Introduction

Mobile phones have become easily affordable and increasingly popular worldwide. They facilitate communications between transiting persons, they are often essential tools for mobile workers and have become trendy among youngsters. Mobile phone use has exploded in the last few years, the number of global subscribers having quadrupled from around 1 billion in 2002 to 4.1 billions at the end of 2007 according to the International Telecommunications Union (ITU). In Canada, the Canadian Wireless Telecommunication Association (CWTA) estimated that more than 62% of the population subscribed to wireless phone services at the end of March 2008, a number that is growing by 10% annually. In some major urban centres, almost 80% of the population is using wireless telecommunications technology. This widespread use of cell phones brings social and economic benefits to large sections of society, however, raises questions about the effects of RF emissions from mobile phone and base-station antennas on the human body. Given the immense number of mobile phone users, even small adverse effects on health could have major public health implications.

Mobile phone effects

A cell phone works like a radio, with both the portable phone and the ground antennas emitting non ionizing electromagnetic radiation in the radiofrequency zone of 824–924 MHz, while digital phones use frequencies up to 1900 MHz. Cell phone devices can emit up to 2 W of power. The specific absorption rate (SAR) is the energy absorption by the tissue from radiofrequency fields of the mobile phones. It is defined as the rate of energy absorption per unit mass, and is measured in watts per kilogram (W/kg). Guidelines for exposure to microwaves have been based on thermal (heating) effects. The Canada safety code 6 allows a maximum of 1.6 W/kg SAR (1). Most studies have however focused on the non-thermal effects (bioeffects) of electromagnetic radiation (EMR) (2, 3). The majority of research has focused on exposure to the phone itself while the effects from base-station antennas have received less attention, probably due to the low exposure level they induce at long distances (4). Due to the close proximity of the mobile phone device to the head, most of the radiation absorption occurs in the head, especially the ipsilateral brain (5). Weinberger et al. hypothesized that these effects result from the head serving as an antenna and brain tissue as a radio receiver (6). The primary concern has been the risk of cancer for exposed tissues: meninges, brain, parotid gland, and acoustic tissue (7, 8).

In animals, effects have been reported on neuronal structures (9-11) and blood brain barrier permeability to various agents (12-14). DNA mutations were reported in cell studies (15-17). However, other studies measured no effect on neuronal structures (18, 19), blood brain barrier permeability (20-22) and cell DNA structure (22), for example.

In humans, several studies have demonstrated significant effects from RF on cognitive performances (23-28) but other studies have shown no effects (29-35). However, the major concern and the most investigated effect is the possible induction of brain tumors by microwaves used in cell phones. Hardell et al. found an increased risk of brain tumors associated with the use of analog cellular phones over a 10-year period in 1358 adults (8).

The findings were similar to those of previous studies (36-44). However, other studies found no increase in brain tumors associated with the use of cell phones (45-53), and an association between mobile phone use and cancer remains controversial. It appears likely that if cell phone use is associated with a risk of brain cancer, it will appear after a multi year extensive use, which has not been thoroughly tested yet due to the recent appearance of the technology.

Although a vast literature exists on the effects of cell phones on human health, a consensus has not been reached on the subject. However, the possibility of harmful effects seems to become more credible as evidenced by recent warnings issued by researchers and health organizations. In July 2008, D^{r} Ronald B. Herberman, director of the University of Pittsburgh Cancer Institute issued a warning to limit cell phone use, especially for children, due to the risk of brain cancer based on early unpublished reports (54). This was followed by a warning memo to employees from the World Health Organization to limit cell phone use in children (55).

Mobile phone and children

Children and teenagers have recently become the new marketing target for cell phones. According to the CWTA, 65% of Canadians aged 16-17 years and 30% of kids aged 13-15 years possessed a cell phone in 2008, but there are no Canadian statistics on users under 12 years. Children are increasingly exposed to RF at earlier and earlier ages and will experience a longer period of exposure in their life. This might be important because cumulative dose may have a strong influence on increased risk of brain tumors (56, 57). Compared to adults, children present a relatively higher potential risk and are more susceptible to RF, depending on their phase of development. Their brain tissue is more conductive and RF penetration is greater relative to head size than for adults (58) (Figure 1; www.willthomas.net/Investigations/Articles/cellphones.htm). Recent studies indicated higher SAR values for children in comparison to adults (59-62). Leitgeb et al. (63) showed that the local SAR systematically increases from 15% to 50% with age decreasing from adulthood to 3 years. The consequence of prolonged exposures to RF in children is unknown at this time; only few studies have been published that focused on children and adolescents (64). Grigor'ev and Grigor'ev (65) mention in their review a direct influence of RF on sleep, memory, fatigue, blood-brain barrier permeability, nervous cells of children and teenagers and the remote possibility of the development of brain and acoustic nerve tumors. The results of three epidemiologic studies in adolescents showed that frequent mobile phone use was associated with poor perceived health (66-68). In another epidemiologic study from a large cohort, Divan et al. (69) demonstrated statistically significant associations between prenatal and postnatal exposures to mobile phones and behavioural difficulties in children. A few child studies did not show any effects on cognitive function and wellbeing in children exposed to RF (70, 71). Otto et al. (72) concluded in their review that there are presently no scientific data supporting the concept of a special vulnerability of children and adolescents to high-frequency EMF but support the precautionary principle as long term effects cannot be tested yet.

Base station antennas

Mobile phone base stations are low-power multi-channel two-way radio transmitters with antennas, typically about 20-30 cm in width and 1 m in length mounted on either a tower, free-standing masts or on buildings at a height varying between 15 and 50 m above ground. The frequent use of mobile phones has necessitated an increased deployment of base stations close to homes, schools and other inhabitated buildings. Across Canada, there are approximately 8000 base station antenna sites. The RF beams emitted by antennas are very narrow in the vertical direction but broad in the horizontal direction. The RF field intensity increases as one moves away from the base station and then decreases at greater distances from the antenna. Viel et al (73) found that two distinct peaks are observed for the GSM detectable exposure distribution with distance: one around 280 m, mainly in urban areas; the other one, around 1000 m, mainly in periurban areas. Typical maximum powers for base station transmitters are from a few watts to 100 W or more depending on the size of the region covered. According to the FCC (Federal Communications Commission, USA), measurement data obtained from various sources have consistently indicated that ground-level power densities near typical cellular towers are on the order of 1 $\mu W/cm^2$ or less. In Canada, *Safety Code 6* (1) specifies a general public limit for human exposure to a power density of 590 $\mu W/cm^2$ for the analog band (824-894 MHz) and of 1000 $\mu W/cm^2$ for the newer digital communications band (1850-1975 MHz). These values of power density produce a worst-case SAR with respect to all human body sizes of 0.08 W/kg. To put this number into perspective, the total radiofrequency power absorbed by a 180 lb (82 kg) person would be 6.6 W when exposed to *Safety Code 6* limit-level power densities (1). The factors that influence how much radiofrequency radiation an individual may be exposed to include: the type of antenna and the direction of the transmitted beam, the location of the person with respect to the transmitted beam, the average number of connected calls, the topographic characteristics of the covered area (the presence of other structures near the person that may shield them or reflect the RF signals towards them). It must be noted that the Canadian safety limit is relatively high and other countries have adopted much stricter limits. For example, the Salzburg Resolution invoking the precautionary principle, recommends safety limits at 0.1 $\mu W/cm^2$ (74, 75). Switzerland has guidelines that restrict public exposures at 900 MHz (GSM frequency) to 6 $\mu W/cm^2$ and restrict public exposures at 1800 MHz to 10 $\mu W/cm^2$. Italy has an exposure limit of 6 $\mu W/cm^2$ for broadcast and mobile phone transmitters in buildings where people work for more than four hours per day. Russia has public exposure limits of 8.4 $\mu W/cm^2$ at 900 MHz and 1800 MHz. The Toronto City Council has introduced a Prudent Avoidance Policy for the siting of mobile phone antennas to keep levels in areas where people normally spend time at least 100 times lower than Health Canada's *Safety Code 6* limits.

There is public concern and extensive scientific debate about the safety of exposure to RF fields from base station antennas used for cell phones, but only a few investigations of effects of base station exposure on health exist. Symptoms such as fatigue, headaches, sleeping problems, concentration difficulties, memory impairment, dizziness, tremors, depressive symptoms, cardiovascular symptoms, libido decrease, restlessness as well as tinnitus are the frequent effects reported by subjects living close to a base station antenna

(73, 76-81). Hutter et al. (82) reported adverse effects on wellbeing and performance from exposure to total high frequency electromagnetic fields (0.005 μW/cm^2, distance = 24-600 m in rural areas; 0.002 μW/cm^2, distance = 20-250 m in urban areas) from the base station, far below recommended levels (max. 1000 μW/cm^2). Several studies reported an association between increased incidence of cancer and living in proximity to a cell phone transmitter station (83-85). Other studies have found no adverse health effects from mobile phone base station antennas (86-88). Two studies concluded that exposure to low-level RF radiation of up to a SAR of 800 mW/kg does not induce cell transformations responsible for tumor formation (89, 90).

As in the case of the mobile phone, the effects of exposure to base station antennas can be expected to be more severe in children and teenagers. To our knowledge, these effects have not been thoroughly investigated. A recent study reported no association between exposure to base station and well-being in children exposed for a period of 24 hours only (71).

Conclusions from epidemiologic studies

The body of epidemiologic evidence regarding mobile phones and cancer or regarding base stations and cancer remains controversial and inconclusive. The studies on cancer are mainly case-control studies which were susceptible to selection biases and reporting biases (91, 92) and most of which were small and lacked power. The studies on symptoms were susceptible to reporting biases. Cancer may be a manifestation with long latency. It would therefore be most useful if intermediate markers of biological effects of RF radiation could be demonstrated in relation to mobile phone or base station exposure. Fortunately there are some markers that may be indicative of biologic effect of RF radiation and that could be exploited to increase our understanding of possible harmful effects of RF radiation.

Magnetic resonance imaging (MRI) and spectroscopy (MRS)

Magnetic resonance imaging (MRI) is now widely used in radiology to obtain images of internal tissues in order to detect lesions or identify diseased tissue. The multiple weighting factors that can be used (T1, T2, PD, diffusion…) allow to vary contrast and provide increasingly useful clinical information. The development of higher magnetic fields in recent years along with multiple technical improvements allow to increase image quality and shorten acquisition time. The technique is noninvasive and safe and permits repeated dynamic measurements. Magnetic resonance spectroscopy (MRS) is based on the same principles as MRI but aims at detecting certain metabolites in a selected tissue volume. In the brain, the main metabolites detected are *N*-acetylaspartate (NAA, neuronal marker), creatine and phosphocreatine (Cr), choline-containing compounds (Cho, membrane marker), *myo*-inositol (mI), glutamate (Glu), glutamate + glutamine (Glx), lactate (Lac), lipids (Lip) and others. Changes observed by MRS precede those measured by MRI. Increases in Cho are generally observed in tumors. RF radiations are widely believed to affect brain function and to potentially cause brain tumors. Some epidemiological studies have concluded that brain tumors are more prevalent for mobile phone users especially after many years of use (36-42, 93).

However, few studies have evaluated the brain tissue condition *in situ*. In a previous study of a small sample of subjects, we used MRS to compare metabolite levels between extensive cell phone users and non-users in the pontobulbar, left and right temporal areas (Figures 2, 3). Comparison of spectra between the brain side exposed to cell phone radiation and the contralateral area showed no statistically significant difference (94). However, these data were recorded at a magnetic field of 1.5 T and analyzed with an earlier version of the LCModel software. We recently reanalyzed the data and found a strong tendency toward a Cho/Cr increase in the right temporal and pontobulbar areas of mobile phone users relative to non-users and between the exposed right temporal area relative to the non-exposed left temporal area (Table 1). These data suggest that differences might become significant with a larger number of subjects and with improved data acquisition and processing. A Cho increase would be compatible with early malignancy. Also noticeable in Table 1 are decreases in Glx/Cr in the exposed right temporal area and in mobile phone users relative to controls. These promising findings need to be replicated and evaluated in a variety of settings.

Objectives

The overall objective of this proposal is to use the *in vivo* high field magnetic resonance spectroscopy (MRS) and imaging (MRI) techniques to compare the brain metabolite levels and images 1. in extensive mobile phone users relative to non users, and 2. in the population living in close proximity of base-station antennas relative to the population living at a long distance. Reported health symptoms, and complaints assessed with a questionnaire will be correlated with MRS and MRI results. This study should help to determine whether physical evidence of brain effects can be measured in people exposed to cell phones and base-station antennas.

Hypotheses

We hypothesise that children and teenagers exposed to cell phones and base station antennas may manifest brain MRS parameters that differ from unexposed children and adolescents. Specifically, we hypothesise that there will be measurable differences in Cho/Cr and in Glx/Cr. We do not anticipate to detect differences in other parameters. We further hypothesise that MRS effects will be correlated with reported health symptoms. If such results are found, they would provide direct noninvasive evidence of the effects of radiation on the human brain.

Research Design Outline

Two parallel pairs of study groups will be constituted : a) cell phone users and a comparison group of non-users and b) subjects who are in close proximity to a base station and a comparison group that is distant from any base station. Distinct subgroups of children and adults will be constituted in each exposure subgroup. Each of the subjects in each of the various study groups will be subjected to three dimensions of data collection:

i) questionnaire information to characterise their exposure (to the cell phone or to the base station);
ii) questionnaire responses regarding a list of health symptoms and conditions;
iii) MRI and MRS measured parameters.

The analytical task will be to compare the respective pairs of exposed and unexposed study groups on the measured parameters and responses.

Sample selection

a. Cell phone users and comparison group

A total of 120 subjects will be included, equally divided in four groups of 30 as follows: adolescent mobile phone users; adolescent non mobile phone users; adult mobile phone users; adult non mobile phone users. Eligible adolescents will be 12-18 years old; eligible adults will be 20-60 years old. Mobile phone users will be included if they cumulate more than 2 years of phone use for at least 1 hour per day. Control subjects will be non users of cell phones. Mobile phone users and non-users will be matched for age, sex and education level. Subjects will be excluded if they suffer from any chronic neurological or psychiatric disease, alcoholism, drug addiction, previous cerebral trauma, or if they have been living in the vicinity of mobile phone-station antennas. Subjects with a contra-indication for magnetic resonance examination such as body weight exceeding 115 kg, metal implants, pacemaker and severe claustrophobia will also be excluded. All subjects will be recruited with public announcements or word of mouth.

b. Subjects near and distant from base station

As a model to study the effects of base-station antennas, the situation of the Terrebonne, Québec town has been chosen. This situation has become well known because of the actions taken by some of its citizens concerned about the presence of four base-station antennas in the steeple of the local church. Detailed information about the situation can be found on the website of the committee for the removal of base-station antennas from the Terrebonne church steeple (95). In the immediate vicinity of the church are located a private high school college (Collège St-Sacrement, 1400 students; 60 m), an administrative school board building (Commission scolaire des Affluents, 40 workers; 40 m), a daycare center (Garderie les Bourgeons-Soleil, 80 children; 80 m), a school for young adults (Centre l'Avenir, 450 students; 95 m), a primary school (École primaire Saint-Louis, 780 students; 130 m), a public high school (École Léopold-Gravel, 900 students; 250 m) as well as many homes. Figure 4 shows a layout of the area.

Thirty adolescents (age 12-18 years) having studied for at least 2 years at the Collège St-Sacrement, Terrebonne will be recruited. A power exposure to RF of about 0.64 $\mu W/cm^2$ has been measured at the college with the Gigahertz Solutions model eHFE59B HF/RF Analyzer (measured by Stéphane Belainsky from 3E Electromagnetic Environmental Expertise, Inc.; www.em3e.com). As control subjects, 30 adolescents will be recruited from Jean de la Fontaine college, 192 rue de l'Église, Terrebonne (Lachenaie sector) located in an area free of base-station antennas in its vicinity for at least 2000 m. Exposed Terrebonne college students and control subjects will be matched for age, sex and education level.

Thirty adults (20-60 years) having worked in the Commission scolaire des Affluents administrative service building in Terrebonne for at least 2 years will be recruited. The power exposure to RF at the building is about 0.82 $\mu W/cm^2$. As control subjects, 30 adults will be recruited from teachers and administrative staff of Jean de la Fontaine college, 192 rue de l'Église, Terrebonne (Lachenaie sector) which is free of base-station antennas in the vicinity for at least 2000 m.

Subjects exposed to base-stations and control subjects will be matched for age, sex and education level. Subjects will be excluded if they suffer from any chronic neurological or psychiatric disease, alcoholism, drug addiction, previous cerebral trauma, or if they have been extensive mobile phone users (2 years at more than 1 hour/day). Subjects with a contra-indication for magnetic resonance examination such as body weight exceeding 115 kg, metal implants, pacemaker and severe claustrophobia will also be excluded.

Exposed subjects and adolescent control subjects will be recruited by announcements in the identified institutions. A contact has already been established with Mr François Therrien, a resident of Terrebonne and teacher, who will help us communicate with the schools and residents. Adult control subjects will be recruited by public announcements.

Informed consent

All subjects will sign an informed consent form approved by the research scientific and ethics committees of the Centre Hospitalier de l'Université de Montréal (CHUM). In the case of minor adolescents, a parent or tutor will sign the informed consent form.

Data collection

a. Information on exposure

Participants in the cellphone pair of groups will be asked to complete a questionnaire to characterize their cell phone use. They will be asked specifically about the cell phone type, duration of use, average daily period of use. Participants in the base station pair of groups will be asked to complete a questionnaire to characterize their exposure to base station antennas. They will be asked to determine the base station antenna type, their average distance from the antennas, their cumulative period of exposure and their daily exposure time (see attached questionnaire).

b. Information on symptoms and health conditions

All participants will complete a health questionnaire enquiring about their general health and symptoms that may be attributable to cell phone use or base station antenna exposure such as headache, fatigue, irritability, nausea, loss of appetite, sleep disturbances, depressive tendencies, feeling of discomfort, difficulties in concentration, memory loss, skin problems, visual disturbances, hearing disturbances, dizziness, movement difficulties, cardiovascular problems and others (see attached questionnaires). The level of complaints for the studied symptoms will be graded by the study participants using the scale: 0 = no, 1 = weak, 2 = medium, and 3 = strong effect.

c. MRI and MRS parameters

All subjects will be submitted to brain ^{1}H magnetic resonance imaging (MRI) and spectroscopy (MRS) examinations performed on a Philips Gyroscan Achieva 3.0 Tesla MRI scanner (Philips Medical Systems, Best, The Netherlands) at Hôpital Notre-Dame du CHUM. The Philips ^{1}H headcoil will be used for all experiments.

Total brain MRI
The 3D images will be obtained with a coronal T1-weighted SPGR sequence with the following parameters: TR = 30 ms; TE = 6 ms; acquisition matrix, 256 x 256; field of view, 230 mm; flip angle, 45°; slice thickness, 1.2 mm with no space, 15-20 slices.

MRS
For mobile phone users and control subjects, single-voxel MR spectra will be acquired using the PRESS sequence for three 8-cc voxels located in the left and right temporal lobes and the pontobulbar area (Figure 2). Acquisition parameters will be TR = 2000 ms, TE = 30 ms, number of acquisitions = 64, spectral width = 2000 Hz, number of points = 1024, total acquisition time = 2.2 min. For subjects exposed to base station radiation, single-voxel MR spectra will be acquired using the same parameters but in the frontal, parietal and occipital areas (Figure 5).

MRSI
Brain MRS imaging data will be recorded from a single 15 mm coronal slice for cell phone users (Figure 6) and from a single axial slice (Figure 7). Acquisition parameters will be a 24 x 24 matrix, voxel size = 2 ml, acquisition time = 17 min, field of view = 240 mm. Data from voxels located in the frontal, temporal and occipital lobes will be analyzed.

MR parameters to be measured

MR images of the total brain will be analyzed by an experienced neuroradiologist to detect the presence of possible lesions or anomalies in all enrolled subjects. Spectra from

MRS and MRSI experiments will be analyzed using the LCModel software (96) to obtain the metabolite to creatine + phosphocreatine (Cr) ratios for *N*-acetylaspartate (NAA/Cr), choline containing compounds (Cho/Cr), *myo*-inositol (mI/Cr), glutamate (Glu/Cr), glutamine (Gln/Cr), lipids (Lip/Cr) and lactate (Lac/Cr).

Statistical power

Using a power analysis based on a 15% variation of the MRS signal, we determined that a minimum of 18 subjects would be necessary to demonstate a statistically significant difference between cell phone users and non-users or subjects living near a base station antenna and those living at a long distance. To increase the statistical power analysis, groups of 30 subjects will be used.

Statistical analyses

Exposed and unexposed subjects (to cell phones and to base stations) will be compared in terms of two types of outcome variables: MRS metabolite ratios and reported health symptoms. This will be done separately for the adolescents and the adult samples. Continuous variables will be compared using Student t tests and categorical ones using appropriate categorical value tests. We will also assess the correlation between reported health symptoms and metabolite ratios. Statistical analyses will be performed by D^{r} Miguel Chagnon, an expert statistician at the Université de Montréal (see letter attached).

Impact of the project

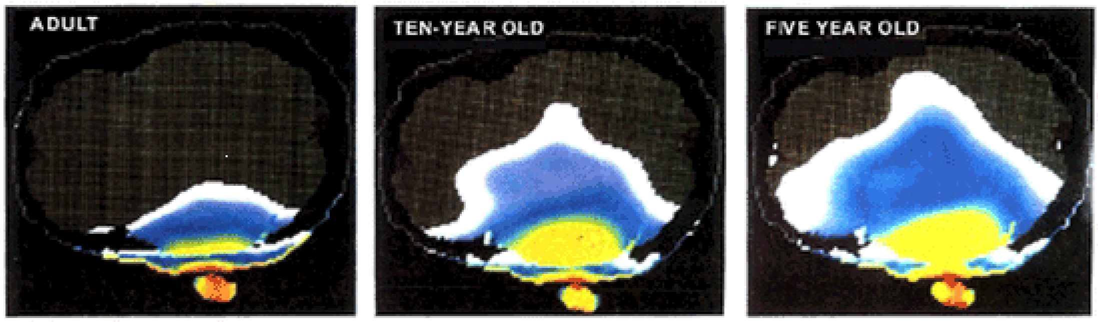
The finding of brain markers of the effects of exposure to cell phone and base station antenna radiation could have a very significant impact on the existing debate about the effects of this technology. The marker would be an objective parameter that could be used to monitor specific sites.

Table 1: MRS metabolite ratios for mobile phone users and control subjects

Brain ROI	**Metabolite ratio**	**Mobile phone users (n = 21)**	**Control subjects (n = 12)**	***p* users vs non-users**	***p* left vs right in users**
Left temporal					
	NAA/Cr	1.42 ± 0.15*	1.40 ± 0.12		0.49
	Cho/Cr	0.25 ± 0.05	0.26 ± 0.03		0.06
	mI/Cr	0.93 ± 0.18	0.90 ± 0.15		0.56
	Glx/Cr	2.13 ± 0.32	2.01 ± 0.25		0.13
Right temporal					
	NAA/Cr	1.39 ± 0.13	1.43 ± 0.17	0.50	
	Cho/Cr	0.28 ± 0.03	0.25 ± 0.06	0.19	
	mI/Cr	0.90 ± 0.15	0.92 ± 0.13	0.74	
	Glx/Cr	1.99 ± 0.27	1.82 ± 0.16	0.10	
Pontobulbar					
	NAA/Cr	1.81 ± 0.23	1.83 ± 0.53	0.88	
	Cho/Cr	0.54 ± 0.09	0.46 ± 0.15	0.08	
	mI/Cr	1.30 ± 0.30	1.16 ± 0.23	0.24	
	Glx/Cr	1.85 ± 0.42	2.08 ± 0.54	0.23	

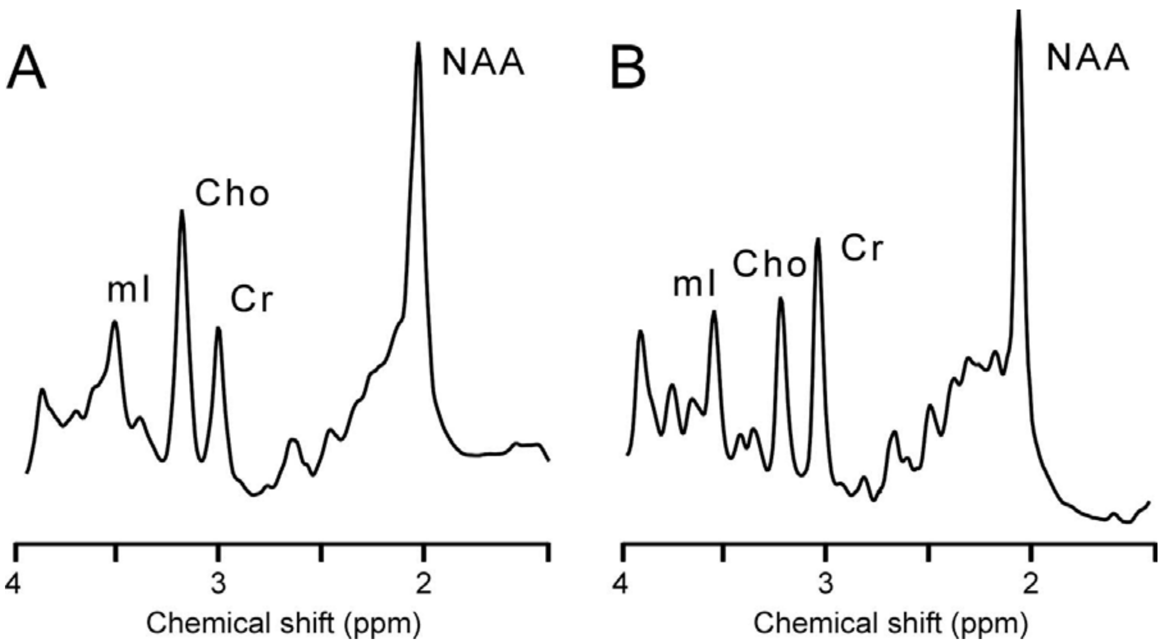
* Results are expressed as mean ± 1 SD.

Figure 1



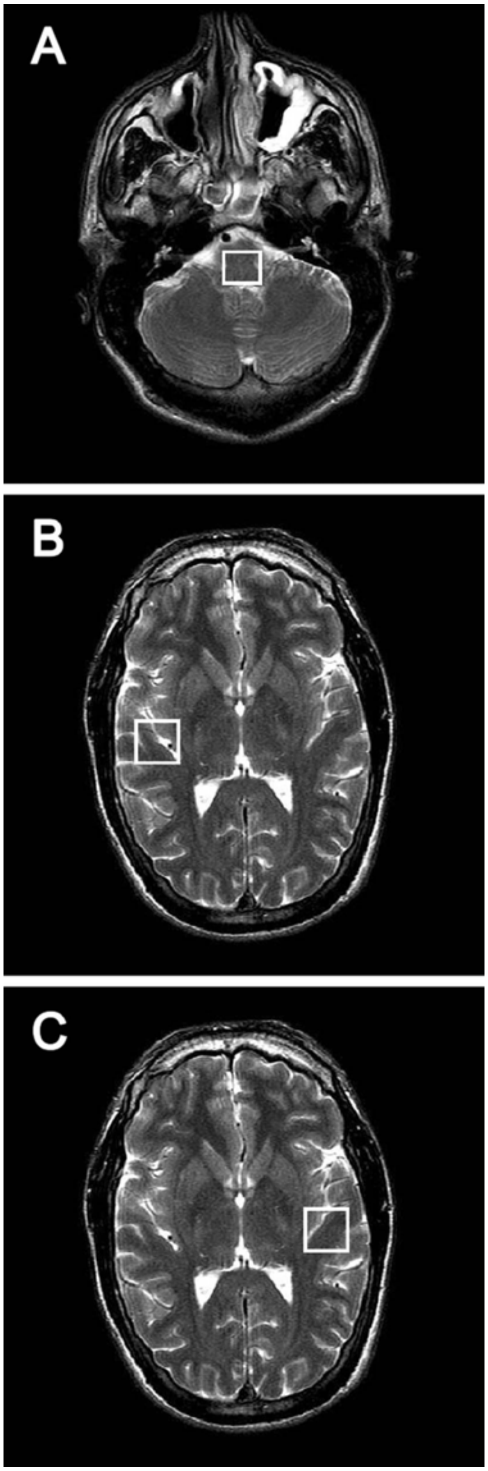
Scan showing human brain cell phone microwave penetration for an adult (left), a ten year old child (center) and a five year old child (right).
From www.willthomas.net/Investigations/Articles/cellphones.htm.

Figure 2



MR spectra of the pontobulbar region of (a) an intensive cell phone user and (b) a control subject.

Figure 3



Location of the MRS voxels in the (a) pontobulbar, (b) right temporal and (b) right temporal areas for cell phone users and control subjects. The voxel size is 2 x 2 x 2 cc.

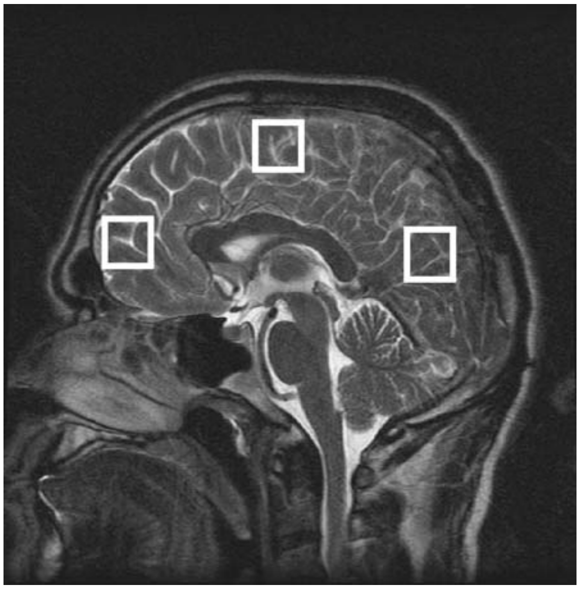
Figure 4

Map of central Terrebonne illustrating the locations of the buildings from the base stations installed in the church steeple.

Figure 5

MR image illustrating the position of the slice to be used for MRSI data acquisition in cell phone users and control subjects.

Figure 6



MR image illustrating the position of the voxels to be analyzed by MR spectroscopy for subjects exposed to base station radiation and their control subjects.

Figure 7

MR image illustrating the position of the slice used to perform MRSI data acquisition for subjects exposed to base station radiation and their control subjects.

References

1. Health Canada's Safety Code 6 for Exposure of Humans to Radio Frequency Fields", http://www.hc-sc.gc.ca/ewh-semt/pubs/radiation/99ehd-dhm237/index-eng.php
2. BioInitiative report: a rationale for a biologically-based public exposure standard for electromagnetic fields (ELF and RF). http://www.bioinitiative.org.
3. Hardell L, Sage C. Biological effects from electromagnetic field exposure and public exposure standards. Biomed Pharmacother. 2008 Feb;62(2):104-9.
4. Riddervold IS, Pedersen GF, Andersen NT, Pedersen AD, Andersen JB, Zachariae R, et al. Cognitive function and symptoms in adults and adolescents in relation to rf radiation from UMTS base stations. Bioelectromagnetics. 2008 May;29(4):257-67.
5. Cardis E, Deltour I, Mann S, Moissonnier M, Taki M, Varsier N, et al. Distribution of RF energy emitted by mobile phones in anatomical structures of the brain. Phys Med Biol. 2008 Jun 7;53(11):2771-83.
6. Weinberger Z, Richter ED. Cellular telephones and effects on the brain: the head as an antenna and brain tissue as a radio receiver. Med Hypotheses. 2002 Dec;59(6):703-5.
7. Auvinen A, Toivo T, Tokola K. Epidemiological risk assessment of mobile phones and cancer: where can we improve? Eur J Cancer Prev. 2006 Dec;15(6):516-23.
8. Hardell L, Hallquist A, Mild KH, Carlberg M, Pahlson A, Lilja A. Cellular and cordless telephones and the risk for brain tumours. Eur J Cancer Prev. 2002 Aug;11(4):377-86.
9. Lopez-Martin E, Bregains J, Relova-Quinteiro JL, Cadarso-Suarez C, Jorge-Barreiro FJ, Ares-Pena FJ. The action of pulse-modulated GSM radiation increases regional changes in brain activity and c-Fos expression in cortical and subcortical areas in a rat model of picrotoxin-induced seizure proneness. J Neurosci Res. 2009 May 1;87(6):1484-99.
10. Minasyan SM, Grigoryan GY, Saakyan SG, Akhumyan AA, Kalantaryan VP. Effects of the action of microwave-frequency electromagnetic radiation on the spike activity of neurons in the supraoptic nucleus of the hypothalamus in rats. Neurosci Behav Physiol. 2007 Feb;37(2):175-80.
11. Salford LG, Brun AE, Eberhardt JL, Malmgren L, Persson BR. Nerve cell damage in mammalian brain after exposure to microwaves from GSM mobile phones. Environ Health Perspect. 2003 Jun;111(7):881-3; discussion A408.
12. Eberhardt JL, Persson BR, Brun AE, Salford LG, Malmgren LO. Blood-brain barrier permeability and nerve cell damage in rat brain 14 and 28 days after exposure to microwaves from GSM mobile phones. Electromagn Biol Med. 2008;27(3):215-29.
13. Schirmacher A, Winters S, Fischer S, Goeke J, Galla HJ, Kullnick U, et al. Electromagnetic fields (1.8 GHz) increase the permeability to sucrose of the blood-brain barrier in vitro. Bioelectromagnetics. 2000 Jul;21(5):338-45.
14. Salford LG, Brun A, Sturesson K, Eberhardt JL, Persson BR. Permeability of the blood-brain barrier induced by 915 MHz electromagnetic radiation, continuous wave and modulated at 8, 16, 50, and 200 Hz. Microsc Res Tech. 1994 Apr 15;27(6):535-42.
15. Schwarz C, Kratochvil E, Pilger A, Kuster N, Adlkofer F, Rudiger HW. Radiofrequency electromagnetic fields (UMTS, 1,950 MHz) induce genotoxic effects in

vitro in human fibroblasts but not in lymphocytes. Int Arch Occup Environ Health. 2008 May;81(6):755-67.
16. Kim JY, Hong SY, Lee YM, Yu SA, Koh WS, Hong JR, et al. In vitro assessment of clastogenicity of mobile-phone radiation (835 MHz) using the alkaline comet assay and chromosomal aberration test. Environ Toxicol. 2008 Jun;23(3):319-27.
17. Diem E, Schwarz C, Adlkofer F, Jahn O, Rudiger H. Non-thermal DNA breakage by mobile-phone radiation (1800 MHz) in human fibroblasts and in transformed GFSH-R17 rat granulosa cells in vitro. Mutat Res. 2005 Jun 6;583(2):178-83.
18. Yamaguchi H, Tsurita G, Ueno S, Watanabe S, Wake K, Taki M, et al. 1439 MHz pulsed TDMA fields affect performance of rats in a T-maze task only when body temperature is elevated. Bioelectromagnetics. 2003 May;24(4):223-30.
19. Tsurita G, Nagawa H, Ueno S, Watanabe S, Taki M. Biological and morphological effects on the brain after exposure of rats to a 1439 MHz TDMA field. Bioelectromagnetics. 2000 Jul;21(5):364-71.
20. Masuda H, Ushiyama A, Hirota S, Wake K, Watanabe S, Yamanaka Y, et al. Effects of subchronic exposure to a 1439 MHz electromagnetic field on the microcirculatory parameters in rat brain. In Vivo. 2007 Jul-Aug;21(4):563-70.
21. Finnie JW, Blumbergs PC, Cai Z, Manavis J, Kuchel TR. Effect of mobile telephony on blood-brain barrier permeability in the fetal mouse brain. Pathology. 2006 Feb;38(1):63-5.
22. Zeni O, Romano M, Perrotta A, Lioi MB, Barbieri R, d'Ambrosio G, et al. Evaluation of genotoxic effects in human peripheral blood leukocytes following an acute in vitro exposure to 900 MHz radiofrequency fields. Bioelectromagnetics. 2005 May;26(4):258-65.
23. Regel SJ, Gottselig JM, Schuderer J, Tinguely G, Retey JV, Kuster N, et al. Pulsed radio frequency radiation affects cognitive performance and the waking electroencephalogram. Neuroreport. 2007 May 28;18(8):803-7.
24. Regel SJ, Tinguely G, Schuderer J, Adam M, Kuster N, Landolt HP, et al. Pulsed radio-frequency electromagnetic fields: dose-dependent effects on sleep, the sleep EEG and cognitive performance. J Sleep Res. 2007 Sep;16(3):253-8.
25. Eliyahu I, Luria R, Hareuveny R, Margaliot M, Meiran N, Shani G. Effects of radiofrequency radiation emitted by cellular telephones on the cognitive functions of humans. Bioelectromagnetics. 2006 Feb;27(2):119-26.
26. Keetley V, Wood AW, Spong J, Stough C. Neuropsychological sequelae of digital mobile phone exposure in humans. Neuropsychologia. 2006;44(10):1843-8.
27. Curcio G, Ferrara M, De Gennaro L, Cristiani R, D'Inzeo G, Bertini M. Time-course of electromagnetic field effects on human performance and tympanic temperature. Neuroreport. 2004 Jan 19;15(1):161-4.
28. Edelstyn N, Oldershaw A. The acute effects of exposure to the electromagnetic field emitted by mobile phones on human attention. Neuroreport. 2002 Jan 21;13(1):119-21.
29. Wiholm C, Lowden A, Kuster N, Hillert L, Arnetz BB, Akerstedt T, et al. Mobile phone exposure and spatial memory. Bioelectromagnetics. 2009 Jan;30(1):59-65.

30. Haarala C, Takio F, Rintee T, Laine M, Koivisto M, Revonsuo A, et al. Pulsed and continuous wave mobile phone exposure over left versus right hemisphere: effects on human cognitive function. Bioelectromagnetics. 2007 May;28(4):289-95.
31. Haarala C, Ek M, Bjornberg L, Laine M, Revonsuo A, Koivisto M, et al. 902 MHz mobile phone does not affect short term memory in humans. Bioelectromagnetics. 2004 Sep;25(6):452-6.
32. Haarala C, Bjornberg L, Ek M, Laine M, Revonsuo A, Koivisto M, et al. Effect of a 902 MHz electromagnetic field emitted by mobile phones on human cognitive function: A replication study. Bioelectromagnetics. 2003 May;24(4):283-8.
33. Russo R, Fox E, Cinel C, Boldini A, Defeyter MA, Mirshekar-Syahkal D, et al. Does acute exposure to mobile phones affect human attention? Bioelectromagnetics. 2006 Apr;27(3):215-20.
34. Wilen J, Johansson A, Kalezic N, Lyskov E, Sandstrom M. Psychophysiological tests and provocation of subjects with mobile phone related symptoms. Bioelectromagnetics. 2006 Apr;27(3):204-14.
35. Besset A, Espa F, Dauvilliers Y, Billiard M, de Seze R. No effect on cognitive function from daily mobile phone use. Bioelectromagnetics. 2005 Feb;26(2):102-8.
36. Hardell L, Nasman A, Pahlson A, Hallquist A, Hansson Mild K. Use of cellular telephones and the risk for brain tumours: A case-control study. Int J Oncol. 1999 Jul;15(1):113-6.
37. Hardell L, Nasman A, Pahlson A, Hallquist A. Case-control study on radiology work, medical x-ray investigations, and use of cellular telephones as risk factors for brain tumors. MedGenMed. 2000 May 4;2(2):E2.
38. Hardell L, Mild KH, Pahlson A, Hallquist A. Ionizing radiation, cellular telephones and the risk for brain tumours. Eur J Cancer Prev. 2001 Dec;10(6):523-9.
39. Hardell L, Carlberg M, Soderqvist F, Mild KH, Morgan LL. Long-term use of cellular phones and brain tumours: increased risk associated with use for > or =10 years. Occup Environ Med. 2007 Sep;64(9):626-32.
40. Stang A, Anastassiou G, Ahrens W, Bromen K, Bornfeld N, Jockel KH. The possible role of radiofrequency radiation in the development of uveal melanoma. Epidemiology. 2001 Jan;12(1):7-12.
41. Hardell L, Mild KH, Carlberg M. Case-control study on the use of cellular and cordless phones and the risk for malignant brain tumours. Int J Radiat Biol. 2002 Oct;78(10):931-6.
42. Hardell L, Carlberg M, Hansson Mild K. Epidemiological evidence for an association between use of wireless phones and tumor diseases. Pathophysiology. 2009 Mar 4.
43. Hardell L, Carlberg M, Soderqvist F, Hansson Mild K. Meta-analysis of long-term mobile phone use and the association with brain tumours. Int J Oncol. 2008 May;32(5):1097-103.
44. Kundi M. Mobile phone use and cancer. Occup Environ Med. 2004 Jun;61(6):560-70, 487.
45. Johansen C, Boice J, Jr., McLaughlin J, Olsen J. Cellular telephones and cancer--a nationwide cohort study in Denmark. J Natl Cancer Inst. 2001 Feb 7;93(3):203-7.

46. Klaeboe L, Blaasaas KG, Tynes T. Use of mobile phones in Norway and risk of intracranial tumours. Eur J Cancer Prev. 2007 Apr;16(2):158-64.
47. Repacholi MH, Basten A, Gebski V, Noonan D, Finnie J, Harris AW. Lymphomas in E mu-Pim1 transgenic mice exposed to pulsed 900 MHZ electromagnetic fields. Radiat Res. 1997 May;147(5):631-40.
48. Moulder JE, Erdreich LS, Malyapa RS, Merritt J, Pickard WF, Vijayalaxmi. Cell phones and cancer: what is the evidence for a connection? Radiat Res. 1999 May;151(5):513-31.
49. Elwood JM. Epidemiological studies of radio frequency exposures and human cancer. Bioelectromagnetics. 2003;Suppl 6:S63-73.
50. Hansson Mild K, Hardell L, Kundi M, Mattsson MO. Mobile telephones and cancer: is there really no evidence of an association? (review). Int J Mol Med. 2003 Jul;12(1):67-72.
51. Christensen HC, Schuz J, Kosteljanetz M, Poulsen HS, Boice JD, Jr., McLaughlin JK, et al. Cellular telephones and risk for brain tumors: a population-based, incident case-control study. Neurology. 2005 Apr 12;64(7):1189-95.
52. Schuz J, Bohler E, Berg G, Schlehofer B, Hettinger I, Schlaefer K, et al. Cellular phones, cordless phones, and the risks of glioma and meningioma (Interphone Study Group, Germany). Am J Epidemiol. 2006 Mar 15;163(6):512-20.
53. Kan P, Simonsen SE, Lyon JL, Kestle JR. Cellular phone use and brain tumor: a meta-analysis. J Neurooncol. 2008 Jan;86(1):71-8.
54. Memo cancer director warns of cell phone risks. http://www.msnbc.msn.com/id/25821899/. MSNBC. 2008.
55. Nicholas D. Cell phones warnings released by the World Health Organization. http://www.enews20.com/news_Cell_Phones_Warnings_Released_by_World_Health_Organization_09885.html eNews 20. 2008.
56. Sadetzki S, Chetrit A, Freedman L, Stovall M, Modan B, Novikov I. Long-term follow-up for brain tumor development after childhood exposure to ionizing radiation for tinea capitis. Radiat Res. 2005 Apr;163(4):424-32.
57. Morgan LL. Estimating the risk of brain tumors from cellphone use: Published case-control studies. Pathophysiology. 2009 Apr 6.
58. Kheifets L, Repacholi M, Saunders R, van Deventer E. The sensitivity of children to electromagnetic fields. Pediatrics. 2005 Aug;116(2):e303-13.
59. Wiart J, Hadjem A, Gadi N, Bloch I, Wong MF, Pradier A, et al. Modeling of RF head exposure in children. Bioelectromagnetics. 2005;Suppl 7:S19-30.
60. Wiart J, Hadjem A, Wong MF, Bloch I. Analysis of RF exposure in the head tissues of children and adults. Phys Med Biol. 2008 Jul 7;53(13):3681-95.
61. Gandhi OP, Lazzi G, Furse CM. Electromagnetic absorption in the human head and neck at 835 and 1900 MHz. IEEE Trans Microwave Theory Tech. 1996;44:1884-7.
62. de Salles AA, Bulla G, Rodriguez CE. Electromagnetic absorption in the head of adults and children due to mobile phone operation close to the head. Electromagn Biol Med. 2006;25(4):349-60.
63. Leitgeb N. Mobile phones: are children at higher risk? Wien Med Wochenschr. 2008;158(1-2):36-41.

64. Thomas S, Kuhnlein A, Heinrich S, Praml G, von Kries R, Radon K. Exposure to mobile telecommunication networks assessed using personal dosimetry and well-being in children and adolescents: the German MobilEe-study. Environ Health. 2008;7:54.
65. Grigor'ev Iu G. [The electromagnetic fields of cellular phones and the health of children and of teenagers (the situation requiring to take an urgent measure)]. Radiats Biol Radioecol. 2005 Jul-Aug;45(4):442-50.
66. Punamaki RL, Wallenius M, Nygard CH, Saarni L, Rimpela A. Use of information and communication technology (ICT) and perceived health in adolescence: the role of sleeping habits and waking-time tiredness. J Adolesc. 2007 Aug;30(4):569-85.
67. Koivusilta L, Lintonen T, Rimpela A. Intensity of mobile phone use and health compromising behaviours – how is information and communication technology connected to health-related lifestyle in adolescents? J Adolesc. 2005;28:35-47.
68. Soderqvist F, Carl berg M, Hardell L. Use of wireless telephones and self-reported health symptoms: a population-based study among Swedish adolescents aged 15-19 years. Environ Health. 2008;7:18.
69. Divan HA, Kheifets L, Obel C, Olsen J. Prenatal and postnatal exposure to cell phone use and behavioral problems in children. Epidemiology. 2008 Jul;19(4):523-9.
70. Preece AW, Goodfellow S, Wright MG, Butler SR, Dunn EJ, Johnson Y, et al. Effect of 902 MHz mobile phone transmission on cognitive function in children. Bioelectromagnetics. 2005;Suppl 7:S138-43.
71. Kuhnlein A, Heumann C, Thomas S, Heinrich S, Radon K. Personal exposure to mobile communication networks and well-being in children--a statistical analysis based on a functional approach. Bioelectromagnetics. 2009 May;30(4):261-9.
72. Otto M, von Muhlendahl KE. Electromagnetic fields (EMF): do they play a role in children's environmental health (CEH)? Int J Hyg Environ Health. 2007 Oct;210(5):635-44.
73. Viel JF, Clerc S, Barrera C, Rymzhanova R, Moissonnier M, Hours M, et al. Residential exposure to radiofrequency fields from mobile-phone base stations, and broadcast transmitters: a population-based survey with personal meter. Occup Environ Med. 2009 Mar 30.
74. Santini R. Arguments in favor of applying the precautionary principle to counter effects of mobile phone base stations. http://www.emrnetwork.org/position/santini. 2002.
75. . Salzburg resolution on mobile telecommunication base stations. Proceedings of International conference on cell tower siting linking sciences and public health; 2000; Salzburg, Austria.
76. Santini R, Santini P, Danze JM, Le Ruz P, Seigne M. [Investigation on the health of people living near mobile telephone relay stations: I/Incidence according to distance and sex]. Pathol Biol (Paris). 2002 Jul;50(6):369-73.
77. Santini R, Santini P, Danze JM, Le Ruz P, Seigne M. [Symptoms experienced by people in vicinity of base stations: II/ Incidences of age, duration of exposure, location of subjects in relation to the antennas and other electromagnetic factors]. Pathol Biol (Paris). 2003 Sep;51(7):412-5.
78. Navarro EA, Segura J, Portolés M, Gomez-Perretta de Mateo C. The microwave syndrome: A preliminary study in Spain. Electromagn Biol Med. 2003;22:161-9.

79. Bortkiewicz A, Zmyslony M, Szyjkowska A, Gadzicka E. [Subjective symptoms reported by people living in the vicinity of cellular phone base stations: review]. Med Pr. 2004;55(4):345-51.
80. Abdel-Rassoul G, El-Fateh OA, Salem MA, Michael A, Farahat F, El-Batanouny M, et al. Neurobehavioral effects among inhabitants around mobile phone base stations. Neurotoxicology. 2007 Mar;28(2):434-40.
81. Augner C, Florian M, Pauser G, Oberfeld G, Hacker GW. GSM base stations: short-term effects on well-being. Bioelectromagnetics. 2009 Jan;30(1):73-80.
82. Hutter HP, Moshammer H, Wallner P, Kundi M. Subjective symptoms, sleeping problems, and cognitive performance in subjects living near mobile phone base stations. Occup Environ Med. 2006 May;63(5):307-13.
83. Wolf R, Wolf D. Increased incidence of cancer near a cellphone transmitter station. Int J Cancer Prev. 2004;1:123-8.
84. Eger H, Hagen KU, Lucas B, Vogel P, Voit H. [Influence of the spatial proximity of mobile phone base stations on cancer rates]. Umwelt-Medizin-Gesellschaft. 2004;17:273-356.
85. Meyer M, Gärtig-Daugs A, Radespiel-Tröger M. [Cellular telephone relay stations and cancer incidence]. Umweltmed Forsch Prax. 2006;11:89-97.
86. Eltiti S, Wallace D, Ridgewell A, Zougkou K, Russo R, Sepulveda F, et al. Does short-term exposure to mobile phone base station signals increase symptoms in individuals who report sensitivity to electromagnetic fields? A double-blind randomized provocation study. Environ Health Perspect. 2007 Nov;115(11):1603-8.
87. Berg-Beckhoff G, Blettner M, Kowall B, Breckenkamp J, Schlehofer B, Schmiedel S, et al. Mobile phone base stations and adverse health effects: phase 2 of a cross-sectional study with measured radio frequency electromagnetic fields. Occup Environ Med. 2009 Feb;66(2):124-30.
88. Furubayashi T, Ushiyama A, Terao Y, Mizuno Y, Shirasawa K, Pongpaibool P, et al. Effects of short-term W-CDMA mobile phone base station exposure on women with or without mobile phone related symptoms. Bioelectromagnetics. 2009 Feb;30(2):100-13.
89. Hirose H, Suhara T, Kaji N, Sakuma N, Sekijima M, Nojima T, et al. Mobile phone base station radiation does not affect neoplastic transformation in BALB/3T3 cells. Bioelectromagnetics. 2008 Jan;29(1):55-64.
90. Sakuma N, Komatsubara Y, Takeda H, Hirose H, Sekijima M, Nojima T, et al. DNA strand breaks are not induced in human cells exposed to 2.1425 GHz band CW and W-CDMA modulated radiofrequency fields allocated to mobile radio base stations. Bioelectromagnetics. 2006 Jan;27(1):51-7.
91. Vrijheid M, Armstrong BK, Bedard D, Brown J, Deltour I, Iavarone I, et al. Recall bias in the assessment of exposure to mobile phones. J Expo Sci Environ Epidemiol. 2009 May;19(4):369-81.
92. Vrijheid M, Richardson L, Armstrong BK, Auvinen A, Berg G, Carroll M, et al. Quantifying the impact of selection bias caused by nonparticipation in a case-control study of mobile phone use. Ann Epidemiol. 2009 Jan;19(1):33-41.
93. Hardell L, Carlberg M. Mobile phones, cordless phones and the risk for brain tumours. Int J Oncol. 2009 Jul;35(1):5-17.

94. Khiat A, Boulanger Y, Breton G. Monitoring the effects of mobile phone use on the brain by proton magnetic resonance spectroscopy. Int J Radiat Biol. 2006 Sep;82(9):681-5.
95. Réseau québécois des groupes écologistes. Comité pour le retrait des antennes cellulaires du clocher de Terrebonne. www.rqge.qc.ca/ clocherdeterrebonne.
96. Provencher SW. Estimation of metabolite concentrations from localized in vivo proton NMR spectra. Magn Reson Med. 1993 Dec;30(6):672-9.

Our research teams have been interested in the effects of the cell phone on human health for several years. D^r Boulanger's group has realized a preliminary study on the effects of cell phones on the brain using magnetic resonance spectroscopy (MRS) and imaging (MRI) at 1.5 T. The results of this study were published in Int. J. Radiat. Biol. in 2006 (document attached; ref. 94). Although the results did not reach statistical significance due to the low number of subjects and low field strength, a reanalysis of the data with improved software suggests a tendency toward statistically significant changes for the choline/creatine (Cho/Cr) and glutamate- + glutamine/creatine (Glx/Cr) ratios (Table 1). D^r Siemiatycki's group has been involved in a multinational epidemiological study of the effects of cell phones on the brain (INTERPHONE study described in Cardis, E. et al. Eur. J. Epidemiol., 2007; 22(9): 647-64). The full results of this study have not been published yet but D^r Siemiatycki and his colleagues have published two articles in 2009 discussing the importance of a proper selection of subjects for cell phone studies (documents attached; refs. 91, 92).

For the development of this project, D^r Khiat and Boulanger has established contact with Mr François Therrien of Terrebonne who is involved in a committee for the removal of base stations from the church steeple in Terrebonne and a physics teacher. Mr Therrien has provided us precious information about the existing knowledge on the effects of these base stations in his town and elsewhere. He will help us with the recruitment for this project.