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# HEALTH RISKS OF U.S. NAVY DIVING

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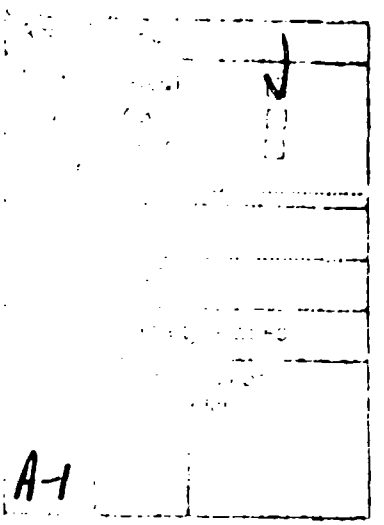
## Contents





## List of Illustrations

## SUMMARY

### Problem

Diving is one of the most hazardous of occupations, primarily because divers perform their duties in an environment unnatural for humans. In the event of equipment failure or a change in the environment, the diver could be injured or suffer a disorder that might be manifest immediately or many years later.

### Objectives

From 1981 to 1985, eight studies were conducted at the Naval Health Research Center (NHRC) to identify the short- and long-term health effects possibly associated with being a U.S. Navy diver. The purpose of this report was to summarize and evaluate the eight studies and develop conclusions and recommendations for the Medical Department and diving community.

### Approach

Diver information from 1968 to 1979 on 11,664 enlisted male and female divers, 2,027 male and female diving officers, and 1,174 diving accidents was obtained from the computerized file of Diving Log-Accident/Injury Reports (OPNAV 9940/1), which was provided to NHRC by the Naval Safety Center in Norfolk, VA. Records from the Naval Medical Inpatient file were extracted for all divers and nondiver controls who were hospitalized during the 12-year study period. Variables obtained from the service and career history files included dates of service entry and separation from active duty, reason for separation, birth year, and Navy occupation. Analyses consisted of computations of age-adjusted observed and expected frequencies of hospitalizations and rates per 10,000 strength of hospitalizations, medical boards, physical evaluation boards, and mortality. To determine the significance of differences in rates between groups, 95% confidence intervals were computed.

### Results

Results showed that enlisted male divers had significantly higher hospitalization rates than controls for environmentally induced disorders (primarily decompression sickness) as well as joint disorders, respiratory diseases, and deflected nasal septum at ages 23-28. Inexperienced enlisted divers and officers as well as nongraduates from training were at increased

risk of being hospitalized for stress-related conditions, especially alcohol abuse. Diving officers had higher hospitalization rates than other officers for joint and neurological disorders. Other potential diving-related health risks included musculoskeletal disorders among UDT/SEAL divers and respiratory diseases and pain symptomatology among master divers. Dives performed at the greatest depths and those specifically conducted for "selection" and "experimental" purposes had the highest accident incidence rates. Divers older than 37 years had the lowest mishap rates. The aftereffects of decompression sickness consisted of the two diagnostic clusters of symptoms and headache and disorders of the arteries and veins. Three lives were lost to air embolism, and three divers suffered ear and hearing problems because of a barotrauma incident.

## Conclusions

Results of these studies pointed up the minimal adverse effects of diving experience on the incidence of hospitalizations and accidents among members of the U.S. Navy diving community. The impact of the aging process was greater among nondivers than divers which was inferred from nondivers' higher rates of circulatory disease hospitalizations. The lowest diving accident rates were observed among older divers.

## Recommendations

The Navy Medical Department and members of the diving community should be apprised of the potential diving-related health risks identified in this study. Also to be emphasized is the need to promote and continue adherence to the procedures developed in the U.S. Navy diving community to ensure the safety and excellent health status of all divers. To fully assess the health consequences of diving, future research should be designed to examine the medical problems treated at diving sites and outpatient medical facilities and to explore the relationship of other factors to hospitalizations and diving mishaps.

# Health Risks of U.S. Navy Diving

Diving is considered to be one of the most hazardous of occupations, primarily because divers perform their duties in an environment unnatural for humans (1). In the event of equipment failure, an incorrect decision, a change in the underwater surroundings, or even a lapse in concentration, the diver could be injured or suffer a disorder that might be manifest immediately (e.g., nitrogen narcosis or high pressure nervous syndrome) or many years later, such as dysbaric osteonecrosis or the "silent bend" (2-3). At least 20 specific types of illnesses and injuries, including decompression sickness (DCS), otitis externa, pneumothorax, barotrauma, and air embolism, have been identified in the literature as associated with diving (4-7). Other disorders might occur in the musculoskeletal, respiratory, circulatory, or nervous systems, all of which have been determined to be susceptible to injury or disease from adverse diving circumstances. Moreover, because diving is a hazardous occupation, perhaps the incidence of stress-related disorders would be higher than expected, particularly in relation to the extent of diving exposure and the rigors of training.

From 1981 to 1985, a series of studies was conducted at the Naval Health Research Center to identify the short- and long-term health effects possibly associated with being a U.S. Navy diver (8-15). The rationale for these eight projects was to provide the Medical Department of the Navy and the diving community with information concerning the health risks of diving. The purpose of this report was to summarize and evaluate the eight studies and develop overall conclusions and recommendations for the Medical Department and diving community.

In the first study, extent of diving exposure was examined in relation to hospitalizations for 31 specific environmentally induced and stress-related conditions, which were subsumed under six diagnostic categories. The second study compared hospitalization rates between divers and nondivers to determine whether or not risks for the aforementioned diagnoses and categories were higher among diver than nondiver enlistees. Also examined were differences in rates between groups for deaths and medical and physical evaluation boards. A similar study, the third, was designed to identify

health risks unique to the diving officer population; comparisons of hospitalization rates for the six categories and 31 diagnoses were conducted between diving officers and a control group of nondiving officers. The fourth project focused on the differences in hospitalizations among six enlisted diver classifications and two diving officer designations. In the fifth study, the underlying factors of U.S. Navy diving accidents were analyzed with and without dive depth adjustment. The sixth and seventh studies concerned the short- and long-term health effects possibly associated with such specific diving mishaps as DCS, air embolism, and barotrauma. The final study was designed to follow the posttraining inpatient medical and career histories of graduates and nongraduates of U.S. Navy diving school during a 12-year follow-up.

**DATA SOURCES**

Four data bases were used as sources for these studies. Diver information was obtained from the computerized file of Diving Log-Accident/Injury Reports (OPNAV 9940/1), which was provided to the Naval Health Research Center, San Diego, CA, by the Naval Safety Center in Norfolk, VA. This file consists of records of each dive performed by a Navy diver as well as a separate report for each diving accident that occurred. Identified from this file, the diver population was comprised of 11,584 enlisted men and 80 enlisted women and 1,977 male and 50 female officers who performed approximately 700,000 dives during the period from January 1968 through December 1979. Data extracted from this file included diver classification; number of dives, bottom hours, and diving months; last year of diving; height and weight; and first year of diving in each diver classification. Also examined were 1,174 diving mishaps recorded from January 1968 to May 1981. Data extracted on each diving mishap consisted of dive depth, time of day, temperature (air, surface, and bottom), dive purpose, decompression schedule type, number of dives performed during the previous 24 hours, submergence time, and age as well as type of accident, most significant manifestation or symptom, organ system involved, phase of the dive when complications were initially detected, treatment outcome, and number of days lost from duty for treatment.

Records from the Naval Medical Inpatient file were extracted for all divers and nondiver controls who were hospitalized in a naval medical

facility during the period from January 1968 through December 1979. Data selected from this file, which was obtained from the Naval Medical Data Services Center, Bethesda, MD, included dates and diagnoses for all hospitalizations as well as the patient's age at admission and the cause code for each accidental injury hospitalization. Comparable information was extracted from all records of deaths and medical board and physical evaluation board actions. Numeric codes for all diagnoses were adapted from the Eighth Revision of the International Classification of Diseases Adapted for Use in the United States (ICDA-8).

The Naval Enlisted Service History file and the Naval Officer Career History file provided data for enlistees and officers, respectively, on date of service entry, birth year, occupational specialty or designator, and date and reason for separation or retirement from active duty. Dates of service entry and separation or retirement from active duty were used to compute either the mean number of individuals on active duty per year or the number of person-years at risk for a specified period of time. The mean populations at risk were determined by averging the numbers of personnel on active duty by year while person-years at risk were computed by summing the number of men on active duty for each year of the specified time range.

**METHODS**

Analyses of the medical events included the computation of rates per 10,000 strength of hospitalizations, medical boards, physical evaluation boards, and mortality. To calculate these rates, the numbers of medical events or deaths were tabulated for a specified diagnosis or diagnostic category, multiplied by 10,000, and divided by the mean population or person-years at risk. To determine the significance of differences in rates between groups, 95% confidence intervals were computed using the normal distribution for admissions and medical boards and the Poisson distribution for physical evaluation boards and deaths (rarely occurring events).

To eliminate the effects of age in computations that were not performed by specific ages, the data were adjusted using the indirect method of age adjustment (16). This procedure was accomplished by compiling the numbers of medical events for any diagnostic category or diagnosis in each specified age

range of the total diver population which provided the standard population figures to be used in computing the expected number of these events. Proportions of each age interval in the study population then were computed from a frequency distribution. Frequencies in the standard population were multiplied by the proportions in the study population, and the values were summed to obtain the expected number of hospitalizations for each category and diagnosis. Comparisons were conducted between observed and expected frequencies of disease. Miettinen probabilities were calculated to determine the significance of differences between these observed and expected frequencies (17).

## Effects of Exposure on the Health Status of U.S. Navy Enlisted Divers

The objectives of this study were (a) to examine the hospitalization rates of U.S. Navy enlisted divers for disorders reported to be diving related or stress induced and diseases in organ systems identified as being susceptible to diving-related conditions and (b) to establish whether or not exposure (number of dives) was associated with hospitalization rates.

### METHOD

To assess the impact of exposure on hospital admissions, the male enlisted diver population ($n$ = 11,584) was divided into subpopulations on the basis of number of dives performed (1-20, 21-100, and more than 100 dives). Diagnoses identified in the literature as associated with diving or hypothesized as stress related (18) were included in the tabulations of hospitalizations for this study. These diagnoses were condensed into 31 subcategories which, in turn, were subsumed under the six categories of Diseases of the Musculoskeletal System, Diseases of the Circulatory System, Diseases of the Nervous System and Sense Organs, Diseases of the Respiratory System, Stress-related Disorders, and Environmentally Induced Disorders. Data extracted from the Naval Enlisted Service History file were birth year, year entered service, and reason and date of separation from active duty.

Annual hospitalization rates per 10,000 strength across the 31 diagnoses were computed by age interval and level of diving experience. The numbers of hospitalizations for the three exposure levels also were age adjusted using the indirect method of age adjustment (16). Comparisons of the Miettinen probabilities revealed whether or not there were significant differences among the three exposure levels (17).

### RESULTS AND DISCUSSION

Figure 1 is a graphic presentation of total hospitalization rates for the six selected disease categories across intervals of age and diving experience. As shown, total rates increased significantly ($p < .05$) with age but did not vary with level of exposure.

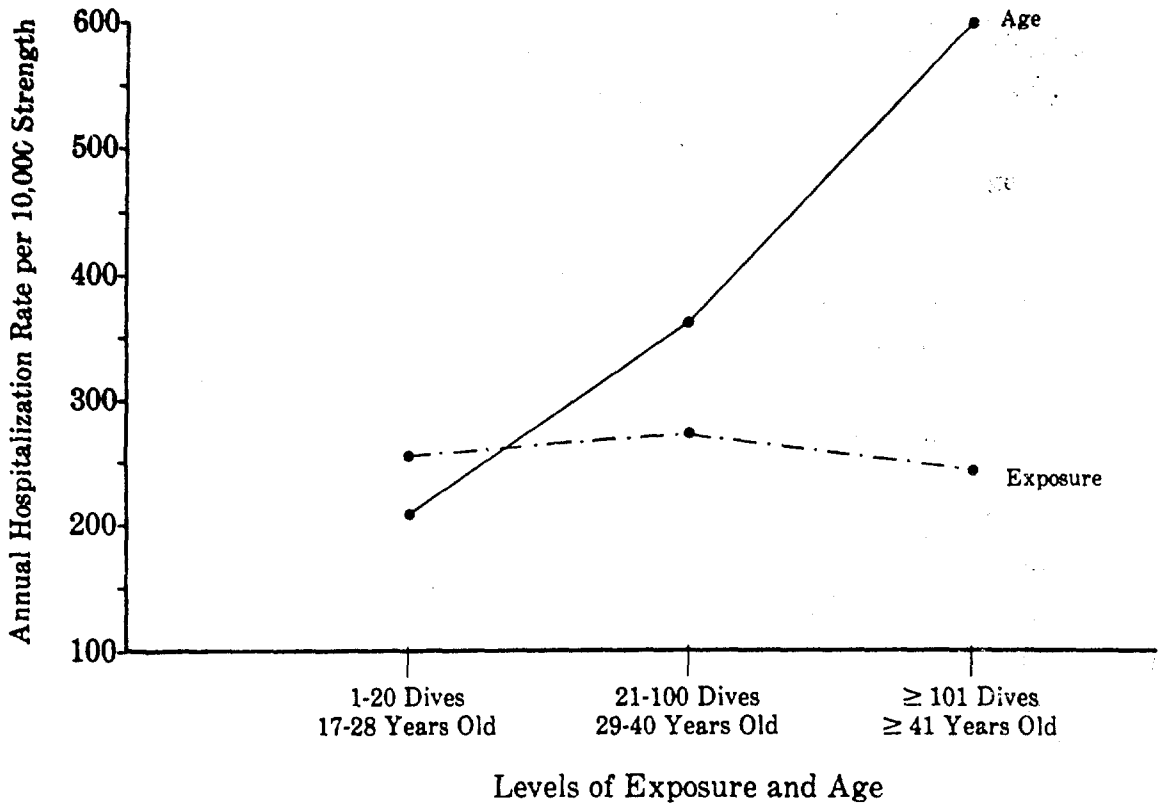



Figure 1. Hospitalization rates for diving-related disorders by age and exposure level.

Age-adjusted hospitalizations by exposure level and diagnosis are shown in Table 1. The musculoskeletal disease category alone accounted for more than 40% of all hospital admissions recorded for the six categories. In comparisons across exposure levels, results indicated that divers who performed more than 100 dives had significantly fewer hospitalizations than expected for musculoskeletal conditions. Divers with records of 21 to 100 dives were observed to have significantly more hospitalizations than expected for diseases of the bone. No hospitalizations were reported for dysbaric osteonecrosis, which indicated that the prevalence of this very serious, but uncommon and rarely symptomatic (19-20), disease could not be determined on the basis of Navy divers' hospital records.

For the category of stress-related disorders, the least experienced group (1-20 dives) had significantly more hospitalizations than expected while the most experienced divers had fewer than expected. Other comparisons

TABLE 1

COMPARISON OF EXPECTED AND OBSERVED HOSPITALIZATION FREQUENCIES AMONG U.S. NAVY DIVERS BY AGE-ADJUSTED LEVELS OF DIVING AND MAJOR DIAGNOSTIC CATEGORY, 1968-1979

| | Number of Dives and Hospitalizations | | | | | |
|---|---|---|---|---|---|---|
| | 1-20 Dives | | 21-100 Dives | | ≥ 101 Dives | |
| Diagnostic Category | Expected | Observed | Expected | Observed | Expected | Observed |
| Diseases of the Musculoskeletal System | 357 | 378 | 340 | 345 | 216 | 190* |
| Diseases of the Joint | 132 | 144 | 114 | 106 | 69 | 65 |
| Disorders of the Spinal Column and Back | 98 | 110 | 104 | 100 | 70 | 62 |
| Diseases of the Connective Tissue and Muscle | 63 | 65 | 60 | 66 | 38 | 30 |
| Diseases of the Bone | 35 | 26 | 34 | 50** | 22 | 15 |
| Arthritis/Rheumatism | 29 | 33 | 28 | 23 | 17 | 18 |
| Stress-related Disorders | 134 | 180** | 132 | 115 | 84 | 55** |
| Alcohol Drug Abuse | 59 | 72* | 66 | 61 | 45 | 37 |
| Transient Situational Disturbances | 25 | 36* | 22 | 18 | 13 | 6* |
| Neuroses | 21 | 35** | 18 | 10* | 11 | 5* |
| Psychoses | 11 | 18* | 8 | 4 | 4 | 1 |
| Ulcers | 13 | 14 | 14 | 17 | 9 | 5 |
| Diabetes Mellitus | 5 | 5 | 4 | 5 | 2 | 1 |
| Diseases of the Respiratory System | 108 | 109 | 90 | 93 | 55 | 48 |
| Diseases of the Respiratory Tract | 46 | 43 | 39 | 43 | 23 | 22 |
| Deflected Nasal Septum | 39 | 42 | 32 | 33 | 20 | 16 |
| Sinusitis | 12 | 11 | 9 | 10 | 6 | 6 |
| Pleurisy/Respiratory Tuberculosis | 2 | 2 | 2 | 2 | 2 | 2 |
| Spontaneous Pneumothorax | 5 | 9 | 5 | 3 | 3 | 1 |
| Emphysema | 4 | 2 | 3 | 5 | 1 | 1 |
| Diseases of the Nervous System and Sense Organs | 76 | 82 | 69 | 72 | 41 | 32 |
| Diseases of the Nervous System | 34 | 33 | 31 | 36 | 20 | 16 |
| Otitis Externa Other Ear Disorders | 25 | 28 | 20 | 18 | 10 | 9 |
| Deafness | 10 | 11 | 9 | 9 | 5 | 4 |
| Neuritis/Neuralgia/Sciatica | 5 | 8 | 7 | 7 | 5 | 2 |
| Facial Paralysis/Cerebral Paralysis | 2 | 2 | 2 | 2 | 1 | 1 |
| Diseases of the Circulatory System | 63 | 64 | 63 | 65 | 37 | 34 |
| Cardiovascular Disease | 19 | 25 | 21 | 16 | 12 | 11 |
| Hypertension/Other Cerebrovascular Disease | 12 | 12 | 14 | 14 | 9 | 9 |
| Other Diseases of the Circulatory System | 16 | 11 | 14 | 19 | 9 | 9 |
| Phlebitis/Thrombophlebitis | 11 | 10 | 8 | 11 | 5 | 3 |
| Embolism: Cerebral, Arterial, Venous, etc. | 5 | 6 | 6 | 5 | 2 | 2 |
| Environmentally Induced Disorders | 29 | 16** | 24 | 30 | 15 | 22* |
| Decompression Sickness | 15 | 9 | 13 | 13 | 8 | 14* |
| Effects Other External Causes: Drowning/Hypothermia | 8 | 2** | 7 | 13** | 4 | 4 |
| Effects of Gas | 6 | 5 | 4 | 4 | 3 | 4 |
| Barotraumas | 0 | 0 | 0 | 0 | 0 | 0 |

*$p < .05$ **$p < .01$

yielded higher-observed-than-expected hospitalizations among inexperienced divers for alcohol/drug abuse, transient situational disturbances, neuroses, and psychoses. Fewer hospitalizations than expected were noted for neuroses among divers with 21 to 100 dives and for transient situational disturbances among the most experienced.

These significant differences for both inexperienced and experienced divers suggested that the factor of selectivity contributed to these results. That is, to continue in their occupation, divers must meet strict physical and mental requalification standards; divers with alcohol/drug abuse problems or other stress-related conditions probably were disqualified from diving during the early stages of their careers. Many of these divers also may have self-selected themselves out of diving prior to having problems with alcohol or drugs.

For the third, fourth, and fifth ranked categories of respiratory, nervous system, and circulatory system disorders, there were no significant differences between low and high experience groups. Diving experience, therefore, was shown to have no significant impact on the number of hospital admissions for conditions in these categories.

Admissions for environmentally induced disorders were observed to be quite low across exposure levels, although a total of 1,174 diving-related accidents had been reported (5). The relatively low number of hospital admissions for DCS and other environmentally induced conditions pointed up that very few diving-related injuries were treated in a hospital. Experienced divers, however, had significantly more admissions than expected for this category, primarily for DCS. Such findings suggested that experienced divers probably were diving more frequently than others or were performing more of the deeper dives of considerable duration, both of which would increase the probability of an occurrence of DCS.

To conclude, very few disorders appeared to be associated with either high or low levels of diving experience. Inexperienced divers had significantly more hospitalizations than expected for almost all stress-related disorders whereas the only conditions for which higher exposure

divers were hospitalized at a greater rate than expected were environmentally induced disorders--a reflection of DCS cases. Although hazardous, diving among experienced Navy divers resulted in relatively few hospitalizations for adverse diving-related health consequences.

## Age-specific Morbidity and Mortality Rates among U.S. Navy Enlisted Divers and Controls

While the results discussed in the previous section indicated that few disorders were associated with either high or low levels of diving experience, hospitalization rates for divers should be compared with those of a sample of nondivers to determine whether or not divers' rates reflected an increased health risk. The primary purpose of this study was to compare total and age-specific annual hospitalization rates of U.S. Navy enlisted divers with those of a matched sample of nondiver controls. Another objective was to identify similarities and differences between groups in age-specific rates of medical board actions, physical evaluation boards, and mortality.

### METHOD

Selecting the control sample for the enlisted male diver population ($n$ = 11,584) entailed a two-step process of extracting the service history records of a 5% random sample of nondivers and then matching each diver's record with those in the total nondiver pool to obtain as many matches as possible on the basis of age and primary occupational specialty ($n$ = 11,517 controls). Information on age, diagnoses, and date were obtained for each hospitalization, medical board, physical evaluation board, and death. Annual hospitalization rates per 10,000 strength were computed for the six major diagnostic categories and 31 subcategories by six-year age intervals within each group. Age-specific mortality rates (numbers of deaths per 10,000) and medical board and physical evaluation board rates also were computed for divers and controls. Ninety-five percent confidence limits were calculated to determine whether or not rate differences between groups were significant.

### RESULTS

As shown in Table 2, the highest hospitalization and medical board rates for both divers and controls were observed for the category of musculoskeletal disorders; no significant differences between groups were observed for this category or any specific musculoskeletal condition. Divers had significantly higher rates than controls for the category of environmentally induced disorders and the subcategory of deflected nasal septum.

TABLE 2

COMPARISONS OF TOTAL ANNUAL HOSPITALIZATION AND MEDICAL BOARD RATES BETWEEN U.S. NAVY ENLISTED DIVERS AND CONTROLS BY DIAGNOSTIC CATEGORY, 1968–1979

| Diagnostic Category | Rate per 10,000 by Group | | | |
|---|---|---|---|---|
| | Hospitalization | | Medical Board | |
| | Divers | Controls | Divers | Controls |
| Diseases of the musculoskeletal system | 124.6 | 116.1 | 34.5 | 42.3 |
| Diseases of the joint | 43.0 | 35.6 | 15.0 | 18.4 |
| Disorders of the spinal column and back | 37.1 | 35.5 | 11.3 | 11.1 |
| Diseases of connective tissue and muscle | 22.0 | 22.0 | 0.8 | 2.3 |
| Diseases of the bone | 12.4 | 13.4 | 3.1 | 6.8* |
| Arthritis and rheumatism | 10.1 | 9.5 | 4.2 | 3.6 |
| Stress-related disorders | 47.8 | 98.7* | 6.4 | 15.0* |
| Alcohol and drug abuse | 23.2 | 36.2* | — | — |
| Transient situational disturbances | 8.2 | 17.7* | 1.2 | 3.6 |
| Neuroses | 6.8 | 13.6* | 1.2 | 3.8 |
| Psychoses | 3.1 | 10.9* | 1.0 | 2.2 |
| Ulcers | 4.9 | 11.6* | 2.0 | 1.8 |
| Diabetes mellitus | 1.5 | 8.6* | 0.7 | 3.4* |
| Diseases of the respiratory system | 34.5 | 34.7 | 1.0 | 0.5 |
| Diseases of the respiratory tract | 14.7 | 16.3 | — | — |
| Deflected nasal septum | 12.4* | 7.2 | 0 | 0 |
| Sinusitis | 3.7 | 5.0 | 0 | 0 |
| Pleurisy and respiratory tuberculosis | 0.8 | 2.3 | 0.4 | — |
| Spontaneous pneumothorax | 1.8 | 3.4 | 0 | 0 |
| Emphysema | 1.1 | 0.5 | — | 0 |
| Diseases of the nervous system and sense organs | 25.4 | 34.9 | 4.4 | 7.7 |
| Diseases of the nervous system | 11.6 | 15.2 | 1.9 | 4.3 |
| Otitis externa and other ear disorders | 7.5 | 10.5 | — | 1.4 |
| Deafness | 3.3 | 5.9 | 1.5 | 1.4 |
| Neuritis, neuralgia, sciatica | 2.3 | 2.7 | 0.7 | — |
| Facial paralysis and cerebral paralysis | 0.7 | 0.5 | 0 | — |
| Diseases of the circulatory system | 22.2 | 35.6* | 4.2 | 6.1 |
| Cardiovascular disease | 7.1 | 15.6* | 1.6 | 2.9 |
| Hypertension and other cerebrovascular disease | 4.8 | 9.5* | 0.7 | 1.8 |
| Other diseases of the circulatory system | 5.3 | 5.7 | 0.8 | 0.5 |
| Phlebitis and thrombophlebitis | 3.3 | 3.6 | 0.6 | 0.7 |
| Embolism: cerebral, arterial, venous, etc. | 1.8 | 1.2 | 0.6 | — |
| Environmentally induced diseases | 9.3* | 1.2 | — | — |
| Decompression sickness | 4.9 | 0 | — | 0 |
| Effects other external causes, drowning, hypothermia | 2.6 | 0.9 | — | — |
| Effects of gas | 1.8 | — | 0 | 0 |
| Barotraumas | 0 | 0 | 0 | 0 |
| Mean population at risk | 6,106 | 4,652 | 6,106 | 4,652 |

*Rate differs significantly ($P < 0.05$) between divers and controls as determined by nonoverlapping confidence intervals. Rates are not presented for diagnoses with a frequency of less than 3.

Controls had higher rates than divers for the categories of stress-related disorders and circulatory diseases as well as for the subcategories of cardiovascular disease, cerebrovascular disease, and all six of the stress-related disorders. Controls also had significantly higher medical board rates than divers for the category of stress-related disorders and the subcategories of bone disease and diabetes mellitus.

In examining the age-specific hospitalization rates, which are presented in Table 3, only the rates among 23-28-year olds for joint diseases, respiratory diseases, and deflected nasal septum were significantly higher among divers than controls; divers also had higher hospitalization rates than controls for the category of environmentally induced disorders, with significant differences observed for the 17-22 year interval. Hospitalization rates for controls, on the other hand, were significantly higher than divers for the major diagnostic categories of stress-related disorders (from ages 17-40), respiratory diseases (ages 35-40), nervous system disorders (ages 23-28 and 35-40), and circulatory diseases (29 years of age and older) as well as at various ages for the subcategories of alcohol and drug abuse, transient situational disturbances, ulcers, respiratory tract disorders, and cardiovascular disease. The control group also had a significantly higher physical evaluation board rate than divers for stress-related disorders. In comparisons of age-specific rates of medical boards and physical evaluation boards, controls had significantly higher rates than divers across the age intervals from 17 to 40. There were no differences between groups in mortality rates.

## DISCUSSION

Results of this study determined that divers only had significantly higher hospitalization rates than controls for the category of environmentally induced disorders and for the subcategories of joint diseases, respiratory diseases, and deflected nasal septum at ages 23-28. Explanations for the few higher rates observed among divers included the following: First, the major reason is that divers must be in excellent physical and mental condition to be accepted into diver training. Second, to continue in their occupation, divers must meet the screening criteria specified in the annual physical examination for requalification. The significantly higher

TABLE 3

COMPARISONS OF ANNUAL HOSPITALIZATION RATES BETWEEN U.S. NAVY ENLISTED DIVERS AND CONTROLS BY AGE AND DIAGNOSTIC CATEGORY, 1968–1979

| | Hospitalization Rate per 10,000 by Age and Group | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 17–22 Yr | | 23–28 Yr | | 29–34 Yr | | 35–40 Yr | | ≥ 41 Yr | |
| Diagnostic Category | Divers | Controls | Divers | Controls | Divers | Controls | Divers | Controls | Divers | Controls |
| Diseases of the musculoskeletal system | 87.3 | 97.2 | 116.9 | 94.6 | 187.2 | 170.6 | 201.7 | 201.2 | 262.8 | 197.7 |
| Diseases of the joint | 38.4 | 38.7 | 46.9* | 26.9 | 52.4 | 37.0 | 34.8 | 42.8 | 42.6 | 39.5 |
| Disorders of the spinal column and back | 17.5 | 22.6 | 31.2 | 28.9 | 64.4 | 64.0 | 88.7 | 83.5 | 142.1 | 69.2 |
| Diseases of connective tissue and muscle | 15.6 | 17.6 | 21.0 | 19.7 | 36.1 | 28.4 | 29.6 | 45.0 | 35.5 | 29.7 |
| Diseases of the bone | 8.1 | 12.6 | 11.6 | 11.2 | 19.8 | 19.9 | 24.3 | 15.0 | 21.3 | — |
| Arthritis and rheumatism | 7.8 | 5.7 | 6.2 | 7.2 | 14.6 | 21.3 | 24.3 | 15.0 | 21.3 | 39.5 |
| Stress-related disorders | 30.6 | 71.4* | 45.1 | 79.5* | 67.9 | 187.7* | 99.1 | 164.8* | 106.6 | 217.5 |
| Alcohol and drug abuse | 10.0 | 21.2* | 17.4 | 26.9 | 41.2 | 76.8* | 71.3 | 94.2 | 71.0 | 39.5 |
| Transient situational disturbances | 5.9 | 17.6* | 12.9 | 14.5 | 6.0 | 29.9* | 7.0 | 12.8 | 0 | — |
| Neuroses | 7.2 | 13.3 | 4.5 | 9.9 | 11.2 | 22.8 | 7.0 | 17.1 | 0 | 0 |
| Psychoses | 3.1 | 12.6 | 5.8 | 11.8 | 0 | 7.1 | — | — | 0 | — |
| Ulcers | 3.4 | 5.7 | 3.1 | 12.5* | 8.6 | 21.3 | 10.4 | 21.4 | — | 49.4 |
| Diabetes mellitus | 0.9 | 1.1 | 1.3 | 3.9 | — | 29.9 | — | 15.0 | 21.3 | 108.7 |
| Diseases of the respiratory system | 27.8 | 28.3 | 46.9* | 28.3 | 30.9 | 37.0 | 26.1 | 89.9* | 63.9 | 39.5 |
| Diseases of the respiratory tract | 12.5 | 11.3 | 17.4 | 10.5 | 12.9 | 19.9 | 12.2 | 57.8* | 49.7 | 29.7 |
| Deflected nasal septum | 9.0 | 6.8 | 19.6* | 7.9 | 12.0 | 7.1 | 7.0 | 8.6 | 0 | 0 |
| Sinusitis | 3.1 | 5.7 | 4.9 | 5.3 | 2.6 | — | — | — | 0 | 0 |
| Pleurisy and respiratory tuberculosis | — | 1.1 | 1.3 | 2.0 | — | — | — | 12.8 | 0 | 0 |
| Spontaneous pneumothorax | 1.6 | 3.6 | 2.7 | 2.0 | — | 5.7 | 0 | — | 0 | 0 |
| Emphysema | 1.2 | 0 | — | — | — | 0 | 0 | — | — | — |
| Diseases of the nervous system and sense organs | 25.6 | 24.4 | 20.1 | 40.7* | 35.2 | 49.8 | 27.8 | 53.5* | 35.5 | 49.4 |
| Diseases of the nervous system | 11.2 | 11.1 | 9.4 | 14.5 | 18.9 | 18.5 | 15.6 | 32.1 | 0 | 39.5 |
| Otitis externa and other ear disorders | 10.6 | 9.3 | 5.4 | 11.8 | 4.3 | 15.6 | — | 8.6 | — | 0 |
| Deafness | 3.1 | 2.2 | 3.1 | 6.5 | 3.4 | 11.4 | — | 10.7 | — | — |
| Neuritis, Neuralgia, Sciatica | — | 1.1 | 1.3 | 5.3 | 6.9 | 4.3 | 7.0 | — | 0 | 0 |
| Facial paralysis and cerebral paralysis | 0 | — | — | — | — | 0 | 0 | 0 | — | 0 |
| Diseases of the circulatory system | 15.6 | 18.6 | 18.3 | 21.0 | 24.9 | 51.2* | 38.3 | 96.3* | 120.8 | 336.1* |
| Cardiovascular disease | 4.4 | 4.7 | 4.0 | 9.9 | 6.9 | 24.2* | 17.4 | 51.4* | 78.2 | 177.9 |
| Hypertension and other cerebrovascular disease | 1.6 | 3.2 | 3.6 | 3.3 | 7.7 | 15.6 | 15.6 | 36.4 | — | 108.7 |
| Other diseases of the circulatory system | 4.7 | 6.8 | 4.5 | 3.3 | 6.9 | 5.7 | — | 6.4 | 21.3 | — |
| Phlebitis and thrombophlebitis | 3.7 | 2.9 | 3.6 | 3.9 | 2.6 | 4.3 | 0 | 0 | 0 | 29.7 |
| Embolism: cerebral, arterial, venous, etc. | 1.2 | 1.1 | 2.7 | — | — | — | — | — | — | — |
| Environmentally induced disorders | 8.7* | 1.4 | 12.9 | | 4.3 | | 8.7 | 0 | | 0 |
| Decompression sickness | 4.0 | 0 | 7.6 | 0 | 2.6 | 0 | 5.2 | 0 | 0 | 0 |
| Effects other external causes, drowning, hypothermia | 3.1 | — | 2.7 | — | — | — | — | 0 | — | 0 |
| Effects of gas | 1.6 | — | 2.7 | 0 | — | 0 | — | 0 | 0 | 0 |
| Barotraumas | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Mean population at risk | 2,672 | 2,324 | 1,867 | 1,268 | 970 | 586 | 479 | 389 | 117 | 84 |

*Rate differs significantly ($P \leq 0.05$) between divers and controls as determined by nonoverlapping confidence intervals. Rates are not presented for diagnoses with a frequency of less than 3.

rate for deflected nasal septum, for example, suggests a greater necessity among divers than nondivers of having a clear nasal passage to facilitate breathing with a mask. Third, another explanation for the few higher rates is the possibility that divers do indeed live up to their image, which is one of toughness and hardiness--and of having a high pain threshold (4). Another explanation for the lower rates is that some divers might engage in symptom denial in order to continue diving.

The effectiveness of these selection and retention screening standards was reflected in the results of the disease by age comparisons. Before age 41, divers had significantly lower hospitalization rates than controls for stress-related disorders and circulatory diseases as well as lower medical and physical evaluation board rates. After 40 years of age, differences between the two groups were nonsignificant except for the control group's higher rate for the category of diseases of the circulatory system. These results pointed up the overall better physical and mental "fitness" among divers than controls throughout the most active years of a diving career, the years before the age of 41.

Another point to raise was that divers did not have significantly higher hospitalization rates than controls for several diving-related disorders, as would be expected from such previous results as those on hearing loss (21). Divers' rates for otitis externa and other ear disorders and hearing loss were quite low and failed to differentiate significantly between the two groups. These low rates as well as those for several of the environmentally induced disorders suggested that relatively few diving-related disorders resulted in a hospitalization. Acute health problems experienced at the diving site probably were treated by an attending hospital corpsman or possibly at a medical outpatient facility. The findings of this study, therefore, determined that the only risks of being hospitalized among divers were for environmentally induced disorders and joint diseases, respiratory diseases, and deflected nasal septum at ages 23-28.

Few, if any, studies have been conducted that identified the health risks specifically associated with being a U.S. Navy diving officer. In addition to the hazards and health risks associated with diving, which were identified in previous sections, diving officers also are trained to deal with the stressors related to being in a leadership role and assuming responsibility for the health and safety of enlisted divers. Perhaps the added responsiblities of serving in a leadership position in a hazardous occupation and assuming responsibilty for the well-being of subordinates (22) would have an adverse impact on the health of diving officers which would be reflected by an elevated hospitalization rate of stress-related disorders.

The purpose of this study was to examine the hospitalization, medical board, and mortality rates of diving-related disorders and stress-induced diseases in U.S. Navy diving officers. Comparisons of these rates with those for a sample of nondiving officers were conducted to determine whether or not diving officers were at increased risk for the specified disorders. The diving officer population also was divided into two subgroups on the basis of diving experience; hospitalization rates were compared between the two groups to identify exposure-related health effects.

**METHOD**

The male diving officer population was divided into two levels of experience: officers with less than 21 dives and less than 11 bottom hours ($n$ = 1,065) and officers with more than 20 dives and more than 10 bottom hours ($n$ = 912). Using records on the Naval Officer Career History file, a control sample of nondiving officers ($n$ = 1,973) was selected on the basis of having a similar occupational designator, birth year, and number of active duty years as diving officers.

Annual rates per 10,000 strength of hospitalizations, medical boards, physical evaluation boards, and mortality for the 31 diagnoses and six major diagnostic categories were computed for the two officer groups and diving-exposure groups. Ninety-five percent confidence limits were calculated to determine whether or not rate differences between groups were significant.

## RESULTS AND DISCUSSION

Results of this study revealed no unique health risks attributable to a higher level of hyperbaric exposure in diving officers. Officers with a low level of diving experience were more likely than their more experienced counterparts to be hospitalized for alcohol/drug abuse or cardiovascular disease. The higher rates among inexperienced officers could not be explained in terms of diving exposure as a causal factor nor a direct relationship in time between diving and the hospitalization. A highly plausible explanation was that many of these officers may have been screened out of diving because of substance abuse or a cardiovascular condition and, therefore, were disqualified during the early phases of their diving careers. A self-selection out of diving for a variety of reasons also may have occurred among these inexperienced divers. Among experienced diving officers, on the other hand, low hospitalization rates might be interpreted as a reflection of a health-conscious life style and high level of physical fitness.

As shown in Table 4, other results indicated that diving officers were at increased risk of being hospitalized for a nervous system disease and certain musculoskeletal disorders (a higher rate of hospitalizations for joint diseases and a higher medical board rate for back disorders). Of all specific conditions, joint disorders accounted for the largest proportion of hospitalizations among diving officers. Although considered possible manifestations of having suffered DCS in the past, an examination of both diving accident and hospital records revealed that none of the hospitalized officers had a recorded incident of DCS. The joint and neurological disorders, therefore, were more likely to be a consequence of diving in general rather than DCS in particular. No significant differences in hospitalization rates for stress-related disorders were noted between diving officers and controls, which suggested that the added responsibilities of serving in a leadership role in the hazardous occupation of diving had no adverse impact on their mental health. No significant differences between groups were observed in rates of physical evaluation board actions and mortality. Thus, diving officers who had higher levels of diving exposure were not at higher risk of being hospitalized for either a diving- or stress-related disorder than less experienced officers. In comparisons with other officers, diving officers had higher hospitalization rates for joint and neurological disorders.

## TABLE 4

ANNUAL HOSPITALIZATION RATES PER 10,000 BETWEEN U.S. NAVY MALE DIVING OFFICERS AND CONTROLS BY DIAGNOSTIC CATEGORY, 1968–1979

| Diagnostic Category | Diving Officers | | Controls | |
|---|---|---|---|---|
| | No. | Rate | No. | Rate |
| Diseases of the musculoskeletal system | 96 | 78.2 | 68 | 51.8 |
| Diseases of the joint | 43 | 35.0* | 21 | 16.0 |
| Disorders of the spinal column and back | 27 | 22.0 | 23 | 17.5 |
| Diseases of connective tissue and muscle | 15 | 12.2 | 12 | 9.1 |
| Diseases of the bone | 5 | 4.1 | 8 | 6.1 |
| Arthritis and rheumatism | 6 | 4.9 | 4 | 3.1 |
| Diseases of the nervous system and sense organs | 25 | 20.4* | 8 | 6.1 |
| Diseases of the nervous system | 15 | 12.2* | 2 | 1.5 |
| Otitis externa and other ear disorders | 5 | 4.1 | 3 | 2.3 |
| Deafness | 3 | 2.4 | 2 | 1.5 |
| Neuritis, neuralgia, sciatica | 1 | 0.8 | 1 | 0.8 |
| Facial paralysis and cerebral paralysis | 1 | 0.8 | 0 | 0 |
| Stress-related disorders | 23 | 18.7 | 28 | 21.3 |
| Alcohol-drug abuse | 17 | 13.8 | 12 | 9.1 |
| Transient situational disturbances | 1 | 0.8 | 2 | 1.5 |
| Neuroses | 2 | 1.6 | 3 | 2.3 |
| Psychoses | 0 | 0 | 2 | 1.5 |
| Ulcers | 1 | 0.8 | 8 | 6.1 |
| Diabetes mellitus | 2 | 1.6 | 1 | 0.8 |
| Diseases of the circulatory system | 20 | 16.3 | 29 | 22.1 |
| Cardiovascular disease | 10 | 8.2 | 22 | 16.8 |
| Hypertension and other cerebrovascular disease | 4 | 3.3 | 7 | 5.3 |
| Other diseases of the circulatory system | 3 | 2.4 | 0 | 0 |
| Phlebitis and thrombophlebitis | 0 | 0 | 0 | 0 |
| Embolism: air, cerebral, arterial, venous | 3 | 2.4 | 0 | 0 |
| Diseases of the respiratory system | 19 | 15.5 | 46 | 35.0* |
| Diseases of the respiratory tract | 10 | 8.2 | 23 | 17.5 |
| Deflected nasal septum | 8 | 6.5 | 10 | 7.6 |
| Sinusitis | 1 | 0.8 | 4 | 3.1 |
| Pleurisy and respiratory tuberculosis | 0 | 0 | 2 | 1.5 |
| Spontaneous pneumothorax | 0 | 0 | 6 | 4.6 |
| Emphysema | 0 | 0 | 1 | 0.8 |
| Environmentally induced diseases | 3 | 2.4 | 0 | 0 |
| Decompression sickness | 1 | 0.8 | 0 | 0 |
| Effects other external causes, drowning, hypothermia | 1 | 0.8 | 0 | 0 |
| Effects of gas | 1 | 0.8 | 0 | 0 |
| Barotrauma | 0 | 0 | 0 | 0 |
| Total | 186 | 151.6 | 179 | 136.3 |
| Person-years at risk | 12,273 | | 13,131 | |

*Rate differs significantly ($P < 0.05$) between diving officers and controls as determined by nonoverlapping confidence intervals.

## Longitudinal Study of Hospitalizations among Classifications of U.S. Navy Divers

In addition to the general division of divers into enlistees and diving officers, U.S. Navy diving consists of several diver classifications which encompass a wide spectrum of hazardous duties. These include underwater search for explosives; work at depths in a saturated condition for extended periods of time; accomplishment of salvage, unconventional, and special warfare operations; and beach reconnaissance and underwater surveillance. Diver classifications range from second class, or the entry level diver, to master diver which is the highest level of achievement in Navy diving. Little is known of the health effects that may be associated with each specific diver classification. The objectives of this longitudinal study were to assess the frequencies and causes of hospitalizations among U.S. Navy divers who were categorized according to one of eight diver classifications and to determine if the observed frequencies of hospitalizations were significantly higher or lower than expected for all divers.

### METHOD

Participants included 3,748 U.S. Navy male divers whose primary diver classification was one of the following: second class, explosive ordnance disposal diver (EOD), underwater demolition team diver/combatant swimmer (UDT/SEAL), first class, saturation, master, diving officer, and $HeO_2$ diving officer. Selection of experienced divers for each classification was accomplished by extracting diving log records of divers who had at least 10 dives in one of the eight classifications and who also had 50% or more of their total number of dives and bottom hours in that specific classification. Data selected from the Naval Medical Inpatient file included dates and diagnoses of all hospitalizations as well as the diver's age at admission and the cause code for each accidental injury hospitalization. Hospitalization rates per 10,000 strength by diagnostic category were computed within each diver classification. Only those hospitalizations that occurred after the diver began diving in his major class were included in these tabulations. Comparisons were conducted between age-adjusted observed and expected frequencies of hospitalizations by disease category. The numbers of expected hospitalizations were obtained by computing the overall age-adjusted total

and totals for each of 16 diagnostic categories for all enlisted divers ($n$ = 11,584) and diving officers ($n$ = 1,977). The observed frequencies of admissions for each enlisted diver classification were compared with the expected number for the enlisted population whereas the observed frequencies for the two officer groups were compared with the expected number for the officer population. Miettinen probabilities were calculated to determine the significance of differences between observed and expected frequencies (17).

## RESULTS

As shown in Table 5, the major diagnostic categories were rank ordered across all diver classifications according to frequency of hospitalizations. The categories with the highest rates were accidental injuries, musculoskeletal disorders, and diseases of the digestive system. These three top-ranked categories accounted for more than one-half (54.4%) of all hospitalizations. The proportion of all hospitalizations caused by accidental injuries was 28.7%; less than 6.2% of these were caused by a diving or swimming mishap.

In Table 6 are presented the age-adjusted expected and observed frequencies of hospitalizations by diagnostic category. Five of the eight diver classifications (EOD, UDT/SEAL, second class, first class, and diving officers) had significantly fewer hospitalizations than expected for total admissions and for several diagnostic categories.

Significantly higher-than-expected frequencies of hospitalizations were observed for UDT/SEAL divers (musculoskeletal disorders), first class divers (infective and parasitic diseases), master divers (accidental injuries, respiratory diseases, and symptoms and ill-defined conditions), and saturation divers (digestive diseases). $HeO_2$ diving officers also had a higher-than-expected number of hospitalizations for respiratory diseases; however, only three cases were observed.

## DISCUSSION

Results of this study indicated that none of the eight diver groups had a higher number of observed-than-expected total hospital admissions, and five groups had significantly fewer total hospitalizations. No specific diver

TABLE 5

ANNUAL HOSPITALIZATION RATES PER 10,000
BY DIAGNOSTIC CATEGORY AND DIVER CLASSIFICATION, 1968-1979

| Diagnostic Category | Diver Classification | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Second Class | EOD | UDT/ Seal | First Class | Satu- ration | Master Diver | Diving Officer | $HeO_2$ Diving Officer |
| Accidents, poisonings, and violence | 239.0 | 153.4 | 309.8 | 213 2 | 161.5 | 408.2 | 0 | 126.8 |
| Diseases of the musculo-skeletal system | 101.8 | 84.9 | 159.6 | 120.9 | 88.1 | 153.1 | 72.5 | 21.1 |
| Diseases of the digestive system | 66.5 | 49.0 | 84.5 | 118.9 | 190.9 | 102.0 | 8 0 | 63.4 |
| Mental disorders | 47.8 | 68.5 | 39.9 | 86.1 | 88.1 | 25.5 | 0 | 0 |
| Diseases of the respiratory system | 45.7 | 26.1 | 35.2 | 63.5 | 44.0 | 204.1 | 29.0 | 63.4 |
| Symptoms and ill-defined conditions | 39.5 | 19.6 | 28.2 | 45.1 | 44.0 | 153.1 | 0 | 21.1 |
| Diseases of the circulatory system | 24.9 | 32.6 | 39.9 | 43.0 | 88.1 | 51.0 | 0 | 0 |
| Diseases of the genitourinary system | 47.8 | 39.2 | 28.2 | 22.6 | 58.7 | 0 | 14.5 | 21.1 |
| Infective and parasitic diseases | 12.5 | 35.9 | 28.2 | 63.5 | 14.7 | 51.0 | 0 | 0 |
| Diseases of the nervous system and sense organs | 31.2 | 16.3 | 37.6 | 26.6 | 29.4 | 76.5 | 0 | 63.4 |
| Diseases of the skin and subcutaneous tissue | 24.9 | 22.8 | 28.2 | 32.8 | 0 | 25.5 | 14.5 | 0 |
| Neoplasms | 12.5 | 13.0 | 30.5 | 28.7 | 29.4 | 0 | 0 | 0 |
| Supplementary classifications—special conditions | 18.7 | 19.6 | 14.1 | 20.5 | 44.0 | 51.0 | 0 | 0 |
| Congenital anomalies | 12.5 | 13.0 | 16.4 | 14.4 | 0 | 0 | 14.5 | 0 |
| Endocrine, nutritional, and metabolic diseases | 2.1 | 13.0 | 2.4 | 4.1 | 14.7 | 0 | 0 | 21.1 |
| Diseases of blood and blood-forming organs | 2.1 | 0 | 0 | 1.1 | 0 | 0 | 0 | 0 |
| Total hospitalization rate | 729.4 | 607.0 | 882.4 | 908.0 | 895.7 | 1,301.0 | 231.9 | 401.7 |
| Person-years at risk | 4,812 | 3,064 | 4,261 | 4,879 | 681 | 392 | 690 | 473 |

TABLE 6

AGE-ADJUSTED EXPECTED AND OBSERVED HOSPITALIZATION FREQUENCIES BY DIAGNOSTIC CATEGORY AND DIVER CLASSIFICATION, 1968-1979

| Diagnostic Category | Second Class | | EOD | | UDT/Seal | | First Class | | Saturation | | Master Diver | | Diving Officer | | HeO Officer | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ex. | Ob. | Ex. | Ob. | Ex. | Ob. | Ex. | Ob. | Ex. | Ob. | Ex. | Ob. | Ex. | Ob. | Ex. | Ob. |
| Accidents, poisonings, and violence | 140 | 115* | 79 | 47** | 122 | 132 | 126 | 104* | 17 | 11 | 8 | 16** | 6 | 0** | 5 | 6 |
| Diseases of the musculoskeletal system | 48 | 49 | 43 | 26** | 49 | 68** | 68 | 59 | 10 | 6 | 7 | 6 | 5 | 5 | 3 | 1 |
| Diseases of the digestive system | 43 | 32* | 31 | 15** | 39 | 36 | 49 | 58 | 7 | 13* | 5 | 4 | 4 | 6 | 4 | 3 |
| Mental disorders | 27 | 23 | 22 | 21 | 26 | 17* | 36 | 42 | 5 | 6 | 3 | 1 | 2 | 0 | 2 | 0 |
| Diseases of the respiratory system | 57 | 22** | 23 | 8** | 43 | 15** | 36 | 31 | 4 | 3 | 2 | 8** | 2 | 2 | 1 | 3* |
| Symptoms and ill-defined conditions | 23 | 19 | 14 | 6** | 20 | 12* | 22 | 22 | 3 | 3 | 2 | 6* | 2 | 0 | 1 | 1 |
| Diseases of the circulatory system | 14 | 12 | 15 | 10 | 16 | 17 | 23 | 21 | 3 | 6 | 4 | 2 | 2 | 0 | 2 | 0 |
| Diseases of the genitourinary system | 26 | 23 | 16 | 12 | 23 | 12** | 25 | 11** | 3 | 4 | 2 | 0 | 1 | 1 | 1 | 1 |
| Infective and parasitic diseases | 35 | 6** | 13 | 11 | 26 | 12** | 20 | 31* | 2 | 1 | 1 | 2 | 2 | 0 | 1 | 0 |
| Diseases of the nervous system and sense organs | 14 | 15 | 11 | 5* | 13 | 16 | 18 | 13 | 3 | 2 | 2 | 3 | 2 | 0 | 2 | 3 |
| Diseases of the skin and subcutaneous tissue | 30 | 12** | 13 | 7* | 24 | 12** | 21 | 16 | 3 | 0* | 2 | 1 | 1 | 1 | 0 | 0 |
| Neoplasms | 9 | 6 | 8 | 4 | 9 | 13 | 13 | 14 | 2 | 2 | 1 | 0 | 1 | 0 | 1 | 0 |
| Supplementary classifications—special conditions | 14 | 9 | 9 | 6 | 12 | 6* | 15 | 10 | 2 | 3 | 1 | 2 | 0 | 0 | 0 | 0 |
| Congenital anomalies | 5 | 6 | 4 | 4 | 5 | 7 | 7 | 7 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 |
| Endocrine, nutritional, and metabolic diseases | 3 | 1 | 2 | 4 | 3 | 1 | 4 | 2 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 |
| Diseases of blood and blood-forming organs | 2 | 1 | 1 | 0 | 1 | 0 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total hospitalization rate | 489 | 351** | 305 | 186** | 431 | 376** | 483 | 443* | 67 | 61 | 41 | 51 | 30 | 16** | 25 | 19 |

*$p < 0.05$ **$p < 0.01$ Note: The column headings for *expected* and *observed* frequencies are abbreviated to Ex. and Ob.

classification, therefore, was at increased risk of having a total hospitalization rate higher than that expected for all divers. Other comparisons revealed several lower observed-than-expected numbers of hospitalizations for many diagnostic categories. Factors that may play a role in these differences included physical fitness, diver requalifications, love of diving, elitism, and monetary remuneration. With regard to physical fitness and diver requalifications, it seemed likely that these divers adhered to a physical conditioning program that not only would enhance their health and physical fitness but also would promote their own safety and that of their coworkers. Another explanation for the low number of hospitalizations was that of symptom denial. Because the image of the diver has been one of strength and endurance, some divers may have felt less inclined than others to report an injury or illness. Also, divers enjoy their work, as well as the extra pay that they receive, which probably contributed to the promotion of physical conditioning and health maintenance in their lives.

The elevated rate of musculoskeletal disorders among UDT/SEAL divers probably was associated with the enormous physical demands placed on them. Not only is the initial UDT/SEAL training arduous and highly stressful, but severe physical stressors are involved in performing the posttraining diving duties and participating in the rigorous physical fitness regimens. These divers, therefore, probably engaged in diving tasks that required more strength, stamina, and physical exertion than other divers, which would increase their likelihood of experiencing musculoskeletal problems.

Master divers had a significantly higher-than-expected age-adjusted number of admissions for accidental injuries, respiratory diseases, and symptoms and ill-defined conditions. While none of the accidental injuries had a diving-related cause code, the other two categories were considered potential health risks for these divers of high career achievement. The significantly higher age-adjusted hospitalization rates than other divers suggested that being hospitalized for respiratory disorders and symptoms and ill-defined conditions probably was a manifestation of many years of hyperbaric exposure.

Less readily explainable were the higher than expected numbers of admissions for digestive diseases (primarily hernias) among saturation divers

and infective and parasitic diseases (primarily hepatitis and other viral diseases) among first class divers. Exposure to contaminated water, however, may have been a factor contributing to the higher rates of hepatitis.

The implications of this study were that divers should be apprised of the potential diving-related health risks of musculoskeletal disorders, respiratory diseases, and pain symptomatology, particularly among UDT/SEAL and master divers. An increased awareness of these risks may encourage divers not only to seek medical treatment during the initial stages of such conditions but also to identify the diving procedures that might have contributed to the incidence of these medical problems.

## Analyses of Variables Underlying U.S. Navy Diving Accidents

Diving is a complex activity in which many factors contribute to the success or failure of a dive mission. Underlying factors that could influence the incidence of a diving mishap include environmental circumstances and individual diver characteristics. The purpose of this study was to determine the most frequently occurring underwater accidents and to identify the most prevalent factors associated with these mishaps.

### METHOD

The computerized files containing information on all U.S. Navy dives (706,259) and accidents (1,174) recorded from January 1968 through May 1981 were used as the data bases for this study. Data extracted from the accident log consisted of type of accident, most significant manifestation or symptom, phase of the dive when complications were initially detected, and treatment outcome. Information selected from the diving log included dive depth, time of day, temperature (air, surface, and bottom), dive purpose, decompression schedule type, submergence time, age, height, weight, and number of dives performed during the previous 24 hours.

### RESULTS AND DISCUSSION

#### Accidents, manifestations, and outcome

With a total of 1,174 accidents recorded during more than 706,000 dives from 1968-81, the overall percentage rate of dives terminating in a mishap was 0.17%. In examining all Navy diving accidents, as shown in Table 7, DCS and barotraumas accounted for almost two-thirds of the total number (41.1% and 21.9%, respectively). The most frequently recorded manifestation was localized pain, followed by dizziness and numbness. The location of the initial occurrence of dive complications and their respective percentages included the following: 20% during descent, 12% while on the bottom, 14% during ascent, 47% after surfacing and/or completed decompression, and 7% either prior to descent or during interrupted or surface decompression. Almost all treatment outcomes resulted in complete relief (80.7%) or substantial relief (17.7%). The remaining 1.6% consisted of fatalities (0.7%) and recurring symptoms (0.9%).

TABLE 7

FREQUENCY AND PERCENTAGE DISTRIBUTION OF TYPES OF ACCIDENTS AND SYMPTOMS AMONG U.S. NAVY DIVERS, 1968–1981

| Accident | No. | % | Significant Sign | No. | % |
|---|---|---|---|---|---|
| Decompression sickness | 426 | 41.1 | Localized pain | 604 | 58.5 |
| Barotrauma | 227 | 21.9 | Dizziness | 80 | 7.7 |
| Other | 76 | 7.3 | Numbness | 55 | 5.3 |
| $O_2$ poisoning | 49 | 4.7 | Other | 46 | 4.5 |
| Mechanical injuries | 49 | 4.7 | Unconsciousness | 44 | 4.3 |
| Missed decompression | 44 | 4.2 | None | 40 | 3.9 |
| Air embolism | 37 | 3.6 | Bleeding | 27 | 2.6 |
| Unknown | 23 | 2.2 | Muscular weakness | 24 | 2.3 |
| $CO_2$ poisoning | 20 | 1.9 | Muscular twitching | 16 | 1.5 |
| Injured by marine organism | 13 | 1.3 | Nausea vomiting | 16 | 1.5 |
| Mediastinal emphysema | 8 | 0.8 | Visual disturbances | 15 | 1.5 |
| Drowning | 8 | 0.8 | Rash | 14 | 1.4 |
| Disorders of consciousness | 7 | 0.7 | Convulsions | 10 | 1.0 |
| Hypoxia | 7 | 0.7 | Itching | 8 | 0.8 |
| Subcutaneous emphysema | 7 | 0.7 | Parasthesia | 7 | 0.7 |
| Near drowning | 5 | 0.5 | Swelling | 7 | 0.7 |
| Blow-up | 5 | 0.5 | Dyspnea | 6 | 0.6 |
| Hyperventilation | 5 | 0.5 | Paralysis | 4 | 0.4 |
| CO poisoning | 4 | 0.4 | Acoustic aura | 4 | 0.4 |
| Mental | 4 | 0.4 | Unknown | 4 | 0.4 |
| Pneumothorax | 3 | 0.3 | Drowsy | 1 | 0.1 |
| Nonpressure related | 3 | 0.3 | Restlessness | 1 | 0.1 |
| Nitrogen narcosis | 3 | 0.3 | | | |
| Bad gas | 3 | 0.3 | | | |
| Total | 1036 | 100.1 | | 1033 | 100.2 |

**Dive conditions and diver characteristics**

Dive depth was shown to be a significant factor associated with mishap incidence. Dives performed at less than 50 feet (75% of Navy diving) had significantly lower accident rates than the overall rate whereas dives at greater depths were at increased risk. As presented in Table 8, the highest rates were observed for the deepest dives: 20.6 per 1,000 for dives of more than 200 feet ( 61.3 meters) and 5.4 per 1,000 for those 101-200 feet.

Because dive depth is an important factor in mishap incidence, rates computed for each of the other variables were depth adjusted, which yielded rates based on the overall distribution of dives. Of all the dive purposes recorded (e.g., work, training, selection, sport/recreation, medical

TABLE 8

DISTRIBUTION OF DIVES, ACCIDENTS, AND ACCIDENT RATES BY DIVE DEPTH AMONG U. S. NAVY DIVERS, 1968-1981

| Dive Depth | | No. Dives* | No. Accidents | Rate/1000 Dives** |
|---|---|---|---|---|
| m | (ft) | | | |
| 0—3 | (1—10) | 56,929 | 31 | 0.54 † |
| 3.4—7.6 | (11—25) | 176,111 | 125 | 0.71 † |
| 7.9—15.2 | (26—50) | 295,704 | 210 | 0.71 † |
| 15.5—30.5 | (51—100) | 90,868 | 211 | 2.32 † |
| 30.8—61.0 | (101—200) | 77,440 | 418 | 5.40 † |
| ≥ 61.3 | (≥ 201) | 8,143 | 168 | 20.63 † |
| Total | | 705,195 | 1,163 | 1.65 |

*Number of dives is based on 10% random sample. **Significance levels of rates are based on Poisson distribution. † Rate differs significantly ($P < 0.05$) from overall rate as determined by nonoverlapping confidence intervals.

TABLE 9

DISTRIBUTION OF DIVES, ACCIDENTS, ACCIDENT RATES, AND DEPTH-ADJUSTED ACCIDENT RATES BY AGE AMONG U.S. NAVY DIVERS, 1968-1981

| Age | No. Dives* | No. Accidents | Rate/1000 Dives** | Depth-adjusted Rate 1000 Dives* |
|---|---|---|---|---|
| 17-20 | 81,546 | 152 | 1.86 | 2.62 |
| 21-24 | 236,487 | 319 | 1.35 ‡ | 1.56 |
| 25-28 | 154,001 | 263 | 1.71 | 1.66 |
| 29-32 | 106,104 | 198 | 1.86 | 1.59 |
| 33-36 | 77,250 | 169 | 2.19 ‡ | 1.78 |
| 37-40 | 34,549 | 47 | 1.36 | 0.99 |
| ≥ 41 | 15,756 | 21 | 1.33 | 1.10 |
| Total | 705,993 | 1,169 | 1.66 | 1.65 |

*Number of dives is based on 10% random sample. **Significance levels of rates are based on Poisson distribution. *Significance levels of depth-adjusted rates are based on normal distribution. ‡Rate differs significantly ($P < 0.05$) from overall rate as determined by nonoverlapping confidence intervals.

treatment, experimental), selection and experimental dives had adjusted rates significantly higher than the overall accident rate. Rates for decompression schedule type, a highly depth-dependent factor, varied markedly from the lowest rate for dives requiring no decompression (91.0% of all Navy dives) to the highest for saturation dives, which represented 0.06% of all dives and averaged 610 feet in depth. In analyzing accident rates for the other variables (time of day, the three temperature readings, age, height, weight, and recent diving experience), no significant differences were observed with depth adjustment. Table 9 is a presentation of accident and depth-adjusted

accident rates per 1,000 dives by 4-year age intervals. As shown, divers aged 37 years and older had the lowest depth-adjusted mishap rates. In comparisons between the two sets of rates, the depth-adjusted rates were lower than the other rates for divers 24 years of age and older; this decrease with depth adjustment indicated that older divers were disproportionately assigned to deeper dives. The final variable examined showed that one-half of all accidents occurred within 25 minutes of submergence.

In conclusion, these results pointed up the importance of dive depth as a significant factor in mishap incidence. Also, selection and experimental dives yielded significantly higher depth-adjusted accident rates than the overall rate whereas divers aged 37 years and older had the lowest depth-adjusted rates.

## Consequences of U.S. Navy Diving Mishaps: Decompression Sickness

As reported in the preceding summary, the risk of experiencing a diving mishap among U.S. Navy divers has been determined to be quite low; of more than 700,000 dives recorded from 1968 through May 1981, the proportion of mishaps reported was 0.17% (5). The most frequently occurring mishap was DCS, of which there were 426 incidents or 41.1% of the total number of accidents. Although previously published research has determined that the aftereffects of DCS tend to disappear within weeks of initial treatment (23-25), little is known of the subsequent health consequences that might be associated with DCS, except for the possibility of a spinal cord injury (26).

The purpose of this longitudinal study was to identify the short- and long-term health effects among U.S. Navy divers who suffered DCS and to compare their rates of hospitalizations and medical board appearances with rates of a matched sample of divers who had no recorded diving accidents. The influence of previous hospitalizations, age, and weight on the incidence of DCS also was examined.

### METHOD

Subjects for this study included 204 U.S. Navy enlisted divers (only one of whom was a woman diver) and 24 diving officers who were identified on the file of Diving Log-Accident/Injury Reports and/or the Naval Medical Inpatient file as having experienced DCS during the period January 1968 through December 1979. The mean age at the time of the DCS mishap was 27.9 with a range from 17 to 44.

Using data extracted from the Naval Medical Inpatient file, frequency and percentage distributions were performed to identify divers who were separated from service and/or who had been hospitalized or reviewed by a medical board subsequent to the DCS incident. The numbers of days, months, and years after the DCS mishap were listed in a tabular chronology for each diagnosis. A distribution of hospitalizations and board actions also was compiled for diagnoses recorded prior to the DCS incident.

Annual rates of these medical events per 10,000 strength were computed after tabulating the numbers of subsequent hospitalizations and board actions into nine diagnostic clusters (symptoms and headache; disorders of the joint, knee, and connective tissue; osteoarthritis, arthritis, and rheumatism; diseases of the circulatory system; disorders of the arteries and veins; disorders of the back; diseases of the respiratory system; alcoholism and drug abuse; and benign and unspecified bone neoplasms). Comparisons of these rates with those of a control sample of divers who had the same birth year as the DCS divers but no recorded diving accidents were conducted after computing the control divers' hospitalization rates per 10,000 strength for the nine categories. Person-years at risk for the control sample were tabulated by summing the number of these divers on active duty during the 1968 to 1979 time period.

Comparisons of mean values for age and a weight/height index (kilogram/meter$^2$) also were conducted between the DCS sample and all other members of the diving community ($n$ = 13,329). The $t$-test technique was performed to ascertain the level of statistical significance between samples for these two variables.

**RESULTS AND DISCUSSION**

Of the 328 divers who experienced a DCS incident, results of this study identified 251 individuals (76.5%) whose records contained no medical events related to diving after the initial DCS incident. Three physical disabilities (one with a spinal cord lesion) were specifically attributed to DCS or diving; there were no diving-related deaths among the 328 DCS divers. Other serious health consequences were observed for two divers hospitalized with air embolism and two admitted with a spinal cord lesion, none of whom was subsequently hospitalized or medically separated.

Immediately after the DCS incident, 34 divers were hospitalized as a result of the mishap. During a time period of five days to almost 11 years after the initial DCS incident, 50 divers experienced one or more medical events, which are listed in Tables 10 and 11. Clusters of diagnoses with the highest frequencies were compiled from these tables: symptoms and headache ($n$ = 10); disorders of the joint, knee, and connective tissue ($n$ = 7);

TABLE 10

DIAGNOSES FOR SUBSEQUENT HOSPITALIZATIONS AND PHYSICAL DISABILITY SEPARATIONS (< 1 YR) AMONG U.S. NAVY DIVERS WITH DECOMPRESSION SICKNESS (DCS), 1968–1979

| Diver | Diagnosis (ICDA-8 Rubrics) | Time Period Since DCS |
|---|---|---|
| 1 | Symptoms referable to the abdomen and lower gastrointestinal tract (abdominal pain)* | 5 d |
| 2 | Spinal cord lesion without evidence of spinal bone injury (cervical, without mention of open wound) and spinal cord lesion (dorsal and lumbar, without mention of open wound) (diving related) | 12 d |
| 3 | Chronic enteritis and ulcerative colitis (first admission) | 46 d |
| | Arthritis, unspecified (second admission)* | 70 d |
| 4 | Anomalies of lumbosacral joint and vertebrogenic pain syndrome | 54 d |
| 5 | Certain symptoms referable to nervous system and special senses (vertigo) and special symptoms (cephalalgia)* | 75 d |
| 6 | Transient situational disturbances | 100 d |
| 7 | Phlebitis and thrombophlebitis | 7 mo. |
| 8 | Symptoms referable to limbs and joints (pain in limb) | 8 mo. |
| | Physical disability retirement for malignant neoplasm of testis | 18 mo. |
| 9 | Other diseases of respiratory system (pulmonary collapse) and chronic sinusitis (first admission) | 9 mo. |
| | Chronic sinusitis (second admission) | 16 mo. |
| | Sprains and strains of knee and leg (unknown cause) (third admission) | 45 mo. |
| 10 | Physical disability retirement for DCS* | 10 mo. |
| 11 | Headache, unspecified cause | 10 mo. |
| 12 | Essential benign hypertension and symptoms referable to respiratory system (pain in chest) (first admission) | 11 mo. |
| | Symptoms referable to respiratory system (pain in chest) and essential benign hypertension (second admission) | 32 mo. |
| 13 | Essential benign hypertension and ulcer of duodenum | 11 mo. |

*Subsequent hospitalization(s) and physical disability separations for divers hospitalized immediately for DCS

osteoarthritis, arthritis, and rheumatism ($n$ = 6); diseases of the circulatory system ($n$ = 6); and diseases of the arteries and veins ($n$ = 5). Comparisons of rates between the two groups yielded significantly higher rates for the DCS sample than controls for the clusters of symptoms and headache and disorders of the arteries and veins as well as for total hospital admissions.

The diagnoses included in the cluster of symptoms and headache have been identified in the literature as diving related: vertigo, abnormal involuntary

TABLE 11

DIAGNOSES FOR SUBSEQUENT HOSPITALIZATIONS AND PHYSICAL DISABILITY SEPARATIONS (> 1 YR) AMONG U.S. NAVY DIVERS WITH DECOMPRESSION SICKNESS (DCS), 1968–1979

| Diver | Diagnosis (ICDA-8 Rubrics) | Time Period Since DCS, yr, mo. |
|---|---|---|
| 1 | Physical disability retirement with no diagnosis available | 1, 1 |
| 2 | Phlebitis and thrombophlebitis (other, unspecified sites) | 1, 2 |
| 3 | Effects of air pressure (other and unspecified effects of high altitude), other aneurysm, and essential benign hypertension | 1, 3 |
| 4 | Deflected nasal septum* | 1, 4 |
| 5 | Alcoholism (other and unspecified) | 1, 4 |
| 6 | Osteoarthritis and allied conditions and arthritis, unspecified | 1, 6 |
| 7 | Symptoms referable to limbs and joint (pain in joint) | 1, 7 |
| 8 | Other muscular rheumatism, fibrositis, and myalgia | 1, 8 |
| 9 | Sprains and strains of sacroiliac region and neurosis (depressive) (first admission) | 1, 8 |
| | Vertebrogenic pain syndrome (lumbalgia) (second admission) | 6, 2 |
| | Vertebrogenic pain syndrome (lumbalgia) (third admission) | 6, 5 |
| | Vertebrogenic pain syndrome (other and unspecified) (fourth admission) | 6, 11 |
| | Physical disability retirement for vertebrogenic pain syndrome (on-duty diving) | 7, 5 |
| 10 | Other diseases of joint/chondromalacia of knee (first admission) | 1, 10 |
| | Other deformities of leg, dislocation of knee, and osteoarthritis (second admission) | 3, 7 |
| | Physical disability separation for other deformities of leg* | 5, 6 |
| 11 | Physical disability retirement for DCS* | 1, 11 |
| 12 | Symptoms referable to limbs and joints (pain in joint—arthralgia) and other unspecified infective-parasitic diseases (first admission) | 2, 1 |
| | Other and unspecified infective-parasitic diseases (second admission) | 2, 8 |
| | Physical disability separation for other and unspecified infective-parasitic diseases | 2, 11 |
| 13 | Other ill-defined and unknown causes of morbidity and mortality | 2, 2 |
| 14 | Physical disability separation for osteoarthritis and allied conditions (spondylitis osteoarthritica) | 2, 2 |
| 15 | Physical disability retirement with no diagnosis available | 2, 3 |
| 16 | Internal derangement of joint (other knee derangement) | 2, 4 |
| 17 | Deflected nasal septum (first admission) | 3, 2 |
| | Deflected nasal septum (second admission) | 4 |
| 18 | Sprains and strains of other and unspecified parts of back and anomalies of lumbosacral joint (first admission) | 3, 5 |
| | Vertebrogenic pain syndrome (lumbalgia) and sprains and strains of other unspecified parts of back (second admission) | 3, 11 |
| | Displacement of intervertebral disc (lumbar and lumbosacral) and unspecified site (third admission) | 4, 8 |
| | Other anomalies of larynx, trachea, and bronchus (fourth admission) | 6, 9 |
| 19 | Transient situational disturbances (first admission) | 3, 6 |
| | Transient situational disturbances (second admission) | 3, 8 |
| 20 | Internal derangement of joint (other knee derangement) | 3, 7 |
| 21 | Physical disability retirement for dislocation of hip (automobile accident)** | 3, 3 |

TABLE 11 (continued)

| Diver | Diagnosis (ICDA-8 Rubrics) | Time Period Since DCS, yr, mo. |
|---|---|---|
| 22 | Diseases of the intestines and peritoneum | 3, 10 |
| 23 | Neoplasm of unspecified nature of skin and musculoskeletal system (bone and cartilage) (first admission) | 4, 1 |
| | Neoplasm of unspecified nature of eye, brain, and other parts of nervous system (spinal cord) (second admission) | 4, 3 |
| | Other diseases of spinal cord (third admission) | 4, 7 |
| | Certain symptoms referable to nervous system and special senses (abnormal involuntary movement) (fourth admission) | 4, 10 |
| | Other diseases of joint (fifth admission) | 5, 1 |
| 24 | Alcoholism (alcoholic addiction) (first admission) | 4, 1 |
| | Alcoholism (alcoholic addiction) (second admission) | 4, 9 |
| 25 | Symptoms referable to cardiovascular and lymphatic system (syncope or collapse) and injury, other and unspecified (trunk) | 4, 8 |
| 26 | Chronic ischemic heart disease, gangrene, and benign neoplasm of bone and cartilage | 5, 1 |
| | Physical disability retirement for chronic ischemic heart disease | 5, 5 |
| 27 | Alcoholism (alcoholic addiction) | 5, 3 |
| 28 | Diseases of the pancreas (acute pancreatitis) and symptoms referable to abdomen and lower gastrointestinal tract (abdominal pain) (first admission) | 5, 5 |
| | Dislocation of knee (second admission) | 6 |
| | Internal derangement of joint (other knee derangement) (third admission) | 7, 9 |
| | Other diseases of muscle, tendon, and fascia (residual foreign body in tissue or bone) (fourth admission) | 8 |
| | Other diseases of joint (fifth admission) | 10, 7 |
| 29 | Alcoholism, improper use of drugs, and essential benign hypertension | 5, 5 |
| 30 | Vertebrogenic pain syndrome (lumbalgia) | 5, 11 |
| 31 | Osteoarthritis (spondylitis osteoarthritica) (first admission) | 6, 2 |
| | Osteoarthritis (spondylitis osteoarthritica) (second admission) | 6, 5 |
| | Osteoarthritis, other congenital anomaly of musculoskeletal system (abnormality of spine), personality disorder (other), and arthritis (unspecified) (third admission) | 7, 11 |
| | Physical disability separation for arthritis* | 8, 10 |
| 32 | Arterial embolism and thrombosis (of mesenteric artery) | 6, 10 |
| 33 | Occlusion of precerebral arteries (without mention of hypertension) (first admission) | 7, 10 |
| | Arterial embolism and thrombosis (of other and unspecified arteries) (second admission) | 7, 10 |
| 34 | Essential benign hypertension | Unknown |
| | Physical disability retirement for diabetes mellitus | 7, 11 |
| 35 | Diseases of the pancreas (chronic pancreatitis) | 8, 7 |
| | Physical disability retirement for diseases of the pancreas (chronic pancreatitis) | 8, 7 |
| 36 | Other diseases of the gallbladder | 8, 7 |
| 37 | Sprains and strains of knee and leg (first admission) | 8, 9 |
| | Internal derangement of joint (other knee derangement) (second admission) | 9 |

*Subsequent hospitalization(s) and physical disability separations for divers hospitalized immediately for DCS. **This diver had six automobile accident-related hospitalizations and medical boards which are not presented.

movement, pain in the limb, pain in the joint, chest pain, abdominal pain, syncope, and headache (7). The category of disorders of the arteries and veins seemed to consist of conditions possibly associated with bubble nucleation and growth. Before concluding that these conditions were causally related to DCS, however, two issues should be addressed: the number of divers hospitalized for these conditions was very low, and only one hospitalization occurred sufficiently close in time to the accident to be potentially related to DCS. Perhaps a more cogent explanation for these results was that the hospitalizations were manifestations of an increased susceptibility to these disorders because of the DCS incident and/or the accumulating effects of hyperbaric exposures.

Other findings showed that no specific disorder was observed to have an elevated number of hospitalizations prior to the DCS incident. Also reported was the finding that the divers in the DCS sample were significantly heavier than other divers but not significantly older.

In conclusion, this longitudinal study examined all illnesses requiring a hospital admission or board appearance in a sample of DCS divers as well as those disorders that differentiated these divers from controls. Two clusters of 12 diagnoses were identified as potential subsequent health risks for divers who suffered a DCS mishap.

## Consequences of U.S. Navy Diving Mishaps: Air Embolism and Barotrauma

As noted in a previous summary, the most frequently reported U.S. Navy diving accident was DCS, which accounted for 41.1% of all mishaps. Also identified were the health risks that might be associated with DCS. For divers who have experienced an air embolism or barotrauma, however, little is known of the ill health effects that could be manifest as a result of these diving-related conditions. The purpose of this study was to examine the reasons for hospitalizations subsequent to the occurrence of an air embolism or barotrauma and to determine whether or not these admissions could be attributed to the diving mishaps. The medical events or health consequences included hospital admissions, physical evaluation boards, deaths, and physical disability separations and retirements.

### METHOD

The two samples for this study consisted of 165 U.S. Navy male enlisted divers and diving officers, 27 of whom had experienced an air embolism and 138 a barotrauma from January 1968 through December 1979. All but two of the 165 divers were identified from their diving accident records on the Diving Log-Accident/Injury Report file; the other two had no diving accident data but had a hospitalization or physical evaluation board for an air embolism.

Using medical inpatient and service history data, frequency distributions were compiled to identify divers in both samples who were separated from active duty and/or who had been hospitalized or reviewed by a physical evaluation board subsequent to the diving accident. After excluding diagnoses attributed to nondiving-related diseases or accidents (e.g., an appendectomy or motor vehicle accidental injury), all hospital admissions were listed in tabular form according to their occurrence prior to, in conjunction with, and subsequent to the diving mishap.

### RESULTS AND DISCUSSION

#### Air embolism

Table 12 is a presentation of the frequency distribution of treatment outcomes and the immediate and subsequent medical events. Of the 27 divers

TABLE 12

SUBSEQUENT HOSPITALIZATIONS AMONG U.S. NAVY DIVERS TREATED FOR AIR EMBOLISM (n = 27) OR BAROTRAUMA (n = 138), 1968-1979

| Medical Event* | Complete Relief | Substantial Relief | Recurrence | No Diving Record |
|---|---|---|---|---|
| *Air Embolism: Treatment Outcome* | | | | |
| Immediate hospitalization | 9 | 0 | 1 | 1 |
| Subsequent hospitalization | 2 | 0 | 0 | 0 |
| No medical event | 7 | 2 | 2 | 0 |
| Total | 18 | 2 | 3 | 1 |
| *Barotrauma: Treatment Outcome* | | | | |
| Immediate hospitalization | 2 | 1 | 0 | 0 |
| Subsequent hospitalization | 4 | 3 | 0 | 0 |
| No medical event | 79 | 49 | 0 | 0 |
| Total | 85 | 53 | 0 | 0 |

*Three divers died as a result of the air embolism incident.

who had an air embolism mishap, three died as a direct result of the incident. Five divers were listed as having experienced either substantial relief or a recurrence; none of these divers had a subsequent recorded medical event. The records for 18 other divers indicated that they experienced complete relief subsequent to treatment although 9 had been hospitalized immediately because of the air embolism incident. Two of these divers as well as two others were subsequently hospitalized: one for emphysema, one for other diseases of the upper respiratory tract, and two for alcoholism. The diver with the upper respiratory tract condition had had a hospitalization for synovitis prior to the air embolism incident and an admission three years later for an unspecified neoplasm of the larynx. (The only other precursory disorder observed in this sample was an admission for tonsilitis.) At the end of the follow-up period, the remaining divers either continued to serve on active duty or had been retired, separated, or released from active duty. There were no physical disability separations or retirements recorded for this sample. Thus, although the consequences of an air embolism were shown to be fatal for three divers, the incidence of a specific disorder or cluster of diagnoses as a potential aftereffect of air embolism was not established.

**Barotrauma**

The largest proportion of the 138 cases involved barotrauma of the senses, primarily auditory (59 cases or 42.8% of all barotraumas). No other category accounted for a sizable percentage of the total cases. The most serious barotraumas included one case in the respiratory or cardiovascular system and three in the central nervous system (two divers who suffered unconsciousness and one case of numbness or paresthesia). Only one of these four men was hospitalized immediately after the incident (for observation), and all four divers continued to serve on active duty for periods of time that ranged from one to six years after the incident.

As shown in Table 12, the treatment outcomes were complete relief and substantial relief for 85 and 53 divers, respectively. Immediately after the barotrauma mishap, three divers were hospitalized for the following reasons: DCS, observation (noted above), and vertigo. No subsequent adverse health consequences were recorded for these men. During the first year after the barotrauma, five divers were hospitalized for transient situational disturbances (one diver), displacement of the intervertebral disc (one diver), and various combinations of hearing impairment--otitis media, otitis externa, and other diseases of the ear (three divers). One of the divers who was hospitalized for a hearing problem was separated from active duty with a physical disability for deafness. After the first year, one diver was hospitalized for alcoholism and another for displacement of the intervertebral disc.

The most frequently reported disorders that occurred prior to the barotrauma included respiratory diseases for nine divers, diarrheal disease for four divers, and two each with other viral diseases, alcoholism, and other diseases of the blood. In examining the time sequence of these events in relation to the barotrauma, the most proximal admissions were 10 and 13 months, respectively, for pneumonia and hay fever. Because of the time differential between hospitalizations, these conditions did not appear to increase the diver's susceptibility for experiencing a barotrauma.

When one considers the fact that Navy divers performed more than 700,000 dives during the time period of this study, the incidence of 27 air emboli sms and 138 barotraumas represented an extremely low diving accident rate for

these conditions. However, the loss of three lives to air embolism and the incidence of ear and hearing problems in three divers (one of whom was separated with a physical disability for deafness) emphasized the need to further promote adherence to the safety procedures established by the Navy diving community and to the medical standards developed for divers.

## Longitudinal Health Risks among Graduates and Nongraduates of Diving School

Results of occupational health research suggest that most occupations in general, and hazardous ones in particular, involve a set of risks that can adversely affect the physical and mental well-being of individuals so employed. Failure to succeed in one's chosen field or in a training program also may negatively influence the individual's health. The primary objective of this study was to examine the health risks related to the hazardous occupation of diving. A secondary objective was to identify any adverse health effects that might be associated with failure to successfully complete a diver training program.

### METHOD

Participants for this longitudinal study were 874 men assigned to the U.S. Navy Diving School in Washington, D.C., during the time period from 1964 through 1971; 684 graduated from training and 190 failed to successfully complete the program. The training outcome for all nongraduates was listed as "fail"; none of these disenrollments was attributed to a medical disqualification. Throughout the 12-year follow-up, which ended in December 1978, 582 enlistees were separated from service; 235 graduates (34.4%) and 57 nongraduates (30.0%) were listed on active duty at the end of follow-up.

Annual hospitalization rates per 10,000 strength were computed for each of the 16 ICDA-8 diagnostic categories and for specific diagnoses associated with hyperbaric exposure or training failure (7,18). The $\chi^2$ technique was used to determine whether or not the numbers of hospital admissions differed significantly between groups. Populations at risk for graduates and nongraduates were separately determined by tabulating the number of men on active duty for each of the six 2-year postschool intervals and computing the mid-point population value. Comparisons of rates between the two groups (tests for the significance of differences between proportions) were conducted to identify the most vulnerable time period for the occurrence of a serious disease (i.e., one requiring a hospitalization). Similar comparisons of proportions of admissions were performed during the 2-year preschool

period, which would establish if there was a significant difference between graduates and nongraduates in morbidity prior to the follow-up period.

## RESULTS

During the preschool period (or baseline), the proportion of graduates who were hospitalized (15.9%) did not differ significantly from the proportion of nongraduates hospitalized (13.0%). An equitable baseline, therefore, was established from which to conduct comparisons of hospitalization rates reported for the 12-year follow-up.

In comparing rates for the 16 major diagnostic categories and several specific diagnoses during the follow-up period, results showed that nongraduates had a significantly higher admission rate of mental disorders than graduates. Contributing the most to this difference was the rate of alcohol/drug abuse which was almost three times greater for nongraduates than graduates. No significant differences in rates between groups were observed for any of the diving-related disorders. The interval of greatest vulnerability for both groups to be hospitalized was the first 2-year interval after training; nongraduates had a significantly higher percentage of individuals who were hospitalized than graduates during this time period.

## DISCUSSION

Several issues should be considered in interpreting the low rates and the few differences observed. First, the number of enlistees who remained on active duty continued to decrease over time which made it impossible to identify the health problems experienced by those individuals who left the Navy. Second, many diving-related disorders rarely occurred, as was shown in previous summaries, especially in a sample as small as this one. Third, the data selected for this study pertained to medical inpatient records, which included only those conditions serious enough to require a hospital admission and precluded information on disorders treated at the diving site or in an outpatient medical facility. Fourth, the low rates reflected in part the high standards established for diver selection and retention.

Of the disorders postulated as related to failure, the diagnosis of alcohol/drug abuse was the only one that yielded a significantly higher

hospitalization rate for nongraduates than graduates. Their rate also was higher than that reported for the total Navy enlisted population: 64 per 10,000 for all enlistees versus 110 per 10,000 for nongraduates (27). While such results suggested that failure may be implicated in the increased rate of substance abuse hospital admissions, it is equally plausible that prior alcohol/drug problems contributed to diving school failure although no medical disqualifications for these conditions were reported. Also noted was the finding that nongraduates did not have an elevated admission rate for any of the other stress-related disorders.

Results of this study suggested that the Navy might consider providing a special intervention program designed to help nongraduates successfully adjust to another Navy career path than diving. Overall, these findings seemed to imply that failing to complete an occupational training program may represent a greater health risk to the individual than the health risks associated with the hazardous occupation itself.

## CONCLUSIONS

Results of these studies pointed up the influence of diving experience and age on the incidence of hospitalizations and accidents among members of the U.S. Navy diving community. Diving experience seemed to have a minimal adverse impact on numbers of hospital admissions; to be specific, only hospitalizations for environmentally induced disorders, primarily DCS, were shown to be related to higher levels of diving experience in the total enlisted diver population. Other results determined that significantly higher-than-expected numbers of hospital admissions were observed for the diagnostic categories of musculoskeletal disorders among UDT/SEAL divers and respiratory diseases and pain symptomatology among master divers. Among diving officers, no unique health risks were attributed to a higher level of hyperbaric exposure.

Lower levels of experience, on the other hand, tended to be associated with higher hospitalization rates of stress-related disorders. At the lowest level of experience, or the diver training phase, nongraduates from diving school had significantly higher hospitalization rates for alcohol/drug abuse than graduates during a 12-year posttraining follow-up period. Inexperienced enlisted divers had significantly more hospitalizations than expected for almost all stress-related conditions. Officers with a lower level of diving experience were more likely than their more experienced counterparts to be hospitalized for alcohol/drug abuse or cardiovascular disease.

The similarity of results in three different diving populations provided the basis for formulating several explanations that lent support for the selection and retention policies established by the Navy diving community. The first explanation was that inexperienced divers with alcohol or drug abuse problems probably were disqualified from diving during the early phases of their careers. Many divers also may have decided on their own to discontinue diving for a variety of reasons, including a fear of the effect of alcohol or drugs on underwater safety. Second, another explanation was that failure to remain in the diving community might have led to increased alcohol or drug involvement--to the point of being hospitalized. Third, among experienced divers, on the other hand, the low rates for these conditions were considered a reflection of their concern for maintaining a healthy life style

or a high level of physical conditioning. The dangerous nature of diving requires a dedication to fitness which would include an avoidance of abusing alcohol or drugs. The low rates observed, therefore, indicated that the retention standards and safety procedures implemented in the diving community have been effective in protecting the health and safety of Navy divers.

The aging process in both control and diver groups was shown to be associated with an increasing rate of hospitalization, particularly for musculoskeletal disorders, diseases of the circulatory system, and alcohol/drug abuse. Age-specific rates were significantly higher among enlisted divers than nondivers for the subcategories of joint diseases, respiratory disorders, and deflected nasal septum at ages 23-28. Divers had significantly lower hospitalization rates than controls for stress-related conditions before age 41 and circulatory diseases after age 28. The impact of the aging process, therefore, was significantly greater among nondivers which was inferred from their higher rates for circulatory disease than divers. Diving officers had significantly higher hospitalization rates than nondiving officers for joint disorders and diseases of the nervous system.

Experience and age also were examined in relation to diving accidents. Comparisons showed that dives performed at the greatest depths and those specifically conducted for "selection" and "experimental" purposes had the highest accident incidence rates. Divers older than 37 years of age had the lowest accident incidence rates. Other results indicated that the long-term health consequences of DCS included a statistically significant risk of being hospitalized for pain symptomatology and disorders of the arteries and veins. Findings from another longitudinal study showed that three lives were lost to air embolism and three divers suffered ear and hearing problems because of a barotrauma incident. Among all other divers who experienced an air embolism or barotrauma, no subsequent hospitalizations for a diving-related condition were observed.

**RECOMMENDATIONS**

The Navy Medical Department and members of the diving community should be apprised of the potential diving-related health risks of musculoskeletal disorders, respiratory diseases, and pain symptomatology, primarily among

UDT/SEAL and master divers, as well as joint and nervous system disorders among diving officers. Awareness of these conditions might encourage divers to seek immediate medical treatment and to report the diving or equipment hazards that may be causative factors. Another important recommendation is to emphasize the need for promoting and continuing adherence to the procedures developed in the U.S. Navy diving community to ensure the safety and excellent health status of all divers; such endeavors should reduce even further the hospitalization rates for environmentally induced disorders. Moreover, all possible precautions should be taken on experimental, selection, and saturation dives. Future research should examine the relationship of other factors in conjunction with DCS and the health risks of symptoms and headaches and diseases of the arteries and veins. And last, these eight studies only examined the short- and long-term health effects that were serious enough to warrant a hospitalization. To fully assess the health consequences of diving, future research should examine the medical problems that are treated at the diving site or in an outpatient medical facility.

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The purpose of this report was to summarize and evaluate in one volume studies that examined the short- and long-term health effects associated with being a U.S. Navy diver during the time from January 1968 through December 1979. Results showed that enlisted male divers (n = 11,584) had significantly higher hospitalization rates than controls for environmentally induced disorders as well as joint disorders, respiratory diseases, and deflected nasal septum at ages 23-28. Diving officers had higher hospitalization rates than other officers for joint and neurological disorders. Other potential diving-related health risks included musculoskeletal disorders among UDT/SEAL divers and respiratory diseases and pain symtomatology among master divers. The aftereffects of decompression sickness consisted of the two diagnostic clusters of symptoms and headache and disorders of the arteries and veins. Three lives were lost to air embolism, and three divers suffered ear and hearing problems because of a barotrauma incident. Other results showed that inexperienced enlisted divers and officers as well as nongraduates from training were at increased risk of being hospitalized for stress-related conditions, especially alcohol/drug abuse. Keywords: health surveys

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