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Assessment of the Risk of Fractures Because of Service on Diesel Submarines: A Retrospective Cohort Study

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ABSTRACT Introduction: Submariners are known to have decreased bone mass following periods of long submersion. We examined whether this produces a higher predilection to fractures. Methods: This is a retrospective cohort study. Data were collected from the computerized medical records of 457 consecutive submariners (serving 1091.42 man-years). The control group included 3,219 consecutive sailors, (serving 5845.04 man-years). Groups were stratified according to age at induction, body mass index, place of birth, and status of service (i.e., compulsory versus professional). Analysis of fracture incidence and comparison of proportions between the groups was conducted using χ^2 tests and Fisher's exact test. The hazard ratio for fractures was performed using a survival analysis regression model for each group (Cox Proportional Hazard Model). Results: Nineteen submariners (4.2%) and 94 sailors (2.9%) were shown to have fractures during their service (RR = 1.42, p = 0.15). A Cox proportional hazard model was employed. No statistically significant difference was found between the 2 groups (HR = 1.037, p = 0.89). No correlation was found between length of service and risk of fracture. Most fractures suffered by submariners occurred outside their work environment. Conclusions: Submariners are repeatedly exposed to prolonged submersions that are deleterious to bone strength. However, no statistically significant difference in the incidence of fractures was found between submariners and surface sailors. This is an important finding for the bone and occupational health of submariners in general.

INTRODUCTION

Submariners are required to work in tight quarters and handle mental and physical stress for prolonged periods in a hostile environment.

The submarine is a vessel that creates a physiologically inimitable milieu. The submarine's atmosphere is monitored and kept in controllable physiologic limits (Oxygen level at 18–21kPa. Carbon dioxide levels at 0–1.2kPa). Air in the submarine is freshened by suction of air from the surface and from a supply of compressed oxygen and removal of carbon dioxide using unique scrubbers.

Service onboard a submarine is related to several risk factors for decline in bone density (bone mass per unit of volume). The levels of Vitamin D and its active metabolites are known to decrease during prolonged submersions.[1–4] This phenomenon is mostly attributed to lack of exposure to UV sunlight (290–320 nm), a key player in the metabolism of Vitamin D3.[3,5–8] The active metabolite of vitamin D, 1-25 Dihydroxyvitamin-D, has an important role in the homeostasis of calcium and phosphorus levels in the blood and in the mineralization of bones.[9–11] Indeed, a temporary decrease in vitamin D among submariners was found to correlate with decreased bone density.[12] In addition, submariners are exposed to high levels of carbon dioxide for prolonged periods. The relationship between carbon dioxide and bone metabolism has been studied among chronic obstructive pulmonary disease patients,[13,14] among workers in closed spaces,[15] and in an isolated pressure chamber study that simulated submarine conditions.[16] These studies have pointed out that high levels of carbon dioxide correlate with a temporary decrease in the excretion of calcium in urine and stools, concurrent with a mild increase in bone resorption.[16,17] It is not clear, however, if this is related to a long-term decrease in bone density. Finally, we note that the volume of the submarine is limited, not allowing for normal movement and physical exercise, both vital for normal building of bones and skeletal muscles.

A previous study conducted by the Israeli Navy examined the effect of a long (30 days) submersion on bone metabolism and strength.[12] The findings of this study indicated a simultaneous decrease in bone building and resorption markers in the blood, indicating a decrease in bone metabolism. In addition, tests of bone strength using speed of sound (quantitative ultrasound–QUS) in the Tibial mid-shaft indicted a decrease in bone strength at the end of the patrol. This decrease continued a month after conclusion of the patrol. However, at the 6-month follow-up, bone density appeared to return to its pre-embarkation normal level. A decline in QUS values has been shown to correlate with an increased risk of fractures.[18,19]

As prolonged submersions are shown to be correlated with a temporary decrease in bone density, and serving on a submarine entails recurrent submersions, the question arises as to whether this decrease is of any clinical significance and if submariners are thus more susceptible to fractures.

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Furthermore, modern diesel submarine fleets debate whether supplementary vitamin D or the introduction of exercise machines is warranted to protect submariners' bone strength.

The study's primary objective was to compare the incidence of fractures among submariners with that of a control group of surface seamen who serve on the same naval base. Secondary objectives were to examine the relationship between length of service on the submarine flotilla and the risk of fractures and to classify the causes of fractures among submariners.

METHODS

Ethical approval was obtained from the institutional review board of the Israeli Defense Force's Medical Corp.

Study Population

The study examined the computerized medical records of submariners and missile boat sailors from 2002 until 2012. Computerized records were available for 457 consecutive participants from the study group who served a total of 393,872 days (1091.42 man-years). Typical submarine patrols lasted several days to 6 weeks. Specific data such as the frequency of patrols or total man-days at sea is classified. The control group included 3219 consecutive sailors, serving a total of 2,133,457 days (5845.08 man-years). Figure 1 describes the case recruitment process.

The control group used was chosen for three reasons: both groups underwent a similar physical education regimen in both the Israeli Naval Academy and Haifa Naval Base; work environment and exertions were inherently similar for both groups; the level of physical fitness and health for both groups was similar as both had to comply with the same navy regulations. No designated swimmers or scuba divers were included in the analyses.

All participants were male, 18 to 42 years of age. In the study group, all sailors were found to be fit for submarine service by the Israel Naval Medical Institute. In the control group, all sailors were considered fit for combat duty on surface vessels according to the Regulations of the Chief Surgeon of the Israeli Navy.

After collection of all data, we excluded fracture diagnoses from the final analysis in the cases of multiple doctor visits having identical diagnoses, or "suspected" fracture diagnoses found to be erroneous according to X-ray. All diagnoses analyzed were confirmed by imaging studies, as recorded in the computerized medical record. Data recorded included anatomic site of the fracture, physical cause of the fracture, and "geographical" location at the time of injury, if known (e.g., onboard home vessel, during physical exercise on shore, etc.) (Fig. 1).

Statistical Methods

Groups were stratified according to age at induction into the flotillas, BMI, and the IDF combat fitness index; further stratification was performed for place of birth and status of service (i.e., compulsory service versus professional navy).

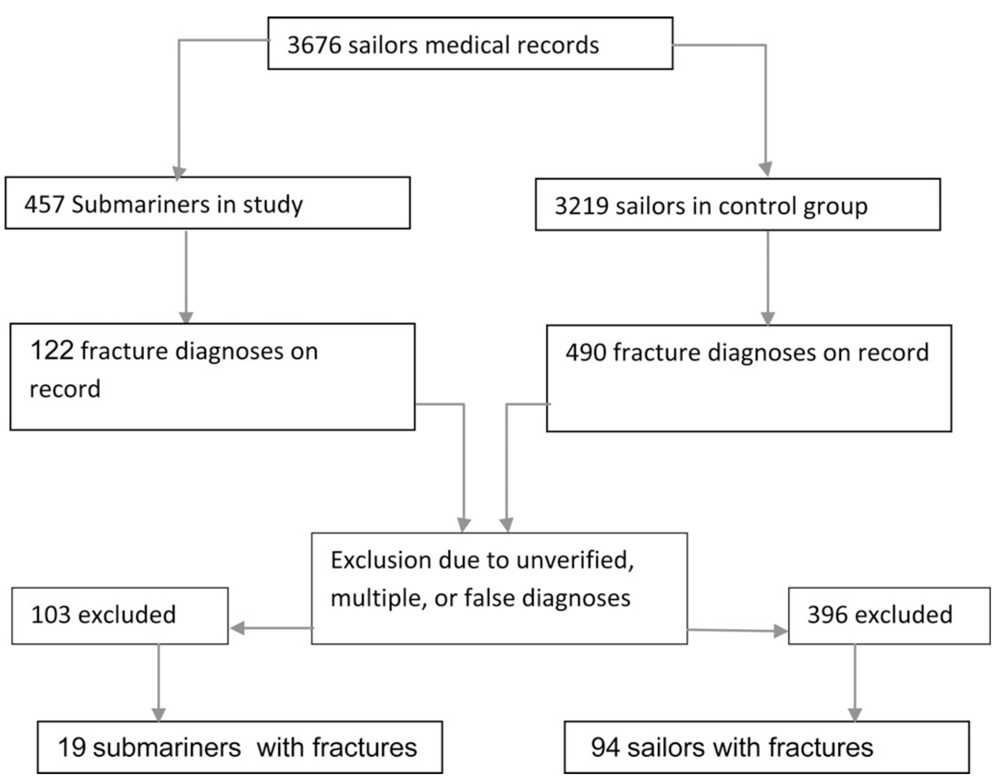

FIGURE 1. Case recruitment.

TABLE I. Population Characteristics

	Submarines	Missile Boats	Levene's Test for Quality of Variances F	Significance
N	457	3,219		
Average BMI at Induction Physical (Age 16)	17.09	17.12	1.461	0.227
Age at Commencement of Follow-Up	20.08	19.46	1.888	0.169
Age at End of Follow-Up	22.46	21.27	7.779	0.005
Average Length of Follow-Up (Days)	871.71	662.77	1.397	0.237
Range of Follow-Up (Days)	103–2,644	101–4,151	—	—
Median Follow-Up (Days)	880	824	—	—

Analysis of fracture incidence and comparison of proportions between the groups was conducted using χ^2 tests and Fisher's exact test. The hazard ratio for fractures depending on length of service was performed using a survival analysis regression model for each group (Cox Proportional Hazard Model).

The causes of the fractures and locations in which the injuries which caused the fractures had occurred were analyzed to identify unknown confounders which might lead to a higher incidence of fractures among one of the groups.

Follow-up was commenced upon induction into the flotilla (after completion of basic and naval training), and ended upon discharge from the navy. For sailors discharged from the IDF from a unit other than their original flotilla, follow-up ended 6 months after leaving the flotilla.

Statistical analysis was performed with the kind assistance of the IDF Medical Corp's Information Branch, using SPSS statistical software.

RESULTS

Population

Table I shows the background features of the two groups. In addition, note that 416 of the submariners (91.3%) and 2,732 of the sailors (84.87%) were born in Israel ($P_v = 0.101$).

Primary Objective

Table II shows the prevalence and features of fractures. 122 and 490 diagnoses of fractures were made in the study and the control group, respectively. After exclusion attributable to unverified, or recurrent diagnoses of the same event, 19 submariners (4.2%) and 94 sailors (2.9%) were shown to have fractures during their service (RR = 1.42, $P_v = 0.15$).

Because of the disparate length of service of the two groups, a Cox proportional hazard model was employed. No statistically significant difference was found between the two groups (HR = 1.037, $P_v = 0.89$).

TABLE II. Omnibus Tests of Model Coeffecients

	Significance	Exp (B)	95% CI
Israeli Born	0.047	2.079	1.011–4.274
Higher BMI at Induction Physical	0.054	1.563	0.993–2.460
Age of Commencement of Follow-Up	0.040	0.735	0.547–0.986

Assuming the incidence of fractures was similar to the one which has been found in our study, the power of the study to identify a real difference between the two groups is 82.12% in case the risk of fractures in submariners were double the risk of fractures in sailors ($\alpha < 5\%$, 2-sided test).

Secondary Objectives

Table III lists the causes of the fractures and the locations of the injuries, which caused the fractures (whether they occurred while doing sports, working onboard, etc.). The differences in either the cause or the location of the injuries between the two groups were not statistically significant. As high as 78.9% of the fractures of the submariners and 44.7% of the fractures of the sailors were caused while they were outside their work environment (i.e., vessel) (Fisher's exact test < 0.01).

Mandatory military service in Israel is sometimes followed by continued "professional" service. Submariners on continued professional service were not more prone to fractures than their younger counterparts according to our findings. Length of service was not found to correlate with a higher risk of fractures.

Omnibus tests of model coefficients of other risk factors showed that obesity, Israeli origin, and younger age at induction into the flotilla correlated independently with high risk of fractures.

TABLE III. Cause and Geographical Location of the Fractures

	Submarines	Missile Boats	Pearson's χ^2
Cause			
Fall	3 (15.79%)	37 (39.36%)	4.924 (3 df)
Striking Against Person/Object	14 (73.68%)	51 (54.26%)	P_v (2-tailed) < 0.1775
Other	1 (5.26%)	2 (2.13%)	
Unknown	1 (5.26%)	4 (4.26%)	
Location			
Working Area	2 (10.53%)	28 (29.98%)	7.417 (3 df)
Sport	9 (47.37%)	28 (29.98%)	P_v (2-tailed) < 0.0597
Other	6 (31.58%)	17 (18.08%)	
Unknown	2 (10.53%)	21 (22.34%)	

DISCUSSION

Prolonged submersions have been shown to be deleterious to bone strength. Furthermore, submariners are likely to be exposed to such submersions repeatedly during the course of their military service. This may lead one to suspect that the risk of fractures among submariners is higher than in other similar groups. In our study, the incidence of fractures among submariners was shown to be higher than in the control group. However, this finding was not significant. As the power of the study to detect significant differences between the two groups is relatively high, we can conclude that submariners' risk of fractures is not higher than that of surface seamen. This may be of significance to diesel submarine fleets throughout the world, as it may render unnecessary the interventions undertaken for correction of this assumed risk factor for fractures (e.g., exercise, food supplements).

We have found statistically significant correlations between demographic characteristics and fractures. Higher BMI has been shown in previous studies to cause a predilection for fractures,[20] as it did in the present investigation. Although the data of BMI during service were unavailable to us, we feel that having a highly verifiable account of BMI at the induction physical is indicative of BMI during young adulthood, as shown in the literature.[21] The average period of time from the physical (at age 16–17) to commencement of service (as seen in Table I) is most likely not significant as it spans 2 to at most 4 years.

The correlation between age of joining the fleet and a higher tendency for fractures may seem coincidental. However, an alternative explanation may be found in the different standards of naval training, some of which require longer periods before actually embarking on service aboard ship. Traditionally, there are different types of naval professions onboard a missile boat. In the Israeli Navy, a longer period of training (and hence an older age of graduation from the naval academy into active duty) signifies a more technological, and therefore sedentary, role on the ship, such as combat information center duties.

The apparent correlation between native-born Israelis and fractures may warrant further study as the authors are not aware of increased incidence of fractures among the local population compared with international data.

The selection of a control group in observational studies is always challenging. The purpose of our study was to detect a unique clinical effect of the submarine environment, and hence we chose as a control group sailors who serve in the same base and perform similar jobs. However, one may wonder whether naval service aboard ship does not increase the risk of fractures in general. The possibility that naval service may represent a risk factor for fractures is reinforced by recent findings of low bone strength values in sailors.[22] Tsuchihara et al showed that sailors serving in posts with less physical roles and exposed to less sunshine on Japanese boats had lower QUS values; however, this study did not examine the rate of fractures and their relationship to bone mass reduction. Further study would be required to assess whether it is naval service per se that is hazardous to bone density.

Our study did not address the possibility of effects of prolonged submersions on the risk of osteoporosis and fractures at older ages, and cannot rule out such risks However, some corroboration may be found in studies performed on veterans, such as the cross-sectional study performed by Gasier et al.[23] The authors examined 462 veteran submariners by Dual Energy X-ray Absorptiometry. Of these, 108 were above 50 years of age. The researchers found that self-reported time at sea was not associated with osteopenia or osteoporosis in submariners, whereas serving onboard a diesel submarine was negatively associated with low total hip bone mass density.

In conclusion, service onboard a submarine was not found to increase the risk of fractures compared to service onboard surface vessels, despite the known adverse effects of submarine service on bone metabolism.

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