A and Creaser, T. Maine fishery and licensure statistics. Maine Department of Marine Resources; Augusta, Maine. 1998.
31. McHugh, N and Tweed, J. Sea urchin spine synovitis. *New Zealand Medical Journal*. 10:700, 1984.**
32. McWilliam, L et al. Spinous injury caused by a sea urchin. *Journal of Clinical Pathology*. 44:428, 1991.
33. Meneghini, C. Cases of sea urchin granuloma with positive intradermal tests to spines extracts. *Contact Dermatitis Newsletter*. 12:316, 1972.
34. Moynaham, E and Montgomery, P. Echinoderm granuloma: a skin lesion resulting from injury by the spines of sea urchins inhabiting temperate waters. *British Journal of Clinical Practice*. 22:265-269, 1968.**
35. -------. On the rocks. *Lancet*. 1:1091-1092, 1974.
36. O'Neal, R et al. Injury to human tissues from sea urchin spines. *California Medicine*. 101:199-202, 1964.**
37. Rocha, G and Fraga, S. Sea urchin granuloma of the skin. *Archives of Dermatology*. 85:406-408, 1962.**
38. Rosco, M. Cutaneous manifestations of marine animal injuries including diagnosis and treatment. *Cutis*. 19:507-511, 1977.
39. Russell, F. Marine toxins and venomous and poisonous marine plants and animals (invertebrates). *Advances in Marine Biology*. 21:59-217, 1984.
40. -------. Sea urchins. University of California Cooperative Extension, Sea Grant Extension Program. 1995.
41. Steele, B. California urchin diver. Internet web site. 1998.
42. Strauss, M and MacDonald, R. Hand injuries from sea urchin spines. *Clinical Orthopedics and Related Research*. 114:216-218, 1976.**
43. Warin, P. Sea urchin granuloma. *Clinical and Experimental Dermatology*. 2:405-407, 1977.**

** denotes references that have case reports of urchin spine injuries examined in this discussion

California Red Sea Urchin
(Strongylocentrotus franciscanus)



DISCUSSION

Mr. Dodie: (Vancouver Island). You mentioned the urchin venom. In your experience with the species you've dealt with, are the urchins in fact producing venom or is it organisms that live on the spine causing the infection?

Dr. Butler: I think what's happening is that you can get the marine organisms which give you an infection. There has been at least one report in the literature where this particular species has been described as having a venom. However, that report that I could find was described in another report and I could not find a source document no matter how hard I attempted.

So I can't honestly say that there is a venom specifically with this species. There are vibrios, there are aerosipothrex, very commonly involved in marine punctures. Micro bacteria people talk about but in my particular series, I actually had one come up with a positive acidfast stain where we could not grow anything from it at all no matter how hard we tried.

Unidentified Speaker: (Indiscernible) that host of venom or other infection agent (indiscernible). (Indiscernible) is there something like a serum to fight the infection (indiscernible)? What purpose (indiscernible) and dissolves (indiscernible) and even though (indiscernible) at all. So (indiscernible) perhaps something on the side (indiscernible).

Dr. Butler: Certainly the epithelium that is on the spines, a lot of people seem to think is something that sensitizes the individual. There has been at least one study where the (indiscernible) took the spines on a couple of people -- took the spines of an urchin that had hit a couple of people, ground them up and then injected them subdermally without a reaction to it. So perhaps the epithelium can give an antigenic response.

Now, what you also described "breaking up" in your heel, there are a number of folk remedies for urchins described in the literature. One of them is to take a rock and beat the hell out of the urchin spine that's in you, break it up, and it will take care of itself.

Unidentified Speaker: (Indiscernible).

Dr. Butler: They're very brittle They're very, very brittle and that's very common to see them break up if you try to mess with them.

Unidentified Speaker: How much work did it take after you caught the urchins in harvesting the roe? Is that when most of the injuries took place?

Dr. Butler: That's right. Actually harvesting. Because what happens is that they get into a processor and the processor takes care of it from there. These guys don't open their mouth at all. If they open their mouth, they'd lose everything.

It's interesting in the urchin industry itself. There are two ways of handling the roe. You can either send it to Japan on a rapid air freight without ever having processed it, just plop them in a box and send them. Or you can actually open them and separate out the roe. But it has to be done in a very proscribed fashion.

The Japanese buyers are very, very picky about this and they'll come in and actually watch and make sure that it's done properly. Because if it isn't, it's not worth anything to them. The urchin roe on the Japanese market is worth about $100 a pound. The raw urchin itself picked up off the sea bottom is worth -- it's stabilized about -- right now, it's stabilized at about a dollar a pound, the urchin itself.

In California there's a company that has a neat little tool that will slice the urchin right in half without having to crack it open and they advertise that on the Internet. I thought about you on that picture but I didn't want to take too much time.

Dr. Lepawsky: More questions for Dr. Butler? Thank you very much, Doctor Butler.

Dr. Butler: Thank you.

Dr. Wong The last speaker of this session needs no introduction, it's Dr. Lepawsky. He's the Director of the Hyperbaric Unit at Vancouver General Hospital. Now, if it wasn't for his enthusiasm and inexhaustible energy and untiring effort in organizing this workshop, this would not have happened. So I ask Mike to come and speak to us about the Emerald Sea geoduck harvesters. I can even pronounce that word.

BRITISH COLUMBIA EMERALD SEA COMMERCIAL DIVING GEODUCK HARVESTERS

M. Lepawsky

Geoduck clams, *Panopea abrupta*, are the largest edible bivalves in Pacific Northwest waters. They inhabit ocean bays, estuaries, and steep sloping bottoms from inter-tidal zones down to 110 m. When young they dig with their foot down into what becomes their adult dwelling a meter under sandy, gravelly, and/or muddy ocean floors. From this, their permanent habitat, they extend their long, large, muscular siphon to feed by drawing in plankton and nutrient-rich waters, extracting food requirements, then expelling utilized fluid into waters surrounding their home. The oldest geoduck recorded was estimated at 146 yr old. Geoducks thrive in Pacific Northwest seawaters (1–4).

The name geoduck derives from the Nisqually North American Native word gueduc meaning "dig deep" (5). The pronunciation is described as in "oe" or "oi" sounding like "goe" or "gui" duck (6). Geoducks used to be plentiful in lower intertidal zones so they could be obtained by digging on beaches, but those stocks have been depleted so geoducks are no longer easily found in this zone. The shell is not large enough to contain the entire body and neck.

The large siphon and some body parts are edible. Geoducks are a commonly consumed protein source and popular delicacy especially in the Orient where they may cost more than $25–30 per pound on the plate. Buyers prefer sizes of 1–2 kg, i.e., about 2–4.5 lb. Cleaned geoducks ready for immediate preparation to eat cost $10–15 per lb for product to transport to buyers who usually sell to fish food markets or restaurants.

Beginning in 1976, geoducks were commercially harvested in the coastal waters of British Columbia (BC) by commercial diving sea harvesters using scuba or, now most commonly, surface-supplied air as their breathing medium. In one hand, diving geoduck harvesters hold a water "gun" called a "stinger" which jets water at 60 lb per square inch, and with the other hand they immobilize the geoduck siphon simply blowing away the geoduck habitat. The process may require 15–20 s per geoduck and harvesters may take up to 1,000 lb of geoducks in a period of a few hours from beds of many hectares with 3–10 geoducks per m^2 (1) (Anysymiw V, personal communication).

The coastal seawaters of BC are in the region of 8°–14°C. Divers wear full dry suits with heavy insulating undergarments. BC Workers' Compensation Board (BC WCB) regulations mandate that divers must wear safety back-up air breathing sources in case their surface air supply fails (7). Divers must follow Defense and Civil Institute of Environmental Medicine (DCIEM), United States Navy (USN), or other tables authorized by the BC WCB (7). Usual dive profiles are up to 60 feet of seawater (fsw) within USN no-decompression limits. Decompression diving is allowed only with written pre-authorization by the BC WCB. No-decompression limits at any given depth must be followed with due care and attention. Divers make one or two dives per day, rarely more.

British Columbia geoduck divers used to have to work much longer hours underwater for significantly lower wages before 1989 when a quota system was instituted. Also, increased product marketability, popularity, recognition, and unit cost increases led to decreased total diving time as earnings escalated. The quota system, established cooperatively by the industry and the Canadian Department of Fisheries and Oceans (DFO), provides for only 55 BC geoduck licenses. Each geoduck license has an annual harvest quota of 72,000 lb. Buyers manipulate the market so they can tell harvesters exactly how much product they will buy at any given time. Divers earn $70,000 to more than $100,000 Canadian within a diving year of 70–100 diving days (Anysymiw V, personal communication).

The total number of diving geoduck harvesters in given years varies (Table 1). It began at 93 in 1978, rose to as many as 233 in 1988 just before the quota system, and since dropped to 86 in 1997. Many of the same divers are represented in multiple years (8).

Beginning in 1978, the DFO has estimated annual numbers of geoduck dives from mandatory record counts kept by the harvesters. Total numbers are considered as a minimum because in some years dives by the same diver, on the same date, and in the same bed location may be rolled into one fishing record in the DFO database. Data include total divers per year, total dive minutes, average diving minutes per diver, estimated number of dives, and mean depth (8).

The mean dive depth is 39.6 fsw. The average dive time is 155.5 min (Table 1). This dive profile is within USN diving tables no-decompression limits. But it is arguably outside DCIEM no-decompression limits and by these tables could require a 3-min decompression stop at 10 fsw. As an example of the empirical nature of the commercial geoduck diving sea harvester cohort, for safety some geoduck divers take a 2-min decompression stop at 20 fsw and a 3- to 5-min decompression stop at 10 fsw. This is unfortunately not a universal practice among geoduck divers although it has been recommended (Anysymiw V, personal communication).

Table 1: (8)

Year	No. Divers per Year	Mean Depth, fsw	Avg Min per Diver per Dive	Estimated No. Dives
1978	93	36.8	167.81	2,503
1979	213	36.7	150.73	7.048
1980	226	36.4	141.53	7,649
1981	184	35.7	147.94	6,078
1982	189	35.7	150.50	7,395
1983	145	34.5	148.15	4,978
1984	156	36.6	175.16	6,699
1085	189	42.1	161.96	8,430
1986	215	41.6	158.08	8,557
1987	191	47.5	165.06	8,460
1988	233	44.1	159.19	7,675
1989	178	44.7	160.57	6,262
1990	146	36.3	183.94	6,191
1991	133	39.4	173.61	5,840
1992	137	38.3	184.87	4,612
1993	112	40.5	161.88	4,808
1994	108	41.4	146.29	5,070
1995	108	39.9	148.42	4,404
1996	93	43.3	111.35	5,856
1997	86	40.7	112.51	6,412
All years	Avg/yr 156	Mean fsw 39.6	Avg min/dive 155.48	Total 124,927

Consistent with their dive profiles and the nature of their activity, commercial diving geoduck harvesters have had some health and safety problems. In the 13 yr from 1976 to 1988 before the quota system began in 1989, geoduck divers pushed diving tables to their absolute maximum within no-decompression limits to remain compliant with BC WCB regulation. During the 13 pre-quota years, 1976–1988, seven non-fatal decompression sickness (DCS) cases occurred, the last in 1988. In those 13 yr, there were two non-fatal pulmonary overpressure syndrome (POPS) with cerebral gas embolism (CGE) cases, the last in 1987. In the same years there were four deaths among geoduck divers, the last in 1982. In the 13 pre-quota years 1976–1988, then, there were 13 total incidents including 7 DCS cases, 2 POPS with CGE cases, and 4 deaths separate from the DCS and POPS with CGE, i.e., 1 incident every 12 months (9,10).

When the quota system was instituted in 1989, however, such problems became more rare. Since the quota system was declared 9.5 yr ago up to the present in 1998, there were two treated non-fatal DCS cases, the last in 1993. In this 9.5-yr period there were no POPS with CGE cases and but one separate fatality among BC commercial geoduck divers in 1989, the first year of the quota system. This amounts to three incidents in 9.5 yr, an obvious reduction in occurrence to one episode every 38 months. While there was never a large occurrence of diving complications among BC commercial diving geoduck harvesters, any incident is viewed with deep concern because of BC WCB regulation that closely regulates the methods divers must use to do any compressed gas diving work in BC.

There are anecdotal reports of non-fatal, untreated DCS cases of unknown numbers and dive profiles. Treated DCS cases in geoduck divers account for nine separate incidents in 22.5 yr, the last in 1993. Known cases of geoduck divers treated for POPS with CGE total two separate cases in 22.5 yr, the last in 1987. No fatalities occurred in treated cases of DCS or POPS with CGE. In this same time, five geoduck diving fatalities occurred too rapidly for transport to receive recompression treatment. At the end of 1997 there had been 124,927 dives among geoduck divers. Since the start of the BC geoduck industry in 1976, the incidence of treated DCS has been 0.0072%, that of POPS with CGE has been 0.0016%. During the same time frame, the calculable fatality rate has been 0.004% in the 124,927 dives.

There are three known cases of dysbaric osteonecrosis (DON) identified among BC commercial geoduck divers. More cases are suspected but seem lost to follow up and the exact incidence of DON is under investigation. The calculable occurrence rate of DON per dive is 0.0024%.

The BC commercial geoduck diving community acts with the DFO as a model of industrial-governmental cooperation in that there has been careful survey, assessment, and monitoring of known available geoduck stocks to this time by the industry itself. The DFO has assumed a supervisory role in the process. Techniques have been devised to harvest geoducks within the limits of the known available biomass. Industry initiated replanting of harvested areas, furthermore, has resulted in rapid replenishment of harvested quantities. At present, it appears that the native biomass has been approximately maintained and perhaps stands a good chance of increasing to even larger quantities than naturally evolved resources presented before commercial harvesting began.

REFERENCES

1. Campbell A, Harbo RM, Hand CM. Harvesting and distribution of geoduck clams, *Panope abrupta*, in British Columbia. 1998, in press.
2. Gordon DG. Field guide to the geoduck. Seattle, WA: Sasquatch Books, 1996.
3. Harbo RM, Adkins BE, Bren PA, Hobbs KL. Age and size in market samples of geoduck clams (*Panope generosa*). Can MS Rep Fish Squat Sci, 1983.
4. Ricketts EF. Between Pacific tides, 3rd ed. Stanford University Press, 1952.
5. Quayle DB. The intertidal bivalves of British Columbia. B.C. Provincial Museum Handbook 17, 1978.
6. Ricketts EF. The intertidal bivalves of British Columbia. B.C. Provincial Museum Handbook 17, 1978.
7. WCB BC Occupational health and safety regulation. Diving Operations, Section 24.
8. Wylie ES, Heizer S, Harbo RM. Canadian Department of Fisheries and Oceans.
9. Lepawsky M. Vancouver Hospital and Health Sciences Centre Hyperbaric Unit Statistics.
10. Duffy S. BC WCB Diving accident statistics.

DISCUSSION

Mr. Farm: Just a question about the medical science. How long does it take to deplete and then the restock the biomass?

Dr. Lepawsky: Two to four years to grow to harvestable size. So their favored size is 1–2 kilograms. So up to, let's call it 4 pounds in 4 years; about a pound a year in that regeneration time.

Unidentified Speaker: Would you attribute maybe some of the increased safety on statistics as far as going to the quota system and not having the race anymore as you would have for, you know -- as far as keeping dollars?

Dr. Lepawsky: Without question. I give full credit to the industry itself and the Department of Fisheries and Oceans—the quota system was declared partly out of concerns that the biomass would be stripped because of, amongst other factors, the abalone experience that I told you about and also because of concerns with decompression illness and concerns for the divers' health and safety, yes. The WCB regulations are clearly part of the formula and very helpful in reducing the incidence of DCI and fatality.

Dr. Kawashima: Thank you very much for a very nice presentation. I noticed that some findings of the MRI for the right humeral tip. The one is the study and MRI, and the other is findings of rotator cuff lesion/rupture, seems to me .....

Dr. Lepawsky: I'm sure you're right.

Dr. Kawashima: Also, dysbaric osteonecrosis does not cause the limitation of the elevators. Should he not have had a laser treatment.

Dr. Lepawsky: Thank you. That is his right arm and it's what he held his stinger with. Sixty pounds per square inch, thousands of times per day for 10 years, 15 year minimum.

Unidentified Speaker: Are there any recreational harvesters?

Dr. Lepawsky: Not that I'm aware of. Very little, if any recreational geoduck harvesting remains in this province. I could be wrong but I don't think there's much, if any.

Dr. Wong: I thought I saw a few more questions. If not, although the hour is late and we had a discussion time scheduled, I will say that we have a longer discussion tomorrow afternoon. Maybe this is a good time then in this 10 minutes, let's say, until 5:30 because the supper starts at 6:00.

Dr. Lepawsky: Is there anyway that we can begin to move to a consensus in terms of looking at devising safer workplace for this particular group of sea harvesters that we've gone through today? After all, we've seen a number of different types of sea harvesting. Is there any way that we can begin to solicit a consensus? It would appear that British Columbia is not alone in terms of declaring a quota. I think that—Dr. Wong, did you say that there's been an abalone quota declared in Australia?

Dr. Wong: Yes, there has been.

Dr. Lepawsky: Is there any kind of quota in Norway, Dr. Brubakk, of any variety?

Dr. Brubakk: No, the clam or the seashell harvesting is sort of small yet so there has never been any; as far as I know, there is no harvesting of any sea urchins or things like that. The salmon fishery obviously is regulated by quotas.

Dr. Wong: So there is a salmon quota?

Dr. Brubakk: Well, but that is -- I mean, this is the fish farming.

Dr. Wong: I understand.

Dr. Brubakk: Although you're not farming; you're officially farmed --

Dr. Wong: Sure.

Dr. Brubakk: Just to quote down the number of -- as I said, about 700 of these concessions in Norway .

Dr. Wong: Right. Dr. Ross, clam digging? Is there a quota?

Dr. Ross: There's a size you're supposed not to take but that only applies in a registered diver. If you're an unregulated diver diving without the regulations then there's no controlling it.

Dr. Wong: Interesting.

Dr. Ross: I mean, it seems to me on the day that if you dive for a long time and you dive deep, you're going to get a more severe illness and that's what concerns me. In the North Sea, there has been a time/depth blanket limitation placed in diving—for air diving, especially surface oxygen support and that has reduced instances of decompression illness dramatically. Perhaps some kind of guideline along these lines could be offered to these divers.

Not so much to try and prevent them from having decompression illness but to enable them so that when they get decompression illness at least it's going to be the kind that's treatable for both the acute and chronic aspects.

Dr. Wong: Good. There was a question or a comment here?

Mr. Hubner: (Undersea Grading Systems) We do nitrox systems so this is—you might view it as biased but I've traveled around. I did urchin diving out of California; I've done diving in Australia for 18 years now.

The last 2 years I've been doing nitrox systems around the world really. My finding has been—well, I think the quota system is fantastic for slowing things down for biological reasons for everybody. But the nitrox systems, I found that divers will not give up or want to give up what they're already doing.

In other words, if they're producing at a certain amount and any kind of regulation that's going to slow them down or anything that's going to cause them to take money out of their pocket or make less, they're going to be very anti.

I've met with divers that have quotas and they're just looking to add some safety now. They're limited in what they can get, not that they get any more. They're not looking to make any more money but they're looking at, "Hey, I've pushed it all these years. If I could add some safety" and they've switched over to nitrox with very good results. Of all the divers I've ever set up—of harvest divers on nitrox, I have never had one go back to air after doing nitrox just because they feel better afterwards. Their wives tell me they can carry on a conversation with them at night and some really good results I've had.

I'm not one to talk to as far as on the medical level. You know, Dick Rutkowski, is a very strong advocate of it [nitrox] and some other people. I'll let them talk on the medical level. I'm just a diver that switched to it after many years of air is what it comes down to.

Dr. Brubakk: This reminds me. I'm not saying anything against nitrox because nitrox is just simply nitrogen in the mixture with higher oxygen, but what has happened in Norway at least is that we have had a lot of instructors telling something to the effect that "Go over to nitrox, you'll get longer bottom times and you will not have any decompression problems anymore."

I just want to point out that the reason why nitrox is good is that you dive on air tables using nitrox, which give you an advantage. But if you try to stretch the tables -- and our experience, the air tables, regardless who makes them, are pretty bad when it comes to the long bottom times. You get then obviously an advantage by using nitrox. You'll only get an advantage as long as you do not increase the bottle time.

Mr. Gold: This idea posed, I think, is very, very good to consider. People other than in the 3rd world are making a lot of money. On the other hand, in the 3rd world where people aren't making a lot of money and this is survival, I'm not sure how well the orders are going to look.

If you look at Indonesia, Thailand, Philippines, and Sri Lanka, these people are living in poverty levels and they're barely surviving, taking what they can out of the sea. To tell them that they can't take a certain amount may put them below the level at which they can survive. So then we have to be a little careful, perhaps differentiating between people who are making a lot of money by diving and people who are just surviving.

Dr. Lepawsky: Yes, in all honesty, I begin to wonder if you don't need to tell them that the devils of the sea will take them back quicker if they overdo their physiological bounds, with all due respect.

Mr. Heywood: (Vancouver) Just further to that comment. Nitrox is graded by percentage and you're developed and you're already diving safely but I think the point is that if I've gotten anything from this day is that people are blowing tables out of the water so that's getting them to spend less time under water, come up slowly—the basics before we start talking about mixed gases like nitrox. Although the comments about nitrox are valid, I think we need to get the core things down first.

Dr. Lepawsky: That's well taken, Jeremy. Yes, John Ross?

Dr. Ross: The thing about nitrox is it's great but it is being sold with the equivalent air that is important. People that are using nitrox do come to us. They've been diving the maximum amount that they can do on that [nitrox] table [and they are not using nitrox on air tables, as they should be. – Editor].

Dr. Wong: On the nitrox table?

Dr. Ross: Yes. There's actually no improvement to safety; it just lets them stay under the water for longer.

Mr. Dunford: The problem with the quota system and you may correct me in some of this, but the Honduran government has placed a three-month moratorium on the harvesting of geoducks in the conch. Or excuse me, lobster.

But that doesn't really do anything for the divers who still have to go into the water 9 months a year and do these horrendous tables. And in order to put a moratorium or limit the product, as some people have said here, they are not going to buy into that at all.

There's a large structure, socioeconomic structure around this diving that needs that profit from those lobsters, and including the divers. So I think that a moratorium in that kind of environment is going to have a lot of problem as being accepted and implemented.

Restricting divers from taking lobster—it's easy to tell captains they can't go out and tell those buyers they can't buy by law. But once you've let them go out then regulating the way the divers do their work is going to be much more difficult.

I think that perhaps a better method may be some kind of intervention method in terms of not limiting diving but trying to provide something in the way of helping an individual once they actually develop decompression sickness. Because I don't think you're going to be able to limit the bottom time as the first course into making a change.

That may come later as they learn to trust your system but I think initially you've got to show them that you can do something for them and the way we're going to do that is to try to limit the acuity of the sea.

Dr. Lepawsky: Something else to add?

Dr. Barratt: Also in regards to the scuba divers, I thought a lot about what kind of recommendations we could make?. I really didn't come up with much because as a coroner I feel uncomfortable making recommendations for their diving conditions and it could end causing problems for us doing research down there to say, "Well, you know, we're the academics. We think you should be doing this." If we want to keep studying down there.

The only thing I could really think of that I could potentially ask them to do is to search everyone's bags and not allow cocaine and crack onboard. Of the three fatalities that Dr. Aleyo (phonetic) saw—he was asked to come down to the dock and evaluate the bodies—all three of them had been using cocaine or crack.

As far as limiting their alcohol or drug use, it's now in the Nicaraguan regulations but it's not enforced. But I understand that they need to be on drugs or alcohol in order to get their nerve up to go down and dive because they're afraid of not only the mermaids but there are sharks that are common, they could drown, could have equipment failure, so they can't do their job without the drugs. Perhaps they could do it (indiscernible).

Dr. Lepawsky: That's another good point.

Unidentified Speaker: The problem with the performance is really—just because they had cocaine in their blood, is there a connection there? What does the cocaine do (indiscernible)?

Dr. Lepawsky: I would suggest that as far as a performance-enhancing drug, I think you probably would feel better but I don't know whether you'd do any better. I do not trust the pathophysiology of cocaine at all. But I think that she had an important point here.

These Miskito divers, as I read the notes from the observer on board, and reading between the lines of his very dry and factual accounts, was the distinct impression that this 11- or 12-day trip by the Miskito divers was an ordeal. That they took drugs to get through it.

They did not want to be there but they wouldn't tell anybody they don't want to be there. When that last day of diving came through, they were very, very happy to see it come. They wanted out. So I think these people are really pushing themselves physically and emotionally on that boat. I think the drugs are part of the reason because it's one of the mechanisms how they cope.

Certainly, we might have heard that, you know, "We can do what we know how to do", and an attempt at education.

Education is – you can, I think, be sure that it's perhaps best done consensually rather than confrontationally. That means getting in and understanding the local populations. We'll get to you in just a sec. I thought another question in the back. Yes?

Dr. Sanchez: I'd like to second that observation. Many years ago when we first started our studies in Mexican scuba divers, the drugs of choice were alcohol and marijuana.

Just a couple of months ago in our last follow up, Dr. Ramirez, who handles this group of divers, found over 95 percent of them are now cocaine addicts and he's had several deaths from cardiac arrhythmia since diving as proof. So there seems to be a significant change just in the last 10 years.

Mr. Gold: It was interesting when we started that project 2 or 3 years ago—this is a comment, not a question so much. But we started that project 2 or 3 years and the person who advised me was a diving instructor, a blonde-haired, blue-eyed diving instructor who decided he wants to make changes.

His advice to me was to get a bottle of [Mekong] whiskey and then sit down with the chief of the village and get ourselves drunk together and that's the only way we'll make change. He went into the village for about 2 or 3 years with his bottles of [Mekong] whiskey and it was all he managed to do was get him and the chief drunk.

Our intervention, on the other hand, was not our intervention. Our intervention was to empower the primary health care worker in the village and the public health system around it. I think Diane said something very, very important if I can interpret and read between the lines.

Working in the Thai environment and Richard working in the Indonesian environment, I and others working with the Miskito Indians, they'd look at our face, they'd look at our hair color, they'd look at our eyes, and you're not one of them. You'll never be one of them. At least that's from my own experience.

There are certain rites of passages that we have to go through. In fact, for me to work effectively with the Urak Lawoi, the sea gypsies, I had to do a dive with their equipment. I was challenged. They said to me, "There was a Russian here a couple of months ago. He wanted to make some changes. And he put the mask on his face and he never got below one centimetre below the water. Can you do better?"

I don't know if I would have succeeded if I didn't go underwater with them and do a dive. This is part of the primitive rites of passage perhaps that exist. But the important thing to come back to, in my mind, is the issue that we shouldn't be going in there for our glory. We shouldn't be going in there saying, "We are going to make the change."

We should be trying to build systems based on local people and having those local people (indiscernible) recognize the need of change so that change will be sustainable. I think therein we're going to see the solutions to the problems. They will know the cultures in which they have to deal to make the changes. I'm not sure we'll be that sensitive.

So I encourage you—I encourage us—if we're looking at this sort of thing to take it from the perspective of public health and try to make the changes that will be long term and acceptable within the scope of what they are going to do.

Also to give them goals for change that are realistic. To tell someone with 3 years of formal education who has been diving for 30 years by sticking something in his mouth and jumping over the side, that we're going to start to calculate tables, okay, and that you have to go to such-and-such a depth for such-and-such a time, come up and do this and do that, I think, with all due respect to all parties concerned, they're not going to be terribly comfortable and they're going to make jokes about it.

So we've got to find alternatives for them that are easily understandable, easily implemented, and find steps that we can achieve that are little successes leading to a big success. Then I think we're going to be able to make a positive change. I'd applaud any effort we can make, with respect, but I think information and education is one of the key factors in making it happen. Thank you.

Ms. Liebman: (Washington State) May I make a comment? I had two comments and one is referring to the quota system you're talking about here. I just want to make a point that in Washington we have quotas for a lot of the harvested seafood.

However, because of over-harvest, it has created a need for a lot of the sea harvesters to go quite a bit deeper to get the quota that is now allowed for them to harvest and it's created a lot more problems than anything. So there are pros and cons with quotas.

The second thing I wanted to point out is that not only in Honduras and Nicaragua, but also with a lot of the Indian tribes that are now harvesting seafood in Washington State, there is a lot of drug use: heroin, crack, cocaine, marijuana, alcohol and no one that I know has addressed any of that: why or what we can do.

Dr. Lepawsky: Well, regarding quotas. If quotas are set not on the basis of science, then you've got to know what your biomass is and then, you know, you have to work according to your biomass. But that takes enforcement and enforcement takes infrastructure and infrastructure takes taxes and that doesn't come easily. So you know, it's not an easy problem. It's based on politics.

Mr. Olson: Coming back is the values of the drug use. I think what you have to realize is that there is a vast gulf between the diving that this side among developing countries and the diving in the undeveloped countries. Out there it is survival.

The people out there drink heavily every night purely to dull the pain they suffer as a regular part of their work. I did not observe any hard drug abuse. I didn't actually even observe any marijuana abuse. It hasn't gone that far yet but I have no doubt it will.

We get very moral. Again, when it comes down [quotas and enforcement] in the developing countries, they do not have the resources to police it. They do not have the resources to police quotas. Nobody's going to be there to count. Nobody at all.

So they'll carry on doing exactly what they were doing before simply because they have to. They have no choice. If they don't dive today, regardless of injury to themselves, their children go hungry.

This is what has to be understood when it comes to the work that they and I are doing out in the Far East. Any suggestions from anyone as to how we can assist the divers in what they do --

Dr. Lepawsky: Of course, that pain is not just physical. There is the pain of living with abject poverty day in and day out since the day of birth to the day of death. Until income redistribution is achieved within oppressive regimes nobody's going to get anywhere with this kind of problem.

Dr. House: (Vancouver) Just a couple of brief comments. I agree with a lot of what we've already heard. I think we could use the example of British Columbia Native Indians and to look at what the background of the Europeans brought to the Native subculture and to really seriously question whether we're in a position to have this debate other than out of interest.

I think in debate it's very interesting but I think Mike's right; we should take to these underdeveloped areas what our skill is and our skill is the management of the underwater environment, not biomasses particularly. That's other people's expertise. We have medical scientific expertise and we have some knowledge of biomass. But what we can bring is basic public health standards.

The other thing in British Columbia is that as a physician who examines the majority of the divers in British Columbia, the majority of them smoke 20 cigarettes a day, the majority are young and machismo, they use marihuana and they drink excessive amounts of alcohol. I think that in the developed world, we do have some control over this issue to improve their overall quality of life and maybe that's where we should put our emphasis, you know, in our own backyard.

Then something Mr. Gold mentioned, work with the public health in the underdeveloped areas, like the United Nations does, for example. Train local people rather than walk in with ideas because obviously a fragile change in even life expectancy among divers will probably be significantly changed with the socioeconomic environment of that fishing community.

Dr. Lepawsky: So good, other comments perhaps?

Dr. Lim: (Singapore) What is your penalty here for illegal fishing of your shellfish?

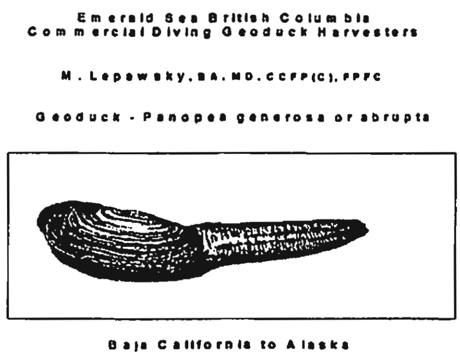
Dr. Lepawsky: Well, the penalties—the potential penalties are heavy. I believe that there probably is a black market in geoduck and there probably is in abalone and urchin and cucumber, and you know, octopus and so forth. But if you're talking about a registered company in British Columbia, then Mr. Duffy is going to be able to tell us what the penalties are.

Those penalties can be heavy. They can be financial, they can be incarceration. I don't know, Steve, if you want to come down and tell us what kind of penalties the Workers' Compensation Board can inflict on registered companies. But if the company is not registered in the Province of British Columbia, then there is virtually no jurisdiction that can—I would think, other than a straightforward criminal prosecution and those have been few and far between, if any.

Dr. Lim: I'm sorry. On my questions, why I ask them is I'm just curious. Would that be pushing somebody into, so-called doing it under the currents and would that be more dangerous in the end? Restricting biomass, would that push up the market price for such an item and push more people to dive so-called unregulated?

You know how many fatalities actually are due to diving illegally here? I don't know. Are there any statistics available? That's first.

Secondly, what I want to ask is the drugs used among the divers.. Do they use drugs as (?) money, and because of the allegation that they are stateless, maybe that's the real occupation that they can get enough money by selling drugs.



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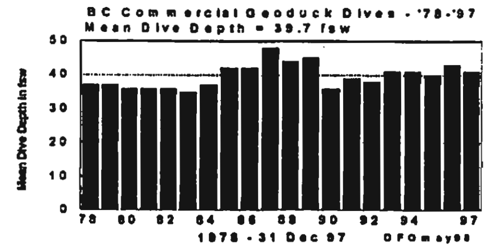

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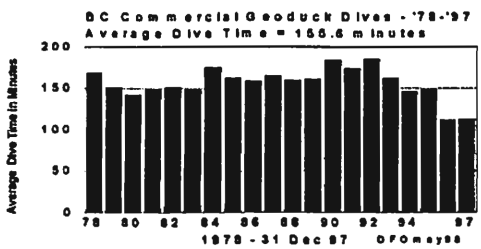

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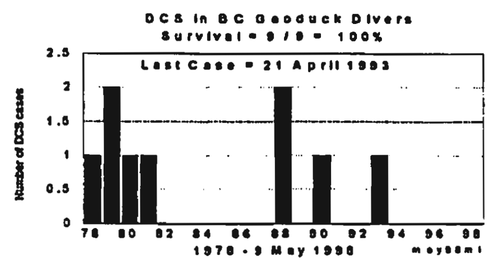

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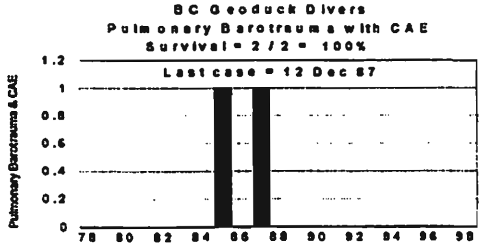

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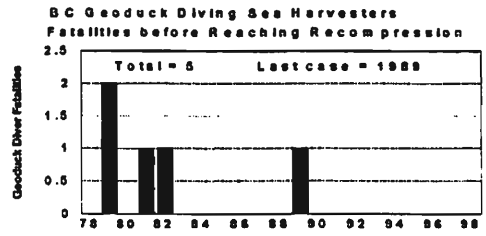

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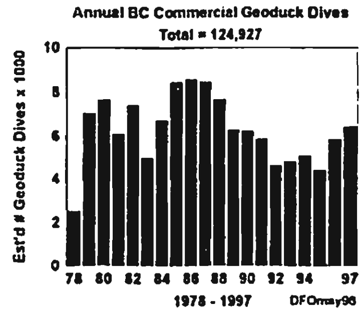
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6
4
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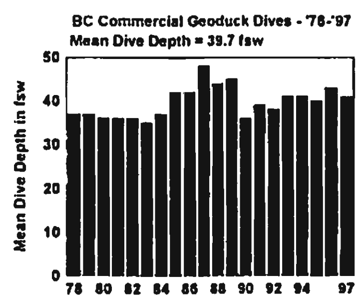
1978 - 1997
DFOmay98


BC Commercial Geoduck Dives - '78-'97
Mean Dive Depth = 39.7 fsw
Mean Dive Depth in fsw
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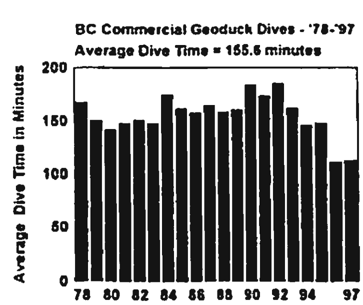
BC Commercial Geoduck Dives - '78-'97
Average Dive Time = 155.6 minutes
Average Dive Time in Minutes
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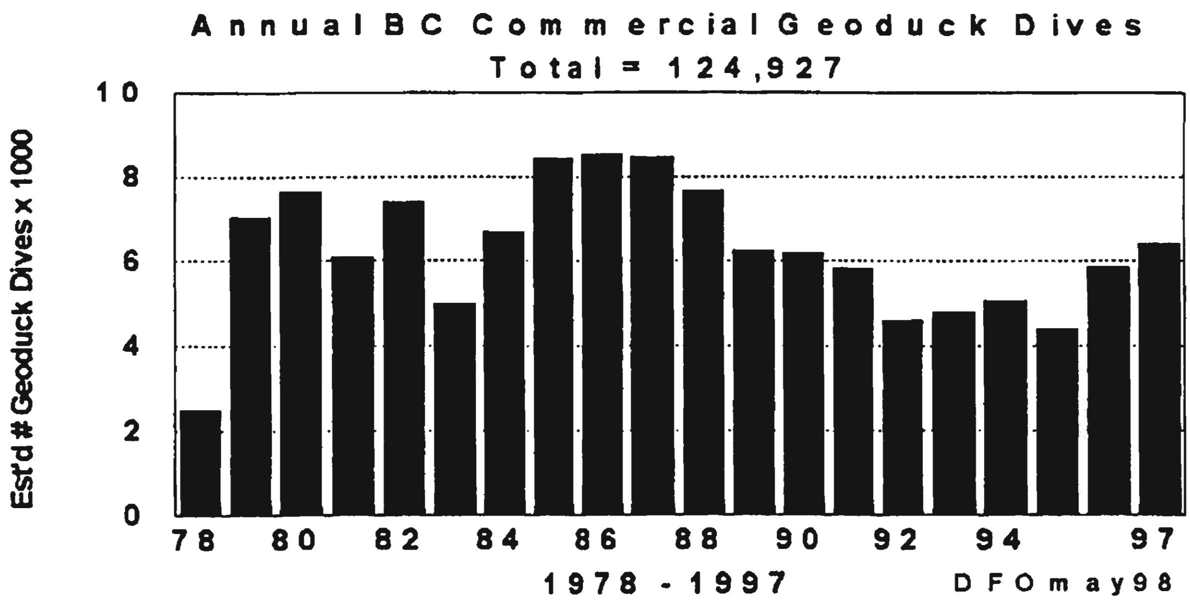
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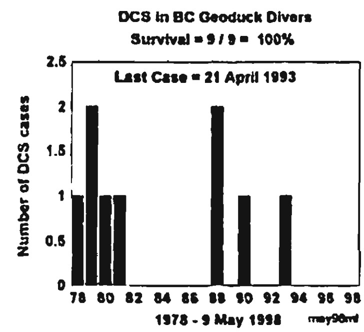
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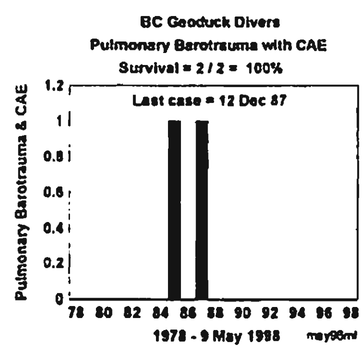
BC Geoduck Divers
Pulmonary Barotrauma with CAE
Survival = 2 / 2 = 100%
Last case = 12 Dec 87
Pulmonary Barotrauma & CAE
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0.6
0.4
0.2
0
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1978 - 9 May 1998
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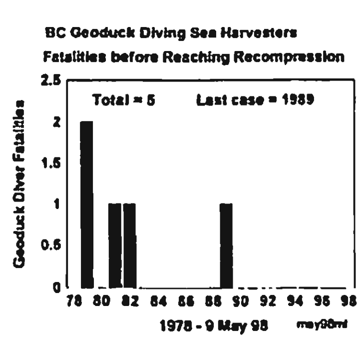
BC Geoduck Diving Sea Harvesters
Fatalities before Reaching Recompression
Total = 5
Last case = 1989
Geoduck Diver Fatalities
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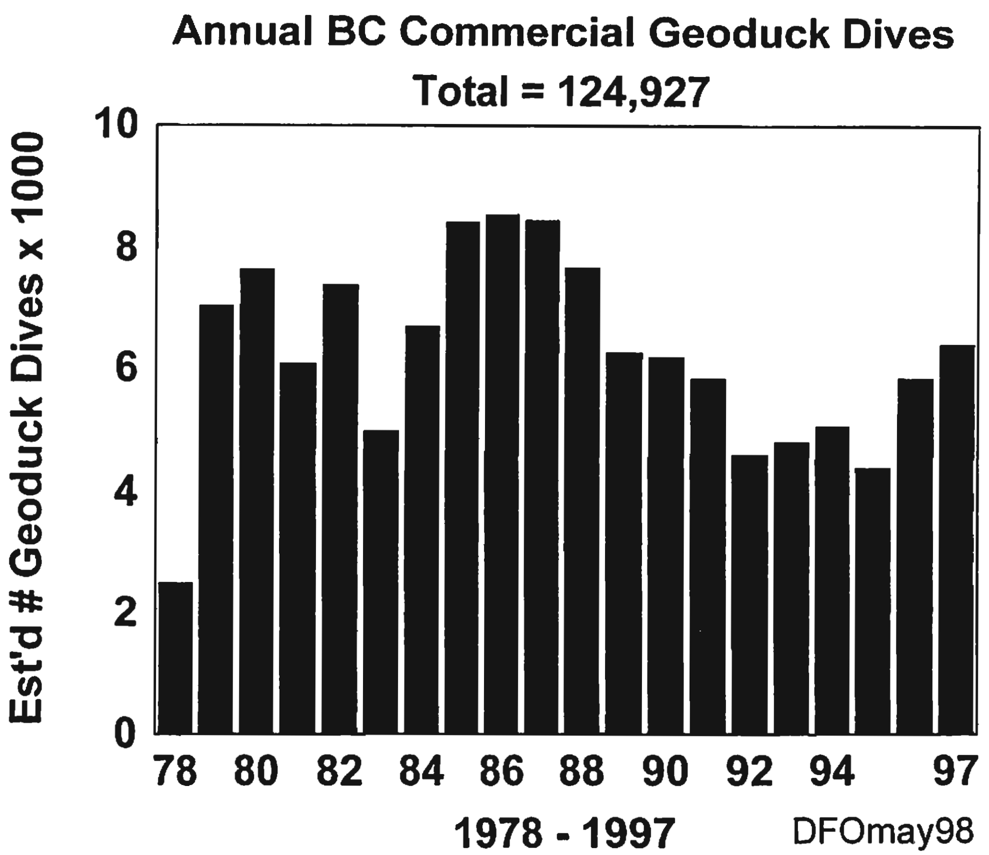
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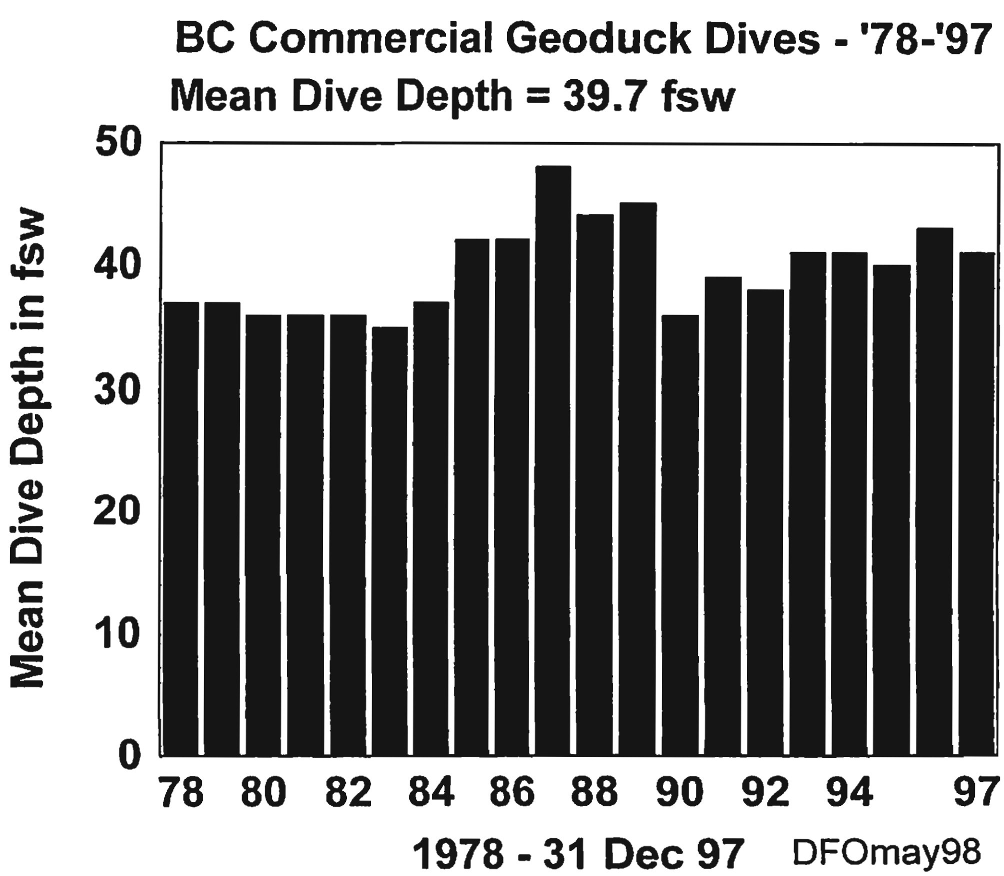
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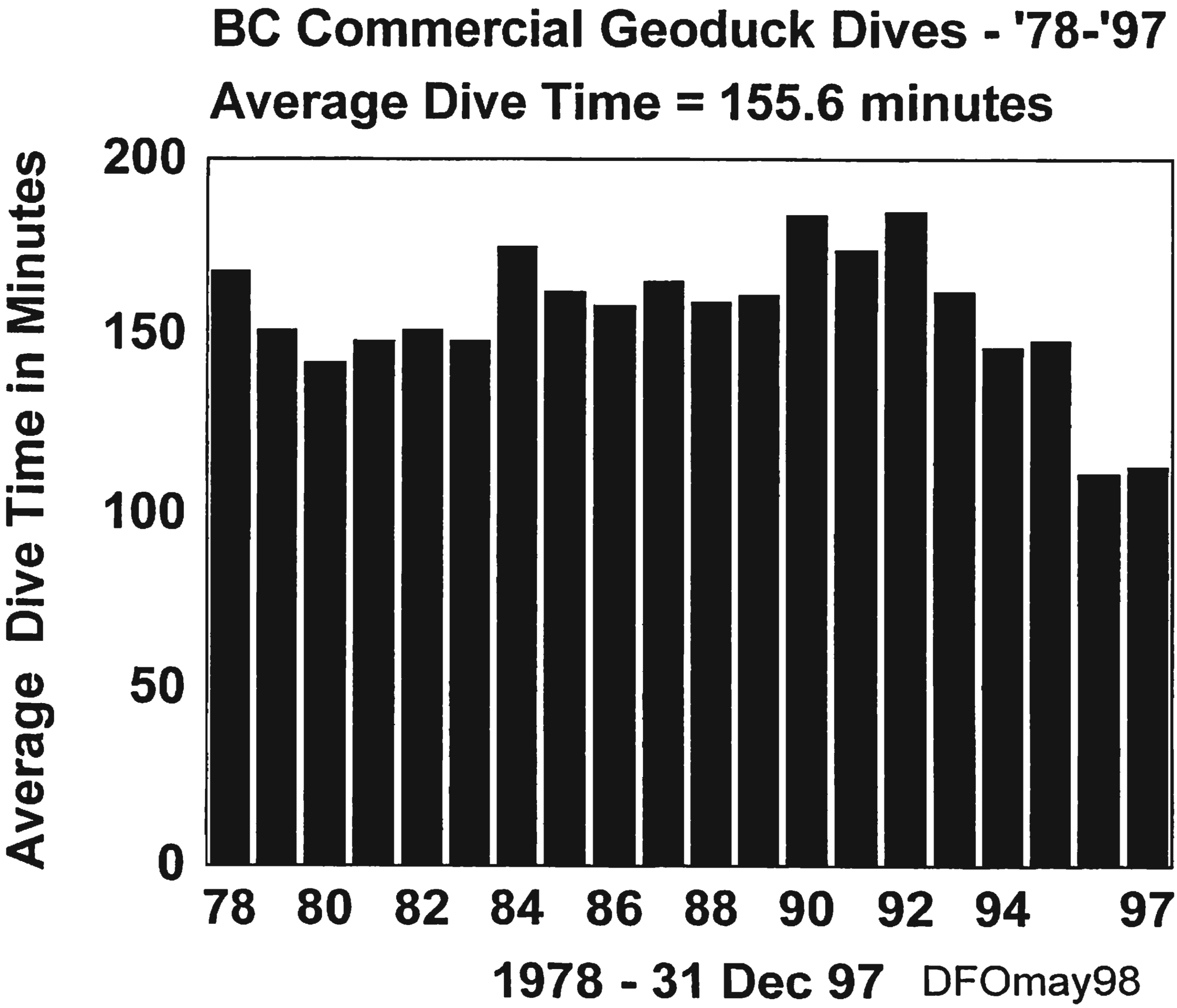
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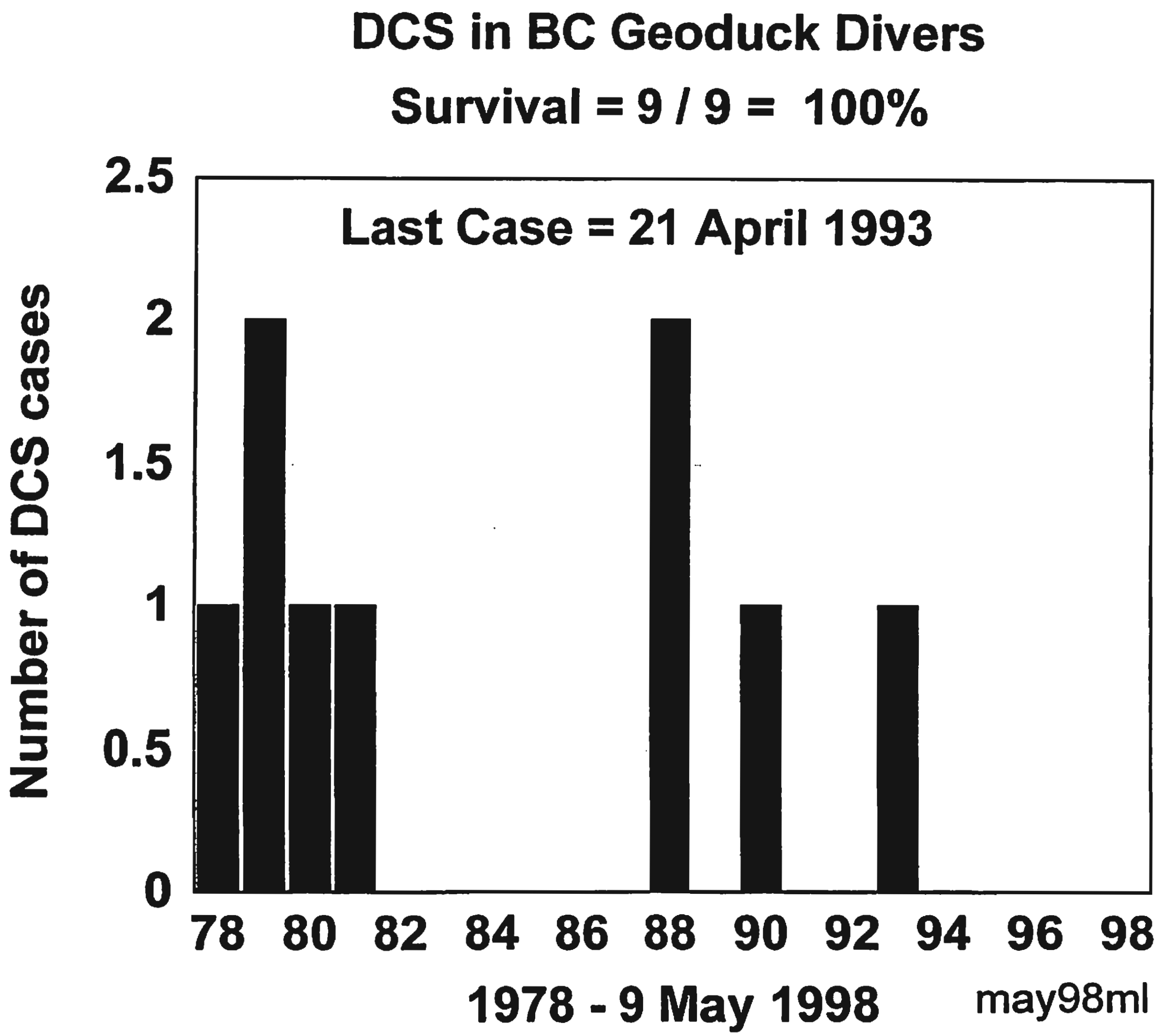
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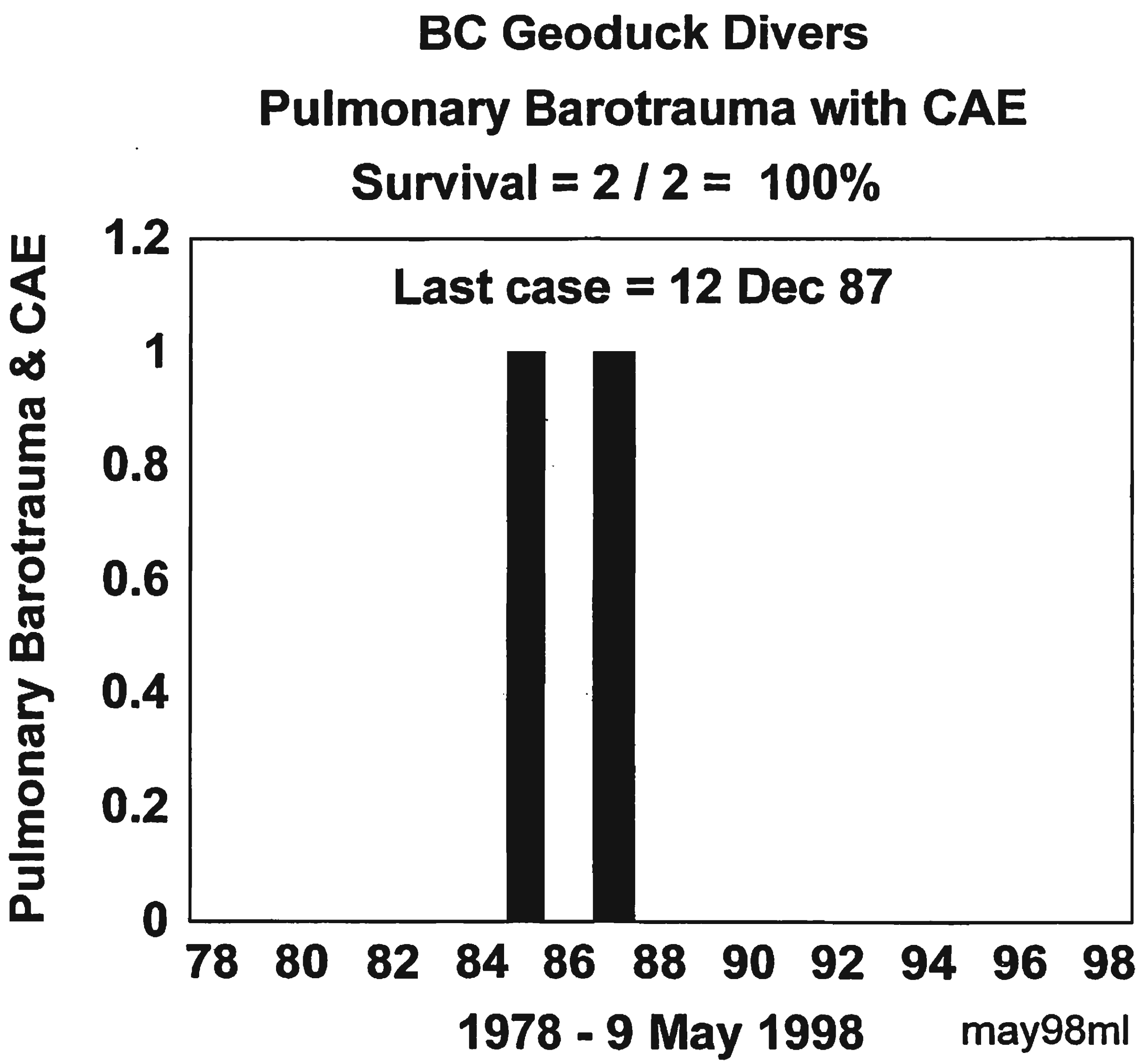
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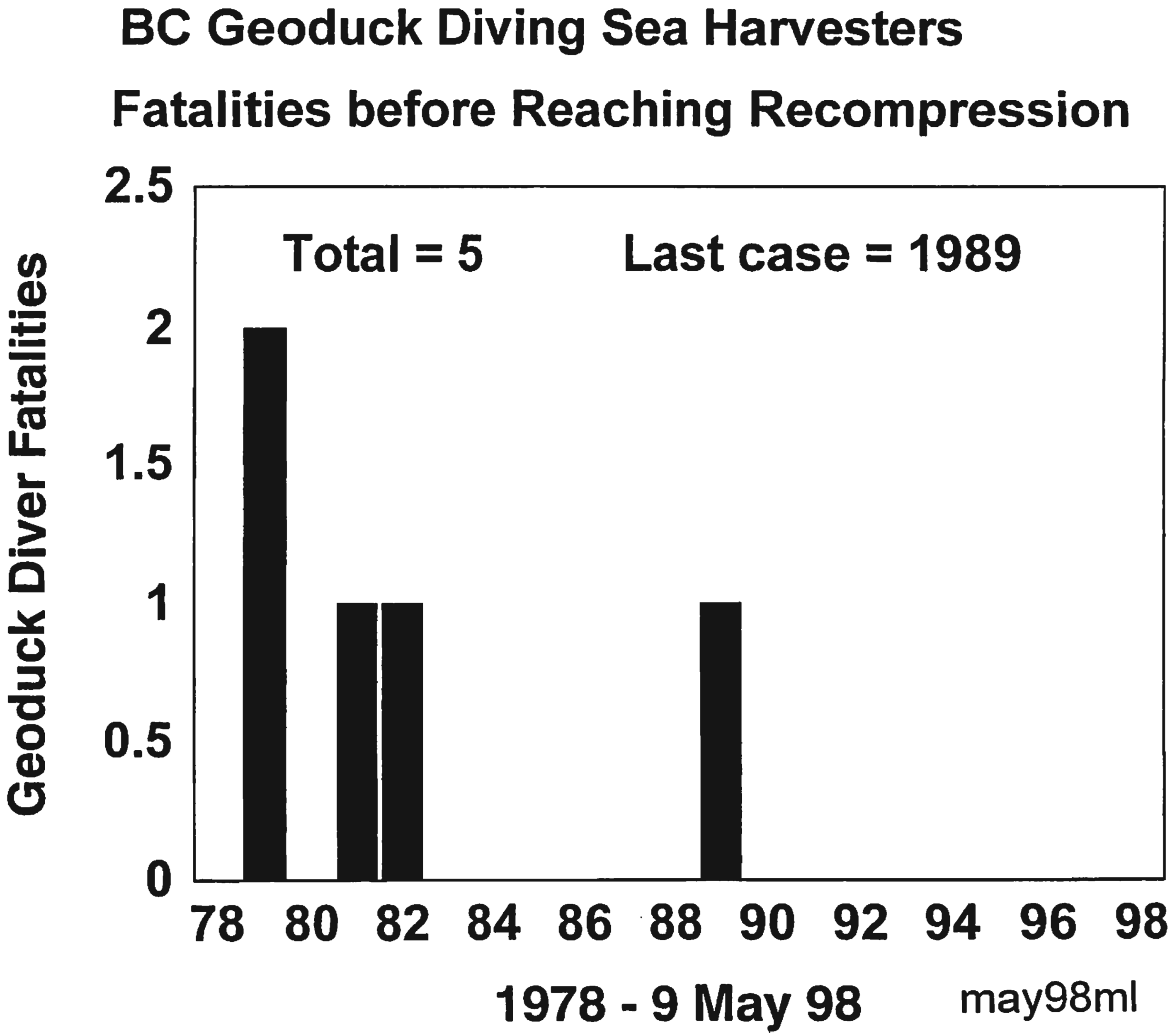
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DYSBARIC OSTEONECROSIS IN TURKISH SPONGE AND SHELLFISH DIVERS

Maide Çimşit

In searching the history of Turkish sea harvesters and their diving habits it was possible to trace them back to the 1930s. Apparently the first diving experience of Turkish divers started with their Greek neighbors in these early years. Some years later, diving in Turkish territorial waters became possible only with official permission for the foreigners, and that was the end of the partnership. At that time, divers, all male, used to dive on air using standard diving gear, 7 days a week, 6–8 h/day with a surface interval not less than 3 h between two dives. A diving season was 3 or 4 months from June to October depending to the sea conditions. Although diving was generally learned at the age of 15, starting age as a professional was 18 since the boat owners used to ask a written affirmation from each diver. Retiring time was 40–45 yr of age for shallow water and 30–35 for deep water divers. Medical examination was not obligatory, but some captains asked a physicians' affirmation. Any drugs or alcohol were forbidden on the boat as was eating during the day. Meal was eaten at the end of the day. Olive oil was used not only for cooking but also for lubrication of piston of the air pump.

The team of deep divers consisted of 11 or 12 divers on a 12- to 16-m boat, while the shallow water team consisted of 4 or 5 divers on a 10- to 12-m boat. Each boat had two diving gears. When the diver in the water started to surface, the next one on board started to gird on.

Deep divers used to dive to 50–60 meters of sea water (msw) with a bottom time of about 15 min, and it was habitual to dive shallower for the last dive of the day. The usual diving time for shallow water divers was 60–90 min to a depth of 25–30 m. Between 1930 and 1963, both groups of divers used no decompression table whatsoever. They used to surface with a 10 m:1 min ratio. Although it was not possible to reach any records, according to the stories of the old divers we have listened to, with a couple of crippled divers around and five or six deaths per diving season, it was almost clear that the death ratio and the incidence of decompression sickness (DCS) was very high.

Headache was said to be very common among shallow water divers. Severe headache with confusion, called "Calada" by the locals, was seen in deep divers. Aiming to treat, hair used to be shaved, a small incision was made on the scalp with a razor, bleeding obtained with a vacuum pump, followed by application of a freshly slaughtered chicken over the head. In the case of DCS, Fernez divers tried to be cured by applying massage to the affected area using olive oil and onion. Fernez, "Muçuna" among locals, was used in the 1950s, followed by hookah (Nargile) and scuba 1963 onward.

Severe DCS cases were lowered into the water to the same depth of the actual dive, providing that feet were not touching the bottom, and then ascending the diver 1 fathom every 5 min. If no improvement was obtained on surfacing, the same procedure was repeated. In case of a second failure he was left to his destiny.

The year 1963 was a major milestone in the history of Turkish sea harvesters. That year not only the diving instruments but the habits and diving profiles also started to change. Decompression concept was introduced, US Navy decompressing tables began to be used with some modifications. Extending the bottom time and shortening the decompression stops by 30–50% were the main modifications made by the divers. They called that modified decompressions procedure "Aksuna", which is still in use among divers.

With the freedom they gained underwater, by using hookah and scuba, they harvested more sponge, which caused a socioeconomic change in the southwest shores of Anatolia. Sponge divers became popular personalities, their economic status grossly improved, families started to permit their daughters to marry the divers. A new-starter had 20% of the harvest while an experienced diver possessed 30%.

Unfortunately sponge gradually disappeared in the following years in the eastern Mediterranean, and for a couple of years there was almost no diving in the area. At that point, Japanese friends, who enjoy seasnails as a delicacy, gave a new acceleration to sea harvesting activity in Turkey. Divers who previously dived for sponge became shellfish divers and the new ones started to dive.

Between 1984 and 1997, we performed three studies on sponge and shellfish divers with a special interest about the incidence and types of dysbaric osteonecrosis (DON). The characteristics and empirical diving techniques of these divers, and the main results of these three studies were as follows: Sponge and shellfish divers of Turkey dive on air, usually between 30 and 50 msw, using hookah, or rarely scuba. They dive 2–3 times a day depending on the depth of the dive. During the diving season which has not changed since 1930s, they dive 7 days a week, 6–8 h/day with a surface interval not less than 2 h between two dives. Descending rate is 25–30 m/min, ascending rate is 25 m/min, with a bottom

Table 1: *Divers, Diving Features, and Incidence of DCS and DON in the 1985, 190, and 1996 Studies*

Year	No. Dives	Diving for	Mean Age	Experience, yr	Mean Depth, m	DCS	DO
1985	21	sponge	26 (19–35)	4.3 (1–13)	35.4 (20–60)	28.5	85.7
1990	72	shellfish + sponge	26 (19–38)	5.0 (0–21)	35.9 (10–90)	25.3	52.1
1996	51	sponge	43 (32–54)	15.6 (7.7–23.5)	41.7 (15–90)	74.5	70.6

Table 2: *Type and Incidence of DON Lesions in the 1985, 1990, and* 1996 Studies

Year	Type A, %	Type B, %
1985	16.0	84.0
1990	18.6	81.4
1996	36.3	63.5

time of about 25 min. Decompression stops are 3 min at 9 m, 7–8 min at 6 m, and 8–9 min at 3 m. Oxygen decompression or surface decompression are not used.

The incidence of DO and DCS in Turkish sea harvesters were investigated and presented previously (1,2). These two studies and the recent one which was performed in 1996 resulted in very high incidence rates of DCS and DO. Incidence of DCS were 28.5% in 1985, 25.3% in 1990, and 74.5% in 1996 studies. 6 divers out of 21 in the 1985 study have had 10 DCS accidents, 7 of them were type I, and 3 were type II. Two divers had both type of DCS. In the 1990 survey, 18 divers out of 71 had DCS; 15 type I, and 3 type II. 7 divers had type I several times, and one diver had type II DCS 3 times.

In the 1996 survey, 38 divers out of 51 reported DCS; 23 divers were treated in a pressure chamber. Others either have made recompression treatment in the water, which is also called "Acsuna" among divers, or did nothing. 17 of the 23 divers experienced type I DCS more than once. Among 15 divers with type II DCS, 6 patients were treated with recompression and appropriate medical and rehabilitation therapies, others had made "Aksuna". Three divers had type II DCS more than once. Since the mean age and diving experience of the 1996 group were strikingly higher than the 1985 and 1990 groups, this was thought to be the explanation of the higher DCS incidence among these divers. The mean value for the maximum diving depth was also high (74.6 m) in this group (Toklu and Çimşit, unpublished data, 1996).

The incidence of DON lesions were 85.7% in the 1985 group, 52.1% in the 1990 group, and 70.6% in the 1996 group. DON lesions were far more common among the sponge divers compared to the shellfish harvesters.

The main characteristics of divers and the incidence of DCS and DON are given in Table 1. Humerus was the primary site for DON lesions, followed by femur and tibia. Most of the juxta-articular lesions took place in humerus. Type and incidence of DON lesions are given in Table 2.

Alcohol intake was very common among our subjects (90%). With few exceptions, all divers reported to drink a certain beverage with a high alcohol content, every day. This habit may have contributed to the high incidence rates of DCS and DON. On the other hand, there were divers who never had alcohol but had experienced type I or II DCS and manifested DON lesions.

Dysbaric osteonecrosis is one of the important effects of diving on health and we need to gather more information about it, especially about the changes in DON lesions with time. We have started a study to investigate the course and changes, if any, in DON lesions of the Turkish sea harvesters who underwent their first radiological evaluation in 1985. Though this study is still in process, the first results showed that, with time, the total number of type A and B lesions increased in 10 out of 11 divers who were reexamined. Type A lesions worsened in four divers, remained the same in six, and decreased in one diver. There were no malignant changes in any one of the lesions (3).

To summarize, we can say that both DON and DCS have high incidence rates among Turkish sea harvesters. Empirical diving habits are thought to be responsible for that finding. High alcohol intake, which is very common among these divers, may also have contributed to these results.

We thank our friends Tosun Sezen, for providing us with his photography archives, and Mehmet Baş (Aksuna Mehmet) for helping us to reach the divers, and all the divers without whose contribution it would not have been possible to produce these studies.

REFERENCES

1. Çimşit M, Babuna C, Karaçallık A, et al. A survey of aseptic bone necrosis in Turkish sponge divers; Interim report. In: Örnhagen H, ed. Proceedings of XIth annual meeting of EUBS; ISSN 0347-7665, Göteborg, 1985:147–157.
2. Çimşit M, Aydın S, Aktaş Ş, Varan G. Aseptic bone necrosis in Turkish sponge divers. In: Sterk W, Geeraedts W, eds. Proceedings of XVIth annual meeting of EUBS, ISBN 90-9003550-8, Amsterdam, 1990:115–120.
3. Çimşit M, Toklu AS, Aslan O. Long term health effects of diving: the changes in dysbaric osteonecrosis lesions with time. Undersea Hyper Med 1998; 25(suppl):31.

DISCUSSION

Unidentified Speaker: How many of these divers end up with joint replacements?

Dr. Çimşit: As far as I know, nil.

Unidentified Speaker: And they drink a lot of alcohol. How many of them would?

Dr. Çimşit: All of them.

Unidentified Speaker: All of them and it was normal?

Dr. Çimşit: Everything was normal. We found very few cases, we found diabetes, but not any high values for liver function test or enzymes or anything.

Unidentified Speaker: Just one last question. You mentioned the Aksuna. How does it work?

Dr. Çimşit: Well, as I told you, they would generally go into the water. They put the diver into the water to the depth of relief and then they start to ascend him 1 fathom every 5 minutes. They still use the same procedure as they used in the earlier years.

But in recent years, the new ones, they now know what to do and how to do it and they almost always gave us a call. Our department is on call 24-hours a day and they call us. We recommend to them what they should do, which is usually to use surface oxygen and then steroids, if they can manage, intramuscular steroids, and immediately transfer to the hyperbaric center which is in Bodrum, and there's one in Istanbul for civilians.

Unidentified Speaker: Just on that, there's not the (indiscernible)?

Dr. Çimşit: Well, usually it's by going down. Sometimes they reported to us that by going down, on the way down they started to get relief but usually they waited some 2–5 at the depth of relief before they start to surface and come to the surface at 1 fathom per 5 minutes.

Mr. Dunford: Have I understood correctly? On one of the tables you put up there, where the incidence of type A lesions decreasing over the years, did the incidence of B lesions decrease?

Dr. Çimşit: The incidence what?

Mr. Dunford: Of B lesions.

Dr. Çimşit: B lesions.

Mr. Dunford: Did they decrease from 85% to 66%? Has there been any change in their dive profiles that might account for this change?

Dr. Çimşit: Yes, there could be two things. First, some of the sponge divers became shellfish divers, who use somehow different profiles for diving. They dive shallower but they do much more dives in a day compared to the old sponge diving style. The second thing, of course, there could be a healing process.

Mr. Winger: (Wisconsin) We note there is a strong association between high dose steroids and production of osteonecrosis and I'm curious regarding diving restrictions and steroid usage.

Dr. Çimşit: I'm almost definitely sure that it's not the cause of the lesions in divers because very recently, well-educated, at least people who finished high school; the captains, we recommended the use of steroids on their divers, which has been for the last 2 years and all these studies were done before these 2 years.

The 1996 study might have been affected, although we recommended the steroid injections on board, but this occurrence is very, very low, say, one or two divers at most. Because these data are collected from their villages in the south and the other ones, we recommended steroids to the shellfish divers who dive in the Black Sea. So I don't think that is the reason.

Mr. Winger: As a follow up, would you recommend it on single dose.

Dr. Çimşit: Well, it depends on the clinical studies of the diver. If we believe the medical history over the phone, if we believe that, and if we think that he can manage without steroids, then he comes to us without steroids, but if we think he is grossly affected, then we recommend something between 16 mg up to 40 mg of prednisone intramuscularly or, of course, if they can manage it, intravenously. But if we are on the boat, we do it intravenously as well.

Mr. Winger: Final question. Approximately how many divers are there in this population, sponge and shellfish divers?

Dr. Çimşit: All together?

Mr. Winger: Yes.

Dr. Çimşit: I think it's about something between 150 and 200. But of course, the people die or just go to their old villages which is in central Anatolia or somewhere near Anatolia when they left the sponge or shellfish diving and newcomers arrive. So really, I can't give you the exact number.

Dr. Kawashima: Thank you very much for your very interesting presentation. Your diver has a national license for diving and your diver has what educational training?

Dr. Çimşit: Yes, the old ones don't have any license at all but new ones have diving licenses and some of them are educated in the Navy, some of them educated by the Federation of Diving of Turkey, so they had civilian educators, divers and some learned diving from the old ones.

Unidentified Speaker: A lot of these divers have decompression sickness. I wonder, in this material, is there any relationship between the site of the clinical symptoms and the site where you find the lesions?

Dr. Çimşit: No, actually, we looked very hard for it because personally I always had a belief that even though we can never prove it, there's a correlation between decompression sickness and dysbaric osteonecrosis. But I think that we can never prove it.

The site of the lesion and the site of the decompression sickness don't match. But one very interesting thing that I must say, all of our divers who had either type one or type two decompression sickness always ended up with dysbaric osteonecrosis.

If I'm not wrong, there must be one exception. I'm not so sure. I can't remember definitely but I think there was one exception. But that doesn't mean that every dysbaric osteonecrosis diver had decompression sickness.

Unidentified Speaker: They do not call this DCS. But when asked Do your have such a pain?" they will give an answer as "Yes, it's a dry pain."

But they are losing their liability to collect the sponge and they really work hard in water and they don't accept that decompression sickness has ever been a problem by using one tank only.

Dr. Lepawsky: One last question.

Unidentified Speaker: Am I right here? Did you say they came up as much as 30 meters per minute?

Dr. Çimşit: In the early years, no, 10 meters.

Unidentified Speaker: Ten meters.

[Dr Toklu]: Twenty-five meters per minute.

Dr. Çimşit: It was later years.

HIGH-RISK DIVING AND DYSBARIC OSTEONECROSIS

J. P Jones, Jr., G. W. Salbador, F. Lopez, S. Ramirez, and S. B. Doty

INTRODUCTION

With use of standardized decompression techniques, less than 5% of compressed-air (tunnel or caisson) workers now develop dysbaric osteonecrosis (DON) (1). Lesions of dead bone and marrow also have been reported in over 2% of patients with sickle hemoglobinopathies, and in 4% of patients with inflammatory bowel disease (2). Organ transplant recipients also develop these lesions with a significant incidence, i.e., heart 3%, kidney 5–8%, and allogenic bone marrow 10–22%, and up to 30% of systemic lupus erythematosus patients have also developed this disease.

However, the highest prevalence of nontraumatic osteonecrosis occurs in commercial diving fishermen. Although DON can occur after a single hyperbaric air exposure with inadequate decompression following submarine escape and in hyperbaric sheep experiments, most divers who develop DON have experienced multiple exposures and symptomatic decompression sickness (DCS). DCS occurs when a decrease in ambient pressure is sufficient to cause tissue and venous nitrogen bubble formation.

Kawashima (3) observed that 467 of 905 (52%) of Japanese divers had DON, whereas in Korea, Yoo et al. (4) found that 171 of 256 (67%) divers had DON. We studied the typical diver profiles of two additional groups of diving fishermen with unsafe diving practices. Both cohorts experienced prolonged exposure to compressed air with severely inadequate decompression and rapid (no-stop) ascents to the surface. All of these divers had severe DCS.

MEXICAN SCALLOP DIVERS

Methods: In 1988–1989, we estimated that there were about 500 diving fishermen using surface-supplied compressed air (SSCA) and retrieving scallops along the coastline of the Pacific Ocean at the lower portion of the Baja peninsula of Mexico. To our knowledge, none of these divers had any formal dive training or pre-employment medical examinations. Interviews suggested that many divers and tenders consumed alcohol and/or marijuana either before, during, and/or after diving.

At that time, about 200 dive boats with outboard motors were equipped with portable air compressors and hooka rigs. Ordinarily, these scallops were harvested in under 50 feet of sea water (fsw), and the divers scooped them into sacks from the sandy bottom. Their usual SSCA profile for a 50 fsw dive was about 2–3 h bottom time, a surface interval of 30 min, and a second dive with 1–2 h of bottom time with a no-stop ascent to the surface. Although staged decompression was not used, diving deaths were a relatively rare occurrence. However, during 1988 and 1989 the surface waters became warmer than usual and the resource became depleted in shallow water. During this time the divers found that they had to descend much deeper in colder water to recover scallops, i.e. to a maximum depth of about 108 fsw.

The SSCA was delivered through an air hose using the traditional Mexican hooka-rig technique. Another line was attached to the diver's weight belt which was used to pull filled clam sacks up to the boat. However, equipment failures frequently occurred. Compressors often had very limited, if any, air reserves. They also had no air filters, exhaust control, or water separators, and there were carburetor problems, breakage of fan belts, and leaking gasoline tanks.

Diving fatalities: In 1988, three scallop divers died shortly after surfacing. From May to September 1989 there were 11 additional diving fatalities. None of these 14 divers received recompression treatment. In mid-September 1989, a recompression chamber was installed in the town of San Carlos on Magdalena Bay, and an average of three DCS cases were treated daily for several weeks. However, in December 1989 a diver expired in the chamber (Table I, diver 7).(5) Therefore, within two harvesting seasons (1988-89) 15 divers are known to have died. All 15 fatalities were considered to have had six months or less of diving experience. In 1990, an educational program was begun for the divers, and with the implementation of this chamber, to our knowledge, there have been no further diving fatalities through 1997.

Results: Autopsies were performed on seven of these 15 fatalities. All these autopsied divers were men; their ages ranged from 18 to 45 years (average 31 years). All autopsied divers died within three hours of surfacing. The fatality rate was about 3% (15 of the estimated 500 divers). All 15 SSCA divers had expired from severe DCS and probable arterial gas embolism. Gross autopsies performed on seven of these 15 divers revealed generalized venous and arterial intravascular gas bubbles.

Fatal rapid (no-stop) decompressions occurred in all seven of these autopsied divers after their prolonged bottom times (Table I). The average depth of these seven divers was 81 fsw, and their average bottom time was 5.2 h. Diver 1 and diver 2 (Table I) released their weight belts and made emergency out-of-air ascents directly to the surface, after their air

Table 1: *Fatal (No-Stop) Decompressions in Seven Mexican Divers Who were Autopsied and Who had Used Surface-Supplied Compressed Air*

Diver	Depth, fsw	Duration, h
1	82	6.0
2	79	5.0
3	75	5.0
4	75	5.5
5	79	5.0
6	82	5.0
7	92	4.5

compressors suddenly failed. Divers 3 through 7 also made rapid and direct no-stop ascents to the surface after their prolonged bottom times. Once a multiplace decompression chamber was installed at the town of San Carlos in September 1989, there was one more diving fatality (5). This 28-yr-old male scallop diver (Table I, diver 7) remained at a depth of 92 fsw for 4.5 h on surface-supplied air. DCS occurred after a no-stop ascent to the surface, and he died 70 min later in the recompression chamber. Autopsy showed multiple gas bubbles, not only within his great vessels, but in the fatty marrow of his femoral and humeral heads (Fig. 1). Lipid and platelet aggregates were found on the surface of marrow bubbles (Fig. 2).

Pulmonary and renal fat embolism were also observed (Fig. 3), as well as embolic lipid within subchondral capillaries (Fig. 4). Fibrin thrombi were also observed in subchondral capillaries and venules (Fig. 5), in addition to fibrin-platelet thrombi within arterioles (Fig. 6), suggesting intravascular coagulation (2).

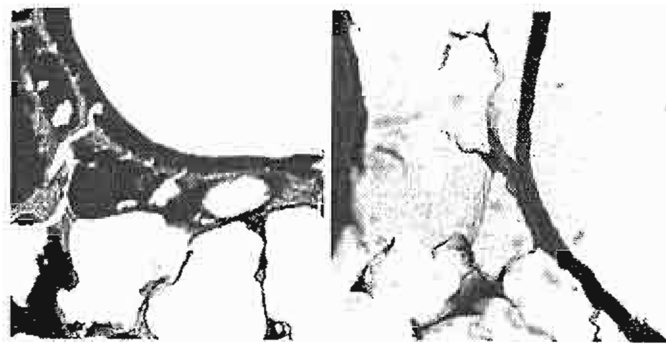


Figure 2. Photomicrograph of humeral head shows a marrow bubble which is coated with a layer of dark lipid adjacent to disrupted marrow adipocytes. [Stain, osmium-potassium dichromate; original magnification, ×460 (*left*).] A similar film of dark lipid extends from damaged marrow adipocytes to the surface of another bubble. [Stain, osmium-potassium dichromate; original magnification, ×460 (*right*).]

HONDURAN LOBSTER DIVERS

Methods: Miskito Indians from southern Honduras and northern Nicaragua were recruited from their Mosquito Coast villages to dive for spiny-tailed lobster in the western Caribbean Sea. These young divers had received no formal training. From 1990 through 1993, at the multiplace hyperbaric chamber of the Cornerstone Emergency Medical Mission on Roatan Island, 336 of the 420 (80%) recompression treatments that were administered, were provided to these Miskito Indian divers. In 1994, Millington and Idzepski estimated that there were about three deaths a month involving these divers, besides a very high incidence of untreated (or delayed treated) type II DCS, with residual paraplegia and hemiplegia (6).

Usually between 25 and 45 paddlers and 25 and 45 divers

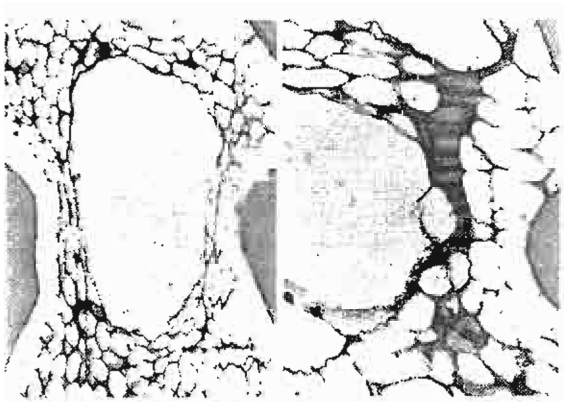


Figure 1. Photomicrograph shows a marrow bubble within disrupted adipocytes, some of which appear to be compressed, as well as fibrin thrombosis of adjacent sinusoids. [Stain, hematoxylin and eosin; original magnification, ×100 (*left*).] A smaller bubble is surrounded by platelet aggregates with fibrin thrombosis of dilated sinusoids.[Stain, hematoxylin and eosin; original magnification, ×200 (*right*).]

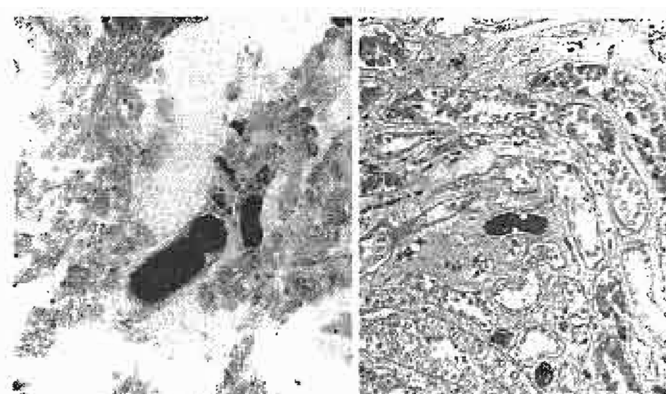


Figure 3. *Photomicrograph of lung demonstrating multiple deformed fat emboli within alveolar vessels and extensive hemorrhage. [Stain, osmium-potassium dichromate and eosin; original magnification, ×300* (left).] *Embolic lipid is also present within renal vessels and tubules. [Stain, osmium-potassium dichromate and eosin; original magnification,* ×100 (right).]

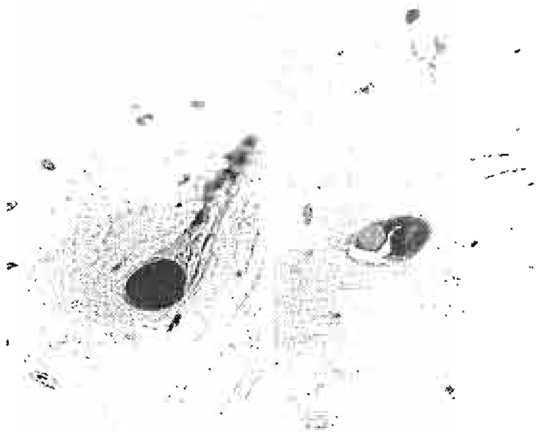


Figure 4. Photomicrograph of a subchondral capillary in the right femoral head, immediately beneath the tidemark, which is obstructed by embolic lipid. [Stain osmium-potassium dichromate; original magnification, ×600 (*left*).] Cross-section of another subchondral capillary which is occluded with both a fat embolus and fibrin thrombus. [Stain, osmium-potassium dichromate; original magnification, ×600 (*right*).]

live on board the 45–65 ft long lobster boats for the 15-day trips (12 continuous diving days). Once at the harvesting site, a paddler and diver leave the ship in their hand-carved dugout canoe with about four scuba tanks. Although usually not obese, these divers almost invariably smoke marijuana before diving, apparently to alleviate anxiety regarding their superstitious "mermaid's curse", i.e., the symptoms of DCS.

These divers use only a tank, mask, fins, and an open-circuit scuba regulator. They do not use a watch, depth gauge, tank pressure gauge, weight belt, snorkel, bouyancy compensator vest, or decompression tables. Ordinarily, a diver will collect the spiny lobster with a long metal hook, until he can either no longer hold any more lobster antennae with one hand, or until he runs out of compressed air. While holding the lobster, he then makes a direct, rapid ascent to the surface. He then exchanges scuba tanks and immediately descends again to the bottom, with a surface interval of about 2–3 min. Usually after

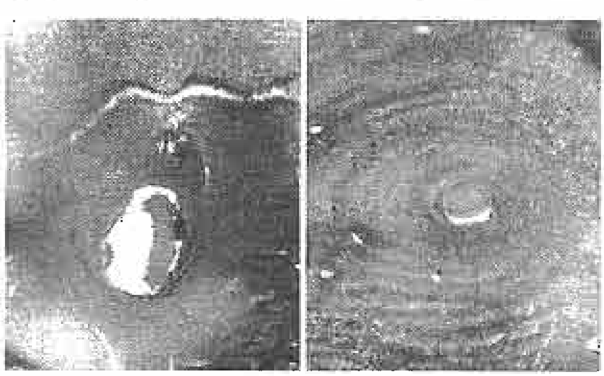


Figure 5. Photomicrograph showing fibrin thrombosis of a dilated subchondral venule. [Stain, Masson trichrome; original magnification, ×430 (*left*).] A subchondral haversian capillary is also occluded by a fibrin thrombus. [Stain, Masson trichrome; original magnification, ×600 (*right*).]

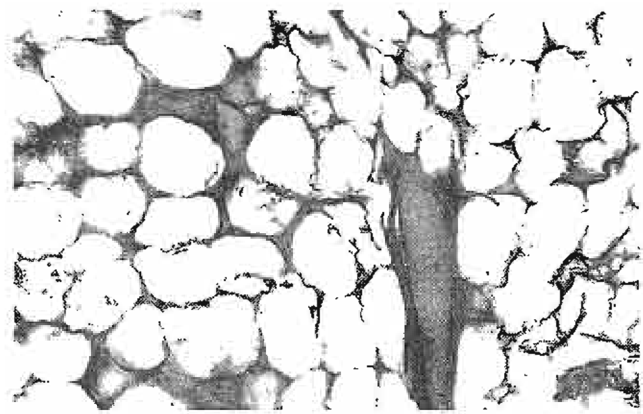


Figure 6. Photomicrograph of right humeral head revealing a fibrin thrombus which is occluding a dilated marrow arteriole. There are also disrupted marrow adipocytes with extensive interadipocytic fibrin deposition. (Stain, Masson trichrome; original magnification, ×300).

the third or fourth tank the diver and paddler return to the ship, transfer the lobster, and replace their tanks, with a surface interval of about two hours. Then the diver makes another similar series of repetitive dives in the afternoon.

In 1993, Moskito Indian divers were studied for 3 wk by Doctor Fermin Lopez, while he was on a commercial lobster boat. Dive profiles were recorded and analyzed using Suunto dive computers, which were provided by Dunford.and colleagues (7). Usually, the dive depths were between 90 and 120 fsw, with bottom times of about 30 min and surface intervals under 6 min. Two examples of their typical dive profiles are as follows:

- Profile I, four tanks at 93 fsw maximum for a cumulative bottom time of 115 min, 2–3 h surface interval, then four tanks at 92 fsw maximum for additional bottom time of 110 min.
- Profile II, four tanks at 97 fsw maximum for 87 min, 1–2 h surface interval, then three tanks at 101 fsw maximum for

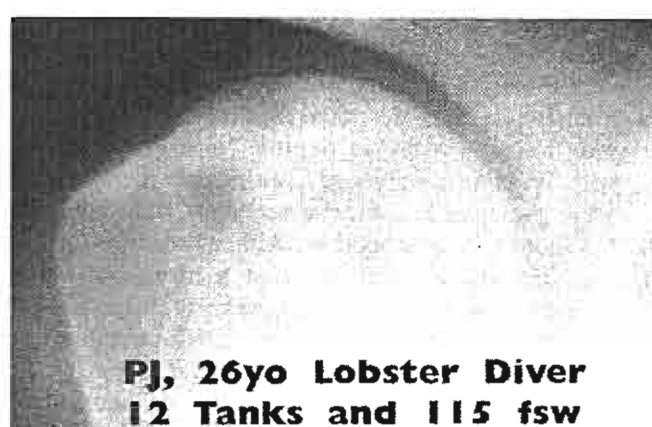


Figure 7. Antero-posterior radiograph of right shoulder. Immediately before this x-ray, this diver had used 12 tanks to a depth of 115 fsw in a single day. There is a diffusely sclerotic lesion with irregular lucencies within his humeral head, but without articular incongruity.

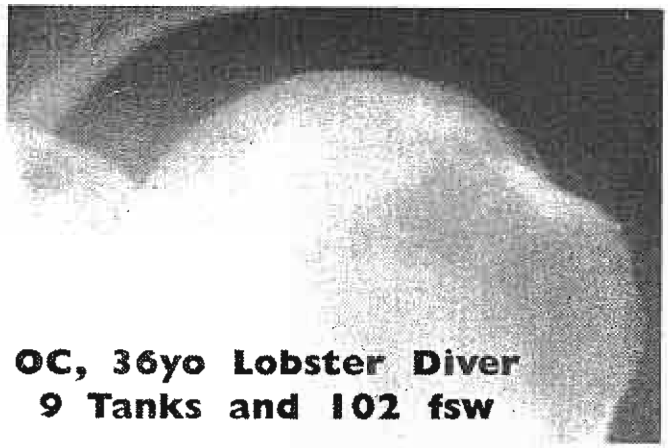


Figure 8. Radiograph of the left shoulder of another diver who had last used nine tanks to a depth of 102 fsw in a single day. Although a pre-existing juxta-articular sclerotic lesion is obvious, there is no evidence of late subchondral collapse.

78 min, 1–2 h surface interval, then two tanks at 104 fsw for an additional bottom time of 54 min. Often after the second tank, these divers experienced some DCS symptomatology.

In 1994–1995 on the Honduran Bay Island of Roatan, we performed a radiographic pilot survey of Miskito divers in an attempt to detect evidence of DON. This group of 13 divers used between 9 and 16 scuba tanks a day, and they had all previously received recompression treatment for DCS. Portable x-ray equipment was used to perform antero-posterior radiographs of both shoulders (in external rotation), both hips (in internal rotation), and both of their knees.

Results: All 13 of these divers were still living despite all having experienced DCS. Radiographs revealed DON in 9 of these 13 (69%) divers, with 30 lesions affecting their distal femurs/proximal tibias (60%), humeral heads (33%) (Fig. 7) or femoral head (7%). All but one of the juxta-articular lesions involved the shoulders. However, none of these humeral head lesions (Fig. 8), nor the femoral head lesion, appeared to have undergone late segmental collapse.

DISCUSSION

The traditional diving profiles of these native fishermen did not protect them from the inherent dangers of harvesting a depleting resource at deeper depths. None of the currently accepted dive profiles were used in either cohort. Their unsafe practices and profiles were associated with equipment inadequacy and diver ignorance. Although several of these Mexican and Honduran divers had a history of chronic alcoholism and marijuana consumption, to our knowledge, none of these divers had any other predisposing medical conditions, except for obesity in the Mexican divers.

Coexistent Alcoholism: The incidence of nontraumatic osteonecrosis in alcoholism has varied from 0.3% in the United States, to 2% in Japan, and 5% in Yugoslavia. In 164 patients with alcohol-induced DON, the average duration of alcohol abuse was 9.5 years.(8) There appears to be a cumulative alcohol dose-related ON response. In my experience,(2,9) the exposure threshold for alcohol-associated DON (at a consumption of 400 ml or more of absolute ethanol a week) is about 150 liters of 100% ethanol. Alcohol-induced ON usually affects younger patients, and alcoholics with hyperlipemia and hypofibrinolysis may have a greater susceptibility for developing intravascular coagulation and DON.

Hyperlipemia and Embolic Lipid. Fat embolism is also well known to complicate dysbaric phenomena and be associated with intravascular coagulation (10). A fat overload syndrome may conceivably occur with DCS. For example, an explosive decompression accident resulted in large amounts of fat in the large arteries and veins (11). C-reactive protein (CRP), an acute-phase protein, can cause the calcium-dependent agglutination of chylomicrons and very-low-density lipoproteins (VLDL) into embolic lipid (12). VLDL are increasingly produced in the fatty liver and contain apolipoprotein (apo) B-100 and endogenous lipids. This mechanism may not only cause DON, but also cause ON in those patients with corticoid- or alcohol-induced hyperlipemia, fatty liver, and fat embolism (13). A diffuse coagulopathy can occur with acute alcoholic liver disease, as well as decreased plasma protein C and antithrombin III (ATIII).

Intravascular Coagulation: The autopsy of Mexican diver 7 (Table I), who expired only 70 min after surfacing despite initially receiving recompression therapy, already had developed extensive intraosseous fibrin thrombosis (5). Although he probably died from massive intravascular gas and fat embolism, this case suggested that there is a secondary injury to the marrow adipose tissue by rapidly expanding nitrogen gas that triggers local, and possibly systemic, intravascular coagulation (1C). Injured marrow adipocytes can release liquid fat, tissue factor (thromboplastin), and other vasoactive substances, which conceivably can also play a systemic procoagulant role in triggering disseminated 1C and an acute intraosseous ischemic event.

In 1974, I theorized that 1C with fibrin thrombus propagation was the specific intermediary event and final common pathway producing nontraumatic ON (14,15). Considerable evidence is accumulating which indicates that a coagulopathy involving the intraosseous microcirculation (capillaries and venous sinusoids) progressing to generalized and residual venous thrombosis, and less commonly retrograde arterial occlusion, is the early pathophysiology of nontraumatic ON (2). Philp(16) reviewed the evidence which suggests that hypercoagulability and DIC may complicate the presence of intravascular bubbles with decompression, including a reduction of platelets of about 25% over 48 h and an increase of fibrinogen/fibrin split products.

However, 1C is only an intermediary event, which is always trigger activated by some underlying etiologic risk factor(s) (2,15,17). Conditions capable of triggering 1C include hyperlipemia and embolic lipid (alcoholism and hypercortisonism) (9,13), sickle hemoglobinopathy, hypersensitivity reactions (allograft organ rejection, immune complexes, arthus phenomenon, anaphylactic shock, and antiphospholipid antibodies), bacterial endotoxic (Shwartzman) reactions and various viral infections, proteolytic enzymes (pancreatitis), tissue factor release (inflammatory bowel disease, malignancies, neurotrauma, and pregnancy), and other hypofibrinolytic, hypercoagulable, and thrombophilic conditions. For example, in dysbaric phenomena (Fig. 9), fibrinogen, lipid, and platelet agggregation at the blood-bubble interface are associated with intravascular coagulation and post-dive thrombocytopenia, accelerated platelet turnover, decreased ATIII activity, and increased fibrin degradation products (5,18). Thrombophilia. Some divers may also have an underlying familial thrombophilia, which is defined as an increased tendency to develop intravascular thrombosis. In 1990, Charles Esmon and one of the authors (J.P.J.) discussed impaired natural anticoagulant mechanisms and first suggested that decreased protein C, protein S, or ATIII may be risk factors for ON (18). Protein C is converted to activated protein C (APC) by the thrombin-thrombomodulin complex on the surface of endothelial cells. APC exerts its natural anticoagulant function by degrading procoagulant factors Va and Villa. Protein S serves as a cofactor for APC. Glueck et al. recently confirmed these coagulation abnormalities in patients with nontraumatic ON (19). It was discovered that the most common type of familial thrombophilia is resistance to activated protein C (RAPC), which is now known to be a significant risk factor for ON (20). To evaluate thrombophilia it is recommended that, in addition to RAPC, protein C and S, and ATIII, that antiphospholipid antibodies (IgA, IgG and IgM) and the lupus anticoagulant be measured.

Thrombocytopenia and Platelet Aggregation: Low platelet counts may be found in association with very early ON lesions, both clinically(18,21) and experimentally (22). Boettcher et al.(21) found that 21 of 37 (56%) patients with ON had significantly abnormal platelet counts, and 15 of the 21 (71%)

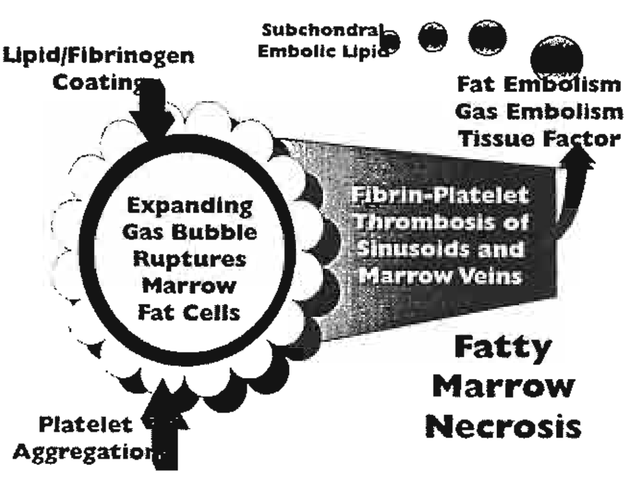


Figure 9. Pathophysiologic concept of rapid decompression of fatty bone marrow. Marrow adipocytes are ruptured by an expanding gas bubble which is coated with lipid, fibrinogen, and aggregating platelets. Embolic lipid and tissue factor are released which further activate intravascular coagulation with fibrin-platelet thrombosis. The result is both local (metadiaphyseal) and systemic subchondral (juxta-articular) osteonecrosis.

had thrombocytopenia. Thrombocytopenia is a feature of fat embolism, alcoholism, disseminated intravascular coagulation, antiphospholipid antibody syndrome, and DCS (18).

Platelet aggregation on bubbles and activation of the clotting mechanism have been described in DCS (5,23). Platelet aggregation, often manifested as a decrease in the circulating platelet count (thrombocytopenia), may also contribute to microvascular obstruction and the subsequent trapping of intravascular gas bubbles. Our pathologic findings of platelet aggregation at the blood-bubble interface in Mexican diver 7 (Table I) are consistent with similar observations of Kawashima et al. (24) in their autopsies of diving fatalities. In experimental DCS in rabbits circulating air bubbles interact with platelets, causing the platelet release reaction, and these activated platelets participate in the formation of thrombi. Postdive thrombocytopenia has also been demonstrated in sheep (25). In goat studies, bubble formation with platelet aggregation and microthrombus formation are considered to initiate subsequent events leading to infarction (26).

Hypofibrinogenemia and Fibrin Thrombosis. Low serum fibrinogen and elevated fibrinopeptide A (FPA) can also be found in association with very early lesions (13). I have observed precollapse lesions in patients with evidence of embolic lipid and 1C, with elevated FPA and arterial interruptions detected by superselective angiography (13). Patients with angiographically documented coronary thrombosis also show a marked increase in FPA. Fibrinopeptides not only induce chemotactic activity for leukocytes but increase vascular permeability, conceivably producing inflammatory marrow edema. Unfortunately, early lesions are rarely discovered and histologically studied. However, there is direct histological evidence in humans of intraosseous fibrin-platelet thromboses within prenecrotic femoral and humeral head segments, both 70 min (5) and 18 h (27) after a known ischemic event, and before complete autolytic reduction of the avascular zone.

Hypofibrinolysis: Sufficient residual fibrin-platelet microhrombi must remain within the intraosseous vasculature for a minimum of 2–6 h, and not be immediately removed by endogenous fibrinolysis (18), to exceed the ischemic threshold and produce ON. Hypofibrinolysis with increased plasmnogen activator inhibitor type 1 (PAI-1) has been found in patients with ON (28,29). Factors which reduce the ability to lyse thrombi should also be measured in ON patients. These include not only PAI-1, but tissue plasminogen activator (TPA) activity and lipoprotein(a) should also be measured. Also a serum lipid panel should be obtained. If the triglycerides and/or cholesterol are elevated, then a lipoprotein electrophoresis can be performed to determine if the diver has a type II or type IV hyperlipoproteinemia, both of which are associated with nontraumatic ON (2).

Intraosseous Hypertension. There is no direct evidence that DON results from the primary embolic or compressive effects of nitrogen bubbles alone on the osseous vasculature. There is also no confirmed evidence that either compression and/or decompression results in any significant changes in intraosseous pressure (IOP). Transient changes in IOP will not be sufficient to cause DON, since it requires a minimum of 2–6 h of significant intraosseous anoxia or severe hypoxia to produce osteocytic necrosis (30).

Increased IOP can be detected in ON, but it probably results from post-ischemic inflammatory marrow edema and perinecrotic intraosseous hemorrhage (27), which probably results from the rupture of necrotic arterioles and capillaries upon reperfusion (2,18). Increased microvascular permeability with edema formation is a reperfusion abnormality (31). Decompression-induced venous bubble formation has been linked to increased neutrophil counts, endothelial cell injury, release of vasoactive eicosanoids (especially thromboxanes and leukotrienes), and increased vascular membrane permeability (32). Also hypoxia induces the release of prostaglandins, especially prostacyclin release, from endothelial cells (33). Adherence of these activated neutrophils and platelets to both the bubble surfaces and to endothelial cells may further contribute to stasis and microvascular injury with leakage, extravasation of plasma, and hemoconcentration.

Moreover, intraosseous hypertension can also be observed in the bone marrow edema syndrome and in several other conditions (30). Therefore, increased IOP now appears to be a very early but nonspecific secondary effect, not a primary etiologic factor in initially causing the osteonecrotic lesion (2,13).

SUMMARY

Decompression sickness and DON occurred in these commercial diving fishermen under conditions of prolonged compressed air exposure (either semi-saturation SSCA dives, or repetitive deep scuba dives), and inadequate, and usually rapid, decompression. Other underlying risk factors, i.e., coexistent alcoholism and obesity, are probably involved in DCS and DON in these two cohorts, particularly if they are associated with hyperlipemia, fatty liver, and abundant fatty marrow.

Intravascular coagulation with fibrin-platelet thrombosis beginning in the vulnerable subchondral microcirculation (capillary-sinusoidal bed) and impaired fibrinolysis, especially with residual venous thrombosis, now appears to be the final common pathway producing nontraumatic ON in several different conditions. Evidence is also accumulating that DON does not result from the embolic or compressive effects of nitrogen bubbles alone on the osseous vasculature, but by secondary injury to the marrow adipose tissue by rapidly expanding nitrogen gas that disrupts adipocytes and releases embolic lipid and tissue factor (Fig. 9). These procoagulants, and other vasoactive agents, most likely cause platelet aggregation with postdive thrombocytopenia, and also trigger-activate local, and probably systemic, intravascular coagulation, intraosseous fibrin thrombosis, and DON.

REFERENCES

3. Jones JP Jr, Behnke AR Jr. Prevention of dysbaric osteonecrosis in compressed-air workers. Clin Orthop 1978; 130:118–128.
4. Jones JP Jr: Osteonecrosis. In: Koopman WJ, ed. Arthritis and allied conditions: a textbook of rheumatology, ed 13. Baltimore, MD: Williams &Wilkins, 1997:1923–1942.
5. Kawashima M. Pathogenesis and prevention of dysbaric osteonecrosis. South Pacific Study 1995; 25:37–46.
6. Yoo MC, Cho YJ, Lee SG. Bony lesions of professional divers in Korea. J Korean Orthop Assoc 1992; 27:331–340.
7. Jones JP Jr, Ramirez S, Doty SB. The pathophysiologic role of fat in dysbaric osteonecrosis. Clin Orthop 1993; 296:256–264.
8. Millington T, Idzepski JB. An epidemic of decompression sickness. Pressure 1994; 23:10–11.
9. Dunford R, Arrazola F, Salbador G, Hampson NB. Computer monitored dive profiles of Moskitia Indian underwater lobster harvesters. Abstract, 21st Annual Meeting, Pacific Chapter UHMS, 1993.
10. Jacobs B: Alcoholism-induced bone necrosis. NY State J Med 1992; 92:334–338.
11. Jones JP Jr: Alcoholism, hypercortisonism, fat embolism and osseous avascular necrosis. In: Zinn WM, ed: Idiopathic ischemic necrosis of the femoral head in adults. Baltimore, MD: University Park Press, 1971:112–132.
12. Halleraker B. Fat embolism and intravascular coagulation. Acta Pathol Microbiol Scand 1970; 78:432–436.
13. Giertsen JC, Sandstad E, Morild I, et al. An explosive decompression accident. Am J Forensic Med Pathol 1988; 9:94–101.
14. Hulman G. The pathogenesis of fat embolism. J Pathol 1995; 176:3–9.
15. Jones JP Jr. Fat embolism and osteonecrosis. Orthop Clin North Am 1985; 16:595–633.
16. Jones JP Jr. Concepts of etiology and early pathogenesis of osteonecrosis In: Schafer M, ed: Instructional course lectures 43. Rosemont, IL: American Academy of Orthopaedic Surgeons, 1994: 499–412.
17. Jones JP Jr, Sakovich L, Anderson CE. Experimentally produced osteonecrosis as a result of fat embolism In: Beckman EL, Elliott DH, Smith EM, eds, Dysbarism-related osteonecrosis. HEW Publ (NIOSH) 75-153. Washington, DC: U.S. Government Printing Office, 1974:117–132.
18. Philp RB: Blood changes associated with decompression and their possible clinical significance. In: Jardine FM, McCallum RI, eds. Engineering and health in compressed air work. London: E and FN Spon, 1994:423–435.
19. Bick RL. Disseminated intravascular coagulation. Clin Lab Med 1992; 14:729–768.
20. Jones JP Jr. Intravascular coagulation and osteonecrosis. Clin Orthop 1992; 277:41–53.
21. Glueck CJ, Crawford A, Roy D, et al. Association of antithrombotic factor deficiencies and hypofibrinolysis with Legg-Perthes disease. J Bone Jt Surg 1996; 78A:3–13.
22. Glueck CJ, Brandt G, Gruppo R, et al. Resistance to activated protein C and Legg-Perthes disease. Clin Orthop 1997; 336:1–14.
23. Boettcher WG, Bonfiglio M, Hamilton HH, et al. Non-traumatic necrosis of the femoral head. Part I. Relation of altered hemostasis to etiology. J Bone Jt Surg 1970; 52A:312–321.
24. Yamamoto T, Sueishi K, Sugioka Y. The pathogenesis of osteonecrosis based on animal models. In: Urbaniak JR, Jones

JP Jr, eds: Osteonecrosis: etiology, diagnosis, and treatment. Rosemont, Il: American Academy of Orthopedic Surgeons, 1997:182–189.
25. Philp RB, Schacham P, Gowdey CW. Involvement of platelets and microthrombi in experimental decompression sickness: Similarities with disseminated intravascular coagulation. Aerosp Med 1971; 42:494–502.
26. Kawashima M, Torisu T, Hayashi K, Kitano M: Pathological review, of osteonecrosis in divers. Clin Orthop 1978; 130:107–117.
27. Atkins CE, Lehner CE, Beck KA, et al. Experimental respiratory decompression sickness in sheep. J Appl Physiol 1988; 65:1163–1171.
28. Palmer AC. Nature and incidence of bubbles in the spinal cord of decompresssed goats. Undersea Hyper Med 1997; 24:193–200.
29. Jones JP Jr. Fat embolism, intravascular coagulation, and osteonecrosis. Clin Orthop 1993; 292:294–308.
30. Glueck CJ, Freiberg R, Tracy T, et al. Thrombophilia and hypofibrinolysis. Pathophysiologies of osteonecrosis. Clin Orthop 1997; 334:43–56.
31. Van Veldhuizen PJ, Neff J, Murphey MD, et al. Decreased fibrinolytic potential in patients with idiopathic avascular necrosis and transient osteoporosis of the hip. Am J Hematol 1993; 44:243–248.
32. Jones JP Jr. Osteonecrosis and bone marrow edema syndrome: Similar etiology but a different pathogenesis. In: Urbaniak JR, Jones JP Jr, eds. Osteonecrosis: etiology, diagnosis, and treatment. American Academy of Orthopaedic Surgeons, 1997:382–388.
33. Seibert AF, Thompson WF, Taylor A, Wilborn WH, Bamard J, Haynes J. Reversal of increased microvascular permeability associated with ischemia-reperfusion: role ofcAMP. J Appl Physiol 1992; 72:389–395.
34. Little TM, Butler BD. Dibutylryl cAMP effects on thromboxane and leukotriene production in decompression-induced lung injury. Undersea Hyper Med 1997; 24:185–191.
35. Nakhostine N, Laurent CE, Nadeau R, Cardinal R, Lamontagne D. Hypoxia-induced release of prostaglandins: mechanisms and sources of production in coronary resistance vessels of the isolated rabbit heart. Can J Physiol Pharmacol 1995; 73:1742–1749.

DISCUSSION

Dr. Aguarda: Generally, it's been said that the hard-hat diver has the hip as the site of pain vs. the scuba diver type of pain, normally shoulder and elbow. In your series of scuba divers it shows predominantly humeral head effects. What about caisson workers and hard-hat divers, have you looked at them just to compare?

Dr. Jones: Yes, they're more likely to get involvement of the distal femur and proximal tibia as compared to the humeral head. Divers more commonly get these humeral head lesions and it's almost to the point that if we see a patient with osteonecrosis that has humeral head lesions we suspect that dysbarism may play a role.

If they don't have humeral head lesions then we think there's a real question whether this is a diving-attributed lesion. So we start narrowing it down and then have to focus on all of these other conditions of which alcoholism, as I mentioned, is a major factor.

Now we know just recently that many of these patients have familial thrombophilia. They have decreased levels of the natural anticoagulants. They're more likely to thrombose the vessels within their marrow with decreased protein C, protein S, and antithrombin 3.

It's been known for 30 years that you do get decreased antithrombin, you get increased fibrin degradation products, decreased platelet counts and so on shortly after diving. So we know there's hypercoagulability and some form of intravascular coagulation, most likely with thrombosis and necrosis.

Mr. Long: (Colorado) Given your studies there and the effects of the thrombosis, do you feel that it would be recommended to offer, say, an aspirin a day for divers to possibly prevent this?

Dr. Jones: Yes, we think that that's important just to minimize or suppress to some degree the platelet aggregation. But most likely, it's going to require, down the line, an agent that is antilipenic, reduces the fats, is a mild anticoagulant, and enhances fibrinolysis.

That's another problem that these patients may have, high blood lipid levels, hyperlipidemia. Patients that have hyperlipidemia also frequently have increased levels of what we call platelet or plasminogen activator inhibitor type one, PAI 1, and that this is an enzyme that (Rotoroots?) Out the thrombi.

If you have low levels, the thrombi stay in for a prolonged period of time. Now, we've seen many cases of non-traumatic necrosis in patients that have increased PAI 1 and decreased levels of all these natural anticoagulants. So anything that we can do to minimize the platelet aggregation is going to be important.

Unidentified Speaker: I have a question about the case who is not a diver, what are the reasons they have necrosis? If he had been a diver, he hasn't been diving. Do you have an idea about the incident among our colleagues or did you find this case by accident?

Dr. Jones: Yes, there have been population studies in the United states showing a prevalence of 0.3% of alcohlics with osteonecrotic lesions, and as high as 3% in former Czechoslovakia. So it's probably somewhere around half a percent to 2% of those with alcoholism will develop osteonecrosis.

Now, it was interesting in your Turkish study which was so fascinating that these patients had normal liver function tests, at least when they were taken. The incidence may have happened several years before. But there are certain biochemical tests that you can use to determine a fairly good idea that a person's an alcoholic because denial is such a primitive response There are five studies:

1. The MCV, mean corpuscular volume. If that's over a 100 and they have macrocytic anemia.
2. If they have hyper-uricemia.
3. If their GGT is elevated.
4. SGOT liver function is elevated.
5. Or if they have hyperlipemia, either a type 2 or type 4 profile.

Those are the Whitehead criteria and ordinarily if you have three or more of those criteria being abnormal, it's a strong possibility that this individual is an alcoholic, whether they deny it or not. So it would be important as a screening measure—relatively inexpensive studies—to make that determination.

Unidentified Speaker: I was fascinated by your diving dinosaurs. Has osteonecrosis ever been described in diving mammals?

Dr. Jones: No, it hasn't. There's been decompression sickness in deep diving turtles that are reptiles, but never in mammals to my knowledge. Their physiological diving parameters are a lot different from these reptiles. So even in the sperm whales that are very deep divers or in the northern elephant seals that are even greater divers, and go down to 5,000 feet in 17 minutes and come back up to the surface without decompression sickness.

At the Ano Nuevo, which is just above Santa Cruz below San Francisco, Dr. Bernie Laboof, a marine biologist, has done time/depth recordings of three northern elephant seals which are the deepest divers that have ever been found, and he has recorded multiple repetitive dives, deep dives short surface intervals, and no evidence of any dysbaric phenomenon.

Unidentified Speaker: You described necrosis of the cerebral column. Is that as big a clinical problem as shoulders and hips?

Dr. Jones: No, it's not, but it's been largely unexamined, and I think we have to start focusing on those lesions because when we do MRIs of the pelvis to examine both hips, it would be very easy to get a few slices through the lumbar vertebra.

Just as a narrow area of necrosis, the vertebral end plate is sufficient to prevent the diffusion of nutrients and oxygen in and out of the nucleus to cause dehydration. So it's an area that's open for further investigation.

Dr. Robinson: (Vancouver) Do you consider that the increased incidence of aseptic necrosis of the hips in tunnel workers is a gravitational effect?

Dr. Jones: You know, that has been one of the biggest problems that we've had. We don't know why we have a higher incidence of these humeral head lesions as you've seen here, and decreased incidence of the femoral head lesions in these divers.

There have been a number of possibilities but no one has ever really investigated these clinical observations. So we do know that gas and fat is coming off pretty much at the same time and that if there's lamination across the aortic sweep that the subclavians would pick it up first.

If you give them recompression therapy, eliminate the gas, you end up with the fat in the humeral heads and triggering intravascular coagulation. That's one of many possibilities. They decompress differently and so on, work habits are different. We just don't have an explanation for that. It's another area of clinical research that should be done.

Unidentified Speaker: Is there a correlation between where the pain hits and the side which subsequently develops dysbaric osteonecrosis.

Dr. Jones: No, I think that was just pointed out very nicely by Dr. Çimşit. But on the other hand, we do see patients that have severe hits in their shoulders that develop lesions—avert early lesions that we can pick up within a month, six weeks by MRI, even sooner on bone scans.

Then with Dr. Lehner's excellent work with the limb-lifting and the lesion at the same place as the hit, which I'm sure he'll mention, here's very good correlation, I think.

Dr. House: (Vancouver) Do you know if after surgical correction of ulcerative colitis, for example, with a colonectomy, whether there's still the tissue factor problem that may make some necrosis susceptible to these individuals.

Dr. Jones: Well, we do know that that's right. In inflammatory bowel disease, both ulcerative colitis and regional enteritis, there is about a 4% incidence of osteonecrosis. It's not only due to the tissue factor release. They have a number of other hemalogical pro-coagulant hypofibrinilytic abnormalities. So those may continue even after you've done a colonectoy.

DIVING PROFILE AND DYSBARIC OSTEONECROSIS

M. Kawashima, H. Tamura, K. Takao, K. Yoshida, M. Kitano, Y. Mano, C. Lehner, and Y. Taya

INTRODUCTION

In our surveys of the Kyushu area, radiological investigation of diving fishermen revealed 467 osteonecrosis cases (51.6%) among 905 divers. This fact seemed to be caused by their prolonged hyperbaric exposure and a rapid decompression. There are many professional diving fishermen in the Kyushu area. The main purpose of their diving is collection of shellfish, abalone, and sea urchins. They are prone to high incidence of dysbaric osteonecrosis and decompression sickness (DCS). The main cause of these injuries seems to be their dive profiles. The clinical study was done on 177 divers, and their dive profiles were investigated.

MATERIALS AND METHODS

This study was based on the clinical review of 177 divers at Kawashima Orthopaedic Hospital from 1981 to 1996. They were all males except one. Their ages ranged from 17 to 64 yr. The average age was 35.9 yr (Table 1). Dysbaric osteonecrosis was seen in 50 cases (28.2%) and was most frequently found in upper humerus, and upper femur (Table 2).

Divers with a diving experience of over 5 yr were highly affected by dysbaric osteonecrosis (Table 3). There was a higher incidence of dysbaric osteonecrosis in the divers who dived over 20 m (Table 4). In the group of men with dysbaric osteonecrosis, 60.0% were known to have been treated for bends (Table 5).

Each diver conducted their own dives according to their own experience. Dive profiles of these divers were investigated in Ariake Sea, Kunisaki, Karatsu, and Inland Sea. Dive profiles were recorded by oral interview or dive-recording computer.

RESULTS

Most of these divers did not use any standard dive table, such as the US Navy dive schedule. Each diver conducted his own dives according to his own experience. Divers in Karatsu used scuba. The characteristic dive profiles involved repetitive diving. We call it Karatsu Type. These types were seen in 10 cases (20.0%) among 50 cases.

Case H.T. was treated for bends and chokes. Fig. 1 shows his dive profile. A radiograph illustrated a dysbaric osteonecrosis at the left femoral head 8 years after the first treatment (Fig. 2). Magnetic resonance imaging (MRI) illustrated the dysbaric osteonecrosis at the left femoral head (Fig. 3).

Case S.Y. was treated for bends. Figure 4 shows his dive profile. A radiograph illustrated a dysbaric osteonecrosis at the right femoral head 5 yr after the first treatment (Fig. 5). MRI illustrated the dysbaric osteonecrosis at the right femoral head (Fig. 6). The diver at Oura used helmet or hooka. The characteristic of the dive profile at Oura is long exposure in the bottom of the sea. We call it Oura type. These types were seen in 40 cases (80.0%) among 50 cases.

Case K.K. was treated for osteonecrosis. Figure 7 shows his dive profile. MRI illustrated the dysbaric osteonecrosis at the right humerus (Fig. 8).

Case O.K. was treated for osteonecrosis (Fig. 9). Fig. 10 shows his dive profile. MRI illustrated the dysbaric osteonecrosis at the right femoral head (Fig. 11). Pre-operative dynamic MRI showed the remarkable decrease of blood flow in the juxta-articular areas of the right femoral head (Fig. 12). Postoperative dynamic MRI showed the remarkable increase of the blood flow in the juxta-articular area of the right femoral head (Fig. 13).

Divers in Ohura and Kunisaki used helmet and are known for the long bottom times in their dives and high incidence of dysbaric osteonecrosis (1–3).

Case Y.T. was treated for osteonecrosis (Fig. 14). A radiograph showed a dysbaric osteonecrosis at the right femoral head. Rotational trochanteric osteotomy was don. A radiograph showed osteoarthritis 9 yr after operation. Figure 15 shows his dive profile. Characteristic of this dive profile was long exposure and surface decompression.

Case F.Y. was treated for osteonecrosis. Figure 16 shows his diving profile. A radiograph showed a osteonecrosis at the right femoral head. MRI illustrated osteonecrosis. A dynamic MRI showed the low blood flow of the juxta-articular area.

Case T.K. was treated for osteonecrosis. A radiograph shows osteonecrosis at the right femoral head. Bone scanning illustrated high uptake of Tc99m at the right femoral head. MRI illustrated osteonecrosis. Rotational trochanteric osteotomy was carried out. Figure 17 shows his dive profile.

Case K.T. shows the typical dive profile in Inland Sea (Fig. 18). He was from Oura. Figure 19 shows the typical dive profile at Kunisaki.

Their characteristic dive profile is long exposure at the bottom of the sea and surface decompression. He was from Oura. Lehner (4) succeeded in producing osteonecrosis in sheep according to modified Ohura diver's dive profile. Their experiment showed the possibility of prevention of osteonecrosis.

CONCLUSIONS

One hundred and seventy-seven diving fishermen with DCS were treated at Kawashima Orthopaedic Hospital and records of the diver patients were analyzed. Fifty cases showed osteonecrosis (28.2%). The high incidence of dysbaric osteonecrosis and DCS was caused by their unconventional, risky dive profiles. Long bottom times and repetitive dive are associated with these diving injuries.

REFERENCES

1. Kawashima M. South Pacific Study 1993; 13:173–182.
2. Kawashima M, et al.. Histopathology of the early stage of osteonecrosis in divers. Undersea Biomed Res 1977; 4:409–417.
3. Kawashima M, et al. Pathological review of osteonecrosis in divers. Clin Orthop Related Res 1978; 130:107–117.
4. Lehner CE, et al. Dive profiles control the manifestations of decompression injury in diving. Undersea Biomed Res 1995; 22:36–37.
5. Lehner CE. et al. Dive profiles control the risk of dysbaric osteonecrosis: Validation in Japanese diving fishermen and sheep. 1991 Proceedings of the 11th meeting of the United States-Japan cooperative program in natural resources, 1995:85–101.

DISCUSSION

Mr. Dawson: The advantage of doing surface decompression using oxygen in these divers ....

Dr. Kawashima: In Japan, it is prohibited to use oxygen by the diver.

Mr. Dawson: Do you agree that surface decompression in oxygen is less likely to cause osteonecrosis and decompression sickness?

Dr. Kawashima: Yes, I recommend the use of oxygen in surface decompression, it is useful. But they smoke in the chamber. Big problem. So I could not recommend that.

Mr. Arnold: (Florida) I wonder what you can say regarding whether there is a difference in the incidence and types of decompression sickness between the hard-hat divers and the scuba divers?

Dr. Kawashima: Yes, in the in the scuba divers, most of the cases were limb bends, but in helmet divers type II DCS is often seen. So the spinal cord type of DCS is often seen in many of the helmet divers.

Unidentified Speaker: You mentioned that in 5 years, you saw several remaining cases of the osteonecrosis. What would you say was the earliest incidence of osteonecrosis in the divers that you studied?

Dr. Kawashima: Early incidence?

Unidentified Speaker: Yes.

Dr. Kawashima: The early cases took 1 year -- 1 year after the first onset of bends. Most of the cases took 2 or 3 years or even 5 years because it needs time to develop

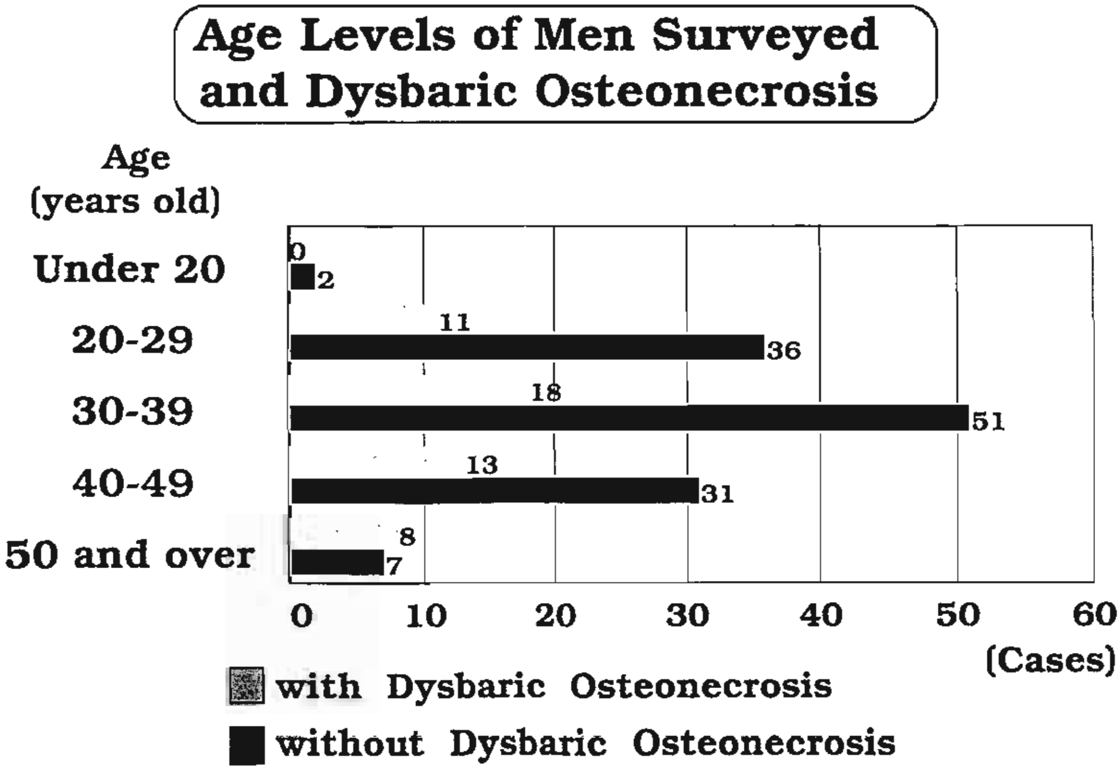
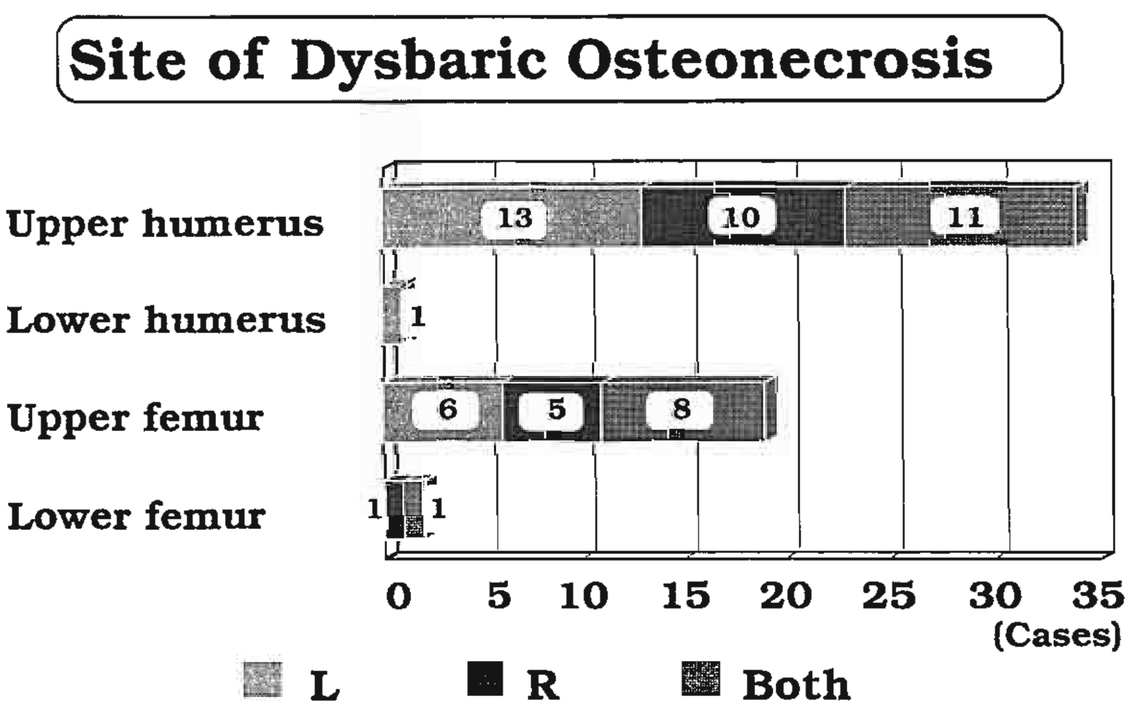


Table 1



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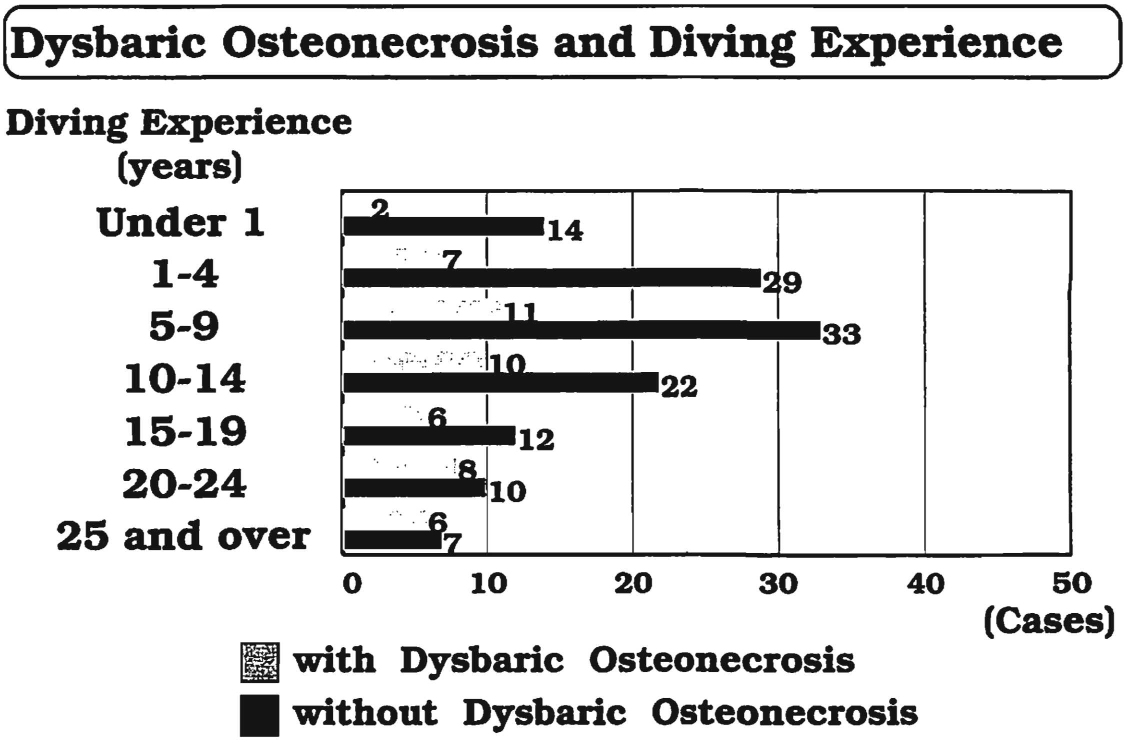

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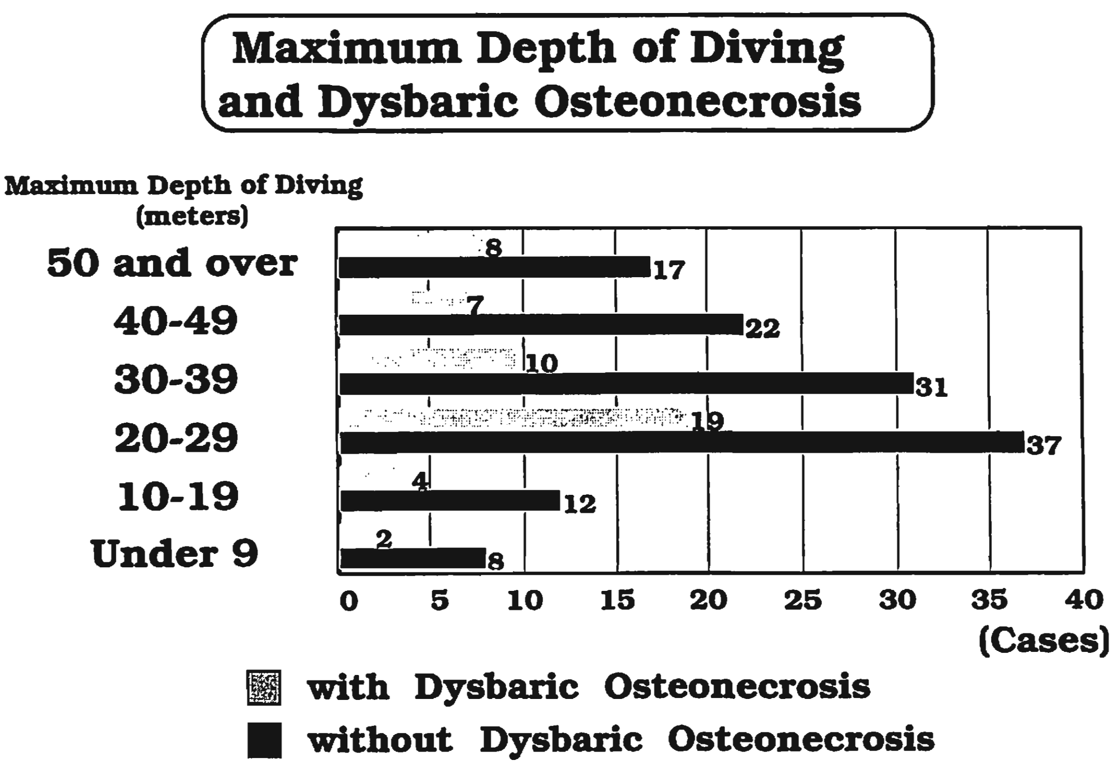


Table 4

Bends and Dysbaric Osteonecrosis

	with Dysbaric Osteonecrosis	without Dysbaric Osteonecrosis	total
with previous bends experience	30 (60.0%)	83 (65.4%)	113 (63.8%)
without previous bends experience	20 (40.0%)	44 (34.6%)	64 (36.2%)
total	50 (100.0%)	127 (100.0%)	177 (100.0%)

Table 5

Diving Profile

Case H. T. Age 36 Scuba

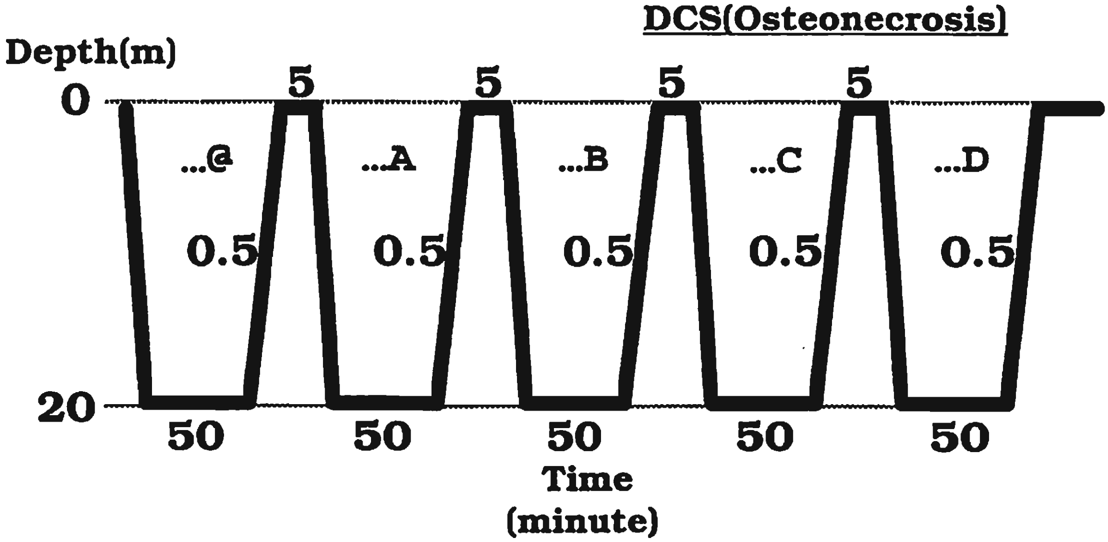


Fig. 1

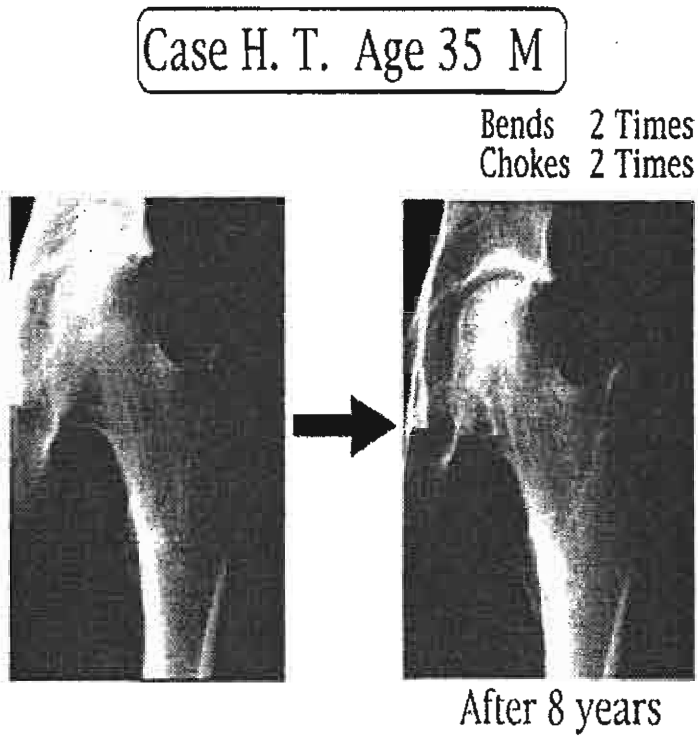

Case H. T. Age 35 M
Bends 2 Times
Chokes 2 Times
After 8 years

Fig. 2

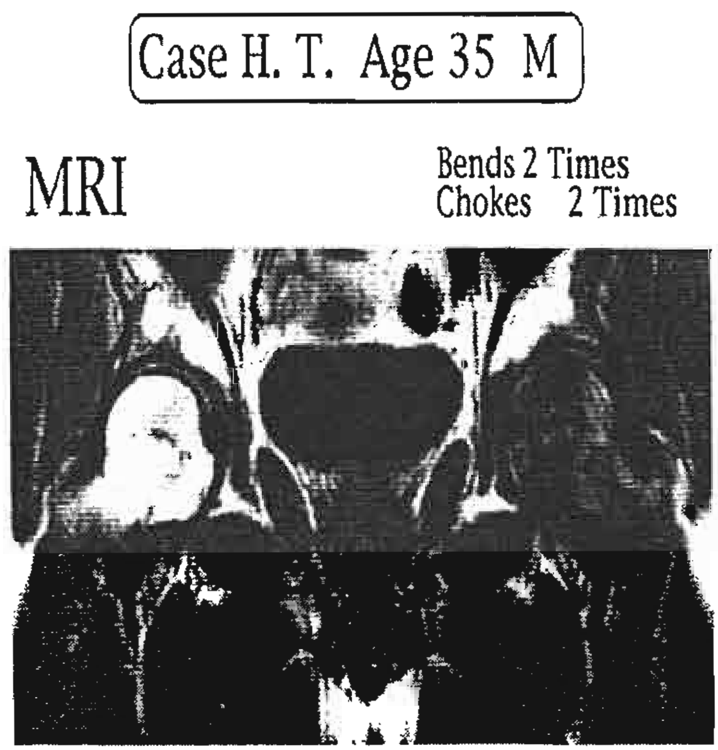

Case H. T. Age 35 M
MRI
Bends 2 Times
Chokes 2 Times

Fig. 3

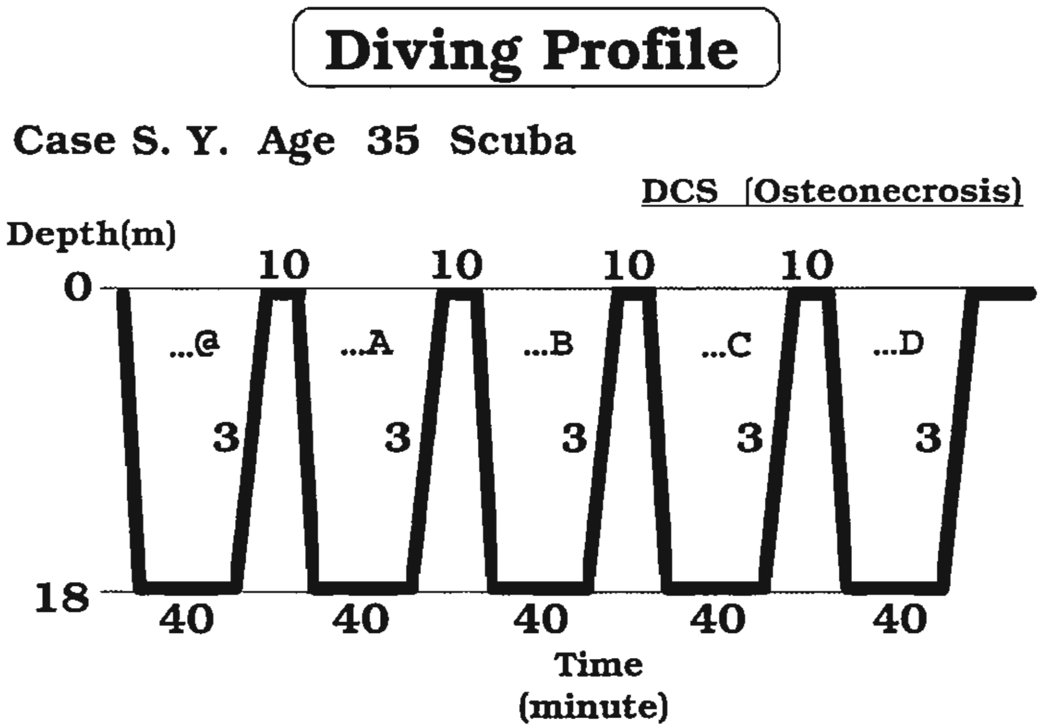

Diving Profile
Case S. Y. Age 35 Scuba
DCS (Osteonecrosis)
Depth(m)
0
18
10
10
10
10
...@
...A
...B
...C
...D
3
3
3
3
3
40
40
40
40
40
Time
(minute)

Fig. 4

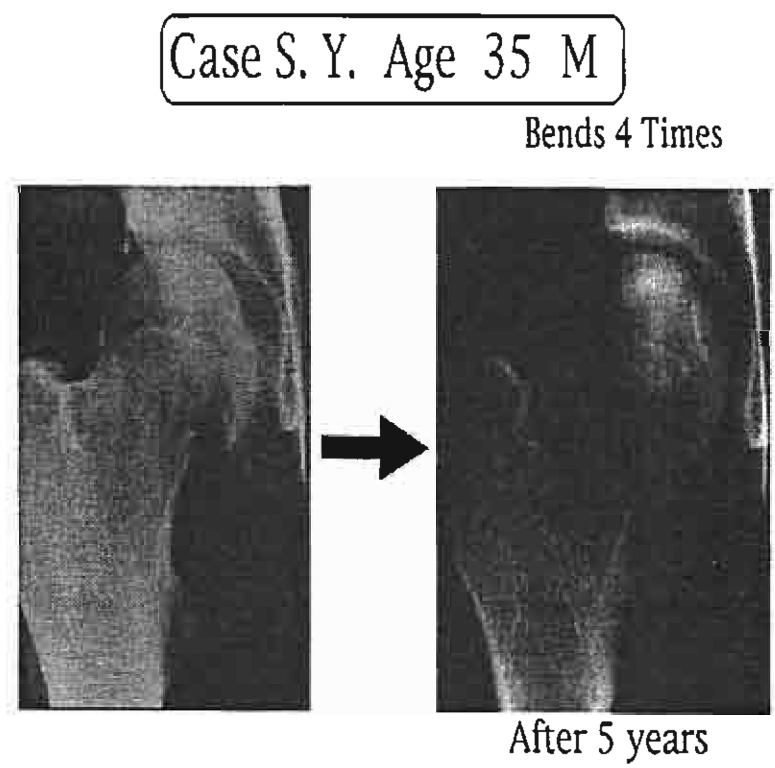

Case S. Y. Age 35 M
Bends 4 Times
After 5 years

Fig. 5

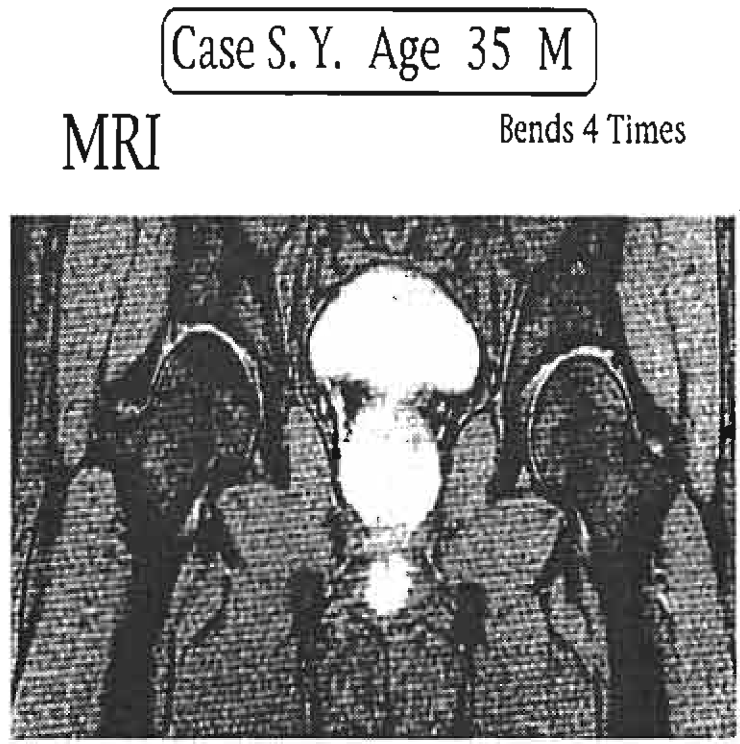

Case S. Y. Age 35 M
MRI
Bends 4 Times

Fig. 6

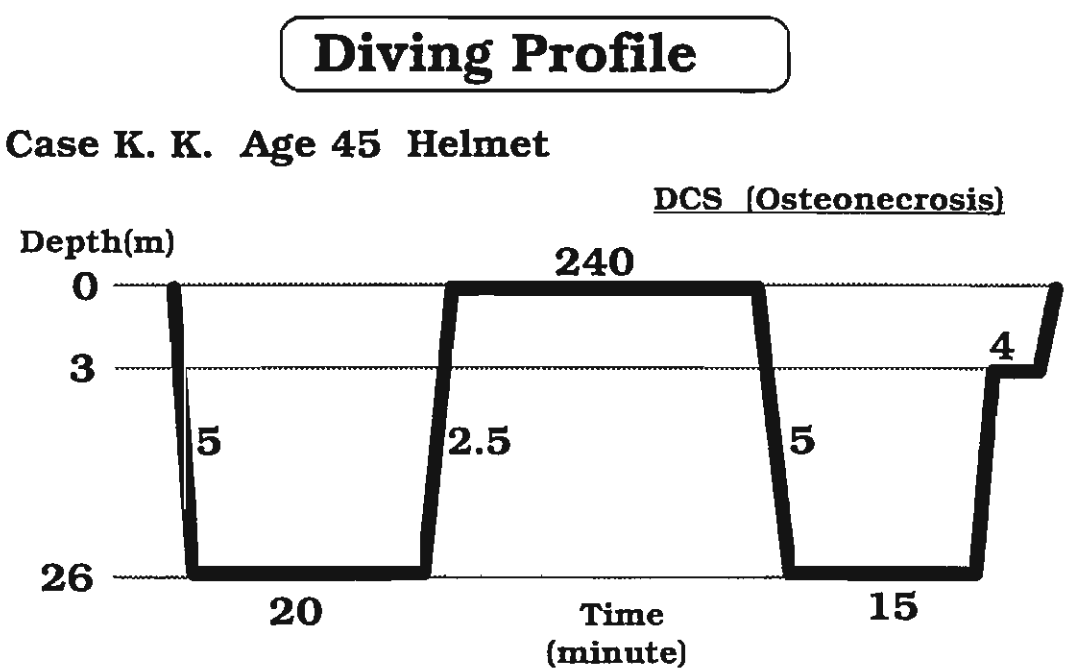

Diving Profile
Case K. K. Age 45 Helmet
DCS (Osteonecrosis)
Depth(m)
0
3
26
240
5
2.5
5
4
20
15
Time
(minute)

Fig. 7

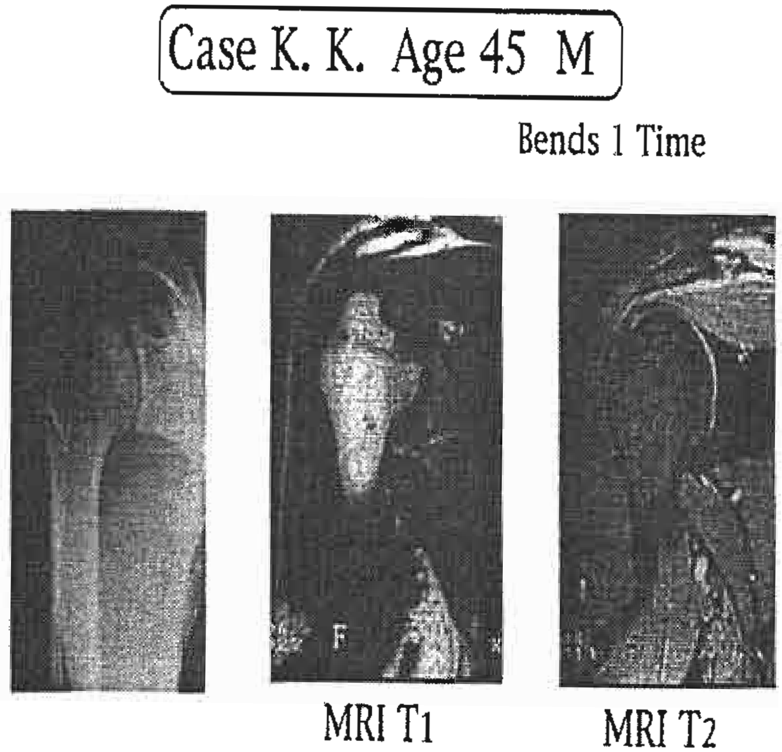

Case K. K. Age 45 M
Bends 1 Time
F
MRI T1
MRI T2

Fig. 8

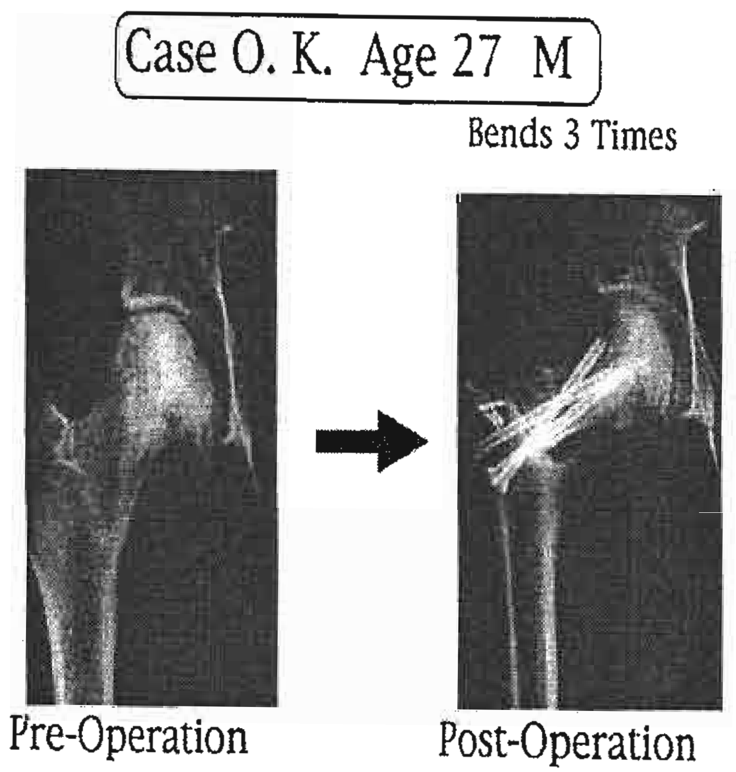

Case O. K. Age 27 M
Bends 3 Times
Pre-Operation
Post-Operation

Fig. 9

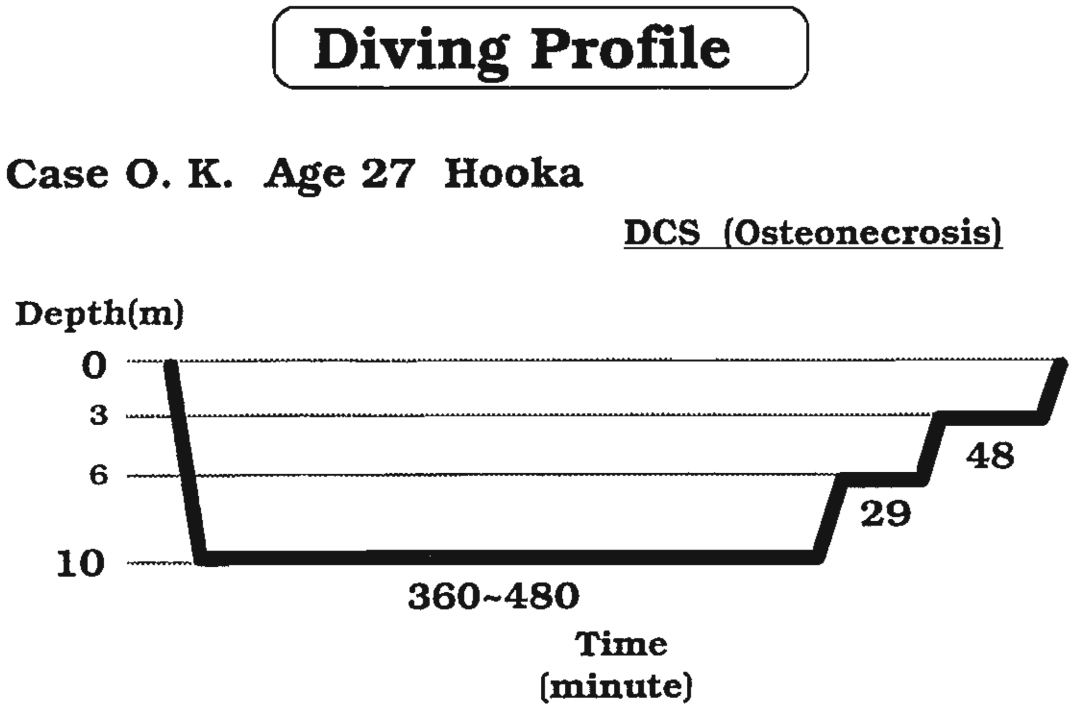

Diving Profile
Case O. K. Age 27 Hooka
DCS (Osteonecrosis)
Depth(m)
0
3
6
10
48
29
360~480
Time
(minute)

Fig. 10

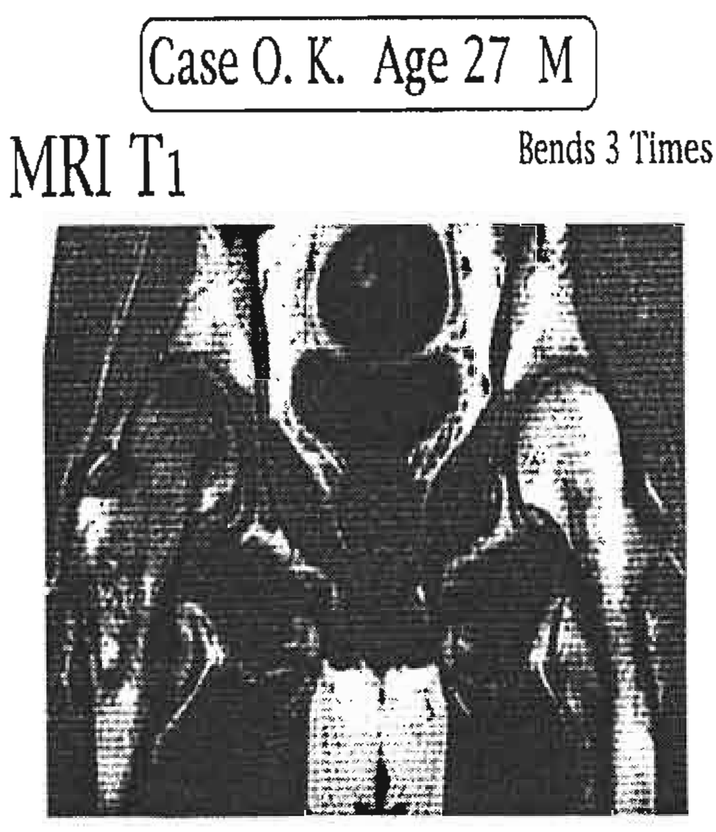

Case O. K. Age 27 M
MRI T1
Bends 3 Times

Fig. 11

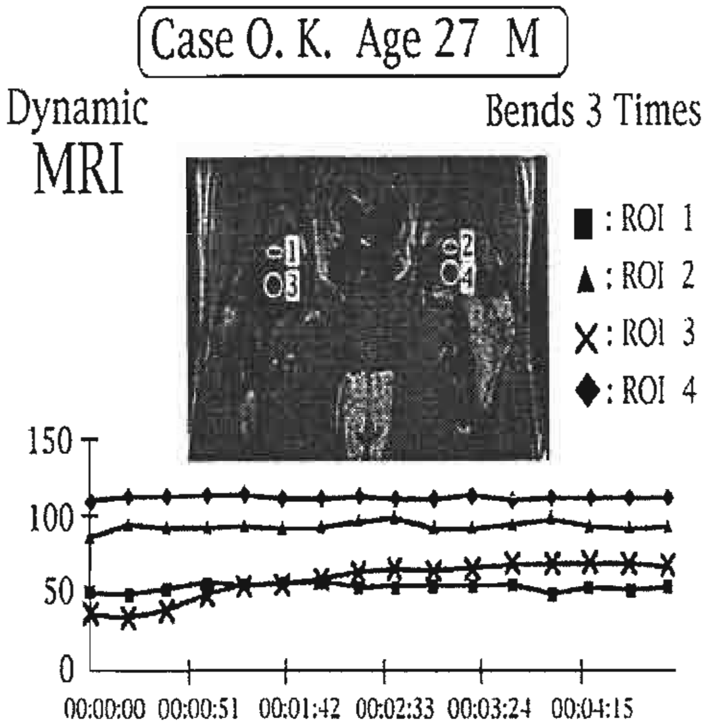

Case O. K. Age 27 M
Dynamic
MRI
Bends 3 Times
: ROI 1
: ROI 2
: ROI 3
: ROI 4
150
100
50
0
00:00:00 00:00:51 00:01:42 00:02:33 00:03:24 00:04:15

Fig. 12

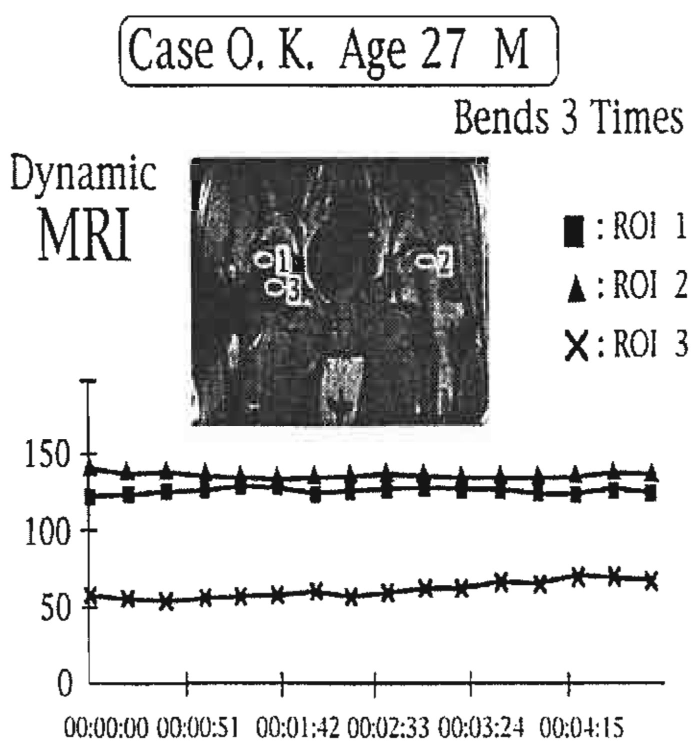

Case O. K. Age 27 M
Bends 3 Times
Dynamic
MRI
: ROI 1
: ROI 2
: ROI 3
150
100
50
0
00:00:00 00:00:51 00:01:42 00:02:33 00:03:24 00:04:15

Fig. 13

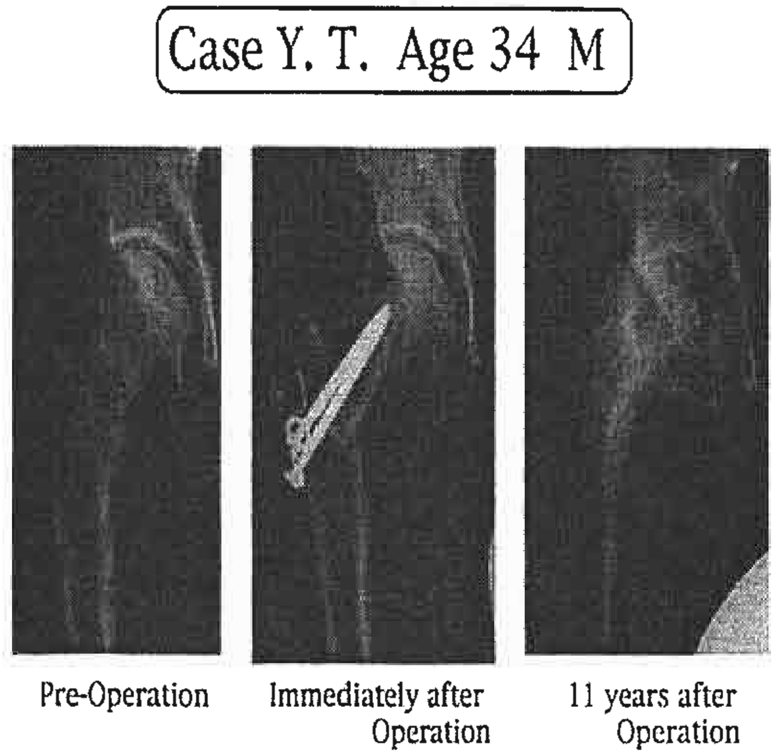

Case Y. T. Age 34 M
Pre-Operation
Immediately after Operation
11 years after Operation

Fig. 14

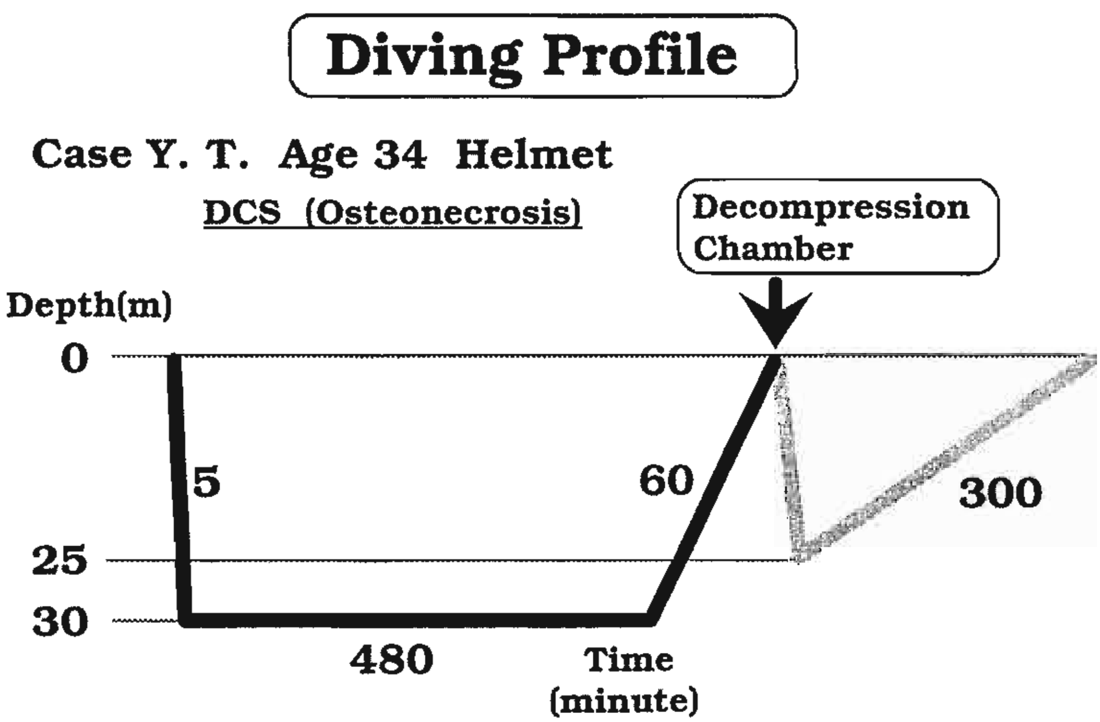

Diving Profile
Case Y. T. Age 34 Helmet
DCS (Osteonecrosis)
Decompression Chamber
Depth(m)
0
25
30
5
60
300
480
Time (minute)

Fig. 15

Diving Profile

Case F. Y. Age 32 Helmet

DCS(Osteonecrosis)

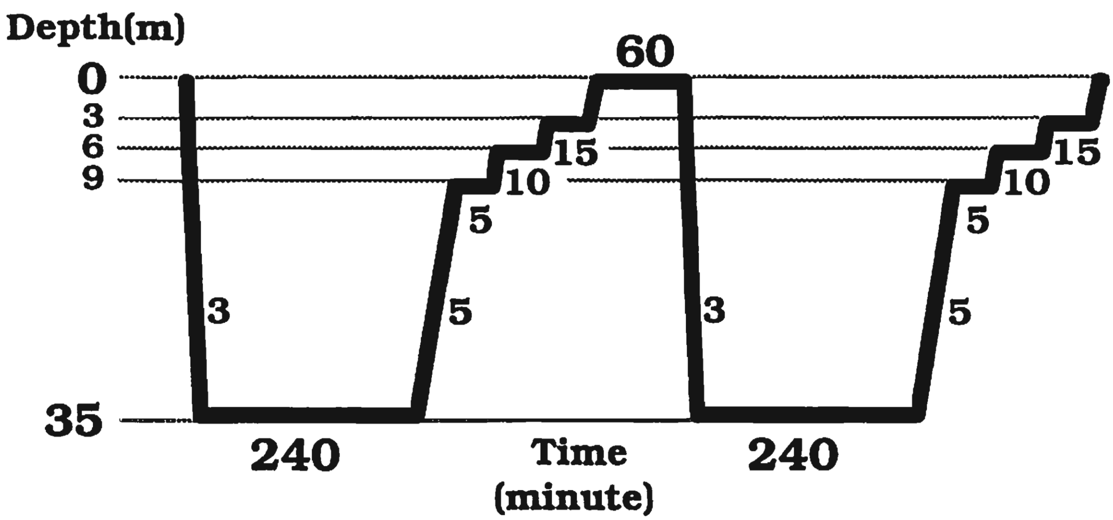


Fig. 16

Diving Profile

Case T.K. Age 36 Helmet

DCS(Osteonecrosis)

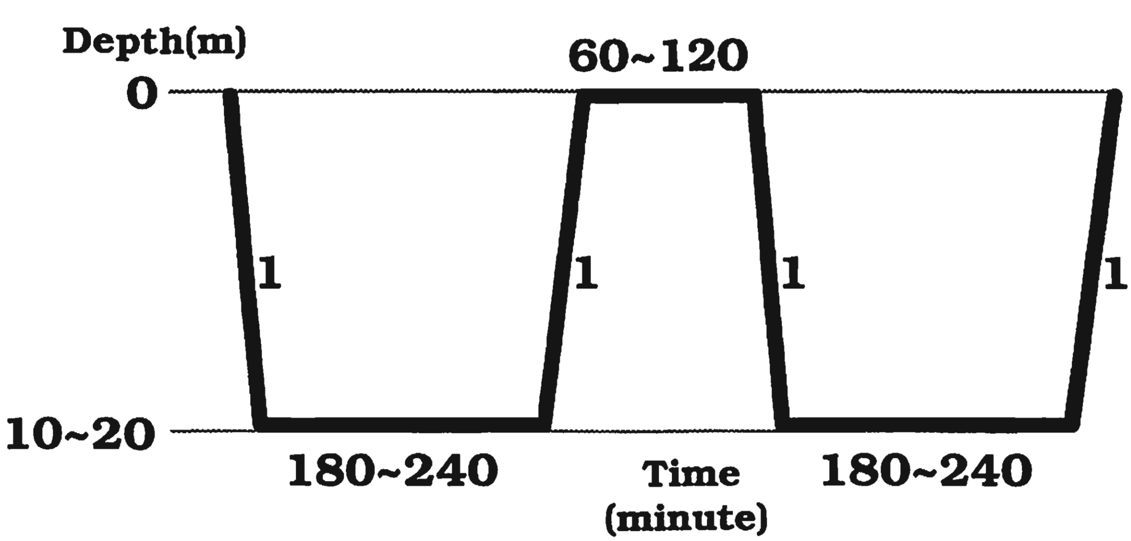


Fig. 17

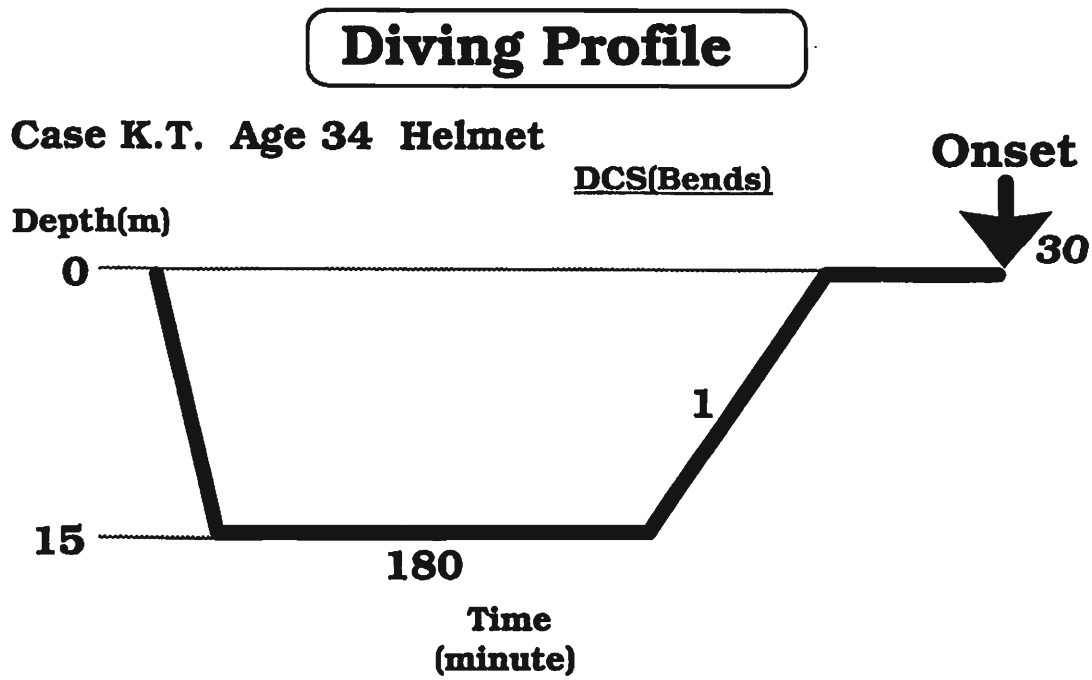

Diving Profile
Case K.T. Age 34 Helmet
DCS(Bends)
Onset
Depth(m)
0
15
30
1
180
Time
(minute)

Fig. 18

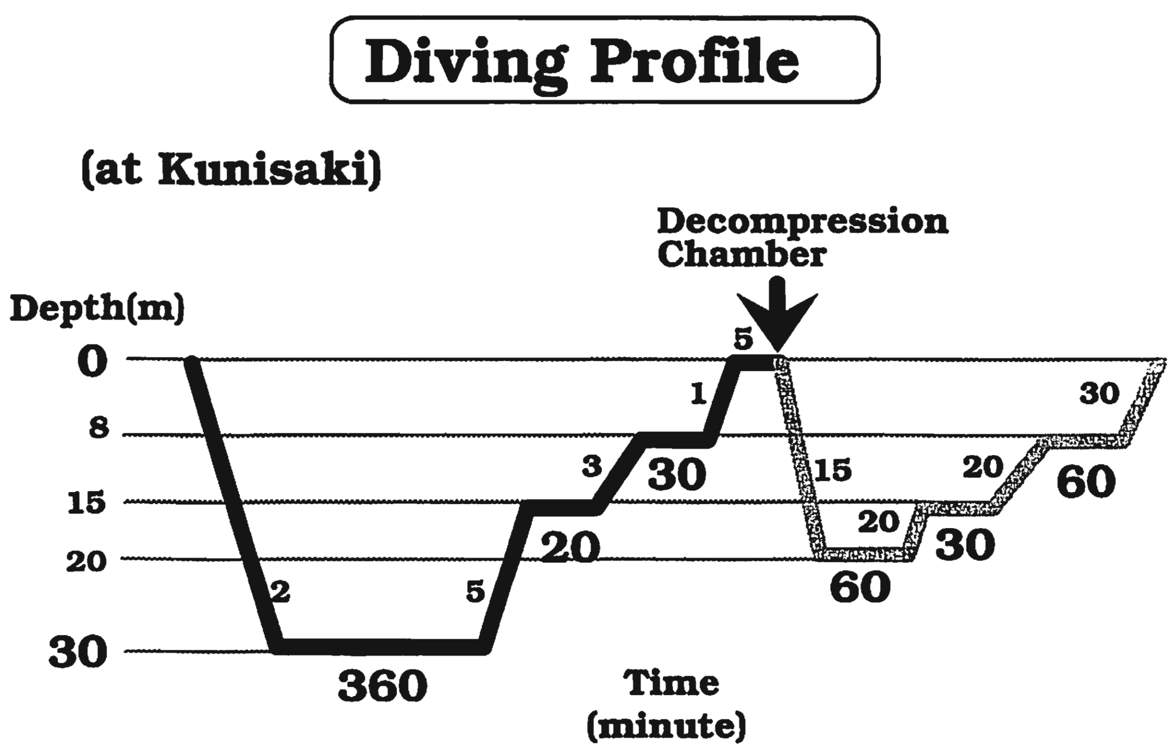

Diving Profile
(at Kunisaki)
Decompression
Chamber
Depth(m)
0
8
15
20
30
2
360
5
20
3
30
1
5
15
60
20
30
20
60
30
Time
(minute)

Fig. 19

PROPOSAL OF PROCEDURES FOR PREVENTION OF DYSBARIC OSTEONECROSIS IN DIVERS: CONCERNING THE PATHOGENESIS OF THIS DISEASE

Motoo Kitano

First slide, please. Ladies and gentlemen, it is my great pleasure to make a presentation to this workshop. The aim of this presentation is to mention the pathomorphogenesis of dysbaric osteonecrosis (DON) and then discuss preventive procedures for the onset of DON regarding etiologic factors.

Dysbaric osteonecrosis is undoubtedly preceded by bone marrow necrosis occurring during the early, initial phase of decompression sickness (DCS). Thus, to understand the development and progression of this bone disease, the most important thing is to understand the etiology of bone marrow necrosis. Today I will talk to you about pathomorphogenesis of bone marrow necrosis just after hyperbaric exposure.

Dysbaric Osteonecrosis = Bone Marrow Necrosis

Dysbaric osteonecrosis is undoubtedly preceded by bone marrow necrosis occurring during the early, initial phase of decompression sickness. Thus, to understand the development and progression of this bone disease, the most important thing is to understand the pathomorphogenesis of bone marrow necrosis.

Table 1 : Autopsy Cases of Acute DCS

	Age	Sex	Profession	Duration from Onset of DCS to Death
Case 1	38 yrs	Male	Helmet diver	0 (died soon after the surfacing)
Case 2	28 yrs	Male	Scuba diver	ca. 6 hours
Case 3	36 yrs	Male	Scuba diver	3 days
Case 4	20 yrs	Male	Scuba diver	15 days

Table 2 : Animals Exposed to a Compression-Decompression Procedure

Animals No	Sex	Body weight	Pressure (ATA)	Compression time	Decompression time
Domestic rabbits 6	Male	3.5–4 kg	5	1 hour	5 minutes
Domestic rabbits 6	Male	3.5–4 kg	5	6 hours	5 minutes
Wistar rats 50	Male	330–450 g	5	3 hours	5 minutes
Sheep*, crossbred 7	Female	69.5–109 kg	2.8–3.2	3 hours	2 minutes

*Lehner and his co-workers has reported (9)

Slide 2: This study is based on autopsy findings of four Japanese diver victims (Table 1) and histopathologic findings of experimental animals [12 male domestic rabbits, 50 male Wistar rats, and 7 crossbred female sheep (Table 2).

1) Activation of coagulability of circulating blood after compression - decompression procedure, i.e., hyperbaric exposure.

2) Inury associated with increase of tissue pressure inside a bone, i.e., 'bone compartment syndrome', after hyperbaric exposure.

Slide 3: For tissue damage in DCS, particularly in DON, two pathophysiologic aspects are very important. One is activation of coagulability of circulating blood after compression–decompression procedure, that is hyperbaric exposure, and the other is tissue injury due to increase of tissue pressure inside a bone, namely, bone compartment, after hyperbaric exposure.

Our recent pathological studies have strongly suggested that thrombus formation can occur in the sinusoidal blood vessles of the bone marrow tissue.

The fact that an extensive necrosis of the bone marrow tissue is often observed with a close association with thrombosed blood vessels impels us to re-evaluate the role of thrombosis in the onset of dysbaric osteonecrosis.

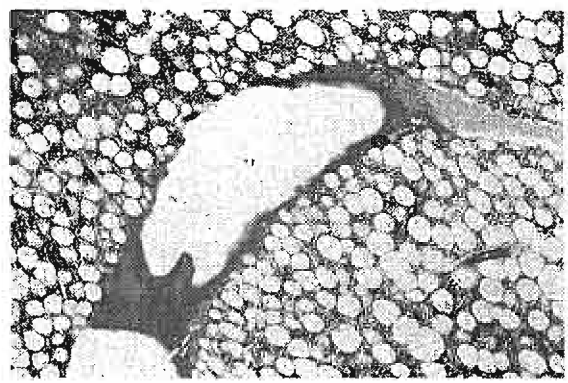
Slide 4: Our recent pathologic studies have suggested strongly that thrombus formation can occur in the sinusoidal blood vessels of the bone marrow tissue. The fact that an extensive necrosis of the bone marrow tissue is often observed with a close association with blood vessels with thrombi impels us to re-evaluate a role of thrombosis in the onset of DON osteonecrosis.

Slide 5: This shows a vigorous dilatation of sinusoidal vessels in the bone marrow of a rabbit femur after a hyperbaric exposure. You can see multiple gas bubbles entrapped by a thrombus. A very important point to discuss here is that the activity of blood clotting system increases during and after hyperbaric exposure. Voluminous literature indicate that intravascular gas bubbles that are created by decompression fully contribute to the formation of thrombi through increase of adhesion and aggregation of blood platelets. When the blood comes into contact with nitrogen gas bubbles, at the interfaces of blood and gas bubbles, the changes of fibrinogen to fibrin appear. Accordingly, the pathogenesis of the ill effects following decompression cannot be ascribed solely to the space occupying and surface tension effects of the gas bubbles altering normal blood flow through the vasculature.

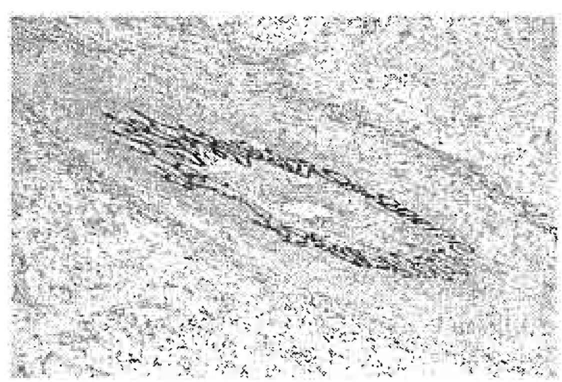
Sinusoidal Thrombosis

Circulatory disturbance of venous side due to sinusoidal thrombosis directly influences to the creation of bone marrow necrosis , or , at least , very importantly contributes to the retardation of descent of intraosseous bone marrow tissue pressure.

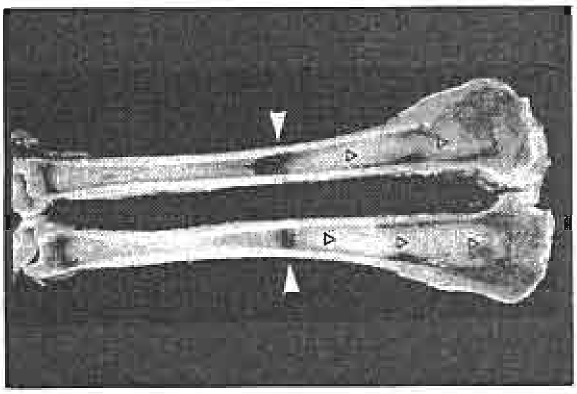
Slide 6: Formerly, we found that intravascular blood coagulation was present only in the bone marrow sinusoids, that is venous vessels. The reasons why thrombi prefer to be formed within the sinusoids are explained by 1) the blood pressure of sinusoids is very low, 2) nitrogen gas bubbles created in the tissue enter the blood stream via sinusoidal walls together with tissue disintegration products, and 3) speed of the blood stream is very slow in the sinusoids.



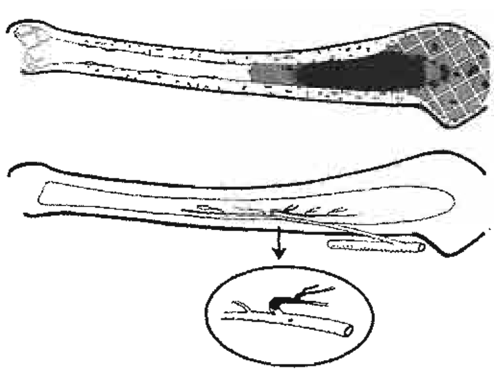
Slide 7: So we considered circulatory disturbance of venous side directly influenced to the creation of bone marrow necrosis, or, at least, very importantly contributed to the retardation of descent of intraosseous bone marrow tissue pressure due to stoppage of venous flow.



Slide 8: But most recently, we have found thrombus formation also in the arterial branches. This is a micro-photo of the bone marrow of right tibia in a sheep that has been treated by a hyperbaric exposure, 8 wk after the autopsy. You can see an old thrombus is present in a branch of the intraosseous nutrient artery.



Slide 9: I will explain the localization of this arterial thrombus. This is the cut surface of diseased tibia of this case. The dark middle area of the shaft bone marrow, indicated by arrowheads, is composed of a fibrous granulation tissue. In this dark area, above-mentioned thrombosed artery is situated. Note the upper half of the shaft, an extensive area of bone marrow indicated by triangles, where necrosis is observed.

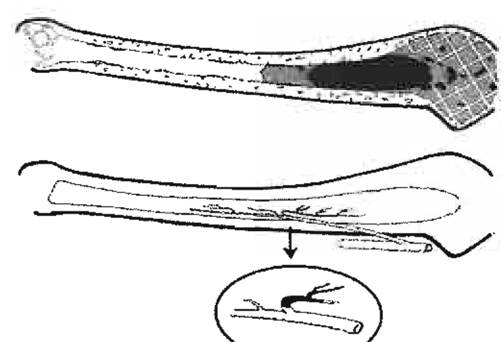


Slide 10: From the anatomical viewpoint, the area of this necrotic bone marrow is supplied by the thrombosed arteries which belong to the ascending branches of the main intraosseous nutrient artery. This finding suggests strongly that arterial thrombosis directly contributes to the creation of bone marrow necrosis.

Tissue pressure in bone marrow cannot be easily dissipated after hyperbaric exposure because: 1) it is a fat cell rich tissue; 2) it is located in a compartment encased by a non-compliant rigid bone; and 3) stoppage of venous flow due to multiple sinusoidal thrombosis.

As a result of the marked retardation in the decrease of bone marrow pressure, this bone marrow pressure often exceeds the blood perfusion pressure.

Slide 11: As already mentioned, tissue pressure in bone marrow cannot be easily dissipated after hyperbaric exposure because: 1) it is a fat cell rich tissue; 2) it is located in a compartment encased by a non-compliant rigid bone; and 3) multiple sinusoidal thrombi are associated with venous flow stoppage. As a result of a marked retardation in the decrease of bone marrow pressure, this bone marrow pressure often exceeds the blood perfusion pressure.



Slide 12: Thus, increased tissue pressure after hyperbaric exposure results in a collapse of the blood vasculature, including the arterioles and smaller arteries and it has also a great responsibility for the pathogenesis of thrombus formation in the arterial branches. If the peripheral branches of the nutrient artery are collapsed, marked circulatory disturbances occur also in the proximal portions of the nutrient artery. Circulatory disturbances include blood stasis, and this blood stasis might have contributed to the thrombus formation within the proximal ascending branches of the main nutrient artery in this sheep case.

Mechanisms for Bone Marrow Damage after Hyperbaric Exposure

Complicated cascade relating to
(1) increase of activity of blood clotting system
(2) elevation of the intraosseous tissue pressure

My conclusion is that, whatever the triggers are, thrombosis seems most importantly contributing to the development of 'dysbaric osteonecrosis'.

Slide 13: Regarding the mechanisms for bone marrow damage after hyperbaric exposures, it should be noted that bone marrow damage is a complicated cascade relating to the increase of activity of the blood clotting system and the elevation of the intraosseous tissue pressure. Conclusively, whatever the triggers are, thrombosis seems most importantly relate to the development of DON. In the case of thrombosis, although the tissue pressure sufficiently decreases to the level of normal perfusion pressure, recovery of blood circulation will never occur, because thrombi remain. Of course, it should be remembered that other factors, such as endothelial damage, angiospasm, release of inflammatory cytokines, etc., may easily modify the features of this bone disease.

Now we propose that therapy to prevent or block the development of 'dysbaric osteonecrosis' should involve administering of anticoagulants and supply of fluid soonafter the onset of clinical signs of limb bends.
This therapy will be more effective if a simultaneous recompression treatment will be applied.

Slide 14: Now we propose that therapy to prevent or block the development of DON should involve administration of anticoagulants and supply of fluid soon after the onset of clinical signs of limb bends. The symptom of limb bends is widely accepted as one of the definite clinical signs of the occurrence of DON. This therapy will be more effective if a simultaneous recompression treatment is applied. To support this proposal, sufficiently designed experimental surveys are still needed.

MAINE SCALLOP DIVERS: DECOMPRESSION SICKNESS AND THE PREVALENCE OF DYSBARIC OSTEONECROSIS

Charles E. Lehner and Albert A. Pollard

SUMMARY

Maine scallop divers, conducting prolonged, repetitive dives with scuba, gather shellfish, often at depths exceeding 30 m, during the coldest months of the year (November to mid-April). Divers generally have some knowledge of dive tables, but the high number of repetitive dives needed to enhance the daily scallop harvest has encouraged the practice of impromptu, multiple bounce dives to significant depths. Dive tables are disregarded. Many of these divers experience joint pains after decompression. Divers frequently experience persistent limb bends pain and presumably risk dysbaric osteonecrosis, a chronic injury associated with disabling joint collapse and secondary osteoarthritis in the long bones. Case records and questionnaires indicate that persistent cases of limb bends are often tolerated by Maine scallop divers without undergoing recompression treatment. Individuals with a history of persistent limb bends are also those who have developed active dysbaric osteonecrosis lesions in their long bones, based on scintigraphic screening with ^{99m}Tc methylene diphosphonate. Limb bends, especially in recent cases with persistent clinical manifestations, are associated with underlying, active dysbaric osteonecrosis. Prompt recompression treatment can alleviate the discomfort of limb bends and prevent the later development of dysbaric osteonecrosis, based on large-animal studies of decompressed sheep at the University of Wisconsin-Madison and on anecdotal reports of recompressed humans with limb bends. These findings suggest the efficacy of prompt recompression treatment of limb bends to alleviate the acute discomfort of limb bends and to prevent injury from the development of dysbaric osteonecrosis in the affected diver's long bones.

DISCUSSION

Mr. Dunford: You didn't say so but it sounds to me like you're describing pathological limb bend pain.

Dr. Lehner: Well, that's one point that I'm glad you brought up because we think that there is a positive association between limb bends pain with elevated intramedullary pressure and the induction of dysbaric osteonecrosis. And elevated intramedullary pressure is also observed clinically in non-diving osteoarthritis and osteonecrosis patients.

A group of Scandinavian orthopedists has demonstrated elevated intramedullary pressure being associated with the clinical presentation of night pain in patients with early osteonecrosis. So I think that limb bends is associated often times with elevated intramedullary pressure which is a pathogenic factor in dysbaric osteonecrosis.

Mr. Dunford: Now, you described the difference between persistent and transient pain. Perhaps there are different mechanisms. Define transient, please.

Dr. Lehner: Well, in transient, we're talking about a few hours or several hours, then it's gone. Whereas in the cases where we had dysbaric osteonecrosis that did not undergo recompression treatment, there was a persistence of clinical signs, although mild and sporadic for several days, sometimes.

I don't know if you've seen this clinically or heard about this clinically but our questionnaire that Dr. Pollard and Chris Leroux, his chamber technician, have circulated among Maine scallop divers, had strong indications for persistent limb bends pain that these people were tolerating.

Mr. Dunford: We see that in recreational divers.

Dr. Lehner: The underlying pathology may be dysbaric osteonecrosis in situations like that. So if a scuba diver is a recreational scuba diver who's doing frequent, repetitive diving and is tolerating unfortunately elevated intramedullary pressure by virtue of the fact it's moderate limb bends pain, he or she may be inducing conditions setting up dysbaric osteonecrosis later and degenerative osteoarthritis which could be totally disabling in the individual's affected limb.

Dr. Mitchell: Thanks, Dr. Lehner, I think that your description of early recompression [to prevent dysbaric osteonecrosis] is very compelling. I was just wondering—I may have missed it—but why did you choose a table, I think it was Table 1A, as opposed to a Table 6, which is the more commonly used treatment in divers?

Dr. Lehner: We don't have hyperbaric O_2 access, one. Secondly, it was a table that we had modified [with longer shallow stops] and we found that when we used it for the sheep, after really lengthy exposures, it was successful in that we were not seeing limb bends signs reoccurring after the decompression when the animals were brought back to atmospheric pressure. That's how we did it experimentally. But you know, certainly the use of oxygen, in my opinion, is efficacious and can reduce the time spent in the chamber.

Dr. Mitchell: Obviously, the concern might be that the data could conceivably change if oxygen was used. It might change the time delay threshold, for example.

Dr. Lehner: Right. Importantly here, I think we're dealing with very slow, poorly perfused tissues and that's the rationale behind using the table that has long times under pressure, especially the equivalent pressures of 30, 20, and 10 feet of sea water.

I think that's absolutely crucial and essential. We're dealing with very slow tissue half times. It's the sort of tissues with incredibly long tissue half times. I think that's because in a bone compartment syndrome, with frankly elevated tissue pressure, you won't have much perfusion and tissue half times approach infinity with ischemia.

Dr. Mitchell: That's an interesting idea. I hope you go on to demonstrate that because that's useful—potentially very useful clinically for us to know.

Dr. Lehner: Thank you. That's something that we would like to pursue.

Unidentified Speaker: The pathophysiological scenario that you're making is compelling but I'm not totally convinced it's true. First of all, we heard here several times that there does not seem to be any relationship between the site of pain and the incidence of osteonecrosis in all these different indigenous divers.

So it would indicate that at least some other mechanisms are happening. In the divers that we did our questionnaire, we found that a lot of divers had had clinical symptoms without being treated.

But in our part of the world, osteonecrosis is more or less unknown. We hardly see it anymore. Following up on that, in your sheep, did you find a correlation between the site of the pain and repetitive diving and where they got their osteonecrosis?

Dr. Lehner: Yes, and the severity and persistence of that limb lifting was associated, I think, closely with dysbaric osteonecrosis, although this is anecdotal, with the underlying pathology that had developed and was observed in necropsy.

With regard to the issue of repetitive diving and the lack of correlation, that's something I attempted to address with a series of hyperbaric exposures which we did subject our sheep to where we found a relatively low correlation between limb bends lifting and radiographic manifestations.

I think what happens is you have an issue here of repetitive exposures confounding the scene where you have relatively mild cases that are potentially important but are just not remembered by the diver or recalled by the diver. I think that can happen.

You have situations where a diver will be complaining of pain for several months and he apparently doesn't have osteoarthritis, but he's complaining of pain and tolerating that pain.

Some of those cases are positive with bone scans. There are two Maine scallop divers with positive bone scans who also complained of pain in the same limb. It's not a hundred percent association between limb bends presentation and dysbaric osteonecrosis, but I think that the correlation is very high.

Unidentified Speaker: This is a question. It's more of a comment than a question, but I was wondering if, in this link between DCS and dysbaric osteonecrosis, are there other cases of dysbaric osteonecrosis that aren't related to a distinct bends or observed bends behavior or reported bends?

Dr. Lehner In the human literature, many papers have mentioned the fact that there have been patients who have presented with dysbaric osteonecrosis and they've never complained of limb bends pain. In the controlled setting of an experiment, such as we conducted with these sheep with a single exposure, we always saw the development of dysbaric osteonecrosis being associated with limb bends.

We had some cases of limb bends that didn't develop much in the way of dysbaric osteonecrosis, maybe a mild case or maybe not. But those which did develop dysbaric osteonecrosis were always associated with limb bends lifting. So I think it's extremely important if you have a case of limb bends to get yourself or the affected diver recompressed.

That's what I'd do for myself, that's what I'd do for my daughters who want to be recreational scuba divers. That would be my recommendation. That recommendation stems from the sheep model and it seems to be consistent with what is happening in the human population as well.

Unidentified Speaker: You discussed Type I decompression sickness and you are seeing limb bends and limb lifting, but did you look for any Type II bends as well? Did you do anything for that in your sheep model?

Dr. Lehner: Neurological signs? Yes, we have looked at proprioception by placing the limb, before and after the experiment, laterally and looking at the briskness of recovery to detect motor dysfunction, presumably as the result of spinal cord involvement.

Then we've also looked at the panniculus response, down the back on either side of the medial line, to detect if the dermatomes were being affected, presumably again having to do with spinal cord involvement or peripheral nerve involvement.

Typically, in these relatively shallow but prolonged hyperbaric exposures, speaking of the 24-hour exposures, we see very little in the way of neurological decompression sickness. We see frequent chokes which is really insidious, and as we all know, potentially fatal, and many cases of limb bends.

But the Type II in these prolonged, relatively shallow simulated exposures give rise primarily to chokes, as the [most common] Type II manifestation, rather than neurological events. So we may see frank paralysis in these animals on short deep dives, and that's a presentation where the animal collapses on the chamber floor.

It's interesting that in those instances we often see transient cases, so that the animal may be quadriplegic, and then within an hour-and-a-half or so be able to stand and walk out of the chamber.

That's interesting in light of some remarks that Shields made about people diving in Scapa Flow, diving very deep, coming up, having a spinal cord hit, being paralyzed, and then recovering quickly to the extent that they did not seek recompression treatment. They should have been seen by a clinician, but they weren't; they were going home.

Mr. Gold: First of all, I'd like to congratulate both of you. I think this has been a very stimulating presentation. I'd like to pose a question to Dr. Pollard, if I may.

Now, there was an indication in the questionnaire. If I understood correctly, the questionnaire was perhaps slanted towards the attitudinal side. Was there recognition by these divers that were at the scene there or was there a recognition by these divers that they were willing to do something about the risk that they face?

Dr. Pollard: When one of them is diving, they're going back and doing the same thing over and over again. There was an awareness that they were injured or risked injury-- a few of these ended up in litigation.

The questionnaire or the part of this other study that we'll probably be talking about is the whole group of divers to see if they want to volunteer for this study on dysbaric osteonecrosis and trying to get out how many of them were diving while in pain. I don't see a whole lot of change in their diving.

Discussion on Dysbaric Osteonecrosis

Dr. Hattori: Well, I just want to give a sort of brief explanation of what you are looking at on the MRI. MRI is in a way similar to looking at a radioactive scan, but in the MRI case you're looking at distribution of hydrogen in the body at various energy states.

What you've been looking at in the study this morning were MRIs with mainly T1 settings which highlighted fatty tissue. So you saw the normal hip. The image was bright in the hip, whereas the necrotic hip showed the irregular areas of decreased signal intensity with T1, and that represented the fluid of lower signal intensity—gray— bone marrow edema fluid.

Dr. Lepawsky: Thanks very much, Takashi. Now, preliminary to discussion, these are copies of the Workers' Compensation Board of British Columbia Regulations and they were brought here at, I think, the request of Dr. Davidson, and she had a discussion with Dr. E. S. Robinson, Dr. Ted Robinson, who is in our audience. I'd like to say that Dr. Robinson has been involved in diving medicine in Vancouver and this province for many years. It's got to be at least 30 years.

He was the primary physician during the work on the Highbury Tunnel which was compressed air excavation work that was done in the western part of Vancouver. I think, if I recollect accurately, there were 153 cases of decompression sickness that Dr. Robinson attended and that there was a high incidence of dysbaric osteonecrosis from those.

It's very intriguing that my recollection is also that none of those cases were granted medical permission to return to work after they had decompression sickness. Is that confirmed, Ted? Are those statistics accurate?

Dr. Robinson: As I remember it. I attended personally over 300 cases of Type I bends, and 6 cases of Type II bends, and we had, I think, 10 cases of osteonecrosis. After the Type IIs, they were not allowed or referred to diving work, but after the Type Is, if they made a good recovery, they could return to work.

But we were working on tables derived from Blackpool, in Britain initially, and we were working 8-hour shifts up to 35 pounds per square inch with a decompression organized according to the Blackpool Tunnel experience.

I think we changed the protocols later on, but there's a fairly high incidence of Type I bends and a fairly small incidence of Type II bends and some dysbaric osteonecrosis afterwards. I think it was a total of six cases or something like that.

Dr. Lepawsky: Thanks for that. It may interest this audience to know that at an early stage in the activity of the Highbury Tunnel, Dr. Robinson involved Dr. Al Behnke, the great-grandfather of modern diving medicine, and engaged him to come to Vancouver.

Dr. Behnke had a lot of input into that work and from that a lifelong friendship developed between the Robinsons and the Behnkes. You may have noticed that Ruth Behnke was at the banquet last night and it's because of her enduring friendship with the Robinsons that we were able to have her at that banquet. So we were very pleased about that.

I wanted to then ask if there are any questions that any of you may have regarding, let's say, specifically this morning's information on dysbaric osteonecrosis. We've had individual discussions after the individual presentations but -- yes, in the background, Dr. Sanchez?

Dr. Sanchez: Has there been any association with bone cancer after dysbaric osteonecrosis?

Dr. Lehner I think that there are, as I recall, 30 or so cases presenting in individuals who have been involved largely in tunnel work. So there is a potential risk and it is in the literature. The prevalence is very low.

Dr. Çimşit: I just wonder if, as Dr. Lehner says, there is a very low number of only type B lesions.

Dr. Jones: Yes, that's exactly the point that it's only for the type B lesions, the shaft lesions, predominantly osteosarcomas of malignant fibrous histiocytomas. Those are the main types. If it's a longstanding lesion, it's ordinarily occult for 10 or more years. Very rare.

Dr. Hattori: Just on the humorous side, Dr. Pollard, his face, by now, he's an OB/GYN and while they're in the chamber, the wives don't find out. I'm a radiologist until they come out of the chamber.

Dr. Lepawsky: There would be more questions? I was interested, Dr. Jones, you said in Pliocene fossils that 11 cases [of dysbaric osteonecrosis] were discovered in deep diving turtles, and yet in the Eocene, there were only six. I wondered if there is a difference between those geological ages that might account for this?

Dr. Jones: I don't know, Mike. What they did was the multi-center survey—think five different countries were involved with their paleopathology group. They assimilated all the material they had in these turtles from the different stratifications regarding depth and those were the actual figures so I don't know if the figures are relatively small numbers, so I don't think there is any degree of specific significance there.

Mr. Walsh: (North Carolina) The question is for Dr. Jones primarily. At the finish of Dr. Kawashima's talk there was mention made of the use of HBO_2 in either idiopathic avascular necrosis or osteonecrosis. Is there any evidence of the use of HBO_2 for recompression treatments of either the femur or humerus?

Dr. Jones: You know, there have been a number of people now that used HBO_2 to treat osteonecrotic lesions worldwide. I know Michael has done a few cases here in Vancouver. They've been done down in Long Beach and in Europe. The way I look at it is I agree with Dr. Kawashima.

If we look at central arterial occlusions, we have a so-called "golden period" where you can reverse the lesion of, oh, perhaps 10, 12 hours, by putting someone in a chamber and giving them HBO_2. I think that is the interval after the hyperbaric exposure that it would be potentially most effective. Of course, we're looking here with Dr. Lehner's interesting material in the early recompression and the 4- and 8-hour period [when recompression was effective]—the golden period, so to speak.

I've seen a number of cases, I've looked at their x-rays and MRIs, and these late lesions that have been treated with HBO_2 with or without decompressions, and I've never been convinced that it's had any therapeutic efficacy.

We have used HBO_2 in rabbit studies to find what normally occurs when you give normal animals HBO_2, with or without osteonecrosis, and we found that HBO_2 increases osteoclastic bone resorption. It regulates the osteoclast which is a metabolically very active cell, multi-nucleated.

It causes an increased amount of bone resorption. Well, ordinarily when we have bone resorption, the bone is structurally weakened, but the object is to strengthen the bone which is done by the osteoblastic new bone formation, particularly in the subchondral regions before collapse.

After the articular surface collapses, it's irreversible and progressively deteriorates into more severe osteoarthritis. So the therapeutic efficacy theoretically for HBO_2 would be in those pre-collapse lesions. The earliest that we can possibly find evidence with, let's say, dynamic MRI showing the very earliest lesion comes in.

We see someone's got a hit. We do a [^{99m}Tc] scan. We see it's photopenic—there's no uptake. That means that it's an ischemic perfusion defect. We get those early enough, give them HBO_2, and there may very well be some therapeutic efficacy. But in any of those late lesions, post-collapse lesions, I don't see any value to it at all.

Dr. Kawashima: This is very important for the treatment of dysbaric osteonecrosis. We must treat early before collapse. So, it is very important. If the collapse occurred in stage 3 or stage 4, there's no effect with the hyperbaric oxygen recompression or such, because if already collapsed, irreversible change has already occurred.

So, if we want to help treat dysbaric osteonecrosis, we must do very early recompression. Compression should be within 48 hours of hyperbaric exposure. So we must differentiate which cases we must treat. This is very important.

Another point is that MRI indicates which case to treat. As I showed in the cases, the MRI is very important.

So for screening purposes, we have the MRI check for divers, especially deep-sea divers. In Japan's Marine Science and Technology Center [JAMSTEC], we have many deep-sea divers - 300 or 400 deep-sea divers. So, these cases came to our hospital every year for the MRI check for the early stage of dysbaric osteonecrosis.

Dr. Jones: You have to remember now this is completely different from the [efficacy] -- non-[efficacy] of HBO_2 in osteoradionecrosis in the mandible or osteomyelitis or something else like this where the osteoblast is up-regulated; it's like a Packman.

Once you surgically go in and debride the necrotic tissue where there would be osteoradionecrosis or osteomyelitis, remove that necrotic tissue, that's the [sequestrum], then you give an HBO_2. That activates those osteoblasts which are like Packman and they go through and they clean up all that necrotic debris with cutting cones. They're very effective at that. But that is a completely different entity. It's a completely different indication. I think a lot of people have gotten confused on that issue.

Dr. Toklu: I think the thing that must be discussed is regarding treatment and HBO_2; we don't have a chance to diagnose dysbaric osteonecrosis without having symptoms of bends. If we have a case which shows bends pain, the treatment is hyperbaric oxygen. So people treat you because you have bends. At that point, you have chance to detect the dysbaric osteonecrosis using MRI. Maybe we must extend the HBO_2 therapy for treating dysbaric osteonecrosis, otherwise we wouldn't detect dysbaric osteonecrosis lesions. You can just only check a case who has bends or other symptoms.

Dr. Wong: If someone has suffered decompression sickness, do you have any recommendation regarding long bone x-rays, MRIs and bone scans?

Dr. Jones: As you know, type B shaft lesions are fairly asymptomatic and not disabling, and they will not of themselves disable a diver really in any way. We're only talking about the juxta-articular, so-called A lesions, and how those are followed.

You're going to find more lesions occurring in different sites. You'll notice in these humerus head lesions that I've presented, all of those divers had humeral head lesions, none of which had collapsed, and they're continuing to dive.

This is the interesting part about it. You notice that they were mainly sclerotic and that means osteoblastic new bone formation. So that supports the foundation, the subchondral plate and helps prevent the collapse. Early on for noviciate divers that are coming up for the first time in the commercial field, they do need a screening profile.

From the imaging standpoint, of course, it used to be the conventional x-rays: hips, knees and shoulders and hip rotation. Now, we strongly feel that these commercial divers should have an MRI of their shoulders, hips and knees, initially. That's prior to starting work. So it's like an astronaut, for example, having echocardiograms performed to make sure they don't have cardiac lesions. This is sort of essential that they have a baseline study.

Then after a severe bends hit, it's advisable, I feel, and very economical, to have a total body bone scan, like Charlie pointed out. Because you can very easily pick up lesions that are either cold or hot or hot and cold. Then you can go into that lesion with MRI and focus on that right shoulder if it's cold or hot, for example, and then follow them.

Then the later lesions we will see eventually in conventional x-rays, but generally speaking, by that time, most of them have collapsed. This is unusual to see all these pre-collapse lesions with conventional x-rays in these Miskito Indians. So now we have the MRI technology. I personally feel the Japanese have absolutely got the right system in place.

Let me mention ambient pressure changes, either a compression or decompression in experimental animals. Now, Dennis Walter, who works on many experimental animals and with instrumented, intramedullary cavities, finds no changes in intramedullary pressure with compression or decompression. Kawashima observed dogs with a 6 ATA exposure found an increase in intramedullary pressure during the exposure compression phase which was very transient but no increase in pressure with decompression.

Charlie's associate, Ed Lanphier, and Charlie did a few sheep that were instrumented for intramedullary pressure and as I understand, Charlie, some had elevations and some didn't. It wasn't --

Dr. Lehner: Some did.

Dr. Jones: Some did not.

Dr. Lehner: Some did not. The process of core decompression itself is a treatment used by orthopedists to treat cases of early osteonecrosis.

The sheep model of dysbaric osteonecrosis involves a situation requiring near-saturation conditions, close to 24 hours, to maximize the likelihood of dysbaric osteonecrosis induction. This came out of looking at the difficulty of inducing dysbaric osteonecrosis in smaller animals with smaller bones and less fatty marrow.

Dysbaric osteonecrosis is less likely in smaller animals: dogs, rabbits and so forth which have less fatty marrow and faster tissue perfusion rates and are less likely to form massive quantities of bubbles that we view are responsible for elevated intramedullary pressure, ischemia, and necrosis in bone and marrow tissues. In smaller animals, the bones are smaller and with much less fatty marrow, there's much less induction of dysbaric osteonecrosis, except in Chryssanthou's obese mouse model.

So, at least in sheep where we can get into dysbaric osteonecrosis, we do see it is based upon clinical presentation of persistent limb bends signs, typically lasting a day or more, and upon a proposed bone compartment syndrome resulting from bubbles in the marrow cavity of the long bones, as suggested by some cases of elevated intramedullary pressure greater than 40 mm of Hg. Recompression treatment can alleviate limb bends signs and also can prevent the later development of dysbaric osteonecrosis. The primary pathogenic mechanism would appear to be bubbles.

Dr. Jones: I think this animal model is key to the whole thing, since you have the very best animal model that we know of in the world producing dysbaric osteonecrosis at 8 weeks out from a known hyperbaric insult. The problem is you haven't done any of the very acute pathological studies at 2, 3, 4, 6, 12, 24 hours after this event.

I think that's going to separate the data, because as you can all see, we have a basic disagreement here in terms of etiopathology. I believe it's a result of intravascular coagulation with thrombosis and necrosis.

Charlie and his group feel that it's due to increased intramedullary pressure causing an ischemic event and so on. So I think it's only going to be with the early studies, we're either going to see thrombi in these early animals that are sacrificed or we're not or we're going to see high pressure. So I think those are the studies that have to be done.

Dr. Lehner: But we keep an open mind, and this is an area for future research.

Dr. Jones: Well, it's a very controversial issue. That's the bottom line. Well, that was the first part of my question, because then if you're looking at it, we're looking at if we have ischemia or thrombotic emboli which is indistinguishable in the bone--which is exactly the same that have been reproduced and proven to be dysbaric osteonecrosis or an a vascular problem. So what is the difference in the treatment?

Unidentified Speaker: Yes, I think there's another major factor as well. Osteonecrosis is formally called "aseptic necrosis." There's no infection involved. When you have osteoradionecrosis, you frequently have secondary osteomyelitis, an underlying infection. These have to be debrided, for example, and, fortunately, the other part of Dr. Kawashima's expertise is in the treatment of chronic osteomyelitis. Maybe you could speak to that Mahito--the importance of HBO_2 when you have osteoradionecrosis and osteomyelitis?

Dr. Kawashima: In our hospital, we treated 206 cases of osteomyelitis by HBO_2 and the clinical result was over 60% successful. But if we found necrotic form in the osteomyelitis earlier, so if it did go to treatment, we must have abrasion.

I think after the collapse of the articular surface of the femoral head it's very difficult to treat.

Dr. Çimşit: I thought we had agreed with Dr. Sanchez because the recognition, I think, that 48 hours is far too short a time to give us. In technical studies in clinical work, we treat patients very successfully for osteomyelitis and osteoradionecrosis.

And they should pass this first 48 hours, maybe hours, maybe days, maybe weeks. So I think we can treat patients with dysbaric osteonecrosis [with HBO_2] before the collapse. And we have much more time then than the first 48 hours. In my opinion, we certainly have this time.

Dr Lepawsky: I would just like to say that both of the cases that I showed at the end of the presentation yesterday were cases which had been exposed to hyperbaric oxygen. The first case I did not show serial studies because we did not get serial studies.

The second case I did show serial studies and I think you could tell from those that I don't think that we could say that we repaired the process by any manner of means. But I can tell you that clinically, pain relief was experienced by both of those individuals.

One of them is sitting in the audience today. Now, he had widespread dysbaric osteonecrosis: shoulders, hips and knees. I'm not sure if he chooses to stand and give his personal experience. He's welcome to do that. So if you would care to give your experience, fine. If not, we don't mind that you don't want to speak about it.

Certainly subjectively there was improvement in pain. I can't say that was complete relief from pain nor that it was long -- that it was permanent. But nonetheless, there was some relief from pain in the cases that I've treated with hyperbaric oxygen. I'll let the individual who had the hyperbaric oxygen think about it for a while. In the meantime, Dr. Brubakk wanted to say something.

Dr. Brubakk: It's just a question of diagnosis. In modern Europe, the dysbaric osteonecrosis is more or less unknown now. The question I had is related to the use of MRI before they start their diving career. The reason for that -- I'm asking that is that there are many other courses of necrosis.

Is there any reason to believe that individuals who have a previous necrosis from other reasons that has nothing to do with diving, that their necrosis would tend to progress if they do, say, diving within reasonable tables? Or is that excluded?

Second, to follow up on that, you have said that there were no reasons to follow sport divers. Now, there is a totally new group of sport divers called the "technical divers" who dive deep. I recently talked to a technical diver who said to me, "Well, I usually never go deeper than 200 meters."

They use scuba and go very deep. So the question is that they -- when they get a hit, my guess would be they had conducted a long, deep dive. There may be a totally new group of individuals that fall into the group of the indigenous divers.

Dr. Jones: Yes, ordinarily, if the individual has a drugstore ticket or a type A lesion, it's contra-indicated that they continue diving. At least in the United States, there's a medical liability exposure if you, as a diving physician, would let that individual continue to dive, and he developed another lesion or collapsed the present one.

I think this second group you're talking about—I think if I were an noviciate technical diver and was going to get into the realm, I would pay the money to have the MRIs performed just as a baseline study.

I think it's -- would be well worth it to determine where I was before, because I've done consultations on osteonecrosis now for about 30 years, and I've seen many cases that were attributed to dysbaric phenomenon that were actually due to a number of other causes, either acting alone or in concert with one another that had nothing to do with dysbaric necrosis.

Through collateral tests, we found out the necrosis actually antedated the dysbaric exposure. But it was from another condition. This is a problem we see in the industrial compensation area as well.

So I think we have to think about that list of all those various entities that can potentially be related as risk factors and determine, number one, if the person has pre-existing lesions prior to diving, if they do then that's one attack on the algorithm. If they don't, then they could be clear. But the MRI technology now is so universal except in the third-world, underdeveloped countries that I think it should be employed for the noviciate divers.

Dr. Brubakk: But just to make it clear -- you may have misunderstood. We have regulations, too, obviously that if you have a lesion determined by radiography, you should not dive. Now, it's obvious that MRI is more sensitive. So my question is more, let's say we changed the regulations -- we go and say, "Okay. We do MRIs instead."

We find changes. Is it still warranted to stop them from diving because the risk in normal diving activities high enough to warrant to say, "Okay. Even if you have no x-ray changes but you have MRI changes, you should not dive." Is that the point?

Dr. Jones: Well, if the individual has shaft lesions exclusively, there's not juxta-articular lesions that you can see on MRI, we let them dive.

Dr. Brubakk: Okay, thank you.

Dr. Jones: But we don't let people go back to diving, if they have juxta-articular lesions.

Dr. Brubakk: I accept that.

Dr. Kawashima: I must talk about MRI. MRI is a very good diagnostic technique. We check one in the shoulder and leg, and the screening goes for more than 1,000 x-ray reviews. We have no evidence of a juxta-articular lesion of the knee.

So MRI is used for a screening check of the knees, and they say not necessary for that knee joint because of the cost problem. We have no lesion juxta-articularly in the knees. So we took MRIs of only the shoulder joint and hip joint.

Dr. Sanchez: This actually isn't one of the issues. We have talked a lot about [empirical] divers. Of course, we don't have MRIs in most areas all around the world.

So my recommendation or my question is: Okay, thinking of that population that is not so fortunate to have an MRI, what criteria would be used to exclude them from diving?

Dr. Wong: The criteria for exclusion from diving.

Dr. Sanchez: Yes, say you have 10 divers who will be perfect divers or the low-risk divers, they're not going to get MRIs. There is no MRI available. So what criteria should we use to rule them out from diving without an MRI available or a bone scans?

Dr. Wong: Dr. Çimşit, you had an answer for this?

Dr. Çimşit: Yes. I'm not sure that it will be an answer but still, unfortunately, I don't think you have any chance of this. The only thing we do in our country -- well, we do -- reviewed so many x-rays so in a sense we have -- well, such device.

So the thing we do is, if we suspect from an x-ray which many of our colleagues say, "No, there's nothing there." But we think that there is something wrong with it, then we take MRI. That is the solution we could find. Otherwise it's so expensive and you have to bring the diver to your institution and pay for him and take the MRI. It's very expensive. It can't be effective.

Mr. Arnold: (Florida) Would there be a role for a bone scan since it's more readily available than an MRI?

Dr. Jones: No, you know, that's exactly the point. It is a less expensive and -- although it's very sensitive, it's not specific. They're not very specific. But Dr. Lehner and his group have done some great work recently with Tc-MDP, using a number of fluorochrome markers.

The situation with scans is -- and he's beautifully pointed that out -- you look at the initial lesions at two hours or two days for their photopenic lesions, initially. That's exactly what happens.

They pick up the earliest lesions and then they convert from cold and to hot. Center remains cold, the outer revascularization portion's hot. Then they go to hot in eight weeks and that's just about what we see in humans as well.

So it is an inexpensive screening technique where you've got a total body bone scan and you can see, "Oh, yeah, there's a hot right humeral head. There's a hot left femoral head. There's a hot distal femur." I agree with Mahito. I've never seen MRIs in divers with actual juxta-articular lesions extending into the subchondral bone to the knee.

I think that just doing the shoulders and the hips is fine with MRI. But if you do have a positive scan, and if in your screening program, you ran all your noviciate divers through that, they got the scan. If there's any area that's hot, you get the MRI. If you don't have MRI, then you just do the scan.

The scanning techniques are available pretty much universal now. You don't have to have to do SPECT imaging, single photon emission computed tomography, to cut through them. You just need a very simple scintigraphy setup. It's inexpensive. You cover all the joints. You can cover your whole population group. And then if an area is hot, then you can do your conventional x-rays focusing in on that upper shoulder.

Dr. Hattori: The only problem with a bone scan, you're using that whole body radiation, so you don't like to do that any more than you have to. The big advantage of the MRI is you have no residual or cumulative effect of ionizing radiation. I know it's expensive, but it's probably the best way and the most sensitive. As Dr. Jones said, a bone scan is not as specific in its finding.

Dr. Sanchez: I agree with your comments but there's another comment that I would like to—well if you're going to do bone scans, make sure they use dynamic imaging--the first 60 seconds every five seconds, because then you will have blood flows-- in a particular area.

So it's much better than x-rays. But it's not as specific, that's true, but at least you get a very quick way to -- I mean, it's the best way to screen extensive skeletal areas.

Mr. Heywood: A question about screening again, talking about recreational versus professional divers. But that line is sometimes a little bit blurred. I was wondering if I could hear from the experts what they consider high risk diving. Like is it deeper than 100 feet, is it deeper than 200 meters? Just a comment.

I read in the newspaper yesterday that in Canada, in British Columbia, the wait to get an MRI is something like 11 months. I think it would be another concern would be that it's going to take months.

So I'd really be interested in hearing from the experts what they define as weeding or screening because it's an extreme profile versus not necessarily recreational but at least not extreme dives?

Unidentified Speaker: The next question really is: what is the price charged for the examination of a commercial diver? An examination costs X number of dollars now, what is the Y factor with X plus all the other investigations? How much are we going to increase the cost of the examination and how often are we going to do them? That's perhaps a question for the Compensation Board.

Dr. Lepawsky: Well, do the Compensation doctors want to say anything regarding this?

Unidentified Speaker: Well, certainly, I think the price would be a major factor here because most of the divers -- well, a large number of the divers in B.C. pay for their own medical and it's not -- they're not usually associated with large diving companies. Secondly, I think of the availability.

I don't know what the availability of MRIs are throughout the province, but it's difficult enough to get a diver to go several miles to a doctor who is trained to do diving medicals. If you ask him to have MRIs as well, I think that would be extremely difficult. What do you think, Michael?

Dr. Lepawsky: I think I agree with you strongly. We have a total of five or six MRI facilities in the province now, not including the two that I know of that are private, so that would bring it to perhaps eight. Most of them are in the Lower Mainland.

We're talking about the equivalent of traveling from Seattle to Los Angeles to get an MRI to be certified to dive commercially in this province. I think that would be rather clumsy. I've had some private MRIs done for patients, and, if my recollection is accurate, I would think that shoulders, hips, and knees would be running somewhere close to $700 Canadian. Dr. House, do you have any experience with this?

Dr. House: (Vancouver) One MRI scan now is running about $825 to $850 in a private scanning unit.

Dr. Wong: Of one joint?

Dr. House: Yes, that would not involve all of them. If you wanted to do shoulders and hips, I think you'd be looking at substantially more, although you could probably get a discount of some kind if they're done at the same time. I have nothing to do with scanners.

But I think that my experience of 15 to 20 years of doing certifications in this province would not indicate a need in this province at this time where the dive profiles are going to change to more mixed gas diving, as harvesting maybe goes into deeper waters, different times of the year. I don't know. But at this time, I wouldn't have thought that it had been indicated.

Dr. Lepawsky: Yes, regarding waiting periods, it depends on whether you -- if you're waiting for an MRI that is going to be covered by your medical insurance, the waits can be, in my experience, four to six months. I'm not saying that all of them are but some of them can be. At the two private facilities that I'm aware of, the intake seems fairly rapid.

The problem that I have is that in my experience, with all due respect, I have not found quite exactly the same quality from the private facilities that I have with the -- the more usually utilized hospital-based facilities.

Dr. House: Just one other comment along that same line. You see, I don't know if you all have the same problem, but general practitioners are unable to order MRI scans in this province. It's interesting. Maybe Michael, being the hyperbaric director, can bypass that system. But I've done a lot of commercial diving certifications and cannot bypass that system at this time.

I can go privately, which is about two days to a week wait, but the public system, if I had a patient that had an injury, if the Compensation Board and I felt that it was appropriate to do an MRI scan, we would have to arrange that through the Board. I couldn't personally order that scan.

Dr. Lepawsky: It's clumsy at best, let's put it that way. At best, it's clumsy.

Dr. Jones: Now, we have the National Osteonecrosis Foundation headquartered in Baltimore at Johns Hopkins, and we're advocating a three-cut flash study MRI of the hips and shoulders. These run between $150 to $250. It's a very short study. It's T1 weighted and if you see a revascularization from the narrow band that Dr. Lehner showed so nicely, that is the hallmark of osteonecrosis.

All it takes is basically three cuts through the humeral or femoral heads. On a reduced basis, I'm sure, the Workman's Compensation group could negotiate a price with these seven or eight MRI centers to do a three-cut flash study only with T1 waiting a very short time. They would get the baseline study. You don't need the complete MRI study, the $800 T1/T2 and all the rest of it.

Dr. Lepawsky: We're going to go to a few more questions .... So I think Dr. Hattori wanted to say something?

Dr. Hattori: Well, I was just going to say, the amount charged for MRIs depends on the number of sequence or the details of the study that you want. So like in a knee, it could run anywhere from -- like in our hospital, it would be from $600 to $1,500, depending on the sequence of studies that you do.

Dr. Sanchez: Returning the question of dangerous diving. According to the advanced data, diving deeper than 80 feet and more than two dives per day more than 2 days in a row incurs risk of decompression sickness--according to others, it's 100 feet or more, but in Latin America it's 80 feet or more.

Mr. Long: (Colorado) I was a little bit confused when the discussions came up as far as the treatment prior to the initiation of hyperbaric oxygen. Presumably in the treatment for DCS and the prevention of DON, and that is the two subjects that were brought up earlier, such as anticoagulation.

I believe the Japanese contingent mentioned using heparin, then also the Turkish contingent mentioned using prednisone and I'm wondering, is there any consensus on this or is that too big of a subject?

Dr. Lepawsky: Well, that gets into treatment of decompression sickness and I think it's a separate question that perhaps -- can you restate that question later this afternoon during the longer discussion period?

RECESS

Mr. Duffy: I only picked up 20 copies of the *Industrial Health and Safety Regulations*. How many other people would like a complete copy of the regulations? I'll bring another case. Just for your information, the regulations under s. 24 are regulations that govern commercial diving in British Columbia.

Those regulations were not written by the Workers' Compensation Board. They were written by a committee consisting of seafood harvesters, scientific divers, commercial divers, provincial government divers, Dr. Lepawsky.

The only requirement of the Workers' Compensation Board is that we enforce those regulations. So when somebody says to me, "I hate your regulations," I say, "Too bad, contact the committee." It makes my job much easier. So I'll now get you some more regulations.

Dr. Lepawsky: Well, further about those regulations, again, Dr. Ted Robinson, who was seated just back here and who worked with Dr. Behnke in the '60s on the Highbury Tunnel, was quite instrumental in developing the earlier version of those regulations.

If you will recall, Mr. McGinn read from regulations from 1933 -- from October 1933. So the Workers' Compensation Board has had those regulations in place for 65-plus years. And the most recent iteration are those that you're getting from Mr. Duffy today.

DEVELOPMENT OF PEARL DIVING PROFILES OF WESTERN AUSTRALIA

Robert M. Wong

INTRODUCTION

Pearl Diving in Western Australia is of two main types; "drift diving" in which wild oysters (*Pinctada maxima*) are collected from the seabed by divers; and "farm diving" where the divers attend to farm husbandry using U.S. Navy (USN) tables.

This paper addresses the drift diving technique, which represents an example of human ingenuity in the development of decompression procedures by "trial and error".

HISTORICAL PERSPECTIVE

The indigenous population has been diving for Mother of Pearl shells since time immemorial. The early settlers noted the pearl shells worn by the Aborigines as far back as 1861, and hence was the birth of the pearling industry in Australia conceived.

The initial mode of diving was breath holding, and this persisted until 1884 when compressed air diving was introduced to Broome. The divers had to dive by trial and error in their development of a safe diving procedure, which was done with a huge sacrifice in terms of morbidity and mortality. At this time, Haldane's decompression tables were still some 24 years away.

EVOLUTION OF DECOMPRESSION PROCEDURES

No reliable records of the early dive profiles are available. In the early days, each pearling company was very secretive about their "own profiles", and these were passed down from generation to generation of divers within the same company.

Interviews with divers revealed a mode of diving that shared some common features. They arbitrarily divided their profiles into three depth zones:

1. Shallow waters—usually less than 10 fathoms.
   - Bottom time was around 50–60 min.
   - Decompression stop (staging)—nil was required at this depth range.
   - Ascent rate—slow, hand-over-hand on a shot line, but this varied with the individual diver.
   - Surface interval—as it took the pearling luggers some 15–20 min to swing around for another drift, this was the "surface interval".
   - Daily dive time—from sunrise to sunset, some 12–13 h of repetitive diving was performed; moreover, consecutive days diving during neap tides for 7–8 days was the norm.
5. Mid-waters—15 fathoms [27 meters of sea water (msw)].
   - Bottom time—shorter than above, around 45 min.
   - Ascent rate—slower than above.
   - Decompression stops—at about 7 fathoms (13 msw) for 5–15 min, the duration was dictated by the Head Diver (number 1 diver). It took about 3 min to reach the decompression stop from the seabed, ascending at 2–3 fathoms/min (2.3–5.5 msw/min). Ascent to the surface was even slower at 1.4 fathom/min (2.5 msw/min).

   At the end of the day, decompression stop was made at 7–8 fathoms for an hour.
8. Deep-waters—up to 25 fathoms (45 msw)
   - bottom time—less than 40 min,
   - ascent rate—slower than above, 1.8 fathoms/min or 3.3 msw/min, and
   - decompression stops—similar to mid-waters.

The lesson learned in these early days was that they needed to follow a few simple rules:

- ascend slowly—there is individual variation, some "strong" divers could tolerate a faster rate of ascent;
- deep decompression stops;
- long decompression stop at the end of the day, and
- voidance of exercise postdive.

Up to and including the 1960s, the mode of diving was very much the same as described above.

THE 1970S

The major changes came about in 1971 when hookah diving was introduced to Broome. This replaced the standard hard-hat diving, and a new technique of shell collection had to be devised. Initially, the ascent rate of the USN at 18 msw/min was adopted, consequent of which brought on an increasing number of decompression sickness (DCS) cases with their mode of diving. The incidence is difficult to ascertain as no record was kept.

THE 1980S

The most significant change in the 1980s was the introduction of oxygen for general use in decompression and for recompression (although one company had experimented in secret with it since 1974). This was introduced out of necessity due to the high incidence of DCS. Another lesson learned from this period was that with this type of diving:

a. the number of drifts per day must be limited (to 7, with bottom time of 30 min when depths were deeper than 30 msw);
b. slow ascent rate has been found to be more important than the use of oxygen in decompression when SI was not longer than 20 min;
c. surface intervals must not exceed 20 min—long SI tended to produce DCS cases;
d. oxygen should be used only at the end of the day and only for a total of 90 min; and
e. air break should be introduced after breathing oxygen for 30 min.

Another group used a different technique which was different from the above in that they used:

a longer surface intervals (minimum of 60 min) between dives; and
b oxygen decompression after each dive.

Both groups adopted a slow rate of ascent. In fact, they had three levels of ascent rate. From deep waters, they ascended at 5 msw/min to about 21 msw; from here, the rate was reduced to 3 msw/min to the decompression stop; after which, the rate was further reduced to 3 min/m to the surface.

CURRENT PRACTICE

Over the years, by trial and error, the pearl divers have developed their dive profiles based on the experience of the divers of earlier days. The current practice is not substantially different from those of yesteryears.

From the experiences gained in the 1980s, they developed two types of diving profiles: non-rotational profiles in "shallow waters" and rotational profiles in deeper waters.

1. Non-rotational profiles (up to 23 msw)—This type of diving means that divers dive every dive, ranging from 10 dives a day (up to 19 msw) to 8 dives a day in 23 msw. Ascent rate is 3 msw/min and surface interval is 20 min. Decompression stops and bottom times vary with the number of dives and depths.
2. Rotational profiles (> 23 to 35 msw)—With this type of diving, divers perform every other dive only. Surface interval is therefore longer and varies from a minimum of 60 min. As with the non-rotational profiles bottom time decreases with depths, and decompression stops increase with depth and number of dives.

INCIDENCE OF DECOMPRESSION SICKNESS

The incidence of DCS in the early days is not known, but it has been estimated to be around 40% in the 1980s. Since the 1990s, with testings and modifications of the profiles, the incidence of DCS has dropped to 0.01%, all of which presented with musculoskeletal symptoms.

LONG-TERM HEALTH EFFECTS

All divers are required to undergo an annual diving medical examination in accordance with the Australian Standard AS2299, including long bone x-rays. To date, no diver who entered the industry in the 1990s has any demonstrable dysbaric osteonecrosis; hearing deficit; or respiratory dysfunction.

BIBLIOGRAPHY

South Pacific Underwater Medicine Journal. SPUMS J 1996; 26(1 suppl).
Bain MA. Fullfathom five. Perth, Western Australia: Artlook Books, 1982.
Bassett-Smith PW. Divers' paralysis. Lancet 1892; i:309–310.
Blick G. Notes on divers' paralysis. Br Med J 1909; ii:1796–1798.
Edwards H. Port of pearls—a history of Broome. Adelaide: Rigby, 1983.
Idress IL. Forty fathoms deep. Sydney: Angus and Robertson, 1937.
LeMessurier Dhm Hills BA. Decompression sickness—a thermodynamic approach arising from a study of Torres Strait diving techniques.. Halradets Skr 1965; 48:54–84.

DISCUSSION

Mr. Heywood: (Vancouver) From what you said, there had to be a pearl divers' license. What do you have to do to get a pearl divers license?

Dr. Wong: They have to pass an Australian standard medical examination and they currently are only required to have a C Card (Open Water Sports Diving Card), and they have to do a pearling industry induction course which is run by a safety officer.

He runs a course to teach them all the different aspects of pearl diving and then the Fisheries Department issues them a licence. But having said that, there are quite a number of ex-divers from the Royal Australian Navy and the Royal New Zealand Navy in the industry as well, some ex-commercial divers as well.

Unidentified Speaker: How do you enforce the ascent rate and diving standards? Is there some sort of government action or fine against the diving company or against the diver? Or is it somewhere – they're let go?

Dr. Wong: No, there is no law enforcing them. It's just a company regulation. If they come up quickly and if they get bent and if the recorded profile in the Citizen HyperAqualand watches that downloaded showed that they come up too quickly, they are fined, I don't know how much and they might be stopped from diving by the company. So that does force them to stick to the slower rate of ascent.

Unidentified Speaker: What depths was the oxygen hang-off at?

Dr. Wong: Nine meters.

Unidentified Speaker: You said the boat has got the booms out and the trailing divers. Is it just drifting in the current or is it under power?

Dr. Wong: It's drifting.

Unidentified Speaker: It's just drifting?

Dr. Wong: Just drifting and they actually sail up against the current and they swing around and drift. That's why I showed you the drogue behind just like a parachute. It's like the sea anchor. They lower it to retard the speed of the drift.

Unidentified Speaker: Do all the divers start at once and then finish the dive at once or is it staggered?

Dr. Wong: Their rotational profiles, they are staggered. They have two teams of divers. One lot come up and the other lot jump in. With the non-rotational profiles, they all jump in at the same time and finish at the same time.

Unidentified Speaker: It sounds like this started out fairly unregulated. What prompted the standardization of this industry?

Dr. Wong: Well, because Broome started to open up and people get to hear about the horrendous stories. Also, in 1987, I conducted a course in diving medicine and one of the students went up there to Broome as a medical officer in the Broome District Hospital. He telephoned me and told me about the horrendous incidence of decompression sickness and that they were not diving to any standard dive tables. Up to that day, I knew absolutely nothing about pearl diving and in 1989, there were three fatalities. One from a drift diver. Why he died, I still don't know, could have been a round window fistula.

But two divers were from the farms and died of carbon monoxide poisoning. Also the divers are more educated, and Broome has opened up to a lot of outsiders. Now there are flights to Broome 4 or 5 times a day, and people are more educated and the fear of litigation. Also at the inquest of the three fatalities, I was called as an expert witness and I was asked about their dive profiles.

Basically, the pearling industry was told that either they adhered to the U.S. Navy table, DCIEM table or let me study the profiles, how safe or unsafe they were and for me to make recommendations about changing the profiles and they found that perhaps the latter was the less of the two evils.

So they asked me to look at the profiles and I managed to get a Fisheries research grant to look at the profiles. That's the change really. They were forced into it more or less by fear of litigation than the inquest and the government control.

Unidentified Speaker: In a recent scientific diving meeting, it was brought up that having a day off in a series of multi-day repetitive dives was perhaps worse than not having that day off. I wonder if this kind of an option ever developed in this kind of operations?

Dr. Wong: They usually dive 8 days or at least 7 days. Beginning of the season, oddly enough, they tend to dive only 6 days, but if due to any reasons that they only dive for 2 or 3 days, or because of the weather, they certainly do a long decompression stop before abandoning the diving.

The other interesting thing is that the luggers have a 2-meters deep tank where they keep the oysters in seawater before they are placed in the "dumping ground".

Sometimes, if they have missed a decompression, and the weather is foul, they ask the divers to go into that tank at 2 m to decompress. I don't know how successful that is. I have actually not witnessed that but that's what they tell me they do.

I certainly have been on many pearling vessels but I haven't seen that done. To answer your question, I don't know. Perhaps Ron Nishi might be able to answer that because he got some analysis of profiles on short surface intervals as opposed to long surface intervals. Because there was one time during the chamber trial the compressor packed up, only broke down temporarily and we had an unexpected and unplanned long surface interval (rather than a 20-minute surface interval). Certainly the bubble grade rose quite high. So I can't answer your question apart from that.

MODELING THE RISK OF DCS IN EMPIRICAL DIVING TECHNIQUES

R.Y. Nishi

INTRODUCTION

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

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

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

METHODS

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

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

RESULTS

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

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

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

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

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

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

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

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

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

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

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

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

SUMMARY

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

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

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

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

REFERENCES

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

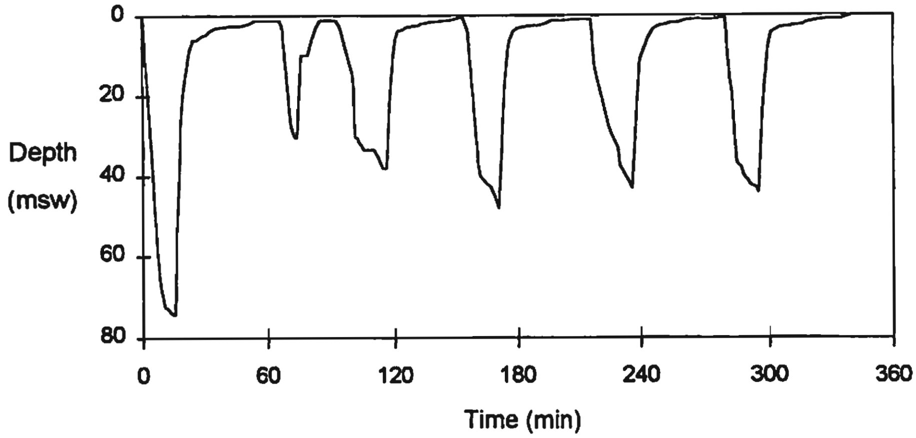


Figure 1. Example of Repetitive Dives Tested (Kidd-Stubbs model, 1964)

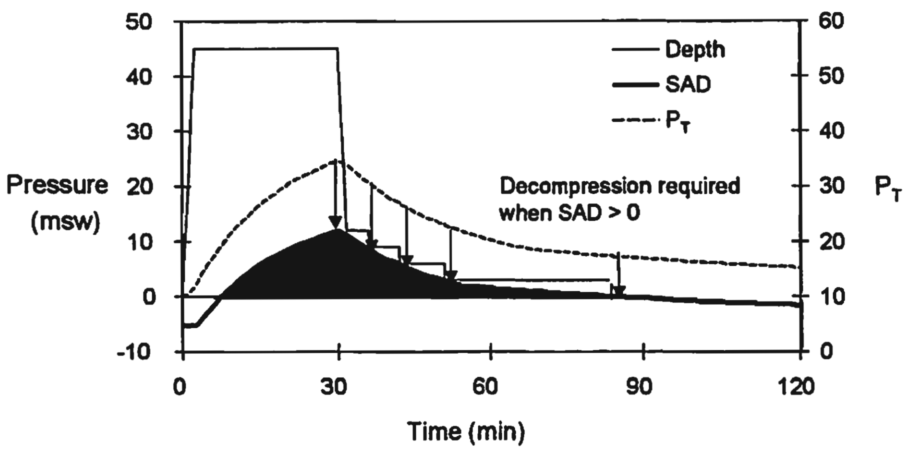


Figure 2. Example S.A.D. (Safe Ascent Depth) Calculation

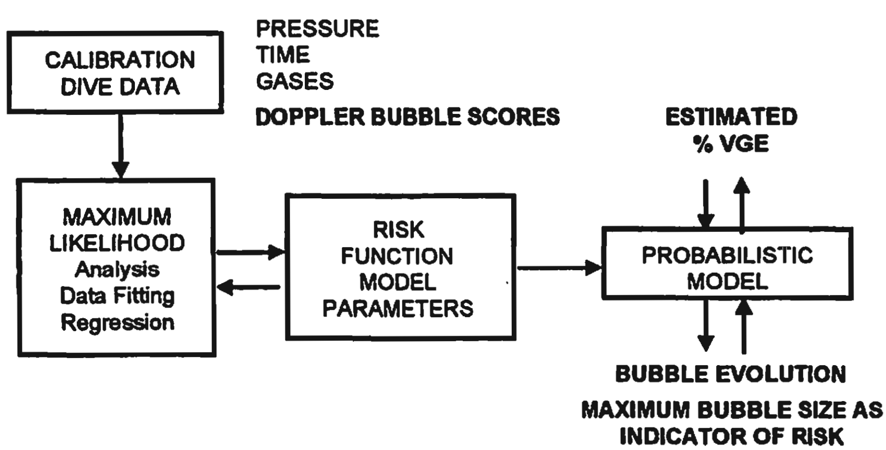


Figure 3. Probabilistic Model of Decompression Based on Venous Gas Bubbles

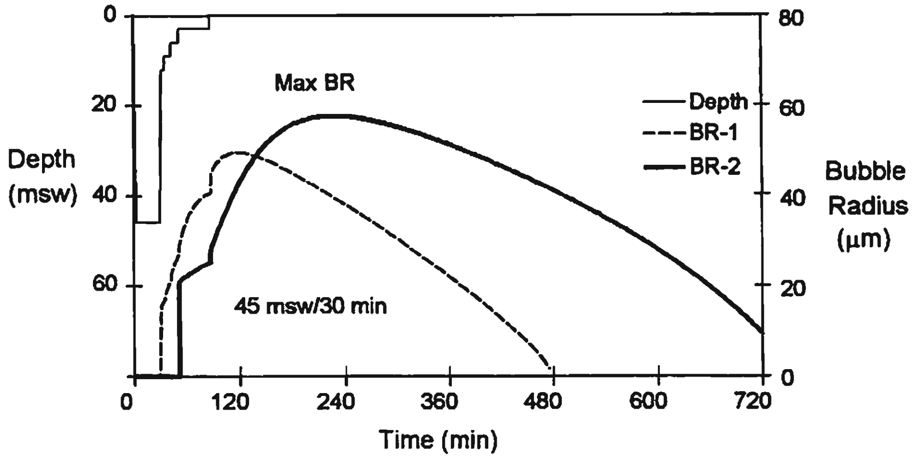


Figure 4. Example - Bubble Evolution Calculation (2 Compartment Model)

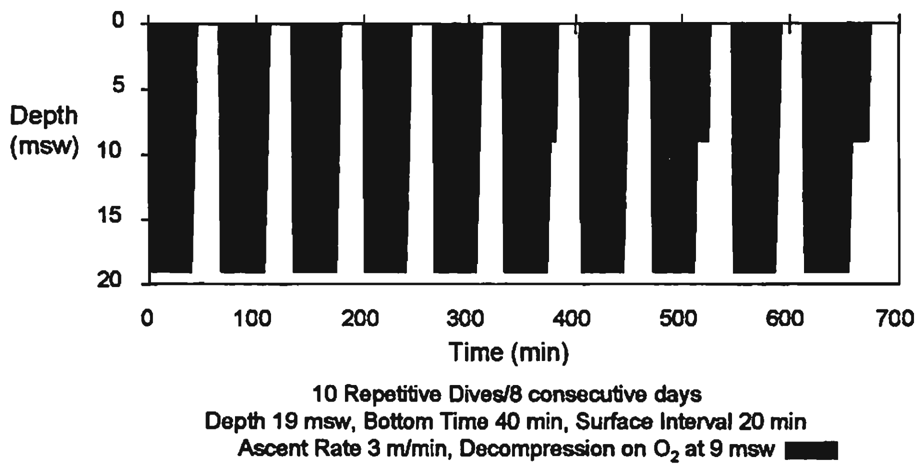


Figure 5. Pearl Divers Dive Schedule

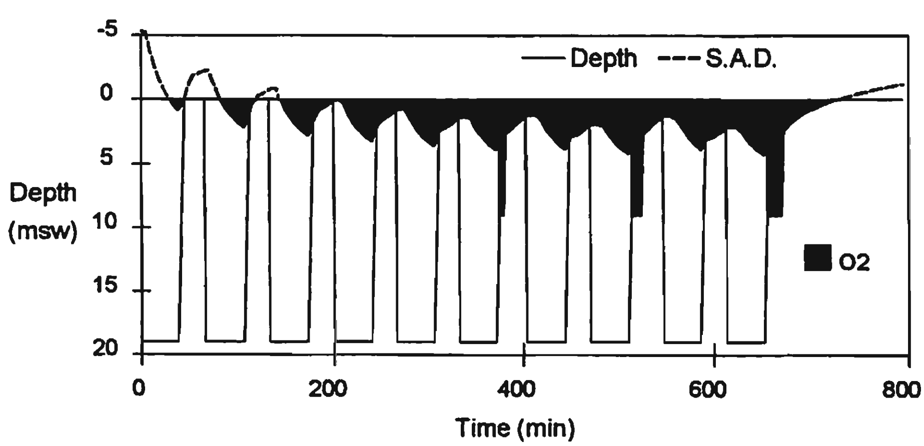


Figure 6. 1992 Dive to 19 Msw - S.A.D. Calculation (DCS)

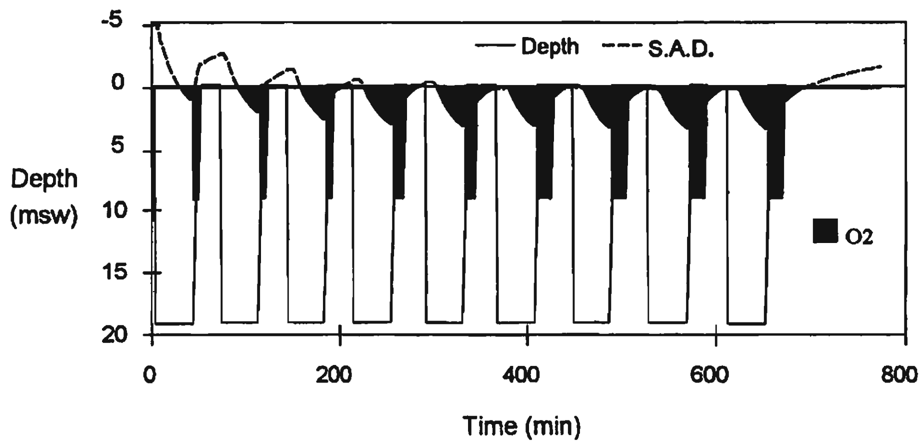


Figure 7. 1996 Dive to 19 Msw - S.A.D. Calculation

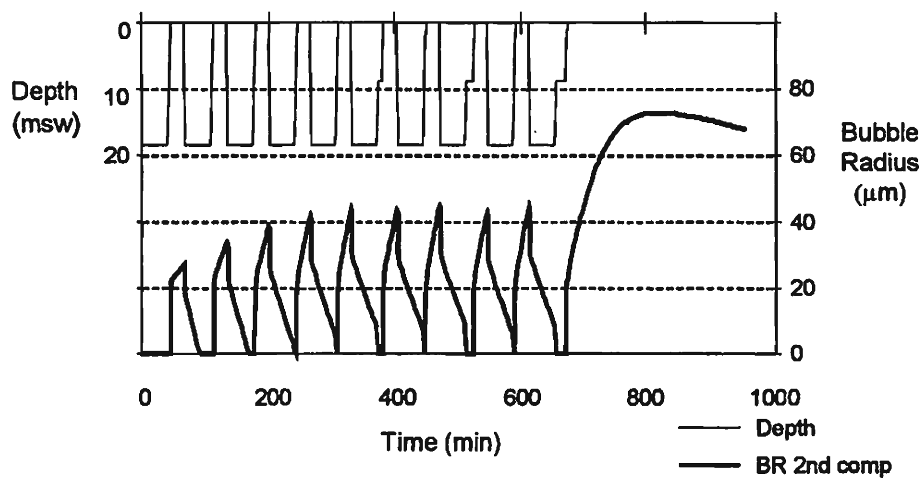


Figure 8. 1992 Pearl Divers' 19 msw Profile (10 dives)

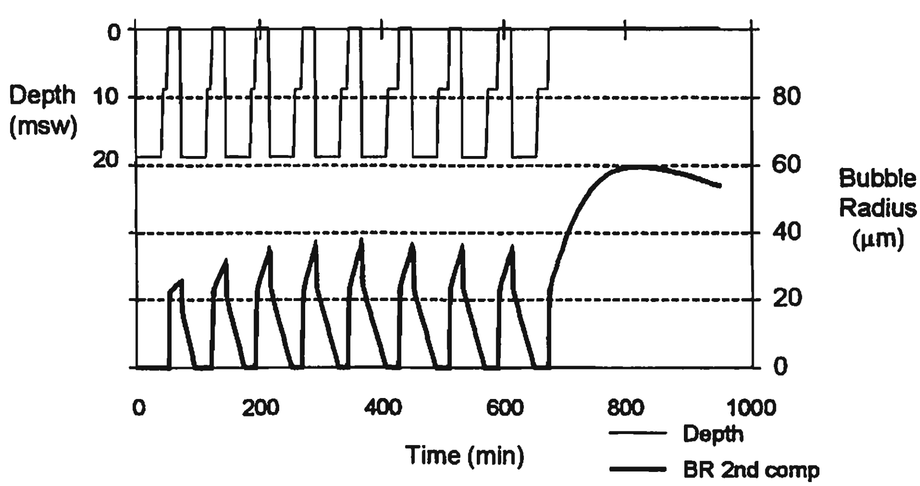


Figure 9. 1996 Pearl Divers' 19 msw Profile (9 dives)

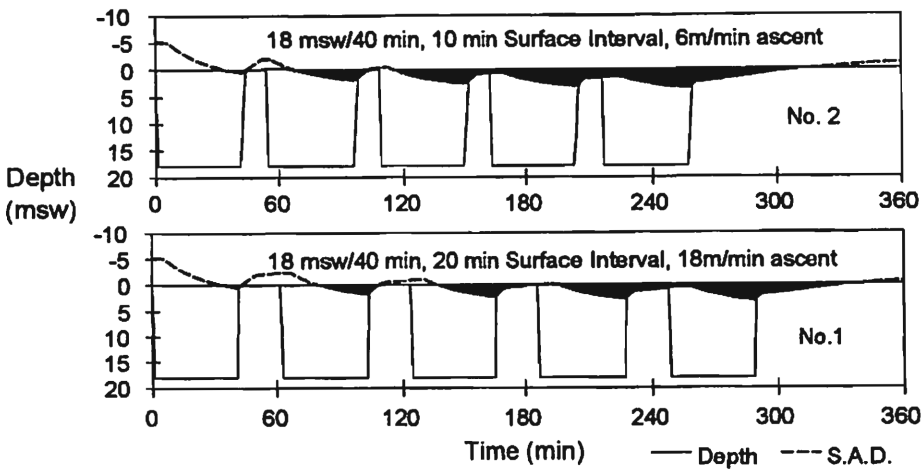


Figure 10. SAD Calculation for Kawashima et al. (UJNR 1995)

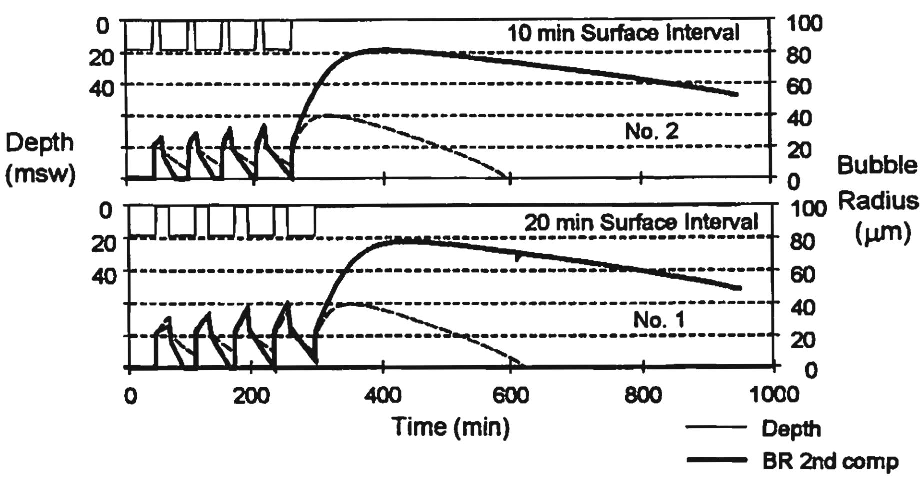


Figure 11. Bubble Evolution for Kawashima et al. (UJNR 1995)

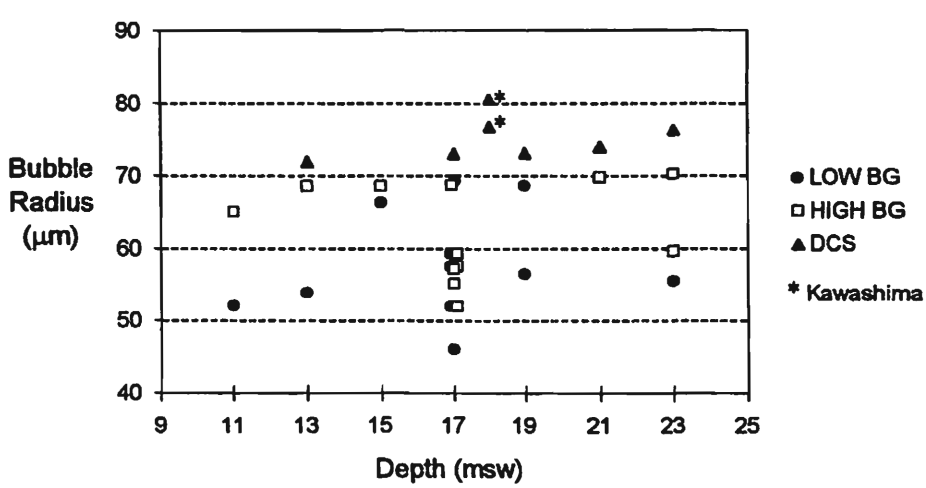


Figure 12. DCS Bubble Radius Threshold Pearl Divers Profiles (1992-97)

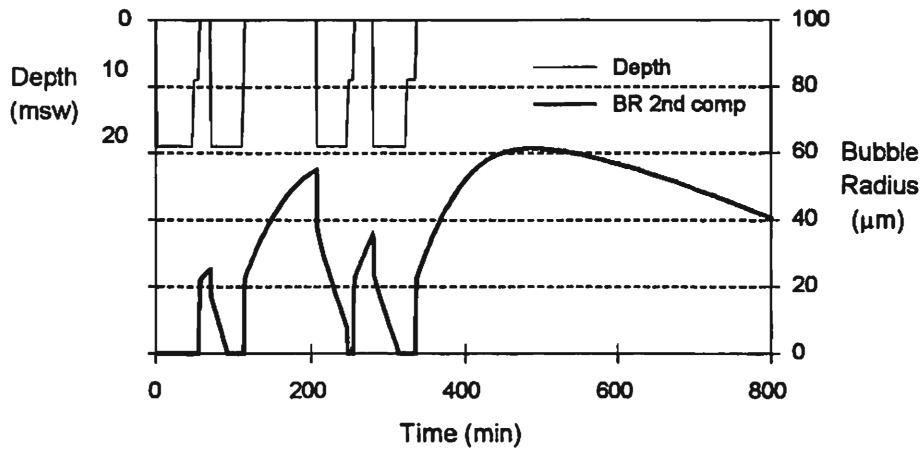


Figure 13. Effect of Long Surface Interval - Pearl Divers Profiles

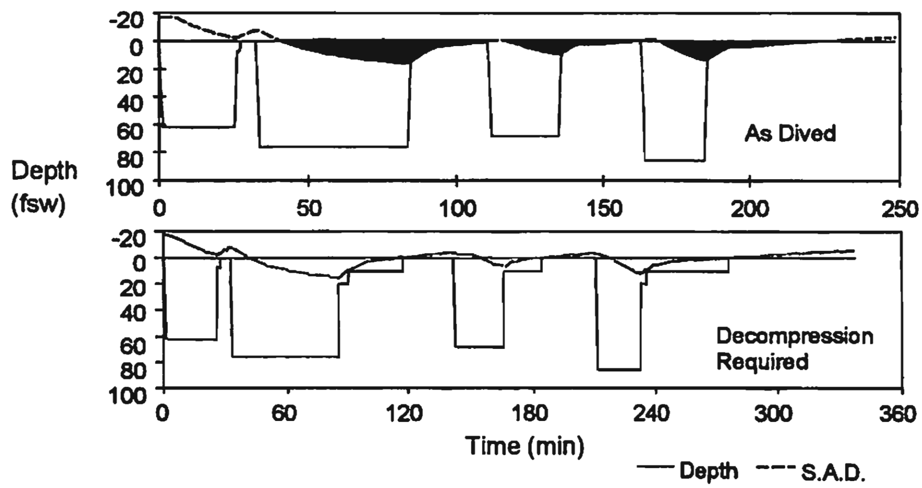


Figure 14. SAD Calculation - BC Dive Profile (DCS) (Lepawsky 1998)

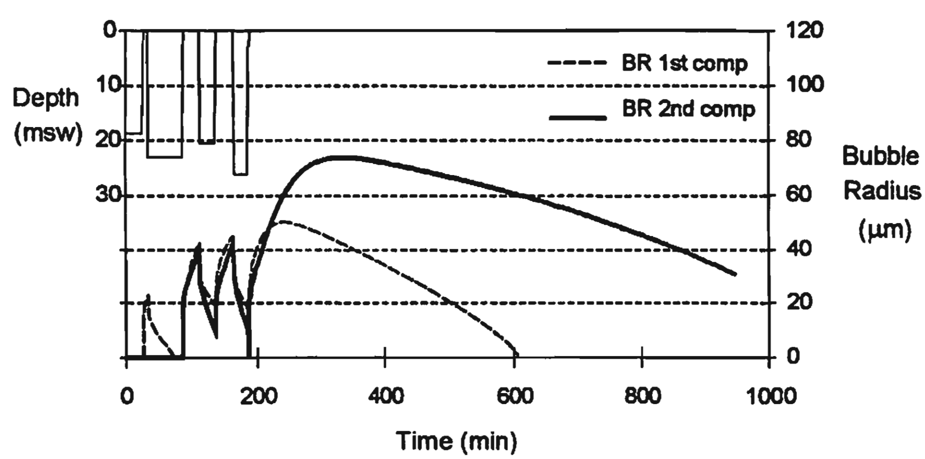


Figure 15. Bubble Evolution Calculation - BC Dive Profile (Lepawsky 1998)

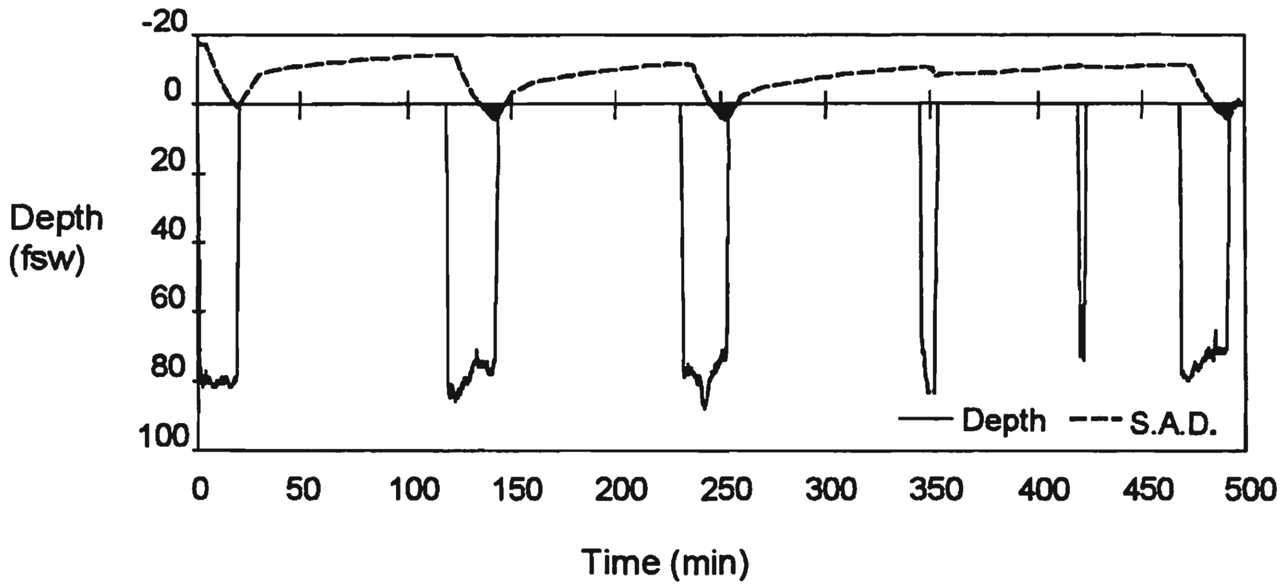


Figure 16. SAD Calculation - Maine Scallop Diver's Profile (Lehner and Pollard 1998)

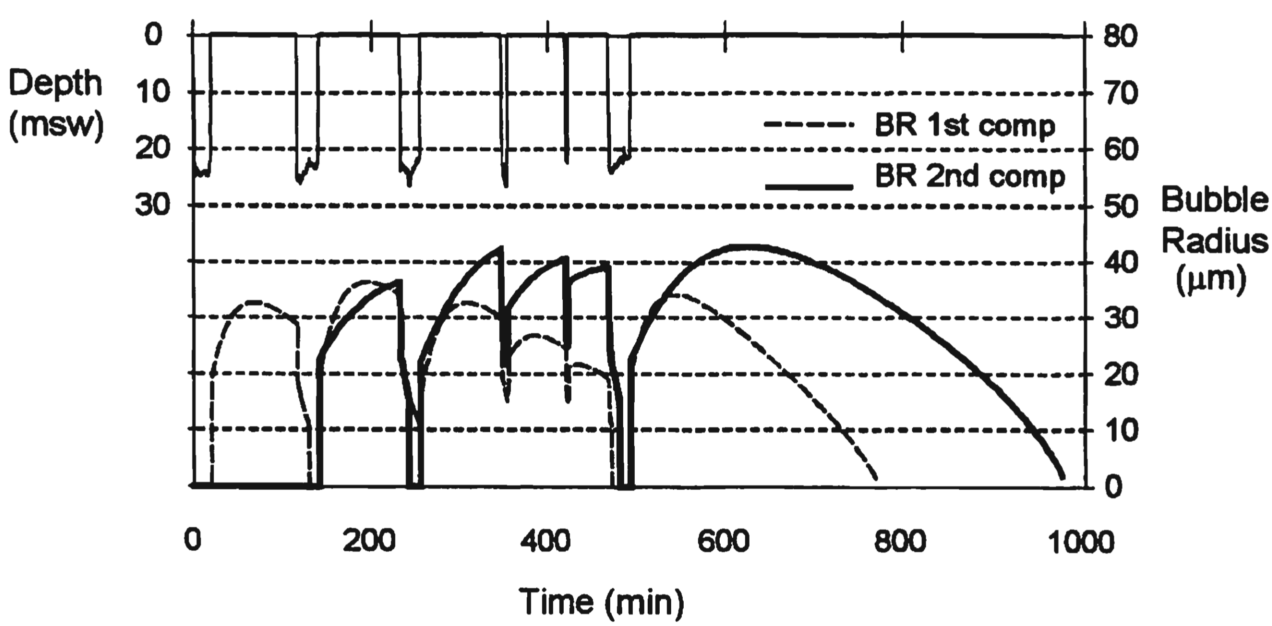


Figure 17. Bubble Evolution Calculation - Maine Scallop Diver's Profiles (Lehner and Pollard 1998)

DISCUSSION

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

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

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

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

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

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

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

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

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

Mr. Nishi: Mm-hmm.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Mr. Nishi: Yes.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Mr. Nishi: How can I make the comparison?

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

PROFILES OF MAINE SCALLOP AND URCHIN DIVING ACCIDENTS TREATED 1989 TO 1997

Albert A. Pollard, Charles E. Lehner, and Christopher E. L'Heureux

INTRODUCTION

Scallop and urchin divers in Maine have an occupational mortality rate 10 times higher than the state average. Five of these divers died between 1993 and 1997 for a mortality rate of 73.1/100,000. Commercial scallop divers engage in repetitive, deep scuba dives during the 1 November through 15 April harvest season. They usually work from open boats, sometimes without tenders, and often with minimal equipment. Typical scallop dives range between 60 and 120 feet of sea water (fsw). Urchin divers tend to be less experienced. Both types of divers are independent businessmen and few have health or dive accident insurance. Self-treatment is common. Recompression therapy is reserved for more serious symptoms and often is initiated by a concerned friend or wife. The actual incidence of diving accidents is unknown—but 2 to 3 more divers inquire about recompression treatment than are treated. Between 1989 and 1997, 41 scallop and urchin divers were treated at the Northern New England Hyperbaric Medical Center in Sanford, Maine. This report summarizes the diver and diving characteristics of those injured and treated.

BACKGROUND

Sanford is a small town in Southern Maine approximately 15 miles from the coast. The Northern New England Hyperbaric Medical Center is privately owned and on the campus of the H. D. Goodall Hospital, a small community hospital. Most of the scallop and urchin diving is done further north up the coast. With New England roads and weather, this distance requires a 3.5- to 6-h drive to the chamber.

Until 1996, we had the only clinical hyperbaric chamber north of Norwalk, Connecticut. Diving accident referrals were made directly from coastal hospitals, Diver's Alert Network (DAN) or divers simply appearing at the chamber. The chamber is a 5 feet diameter, double-locked, steel multiplace hyperbaric chamber. Oxygen is supplied by either Scott aviator masks or head tents.

During this 9-yr period, 107 divers were treated: 66 recreational divers, 7 commercial urchin divers, and 34 commercial scallop divers. Most divers were examined by AAP. Recompression treatments usually followed standard USN treatment tables.

CASE RECORD OF A TREATED DIVER

B.A. was a 20-yr-old male urchin scuba diver referred for pain, numbness, and tingling in his left upper extremity. He was Professional Association of Diving Instructors (PADI) open-water certified and had made an estimated 450 dives. He usually dove 3 days per week using "four tanks" each day at depths between 25 and 70 fsw. He did not use a dive computer or dive table but did have a depth gauge.

On the day of his accident he made three working dives of 40-min duration to 70 fsw. During each "tank" dive, he made one or two ascents to the surface to empty his 200-lb. tote of sea urchins. This reported surface interval was 15 min between the first two dives and 50 min between the last two. (Fig. 1)

He developed pain in his left shoulder after the second dive. The pain resolved during the third dive, but recurred at 30 fsw during the ascent. He rated the pain as an "8" on a 0 to 10 scale. After surfacing, the pain increased to a "10" and progressed down his left arm to his hand. The arm became weak and developed numbness and tingling.

He was treated with oxygen through a loose fitting "non-rebreather" hospital mask during the 5.5-h ambulance transfer. His pain had decreased 50% but he still had decreased strength and sensation in the left arm. He fully recovered after a USN TT6 treatment.

SCALLOP AND URCHIN DIVER PROFILES:

Maine has had a relatively stable population of licensed scallop divers varying between 303 and 366. Most of the Maine scallop harvest is taken by draggers. Scallop divers work in areas inaccessible to the draggers at depths usually between 60 and 130 fsw. They harvest during the coldest months of the year. The urchin market, in contrast, exploded in the late 1980s in Maine. Most of the urchin harvest is taken by divers. In 1992, the state began licensing harvesters and 807 were licensed. Licensees peaked in 1994 at 1,725 but has subsequently dropped to 904 in 1997 as the harvest has dwindled.

The scallop divers we treated tended to be older and far more experienced than urchin divers (Table 1). Approximately 80% of each group were certified, the most common certification was with PADI. Ten divers gave histories compatible with decompression sickness (DCS) which was generally "self" treated. If another five scallop divers with more vague histories of post dive "aches and pains" are included, then 41% of scallop divers surveyed may have had previous DCS.

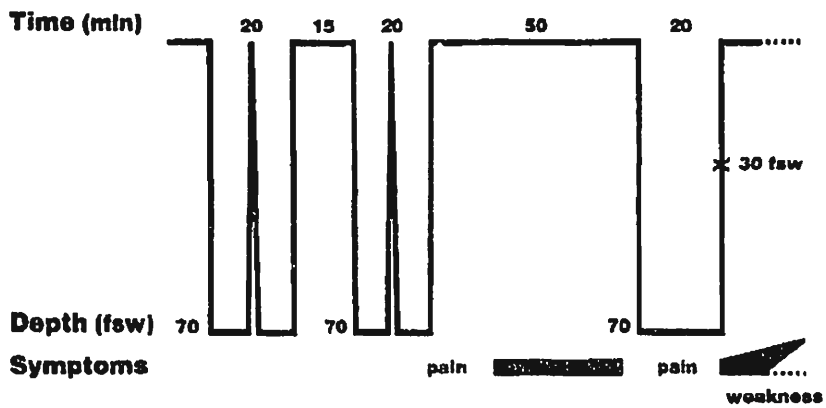


Figure 1: *B.A , a 20-yr-old urchin diver diving in 70 fsw. He usually dives 3 days weekly using four tanks per day.*

These divers record their dives by the number of "tanks" they use. A "tank" usually represents continuous time in the water. Many divers ascend to the surface once or twice during that "tank" to empty harvest bags. These divers averaged four "tanks" on the day they were injured (Table 1). They did not reduce the number or dives at greater working depths. Table 2 groups the divers by working depth and by the number of tanks used on the day of injury. Seventy-three percent were injured while performing repetitive dives in which the deepest dive was greater than 60 fsw. Most divers worked in a depth area where all dives were within 10 fsw of the maximum depth.

DIVING ACCIDENTS

The initial symptom in 4 urchin and 24 scallop divers with DCS was pain. In 1 urchin and 17 scallop divers, the pain progressed to paresthesia, anesthesia, and weakness. Eighty percent of the scallop divers had a neurologic component to their DCS (Table 3). Mild pain was not a presenting complaint. These divers described pain as if being "hit by a hammer" or a deep, gnawing ache in their joints that progressed up and down the affected limb(s). The pain either did not abate with alcohol or analgesics and/or kept them awake. Most symptoms were in the upper extremity. The urchin divers' symptoms of arterial gas embolism (AGE) began after being tossed upward in the surge. AGE in scallop divers resulted from emergency ascents when out of air or from buoyancy problems.

TREATMENT

One quarter of the divers pretreated themselves with alcohol or oxygen usually obtained from a welding source. They arrived at the chamber for treatment 6 h to 6 days after the decompression incident. Most of the divers were treated with USN TT6 or 6A. Symptoms resolved completely in about one half of them; the rest had some residual symptoms.

Most divers were injured in an area about 200 miles north of the chamber. They were typically seen in the local hospital emergency room where the base charge was $450 (Table 4). The 5 to 6 hour ambulance transfer and our emergency room fees added another $2,400. These charges were often higher depending upon their complaints and the knowledge of the initial emergency room caregiver. The prechamber charges were at least twice as much as the recompression treatment. Since most of these divers did not have diving or health insurance, these costs were often prohibitive.

CONCLUSIONS

The diving practices of the Maine scallop and urchin divers have led to unacceptably high risks. The five diver fatalities in the past 5 yr yields a non-seasonally adjusted fatality rate of 73.1/100,000. During the same period, the non-seasonally adjusted fatality rate for the entire Maine commercial fishery was 20.33/100,000 and the overall Maine occupational fatality rate was 7.13/100,000 (1). In the 9 yr between 1989 and 1997, we treated 34 scallop divers for DCS and AGE. Since the licensed scallop diver population has remained

Table 1: *Diver Profiles*

	Urchin	Scallop
n	7	34
Age, range in yr	26 (18–39)	34 (20–48)
Certification	6	27
Hx prev DCS	1	9 (+5 Poss. DCS)
Average reported dives	815 (25–2,000)	2,164 (50–10,000)
Tanks per day	4 (1–6)	4 (1–7)

Table 2: *Diving Profiles on Day of Injury*

Deepest Dive	Number of Tanks Used							
	1	2	3	4	5	6	7	8
<60 fsw	1	1	4	2	2	–	–	–
60–90 fsw	2	3	4	8	3	4	1	–
>90 fsw	–	–	1	3	1	1	–	–

Table 3: *Diving Accidents*

	Urchin, $n = 7$	Scallop, $n = 34$
Pain-only DCS	3	7
Neurologic DCS	2	25
AGE	2	2

Table 4: *Costs of Typical DCS Treatment* (Diving: Mt. Desert Island)

Initial ER	$ 450
Ambulance, 238 miles	1,988
Receiving ER	306
Chest x-ray	120
USN TT6	1,400
Total	$ 4,264

stable between 303 to 366 each year, we have treated approximately 10% of these divers. Conversations with these treated divers about their diving associates and inquiries from other apparently injured divers who did not present for treatment would suggest that the number of diving accidents is at least twice as many. Twenty-five to possibly 40% of those divers we treated had histories compatible with previous DCS. Butler (2), from his questionnaire survey of Maine urchin divers, found 78% of respondents claimed symptoms of DCS, AGE, or barotrauma. Clearly, scallop and urchin dive harvesting is among the most dangerous occupations in Maine.

The treated divers generally worked as often as weather permitted. As the urchin stock in shallow water has been depleted, divers have looked for them in deeper water. Some of the best scallop beds have been along previously closed underwater cable pathways in 90–120 fsw. These divers apparently used as many tanks in deep water as in shallow water. When the urchin fishery first boomed, the accidents may have been attributed to diver inexperience. Most of the treated divers had made hundreds to thousands of dives. Less than half these divers used dive computers or tables to plan their dives. Some believed the amount of air in the dive tank would always keep them within the "no decompression" limits, even with repetitive diving as long as the surface interval was about equal to the previous bottom time. Although only a few of these divers could use dive tables to plan repetitive dives; most knew they were diving "over the limits".

These seafood divers are a tough group that considers aches, pains, numbness, and tingling as part of the job. Many dive harvesters are from low socioeconomic backgrounds and can not get other jobs that offered the prospects of as much money (3). If symptoms develop, they self-treat. They wait for the symptoms to resolve spontaneously. Often it is a spouse or friend that convinces them to seek recompression treatment. Few of the treated divers had dive or health insurance. They function as independent businessmen and do not qualify for Worker's Compensation Insurance. Some of the divers that call apparently do not seek treatment because of cost. They also fear they will be told not to dive again or to change their diving patterns. Few understand the potential disabling consequences of DCS.

The long-term sequelae in these affected divers have not been studied. Multiple, repetitive dives with short surface intervals have been shown in Japanese diving shellfish harvesters to produce a high prevalence of dysbaric osteonecrosis (4). Maine scallop and sea urchin divers treated in the NNEHMC chamber follow similar dive profiles and presumably carry a high risk of developing dysbaric osteonecrosis (5) and disabling secondary osteoarthritis.

We acknowledge the important contributions of William C. Meade, M.D., Michael Perro, EMT, and Jeff Ciampa to this study.

REFERENCES

1. Ciampa J. Summary of fatal injuries experienced within the commercial fishing industry of Maine, 1993 through 1997. U.S. Coast Guard Marine Safety Office, Portland, Maine.
2. Butler WP. Maine's urchin diver: a survey of diving experience, medical problems and diving-related symptoms. Undersea Hyper Med 1995; 22:307–313.
3. Ciampa J. U.S. Coast Guard Marine Safety Office, Portland, Maine, Personal Communication.
4. Amako T, Kawashima M, Torisu T, Hayaski K. Bone and joint lesions in decompression sickness. Semin Arthritis Rheum 1974; (4):151–190.
5. Lehner CE, Pollard AA, Wilson MA, et al, Potential risk of dysbaric osteonecrosis among Maine scallop divers. Undersea Hyper Med 1996; 23(suppl):62.

COMPARATIVE ANALYSIS OF SOME EMPIRICAL SEA HARVESTING DIVE PROFILES

R. W. Bill Hamilton

INTRODUCTION

"Empirical diving" as covered in this Workshop comprises a wide variety of diving patterns and modes. These vary widely in techniques, and, as practiced, they vary widely in risk or occurrence of decompression sickness. Although some of the methods are clearly dangerous, in comparing the different methods it is not always easy to see intuitively which exposures are more risky, or to know the extent of the differences between different profiles in a quantitative way.

Many different types of empirical diving are addressed. These include sea urchin divers from both coasts of North America, abalone divers from the U.S. West Coast and South Australia, Mosquito Indian lobster harvesters, Turkish sponge and shellfish harvesters, Philippine and Thai fishermen, Baja California and Japanese Kyushu shellfish divers, Western Australia pearl divers, Hawaiian fishermen, Western Canadian geoduck harvesters and fish farmers, and several others. While there are similarities, there are also many differences in the various methods in use. To compare these profiles with each other it is necessary to submit them to the same type of analysis.

This paper attempts to make simple comparisons of some of the empirical dive patterns. These are based on computations, the same sort of computations that are used for developing new decompression tables. Because we wanted to analyze a wide variety of diving patterns, we chose two straightforward analytical methods and attempted to apply them in the same manner to all the profiles we examined.

METHODS

We analyzed representative profiles from the various groups for which we had data with two techniques. The most relevant technique is to follow through the dive profile in question and calculate a required decompression at the end. If little or no decompression is required then the empirical table should be about as conservative as the method used for the analysis, but if the empirical table provides inadequate decompression then the analysis will show that much more decompression time is needed.

The other analytical method is a maximum likelihood statistical method that compares the test profiles with a data set of some 2000 documented air and oxygen-nitrogen dives. For each test profile this yields a probability that decompression sickness will occur. This makes a rough comparison possible even though the profiles in question come from dives with different characteristics.

We also tried to compare the profiles by inspection of hypothetical gas loadings. It is difficult to interpret a comparison of these values from different types of dive profile, so the amount of additional decompression needed at the end of the dive seemed to be the appropriate way to use gas loading information in making comparisons.

Maximum likelihood: This is a method of estimating a probability of decompression sickness using the method of maximum likelihood. This technique allows dive profiles of the same general type or pattern to be compared, but the dives need not have the same profile. The method is somewhat like the method of least squares that is used to fit a line to a set of data points. The maximum likelihood method compares a specific profile to a "data set" of dive profiles for which the incidence of decompression sickness is known and to which the analytical program is "calibrated." The method works better and has more narrow confidence limits, when the profiles being evaluated are similar to those used in compiling the calibration data set. In this case, dive profiles are compared to a data set of basic air dives. The program yields a single estimated probability of decompression sickness, P_{DCS}, and a set of 95% confidence limits which show how well the tested profile fits to the data set.

The algorithm for this maximum likelihood technique was obtained from Peter Tikuisis and Ron Nishi at DCIEM (the method is discussed in Tikuisis, et al, 1988). This algorithm is useful for comparing typical air dive profiles. The algorithm has been "calibrated" with a data base of some 2000 typical air dives. The method seems to overestimate P_{DCS} on standard dives. In this configuration it is not well suited to analysis of multiple dives; it appears to retain the high estimates of dives in a sequence even if a proper decompression is done after the last dive (e.g.., Example 2a, below), and the sort of dives done by most sea harvesters are so different from the data set used to calibrate the program that the confidence intervals are rather high. However, the method is useful for comparisons and provides potentially useful estimates in orders of magnitude. Typical P_{DCS} values for air dives of the sort used in the data set that are acceptable for routine diving, such as those in the U.S. Navy Diving Manual, would be in the range of 2 to 3 %.

Table 1: Analysis of Fatal No-Stop Dives[a]

Diver	Depth, msw/t, min	No-stop P_{DCS} %	95% Confidence	Deco Needed, min	Deco P_{DCS}, %	95% Confidence	Basecase DJ48a-
1	25.2/360	26.3	14.8-46.7	541	8.9	2.9-24.7	0.h00; h01
2	24.3/300	23.0	13.4-39.2	412	8.9	3.6-22.7	a.h00; h01
3	23.0/300	21.7	12.7-37.1	366	9.3	3.8-23.1	b.h00; h01
4	23.0/330	22.8	13.0-39.9	407	9.1	3.5-23.8	b/h00; h01
5	24.3/300	23.0	13.4-39.2	412	8.9	3.5-22.8	a.h00; h01
6	25.2/300	24.2	14.2-41.3	444	8.9	3.4-23.2	0.h00; h01
7	28.2/270	26.3	15.8-3.7	494	8.9	3.4-23.8	c.h00; h01

[a]Analysis of a set of seven no-stop dives. Shows decompression time needed for a "proper" decompression, and probability of DCS for air decompression and no-stop ascent. These dives were done by Mexican seafood harvesters is Baja California. The P_{DCS} and confidence limits for the original dives are shown in the 3rd and 4th columns. (Data from Dr. John Paul Jones.)

Decompression needed: The second method of analysis was based on the hypothetical "gas loadings" accumulated on a dive and remaining after decompression to the surface. Looking at arrays of these numbers would be a difficult way to compare dives of different profiles (specifically , profiles that are limited by different compartments), and interpretation is not intuitive or consistent. Therefore we "evaluated" the accumulated gas loading on each profile examined by calculating the decompression needed to take the diver to the surface at the end of the bottom time of each dive or dive sequence against the same set of ascent constraints. This would be equivalent to allowing the gas loadings to decay to the appropriate values for a diver at surface pressure. These calculations used the same computational algorithm and parameters for all dives.

We performed the computations with Hamilton Research's DCAP, using a practical neo-Haldanian algorithm identified as Tonawanda IIa, which uses 11 compartments from 5 to 670 min and a constraint matrix of M-values designated MM11F6 and designed for stressful air dives (Hamilton, et al, 1980; Hamilton and Kenyon, 1990; Hamilton, 1992). This matrix has been quite successful in application (Hamilton, Muren, et al, 1988; Hamilton, Yamaguchi, et al, 1998). The significant point here is that the same criteria were used for all dive analyses. All displays use meters of sea water, defined as 0.1 bar. The input criteria for each computation are recorded in a "Basecase" that allows each trial to be recovered when needed; the actual Basecases are not include in this report.

The amount of time needed for decompression is a single more or less uncomplicated number that can be compared with others, even though it may not take all factors into account. If this number is greater than the time used by the empirical diver the difference in time is equivalent to "omitted decompression" according to the criteria for the basic calculation.

The fact that a calculation shows additional decompression time would be needed according to the 11F6 computation criteria does not necessarily mean that the analyzed dive does not provide an adequate decompression, since factors such as accommodation due to frequent daily diving, fitness, etc., may be beneficial and are not taken into account. Likewise factors such as yo-yo diving, reverse dive profiles (deep after shallow), etc., are not taken into account. However, profiles that require many minutes of additional decompression are likely to be risky.

RESULTS

Acquiring profiles: In addition to the problem of how to do the analysis, we had the problem of determining what profiles to look at. We requested "typical" or "sample" profiles from other participants in this workshop with whom we had contact. We received many profiles by mail and e-mail, and were able to get some additional ones at the workshop, but for a variety of reasons we were not able to get samples of all the profiles reported on in the Workshop. However, most of the different types of empirical diving discussed at the Workshop are represented. In some cases we constructed what we regard as a "typical" profile from information presented. Most profiles analyzed are approximate and intended more to be typical than precise, but this does not affect the analysis or its interpretation.

We also include a chart of 7 diving fatalities that we analyzed for Dr. John Paul Jones, prepared for another report (Table 1).

These examples show the characteristics of the dive profile used for the analysis. Each uses 3 bullets. The notation is as follows:

- Profile identification and source.
- (Depth in msw)/(time in min) + (surface interval in min) + (next dive, etc), followed by the estimated P_{DCS} for the sequence with the confidence interval and the identification of the Basecase used for the computation. P_{DCS} values are percentages, but the % sign is not shown.
- Calculated additional decompression that might be needed for that dive using the conservative criteria mentioned above, and the estimated P_{DCS} of the newly calculated profile with the confidence interval and identification of the Basecase used for the computation.

ANALYSES

Example 1:

- Philippine diver fatality reported by Richard Dawson, data from Alan Bourke.
- 60 msw/105 min + 15 min + 60 msw/45 min, no stops. P_{DCS} = 44.8! ±31.2-64.1. DH5NA6.H00.
- Decompression needed: 1005 min. With decompression P_{DCS} = 13.8. ±7.8-25.0. DH5NA6.H01.

Example 2a

- Mosquito Indian lobster divers, data from Richard Dunford, profile taken from *Pressure* 23(2), 1994 March.
- 30msw/120 min + 180 min + 30 msw/120 min, no stops. P_{DCS} = 31.8 ±20.7-48.9. DH5NA1.H00.
- Decompression needed: 330 min. With deco, P_{DCS} = 22.4 22.5 ±14.1-35.8 . DH5NA1.H01.

Example 2b:

- Mosquito Indian lobster divers, 3 five-excursion sets, 18 min each excursion. By Richard Dunford.
- Roughly 20msw/18min x 5 (total per set 104 min), three times, with surface intervals of 81 and 101 min, no stops. P_{DCS} = 28.2 ±14.6-54.7. DH5NA0.H02.
- Decompression needed: 153 min. With decompression, P_{DCS} = 24.5 ±11.6-52.2. DH5NA0.H03.

Example 3:

- Japanese Kyushu shellfish divers, reported by Dr. Mahito Kawashima.
- 20 msw/50 min + 5 min at surface, repeated for total of 5 times, no stops. P_{DCS} = 19.5, ±11.8-32.7. DH5NA2.H00.
- Decompression needed: 200 min. With decompression, P_{DCS} = 13.4 ±7.4-24.2. DH5NA2.H01.

Example 4:

- Baja California shellfish diver, reported by Dr. John Paul Jones. Similar dives are shown in Table 1.
- 28 msw/150 min, fast ascent, no stops. P_{DCS} = 17.3 ±11.5-26.1 DH5NAA.H00.
- Decompression needed: 245 min. P_{DCS} with this decompression = 9.0 ±5.0-16.1 DH5NAA.H02.

Example 5a:

- Turkish sponge/shellfish divers, reported by Dr. Maida Çimçit.
- First (easy) option: 30 msw/25 min + 120 min + 30 msw/25 min, no stops. P_{DCS} = 5.1 ±2.5-10.4. DH5NA9.Hz0.
- Decompression needed: 8 min. P_{DCS} 4.5 ±2.7-7.8. DH5NA9.Hy0.

Example 5b:

- Turkish sponge/shellfish divers, reported by Dr. Maida Çimçit.
- Second (stressful) option: 50msw/30min + deco 9msw/3min, 6msw/8min, 3msw/9min + 120min at surface + 50msw/30min + deco 9msw/3min, 6msw/8min, 3msw/9min + 120min at surface + 50msw/25min + deco 9msw/3min, 6msw/8min, 3msw/9min Total time 402 min. P_{DCS} = 23.0 ±16.7-32.0. DH5NA9.H01
- Decompression needed: 159 min (less the normally used 20 min = 139 min more). P_{DCS} with deco = 19.7. ±14.2-27.3. DH5NA9.H02.

Example 6:

- Thai fishermen, reported by David Gold.
- 20 msw/60 min + 20 min + 18 msw/50 min + 80 min + 16 msw/40 min + 30 min + 15 msw/100 min + 15 min + 28 msw/20 min. P_{DCS} = 18.8 ±12.9-27.3. DH5NAC.H00.
- Decompression needed: 104 min. After deco: P_{DCS} = 15.7 ±10.7-23.0. DH5NAC.H01.

Example 7a:

- Hawaiian fisherman, reported by Frank Farm and Dr. Bob Overlock, included as part of an example of successful inwater recompression treatment.
- Three dives. 43 sw/14 min + 22 min + 33 msw/15 min + 32 min + 49 msw/12 min, no stop P_{DCS} = 11.3 ± 8.3-15.3. DH5NA5.H00.
- Decompression needed after 3rd dive: 59 min. After deco P_{DCS} = 9.0 ± 6.7-12.1. DH5NA5.H01.

Example 7b:

- Hawaiian fishermen, looking only at the first two dives from 7a, to be more typical of the way these fishermen work.
- 43 msw/14 min + 22 min + 33 msw/15 min P_{DCS} = 5.5 ±3.7-8.0. DH5NA5.H02.
- Decompression needed: 30 min. After deco P_{DCS} = 4.6 ±3.1-6.8. DH5NA5.H03.

Example 8a:

- Australian pearl divers (1998 version), reported by Dr. Bob Wong Nine dives/day, with oxygen decompression.
- 3 dives (1, 2, & 3): 19 msw/40 min + 12 msw/2 min air + 9 msw/5 min O_2 + 20 min sfc, then
  2 dives (4 & 5): 19 msw/40 min + 12 msw/2 min air + 9 msw/10 min O_2 + 20 min sfc, then
  3 dives (6, 7, & 8), 19 msw/40 min + 12 msw/2 min air + 9 msw/8 min O_2 + 9 msw/4 min air + 9 msw/8 min O_2 + 20min sfc, then
  1 dive (9): 19msw/40min + 12msw/2min air + 9msw/10min O_2 + 9msw/4min air + 9msw/10min O_2 for a total of 9 dives. P_{DCS} at the end = 12.6 ±7.6-20.8. DH5NA7.H05.
- Decompression needed: 15 min. After deco, P_{DCS} = 12.3 ±7.4-20.3. DH5NA7.H06.

After the third day of this routine, needed deco seems stable at 18 min. DH5NA7.H07.

Example 8b:

- Australian pearl divers, 35 msw rotational dive, for deeper work, reported by Dr. Bob Wong

- Four dives/day, with decompression. Ascent rate 5msw/min to 21msw, then 3 msw/min.
  First dive: 35msw/25min + 12msw/2min + 9msw/10min O_2 + 80min sfc, then
  2nd dive: 35msw/25min + 12msw/2min + 9msw/15min O_2 + 90min sfc, then
  3rd dive: 35msw/25min + 12msw/2min + 9msw/20min O_2 + 100min sfc, then
  4th dive: 35msw/25min + 12msw/2min + 9msw/25m O_2
. P_{DCS} = 9.3 ±6.4-13.5. DH5NA7.H08.
- No additional decompression needed; same P_{DCS}. DH5NA7.H09.

Example 9:
- British Columbia geoduck diver, reported by Dr. Mike Lepawsky
- 12 msw/200 min (USN no-stop limit) P_{DCS} = 5.3 ±3.5-8.0. DH5NAB.H00.
- Decompression needed: 28 min After deco, P_{DCS} = 4.4 ±2.9-6.8. DH5NAB.H01.

Example 10:
- Dive by a Maine sea urchin diver, reported by Col. Bill Butler.
- 4 dives: 9 msw/60 min + 15 + 9 msw/60 min + 30 + 9 msw/60 min + 25 + 9 msw/60 min; no stops. P_{DCS} = 3.9 ±2.3-6.5. DH5NAD.H00.
- No decompression needed after these dives. Same P_{DCS}. DH5NAD.H01.

DISCUSSION

Review of the analyses: The table includes information on 7 fatal dives in Baja California investigated by Dr. John Paul Jones, who is primarily interested in bone necrosis. It is not surprising that dives that skip this much decompression can be fatal.

Example 1, a fatality reported by Dawson and Bourke, calls for about 1000 min of decompression using air as the breathing gas. This of course is not realistic to perform, but by way of comparison the U.S. Navy Exceptional Exposure Air Tables, which are not regarded as being especially reliable in this range, would call for more than 500 min of additional decompression.

The severity of the dives in Examples 2a, 2b, and 3 are intuitively risky. It is surprising, not that these harvesters eventually get serious neurological and debilitating DCS, but rather that are able to carry on this work as long as they do. Note that the P_{DCS} values for the dives that include the additional decompression are almost as high as those without the extra decompression. The reason is that this particular maximum likelihood program accumulates the risk from the initial dives and does not "recover" from inadequate decompression in a sequence the way a final decompression can deal with accumulated gas loading (more or less).

Examples 5a and 5b, the Turkish sponge and shellfish divers use relatively responsible decompression patterns.

The Australian Pearl Divers in Example 7a use an empirical table that provides a quality decompression. This table has been revised over the years to virtually eliminate DCS. The decompression needed at the end of this day of diving is 15 minutes, a trivial addition to a full day of diving. The stated incidence (Wong, this Workshop) is 0.01%, and the profiles look as if that low incidence can be expected. The decompression is quite sophisticated and custom-designed for these dives. Decompression becomes more thorough as the number of dives increases. The calculated P_{DCS} scores for these multiple dives, as mentioned, are artificially high, undoubtedly because of the way the program handles multiple dives. Breathing oxygen at 9 msw, a PO_2 of 1.9 atm, invokes a warning during the calculations. This is too high for untethered scuba divers, but for a diver on surface supply with some supervision it is acceptable. To guard against CNS toxicity the table provides air breaks during the oxygen breathing when longer times are required.

The tables for the "rotational" deeper dives in Example 7b used by the Australian pearl divers are also highly reliable. Two teams of divers alternate, with one team diving during the surface interval of the other team. This analysis found that no extra decompression was needed.

The geoduck divers in Example 8 use a no-stop profile from the U.S. Navy Standard Air Decompression Tables, so this is not exactly an "empirical" example. Calculations of this dive call for an additional 28 min of decompression, indicating the table as it is being used is not especially risky. The specific table examined here is among those whose no-stop time was shortened in the 1993 USN statistically-based tables.

Comments: Clearly some of the sea harvesters have learned one way or the other to make reliable decompressions. As the main message of the Workshop states, the situation is dreadful and out of control in some areas, and seems not to be troublesome in others.

The examples are reasonably clear as to the risk of the various profiles, but one thing we lack on many of these is good information on the outcome of the use of the profiles. The general level of reliability in some cases is given in other parts of the Workshop proceedings. Some profiles, such as those of the Mosquito divers, are clearly so bad as to leave virtually all the divers with significant neurological problems for the future, and this has been well reported. Table 1 and Example 1 deal with fatalities.

A comment on the word "empirical." An inclusive term for the many types of diving covered in this workshop was not obvious. Other terms used for similar situations were "indigenous diving," "diving fishermen," "native diving," "sea harvesting," etc. In the past the word "empirical" has been applied in a negative way to some methods of decompression computation, when the proper word would have been "arbitrary." A popular apothegm addressing this is, "What works, works." In fact all successful contemporary decompression methods, no matter how sophisticated the mathematics and the modeling, have an empirical basis. This phenomenon is documented in the UHMS Workshop on Validation of Decompression Tables, Schreiner and Hamilton, 1989) and in commentary that has followed it (Hamilton, 1992)..

REFERENCES

Hamilton RW. 1992 Winter. Preparing decompression tables based on operational experience. Underwater Magazine 3(4):10-12.

Hamilton RW, Kenyon DJ. 1990. DCAP Plus: New concepts in decompression table research. In: MTS 90: Science and technology for a new ocean's decade. Vol 3. Washington: Marine Technology Society.

Hamilton RW, Kenyon DJ, Peterson RE. 1980. Effect of duration of exposure to M-values on their validity. In: Berghage TE, ed. Decompression theory. 29WS(DT)6-25-80. Bethesda, MD: Undersea Medical Society.

Hamilton RW, Muren A, Röckert H, Örnhagen H. 1988. Proposed new Swedish air decompression tables. In: Shields TG, ed. XVth annual meeting of the EUBS: European Undersea Biomedical Society. Aberdeen: National Hyperbaric Center.

Hamilton, RW, Yamaguchi H, Okamoto M, Naraki N, Mohri M. 1998 Mar. Development of advanced decompression tables for diving scientists in Japan. Tarrytown, NY; Kanagawa, JAPAN: Hamilton Research, Ltd.; JAMSTEC.

Schreiner HR, Hamilton RW, eds. 1989 May. Validation of decompression tables.UHMS 74(VAL)1-1-88. Bethesda, MD: Undersea Hyperbaric Medical Soc.

Tikuisis P, Nishi RY, Weathersby PK. 1988 Jul. Use of the maximum likelihood method in the analysis of chamber air dives. Undersea Biomed Res 15(4):301-313.