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Aseptic bone necrosis among U.S. Navy divers: survey of 934 nonrandomly selected personnel

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Hunter, W. L. Jr., R. J. Biersner, R. L. Sphar, and C. A. Harvey. 1978. Aseptic bone necrosis among U.S. Navy divers: survey of 934 nonrandomly selected personnel. Undersea Biomed. Res. 5(1): 25–36.—Nine hundred thirty-four U.S. Navy divers were selected and surveyed radiographically using standard techniques developed for detecting aseptic bone necrosis (ABN). X rays were read by qualified radiologists. A total of 16 positive cases was detected, and another 11 were interpreted as doubtful. ABN was found to be related to age and number of months in diving. After controlling for these factors, ABN could not be related to any of seven indices of diving activity. Divers with ABN did, however, have a history of more treatments for decompression sickness (DCS) than did divers without ABN. Implications of these findings are discussed, and the suggestion is made that ABN and DCS may not be related causally, but may be related to a third common factor. The need for controlled studies is discussed. The conclusion is made that the low prevalence rates of ABN among U.S. Navy divers cannot be related to any specific index of diving activity, and may not be causally related to DCS.

radiography
dysbaric osteonecrosis
decompression sickness

For nearly 70 years, aseptic bone necrosis (ABN) has been postulated to be related to hyperbaric exposure, having first been described accurately in caisson workers in 1911 by Bornstein and Plate (*see* McCallum and Walder 1966). (This condition is referred to by a variety of other names, among them dysbaric osteonecrosis, caisson disease of bone, barotraumatic arthropathy, and so forth.) For many years, the assumption was made that the disorder involved caisson workers only. In 1936, however, Seifert reported a case of ABN in a diver (Seifert, 1948). Subsequently, sporadic case reports of symptomatic divers appeared in European and American journals. During the late 50's and early 60's, radiographic surveys of asymptomatic commercial shellfish divers in Japan revealed prevalence rates exceeding 75% (Ohta and Matsunaga 1974). These findings indicated that ABN may have been more prevalent than assumed originally. As a result, medical research interest in the disorder was heightened.

In response to the earlier data on caisson workers and to the more recent findings among Japanese shellfish divers, the Royal Navy began conducting a radiographic survey of clearance divers during the middle 60's. This survey demonstrated a prevalence rate of 4.7% in this population (Harrison 1971). Concomitantly, the U.S. Navy was conducting a survey of long-bone radiographs (primarily shoulder and femur views) using unstandardized procedures that had been performed on a nonrandom sample of U.S. Navy divers. This survey was conducted in response to the first reported case of ABN in a U.S. Navy diver (Uhl 1968). Positive X-ray evidence was present in 4% of this U.S. Navy sample. A restructured survey was then performed on 335 U.S. Navy divers. Preliminary reports showed that X rays indicated a much higher percentage of personnel with lesions. As a result, the sample was expanded, and expertise was obtained from radiology consultants of the Medical Research Council Decompression Sickness Panel (U.K.). The methods and results of this expanded analysis are described below.

METHODOLOGY

The sample

All participants were active-duty U.S. Navy divers. They were obtained primarily from three sources: 1) divers stationed in the immediate vicinity of the Naval Submarine Medical Research Laboratory, Groton, Connecticut, (NSMRL); 2) divers who were participants in a separate research project assessing longitudinal health; and 3) divers who were students in the Naval School, Deep Diving Systems, San Diego, California. The radiographs of 1086 personnel were evaluated. Of these, the films on 152 divers were judged to be technically unsatisfactory (TU) and could not be accurately interpreted. These personnel were excluded from the sample, leaving a total sample of 934.

Radiological evaluation

Technical methodology

The divers were surveyed using the protocol developed by the Medical Research Council Decompression Sickness Panel (MRC–DCS) of the United Kingdom (McCallum and Walder 1966; Elliott and Harrison 1970; Davidson 1976; Harvey and Sphar 1976). The protocol delineates the X-ray projections required and the specific techniques to use in obtaining these projections.

Classification

Radiographs were also classified under the system developed by the MRC–DCS Panel. This system is in widespread use and can be found in a number of sources (Elliott and Harrison 1970; Harrison 1974; Davidson 1976).

Interpretation

Each film set was read initially by two members of a panel of four radiologists who were trained by radiology consultants of the MRC–DCS. In the event of disagreement in interpretation, differences were resolved at periodic workshops held at NSMRL. These workshops were attended by all members of the panel, as well as by MRC–DCS consultants. Films were classified by each pair of panel members into one of three categories: positive, doubtful, or negative.

Additional data sources

Questionnaire

A questionnaire containing items about diving experience was administered to about 70% of the divers. Data were not available on the remaining 30% because administration of the questionnaire was not begun until the project was well underway. The questionnaire asked about number and depths of dives, accident history, years of diving experience, age, and so forth. These data were available from 15 of the 16 cases later classified as positive.

Diving logs

To assess recent diving activity (and to verify questionnaire responses), diving logs were obtained from the Naval Safety Center, Norfolk, Virginia. These logs contain detailed information about the dives which have been made by a diver (such as frequency, depth, bottom time, and so forth). Diving data were obtained only for the two calendar years 1974 and 1975 because the data collection system was still under development prior to this period. Diving log data were available on 10 of the 16 cases later classified as positive.

Statistical analyses

As mentioned above, the films were classified into one of three categories: positive (definite radiographic evidence of ABN); negative (an absence of such evidence); and doubtful (equivocal). For the statistical analyses described below, data on those in the doubtful category were eliminated and comparisons were made between positives and negatives only.

Chi-square analysis was used to determine if observed frequencies differed significantly from expected frequencies for factors that were classified according to nominal or ordinal scales. A Yates correction was used in computing chi squares if the expected frequencies were less than five. For ratio data, comparisons between groups were made using t-tests for independent samples. Pearson product-moment correlations were used for correlational analyses. Levels of significance are $P \leq 0.05$ (two-tailed for t-tests).

To reduce the data collation involved in making comparisons between the positive group and total negative sample, a subsample of 70 divers was selected randomly from among the total negative sample by choosing those with an "1" as the last digit in their Social Security Number. (The size of this negative subsample, and the number of positives, may vary according to the availability of questionnaire data.)

Results

Inasmuch as the sample was not selected in a random or stratified manner, a determination was made of the extent to which the sample was representative of the Navy diving population. Data for the Navy diving population were obtained from several sources. Data on ages were obtained from Biersner (1975). Data on diver classification were obtained from departments of the U.S. Navy Bureau of Personnel and the U.S. Navy Bureau of Medicine and Surgery. In the tables and statistics cited below, expected frequencies were determined either from these Navy diving population data (Tables 1, 2, and 3), or from data obtained from those whose X rays were classified as negative (Tables 4, 5, 6, 7, 8, and 9).

Table 1 compares age distribution between the total sample and the Navy diving population. This total sample differs significantly from the diving population, being weighted toward the older age groups. Table 2 compares diving classification within the total sample to the Navy diving population. Again, the sample is significantly biased. Diver classifications in the groups with more diving experience or advanced diver training (saturation divers, master divers, first class divers) are overrepresented, while those classifications in the diving population that require less diving experience (second class diver, EOD officer, submarine medical officer,

TABLE 1
COMPARISON OF AGE GROUPS BETWEEN THE TOTAL SAMPLE AND THE NAVY DIVING POPULATION

Age Group, yr	Observed	Expected
18–25	240	393.79
26–30	229	208.34
31–35	204	136.44
36–40	109	60.46
41 and over	35	17.97
Total	817	817.00

$\chi^2 = 195.22$; df = 4; $P < 0.001$.

TABLE 2
COMPARISON OF DIVING CLASSIFICATIONS BETWEEN THE TOTAL SAMPLE AND THE NAVY DIVING POPULATION

Diving Classification	Observed	Expected
Saturation diver	187	54.93
Master diver	31	16.61
Diver first class	216	172.04
Diver second class*	96	151.22
Scuba diver*	38	120.73
Diving medical technician	71	35.31
HeO_2 officer	30	38.33
Ships salvage officer*	18	53.73
EOD officer	14	42.86
Undersea medical officer	24	39.24
Total	725	725.00

$\chi^2 = 505.08$; df = 9; $P < 0.001$. *No mixed gas training; air only.

and so forth) are underrepresented. This finding is further verified by the results found in Table 3, which classifies the divers according to the breathing mixtures/modes that they used in diving.

TABLE 3
COMPARISON OF BREATHING MIXTURES/MODES BETWEEN THE TOTAL SAMPLE AND THE NAVY DIVING POPULATION

Mixtures/Modes	Observed	Expected
Saturation	187	62.46
Mixed gas	372	342.81
Air only	128	281.73
Total	687	687.00

$\chi^2 = 334.70$; df = 2; $P<0.001$.

Radiographic findings

Table 4 presents the overall prevalence rates of ABN in this sample of divers. A total of 16 divers (1.71%) were classified as positives, while 907 were classified as negatives (97.11%). An additional 11 divers (1.18%) had doubtful readings. A noteworthy finding is that of the 16 divers with positive X rays, only one (0.11% of the total sample) had any symptoms that could be attributed to ABN.

TABLE 4
PREVALENCE OF ASEPTIC BONE NECROSIS IN THIS SAMPLE OF NAVY DIVERS

Radiological Classification	Number of Divers	Prevalence,%
Positive	16	1.71
Doubtful	11	1.18
Negative	907	97.11
Total	934	100.00

Data in Table 5 show the radiological classification of the lesions seen on X ray among the 16 positives and the anatomical distribution of these lesions. The radiological classification categories are those developed by the MRC–DCS Panel. Type A lesions are juxtarticular, while Type B lesions are located in the head, neck, or shaft of the involved bone. (The probability that Type A lesions may result in disability is indicated by the suffix numeral; higher numerals indicate a higher probability.) A total of 21 lesions was seen in the 16 divers with positive films. Eight lesions (38.1%) were Type A, and 13 lesions (61.9%) were Type B. However, of the Type A lesions, all but one (7/8) were in the shoulders, while most (7/13) Type B lesions were in the femurs. The prevalence of ABN in the shoulders of divers has been reported previously (Fagan, Beckman, and Galletti 1974; Ohta and Matsunaga 1974).

TABLE 5
DISTRIBUTION OF LESIONS BY ANATOMICAL SITE

	Lesion classification									
Anatomical	Juxtarticular							Head, Neck, or Shaft		
Site	A1	A2	A3	A4a	A4b	A4c	A5	B1	B2	B3
Left shoulder	2	1						1	1	
Right shoulder		3			1			1		
Right hip			1							
Left hip									1	
Right knee (femur)									2	
Right knee (tibia)									2	
Left knee (femur)									5	
Left knee (tibia)										
Total				8					13	
Percentage				38.1					61.9	

Other factors

Table 6 shows an age comparison between the 16 positives and 39 of the randomly selected subsample of negatives, using questionnaire data. These results showed that the positive group is older, and that ABN is especially prevalent among divers over 35 years of age. Table 7 compares months in a diving billet (MIDB) using questionnaire data available for 15 positives and 39 of the randomly selected negatives. These data show that divers in the positive group have occupied diving billets significantly longer than have divers in the negative group. MIDB was, however, found to be significantly related to age in both groups combined ($r = 0.735$; df = 45; $P < 0.001$). The results in Table 8 show that despite significant differences in age and MIDB, positives and negatives did not differ significantly in level of training as reported on the questionnaires. In addition, Table 9 shows that the two groups did not report differences in the breathing mixtures/modes used in diving.

TABLE 6
COMPARISON OF AGE GROUPS BETWEEN POSITIVES AND THE NEGATIVE SUBSAMPLE

Age Group	Positives Observed	Positives Expected
18–25	1	4.72
26–30	2	4.49
31–35	3	3.96
36–40	5	2.14
41 and over	5	0.69
Total	16	16.00

$\chi^2 = 26.73$; df = 4; $P < 0.001$; positives, $n = 16$; negatives, $n = 39$.

TABLE 7
COMPARISON OF MONTHS IN DIVING BILLET BETWEEN POSITIVES AND THE NEGATIVE SUBSAMPLE

	Positives	Negative
Mean	99.7	48.6
SD	53.0	44.2

df = 52; t = 3.60; $P<0.01$; positives, n = 15; negatives, n = 39.

Inasmuch as age and MIDB were found to differ significantly between the positive sample and the negative subsample, subsequent comparisons involved a subsample of 15 negatives (selected from among the total sample of 907 negatives) who were matched as closely as possible on these two variables with the 15 positives for whom questionnaire and diving log data were available. Table 10 presents the ages, MIDBs, and ranks/ratings as determined from questionnaire data for each member of the two matched samples. *T*-tests showed that age and MIDB did not differ significantly between these two groups.

Comparisons between the matched positive and negative groups for eight parameters of diving experience are shown in Table 11. These comparisons include both questionnaire and diving log data. A noteworthy observation is that diving log data substantiated the questionnaire findings in each case.

Table 11 provides evidence that the two diver groups did not differ significantly in frequency of diving, nor did the two groups vary significantly in the number of hazardous dives (such as deeper dives, saturation dives, and so forth). Despite these similarities in diving activity, the divers with ABN experienced significantly more decompression sickness (DCS) than those who were in the negative group. Inasmuch as the two groups are also matched for age and MIDB (and fairly well matched for rank/rate), this DCS effect would appear to be independent of these other variables.

TABLE 8
COMPARISON OF DIVING CLASSIFICATIONS BETWEEN POSITIVES AND THE NEGATIVE SUBSAMPLE

Diving Classification	Positives Observed	Positives Expected
Saturation diver	4	3.606
Master diver	2	0.582
Diver first class	4	4.169
Diver second class*	0	1.842
Scuba diver*	0	0.737
Diving medical technician	0	1.338
HeO_2 officer	2	0.640
Ships salvage officer*	0	0.349
EOD officer	1	0.272
Undersea medical officer	1	0.465
Total	14	14.000

$\chi^2 = 4.38$; df = 9; $P<0.8$ (NS); positives, n = 14; negatives, n = 39. *No mixed gas training; air only.

TABLE 9
COMPARISON OF BREATHING MIXTURES/MODES BETWEEN POSITIVES AND THE NEGATIVE SUBSAMPLE

Mixtures/Modes	Positives Observed	Positives Expected
Saturation	4	3.60
Mixed gas	10	7.42
Air only	0	2.98
Total	14	14.00

$\chi^2 = 2.646$; df = 2; $P<0.2$ (NS); positives, $n = 14$; negatives, $n = 39$.

DISCUSSION

These findings must be interpreted cautiously, and extrapolation to other groups may not be warranted because of dissimilarities between groups. For example, the present sample was not representative of the Navy diving community (Tables 1, 2, and 3), since it was weighted toward older, more experienced personnel. In view of the demonstrated relationship of ABN to age (Table 6), the 1.71% prevalence rate in the sample may overestimate the true prevalence

TABLE 10
COMPARISON OF POSITIVES AND MATCHED NEGATIVES FOR AGE, MIDB, AND RANK/RATE

Positives				Matched negatives			
Subject	Age	MIDB	Rank or Rate	Subject	Age	MIDB	Rank or Rate
P–1	47	216	DCCM	N–1	49	294	BMCM
P–2	50	48	CDR	N–2	45	36	BMCS
P–3	40	120	PH2	N–3	40	156	BMC
P–4	39	156	EN1	N–4	40	132	MMCS
P–5	39	132	HTC	N–5	39	139	MM1
P–6	35	48	LT	N–6	35	33	BMC
P–7	24	36	EM3	N–7	24	33	HT2
P–8	32	125	HTC	N–8	32	120	BMC
P–9	44	148	ST1	N–9	42	156	HTC
P–10	42	72	CWO3	N–10	40	72	HMC
P–11	33	96	MM1	N–11	34	95	HT1
P–12	36	135	QMC	N–12	36	156	QM1
P–13	26	36	ENS	N–13	26	21	LTJG
P–14	40	72	CDR(MC)	N–14	42	120	CDR(MC)
P–15	28	55	MR2	N–15	28	53	HT1
Mean	37.0	99.7		Mean	36.8	107.7	
SD	7.49	53.0		SD	7.06	71.6	

T-tests: Age, df = 28; t = 0.075 $P > 0.50$; MIDB, df = 28; t = 0.351 $P > 0.50$. MIDB = months in diving billet.

TABLE 11
COMPARISON OF POSITIVES AND MATCHED NEGATIVES
FOR EIGHT PARAMETERS OF DIVING EXPERIENCE

	Positives		Negatives				
Variable	Mean	SD	Mean	SD	df	t	*P*
Total career dives*	904.6	1027.0	1773.4	1948.9	28	1.527	>0.2 (NS)
Total dives 1974–1975**	16.9	11.1	59.7	47.3	18	2.135	<0.05
Total career dives* > 100 fsw	156.5	187.9	403.9	587.7	28	1.553	>0.2 (NS)
Total dives >100 fsw, 1974–1975**	3.8	3.99	6.8	7.6	18	1.103	>0.2 (NS)
Depth of deepest Dive, fsw*	440.0	219.4	438.3	199.5	28	0.022	>0.5 (NS)
Depth of 4 deepest Dives, fsw*	354.5	183.1	316.1	158.8	118	1.227	>0.02 (NS)
Total career saturation dives*	4.27	10.13	1.27	3.62	28	1.080	>0.2 (NS)
Total career treatment for DCS*	1.07	1.16	0.20	0.41	28	2.719	<0.02

*Data obtained from questionnaire;** data obtained from diving logs.

of ABN among Navy divers. The extent to which the findings for this group of 934 Navy divers are related to other groups, such as commercial divers or sport divers, is therefore unknown.

ABN in this sample was related significantly to age (Table 6) and to MIDB (Table 7). These two factors were, however, found to be significantly interrelated, and are therefore unlikely to be associated independently with ABN. The finding that ABN was not related to diving classification (Table 8), breathing mixtures/modes (Table 9), or total number of dives (Table 11), further substantiates the interpretation that MIDB per se was not related independently to ABN. Another noteworthy finding is the absence of positive cases in the "air-only" category. Although this finding may be valid, the possibility remains that the effect is spurious because of the small number of expected cases.

After controlling for age and MIDB by carefully matching members of the negative group to each positive case, ABN was found to be unrelated to any index of diving experience (Table 11). This finding does not agree with many previous reports (Kawashima, Torisu, Hayashi, and Kamo 1974; Ohta and Matsunaga 1974; Davidson 1976; Thickett and Evans 1977), but the disparity could be the result of sample differences or variations in matching (control) procedures. The single, major finding from this analysis was that divers with ABN had a history of significantly more treatments for DCS than the matched group of negatives. Furthermore, the data show that the occurrence of DCS among the positive group cannot be attributed to age, MIDB, training level, gases breathed, or number, type, and depth of dives. Such a finding suggests that some divers are more susceptible to both decompression sickness and ABN, while other divers are more resistant to both disorders. Inasmuch as differences in susceptibility to DCS are strongly suspected (Walder 1975; Pilmanis 1976), perhaps a similar effect is true of ABN. Such susceptibility, as well as the positive relationship found between ABN and decompression sickness, would indicate that ABN is a manifestation of subclinical decompression sickness. Another possibility is that some divers may have one or more physical/

physiological characteristics that enhance susceptibility to both ABN and DCS. Such hypothetical characteristics may include unusual microcirculatory patterns, a propensity to form lipid emboli in response to minimal stress, or unusual sensitivity of the coagulation system. If this were true, then ABN and DCS may not be causally related, but instead may be associated with some common (third) variable.

None of the above interpretations can be substantiated from either the present or previous findings. The etiology of ABN in divers is not well understood (Davidson 1976), and a completely satisfactory animal model has been elusive (Walder 1977). Animal experiments have used either extreme decompression liabilities (Smith and Stegall 1974) or artificial emboli (Jones, Sakovich, and Anderson 1974; Cox 1977), and the resulting lesions therefore may not be comparable to those seen in divers. In addition, ABN appears to develop in response to a variety of insults and disease states that are completely unrelated to diving (Jones and Sakovich 1966; Solomon 1973; Leach and Baskies 1973; Park 1976). Many of these states could be readily excluded in arriving at a differential diagnosis of ABN in divers, but some, including syphilis, gonorrhea, alcoholism, pancreatitis, cirrhosis, and obesity, would have to be taken into account.

An adequate radiological survey of a carefully chosen control sample would greatly aid in addressing some of these problems. To date only a single control group without previous pressure exposure has been surveyed for ABN and compared to divers (Harrison 1971, 1974). These controls were Royal Navy (RN) personnel who were matched according to age and rank/rate with a group of RN clearance divers. ABN was not found among any of the members of this control group. Although this control group was supposedly matched for age and rank with the divers, the data as presented indicate that the age categories are so broad and unsystematic that the groups are essentially matched only for rank. Rank alone is probably not an adequate control variable because rank is independent of occupational specialty. Occupational specialty would be a more valid measure than rank of trauma and other nondiving variables that may be related to ABN. In addition, radiographs of the above control group were not interpreted using double readings (which was the method used for the clearance divers). The radiographs were interpreted by a single radiologist who apparently knew that they were controls. Observer bias, therefore, could be a significant factor in the results.

At present, the prevalence of ABN in a valid control group without a history of pressure exposure is not known. Therefore, the direct and independent association between ABN and diving is also unknown. Certainly, the prevalence rates of 50–75% reported among Japanese shellfish divers suggest some unique hyperbaric factor. However, identification of this factor and of the extent to which this factor contributes to ABN remains elusive because of the absence of an adequate control group for the Japanese sample, possible physiological differences between the Japanese and U.S. Navy divers, and variations in diving procedures between the Japanese and American groups. Until the prevalence of ABN in an adequate control group is determined, the prevalence of ABN among the present diving sample cannot be attributed to diving operations as currently conducted by the U.S. Navy.

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maladie de décompression
radiographie
ostéonécrose dysbarique

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