Epidemiological evidence on health risks of cellular telephones

Kenneth J Rothman

It is too soon for a verdict on the health risks from cellular telephones, especially in view of changing technology. From the Interphone project and some other large studies in progress, better information may emerge. Based on the epidemiological evidence available now, the main public-health concern is clearly motor vehicle collisions, a behavioural effect rather than an effect of radiofrequency exposure as such. Neither the several studies of occupational exposure to radiofrequencies nor the few of cellular telephone users offer any clear evidence of an association with brain tumours or other malignancies. Even if the studies in progress were to find large relative effects for brain cancer, the absolute increase in risk would probably be much smaller than the risk stemming from motor vehicle collisions. Cellular telephones affect the quality of our lives in myriad ways, for good and ill; the health risk is just one part of a picture that is slowly coming into focus.

Within only a few years a substantial proportion of the world's population has adopted a new technology that involves placing a small radio transmitter up against the head, in some instances for hours a day. While not all models place the antenna next to the head, hand-held models that do have become widespread. As prices fall cellular telephony will spread rapidly and is likely to infiltrate poor as well as wealthy countries because the technology delivers a telephone service without the large capital investment needed for land lines.

Cellular telephones transmit radiofrequency (RF) waves to nearby relay stations. Should a RF wave encounter a water molecule, it transfers energy to that molecule, which is what happens in microwave ovens. Microwave ovens pose no health hazard, but at high doses the energy transfer from other sources of microwaves can cause cataracts in those whose corneas are inadvertently exposed.[1]

Cellular telephones transmit RF of very low intensity; the thermal effects on tissues are no greater than 0·1°C for the highest-powered models.[2] Can such low exposures adversely affect body tissues? A similar question is asked about extremely low-frequency (ELF) electromagnetic field (EMF) exposure and possible adverse health effects, a controversy that has been burdened with inconsistent study results and contention over the best way to measure individual exposure. Although there are some similarities between the study of ELF exposure and RF exposure (both sometimes confusingly referred to as EMF exposure), the differences are greater than the similarities. ELF exposure is mostly continuous over long periods; it is surreptitious; it has not changed much at a population level over the past couple of decades; and it often exposes the entire body uniformly. RF exposure comes in crisp episodes (telephone calls) of which the individual is well aware and which may be monitored by billing records or more direct measurement; it has increased sharply at a population level in only a few years; and for typical hand-held telephones it is tightly focused on the side of the head.[3] These differences should make any effects of RF easier to evaluate, because one can identify those who are exposed and more readily rank them, at least roughly, by exposure amount. Also, to the extent that RF exposure is localised in the side of the head, we know which tissues are likely to be affected. The rapid increases in exposure at a population level may also lead to time trends in population rates if there are strong effects. RF exposure assessment is not without its challenge, however, and frequent changes in the technology add to the hurdles that epidemiologists face.

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Epidemiology Research Institute, One Newton Executive Park, Newton Lower Falls, MA 02462-1450, USA (K J Rothman DrPH)
(e-mail: KRothman@aol.com)

Neoplasms

The public focus on cancer as a health concern of RF exposure may be a spillover from anxiety about the carcinogenic effects of ionising radiation, rather than being due to any direct biological theories or findings relating to RF exposure. Because RF exposure from cellular telephones is concentrated in the head close to the handset,[4] cancer of the brain has been the primary concern. Other neoplasms of potential concern include neurinoma of the eighth cranial nerve and malignancy of the salivary gland.

Epidemiologists have begun to study cancer occurrence in cellular telephone users, but so far most published information on the epidemiology of RF exposure has come from other exposures (panel 1). Epidemiologists can study effects only after they have (or might have) occurred; cellular telephone use is comparatively new, and it could take many years for RF exposure to induce cancer, if indeed it has such an effect. Furthermore, the evidence we do have is largely indirect epidemiological information about RF exposure, from studies of cancer risks among those with occupational RF exposure and amateur radio enthusiasts. These exposures are more varied in dose, type of signal, and anatomical localisation than exposures from cellular telephones. The findings vary as well, as indicated in some of the most pertinent occupational studies (panel 2).

Information from these studies about the health effects of RF exposure is of marginal value. Some studies compare data from specific working populations, or

Panel 1: **Literature search for epidemiological studies on radiofrequency exposure and neoplastic disease**

The literature search was based on Medline searches using various combinations of the terms "cellular telephones", radiofrequency, microwave, radiation, epidemiology, neoplasm and cancer, supplemented with citations from identified studies and investigations mentioned at a recent conference on the epidemiology of cellular telephone effects.[5]

Subsequently, the search was checked against the chapter on epidemiological evidence in a May, 2000, UK official report (the "Stewart report"). This report is available on the internet at www.iegmp.org.uk.

Panel 2: **Seven studies of cancer risks and occupational or avocational RF exposure**

Ref	Population	Exposure	Findings
Lilienfield et al[6]	US Embassy personnel and dependents in Moscow.	Embassy had been showered with up to 18 μW/cm² of microwave radiation for up to 18 h/day as part of an espionage effort. Whole-body exposure.	No brain cancers but expected number was only 0·9; 17 cases of cancer (19 expected); overall mortality about half of that expected.
Robinette et al[7]	More than 20 000 Navy personnel.	Maximum of 10 mW/cm² in 1950–54. Exposure not concentrated on head.	Follow-up to end of 1974, examining hospital admissions, mortality, and disability compensation, revealed no important increase in mortality or in cancer generally or in any specific cancer type.
Hill[8]	1492 men who worked in Massachusetts Institute of Technology Radiation Laboratory during 1940–46 on development of radar.	Exposure from 2–5 mW/cm².	Mortality experience up to end of 1966 revealed no excess of brain nor other cancers, except for a slight excess of lymphatic and haematopoietic cancer.
Milham[9]	67 829 men from California and Washington State who were amateur ("ham") radio operators and who obtained a radio licence during 1979–84.	Unknown.	No excess overall cancer mortality, but slight excess (29 *vs* 20·8 expected) in deaths from brain cancer and small excesses within subgroups of lymphatic and haematopoietic cancers.
Szmigielski[10]	Polish military personnel with high RF exposure.	About 0·2 mW/cm².	Nearly a doubling in deaths from brain cancer, and larger relative increases in some haematopoietic cancers. Also a doubling in overall cancer rate, an effect so large, broad, and inconsistent with other studies as to provoke considerable scepticism.
Grayson[11] 1970–89.	Male members of US Air Force	From job exposure matrix*	Modest increase in risk for those exposed to non-ionising electromagnetic fields (RR=1·3), an effect much smaller than that for military rank, with senior officers having more than triple the risk of enlisted men.
Morgan et al[12]	195 775 Motorola employees 1976–96	From job exposure matrix*	No indication of increase in brain or lymphatic/haematopoietic cancer

*Difficult to characterise on scale that could be compared with other studies.

otherwise self-selected populations, with figures for the general population. Such comparisons may incorporate biases that can affect overall morbidity and mortality as well as the effect on specific outcomes. For example, if a specific employed population is drawn from a low or high level of the socioeconomic spectrum, the effect of employment on any health outcome related to socioeconomic level will be biased. All the above studies were retrospective cohort studies, except for Grayson's case-control study nested within an occupational cohort.[11] Control of confounding can be a problem in such studies. Because the data were collected without research goals in mind, the information available on covariates is limited. Furthermore, these studies of occupational RF exposure give scant insight into the possible health effects of RF exposure from cellular telephones, with their more localised exposure.

The most recently published occupational study, by Morgan et al,[12] addresses some of these shortcomings.

Morgan et al have conducted the largest and most informative occupational study of RF exposure to date. They followed up a cohort of 195 775 Motorola employees from 1976 to 1996, during which these employees accumulated 2·7 million person-years of exposure. Because Motorola designed and manufactured wireless communication devices, many of its employees experienced RF exposure from hand-held transmitters similar or identical to the telephones that were sold in large numbers to consumers. The key comparisons were internal ones among workers categorised by level of RF exposure, assessed from a job-exposure matrix. About 9% of employees had moderate or high levels of RF exposure. There was no indication of any increase in either brain or lymphatic/haematopoietic cancer mortality, by comparison either with general population data or with data for workers who had lower levels of RF exposure.

Cellular telephone users

Three recent reports have examined mortality or cancer occurrence among cellular telephone customers. A large cohort study of cellular telephone users in the USA was, unfortunately, curtailed by a lawsuit; the other was a case-control study of brain cancer and cellular telephone use.

Rothman et al[13] reported overall mortality among nearly 60 000 hand-held cellular telephone users and compared it with mortality among nearly 50 000 users of mobile or transportable telephones (mostly car telephones). Hand-held telephones place the transmitter in close proximity to the head; mobile telephones have a separate transmitter and thus spare any important exposure to the head or other parts of the body because field strength diminishes rapidly with distance from the transmitter. Rothman et al classified hand-held telephone use according to the length of time as a cell-phone customer. Nearly all study participants used analogue telephones. There was no

discernible difference in age-specific overall mortality between the two cohorts; nor was any effect apparent when the cohort of hand-held telephone users was restricted to those who had been customers for at least 3 years. Of course, if an effect is limited to brain cancer it is not likely to be evident in the overall mortality rate. Dreyer et al[14] recently reported cause-specific mortality in an expansion of this cohort of cellular telephone users.[15] They estimated average daily use from billing records. (In the USA both outgoing and incoming cellular telephone calls are billed). Unfortunately the follow-up was halted before it was complete for several reasons, including a lawsuit.[16] Dreyer et al found little indication among hand-held telephone users of increased mortality for brain cancer, leukaemia, or all cancers combined. The small number of deaths observed with the curtailed follow-up, however, hindered any strong conclusion.

Hardell et al,[17] in a case-control study of brain cancer in Sweden, identified participants during 1994–96, by which time digital telephones predominated the cellular market in Sweden. Among 209 patients who survived long enough to be interviewed and 425 population controls, Hardell et al found no indication of any increase in risk for brain cancer or acoustic neurinoma with cellular telephone use. On the other hand, among cellular telephone users who did develop brain cancer, they found an association between the side of the head of a temporal or occipital lobe tumour and the side of the head that the telephone was reported to be positioned during use, with a risk for same-side tumour being about 2·4 times that of the risk of an opposite side tumour. Hardell et al acknowledged that this latter finding was based on very few cases (the 95% CI for the RR was 0·8–7·8). Moreover, since there had been no increase in the overall risk of tumour, an association between side of tumour and side of telephone use requires the implausible inference that telephone use does not affect the risk of whether a brain tumour will occur but only its location. Ahlbom and Feychting[18] raised further questions about selection in this study. Were a study to find an increase in overall risk for brain tumour that was limited to tumours on the same side of the head that the telephone was used, that would be a much more compelling finding. Because many users switch the telephone from side to side,[9] it is not clear that an association with laterality of tumour would emerge even if there was a strong effect on brain cancer risk.

Base-station exposure

Cellular telephony is two-way; those who are in the beam of the signal emanating from a base-station antenna also receive RF exposure. Except for a few people who spend a large part of their day directly in the beam, such exposure is mostly intermittent. Although the RF field can be measured, individual exposure from base station exposure is difficult to assess. The beam is generally aimed at the horizon, so an antenna above ground will not expose people standing directly under it. The signal fades rapidly with distance, and overall population exposure from base stations is thought to be low.[3] Buildings reflect and scatter the beam, the intensity of which varies over time according to the telephone traffic. The few studies to date of populations near microwave, radio, and television towers have produced no consistent finding of increased risk, but these studies typically exhibit problems with exposure assessment or geography-related confounding.[20–24] The epidemiological study of base-station exposure is a formidable problem and is not likely to produce any useful information except in the unlikely event that some heavily exposed cohorts with high home or workplace exposure from a base station can be assembled.[25] Such exposure would be whole-body rather than directed to the head.

Pacemaker interference

Although the case for adverse health effects with respect to neoplasms is not yet compelling, RF exposure does affect health in other ways. One health effect comes about indirectly, through interference with pacemakers. Hayes et al[26] studied 980 patients with pacemakers and found that when a cellular telephone is held over the pacemaker a substantial proportion of pacemakers exhibited interference, in some cases leading to symptoms. The frequency of interference or symptoms depended on the type of pacemaker, and the type and position of the telephone. Holding the telephone against the ear caused essentially no interference, and the main risk relates to inadvertent positioning of the telephone against the chest. The study by Occhetta et al,[27] restricted to telephones in use in Europe, found no pacemaker interference.

Motor-vehicle collisions

The most important health effect of cellular telephony is not related to RF exposure as such. Redelmeier and Tibshirani[28] did a case-crossover study of cellular telephone calls and motor-vehicle collisions and estimated that the risk of a collision was about four times greater when the driver was using the telephone or soon after a call. Use of the telephone in "hands-free' mode was no less risky than holding the telephone to the ear with one hand while talking. This observation raises interesting questions about the possible risks of other "active" distractions while driving,[29] such as talking to passengers. Redelmeier and Tibshirani acknowledged that the risks of collision might be offset to some extent by the advantage of facile communication in medical or other emergencies, though such emergencies seldom demand that the vehicle be moving when the call is made.

Dreyer et al found that the heaviest users of cellular telephones had more than double the mortality from motor-vehicle collisions than the lightest users, despite the fact that the investigators did not have data on the time of the actual calls in relation to the collision.[14] The effect in relation to actual calls is likely to be an even larger increase in the risk of death. On the bright side, the effect on mortality was less strong for longer-term users, suggesting either a learning effect or the triumph of caution.

Work in progress

Several large studies underway may clarify the relation between the use of cellular telephones and cancer. J E Muscat and colleagues are completing a case-control study of brain cancer and neurinoma, with 469 men and women with brain cancer and 422 frequency-matched controls drawn from the same hospitals. Preliminary findings indicated little relation with brain cancer occurrence or tumour laterality, but a moderate increase in risk for neuroepitheliomatous cancers, with no relation to frequency of use (personal communication). The US National Cancer Institute has just completed a large case-control study of intracranial tumours in relation to cellular telephone use (and other risk factors). The study includes about 700 cases of cancer and nearly 100 acoustic neurinomas, identified during 1994–98.[30] First results should be available within a year. Also underway is an international collaborative programme of coordinated studies, the Interphone project. This project, led by Elisabeth Cardis of the International Agency for Research against Cancer, in Lyon, France, comprises population-

based case-control studies in 13 countries, eight in Europe. The project will study gliomas, meningiomas, and acoustic nerve and parotid gland tumours. All Interphone studies will use a common core protocol. Case identification is just beginning, and the first results are expected in 2004.

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References

1 Lipman RM, Tripathi BJ, Tripathi RC. Cataracts induced by microwave and ionizing radiation. *Surv Ophthalmol* 1988; **33:** 200–10.

2 Van Leeuwen GM, Lagendijk JJ, Van Leersum BJ, Zwamborn AP, Hornsleth SN, Kotte AN. Calculation of change in brain temperatures due to exposure to a mobile phone. *Phys Med Biol* 1999; **44:** 2367–79.

3 Rothman KJ, Chou C-K, Morgan R, et al. Assessment of cellular telephone and other radio frequency exposure for epidemiologic research. *Epidemiology* 1996; **7:** 291–98.

4 Gandhi OP, Chen JY, Wu D. 1995, Electromagnetic absorption in the human head and neck for cellular telephones at 835 MHz. *Radio Science* 1995; **30:** 161–77.

5 Independent Expert Group on Mobile Phones (chairman W Stewart). Mobile phones and health. London: Stationery Office, 2000.

6 Lilienfeld AM, Tonascia J, Tonascia S, Libauer CH, Cauthen GM, Markowitz JA, Weida S. Evaluation of health status of foreign service and other employees from selected Eastern European posts. Baltimore: Johns Hopkins University/Washington, DC: Department of State, Office of Medical Services (NTIS no. PB-288-163).

7 Robinette CD, Silverman C, Jablon S. Effects upon health of occupational exposure to microwave radiation (radar). *Am J Epidemiol* 1990; **112:** 39–53.

8 Hill DG. A longitudinal study of a cohort with past exposure to radar: the MIT Radiation Laboratory Follow-up Study. Dissertation/Johns Hopkins University, Baltimore, 1988.

9 Milham S Jr, Increased mortality in amateur radio operators due to lymphatic and hematopoietic malignancies. *Am J Epidemiol* 1998; **127:** 50–554.

10 Szmigielski S. Cancer morbidity in subjects occupationally exposed to high frequency (radiofrequency and microwave) electromagnetic radiation. *Sci Total Environ* 1996; **180:** 9–17.

11 Grayson JK. Radiation exposure, socioeconomic status, and brain tumor risk in the US Air Force: a nested case-control study. *Am J Epidemiol* 1996; **143:** 480–86.

12 Morgan RW, Kelsh MA, Zhao K, Exuzides A, Heringer S, Negrete W. Radiofrequency exposure and mortality from cancers of the brain and lymphatic/hematopoietic systems. *Epidemology* 2000; **11:** 118–27.

13 Rothman KJ, Loughlin JE, Funch DP, Dreyer NA. Overall mortality of cellular telephone customers. *Epidemiology* 1996; **7:** 303–05.

14 Dreyer NA, Loughlin JE, Rothman KJ. Cause-specific mortality in cellular telephone users. *JAMA* 1999; **282:** 1814–16.

15 Dreyer NA, Loughlin JE, Rothman KJ. Epidemiologic safety surveillance of cellular telephones in the US. *Radiat Protect Dosim* 1999; **83:** 115–63.

16 Busse and other *vs* Motorola Inc; Ameritech Mobile Communications, Inc; Cellular Telecommunications Industry Association; Science Advisory Group on Cellular Research; and Epidemiology Resources, Inc. Circuit Court of Cook County, Illinois. Epidemiology Resources Inc. 95 CH 10332 (Cir) (Judge Ellis E Reid).

17 Hardell L, Näsman A, Påhlson A, Hallquist A, Mild KH. Use of cellular telephones and the risk for brain tumours: a case-control study. *Int J Oncol* 1999; **15:** 113–16.

18 Ahlbom A, Feychting M. Re: use of cellular phones and the risk of brain tumours: a case-control study. *Int J Oncol* 1999; **15:** 1045–47.

19 Funch DP, Rothman KJ, Loughlin JE, Dreyer NA. Utility of telephone company records for epidemiologic studies of cellular telephones. *Epidemiology* 1996; **7:** 299–302.

20 Selvin S, Schulman J, Merril DW. Distance and risk measures for the analysis of spatial data: a study of childhood cancers. *Soc Sci Med* 1992; **34:** 769–77.

21 Maskarinec G, Cooper J, Swygert L. Investigation of increased incidence in childhood leukaemia near radio towers in Hawaii: preliminary observations. *J Environ Pathol Toxicol Oncol* 1994; **13:** 33–37.

22 Dolk H, Shaddick G, Walls P, et al. Cancer incidence near radio and television transmitters in Great Britain I: Sutton Coldfield transmitter. *Am J Epidemiol* 1997; **145:** 1–9.

23 Dolk H, Shaddick G, Walls P, Grundy C, Thakrar B, Kleinschmidt I, Elliott P. Cancer incidence near radio and television transmitters in Great Britain II: all high power transmitters. *Am J Epidemiol* 1997; **145:** 10–17.

24 Hocking B, Gordon IR, Grain HL, Hatfield GE. Cancer incidence and mortality and proximity to TV towers. *MJA* 1996; **165:** 601–05.

25 Blettner M, Michaelis J, Wahrendorf J. Workshop on research into the health effects of cellular telephones. *Epidemiology* 2000; **11:** 609–11.

26 Hayes DL, Wang PJ, Reynolds DW, et al. Interference with cardiac pacemakers by cellular telephones. *N Engl J Med* 1997; **336:** 1473–79.

27 Occhetta E, Plebani L, Bortnik M, Sacchetti G, Trevi G. Implantable cardioverter defibrillators and cellular telephones: is there any interference? *Pacing Clin Electrophysiol* 1999; **22:** 983–89.

28 Redelmeier DA, Tibshirani RJ. Association between cellular-telephone calls and motor vehicle collisions. *N Engl J Med* 1997; **336:** 453–58.

29 Lamble D, Kauranen T, Laakso M, Summala H. Cognitive load and detection threshold in car following situations: safety implications for using mobile (cellular) telephones while driving. *Accid Anal Prev* 1999; **31:** 617–23.

30 Inskip PD, Hatch EE, Stewart PA, et al. Study design for a case-control investigation of cellular telephones and other risk factors for brain tumours in adults. *Radiat Prot Dosimetry* 1999; **86:** 45–52.