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Ionizing radiation, cellular telephones and the risk for brain tumours

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A case–control study on brain tumours included 233 patients aged 20–80 years and alive at the study time. They had histopathologically verified brain tumour and lived in the Uppsala-Örebro region (1994–1996) or the Stockholm region (1995–1996). Two matched controls to each case were selected from the Swedish Population Register. Two hundred and nine cases (90%) and 425 controls (91%) answered the questionnaire. Results are presented for the whole study group, as given here, and for malignant and benign tumours separately. For workers in the chemical industry the odds ratio (OR) was 4.10, 95% confidence interval (95% CI) 1.25–13.4 and laboratory workers OR 3.21, 95% CI 1.16–8.85. Radiotherapy of the head and neck region gave OR 3.61, 95% CI 0.65–19.9. Medical diagnostic X-ray of the same area yielded OR 1.64, 95% CI 1.04–2.58. Work as a physician gave OR 6.00, 95% CI 0.62–57.7. All three cases had worked with fluoroscopy. Ipsilateral (same side) use of a cellular telephone increased the risk of tumours in the temporal, temporoparietal and occipital areas, with OR 2.42, 95% CI 0.97–6.05 (i.e. the anatomical areas with highest exposure to microwaves from a mobile phone).

Key words: Brain tumours, medical X-ray investigations, mobile phones, radiotherapy.

Introduction

Ionizing radiation is a known risk factor for brain tumours, with the highest risk for meningioma (Soffer *et al*., 1989; Preston-Martin and Mack, 1996). Some reports have associated pesticides with an increased risk for brain tumours as well as exposure to certain chemicals, although these are not established as certain risk factors (Preston-Martin and Mack, 1996).

Recently we published results from our case–control study on brain tumours and the use of cellular phone (Hardell *et al*., 1999, 2000). For ipsilateral use of a cellular phone an increased risk was found in the anatomical parts with highest exposure (i.e. the temporal, temporoparietal and occipital areas).

We grouped together both sides of anatomical area of the brain and analysed exposure to mobile phones in relation to ear used for the calls. The matched control was assigned the same anatomical localization as for the corresponding case. Further details from the study are reported here, and recent studies on brain tumours and cellular phones are discussed. Results are also presented for malignant and benign brain tumours.

Materials and methods

When the study started in the Uppsala-Örebro medical region of Sweden, only patients with a malignant brain tumour diagnosed in 1994–1996 were included. In order to include a larger study group, the Stockholm medical region was included for the study period 1995–1996. For 1996, patients with a benign brain tumour were also included in the Stockholm area as requested in a feasibility study by the World Health Organization (Cardis and Kilkenny, 1999). All included cases had a histopathological diagnosis and were alive at the study start. The physicians were contacted for permission to include the patient in the study. Two controls to each case were drawn from the population register. They were matched for

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sex and age and lived in the same geographical area of Sweden as the cases.

Assessment of exposure

The ethical committees approved the investigation. A postal questionnaire was used for information on exposures in both cases and controls. A nurse trained for this purpose supplemented unclear answers over the telephone using a written protocol. The questionnaires were blinded as to case or control status. All answers were scrutinized after that in order to ensure uniform assessment of exposure for all cases and controls. If the quality of the answers was judged to fulfil our criteria, the information was coded and registered for statistical analysis. Otherwise the questionnaire was returned to the nurse for additional telephone interview. These procedures were carried out without information as to whether it was a case or a control.

With regard to medical X-rays, the investigated anatomical area was asked for, years for the investigations and total number of X-rays. Subjects who had worked as physicians were asked about radiological work.

Use of cellular phones at work and during leisure time was assessed. This included type of phone, analogue (Nordic Model Telephones; NMT) or digital (Group Special Mobile; GSM) system. Information on years of use and mean number of minutes of daily use over the years was asked for and cumulative use in hours was calculated. Use of a hands-free device with an earpiece and in a car with fixed antenna was taken as no exposure. In one question the ear most frequently used during cellular phone calls was asked for.

Exposure to different agents was assessed (e.g. brand or chemical names, working conditions, years and number of days per year of exposure). One aim of the study was to assess intake of the artificial sweetener aspartame. Since most low-calorie drinks contain aspartame (Bergsten, 1998), information about the consumption of such drinks was asked for, including years of intake, times per day or week and amount of drink each time.

A minimum tumour induction (latency) period of one year was used. The same year as for the case was used for the matched controls. Exposure to chemical agents < 1 day in total was disregarded.

Copies of X-rays for tumour diagnosis and histopathological reports were requested for the cases after informed consent. The anatomical localization of the tumour was determined and whether the tumour was a new diagnosis or a recurrent disease was judged.

Statistical methods

Conditional logistic regression analysis for matched studies was used to calculate odds ratios (OR) and 95% confidence intervals (95% CI) (SAS Institute, Cary, NC, USA). Cellular phone use and some exposures with significantly increased risks were analysed in a multivariate analysis.

Results

In total 270 cases fulfilled the inclusion criteria. Of these, 37 patients were judged by their physicians not to be able to participate. Thus 233 cases and 466 controls remained in the study. Two hundred and seventeen cases and 439 controls answered the questionnaire. Eight of the cases had a recurrent brain tumour and were excluded from further analysis, together with their 14 responding matched controls. The analysis included 209 (90%) cases and 425 (91%) controls. The mean age of both cases and controls was 50 years, range 21–80 years.

All the data for 209 cases and 425 controls were used in the calculations. Histopathological reports were obtained for 197 patients, 136 with malignant and 62 with benign tumour (one case had two benign tumours: ependymoma and acoustic neurinoma). Results are given for all cases for the two groups separately.

Anatomical tumour localization was obtained for 198 patients; 99 with tumour in right brain, 78 in left brain and 21 with no applicable side (e.g. central tumour). The analysis of mobile phone use and the risk for brain tumour according to anatomical localization was based on these 198 cases with corresponding controls.

Occupation as a risk factor was analysed (see Table 1). Work in chemical industry gave an increased risk; OR 4.10, 95% CI 1.25–13.4, with similar results for both malignant and benign tumours. For laboratory work OR 3.21, 95% CI 1.16–8.85 was obtained. Six cases but no control in the group with benign brain tumours reported laboratory work. For patients with malignant brain tumour only a slightly increased risk was found. Electronics, telecommunication or electrical work did not increase the risk of brain tumours. No subject had worked as a railway engine driver.

For physicians the OR was 6.00, 95% CI 0.62–57.7. All three cases had worked with X-ray investigations

Table 1. Odds ratio (OR) and 95% confidence intervals (95% CI) for ever employment in various occupations

Occupation	Malignant		Benign		All		
	OR	95% CI	OR	95% CI	Cases/ controls	OR	95% CI
Building worker	0.84	0.37–1.92	2.50	0.57–11.0	15/27	1.09	0.54–2.21
Chemical industry	4.40	1.13–17.1	3.24	0.29–36.6	9/4	4.10	1.25–13.4
Dressmaker	1.10	0.26–4.63	2.00	0.13–32.0	6/6	1.89	0.61–5.89
Electrician	–	–	–	–	1/12	0.16	0.02–1.20
Electronics work	0.43	0.19–0.96	1.52	0.47–4.89	15/44	0.60	0.32–1.14
Engineer, technician, all	0.69	0.33–1.46	1.16	0.40–3.31	18/42	0.80	0.44–1.45
chemical work	2.00	0.13–32.0	1.41	0.09–23.6	2/2	1.69	0.23–12.2
electronics, telecommunication	–	–	–	–	0/9	–	–
mechanical	0.25	0.03–2.00	7.12	0.79–64.4	5/9	1.05	0.35–3.16
technical, other	4.00	0.73–21.8	1.43	0.27–7.48	7/6	2.41	0.75–7.73
Farmer	0.55	0.21–1.43	0.74	0.22–2.47	14/35	0.68	0.33–1.41
Laboratory work	1.20	0.29–5.02	–	–	10/6	3.21	1.16–8.85
Lineman	0.30	0.04–2.48	–	–	1/7	0.23	0.03–1.91
Lumberjack	0.61	0.26-1.40	2.00	0.28–14.2	13/28	0.84	0.41–1.72
Nurse	1.37	0.36–5.17	2.00	0.13–32.0	5/7	1.27	0.40–4.04
Nurse's assistant	1.31	0.68–2.53	0.96	0.34–2.70	26/40	1.25	0.72–2.17
Painter	0.81	0.27–2.46	–	–	5/16	0.60	0.21–1.70
Plastics work	1.25	0.41–3.82	2.00	0.13–32.0	6/10	1.20	0.44–3.30
Physician	–	–	4.00	0.36–44.1	3/1	6.00	0.62–57.7
Radar work	1.20	0.29–5.02	1.33	0.22–7.98	5/8	1.25	0.41–3.82
Saw mill worker	0.63	0.19–2.09	–	–	4/13	0.58	0.18–1.89
Telecommunication work	0.95	0.52–1.76	1.36	0.54–3.47	25/50	0.97	0.58–1.60

for some period with tumour induction (latency) periods of 20, 28 and 31 years, respectively. They were diagnosed with acoustic neurinoma, meningioma and oligodendroglioma, respectively. In contrast, the only control subject who was a physician had never worked with X-ray investigations.

Work at a radiological department gave OR 1.89, 95% CI 0.61–5.89. Excluding the three physicians, there were four cases and six controls with other job titles in radiology; for these subjects the OR was 1.24, 95% CI 0.35–4.43. No increased risk was found for other occupational categories in health services. These job titles were included among nurses or nurses' assistants in Table 1.

X-ray investigations of the head and neck region yielded OR 1.64, 95% CI 1.04–2.58, increasing to OR 2.10, 95% CI 1.25–3.53 with $\geq$ 5-year tumour induction period ($n = 36$ cases, 37 controls). For meningioma OR 5.03, 95% CI 1.60–15.8 was obtained with $\geq$ 5-year induction period. No increased risk for brain tumours was found for medical diagnostic X-ray investigations of other parts of the body. Radiotherapy for a benign or a malignant disease gave OR 1.58, 95% CI 0.60–4.16 ($n = 8$ cases, 11 controls). Regarding the head and neck region OR 3.61; 95% CI 0.65–19.9 was obtained ($n = 4$ cases, 2 controls).

Exposure to different agents is presented in Table 2. No association was found for exposure to, for example, asbestos, pesticides, organic solvents, smoking or use of a video display unit (VDU). For low-calorie drink consumption (taken as aspartame exposure) an OR of 1.24, 95% CI 0.72–2.14 was found, increasing to OR 1.70, 95% CI 0.84–3.44 for malignant brain tumours.

Results for use of cellular phones are shown in Table 3. Increased risk was only found for cases with a tumour in temporal, temporoparietal or occipital lobe and ipsilateral (same side) use of a mobile phone with OR 2.42, 95% CI 0.97–6.05. This result was based on 13 exposed cases, 10 with a malignant and three with a benign tumour (Hardell *et al*., 1999). Nine cases were exposed to analogue (NMT) only, three to both analogue and digital (GSM) and one to digital phones only. For contralateral (opposite side) use no increased risk was found. Only a few subjects reported equal ispi- and contralateral use of a cellular phone. Due to low numbers OR could not be calculated for malignant and benign brain tumours separately.

Exposure to cellular phones for subjects with brain tumour in the temporal, occipital or temporoparietal anatomical areas, and other exposures with significantly increased risk were included in a multivariate analysis. Chemical industry was not included since only one case with tumour in these areas and no control was exposed. Significantly increased risk was found for subjects with ipsilateral exposure to mi-

Table 2. Odds ratios (OR) and 95% confidence intervals (95% CI) for exposure to different agents

Agent	Malignant		Benign		All		
	OR	95% CI	OR	95% CI	Cases/controls	OR	95% CI
Asbestos	1.00	0.34–2.93	2.00	0.50–8.00	9/15	1.20	0.52–2.74
Aspartame	1.70	0.84–3.44	0.96	0.36–2.54	30/45	1.24	0.72–2.14
Cutting oils	1.00	0.23–4.35	1.00	0.18–5.46	5/11	0.90	0.30–2.69
Exhaust (occupational)	0.89	0.51–1.55	0.93	0.37–2.35	37/76	0.87	0.54–1.39
Fungicides	–	–	–	–	0/3	–	–
Glue	1.04	0.52–2.07	2.33	0.87–6.27	29/43	1.37	0.80–2.38
Herbicides	1.00	0.45–2.22	0.55	0.06–5.39	13/23	1.02	0.49–2.12
Phenoxyacetic acids	0.17	0.02–1.28	2.00	0.13–32.0	3/9	0.46	0.10–2.18
Other	1.16	0.41–3.31	–	–	7/7	1.64	0.57–4.75
Impregnating agents	1.32	0.69–2.54	1.00	0.44–2.29	28/49	1.13	0.69–1.85
Insecticides	0.81	0.34–1.90	0.44	0.10–2.06	11/28	0.74	0.36–1.49
Oils	1.33	0.22–7.98	2.00	0.28–14.2	4/5	1.60	0.43–5.96
Organic solvents	1.26	0.79–2.02	1.04	0.52–2.08	91/160	1.15	0.79–1.68
Smoking, ever	1.14	0.74–1.76	0.76	0.41–1.42	117/218	1.02	0.72–1.45
current smoker	1.13	0.66–1.65	0.68	0.31–1.47	47/94	0.94	0.61–1.46
ex-smoker	1.15	0.69–1.91	0.84	0.40–1.77	70/124	1.09	0.72–1.64
Video display unit	1.45	0.91–2.32	0.92	0.46–1.84	114/196	1.28	0.88–1.86
$<$ 601 working days	1.55	0.91–2.66	0.89	0.39–2.02	63/101	1.36	0.88–2.08
$\geq$ 601 working days	1.35	0.78–2.34	0.96	0.40–2.26	51/95	1.20	0.77–1.87
Occupational use	1.30	0.83–2.03	0.76	0.36–1.59	99/177	1.12	0.78–1.61
Leisure time use	1.42	0.87–2.31	0.64	0.30–1.40	53/95	1.11	0.74–1.66

crowaves from a mobile phone (OR 2.62, 95% CI 1.02–6.71) (Table 4). For laboratory work and medical diagnostic X-ray investigations of the head or neck a non-significantly increased risk was calculated in the multivariate analysis.

Discussion

Different occupational and leisure time exposures were assessed by a questionnaire and the purpose of the study was not disclosed. Phone interviews and

Table 3. Odds ratio (OR) and 95% confidence interval (95% CI) for exposure to cellular phone according to tumour localization in relation to ear (side) used for cellular phone

Tumour localization	Exposure		
	Ipsilatral	Contralateral	Ipsilateral/ contralateral
Brain, hemisphere	1.07 (34/59) 0.64–1.80	0. 70 (20/54) 0.39–1.24	1.35 (10/12) 0.57–3.22
Frontal, frontoparietal, parietal or parieto-occipital	0.88 (20/41) 0.45–1.74	0.57 (9/31) 0.26–1.26	3.07 (8/4) 0.89–10.6
Temporal, occipital or temporoparietal	2.42 (13/12) 0.97–6.05)	1.06 (10/19) 0.42–2.70	0.65 (2/6) 0.13–3.33

Latency period $>$ 1 year.
Note that no area was applicable for 21 cases.
Numbers of exposed cases/controls are given within parentheses.

Table 4. Odds ratio (OR) and 95% confidence interval (95% CI) for exposures in a multivariate analysis

	Univariate		Multivariate	
	OR	95% CI	OR	95% CI
Cellular phone				
Temporal, occipital or temporoparietal lobe ipsilateral exposure	2.42	0.97–6.05	2.62	1.02–6.71
contralateral exposure	1.06	0.42–2.70	0.97	0.36–2.59
ipsilateral/contralateral exposure	0.65	0.13–3.33	0.71	0.14–3.68
Laboratory work	3.21	1.16–8.85	8.81	0.96–80.7
Medical diagnostic X-ray investigations, head/neck	1.64	1.04–2.58	1.66	0.75–3.65

coding of the data were made blinded as to case or control status in order to reduce observational bias. Only people who were thought to be able to answer the questionnaire themselves were included, so as to get the highest data quality possible. For example, it was judged that relatives might have difficulty in answering whether the right or left ear was most used during phone calls.

Different occupations were obtained from the lifetime occupational history. Two of three physicians with brain tumour had worked for only a short time period at a radiological department. However, both reported work with fluoroscopy and the dosimeter of the female case showed 'always maximal exposure'. The third case had worked as an anaesthesiologist at X-ray departments for about 30% of his working time. Thereby he performed angiographies and heart catheterizations. These results seem to support the findings of two cases with brain tumour among Toronto cardiologists with occupational exposure to ionizing radiation (Finkelstein, 1998)

In a register study linking census data on occupation with the Swedish Cancer Registry we did not find an increased risk for brain tumours among physicians (Eriksson *et al*., 1998). However, we had no data on different specialists. Radiological work, especially fluoroscopy, may increase the risk of brain tumours. It is noteworthy that the brain is a part of the body that is not usually shielded during fluoroscopy.

Also radiotherapy of the head and neck region was associated with an increased risk of brain tumours, which is in accordance with previous studies (Shore *et al*., 1976; Colman *et al*., 1978; Ron *et al*., 1988). Menigioma has been reported to be the most common tumour associated with radiation (Soffer *et al*., 1989; Preston-Martin and Mack, 1996) and three of the four cases that had been treated with radiotherapy had meningioma in our study.

Medical X-ray investigation of the head and neck region increased the risk, which is in accordance with other results although the association is somewhat more controversial than for high-dose radiation (Preston-Martin and Mack, 1996).

Exposure to extremely low-frequency electromagnetic fields (EMF) has been suggested to increase the risk of brain tumours. However, in our overview of studies on that topic we concluded that no consistent association could be found (Hardell *et al*., 1995). In the present investigation no association was found with occupations with potential exposure to EMF. Nor did use of a video display unit increase the risk.

No association with exposure to certain pesticides was found, in contrast to some other studies (Musicco *et al*., 1982; Preston-Martin and Mack, 1996).

Aspartame is a sweetener used in different types of food such as beverages, ice cream, cakes and also in sweets. However, the highest per capita exposure is from low-calorie drinks with an estimate of 45% of total intake in a Norwegian study (Bergsten, 1998). We only assessed intake of such beverages, since it is difficult to get information about other exposures to aspartame. We found a non-significantly increased risk for malignant brain tumours. An increased risk for brain tumours associated with aspartame has been discussed by Olney *et al*. (1996). No increased risk was found in a US study on childhood brain tumours and aspartame consumption (Gurney *et al*., 1997).

During a mobile phone call the highest exposure to microwaves occurs in the temporal, occipital and temporoparietal areas of the brain on the same side as used for the call. There is a rapid decline in dose and the other side of the brain is only exposed to a low degree. OR was calculated for ipsilateral, contralateral or both ipsi- and contralateral exposure to microwaves from a mobile phone by combining data for both sides of the head. An increased risk was only found for ipsilateral exposure in the anatomical area with the highest microwave dose. In a multivariate analysis including other exposures with significantly increased risk this result was further strengthened.

The result was based on low number of exposed subjects and must be interpreted with caution. Since most patients do not have exact information of the anatomical area of the tumour, recall bias is less likely to explain the results. All but one of these 13 patients had used the analogue (NMT) system and it should be noted that analogue phones have at least three times higher output power than digital phones. In the 1980s only the analogue system was used and the digital system was introduced on the Swedish market in early 1990s. Thus tumour induction period might also be of relevance for our findings. Due to low numbers it was not meaningful to calculate OR according to tumour induction time, cumulative exposure in hours or type of tumour. Other parts of the brain were also included in multivariate analysis but the results were similar to those in the univariate analysis.

No increased brain tumour mortality was found in a Motorola study on employees with potential radio frequency exposure (Morgan *et al*., 2000). However,

exposure from cellular telephones was not assessed and information on anatomical localization of the brain tumour was not given (Hardell *et al*., 2001).

No increased risk for brain tumours was found in a study from USA on handheld cellular telephone use (Muscat *et al*., 2000). Extending the antenna during the call was usual among 86% of the cases and 85% of controls, reducing the dose to the brain substantially. Only nine cases and 11 controls used the phone without an extended antenna. Also, the mean duration of cellular telephone use of only 2.8 years among the cases was too short for safe conclusions.

Another study from the USA showed no overall increased risk for brain tumours among cellular telephone users (Inskip *et al*., 2001). However, the patients tended to be older than the controls and more proxy interviews were performed in the case group. These circumstances might bias the results since the use of a cellular phone is more common among young subjects and relatives may have difficulty in reporting use accurately. Tumour laterality and side of the brain exposed to microwaves from the phone was not well displayed. No information was given as to whether a phone with extended antenna was used. Also the reference category of unexposed was not held constant, since in some of the calculations the categories 'never use' and 'rarely use' were lumped together. For patients with acoustic neurinoma with regular use of a cellular phone for five years or more an OR of 1.9 (95% CI 0.6–5.9) was calculated.

A Danish cohort study of cellular telephone users is not very informative (Johansen *et al*., 2001). The subjects were followed for only a short period in the Danish Cancer Registry – analogue users on average for 3.5 years and digital users for only 1.9 years. Only 11 patients had a tumour in the temporal lobe, i.e. the area with highest exposure. With a reasonable tumour induction period very few tumours would be expected in this brain lobe due to the short observation time of the cohort. No information was provided on which ear was used during a phone call or if a car-mounted cellular phone with external antenna was used. The results were confounded by social class and should have been adjusted for that effect.

In summary, our study showed increased risk for brain tumours associated with ionizing radiation, chemical industry and laboratory work. Use of cellular telephones increased the risk in the most exposed part of the brain.

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