ELECTRICAL POWER LINES AND CHILDHOOD LEUKEMIA:
A STUDY FROM GREECE

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Residential proximity to electrical power lines of different voltage in relation to childhood leukemia was investigated through a case-control study undertaken in Greece during 1993–1994. The study comprised 117 incident cases of childhood leukemia and 202 age-, gender- and place-of-residence-matched controls. Four measures of exposure to magnetic fields were developed, using data provided by the Public Power Corporation of Greece: Voltage (V) divided by the distance (d), V/d2, V/d3 and an adaptation of the Wertheimer-Leeper code. Conditional-logic-regression modeling was used to adjust for potential confounding influences of 18 variables. No significant trends of childhood leukemia risk with increasing exposure levels were noted, nor were there statistically significant elevations of disease risk at the higher exposure levels in each measure of exposure. These results do not support a causal link between residential proximity to electrical high-voltage wires and childhood leukemia risk, but in themselves do not refute a weak empirical association. Int. J. Cancer 73:345–348, 1997.

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Contract grant sponsors: Europe Against Cancer Program (DGV) of the European Union; Mr. G.S. Livanos.

Received 5 May 1997; Revised 11 June 1997
for at least 4 years before diagnosis (or interview) and whose address was easily identified and accessed. In addition, to preserve the matching in the conditional-logistic-regression analysis, matched sets were retained only if both the case and at least one control had their EMF exposure ascertained. Eventually, a sub-set of 117 cases of childhood leukemia and 202 matched controls was used in the present analysis.

For every study participant, the PPC provided, blindly as to case-control status, the distance between the center of the residence, which depends *inter alia* on the floor, and the 2 closest transmission or distribution lines divided into those of 400, 150, 66, 15–22, 6.6 and 0.4 kV. Distances beyond 100 meters were recorded as 100 m, on the assumption that the strength of the fields sharply declines with distance and becomes immaterial at 100 m and beyond. Underground and twisted pair-wiring lines were not taken into account, since as a rule they generate minimal electric and magnetic fields (Oak Ridge Associated Universities, 1992). All measurements were in reference to residence at time of diagnosis.

A series of measures were used to indirectly assess the generated magnetic fields by each of the identified electric wires. Because electric fields are shielded by structures, it is generally assumed that the critical factor, if any, in carcinogenesis are magnetic rather than electric fields. It is not known, however, which parameter of magnetic fields is involved, if at all, in this process and the variable relations of these parameters with voltage and distance (Oak Ridge Associated Universities, 1992) make it necessary to use several measures in order to minimize the likelihood that a relevant biological effect will be missed. Thus, the voltage of each of the 2 closest transmission or distribution lines was divided by the distance (in m), the square of the distance or the cube of the distance, and the higher of the resulting 2 ratios for each measure was retained. Thus, data from 3 single-exposure measures were utilized. The distribution patterns were further evaluated after matching in the conditional-logistic-regression analysis, matched cases and controls, interview) generated very similar results. The SAS 6.10 statistical package for Microsoft Windows version 1994 was used. Potential confounding variables were either suspected risk factors for childhood leukemia or factors that were strongly, significantly or suggestively related to this disease in the present data set. (Petridou et al., 1997). In addition to the matching variables (age, gender and geographic region), the following factors were introduced into the core model: maternal age (5-year increments); maternal education (4-year increments); sibship size and birth order (increments of one); ever-attendance of day care; maternal smoking and alcohol consumption during the index pregnancy (yes vs. no); anemia during pregnancy (yes vs. no); neonatal jaundice (yes vs. no); birthweight (in 500-g increments); hospitalization for any allergic disease (yes vs. no); BCG vaccination (yes vs. no); total DTP shots, counting every antigen as one shot (in increments of 3); and total viral vaccination shots, counting every antigen as one shot (in increments of 3).

### RESULTS

Table I presents frequency distributions of 117 incident childhood leukemia cases and 202 individually matched controls by levels of 4 EMF measures. The distributions appear fairly similar, irrespective of the measure used, but the likelihood of confounding by some of the other variables studied hindered etiologic evaluation.

Table II presents the core model for the conditional-logistic-regression analysis. Variables representing the 4 different EMF measures were added singly to this model to allow more valid evaluation of the association between EMF exposure and risk of childhood leukemia.

Table III presents conditional-logistic-regression-derived odds-ratio estimates for childhood leukemia by levels of EMF exposure. None of the 4 EMF measures indicates a statistically significant trend for increase in childhood leukemia risk with increasing exposure level. Moreover, in every exposure level for each of the 4 EMF measures, the 95% confidence levels straddle the null odds-ratio value. Nevertheless, the trends are positive and the

### Table I – Distribution of 117 Incident Childhood Leukemia Cases and 202 Matched Controls by Marginal Quintiles of 4 Alternative EMF Metrics

<table>
<thead>
<tr>
<th>EMF metric</th>
<th>Quintile 1 (or wire codes)</th>
<th>Quintile 2 (or wire codes)</th>
<th>Quintile 3 (or wire codes)</th>
<th>Quintile 4 (or wire codes)</th>
<th>Quintile 5 (or wire codes)</th>
<th>p for trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>V × m⁻¹</td>
<td>N (%)</td>
<td>N (%)</td>
<td>N (%)</td>
<td>N (%)</td>
<td>N (%)</td>
<td>0.27</td>
</tr>
<tr>
<td>cases</td>
<td>23 (19.7)</td>
<td>18 (15.4)</td>
<td>26 (22.2)</td>
<td>20 (17.1)</td>
<td>30 (25.6)</td>
<td></td>
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<tr>
<td>controls</td>
<td>42 (20.8)</td>
<td>35 (17.3)</td>
<td>48 (23.8)</td>
<td>44 (21.8)</td>
<td>33 (16.3)</td>
<td></td>
</tr>
<tr>
<td>V × m⁻²</td>
<td>N (%)</td>
<td>N (%)</td>
<td>N (%)</td>
<td>N (%)</td>
<td>N (%)</td>
<td>0.16</td>
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<tr>
<td>cases</td>
<td>24 (20.5)</td>
<td>21 (18.0)</td>
<td>18 (15.4)</td>
<td>24 (20.5)</td>
<td>30 (25.6)</td>
<td></td>
</tr>
<tr>
<td>controls</td>
<td>42 (20.8)</td>
<td>44 (21.8)</td>
<td>44 (21.8)</td>
<td>37 (18.3)</td>
<td>35 (17.3)</td>
<td></td>
</tr>
<tr>
<td>V × m⁻³</td>
<td>N (%)</td>
<td>N (%)</td>
<td>N (%)</td>
<td>N (%)</td>
<td>N (%)</td>
<td>0.37</td>
</tr>
<tr>
<td>cases</td>
<td>25 (21.4)</td>
<td>31 (26.5)</td>
<td>20 (17.1)</td>
<td>21 (17.9)</td>
<td>20 (17.1)</td>
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</tr>
<tr>
<td>controls</td>
<td>44 (21.8)</td>
<td>57 (28.2)</td>
<td>46 (22.8)</td>
<td>28 (13.8)</td>
<td>27 (13.4)</td>
<td></td>
</tr>
</tbody>
</table>

Adapted wire code²

<table>
<thead>
<tr>
<th>EMF metric</th>
<th>Quintile 1 (or wire codes)</th>
<th>Quintile 2 (or wire codes)</th>
<th>Quintile 3 (or wire codes)</th>
<th>Quintile 4 (or wire codes)</th>
<th>Quintile 5 (or wire codes)</th>
<th>p for trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>adapted</td>
<td>N (%)</td>
<td>N (%)</td>
<td>N (%)</td>
<td>N (%)</td>
<td>N (%)</td>
<td>0.39</td>
</tr>
<tr>
<td>cases</td>
<td>30 (25.6)</td>
<td>72 (61.6)</td>
<td>4 (3.4)</td>
<td>7 (6.0)</td>
<td>4 (3.4)</td>
<td></td>
</tr>
<tr>
<td>controls</td>
<td>57 (28.2)</td>
<td>128 (63.4)</td>
<td>3 (1.5)</td>
<td>6 (3.0)</td>
<td>8 (3.9)</td>
<td></td>
</tr>
</tbody>
</table>

²Quintiles for V × m⁻¹: 1.17; 40.0; 150.0; 500.0; V × m⁻²: 0.4; 2.3; 4.2; 25.0; V × m⁻³: 0.02; 0.4; 0.5; 3.2. Adaptation of the Wertheimer-Leeper wire codes into 5 classes relevant to the Greek conditions (see text).
with small risk elevations. Confidence limits in the higher exposure levels are not incompatible with small risk elevations.

**DISCUSSION**

This study is of moderate size and hospital-controlled, and exposure measurements were not available for all the enrolled cases and controls. Nevertheless, given the exposure range, the statistical power of the study was not much smaller than that of some of the larger investigations in this field (National Research Council, 1996). Moreover, missing exposure values were partly due to inaccessibility by the PPC team of some remote areas, or unavailability of relevant official records, and only partly to change due to inaccessibility by the PPC team of some remote areas, or unavailability of relevant official records, and only partly to change in the positive trends for the V/m² and V/m³ measures are partly generated by the biologically implausible reductions of relative risk in the second-lowest exposure quintile.

Several studies have examined the relation between exposure to ELF-EMF and the risk of childhood leukemia (National Radiological Protection Board, 1992, 1994; Oak Ridge Associated Universities, 1992; National Research Council, 1996; Tynes and Haldorsen, 1997; Linet et al., 1997). No association was evident when compared with the results of the first 3 measures in Table III are not independent, since these variables are interrelated, with correlation coefficients close to 0.4; moreover, the positive trends for the V/m² and V/m³ measures are partly generated by the biologically implausible reductions of relative risk in the second-lowest exposure quintile.

Statistically significant risk elevations were documented among children in the high-exposure categories. On the other hand, the overall pattern of results in this study is compatible with that emerging from the collective evidence of 12 investigations presented in a report by the National Research Council (1996) and the results of a Norwegian study (Tynes and Haldorsen, 1997). It should be noted, however, that the positive trends in the first 3 measures in Table III are not independent, since these variables are interrelated, with correlation coefficients close to 0.9; moreover, the positive trends for the V/m² and V/m³ measures are partly generated by the biologically implausible reductions of relative risk in the second-lowest exposure quintile.

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leukemia (National Research Council, 1996). Future epidemiologic studies should be much larger, since uncertainty underlying epidemiologic results and meta-analyses may be substantially larger than generally assumed (Shlyakhter and Kammen, 1992; Greenland, 1994; Shlyakhter, 1995). Judgment of causality, however, with minimal risk deviation can be made only by an optimal randomization process of ample data or with powerful theoretical or biomedical support.

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