

Radiofrequency radiation: summary of epidemiologic evidence

January 1, 2005

1. Overall summary

This section summarizes epidemiologic evidence cited in the tables below and will be updated as new evidence becomes available. I would appreciate feedback on any errors or omissions. don.wigle@sympatico.ca

Health effect	Level of evidence ^a	Comments
Early fetal death	Inadequate	An expert group noted that, among several epidemiologic studies of pregnancy outcome among physiotherapists exposed to microwaves in the RF range, one reported an association between early fetal deaths and maternal periconceptual RF exposure; the group concluded that the weight of evidence from studies of physiotherapists did not supported an association between early fetal death or other adverse pregnancy outcomes and RF (Independent Expert Group on Mobile Phones 2000). A recent review concluded that there is inadequate evidence that prenatal RF exposure can cause fetal deaths in humans (Repacholi 2001). A retrospective cohort study of Israeli physiotherapists found no association between early fetal deaths and maternal occupational shortwave exposure (Lerman et al 2001).
Birth defects	Inadequate	An expert panel review concluded that there is inadequate epidemiologic evidence for an association between birth defects and RF exposure (Royal Society of Canada 1999). A retrospective cohort study of Israeli physiotherapists found no association between birth defects and maternal occupational shortwave exposure (Lerman et al 2001). A review of experimental and epidemiologic studies concluded that, at doses high enough to cause tissue warming, RF can cause birth defects in mammalian and non-mammalian experimental animals but there was no credible evidence for teratogenicity at non-thermal RF levels (Heynick and Merritt 2003). This review also concluded that there is inadequate evidence for an association between human birth defects and RF.
Low birth weight	(Inadequate)	A retrospective cohort study of Israeli physiotherapists found an association between low birth weight and maternal occupational shortwave exposure (Lerman et al 2001).
Preterm birth	(Inadequate)	A retrospective cohort study of Israeli physiotherapists found no association between preterm birth and maternal occupational shortwave exposure (Lerman et al 2001).
Chromosomal abnormalities	Inadequate	A recent review concluded that there is inadequate evidence that prenatal RF exposure can cause chromosomal abnormalities in humans (Repacholi 2001).
Childhood cancer	(Inadequate)	A large hospital-based case-control study in the USA and Canada found a borderline association between neuroblastoma

		and hygienist-evaluated but not self-reported maternal occupational RF exposure; there was no association with paternal occupational RF exposure (De Roos et al 2001). An ecologic study in Rome found an association between childhood leukemia and residential proximity to radio and television transmitters (Michelozzi et al 2002).
Adult cancer: general	Inadequate	Two expert groups concluded that there is inadequate epidemiologic evidence for an association between cancer and RF exposure (Royal Society of Canada 1999, Independent Expert Group on Mobile Phones 2000). The latter review noted that the limited available epidemiologic evidence does not exclude a cancer risk from mobile phone use. Other reviews concluded that there is inadequate epidemiologic evidence that RF increases cancer incidence or progression in humans and is also inadequate to exclude a cancer risk (Repacholi 2001, Elwood 2003). Limitations of existing epidemiologic studies on cancer and RF exposure include crude exposure indices, short follow-up periods and limited control of potential confounders (Elwood 2003). There is equivocal evidence from animal studies that RF increases tumour incidence and some evidence that it enhances tumour progression (Repacholi 2001).
Adult cancer: CNS tumours	Limited	A large Swedish case-control study found associations between brain tumours (all types combined) and ipsilateral analogue and digital cell phone and cordless phone use; among the subgroup with latent periods of at least 10 years, brain tumours were associated with analog cell phone but not cordless phone use (Hardell et al 2003). There were inadequate data to assess associations between brain tumours with latent periods of at least 10 years and digital cell phone use. Another Swedish case-control study found associations between acoustic neuromas (with latent periods of at least 10 years) and cell phone use; the association was stronger for ipsilateral cell phone use and for analog compared to digital cell phones (Lonn et al 2004). A recent review of epidemiologic studies (including 7 reports of CNS tumours) concluded that: (i) all studies had methodologic deficiencies, (ii) all studies with reasonable latencies found associations between tumours and mobile phone use with odds ratios of 1.3-4.6), (iii) cancer risks increased with increasing latency and duration of mobile phone use, and (iv) the strongest associations were those between mobile phone use and acoustic neuroma and intraocular melanoma (Kundi et al 2004).
Adult cancer: uveal melanoma	(Inadequate)	A German case-control study found moderately strong associations between uveal melanoma and ever-use of radio sets and with probable or certain use of mobile phones (Stang et al 2001). A descriptive epidemiologic study of US cancer incidence data observed that ocular melanoma incidence rates (all ages) decreased by an average of 2% per year during 1974-1998, a period when there was a dramatic increase in cell phone use (Inskip et al 2003).
Reproductive system effects	(Inadequate)	A small cross-sectional study of men occupationally exposed to RF found no associations between sperm quality indices and RF exposure status (Grajekski et al 2000).

^a Sufficient evidence = based on peer-reviewed reports of expert groups or authoritative reviews that concluded that a causal relationship existed; limited evidence = relationships for which several epidemiologic studies, including at least one case-control or cohort study, found fairly consistent associations and evidence of exposure-risk relationships after control for potential confounders; inadequate evidence = relationships for which epidemiologic studies were limited

in number and quality (e.g., small studies, ecologic studies, limited control of potential confounders), had inconsistent results, or found little or no evidence of exposure-risk relationships. Levels in parentheses are the author's interpretation of available evidence; other levels are based on expert group reviews.

2. Developmental effects

Reference, location	Design	Exposure	Results	Association ^a	Covariates
(Royal Society of Canada 1999), Canada	Expert group review of health risks of RF from mobile phones		Inadequate epidemiologic evidence for an association between birth defects and RF exposure		
(Independent Expert Group on Mobile Phones 2000), UK	Expert group review of health risks of RF from mobile phones		Among several epidemiologic studies of pregnancy outcome among physiotherapists exposed to microwaves in the RF range, one study found an association between early fetal deaths and maternal periconceptual RF exposure (relative risk 1.3, CI 1.0–1.6). Overall, however, studies of pregnancy in physiotherapists have not supported an association between early fetal death or other adverse pregnancy outcomes and RF		
(Repacholi 2001), WHO, Geneva	Summary of reviews by the World Health Organization (WHO) and the UK Independent Expert Group on Mobile Phones (IEGMP) on health effects of mobile phone use		Inadequate epidemiologic evidence that prenatal RF exposure can cause fetal deaths or chromosomal abnormalities in humans		
(Lerman et al. 2001), Israel	Retrospective cohort study, 434 female physiotherapists; identified 930 pregnancies including 175 early fetal deaths, 45 birth defects and 47 preterm and 33 low birth weight infants	Self-reported occupational exposure to shortwave radiation	Early fetal deaths not associated with maternal occupational shortwave exposure; relative risks, 1-9 and 10+ vs 0 hr/wk	0.9 (0.7-1.4) 0.8 (0.5-1.4)	Relative risk unchanged after adjustment for potential confounders
			Birth defects not associated with maternal occupational shortwave exposure; relative risk, exposed vs unexposed	1.3 (0.7-2.8)	Febrile illness, alcohol, drugs, smoking, maternal age, previous early fetal death, parity

Reference, location	Design	Exposure	Results	Association ^a	Covariates
			Low birth weight associated with maternal occupational shortwave exposure; relative risk, exposed vs unexposed	2.8 (1.1-7.0)	As above
			Preterm birth not associated with maternal occupational shortwave exposure; relative risks, 1-9 and 10+ vs 0 hr/wk	1.0 (0.6-2.0) 0.8 (0.1-1.5)	
(Heynick and Merritt 2003), USA	Reviewed experimental and epidemiologic studies of radiofrequency radiation (3 kHz-300 GHz) and developmental abnormalities in experimental animals		At doses high enough to cause tissue warming, RF can cause birth defects in mammalian and non-mammalian experimental animals; no credible evidence for teratogenic effects at non-thermal RF levels		
			Inadequate evidence for an association between human birth defects and RF because of inconsistent findings		

Developmental effects: summary

Early fetal death

An expert group noted that, among several epidemiologic studies of pregnancy outcome among physiotherapists exposed to microwaves in the RF range, one reported an association between early fetal deaths and maternal periconceptual RF exposure; the group concluded that the weight of evidence from studies of physiotherapists did not supported an association between early fetal death or other adverse pregnancy outcomes and RF (Independent Expert Group on Mobile Phones 2000). A recent review concluded that there is inadequate evidence that prenatal RF exposure can cause fetal deaths in humans (Repacholi 2001). A retrospective cohort study of Israeli physiotherapists found no association between early fetal deaths and maternal occupational shortwave exposure (Lerman et al 2001).

Birth defects

An expert panel review concluded that there is inadequate epidemiologic evidence for an association between birth defects and RF exposure (Royal Society of Canada 1999). A retrospective cohort study of Israeli physiotherapists found no association between birth defects and maternal occupational shortwave exposure (Lerman et al 2001). A review of experimental and epidemiologic studies concluded that, at doses high enough to cause tissue warming, RF can cause birth

defects in mammalian and non-mammalian experimental animals but there was no credible evidence for teratogenicity at non-thermal RF levels (Heynick and Merritt 2003). This review also concluded that there is inadequate evidence for an association between human birth defects and RF.

Low birth weight

A retrospective cohort study of Israeli physiotherapists found an association between low birth weight and maternal occupational shortwave exposure (Lerman et al 2001).

Preterm birth

A retrospective cohort study of Israeli physiotherapists found no association between preterm birth and maternal occupational shortwave exposure (Lerman et al 2001).

Chromosomal abnormalities

A recent review concluded that there is inadequate evidence that prenatal RF exposure can cause chromosomal abnormalities in humans (Repacholi 2001).

3. Childhood cancer

Reference, location	Design	Exposure	Results	Association ^a	Covariates
(De Roos et al. 2001), Children's Cancer Group and Pediatric Oncology Group, USA and Canada	Hospital-based case-control study, 538 cases neuroblastoma, age 0-17 yr, 1992-1994, 504 matched controls	Self-reported information from both parents on occupational exposure to electrical equipment and radiation sources during 2 yr before child's birth; used a job-exposure matrix and published estimates of avg occupational magnetic field exposures	Borderline association between hygienist- but not self-reported maternal occupational RF exposure (odds ratios for self- and hygienist-rated probable exposure)	1.2 (0.6-2.6) 2.8 (0.9-8.7)	Matched for DOB; adjusted for child's age, maternal race, age and education
			No association between hygienist- but not self-reported paternal occupational RF exposure (odds ratios for self- and hygienist-rated probable exposure)	1.2 (0.8-1.8) 1.3 (0.8-2.2)	As above
(Michelozzi et al. 2002), Rome	Ecologic study, childhood leukemia incidence (age < 15 yr) and adult leukemia mortality in area within 10 km of powerful high frequency radio and television transmitters (the Vatican Radio Station of Rome)	Electric field levels near the transmitter were 1.5-25 V/m	Childhood leukemia associated with residence ≤ 6 km from transmitters; risk decreased with increasing distance (p = 0.036)	2.2 (1.0-4.1)	

Childhood cancer: summary

A large hospital-based case-control study in the USA and Canada found a borderline association between neuroblastoma and hygienist-evaluated but not self-reported maternal occupational RF exposure; there was no association with paternal occupational RF exposure (De Roos et al 2001). An ecologic study in Rome found an association between childhood leukemia and residential proximity to radio and television transmitters (Michelozzi et al 2002).

4. Adult cancer

Reference, location	Design	Exposure	Results	Association ^a	Covariates
(Royal Society of Canada 1999), Canada	Expert group review of health risks of RF from wireless telecommunication devices		Inadequate epidemiologic evidence for an association between cancer and RF exposure		
(Independent Expert Group on Mobile Phones 2000), UK	Expert group review of health risks of RF from mobile phones		Leukemia and brain tumours have been linked to RF exposure in some epidemiologic studies. Overall, there is inadequate epidemiologic evidence for an association between cancer and RF; the limited epidemiologic evidence do not prove that RF radiation from mobile phones does not cause cancer		
(Repacholi 2001), WHO, Geneva	Summary of reviews by the World Health Organization (WHO) and the UK Independent Expert Group on Mobile Phones (IEGMP) on health effects of mobile phone use		Equivocal evidence from animal studies that RF increases tumour incidence; some evidence that RF enhances tumour progression; inadequate epidemiologic evidence that RF increases cancer incidence or progression in humans – but cannot exclude a risk because of inadequacies of studies to date including short time periods since first exposure to cell phones		
(Stang et al. 2001), Germany	Case-control study, 118 cases uveal melanoma, 475 controls, age 35-74 yr, 1994-1997	Self-reported exposure to RF-transmitting devices	Uveal melanoma associated with ever-use of radio sets and with probable or certain use of mobile phones; odds ratios	radio sets 3.3 (1.2-9.2) mobile phones 4.2 (1.2- 15)	Matched for sex, age, study region; adjusted for education
(Elwood 2003), Australia	Review of epidemiologic studies of human cancer and radiofrequency electromagnetic radiation (RF) published up to 2002	No study measured individual RF exposure directly	There is inadequate epidemiologic evidence for an association between human cancer and RF exposure		

Reference, location	Design	Exposure	Results	Association ^a	Covariates
			Study limitations, including crude exposure indices, short follow-up periods and limited control of potential confounders, preclude the exclusion of a possible increased cancer risk		
			Research priorities include studies of leukemia in both adults and children and of cranial tumours in relation to mobile phone use		
(Hardell et al. 2003), Sweden	Case-control study, 1429 brain tumour cases, 1470 controls, age 20-80 yr, 1997-2000	Self-reported cell and cordless phone use	Malignant brain tumours associated with ipsilateral analogue and digital cell phone and cordless phone use; odds ratios	analogue 1.7 (1.1-2.7) digital 1.5 (1.1-2.3) cordless 1.4 (1.0-2.1)	Age, sex, SES
			Acoustic neuromas associated with ipsilateral analogue cell phone but not digital cell or cordless phone use; odds ratios	analogue 4.2 (1.6-11) digital 1.5 (0.7-3.2) cordless 1.3 (0.7-2.7)	As above
			Meningiomas not associated with ipsilateral cell or cordless phone use; odds ratios	analogue 1.1 (0.6-1.9) digital 1.1 (0.7-1.7) cordless	As above

Reference, location	Design	Exposure	Results	Association ^a	Covariates
				1.0 (0.6-1.5)	
			Brain tumours (all types) with a latent period of at least 10 yr associated with analogue cell phone use; no association with cordless phone use and inadequate data to assess digital cell phone use	analogue 1.5 (1.0-2.3) cordless 0.9 (0.4-2.3)	
(Inskip et al. 2003), USA	Descriptive study, incidence trends of ocular melanoma, USA, 1974-1998; used SEER cancer incidence data		Ocular melanoma incidence rates decreased in both males and females; avg % change per year	males -0.7% (-2.3, 0.9) females -1.2% (-2.5, 0.0)	
			Dramatic increase in cell phone use not accompanied by increased ocular melanoma incidence rates		
(Lonn et al. 2004), Sweden	Population-based case-control study, 148 cases acoustic neuroma, 604 controls, age 20-69 yr, recruited 1999-2002	Self-reported cell phone use	Acoustic neuromas associated with cell phone use for at least 10 years; odds ratios, <5, 5-9 and 10+ vs 0 yr since first use	0.8 (0.5-1.3) 1.1 (0.6-1.8) 1.9 (0.9-4.1)	Age, sex, residential area, education
			Acoustic neuromas associated with ipsilateral cell phone use for at least 10 years; odds ratios, <5, 5-9 and 10+ vs 0 yr since first use	0.8 (0.5-1.4) 1.1 (0.6-2.2) 3.9 (1.6-9.5)	
			Acoustic neuromas associated with analog cell phone use; odds ratio, analog vs digital	1.6 (0.9-2.8)	
(Kundi et al. 2004), Sweden	Review of 9 epidemiologic studies of cancer and mobile phone use including		All studies had methodologic deficiencies: (i) too short duration of mobile phone use, (ii)		

Reference, location	Design	Exposure	Results	Association ^a	Covariates
	7 studies of CNS tumours (one of these included salivary gland tumours), one study of leukemia/lymphoma and one study of intraocular melanoma		crude exposure indices, (iii) potential for recall bias in some studies		
			All studies with reasonable latencies found an increased odds ratios (range 1.3-4.6) associated with mobile phone use; cancer risks increased with increasing latency and duration of mobile phone use		
			The strongest associations were those between mobile phone use and acoustic neuroma and intraocular melanoma		

Adult cancer: summary

General

Two expert groups concluded that there is inadequate epidemiologic evidence for an association between cancer and RF exposure (Royal Society of Canada 1999, Independent Expert Group on Mobile Phones 2000). The latter review noted that the limited available epidemiologic evidence does not exclude a cancer risk from mobile phone use. Other reviews concluded that there is inadequate epidemiologic evidence that RF increases cancer incidence or progression in humans and is also inadequate to exclude a cancer risk (Repacholi 2001, Elwood 2003). Limitations of existing epidemiologic studies on cancer and RF exposure include crude exposure indices, short follow-up periods and limited control of potential confounders (Elwood 2003). There is equivocal evidence from animal studies that RF increases tumour incidence and some evidence that it enhances tumour progression (Repacholi 2001).

CNS tumours

A large Swedish case-control study found associations between brain tumours (all types combined) and ipsilateral analogue and digital cell phone and cordless phone use; among the subgroup with latent periods of at least 10 years, brain tumours were associated with analog cell phone but not cordless phone use (Hardell et al 2003). There were inadequate data to assess associations between brain tumours with latent periods of at least 10 years and digital cell phone use. Another Swedish case-control study found associations between acoustic neuromas (with latent periods of at least 10 years) and cell phone use; the association was stronger for ipsilateral cell phone use and for analog compared to digital cell phones (Lonn et al 2004). A recent review of epidemiologic studies (including 7 reports of CNS tumours) concluded that: (i) all studies had methodologic deficiencies, (ii) all studies with reasonable latencies found associations between tumours and mobile phone use with odds ratios of 1.3-4.6), (iii) cancer risks increased with increasing latency and duration of mobile phone use, and (iv) the strongest associations were those between mobile phone use and acoustic neuroma and intraocular melanoma (Kundi et al 2004).

Uveal melanoma

A German case-control study found moderately strong associations between uveal melanoma and ever-use of radio sets and with probable or certain use of mobile phones (Stang et al 2001). A descriptive epidemiologic study of US cancer incidence data observed that ocular melanoma incidence rates (all ages) decreased by an average of 2% per year during 1974-1998, a period when there was a dramatic increase in cell phone use (Inskip et al 2003).

5. Reproductive system effects

Reference, location	Design	Exposure	Results	Association ^a	Covariates
(Grajewski et al. 2000), Maryland, USA	Cross-sectional study, 12 men occupationally exposed to RF dielectric heaters, comparison group of 34 men employed in communications equipment manufacturing with minimal exposure to chemical and physical agents; assessed semen quality	Measured personal RF levels in workplace (none exceeded current guidelines)	Total sperm count lower among exposed men but difference not statistically significant; mean sperm count (millions), exposed vs unexposed	73 vs 93, p>0.05	
			% motile sperm <i>higher</i> among exposed men but difference not statistically significant; % motile sperm, exposed vs unexposed	67 vs 52%, p>0.05	
			% normal sperm morphology similar in both groups; % normal sperm morphology, exposed vs unexposed	81 vs 79%, p>0.05	

Reproductive system effects: summary

A small cross-sectional study of men occupationally exposed to RF found no associations between sperm quality indices and RF exposure status (Grajewski et al 2000).

Reference List

- De Roos AJ, Teschke K, Savitz DA, Poole C, Grufferman S, Pollock BH, et al. 2001. Parental occupational exposures to electromagnetic fields and radiation and the incidence of neuroblastoma in offspring. *Epidemiology* 12:508-17.
- Elwood JM. 2003. Epidemiological studies of radio frequency exposures and human cancer. *Bioelectromagnetics Suppl* 6:S63-73.
- Grajewski B, Cox C, Schrader SM, Murray WE, Edwards RM, Turner TW, et al. 2000. Semen quality and hormone levels among radiofrequency heater operators. *J Occup Environ Med* 42:993-1005.
- Hardell L, Mild KH, Carlberg M. 2003. Further aspects on cellular and cordless telephones and brain tumours. *Int J Oncol* 22:399-407.
- Heynick LN, Merritt JH. 2003. Radiofrequency fields and teratogenesis. *Bioelectromagnetics Suppl* 6:S174-86.
- Independent Expert Group on Mobile Phones. 2000. Mobile phones and health. UK: National Radiological Protection Board.
- Inskip PD, Devesa SS, Fraumeni JF Jr. 2003. Trends in the incidence of ocular melanoma in the United States, 1974-1998. *Cancer Causes Control* 14:251-7.
- Kundi M, Mild K, Hardell L, Mattsson MO. 2004. Mobile telephones and cancer--a review of epidemiological evidence. *J Toxicol Environ Health B Crit Rev* 7:351-84.
- Lerman Y, Jacobovich R, Green MS. 2001. Pregnancy outcome following exposure to shortwaves among female physiotherapists in Israel. *Am J Ind Med* 39:499-504.
- Lonn S, Ahlbom A, Hall P, Feychting M. 2004. Mobile phone use and the risk of acoustic neuroma. *Epidemiology* 15: 653-9.
- Michelozzi P, Capon A, Kirchmayer U, Forastiere F, Biggeri A, Barca A, et al. 2002. Adult and childhood leukemia near a high-power radio station in Rome, Italy. *Am J Epidemiol* 155:1096-103.
- Repacholi MH. 2001. Health risks from the use of mobile phones. *Toxicol Lett* 120:323-31.
- Royal Society of Canada. 1999. A review of the potential health risks of radiofrequency fields from wireless telecommunication devices. Ottawa: Royal Society of Canada.
- Stang A, Anastassiou G, Ahrens W, Broman K, Bornfeld N, Jockel KH. 2001. The possible role of radiofrequency radiation in the development of uveal melanoma. *Epidemiology* 12:7-12.