Original Contribution

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Residence Near Power Lines and Mortality From Neurodegenerative Diseases: Longitudinal Study of the Swiss Population

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ABSTRACT

The relation between residential magnetic field exposure from power lines and mortality from neurodegenerative conditions was analyzed among 4.7 million persons of the Swiss National Cohort (linking mortality and census data), covering the period 2000–2005. Cox proportional hazard models were used to analyze the relation of living in the proximity of 220–380 kV power lines and the risk of death from neurodegenerative diseases, with adjustment for a range of potential confounders. Overall, the adjusted hazard ratio for Alzheimer's disease in persons living within 50 m of a 220–380 kV power line was 1.24 (95% confidence interval (CI): 0.80, 1.92) compared with persons who lived at a distance of 600 m or more. There was a dose-response relation with respect to years of residence in the immediate vicinity of power lines and Alzheimer's disease: Persons living at least 5 years within 50 m had an adjusted hazard ratio of 1.51 (95% CI: 0.91, 2.51), increasing to 1.78 (95% CI: 1.07, 2.96) with at least 10 years and to 2.00 (95% CI: 1.21, 3.33) with at least 15 years. The pattern was similar for senile dementia. There was little evidence for an increased risk of amyotrophic lateral sclerosis, Parkinson's disease, or multiple sclerosis.

dementia; neurodegenerative diseases; radiation, nonionizing

Abbreviations: ALS, amyotrophic lateral sclerosis; CI, confidence interval; ELF-MF, extremely low frequency magnetic field(s); ICD-10, *International Classification of Diseases, Injuries, and Causes of Death*, Tenth Revision

INTRODUCTION

Research on the long-term effects of extremely low frequency magnetic fields (ELF-MF) has focused on cancer since Wertheimer and Leeper (1) published their results on childhood cancer and wiring configurations in 1979. In 2001, the International Agency for Research on Cancer classified exposure to residential magnetic fields above 0.4 µT as a "possible" cause of childhood leukemia (2). For noncancer endpoints, an initial report by Sobel et al. (3) on occupational ELF-MF exposure and Alzheimer's disease suggested that the risk could be substantial. Studies published subsequently have produced inconsistent results, but a recent meta-analysis (4) reported elevated risks in cohort, as well as case-control, studies. A recent review of the evidence for an association between ELF-MF and Alzheimer's disease by the World Health Organization (5) concluded that the available data were inadequate, and the topic was identified as a key research priority.

To our knowledge, no study has so far examined whether residential exposure from power lines is associated with an elevated risk of neurodegenerative diseases. Even a small association could be of high public health relevance, since a considerable number of persons are exposed to these fields. For example, 9.2% of the Swiss population live within 600 m of a 220 or 380 kV power line. We used the Swiss National Cohort, a longitudinal study of the Swiss population (6), to investigate whether living in the vicinity of power lines was associated with mortality from neurodegenerative diseases such as Alzheimer's disease, senile dementia, amyotrophic lateral sclerosis (ALS), multiple sclerosis, and Parkinson's disease.

MATERIALS AND METHODS

Study population

The present analysis was based on the 2000 national census. Mortality data were available for the period 2000–2005, with causes of death coded according to the *International Classification of Diseases, Injuries, and Causes of Death*, Tenth Revision (ICD-10). Enumeration in the 2000 census is nearly complete: Coverage was estimated at 98.6% (7). Deterministic and probabilistic record linkages were used to link census records to a death record or an emigration record (6). Of death records of persons older than 30 years, 95.1% could be successfully linked to a 2000 census record. At present, the database includes follow-up data until December 31, 2005.

We excluded persons aged 29 years or less at the census, as well as persons with incomplete information on building coordinates. The database contains information on age, sex, marital status, education, and occupation, as well as additional variables describing, for example, the degree of urbanization of the area or building characteristics such as the number of apartments per building. The geo-coded place of residence of the participants (i.e., Swiss-grid coordinates extracted from the Swiss building registry) is also included in the census data. In general, these coordinates pinpoint a location within a few meters of the building's midpoint. Data from the 1990 census were used to identify the place of residence at that time. The 1990 and 2000 censuses additionally include information on whether individuals had lived at the same place 5 years before the census, that is, in 1985 or in 1995. We were thus able to identify persons who had lived at their place of residence for at least 5, 10, or 15 years.

Outcomes

We considered deaths from the following neurodegenerative diseases: Alzheimer's disease, senile dementia, ALS, Parkinson's disease, and multiple sclerosis. These diseases had to be listed on the death certificate as the primary or a concomitant cause of death. The recording of neurodegenerative diseases on death certificates might be related to socioeconomic position. We therefore included outcomes that are known to be related to socioeconomic position: cancer of the trachea, bronchus, or lung; alcoholic liver disease; and all-cause mortality. The ICD-10 codes used are listed in Table 1.

Exposure

Exposure assessment was based on the distance of the place of residence to the nearest power line. We included all 220–380 kV power lines in Switzerland, over 5,100 km in total. We obtained geodata of the power lines from the Federal Inspectorate for Heavy Current Installations. Figure 1 illustrates localization of the power lines and buildings in Switzerland. We determined the shortest distance to any of the transmission lines and derived the number of persons living within the corridors around the power lines. We defined corridors of 0–<50 m, 50–<200 m, 200–<600 m, and 600 m or beyond. We determined exposure at the time of the 2000 census.

Information about the use of a building as a clinic or nursing home was available from a separate building record, which was completed by the owner of the building, and this information was then matched to the personal records of individuals. Some persons might live in a nursing home or clinic because of a neurodegenerative disease. Therefore, in order to obtain more appropriate exposure data for individuals living in such an institution in 2000, we used the exposure for the place of residence at the time of the 1990 census instead. Persons who lived in a nursing home or clinic in 1990 were excluded from the analysis.

Statistical analyses

We analyzed data using Cox proportional hazard models. We compared the risk of dying from neurodegenerative diseases across corridors and according to the duration of residence in exposed corridors (at least 5, 10, and 15 years). Person-years of observation were defined as the interval between December 4, 2000 (the date of the census), and death, emigration, or December 31, 2005.

We used age as the underlying timescale in our models. All models were adjusted for sex; educational level (compulsory education, secondary level, and tertiary level); highest reported occupational attainment by code (4 levels extracted from the International Standard Classification of Occupations of 1988—1) legislators, senior officials, managers, and professionals, 2) technicians and associate professionals, clerks, service workers, and shop and market sales workers, 3) skilled agricultural and fishery workers, craft and related trades workers, plant, machine operators, and assemblers, and elementary occupations, and 4) no occupation reported); civil status (single, married, divorced, widowed); urbanization category (city, agglomeration, rural municipality); and language region (German, French, Italian). We also included the number of apartments per building into the model, a potential risk factor for magnetic field exposure due to indoor wiring (8).

Finally, because Alzheimer's disease might be associated with benzene exposure, we adjusted models for living within 50 m of a major road. We extracted proximity of the buildings to the "major road network" using data from the Swiss TeleAtlas database for this purpose. The major roads network includes motorways and motorway exits, as well as "major roads of high importance": nearly 8,700 km with 7% of the population exposed to major roads in the 50-m corridor. In sensitivity analyses, we repeated analyses for persons aged less than 85 years, by sex, and examined whether results differed between deaths where Alzheimer's disease or senile dementia had been coded as the primary or concomitant cause of death.

We tested our models successfully for the proportionality assumption using Nelson-Aalen survivor functions and statistical tests based on Schoenfeld residuals. Data were analyzed by using Stata 9 (StataCorp LP, College Station, Texas) software. Results are presented as hazard ratios with 95% confidence intervals.

The Swiss National Cohort was approved by the cantonal ethics committees of Bern and Zurich.

RESULTS

Of the 7.29 million persons recorded in the 2000 census, 2.59 million were excluded because they were under the age of 30 years at the census. Furthermore, 39,871 persons with unknown building coordinates were excluded. The cohort thus consisted of 4.65 million persons. During the study period, 282,378 eligible and linked deaths from all causes were recorded, including 9,228 deaths from Alzheimer's disease, 28,288 deaths from senile dementia, 773 deaths from multiple sclerosis, and 6,683 deaths from Parkinson's disease (Table 1). The total number of person-years of follow-up was 22.82 million for the whole study population and 8.51 million for persons who reported living for at least 15 years at the identical place of residence (Tables 2 and 3).

The adjusted hazard ratio of Alzheimer's disease for persons living within 50 m of a 220–380 kV power line compared with that for persons who lived at a distance of 600 m or more was 1.24 (95% confidence interval (CI): 0.80, 1.92). There was little evidence of an increased risk beyond 50 m. Analysis by exposure duration revealed a dose-response relation with respect to years of residence in the vicinity of power lines: Persons living at least 5 years within 50 m had an adjusted hazard ratio of 1.51 (95% CI: 0.91, 2.51), which increased to 1.78 (95% CI: 1.07, 2.96) for persons with at least 10 years and to 2.00 (95% CI: 1.21, 3.33) for persons with at least 15 years (Figure 2; Table 2). These adjusted hazard ratios of 2.04 (95% CI: 1.06, 3.93) and 1.96 (95% CI: 0.88, 4.38) were similar for women and men, respectively, and for persons under 85 years of age (adjusted hazard ratio = 1.94, 95% CI: 0.97, 3.89).

For senile dementia, we observed the same pattern as with Alzheimer's disease, although associations tended to be weaker. For increasing exposure time in the vicinity of power lines, the adjusted hazard ratio increased from 1.23 (95% CI: 0.96, 1.59) for any exposure duration to 1.34 (95% CI: 0.98, 1.82) for persons with at least 5 years, to 1.36 (95% CI: 0.98, 1.89) with at least 10 years, and to 1.41 (95% CI: 1.00, 1.98) with at least 15 years of residence near the power line (Table 2). For both Alzheimer's disease and senile dementia, there was little evidence for a difference in effects between deaths coded as primary and deaths coded as concomitant cause ($P_{interaction} > 0.2$).

Parkinson's disease and ALS were not associated with residence in the proximity of power lines. The adjusted hazard ratio for any duration of exposure in the 50-m corridor was 0.83 (95% CI: 0.46, 1.49) for Parkinson's disease and could not be estimated (no case occurred in the 50-m corridor) for ALS. The adjusted hazard ratio for multiple sclerosis was 1.20 (95% CI: 0.30, 4.80). Similar results were obtained when restricting analyses to persons with at least 15 years at the same place of residence (Table 3).

No increased risk in the proximity of a power line was found for all-cause mortality, cancer of the lung, bronchus, or trachea, cancer of the esophagus, or alcoholic liver disease, for any duration of residence (data not shown) or when restricting analyses to persons with at least 15 years at the same place of residence (Table 4).

DISCUSSION

This large study of the entire Swiss population found that persons who lived within 50 m of a 220–380 kV power line were at increased risk of death from Alzheimer's disease, compared with persons who lived farther away from power lines. The risk increased with increasing duration of residence in the 50-m corridor. Notably, the risk declined rapidly with increasing distance, with only weak evidence for an increased risk beyond 50 m. A similar pattern was observed for senile dementia. In contrast, we found no consistent association for ALS, Parkinson's disease, or multiple sclerosis. Our study thus indicates a possible association between ELF-MF exposure and risks of Alzheimer's disease and senile dementia.

Comparison with previous studies
Established risk factors for Alzheimer's disease include age and genetic factors (9). Controversy remains regarding environmental risk factors, including ELF-MF (10). The association between Alzheimer's disease and ELF-MF has generally been studied with respect to occupational exposures. Occupational exposures are typically about 0.5 μT for electricians, some machine operators, or train drivers, above 1 μT for some machine operators, and around 3 μT for electrical power installers and repairers (11). In occupational settings, increased risks of Alzheimer's disease have been reported with magnetic field exposures at levels around 0.5 μT (4). To our knowledge, an analysis of the potential association of neurodegenerative diseases and residential exposure has not been reported in the scientific literature, even though ELF-MF exposure from power lines can be of the same magnitude as in occupational settings. In the United Kingdom, propagation of magnetic fields at levels of about 0.5 μT at a distance of 50 m to a 275 kV line was reported (12). At maximum load, these levels could, however, be considerably higher. In Switzerland, the Federal Office for the Environment estimated that, at full load, 1 μT would not be exceeded at a distance of 60–80 m from a 380 kV line and at 40–55 m from a 220 kV line (13).

For ALS, an association between the risk of ALS and employment in electrical occupations, which is related to both magnetic field exposure and the risk of experiencing electric shock, has been reported (14). The electric shock hypothesis would be consistent with our results, as we did not observe an association with residential magnetic field exposure. In the absence of a known biologic mechanism, the World Health Organization recently concluded that the available evidence on a possible association between ELF-MF and Alzheimer's disease, as well as ALS, was inadequate (5).

Of the few studies so far that evaluated magnetic field exposure and multiple sclerosis, none reported statistically significant increased risks, which is in line with the inconsistent results observed here (15–17). Also in line with previous studies, our results for Parkinson's disease provide little evidence for an association (18).

Strengths and limitations

This study combined the mortality register data with nearly complete population data from the 2000 census, complemented with information on duration of residence from the 1990 census. With the exception of persons emigrating from Switzerland, particularly older immigrants who tend to return to their countries after retirement, mortality data are also virtually complete. Record linkage failed in some instances, but this is unlikely to be associated with residence in the vicinity of power lines. Linkage success is very high in the age group above 30 years and highest in the age group between 65 and 85 years. Because mortality from neurodegenerative diseases is negligible in younger people, we restricted our analyses to persons aged 30 years or over. In sensitivity analyses, we excluded people aged 85 years or older and obtained virtually identical results.

The development of neurodegenerative disease, as well as its recording on death certificates, may be associated with socioeconomic position. The availability of data on education and occupation and other potential confounders on an individual level is an important strength of our study. This allowed us to adjust for several indicators of socioeconomic position, but this adjustment had only very small effects on our estimates. In addition, causes of death known to be associated with socioeconomic position were included for comparison but did not show an increased risk in the 50-m corridor.

There is no registry for neurodegenerative diseases in Switzerland, and we had to rely on information given on death certificates, where neurodegenerative diseases are known to be underreported (19–21). The degree of underreporting varies by disease. Death certification of cases of ALS and multiple sclerosis has been found to be reasonably accurate (22, 23). Underreporting of Alzheimer's disease, as well as senile dementia, is more common and increases with the age of the deceased (19, 21, 24–27). Mortality rates for Alzheimer's disease have been increasing since 1995, when a specific code was introduced in the ICD-10 system, indicating that reporting of Alzheimer's disease on death certificates has become more complete in recent years. However, it is unlikely that the completeness of reporting is associated with living in the proximity of power lines.

The magnetic fields produced by power lines depend on a variety of factors, including the load characteristics, distance between conductors, and the placement of phases. Unfortunately, information on these characteristics was not available in our study. We acknowledge that the use of exposure corridors, without measurements or taking the load of the line and other factors into account, may have introduced Berkson-type error into the exposure assessment (28), and this could have reduced the power of our study. On the other hand, it is possible that our surrogate is not predictive for true exposures at all because other sources may be more important, for instance, at work or when travelling. This would imply that the observed association is due to another factor that could not be controlled for in the analysis. However, we believe that we allowed for the most important factors in the analysis, and we are not aware of other exposures that could plausibly explain the observed associations.

There is no consensus as to which exposures from overhead power lines are biologically relevant and should be measured (2). For example, ionized particles or contact currents may also be relevant (29–31). However, all of these exposures are associated with distance to a power line. We extended the corridors around power lines up to a distance of 600 m to make our results comparable with those of the study by Draper et al. (32). In contrast to their study, we found little evidence for an increased risk beyond 50 m. With respect to a potential mechanism, we can only speculate whether one of the mechanisms that have been proposed in the literature (5) might be of importance in the context of magnetic field exposure and neurodegenerative diseases. For example, induced electric fields in neural networks (electric fields induced in tissue by exposure to extremely low frequency electric and magnetic fields) have been reported to affect synaptic transmission in neural networks, as well as the radical pair mechanism (5). Increased free radical concentrations can cause oxidative damage to cellular components, which could play a role in the etiology of Alzheimer's disease.

Finally, underground cables that replace overhead power lines in some urban areas may represent an additional source of residential magnetic field exposure, but these were not considered in our study. In Switzerland, underground cables of 220–380 kV represent only around 0.8% of the grid, and we decided to omit cables from our analyses.

Public health implication

Assuming that the associations observed in this study are causal, what are the public health implications? Considering the relatively small number of cases of Alzheimer's disease and senile dementia diagnosed in the 50-m corridor (Alzheimer's disease: 20 of 9,164 (0.22%); senile dementia: 59 of 28,045 (0.21%)), it is clear that the public health impact appears limited. The true public health impact, however, is difficult to determine. Rates of Alzheimer's disease were reported to be from 2- to 8-fold higher if diagnoses were based on clinical examination instead of death certificates (20, 24). In addition, Alzheimer's disease might go undiagnosed in another group of persons. Finally, although we found only weak evidence for an increased risk beyond 50 m, it is unlikely that there is an abrupt change in risk at 50 m. Nevertheless, our results do provide reassurance for the population living at distances of 50–600 m from a power line.

Conclusions

The results of our study support the hypothesis that magnetic field exposure plays a role in the etiology of Alzheimer's disease and senile dementia but not of ALS or other neurodegenerative diseases. Despite the large sample size covering the whole Swiss population, these findings must be interpreted with caution, because of the lack of known biologic mechanisms.

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