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# Leukemia in US Navy Enlisted Personnel

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*Leukemia is the fourth most commonly occurring cancer in the United States population between the ages of 15 to 34 years, an age group heavily represented in the U.S. Navy. Historical computerized military career records maintained at the Naval Health Research Center were used to determine person-years at risk (4,072,502 person-years) by demographic characteristics and occupation for active-duty Naval personnel during 1974-1984. Computerized inpatient medical records were searched for first hospitalizations for leukemia. Cases of leukemia (N = 102) were verified using pathology reports or Medical or Physical Evaluation Board findings. For comparisons, age-adjusted incidence rates and Standardized Incidence Ratios (SIRs) were calculated using rates for the U.S. population provided by the Surveillance, Epidemiology, and End Results (SEER) Program of the National Cancer Institute. The overall age-adjusted incidence rate of leukemia in active-duty Naval personnel was found to be very close to that of the U.S. SEER population (6.0 versus 6.5 per 100,000 person-years). Leukemia cases occurred in a wide range of occupations with differing estimated exposures, implying that leukemia risk in the young active-duty enlisted Navy population is predominately determined before entrance into service. Only one occupation, electrician's mate, emerged with a statistically significant excess risk of leukemia. This finding is intriguing in the light of several studies showing an excess risk of leukemia associated with exposure to electromagnetic fields.*

The U. S. Navy has one of the largest defined populations of young men in the 18 to 34 year age range, an age range for which leukemia is the fourth most commonly occurring cancer (1). Computerized career history and hospitalization records are maintained for this population on a centralized medical records system at the Naval Health Research Center in San Diego, California. While the causes of leukemia are largely unknown, a number of exposures have been associated with an increased risk of leukemia.

There is long-standing evidence linking ionizing radiation exposure to increased risk of leukemia. Epidemiologic studies of radiologists (2-5), Naval nuclear shipyard workers (6-8), atomic bomb survivors (9-14), and patients receiving high-energy therapeutic x-rays (15) support this association.

A number of recent studies have suggested that occupational or environmental exposure to strong electromagnetic fields may increase the risk of leukemia (16-29). Wertheimer and Leeper reported that children who developed leukemia were more likely to have lived near high-current, high voltage (220KV) transmission lines for a longer time than children free of the disease (16). This finding was not replicated in a similarly designed study in Rhode Island (30), but an increased risk of leukemia (odds ratio = 1.63) in children less than 8 years old was found by Wertheimer and Leeper when they reanalyzed the Rhode Island study, correcting for urban residence of controls (21). In another study, Wertheimer and Leeper found higher risk of cancer in adults living near 60 Hertz electromagnetic fields. These results were statistically significant for lymphomas and cancers of the nervous system, uterus, and breast, but not for leukemia (31).

Occupational studies have identified several groups of electrical workers with increased leukemia risk, particularly for acute leukemias. These groups include: radio and telegraph operators (17,18), power station operators and aluminum reduction workers (19), power and telephone lineman (20,24), electrical engineers (18,22), radio and television repairmen and electronic equipment assemblers (23), and amateur radio operators (25-27).

Occupational exposure to benzene and certain other volatile organic solvents may also be associated with the development of leukemia (32-39), although not all studies support this association (40-45).

Several recent laboratory studies have shown that human-derived promyelocytic leukemia cells (HL-60) can differentiate into mature myeloid cells in the presence of 1,25-dihydroxyvitamin D (46-49). Epidemiologic studies of a rela-

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tionship of leukemia and low levels of vitamin D have not been reported in the literature. Vitamin D is available from two sources: production in the skin on exposure to ultraviolet B light or from diet.

Personnel in some Naval occupational specialties perform job duties involving possible exposure to organic solvents, strong electrical fields, and varying exposures to sunlight. In some occupations, the potential exists for exposure to ionizing radiation. This historical prospective study of leukemia in Naval personnel was undertaken to determine if risk of leukemia varied by occupation during active duty.

## Methods

The Naval Health Research Center (NHRC), San Diego, maintains a computerized Inpatient Follow-up Data System which contains comprehensive information on both service history and hospitalizations. Demographic, occupational, and other service history information was obtained by NHRC quarterly from the Navy Military Personnel Command in Washington, D.C. This system provided occupational and other service history information for active-duty enlisted white males during 1974-1984 (4,072,502 person-years). This analysis is restricted to white males because of the small number of cases which occurred in females and non-whites.

### Table 1

Type of leukemia by diagnostic classification, ICD-9-CM*, active-duty enlisted Naval personnel, white males, ages 17-64 years, 1974-1984

| Type of leukemia | ICD-9-CM Code | Number | Percent |
|---|---|---|---|
| Acute leukemia | | | |
| Lymphoid | 204.0 | 19 | 18.6 |
| Myeloid | 205.0 | 18 | 17.6 |
| Monocytic | 206.0 | 9 | 8.8 |
| Chronic leukemia | | | |
| Lymphoid | 204.1 | 6 | 5.9 |
| Myeloid | 205.1 | 19 | 18.6 |
| Monocytic | 206.1 | 0 | 0.0 |
| Hairy-cell | 202.4 | 4 | 3.9 |
| Acute erythremia | 207.0 | 1 | 1.0 |
| Unspecified | | | |
| Lymphoid leukemia | 204.9 | 7 | 6.9 |
| Myeloid leukemia | 205.9 | 12 | 11.8 |
| Monocytic leukemia | 206.9 | 2 | 2.0 |
| Other and unspecified | 202.8, 207.0-208.9 | 5 | 4.9 |
| Total | | 102 | 100.0 |

* International Classification of Disease, Ninth Revision, Clinical Modification (50).

Leukemia cases from this population were identified from the medical history component of the Inpatient Follow-up Data System. Medical history information for active-duty personnel was obtained by NHRC annually from the Naval Medical Data Services Center in Bethesda, Maryland. Cases were identified for study if a diagnosis of leukemia (ICD-9-CM, codes 204.0-208.9)(50) appeared on an inpatient medical record, a Medical Board or Physical Evaluation Board record, or a death record. Medical and Physical Evaluation Boards consist of specialists who review each case and assign a final diagnosis. If a hospitalization did not have a corroborating Medical or Physical Evaluation Board finding of leukemia, hospital records were sought from the National Personnel Records Center in St. Louis, Missouri; hospitals; or tumor registries to confirm the diagnosis.

Age-specific and age-adjusted incidence rates were calculated for active-duty enlisted Navy personnel (51). The indirect method of age-adjustment was used because of the few cases in some age categories. Using age-specific incidence rates provided by the National Cancer Institute Surveillance, Epidemiology, and End Results (SEER) Program (1) and total Navy leukemia rates, standardized incidence ratios (SIRs) were calculated for all Navy occupations with at least one case of leukemia. Statistical significance was assessed using two-tailed tests based on the Poisson distribution (51).

As a means of testing the hypothesis that vitamin D created from exposure to sunlight may alter risk of leukemia in populations, occupations were grouped by estimated sunlight exposure into indoor, outdoor, and occupations with both indoor and outdoor exposures. This was done using a method detailed elsewhere (52).

## Results

There were 123 first hospitalizations with a diagnosis of leukemia identified from the Inpatient Follow-up System. Of these, 102 were verified and included as cases in this study. Verification was accomplished by review of hospital records (n=81), or by Medical or Physical Evaluation Board findings of leukemia (n=21). Of the twenty-one subjects eliminated from the study, 15 were excluded because a pathology review showed a diagnosis other than leukemia, and 6 because no corroborating information could be obtained after contact with the National Personnel Records Center, hospitals, or tumor registries (Appendix A).

Nearly one-half of the leukemia cases in the Navy were specified as acute, with non-lymphoblastic predominating (Table 1). The predominance of acute leukemia in persons in this age range is consistent with that reported in other studies (53).

The age-adjusted incidence rate of leukemia was slightly lower in Navy enlisted personnel than in the U.S. SEER population (6.0 versus 6.5 per 100,000 person-years)(Table 2). This difference, however, was not statistically significant. Age-specific incidence rates in both the Navy and the SEER population increased with increasing age and there were no statistically significant differences between the age-specific incidence rates in the two populations. The lowest Navy incidence rate appeared in the 17-19 year age-group (1.7 per 100,000 person-years) and the highest rate was among the 45-49 year age-group (8.0 per 100,000 person-years).

Age-adjusted incidence rates of leukemia were lowest for Navy men with less than two years of service (4.4 per 100,000) and highest for personnel with 2.0-3.9 years of service (7.7 per 100,000)(Table 3). No consistent increase in incidence rates was observed with increasing length of service.

Thirty-eight of approximately 95 Navy occupations had at least one case of leukemia, with 16 occupations having 3 or more leukemia cases. Table 4 shows SIRs and 95% confidence intervals for occupations with 3 or more leukemia cases. Only one occupation had a statistically significantly high SIR when compared to the total Navy population: electrician's mate (SIR = 2.5, p = 0.05). The seven leukemias which occurred in electrician's mates were varied; two were classified as acute myeloid, two unspecified myeloid, and one each of chronic myelogenous leukemia, acute myelogenous leukemia, and acute lymphoid leukemia. All occupations with fewer than 3 cases are listed in Appendix B.

Comparisons of age-adjusted incidence rates in persons working in indoor occupations (5.4 per 100,000), outdoor occupations (8.5 per 100,000), and persons working in occupations with both indoor and outdoor exposure (5.4 per 100,000) showed no statisically significant diferences between the groups (not shown).

## Discussion

This study found the overall age-adjusted incidence rates of leukemia in active-duty Naval personnel to be very close to that of the U.S. SEER population (6.0 versus 6.5 per 100,000 person-years). There was no apparent healthy-worker effect.

Leukemia cases occurred in a wide range of occupations with differing estimated exposures. This may imply that leukemia risk in the young active-duty Navy population (97% between ages 17-39) is predominantly determined before entrance into service. This also suggests that these leukemias are not preceded by readily identifiable health problems that could prevent entrance into the Navy. Because this study was restricted to active-duty personnel, we could not

**Table 2**

Age-specific and age-adjusted incidence rates of leukemia per 100,000 person-years, active-duty enlisted Navy personnel and United States population, white males, ages 17-64 years, 1974-1984

| Age (years) | Person-years at risk | No. of cases | Navy personnel: Average annual incidence rate* (95% CI) | US population: Average annual incidence rate† |
|---|---|---|---|---|
| 17-19 | 705,432 | 12 | 1.7 (0.9-3.0) | 2.9 |
| 20-24 | 1,767,202 | 38 | 2.2 (1.5-3.0) | 2.0 |
| 25-29 | 679,509 | 18 | 2.7 (1.6-4.2) | 2.9 |
| 30-34 | 439,894 | 12 | 2.7 (1.4-4.8) | 2.9 |
| 35-39 | 341,651 | 15 | 4.4 (2.5-7.2) | 3.9 |
| 40-44 | 95,347 | 5 | 5.2 (1.7-12.2) | 5.0 |
| 45-49 | 24,998 | 2 | 8.0 (1.0-28.9) | 7.7 |
| 50+ | 8,341 | 0 | - | 20.1 |
| Unknown | 10,128 | 0 | - | - |
| Total | 4,072,502 | 102 | | |
| Crude rate | | | 2.5 | 6.5 |
| Age-adjusted rate†† | | | 6.0 | 6.5 |

* Navy incidence rates based on first hospitalization rates for leukemia, ICD-9-CM, codes 204.0-208.9 (50).

† United States population rates were provided by SEER, Incidence and Mortality Data: 1973-1981, p. 57 (1).

†* Adjusted by the indirect method using age-specific incidence rates provided by SEER applied to the Navy study population and should be compared with the SEER crude rate (51).

**Table 3**

Age-adjusted incidence rates of leukemia per 100,000 person-years by duration of service, active-duty enlisted Naval personnel, white males, 1974-1984

| Length of service (yrs) | Population at risk | No. of cases | Age-adj rate |
|---|---|---|---|
| 0.0-1.9 | 1,288,909 | 22 | 4.4 |
| 2.0-3.9 | 1,000,560 | 25 | 7.7 |
| 4.0-6.9 | 596,657 | 13 | 5.8 |
| 7.0-10.9 | 408,398 | 14 | 7.5 |
| 11.0+ | 767,850 | 28 | 6.1 |
| Unknown | 10,128 | 0 | - |
| Total | 4,072,502 | 102 | 6.0 |

* Incidence rates based on first hospitalizations. Length-of-service specific age-adjusted rates obtained by the indirect method using SEER incidence rates applied to the Navy study population (1,51).

† Based on the Poisson distribution (51).

evaluate long-term occupational risk of leukemia occurring in older age-groups such as retired Navy personnel.

Many occupations were evaluated for their risk of leukemia, and, consequently, results for individual occupations should be evaluated in the context of all existing epidemiologic findings regarding leukemia. Machinist's mates, the occupation in the Navy most likely to have exposure to solvents such as benzene and related compounds, and, in some cases, to ionizing radiation from work aboard submarines, did not show an excess incidence. Machinist's mates have been shown in previous studies to have an excess of testicular cancer and Hodgkin's lymphoma, but no excess risk for non-Hodgkin's lymphoma or melanoma (52,54-56). This and other negative findings of this study should be interpreted with caution due to the need for longer follow-up studies of incidence in older cohorts of machinist's mates.

Only one occupation, electrician's mate, emerged with a statistically significant excess risk of leukemia in this study. This finding is intriguing since several studies have shown an excess risk of leukemia associated with exposure to electromagnetic fields (16-29).

Electrician's mates operate, maintain, repair, and install ships' electrical power plants, lighting systems, and other electrical equipment. On shore, electrician's mates stand watch on generators and other major electrical equipment. Similar civilian occupations are electricians, electrical generator operators, electric power linemen, and electric motor repairmen. Electrician's mates are frequently in contact with running equipment. This study, like other reported occupational studies of the possible association of electric or magnetic fields and leukemia, had no direct measure of exposure. The SMR of 2.5 in this study is at the high end of relative risks reported for leukemia in electrical occupations (29). Savitz and colleagues grouped all studies of electrical workers prior to 1987 and reported a summary risk estimate across eleven studies of 1.4 with a lower 95% confidence limit of 1.2. In the course of their work, electrician's mates also may have been exposed to PCBs, which are used as dielectrics in electrical transformers, and solvents, as well as electromagnetic radiation.

The standard frequency of electrical current in the United States (and on Naval ships and Naval installations) is 60 Hz, and there are 300,000 circuit-miles of 60-Hz AC overhead transmission lines in the United States, with associated transformers (57). The current on Naval ships is produced in shipboard generators and then distributed in power lines, and stepped down with transformers for most uses. Electrician's mates operate in an environment where the 60 Hz electric power is generated, transmitted, and transformed. Workers in many other Navy occupations are exposed to electromagnetic fields associated with radar and radio transmissions, but the predominant frequency of the electromagnetic radiation from these sources is very distant from 60 Hz.

The lack of an elevated risk of leukemia in Naval workers exposed to electromagnetic radiation other than potentially high-intensity 60 Hz may be due to the lack of statistical power to detect a difference or may represent a genuinely low risk of developing leukemia during active-duty service in occupations other than electrician's mate. If magnetic fields are the important variable, several specific factors could be relevant.

Energy is not transferred to objects unless the objects are coupled to the frequency of the energy. Electrical energy at 60 Hz produces harmonics at 120 Hz and 180 Hz as well as subharmonics at 30 Hz and 15 Hz. The production of harmonics and subharmonics is greatest near transformers and other inductive devices. Energy at the 15 Hz harmonic is of particular interest, since this frequency is quite close to the resonant frequency of the calcium ion (16.0 Hz)(58), and therefore couples well to calcium. Calcium is essential to intercellular communication among nonneural cells, and energy at this subharmonic might affect such communication in nonneural tissues including those of the hematopoetic system. Energy at 50 Hz, by contrast, produces subharmonics at 25 Hz and 12.5 Hz, which may couple to the calcium ion, but more weakly (58).

Studies of normal human lymphocytes in tissue culture have shown that magnetic fields at frequencies near 15 Hz induce an influx of $^{45}Ca$ into lymphocytes which is three times greater than observed in controls (58). Magnetic fields at 12.5 Hz produced a weaker response and fields containing only frequencies 10 or more cycles outside this range had no influence (58).

Previous epidemiologic studies suggest a leukemogenic effect of magnetic fields produced by alternating current at 60 Hz, the standard in the U.S. and Canada, but possibly not at 50 Hz, which is the standard in Sweden, Britain, and other

**Table 4**

Standardized incidence ratios (SIRs) for leukemia in Naval occupations with three or more cases, active-duty enlisted Naval personnel, white males, ages 20-64 years, 1974-1984

| Occupation | No. of cases | Person-years | SIR (95% Confidence limits) Compared to the SEER population | Compared to the Navy population |
|---|---|---|---|---|
| Aviation ordnanceman | 4 | 53,943 | 2.7 (0.7-7.0) | 2.9 (0.8-7.3) |
| Electrician's mate | 7 | 111,944 | 2.4 (0.9-5.0) | 2.5* (1.0-5.1) |
| Boatswain's mate | 5 | 78,888 | 2.1 (0.7-4.9) | 2.2 (0.7-5.1) |
| Personnelman | 3 | 52,077 | 2.0 (0.4-5.7) | 2.0 (0.4-5.9) |
| Mess management specialist | 4 | 83,691 | 1.8 (0.5-4.5) | 1.9 (0.5-4.8) |
| Sonar technician | 3 | 71,602 | 1.6 (0.3-4.8) | 1.7 (0.3-4.9) |
| Storekeeper | 3 | 61,626 | 1.6 (0.3-4.8) | 1.7 (0.4-5.0) |
| Gunner's mate | 3 | 69,024 | 1.6 (0.3-4.7) | 1.6 (0.3-4.8) |
| Machinist's mate | 7 | 235,155 | 1.1 (0.4-2.2) | 1.1 (0.5-2.3) |
| Electronics technician | 5 | 178,555 | 1.1 (0.4-2.5) | 1.1 (0.4-2.6) |
| Radioman | 4 | 133,319 | 1.1 (0.3-2.7) | 1.1 (0.3-2.8) |
| Aviation structural mechanic | 4 | 142,165 | 1.0 (0.3-2.7) | 1.1 (0.3-2.7) |
| Hospital corpsman | 5 | 177,943 | 1.0 (0.3-2.4) | 1.1 (0.3-2.5) |
| Hull maintenance technician | 3 | 111,435 | 1.0 (0.2-3.0) | 1.1 (0.2-3.1) |
| Seaman recruit | 10 | 462,341 | 0.9 (0.4-1.6) | 1.1 (0.5-2.0) |
| Airman recruit | 3 | 169,175 | 0.7 (0.2-2.1) | 0.9 (0.2-2.6) |
| All Navy occupations† | 102 | 4,072,502 | 0.9 (0.8-1.1) | 1.0 |

* Significantly different from U.S. (SEER) and Navy population at $p = 0.05$ level, (two-sided test), based on the Poisson Distribution (51). The lower confidence level for the comparison with the SEER population was 0.98, and is represented by the value of 0.9 in the table.

† Includes occupations shown here and all other U.S. Navy occupations.

European countries. Although the apparent difference may be due to methodological differences among the studies, more replications are needed. Further studies are also needed of differences in induction of leukemia and other cancers according to the frequency, harmonics, and subharmonics of the alternating current producing the magnetic field, since such differences might help to explain inconsistencies among existing epidemiologic studies.

Laboratory evidence suggests that human leukemia cells grown in tissue culture respond to vitamin D added to the culture medium by slowing their growth and assuming a more normal appearance (46–49). Despite these reports, we found no evidence of differences in risk of leukemia in Navy personnel related to occupational differences in sunlight exposure. However, the amounts of circulating serum vitamin D produced by sunlight exposure in this population may not have been sufficient to inhibit leukemia development in the occupational groups with even the highest sunlight exposure. It is also possible that dietary sources of vitamin D may have obscured a possible relationship between occupational sunlight exposure and leukemia risk. Surveys of vitamin D levels in the sera of populations exposed to different levels of sunlight may be needed to examine this relationship more fully.

Overall, the findings of this study suggest thet most leukemia appearing in the young Navy population was not the result of occupational exposures while on active duty. This does not preclude the possibility that occupational exposures in the Navy may affect leukemia risk after retirement from military service. We were unable to ascertain risk of leukemia after retirement, since medical records were available for active-duty personnel only.

The finding of a statistically significant excess risk of leukemia in electrician's mates should be considered in the context of the literature supporting an association between exposure to electromagnetic fields and increased risk of leukemia.

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## Appendix A

Diagnosis of cases identified as having a possible leukemia hospitalization but excluded from analysis because of inability to meet case verification criteria, white males, active-duty enlisted Navy personnel, white males, 1974-84. Number of cases shown in parentheses.

Alcoholism (1), Bone fracture (2), Diabetes mellitus (1), Diffuse toxic goiter (1), Infectious mononucleosis (1), Left pectoral abscess (1), Leukopenia (2), Lymphosarcoma (2), Non-Hodgkin's lymphoma (1), Personality disorder (2), Polycythemia (1), No record available (6).

## Appendix B

Standardized incidence ratios (compared to SEER standard population), and 95% confidence intervals for Navy occupations with 1 to 2 cases of leukemia, active-duty Naval enlisted personnel, white males, ages 17-64 years, 1974-1984

Lithographer (SIR=10.0, 0.3-55.9), Construction electrician (SIR=5.1, 0.6-18.3), Commissary man (SIR=4.5, 0.1-25.3), Postal clerk (SIR=4.2, 0.1-23.6), Aviation maintenance administrationman (SIR=3.1, 0.4-11.1), Aviation storekeeper (SIR=2.8, 0.3-10.0), Ship's serviceman (SIR=2.6, 0.3-9.3), Aviation fire controlman (SIR=2.3, 0.3-8.4), Missile technician (SIR=2.2, 0.1-12.0), Tradevman† (SIR=2.1, 0.1-11.7), Electronics warfare technician (SIR=2.0, 0.1-10.8), Quartermaster (SIR=1.8, 0.2-6.4), Builder (SIR=1.2, 0.0-6.8), Boiler technician (SIR=0.6, 0.1-2.3), Aviation electrician's mate (SIR=0.5, 0.0-2.7), Operations specialists (SIR=0.5, 0.0-2.7), Engineman (SIR=0.5, 0.0-2.6), Fire control technician (SIR=0.5, 0.0-2.5), Communications technician (SIR=0.4, 0.0-2.4), Yeoman (SIR=0.4, 0.0-2.3), Aviation electronics technician (SIR=0.3, 0.0-1.9), Aviation machinist's mate (SIR=0.3, 0.0-1.7).

* Standardized incidence ratio. These were obtained by the indirect method using SEER incidence rates applied to the Navy study population (1,51).

† Training device man. Operates audiovisual and other training equipment.

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Leukemia is the fourth most commonly occurring cancer in the Navy and in the United States general population between the ages of 15 to 34 years. Historical computerized military career records maintained at the Naval Health Research Center were used to determine person-years at risk (4,072,502 person-years) by demographic characteristics and occupation for active-duty Naval personnel during 1974-1984. Computerized inpatient medical records were searched for first hospitalizations for leukemia. Cases of leukemia (N = 102) were verified using pathology reports or Medical or Physical Evaluation Board findings. For comparisons, age-adjusted incidence rates and Standardized Incidence Ratios (SIRs) were calculated using rates for the U.S. population provided by the Surveillance, Epidemiology, and End Results (SEER) Program of the National Cancer Institute. The overall age-adjusted incidence rate of leukemia in active-duty Naval personnel (Continued on reverse)

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was found to be very close to that of the U.S. SEER population (6.0 versus 6.5 per 100,000 person-years). Leukemia cases occurred in a wide range of occupations with differing estimated exposures, implying that leukemia in the young active-duty enlisted Navy population is predominately determined before entrance into service. Only one occupation, electrician's mate. emerged with a statistically significant excess risk of leukemia. This finding is intriguing in the light of several studies showing an excess risk of leukemia associated with exposure to electromagnetic fields. (S...)