Factors Associated with Hair Levels of Cadmium and Lead among U.S. Navy Submarine Personnel[1]

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Abstract

Levels of cadmium and lead among 22 submariners were determined using hair samples. These determinations were correlated with several factors including submarine experience (i.e., number of submarine patrols made), training accomplishments and frequency of dispensary visits during a routine submarine patrol, smoking habits, and whether or not the submarines were members of the Engineering Department. Cadmium levels were found to be significantly higher among engineers than non-engineers, as well as related significantly to frequency of submarine patrols. Multiple regression analysis showed that variations in cadmium levels were accounted for almost entirely by the engineer/nonengineer dichotomy. Poor compliance with standard safety procedures probably is responsible for the elevated cadmium levels found among engineers. Hair levels of lead were found to be correlated significantly with training accomplishments, but in the unexpected direction (i.e., submariners with higher levels of lead accomplished more training than submariners with lower lead levels). This relationship likely is confounded by a third, and as yet undefined, variable. Levels of cadmium and lead were not related significantly to health effects as defined by dispensary visits.

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Cadmium and lead are highly toxic trace metals that have been found to be involved in a variety of health and behavioral problems. Cadmium has been implicated in renal disease and hypertension, but other health effects have been observed, including irritation of the upper respiratory tract, emphysema, pulmonary edema, decalcification of bone, and carcinoma of the lung and prostate (Friberg, Piscator, Nordberg and Kjellstrom, 1974; Holden, 1965; Le-men, Lee, Wagoner and Blejer, 1976; Singhal, Merali and Hrdina, 1979; Tibbits and Milroy, 1980; Underwood, 1977). Among jewelry workers, a significant dose-response relationship has been found between systemic absorption of cadmium and symptoms that are typical of cadmium intoxication, including dyspnea, chest pain, dysuria, and dizziness (Baker, Peterson, Holtz, Coleman, and Landrigan, 1979). These symptoms remitted after exposure to cadmium alloys was discontinued.

Unlike cadmium, which is primarily stored in the kidney and liver (Singhal et al., 1979; Underwood, 1977; Webb, 1975), lead is stored principally in bone (Underwood, 1977). Lead and cadmium often occur together in the same ore deposits (Baker et al., 1979), and concentrations of both metals show strong positive correlations (Kubota, Lazaar and Losee, 1968; Petering, Yeager and Witherup, 1973). Deposition of lead has resulted in physical symptoms that are similar to those induced by cadmium, in which renal complications are the major health effect. Elevated levels of cadmium and lead also have been associated with learning disabilities among children (Phil and Parkes, 1977). Subclinical lead toxicity has been found to degrade eye-hand coordination, as well as other forms of sensorimotor and cognitive performance (Moore and Fleischmann, 1975). Elevations of these metals have been associated with disturbances of behavior among children, notably juvenile delinquency and hyperactivity (Cameron, Wunderlich and Loop, 1980; Schmidt, Weir and Asch, 1981; Von Hilsh-eimer, Philpott, Buckley and Klotz, 1977). In the most careful research to date on the performance effects of these two toxic metals, elevated hair levels of cadmium and lead were associated with abnormal variations in the bioelectric activity of the brain in children; similar groups of children also demonstrated impaired levels of intelligence (Lester, Thatcher and Monroe-Lord, 1982; Thatcher, Lester, McAlaster and Horst, 1982; Thatcher, McAlaster and Lester, 1984). These effects were independent of socioeconomic status. Interestingly, lead appears to lower per-formance (i.e., nonverbal) scores on intelligence tests, while cadmium impairs scores on the verbal portion of intelligence tests. Consistent with the differential intelligence effects found between these two toxic metals, lead dampens amplitude and prolongs latency components in the bioe-lectrical activity of the central areas of the brain, while bioelectrical effects found for cadmium were localized in the posterior areas of the brain. Cadmium has been postulated to depress critical neurotransmitters in the brain such as norepinephrine, serotonin and acetylcholine, resulting in impaired neural activity and consequent decrements in intelligence (Singhal et al., 1979; Webb, 1975). Lead also appears to interfere with neurotransmitter activity, but in this case the target neurotransmitter is dopamine (Govani, Memo, Spano and Trabucchi, 1979). Recently, others (Marlowe, Moon, Errera and Stellern, 1983) have found elevated levels of hair cad-mium and lead to be associated with mental retardation among children.

Exposure to elevated levels of toxic metals, especially lead and cadmium, on board modern naval ships is a distinct possibility because these substances are used in a variety of marine materials to prevent rust and corrosion. These materials include paint, fasteners, deck plates and pipes. In the routine maintenance of ships (often performed by members of the Engineering Department), these materials are sandblasted, cut, welded, brazed and ground — processes that can release metal particulates into the environment and contaminate exposed personnel. In the research described below, levels of lead and cadmium were determined among personnel on board a U.S. Navy submarine. Submarines are of particular interest because the self-contained, recirculating atmosphere of a submarine possibly could expose the entire crew to these toxic metals. The performance and health effects of cadmium and lead exposure also will be determined. Additionally, levels of cadmium and lead will be correlated with the number of submarine patrols made in order to determine if these levels are the result of chronic (repeated) exposures, and correlated as well with smoking history inasmuch as earlier findings have demonstrated that smokers have higher levels of cadmium than non-smokers (Fri-berg et al., 1974).

Methods

Subjects

The sample of 22 men included 19 en-listed men, two officers, and a midshipman assigned to a fleet ballistic missile nuclear submarine with a total crew of 155 men. After an explanation of the procedures in-volved, voluntary informed consent was obtained from all men prior to participation. The average age of the subjects was 26.10 years, with a range of 20 to 36 years. The men were free of serious medical problems and did not have a history of major disease. Eight of the men were from the Engineering Department of the submarine, while 14 were from other (non-engi-neering) departments.

Procedure

Hair samples were used to assess cadmium and lead status. These samples were collected for 11 of the 22 men one week before the submerged patrol, while samples were collected from a total of 19 men during the last week of the patrol (which lasted in excess of 60 days). (Hair collections were made for these two periods — the pre- and late-patrol periods — in order to determine if significant variations in lead and cadmium levels occurred as a result of exposure to the submarine environment during the patrol.) Eight of the men were included in both the pre- and late-patrol sampling periods.

Hair samples consisted of total growth (10-30 mm) taken from the nape of the neck or from the back of the head, as close to the scalp as possible. These samples represented a hair growth period ranging from 30-60 days. Each sample weighed at least 1 g and was stored in conical vials until processed. For each hair sample, 1 cm lengths were washed with 10 ml of hex-ane, alcohol, and deionized water. The samples were dried and then wet-ashed with concentrated nitric acid. The residue was diluted with deionized water prior to metal analysis. Using a single-blind design, the hair samples were analyzed for cadmium and lead by emission spectroscopy using inductively coupled argon plasma (Mineralab, Inc., Acton, MA). According to Mineralab, Inc., the reliability of this technique is ± 10 percent for hair samples of lead and cadmium.

After collecting the hair samples, the volunteers were asked to complete a questionnaire providing data on: frequency of shampooing and type of shampoo used; number of submarine patrols made; and number of cigarettes smoked per day. (Note that none of the men washed their hair in shampoo found by Mineralab, Inc. to contain high levels of trace metals, including lead acetate.) Additional data collected from official records maintained on board the submarine included number of visits made to the dispensary and training accomplishments during the patrol. Training accomplishments were classified into two categories — major and minor. The major category consisted of accomplishments, such as qualifying for the submarine insignia, chief of the watch or diving officer. The minor category included qualifying for a division watch section, completing a correspondence course or attending one of the college credit courses that was offered during the patrol. Major training accomplishments, which usually took two or more patrols to complete, were assigned a score of "2". Minor accomplishments, which generally could be completed during a single patrol, were scored as "1". These scores were summed over the entire patrol for each participant.

Statistics

Pearson product-moment correlations were used to determine the relationship between hair levels of cadmium and lead and dispensary visits, training accomplishments, number of submarine patrols made, cigarettes smoked per day, and engineering status. (For correlations involving engineering status, engineers were assigned a value of "1" and non-engineers were assigned a value of "2".) Comparisons between the pre- and late-patrol periods for hair levels of cadmium and lead were made using t-statistics for dependent and independent samples as appropriate. Levels of significance were $p<.05$ (one-tailed).

Results

As noted in Table 1, mean cadmium and lead levels of the pre-patrol (N = 11) and late-patrol (N= 19) samples were similar, as were the corresponding means of the eight participants common to both of these samples. Therefore, the pre- and late-patrol samples were combined (N = 22) for subsequent analyses. (For the eight participants common to both the pre- and late-patrol periods, the average levels of cadmium and lead for these two periods were used in these analyses.) The statistical analyses presented in Table 2 show that cadmium levels were significantly higher among members of the Engineering Department than among crew members from other departments on board the submarine. Cadmium levels also were found to be correlated significantly with number of submarine patrols (i.e., those submariners who made many patrols had higher hair cadmium levels than those submariners who made few patrols). Multiple regression analysis in which engineering status and number of patrols were correlated with cadmium levels resulted in an R of 0.60, indicating that only engineering status was accounting for significant variation in cadmium levels among this sample. None of the remaining factors, including smoking frequency, were found to be associated significantly with the cadmium determinations. The failure to show a relationship between cadmium levels and smoking frequency may indicate simply that the smokers in the sample refrained from smoking while working in environments high in cadmium particulates.

Additionally, hair levels of lead were found to be associated significantly with training accomplishments during the patrol. However, this correlation was in the unexpected direction (i.e., submariners with higher levels of lead accomplished more training than those with lower lead levels). None of the other factors (i.e., engineering status, number of patrols, dispensary visits, and smoking habits) correlated significantly with lead determinations.

Discussion

These data show that those submariners having the highest levels of hair cadmium were from the Engineering Department of the ship. While the exact source of cadmium exposure for this group is unknown, a clue to the source may be found in the types of duties performed by members of this group. In addition to operating and maintaining the nuclear propulsion plant that powers the submarine, the group is also involved in other maintenance activities that typically involve welding, cutting, grinding, and brazing pipes, fasteners, deck plates, holding tanks and heavy equipment, most of which are plated with cadmium alloys to prevent corrosion. In the process of performing these duties, crew members often fail to wear protective masks or to properly ventilate the work space, resulting in inhalation of the metal particulates that are released from these materials. While two other sources of cadmium — batteries and neutron absorbers in the nuclear reactor — are found on board submarines, this equipment is not likely to be a source of cadmium contamination because the crew is not involved in processing or repairing the cadmium materials in this equipment.

These data demonstrate that cadmium contamination is most prevalent among that specific portion of the crew that works directly with cadmium alloys, and that cadmium particulates do not contaminate the general shipboard atmosphere (i.e. personnel not assigned to the Engineering Department). The devices that are used to filter and recirculate the shipboard atmosphere appear to remove toxic metal particulates effectively, thus preventing exposure of the remaining crew members to atmospheric contaminants of this type. None of these findings indicated that elevated levels of cadmium and lead impaired health. However, dispensary visits represent a gross assessment of health status, and the possibility remains that a more detailed evaluation of symptoms and diagnoses (in a larger sample so as to obtain adequate variance) would yield positive results.

Surprisingly, lead determinations were found to be correlated in the unexpected direction with training accomplishments. A possible explanation for this finding is that both training accomplishments and elevated levels of lead are related to a third, confounding variable, the exact identity of which is unknown. Typically, those who are involved in removing paint (the most likely source of lead exposure) from the submarine are the most inexperienced members of the crew. Much emphasis is placed by the more senior crew members to qualify these inexperienced personnel for more specialized duties so that the workload can be more evenly distributed during the patrol. If this assumption is correct, then training accomplishments during this single patrol should correlate significantly and negatively with the number of patrols made previously (a gross measure of experience level). Indeed, training accomplishments during this patrol were found to correlate significantly in the expected direction with number of patrols made previously ($r = -.42$, $p<.05$), with those submariners who made fewer patrols previously having accomplished more training during this patrol than those who made more previous patrols (i.e., training is emphasized among the least experienced personnel, and these are the personnel most likely to be exposed to lead contamination). Surely, a more detailed evaluation of the performance effects of cadmium and lead among submariners is warranted. Such an evaluation should use more refined measures of performance than those used in this research, duplicating as far as possible those performance measures used previously (Thatcher et al., 1982). The significant correlation found between frequency of submarine patrols and cadmium level indicates that cadmium deposition occurs over a fairly long period (several years in some cases), and is not the result of exposure during a single patrol. This interpretation is substantiated further by the absence of significant differences between the pre- and late-patrol samples of hair cadmium and lead collected in association with this single, routine patrol. Inasmuch as elevations in cadmium and lead do not appear to occur over a period of days or months, but instead appear to occur over several years, the environmental levels of cadmium and lead to which these personnel are exposed probably are low. In order to more accurately define exposure history, longitudinal assessments of cadmium and lead status should be conducted. Such longitudinal assessments should determine (1) the extent to which variations in cadmium and lead status are related to specific environmental or work conditions, (2) the rate

Table 1

Comparisons of Hair Cadmium and Lead (mg %) Between the Pre- and Late-Patrol Samples

	Pre-Patrol Sample (N-11)			Late-Patrol Sample (N = 19)			
		M	**SD**	**M**	**SD**	**t**	**P**
Cadmium	0.24	0.24		0.18	0.24	0.60	ns
Lead	1.17	0.92		0.74	0.60	1.54	ns
Subjects Common to Both Pre- and Late-Patrol Samples (N=8)							
		Pre-Patrol Sample		**Late-Patrol Sample**			
		M	**SD**	**M**	**SD**	**t**	**P**
Cadmium	0.30	0.26		0.29	0.32	0.13	ns
Lead	1.24	1.08		1.00	0.79	0.88	ns

Table 2

Correlations Between Hair Cadmium and Lead (mg %) and Training, Health and Occupational Factors

	Correlation with	
Factors	**Cadmium**	**Lead**
Engineer/non-engineer	**-.59****	**-.30**
Number of submarine patrols	**.38****	**.14**
Cigarettes/day	.01	.10
Number of dispensary visits	**.32**	.21
Number of training accomplishments	**.26**	**.41***

*p<.05, df = = 20

**p<.005, df = 20

of cadmium and lead deposition among selected crew members (i.e., members of the Engineering Department and younger, inexperienced submariners), and (3) whether or not a dose-response relationship exists between hair cadmium and lead levels and refined measures of performance and health. Earlier research (Baker et al., 1979) has shown that plasma levels of cadmium may be most useful in documenting acute exposures to cadmium and in identifying most directly the sources of cadmium exposure, while hair levels of cadmium may represent exposure periods lasting longer than several months. Therefore, in addition to hair determinations, levels of cadmium (and lead) in plasma should be determined during longitudinal assessments in order to address the issue of acute exposures to cadmium and lead and to more accurately identify the source(s) of cadmium and lead exposure under these conditions.

Some care should be exercised in attributing cadmium and lead contamination specifically to submarine environments. Inasmuch as cadmium plating and lead paint are used commonly among many naval vessels, those on board ships who work with this material are most likely exposed to environmental levels of cadmium and lead similar to those found on submarines. A determination should therefore be made of the extent to which cadmium and lead contamination is endemic to other shipboard environments, both naval and commercial. Meanwhile, every effort should be made to identify, and reduce exposure to, sources of cadmium and lead particulates among submarine personnel.

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