



Very high radiofrequency radiation at Skeppsbron in Stockholm, Sweden from mobile phone base station antennas positioned close to pedestrians' heads

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ABSTRACT

In urban environment there is a constant increase of public exposure to radiofrequency electromagnetic fields from mobile phone base stations. With the placement of mobile phone base station antennas radiofrequency hotspots emerge. This study investigates an area at Skeppsbron street in Stockholm, Sweden with an aggregation of base station antennas placed at low level close to pedestrians' heads. Detailed spatial distribution measurements were performed with 1) a radiofrequency broadband analyzer and 2) a portable exposimeter. The results display a greatly uneven distribution of the radiofrequency field with hotspots. The highest spatial average across all quadrat cells was 12.1 V m^{-1} (388 mW m^{-2}), whereas the maximum recorded reading from the entire area was 31.6 V m^{-1} (2648 mW m^{-2}). Exposimeter measurements show that the majority of exposure is due to mobile phone downlink bands. Most dominant are 2600 and 2100 MHz bands used by 4G and 3G mobile phone services, respectively. The average radiofrequency radiation values from the earlier studies show that the level of ambient RF radiation exposure in Stockholm is increasing. This study concluded that mobile phone base station antennas at Skeppsbron, Stockholm are examples of poor radiofrequency infrastructure design which brings upon highly elevated exposure levels to popular seaside promenade and a busy traffic street.

1. Introduction

Electromagnetic fields are known physical risk factors. When mobile phone base station antennas are installed, the immediate physical environment, including the public and the living spaces can be greatly affected by microwaves.

Measuring public exposure to radiofrequency fields is significant from public health perspective, but also for future epidemiological studies. Given the rapid development of mobile communication technologies, the radiofrequency landscape is continuously diversifying and intensifying: more frequencies are introduced to provide novel mobile phone and data services; more base station antennas are constantly installed to facilitate the increasing need for data amounts, pushed through the networks. Meanwhile, public exposure also increases.

In previous publications we have reported environmental exposure to radiofrequency (RF) electromagnetic (EMF) radiation at certain places in Stockholm in Sweden such as the Central Railway Station (Hardell

et al., 2016), the Old Town (Hardell et al., 2017), with special attention to Järntorget in the Old Town (Hardell et al., 2019), and Stockholm city (Carlberg et al., 2019). Of special interest was to measure RF radiation in one Stockholm apartment with two groups of base station antennas nearby (Hardell et al., 2018). That apartment was further examined using a RF broadband analyzer and the results were compared with another Stockholm apartment with substantially much lower RF radiation but equally good wireless communication possibility (Koppel et al., 2019).

Earlier studies done in Europe show constant increase of public exposure, especially in urban environment. The increase is attributed to new mobile phone base stations installed, but also to the increased usage of corresponding mobile services. Sánchez-Montero et al. (2017) monitored urban exposure in Alcalá de Henares (Spain) for ten years and reported city mean field increase from 0.277 ($203 \mu\text{W m}^{-2}$) in 2006 to 0.395 V m^{-1} ($414 \mu\text{W m}^{-2}$) in 2015. Sánchez-Montero et al. (2017) admit that during the ten years of monitoring the number of mobile phone base

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station has doubled, but also conclude that the probability of being exposed to a high value of 14 V m^{-1} (519 mWm^{-2}) is less than 0.01% and the probability of being exposed by 28 V m^{-1} (2079 mWm^{-2}) is negligible (Sánchez-Montero et al., 2017).

It is expected, that wherever mobile phone base station antennas are installed, high exposure areas might be encountered. Although these highly exposed areas constitute a minor part of the urban environment, these should be carefully studied for the sake of the people who work and live there.

Urbiniello et al. (2014) emphasized “A continuous monitoring is needed to identify high exposure areas and to anticipate critical development of RF-EMF exposure at public places”, while they informed a steep RF radiation growth in public places within one year. The growth of RF radiation has been substantial in many countries, also in Sweden as exemplified in this study.

Sagar et al. (2018) conducted a literature review, looking at studies in between 2000 and 2013 of radiofrequency electromagnetic exposure in microenvironments in Europe. For outdoor microenvironments they report the mean total RF exposure to be 0.54 V m^{-1} for spot measurements. Typical exposure levels were around 0.5 V m^{-1} and rarely over 1 V m^{-1} . They report downlink contributing the most to the total RF exposure in outdoor microenvironments in all studies except one.

An updated review by Jalilian et al. (2019) on European microenvironments' studies from 2015 to 2018 found mean outdoor exposure ranging from 0.07 to 1.27 V m^{-1} . Mobile phone base stations' downlink signals were the most relevant contributor to total exposure. The review concluded a tendency for RF levels to increase with increasing urbanity. Also, the review found that all different types of studies reported mean exposure levels of less than 1 V m^{-1} ; different types included spot measurement, fixed site monitoring, and personal measurement with volunteers.

The problem with most of the spot measurement studies is their inability to adequately represent spatial RF field distribution. This is due to two reasons: 1) the measurement sample is too small and does not account for highly exposed areas and/or 2) the spots where the measurements are collected do not coincide with the RF hotspots. RF hotspots occur usually around RF sources such as mobile phone base station antennas. Furthermore, RF hotspots depend on the radiation pattern of the antenna and the surrounding environment, hence the field distribution is uneven. It is not possible to visually identify RF hotspots around the antennas, this can only be done by detailed measurements or computer simulations.

For example, Aerts et al. conducted a detailed RF field mapping in Ghent, Belgium. They performed in total 650 broadband measurements in a city subarea of 1 km^2 . The study found five hotspots, with max total electric field ranging from 1.3 to 3.1 V m^{-1} (Aerts et al., 2013). Their study showed, that significantly higher RF exposure levels are likely to occur than those reported by the majority of studies. In addition, they demonstrated that construction of a detailed RF heat map of the investigated area is important to characterize and outline the hotspot area.

1.1. The aim of the study

In this study we identified an area in Stockholm with an aggregation of base station antennas placed at low level, close to pedestrians' heads. The aim of this research is to point out highly exposed radiofrequency areas in the city environment and to analyze the sources and the reasons for the high exposure. We performed detailed measurements and constructed a detailed RF heat map. Such conclusions would help to better design the RF infrastructure sites with the aim of minimizing the public exposure. No ethical permission was needed since no test persons were involved.

2. Materials and methods

In this study spatial distribution of RF radiation sources was

measured. The RF radiation sources were mobile phone base station antennas located at the Skeppsbron street, Stockholm, Sweden. This area is characterized by dense RF infrastructure as 15 mobile phone base station sectoral antennas from several operators are located on the same building complex, where the elevation from the street level is only few meters.

The site was selected by visually identifying radiofrequency sources, based on the dense packing of mobile phone base station antennas. Also the site is well suited for a scientific study, as it is positioned within the city center, whereas one side of the site is open to the sea where there are no RF sources nearby. The old town with old buildings is located on the other side of the street.

2.1. Study design

The measurements were conducted on a business day afternoon (January 14, 2019) with busy traffic which allows to assume higher network traffic. All measurements were done outdoor.

Field distribution was determined covering an area of $60 \times 250 \text{ m}$, representing a street strip of old town buildings at one side and the sea (Strömmen) at the other side. The area is composed of the Skeppsbron street with busy traffic and pedestrians represented by a seaside promenade. Seaside promenade is filled with indoor and outdoor cafés, some operating throughout the year. Antennas are installed on top of those cafés. The promenade and the cafés are packed with hundreds of people on a holiday period – many of which at close range to the mobile phone base station antennas.

The area was covered by 3×11 quadrats, where each quadrat cell (quad) was measured with RF broadband analyzer by registering RF readings from one end of the quad to another by following North-South axis with a slow pace. For each quad, one moving measurement scan was done. Quads were drawn to both sides of the Skeppsbron street. Each quad measurement was done for about 1 min with average and maximum readings registered. The measurements were taken at the height from 1 to 1.8 m by moving the meter in circular movements along the quad. This allows covering the standing waves and detecting maximum radiation points.

RF broadband analyzer used was Narda NBM-520, with an E-field probe E0391 (Narda-Safety-Test-Solutions GmbH, Pfullingen, Germany). This meter of Narda NBM-series is capable of time and spatial averaging and determining the maximum level during the monitored period. Manufacturer's probe EF0391 is intended for base station measurements with a frequency range from 100 kHz to 3 GHz . This meter and the probe cover a large range of RF sources, including different telecommunications protocols: frequency modulation (FM) radio broadcasting; television (TV) broadcasting; TETRA emergency services (police, rescue, etc.); global system for mobile communications (GSM) second generation mobile communications; universal mobile telecommunications systems (UMTS) third generation mobile communications, 3G; long-term evolution (LTE) fourth generation mobile communications standard, 4G; digital European cordless telecommunications (DECT) cordless telephone systems standard; Wi-Fi wireless local area network protocol, 2.45 GHz ; worldwide interoperability for microwave access (WIMAX) wireless communication standard for high speed voice, data and internet.

Later, the measurement readings were entered into vector mapping software 3DFIELD ver. 4.5.2.0 (by Vladimir Galouchko) and field distribution map created (in V m^{-1}). Field distribution map was based on quadrat measurement spatial averages by using kriging, which is a geostatistical calculation method.

Additionally to analyze the frequency composition the entire quadrat was in parallel also measured with an exposimeter EME Spy 200 by Microwave Vision Group, Paris, France. The exposimeter measures 20 predefined frequency bands covering most public RF radiation emitting devices currently used in Sweden. The exposimeter covers frequencies from 88 to 5850 MHz . For FM, TV3, TETRA, TV4&5, Wi-Fi 2.4 GHz and

Wi-Fi 5 GHz the lower detection limit is 0.01 V m^{-1} ($0.27 \mu\text{W m}^{-2}$); for all other bands the lower detection limit is 0.005 V m^{-1} ($0.066 \mu\text{W m}^{-2}$). For all bands the upper detection limit is 6 V m^{-1} ($95,544 \mu\text{W m}^{-2}$; $9.5544 \mu\text{W cm}^{-2}$). The sampling rate used in this study was every 4th second which is the fastest possible sampling rate for the given exposimeter when all bands are active. The exposimeter was held at some distance (about 0.4 m) from the body. The unit reports the exposure in a conservative manner since each reported value is the sampling outcome, where many samples are taken and statistically processed including minimum, mean, median and maximum values. The meters had valid calibration.

Based on [Cellmapper.net](https://cellmapper.net) mobile phone operators and their corresponding services, mobile bands and frequencies were determined (Table 1). A large number of base station sector antennas emit a multitude of downlink frequency spans ($N = 14$) covering 2G, 3G and 4G services. Service providers have their own allocated frequency spans, but some are shared.

2.2. Statistical methods

Broadband RF readings using Narda NBM-520 were collected in Volts per meter (V m^{-1}) based on quadrat measurements covering the entire area. Each quadrat produced a spatial average and maximum reading calculated on the space covered. Based on quadrat cells measurements, two samples were formed: one of spatial averages and the second of spatial maximums. For both samples minimum, quartiles, median and maximum were calculated containing all the spatial measurement values in the area, using MS Excel 2016.

Means in microWatts per square meter ($\mu\text{W m}^{-2}$) were calculated for all measured frequency bands for measurements using the exposimeter EME Spy 200. Values below the lower detection limit were treated as no (0) exposure. Total exposure was calculated as the sum of all measured frequency bands. Stata/SE 12.1 (Stata/SE 12.1 for Windows; StataCorp., College Station, TX, USA) was used for all calculations.

3. Results

The results display a greatly uneven distribution of the RF fields with hotspots. The close proximity to the RF sources creates highly elevated field levels in the immediate vicinity to the base station. Given the antennas elevation from the ground, people walking on the street are highly exposed when passing or hanging around the area.

Fig. 1 presents a boxplot of spatial RF distribution of the entire investigated area. Both spatial average and maximum readings of RF broadband analyzer are included in the graph. The fields emanated by the base station antennas overlapped at several locations, elevating the exposure to high levels. The highest spatial average across all quadrat cells was 12.1 V m^{-1} (388 mW m^{-2}), whereas the maximum recorded reading over the entire area was 31.6 V m^{-1} (2649 mW m^{-2}). These were far-field measurement results, the meter was not used in the near-field of antennas. The lowest spatial average quadrat was 1.4 V m^{-1} (5.2 mW m^{-2}) which is still relatively high, considering the levels reported by the review studies (Jalilian et al., 2019; Sagar et al., 2018) discussed in the Introduction chapter. This emphasizes that the entire microenvironment

Table 1

Mobile phone operators, their corresponding services and frequencies used at Skeppsbron, information from cellmapper.net.

Operator	Bands	Downlink frequency (MHz)
Telia	4G	806, 1815, 1832, 2660
	3G	2152, 2157
	2G	950
Telenor	4G	936, 1857, 2630, 2680
	3G	2112, 2122
Tele2	4G	936, 1857, 2630, 2680
	3G	2152, 2157, 2162

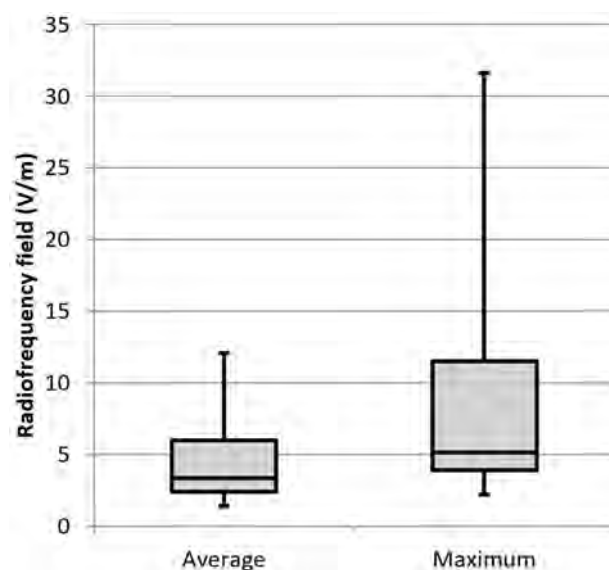


Fig. 1. Boxplot of spatial distribution of the radiofrequency field (V m^{-1}) at Skeppsbron street, based on quadrat measurements covering the entire area; sample is based on spatial averages and maximums of a quadrat cells; boxplot depicts (from bottom up) minimum, first quartile, median, third quartile and maximum of the sample containing all the spatial measurement values in the area.

in Skeppsbron street is covered with relatively high levels of radio-frequency radiation.

Fig. 2 displays a spatial distribution of the RF field at the Skeppsbron street. Exposure readings are based on spatial average of a given quadrat cell. High field levels are encountered close to the base station antennas, whereas the highest levels were not detected below the antenna, but at 26 m distance, directly on the line of the direction of sector antenna. The field decreases with increasing distance from the base station array, but is still significantly elevated at the entire 250 m length of the studied street area.

Highest field levels as registered across the street, may also refer to confounding action of building walls, as some building materials may reflect the incident waves, hence giving rise to resultant exposure level (Koppel et al., 2017a). Also the weather can play a role in microwave propagation as wet walls may increase building material microwave reflection properties (Koppel et al., 2017b).

Exposimeter measurements (mean of sample) showed that the majority of exposure was due to mobile phone downlink bands. Most dominant were 2600 and 2100 MHz bands used by 4G and 3G mobile phone services, respectively. Also 800, 900 and 1800 MHz bands were clearly elevated in the frequency spectrum, which fits the 4G profile (Table 2). The exposimeter was unable to register the highest exposure levels as the upper detection limit was exceeded repeatedly. Therefore, FM, as well as 1800 MHz, 2100 MHz, and 2600 MHz downlinks were not properly evaluated by the exposimeter measurements. Meanwhile, broadband meter measurements were able to register also the highest levels.

Table 3 compares public exposure to radiofrequency fields in Stockholm, based on authors' studies – comparing this study at Skeppsbron street to previous measurements. Comparison is done based only on exposimeter (EME Spy 200) measurements, excluding broadband meter measurements. RF field comparison reveals that Skeppsbron street is one of the highest public exposure areas in Stockholm so far measured with the maximum field level exceeding upper detection limit of the exposimeter.

Figs. 3 and 4 are photographs of the street view with some of the mobile phone base station antennas pointed out. The antennas are placed quite low, near the street level, where microwaves irradiate



Fig. 2. Spatial distribution of the radiofrequency field (values in $V\ m^{-1}$) at Skeppsbron street, based on spatial average of a given quadrat cell; hotspots are displayed in darker red where pedestrians are exposed at close range or rays overlap from several mobile phone base station antennas; the investigated area measures about 250 m North to South; map by Lantmäteriet, Sweden. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 2

Exposimeter measurements of the radiofrequency field at Skeppsbron street, analysis of all data ($\mu W\ m^{-2}$) treating values at detection limit as 0. (Note: Exposimeter's highest detection limit ($95,522.5\ \mu W\ m^{-2}$) was constantly exceeded, therefore Max-values are likely to be much higher, as also confirmed by broadband measurements.) Total (n = 915).

Frequency band	Mean	Median	Min	Max
FM	1304.0	19.6	0.0	95,522.5
TV3	7.2	0.0	0.0	1601.4
TETRA I	0.0	0.0	0.0	1.0
TETRA II	0.0	0.0	0.0	4.7
TETRA III	2.3	0.0	0.0	403.4
TV4&5	17.4	0.6	0.0	2434.4
800 (DL)	751.3	164.5	0.7	12,978.6
800 (UL)	0.0	0.0	0.0	6.6
900 (UL)	0.0	0.0	0.0	8.6
900 (DL)	2545.3	926.5	0.4	35,473.9
1800 (UL)	71.0	8.3	0.0	3291.8
1800 (DL)	3466.6	714.5	3.6	95,522.5
DECT	367.6	0.0	0.0	36,548.9
2100 (UL)	0.1	0.0	0.0	45.5
2100 (DL)	6558.8	1237.4	1.7	95,522.5
WIFI 2G	0.4	0.0	0.0	61.3
2600 (UL)	689.5	154.1	0.0	17,275.1
2600 (DL)	11,338.3	3483.6	1.7	95,522.5
WIMax	0.2	0.0	0.0	58.9
WIFI 5G	0.4	0.0	0.0	93.8
Total	27,120.5	10,481.5	24.4	373,381.0

Table 3

Public exposure to radiofrequency field in Stockholm – this study compared authors' previous studies; exposimeter EME Spy 200 measurements; analysis of all data ($\mu W\ m^{-2}$) treating values at detection limit as 0.

Study	Total (n)	Mean	Median	Min	Max
Stockholm, Central Station (Hardell et al., 2016)	1669	3860.2	920.6	5.8	9206.3
Stockholm, Old Town (Hardell et al., 2017)	10,437	4292.7	534.0	0.0	173,301.8
Stockholm, City (Carlberg et al., 2019)	11,482	5494.2	3346.0	36.6	205,154.8
Stockholm, Järntorget, Old Town (Hardell et al., 2019)	792	21,354.9	12,655.3	381.7	178,928.2
Stockholm, Skeppsbron (current study)	915	27,120.5	10,481.5	24.4	373,381.0



Fig. 3. Street view on the Skeppsbron street with some of the mobile phone base station antennas pointed out with a circle; note the low placement of the antennas, where microwaves irradiate the pedestrian at close range.

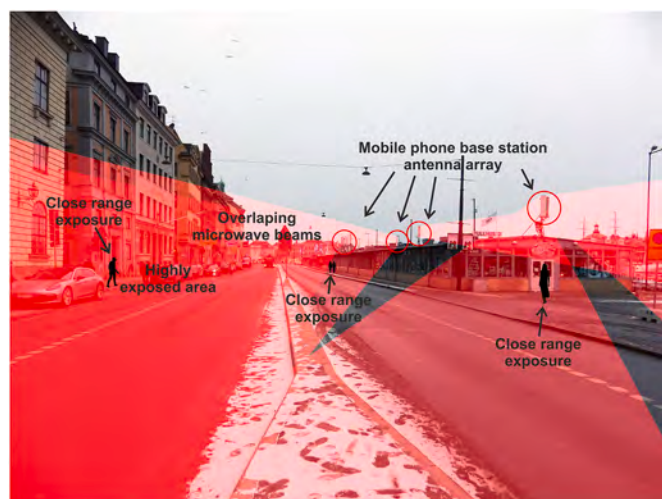


Fig. 4. Problem context of mobile phone base station antennas created high exposure at Skeppsbron street; altogether 15 antenna panels could be counted on that building, all positioned at low elevation close to the street level; the maximum RF exposure was at $31.6\ V\ m^{-1}$, registered at close range to the antennas.



Fig. 5. The antennas are mostly facing the buildings, as the operators want to force the wave into the old town through the narrow streets. Considering the low placement of antennas and pushing all this power - creates very high exposure levels nearby.

pedestrians at close range. Fig. 5 depicts the context – very low placement of the antennas, most of which are targeting the buildings in order to push the microwave into the narrow streets and further into the old town.

4. Discussion

This study, and our previous ones, have recorded the exposure to RF radiation which will provide means for historic comparison for both public and occupational exposure. It is clear from our current study and the previous ones that the level of ambient RF radiation exposure is increasing, see Table 3. Public exposure in different places around the globe is shown in Table 4. Our average and peak RF measurement results are much higher than many of those measurements in that table, indicating a rather recent and rapid increase in radiofrequency radiation levels in city centers. To provide comparison, Bergqvist et al. (2001) measured 0.18 mW m^{-2} highest average levels in Stockholm city center in 2001 (Bergqvist et al., 2001). Swedish radiation protection authorities pointed out recently highest average levels like 720 mW m^{-2} at Järntorget (Estenberg, 2020) and 690 mW m^{-2} at Skeppsbron area (Umeå kommun 2019) in Stockholm. One possible reason for our high RF readings in 2019 was the upgrade of 4G (LTE) base stations with new antenna panels including more antenna elements for the forthcoming 5G (which started officially in Stockholm in 2020). With the development of mobile communications technologies and the widespread use of wireless services the exposure will continue to increase with substantially higher exposure levels and also ever increasing frequency bands, even though several research reports indicate health risks. These risks are relevant to those people working or living in the highly exposed places – in this study they are 1) people living in the apartments across the street from the antennas, 2) workers of the shops across the street and beneath the antennas.

This research identified an increased RF exposure risk area in the center of Stockholm city. Clearly we measured high RF radiation levels of the same magnitude at a square (Järntorget) in the old town (Hardell et al., 2019). These results may be compared with the Ramazzini Institute rat study on far field exposure to 1.8 GHz RF radiation of 0, 5, 25, 50 V m^{-1} with a whole-body exposure for 19 h/day similar to that from base stations (Falcioni et al., 2018). Increased incidence of glioma and heart tumours of the Schwannoma type were found, i.e. similar tumour types as found among people using wireless phones. A statistically significant increase in the incidence of malignant Schwannoma in the heart was found in male rats at the highest dose, 50 V m^{-1} corresponding to whole-body SAR of 0.1 W/kg . Increased non-significant incidence of heart Schwann cells hyperplasia was observed in exposed male and

Table 4
Public exposure to radiofrequency fields at different places.

Study	Investigated locations	Exposure (mean)
Joseph et al. (2010)	Europe, outdoor	$372\text{--}569 \text{ }\mu\text{W m}^{-2}$
Bolte et al. (2011)	Netherlands, railway stations	$304\text{--}354 \text{ }\mu\text{W m}^{-2}$
Bolte and Eikelboom (2012)	Netherlands, outdoor activities	$208 \text{ }\mu\text{W m}^{-2}$
Rowley and Joyner (2012)	23 countries	$730 \text{ }\mu\text{W m}^{-2}$
Urbiniello et al. (2014)	Europe, Basel, Ghent, Brussels	$271\text{--}892 \text{ }\mu\text{W m}^{-2}$
Verloock et al. (2014)	Belgium, public places	$1020 \text{ }\mu\text{W m}^{-2}$
Estenberg and Augustsson (2014)	Stockholm city, Sweden	$6700 \text{ }\mu\text{W m}^{-2}$
	Sweden, urban	$1500 \text{ }\mu\text{W m}^{-2}$
	Sweden, rural	$230 \text{ }\mu\text{W m}^{-2}$
Calvente et al. (2015)	Spain, Granada	$799 \text{ }\mu\text{W m}^{-2}$
Gonzalez-Rubio et al. (2016)	Spain, Albacete	$4.2\text{--}2102 \text{ }\mu\text{W m}^{-2}$
Choudhary and Vijay (2017)	India, Kota city residential	$5452\text{--}77,840 \text{ }\mu\text{W m}^{-2}$
	industrial, commercial	$2386\text{--}68,769 \text{ }\mu\text{W m}^{-2}$
	agricultural	$2378\text{--}68,724 \text{ }\mu\text{W m}^{-2}$
	rural	$1878\text{--}68,724 \text{ }\mu\text{W m}^{-2}$
Sánchez-Montero et al. (2017)	Spain, Alcalá de Henares	2006: 0.278 V m^{-1} (205 $\mu\text{W m}^{-2}$) 2010: 0.407 V m^{-1} (439 $\mu\text{W m}^{-2}$) 2015: 0.396 V m^{-1} (416 $\mu\text{W m}^{-2}$)
Thielsen et al. (2018)	Australia, Melbourne	$0.05\text{--}0.89 \text{ V m}^{-1}$ ($6\text{--}2101 \text{ }\mu\text{W m}^{-2}$)
Misek et al. (2018)	Ziina city, center	1.072 V m^{-1} (3048 $\mu\text{W m}^{-2}$)
	residential	1.852 V m^{-1} (9097 $\mu\text{W m}^{-2}$)
	rural	0.510 V m^{-1} (690 $\mu\text{W m}^{-2}$)
	Visnove, rural	0.093 V m^{-1} (23 $\mu\text{W m}^{-2}$)
Eeftens et al. (2018)	Europe, 5 countries	$150\text{--}160 \text{ }\mu\text{W m}^{-2}$
Zelege et al. (2018)	Australia, Melbourne	0.233 V m^{-1} (144 $\mu\text{W m}^{-2}$)
Christopoulou and Karabetsos (2019)	Greece, urban	0.244 V m^{-1} (158 $\mu\text{W m}^{-2}$)
	Greece, suburban	0.229 V m^{-1} (139 $\mu\text{W m}^{-2}$)

female rats at the highest dose. In irradiated female rats at the highest dose (50 V m^{-1}) the incidence of malignant glial tumours was increased, although not statistically significant. In the current study maximum exposure level of 31.6 V m^{-1} was measured. Thus, there is no reasonable safety limit comparing with the animal study.

Electromagnetic fields are a physical risk factor. However, current legislation does not require the mobile phone services operator to ask for approval from neighboring inhabitants, when installing RF sources. Nevertheless, when mobile phone base station antennas are installed, the immediate physical environment, including the neighborhood living environment is greatly altered by the microwaves.

Studies from recent decades have shown elevated health risk under long term exposure to such highly elevated radiofrequency fields.

A review by [Khurana et al. \(2010\)](#) found in 80% of the available studies neurobehavioral symptoms or cancer in populations living at distances <500 m from base stations ([Khurana et al., 2010](#)). In another review exposure from base stations and other antenna arrays showed changes in immunological and reproductive systems as well as DNA double strand breaks, influence on calcium movement in the heart and increased proliferation rates in human astrocytoma cancer cells ([Levitt and Lai, 2010](#)).

When a GSM 900 MHz base station was installed in the village Rimbach in Germany it had an influence on the neurotransmitters adrenaline, noradrenaline, dopamine and phenylethylamine ([Buchner and Eger, 2011](#)). Influence on cortisol and thyroid hormones in people living near base stations was shown in other studies ([Augner et al., 2010](#); [Eskander et al., 2012](#)).

[Dode et al. \(2011\)](#) compared base station (BS) clusters and cases of deaths by neoplasia in the Belo Horizonte municipality, Minas Gerais state, Brazil, from 1996 to 2006. In their study largest electric field was 12.4 V m^{-1} and the smallest was 0.4 V m^{-1} . They found cancer-related death rates be higher close to base stations. This finding confirmed earlier findings by [Eger et al., 2004](#).

In a study from India, genetic damage using the single cell gel electrophoresis (comet) assay was assessed in peripheral blood leukocytes of individuals residing in the vicinity of a mobile phone base station and comparing it to that in healthy controls. Genetic damage parameters of DNA migration length, damage frequency, and damage index were significantly ($p < 0.001$) elevated in the sample group compared to respective values in healthy controls ([Gandhi et al., 2014](#)).

The effect of RF radiation among 20 subjects living close to mobile phone base station compared with 20 subjects living with a distance of about 1 km was studied ([Singh et al., 2016](#)). The authors concluded that: *"It was unveiled that a majority of the subjects who were residing near the mobile base station complained of sleep disturbances, headache, dizziness, irritability, concentration difficulties, and hypertension. A majority of the study subjects had significantly lesser stimulated salivary secretion ($p < 0.01$) as compared to the control subjects."*

[Zothansiam et al. \(2017\)](#) in India inspected DNA damage and antioxidant status in cultured human peripheral blood lymphocytes (HPBLs) of individuals residing in the vicinity of mobile phone base stations and compared it with healthy controls living further away. The analyses of data from the exposed group ($n = 40$), residing within a perimeter of 80 m of mobile base stations, showed statistically significantly ($p < 0.0001$) higher frequency of micronuclei when compared to the control group, residing 300 m away from the mobile base stations.

The Ramazzini Institute findings ([Falcioni et al., 2018](#)) are supported by the results in the USNTP study on rats and mice exposed to RF radiation ([National Toxicology Program, 2018a, 2018b](#)). A clear evidence of increased incidence of heart Schwannoma and some evidence for glioma and tumours in the adreanal medulla in male rats was found according to the expert panel, for further discussion see [Hardell and Carlberg \(2019\)](#).

4.1. Health risks associated with mobile phone radiation

RF radiation was in 2011 classified as a possible human carcinogen, Group 2B by the International Agency for Research on Cancer (IARC) at the WHO ([Baan et al., 2011](#); [IARC Working Group, 2013](#)). After that the evidence on cancer risk has increased so that RF radiation may now be classified as a human carcinogen, Group 1 according to the IARC

classification ([Carlberg and Hardell, 2017](#)).

By now there is concordance between tumours in human epidemiology ([Belpomme et al., 2018](#); [Miller et al., 2018](#)) and animal studies ([Falcioni et al., 2018](#); [National Toxicology Program, 2018a, 2018b](#)), that is glioma and Schwann cell tumours. These results are supported by mechanistic studies such as oxidative stress ([Yakymenko et al., 2016](#)) and DNA damage from RF radiation ([Smith-Roe et al., 2020](#)).

So far personal use of wireless phones, mobile and cordless phones (DECT), have yielded highest RF radiation exposure especially to children and to the brain ([Gandhi et al., 2012](#)). However, ambient exposure is of increasing concern and may now be of the same magnitude as for increasing cancer incidence in animal studies. This is exemplified in this study.

The [BioInitiative Report \(2012\)](#) defines a target level of $30\text{--}60 \mu\text{W m}^{-2}$, and for chronic exposure and sensitive people such as children one tenth of this, $3\text{--}6 \mu\text{W m}^{-2}$, see Chapter 24 of the BioInitiative Report ([Sage, and Carpenter, 2012](#)).

Already in 2011 Yakymenko et al. stated that: *It is now becoming increasingly evident that assessment of biological effects of non-ionizing radiation based on physical (thermal) approach used in recommendations of current regulatory bodies, including the International Commission on Non-Ionizing Radiation Protection (ICNIRP) Guidelines, requires urgent reevaluation* ([Yakymenko et al., 2011](#)).

This view is supported by 252 EMFscientists from 43 nations www.emfscientist.org:

"Numerous recent scientific publications have shown that EMF [electromagnetic field] affects living organisms at levels well below most international and national guidelines. Effects include increased cancer risk, cellular stress, increase in harmful free radicals, genetic damages, structural and functional changes of the reproductive system, learning and memory deficits, neurological disorders, and negative impacts on general well-being in humans. Damage goes well beyond the human race, as there is growing evidence of harmful effects to both plant and animal life."

5. Conclusions

This study has pointed out a highly exposed radiofrequency radiation area in the Stockholm city environment and identified the sources and reasons of high exposure. By positioning RF infrastructure to the proximity of the public the risk of health effects is increased since members of the public on the street, also inhabitants in nearby buildings are highly exposed. Mobile phone base station antennas are positioned at the height of second floor levels of adjacent buildings spreading microwaves across the street. Highly elevated exposure levels would likely be encountered in the premises next to the windows facing the mobile phone base station array.

The study concluded that Skeppsbron street mobile phone base station antennas are examples of a poor radiofrequency infrastructure design with mobile phone base station antennas positioned into close range to the general public which brings upon high exposure levels. Given the low placement of the antennas (height from the street floor), the highest exposure was often registered at pedestrian head level. Given that head is one of most vulnerable parts of the body, these placements by mobile telephony service providers put pedestrians into unnecessary risk. Position of these antennas, can pose a health risk to people at close range. This is especially critical for people at particular risk, including persons with medical implants, pregnant women or chronically ill persons.

Based on the latest scientific literature regarding RF exposure and adverse health effects, this study recommends repositioning such base station antennas to areas away from the nearby inhabitants, workers and the general public. Alternatively, very low power antennas may also be considered to reduce the exposure. Occupational exposure of people

working close to the antennas should also be considered – shop clerks, restaurant workers are likely to spend considerably longer time under high exposure, compared to the general public.

The following recommendations for radiofrequency infrastructure can be concluded from the current study.

1. Antennas should be positioned as far as possible from the general public, like locations at the high elevations or remote areas, where the antenna targeted area is not regularly/frequently visited by the members of the public.
2. Only low power output mobile phone base station antennas (<15W) should be used in the city environment.
3. To avoid hotspots, created by overlapping arrays, dense packing of many antennas at one site should be avoided.
4. Low power output antennas in the city environment should be positioned into locations where direct beam would not hit members of public closer than 50m.

The conclusions of this study will help to design safer mobile phone base station sites in the city environment, when the aim is to minimize public exposure.

Author contributions

T.K. and M.A. performed the measurements. Conception of the study, design and analyses of the material, writing of the article and approval of the final manuscript was made by all authors.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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COMMENT

Health risks from radiofrequency radiation, including 5G, should be assessed by experts with no conflicts of interest

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Abstract. The fifth generation, 5G, of radiofrequency (RF) radiation is about to be implemented globally without investigating the risks to human health and the environment. This has created debate among concerned individuals in numerous countries. In an appeal to the European Union (EU) in September 2017, currently endorsed by >390 scientists and medical doctors, a moratorium on 5G deployment was requested until proper scientific evaluation of potential negative consequences has been conducted. This request has not been acknowledged by the EU. The evaluation of RF radiation health risks from 5G technology is ignored in a report by a government expert group in Switzerland and a recent publication from The International Commission on Non-Ionizing Radiation Protection. Conflicts of interest and ties to the industry seem to have contributed to the biased reports. The lack of proper unbiased risk evaluation of the 5G technology places populations at risk. Furthermore, there seems to be a cartel of individuals monopolizing evaluation committees, thus reinforcing the no-risk paradigm. We believe that this activity should qualify as scientific misconduct.

Introduction

Most politicians and other decision-makers using guidelines for exposure to radiofrequency (RF) radiation seem to ignore the risks to human health and the environment. The fact that the International Agency for Research on Cancer (IARC) at

the World Health Organization (WHO) in May 2011 classified RF radiation in the frequency range of 30 kHz to 300 GHz to be a 'possible' human carcinogen, Group 2B (1,2), is being ignored. This has been recently exemplified in a hearing at the Tallinn Parliament in Estonia (3).

An important factor may be the influence on politicians by individuals and organizations with inborn conflicts of interests (COIs) and their own agenda in supporting the no-risk paradigm (4,5). The International Commission on Non-Ionizing Radiation Protection (ICNIRP) has repeatedly ignored scientific evidence on adverse effects of RF radiation to humans and the environment. Their guidelines for exposure are based solely on the thermal (heating) paradigm and were first published in ICNIRP 1998 (6), updated in ICNIRP 2009 (7) and have now been newly published in ICNIRP 2020 (8), with no change of concept, only relying on thermal effects from RF radiation on humans. The large amount of peer-reviewed science on non-thermal effects has been ignored in all ICNIRP evaluations (9,10). Additionally, ICNIRP has successfully maintained their obsolete guidelines worldwide.

COIs can be detrimental, and it is necessary to be as unbiased as possible when assessing health risks. There are three points that should be emphasized. Firstly, the evidence regarding health risks from environmental factors may not be unambiguous, and therefore informed judgements must be made. Furthermore, there are gaps in knowledge that call for experienced evaluations, and no conclusion can be reached without value judgements. Secondly, paradigms are defended against the evidence and against external assessments by social networks in the scientific community. Thirdly, the stronger the impact of decisions about health risks on economic, military and political interests, the stronger will stakeholders try to influence these decision processes.

Since the IARC evaluation in 2011 (1,2), the evidence on human cancer risks from RF radiation has been strengthened based on human cancer epidemiology reports (9-11), animal carcinogenicity studies (12-14) and experimental findings on oxidative mechanisms (15) and genotoxicity (16). Therefore, the IARC Category should be upgraded from Group 2B to Group 1, a human carcinogen (17).

The deployment of the fifth generation, 5G, of RF radiation is a major concern in numerous countries, with groups of citizens trying to implement a moratorium until thorough research

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Key words: Switzerland, European Union, World Health Organization, International Commission on Non-Ionizing Radiation Protection, Scientific Committee on Emerging and Newly Identified Health Risks, Swedish Radiation Safety Authority, 5G, electromagnetic field, appeals, moratorium, microwave radiation, radiofrequency electromagnetic field, health risks, non-ionizing radiation guidelines, conflicts of interest

on adverse effects on human health and the environment has been performed. An appeal for a moratorium, currently signed by >390 international scientists and medical doctors, was sent to the European Union (EU) in September 2017 (18), currently with no EU response (19). Several regions have implemented a moratorium on the deployment of 5G motivated by the lack of studies on health effects, for instance Geneva (20).

In the present article, the current situation in Switzerland is discussed as an example (21). Additionally, the ICNIRP 2020 evaluation is discussed (8).

Evaluation of health risks in Switzerland

Several Swiss citizens have brought to our attention that Associate Professor Martin Rösli is the chair of two important government expert groups in Switzerland (directeur), despite possible COIs and a history of misrepresentation of science (22,23). These groups are Beratende Expertengruppe NIS (BERENIS; the Swiss advisory expert group on electromagnetic fields and non-ionizing radiation) (24), and the subgroup 3, the Mobile Communications and Radiation Working Group of the Department of the Environment, Transport, Energy and Communications/Eidgenössisches Departement für Umwelt, Verkehr, Energie und Kommunikation, evaluating RF-radiation health risks from 5G technology (25,26).

The conclusions made in the recent Swiss government 5G report are biased and can be found here (27,28). This 5G report concluded that there is an absence of short-term health impacts and an absence or insufficient evidence of long-term effects [see Table 17 (Tableau 17) on page 69 in the French version (27) and Table 17 (Tabelle 17) on page 67 in the German version (28)].

Furthermore, it was reported that there is limited evidence for glioma, neurilemmoma (schwannoma) and co-carcinogenic effects, and insufficient evidence for effects on children from prenatal exposure or from their own mobile phone use. Regarding cognitive effects, fetal development and fertility (sperm quality), the judgement was that the evidence on harmful effects is insufficient. These evaluations were strikingly similar to those of the ICNIRP (see Appendix B in ICNIRP 2020; 8). Other important endpoints, such as effects on blood-brain barrier, cell proliferation, apoptosis (programmed cell death), oxidative stress (reactive oxygen species) and gene and protein expression, were not evaluated.

According to Le Courrier November 19, 2019, Martin Rösli presented the conclusion in an interview in the following way: *‘Sur l’aspect sanitaire pur, «le groupe de travail constate que, jusqu’à présent, aucun effet sanitaire n’a été prouvé de manière cohérente en dessous des valeurs limites d’immissions fixées», résume Martin Rösli, professeur d’épidémiologie environnementale à l’Institut tropical et de santé publique suisse’* (29). [Regarding the health issue, the working group concludes that, until now, no health effect has been consistently proven below the given exposure limits, summarizes Martin Rösli, professor in environmental epidemiology at the Swiss Tropical and Public Health Institute].

This Swiss evaluation is scientifically inaccurate and is in opposition to the opinion of numerous scientists in this field (18). In addition, 252 electromagnetic field (EMF) scientists from 43 countries, all with published peer-reviewed

research on the biologic and health effects of nonionizing electromagnetic fields (RF-EMF) have stated that:

‘Numerous recent scientific publications have shown that RF-EMF affects living organisms at levels well below most international and national guidelines. Effects include increased cancer risk, cellular stress, increase in harmful free radicals, genetic damages, structural and functional changes of the reproductive system, learning and memory deficits, neurological disorders, and negative impacts on general well-being in humans. Damage goes well beyond the human race, as there is growing evidence of harmful effects to both plant and animal life’ (30).

We are concerned that the Swiss 5G report may be influenced by ties to mobile phone companies (COIs) by one or several members of the evaluating group.

COIs

Funding from telecom companies is an obvious COI. Martin Rösli has been a member of the board of the telecom funded Swiss Research Foundation for Electricity and Mobile Communication (FSM) organization and he has received funding from the same organization (31-33).

It should be noted that the FSM is a foundation that serves formally as an intermediate between industry and researchers. According to their website, among the five founders of FSM who *‘provided the initial capital of the Foundation’* four are telecommunications companies: Swisscom, Salt, Sunrise, 3G Mobile (liquidated in 2011). The fifth founder is ETH Zurich (technology and engineering university). There are only two sponsors, Swisscom (telecommunications) and Swissgrid (energy), who *‘support the FSM with annual donations that allow for both the management of the Foundation and research funding’* (34).

The same situation applies to being a member of ICNIRP (Table I) (35). In 2008, the Ethical Council at Karolinska Institute in Stockholm stated that being a member of ICNIRP is a potential COI. Such membership should always be declared. This verdict was based on activities by Anders Ahlbom in Sweden, at that time a member of ICNIRP, but is a general statement (2008-09-09; Dnr, 3753-2008-609). In summary: *‘It is required that all parties clearly declare ties and other circumstances that may influence statements, so that decision makers and the public may be able to make solid conclusions and interpretations. AA [Anders Ahlbom] should thus declare his tie to ICNIRP whenever he makes statements on behalf of authorities and in other circumstances’* (translated into English).

COIs with links to industry are of great importance; these links may be direct or indirect funding for research, payment of travel expenses, participation in conferences and meetings, presentation of research, etc. Such circumstances are not always declared as exemplified above. A detailed description was recently presented for ICNIRP members (22).

ICNIRP

ICNIRP is a non-governmental organization (NGO) based in Germany. Members are selected via an internal process, and the organization lacks transparency and does not represent the

Table I. Members of the WHO core group and additional experts of the Environmental Health Criteria Document 2014 (54), EU SCENIHR 2015 (52), the SSM 2015-2020 (93) and ICNIRP commission or the Scientific Expert Group 1992-2020 (94).

Members	WHO, 2014	SCENIHR, 2015	SSM, 2015-2020	ICNIRP, 1992-2020
Emilie van Deventer	X		X	X ^a
Simon Mann	X			X
Maria Feychting	X		(X) ^b	X
Gunnhild Oftedal	X			X
Eric van Rongen	X		X	X
Maria Rosaria Scarfi	X	X	X	X
Jukkka Juutilainen	X			X
Denis Zmirou	X			
Theodoros Samaras		X		
Norbert Leitgeb		X		
Anssi Auvinen		X		X
Heidi Danker Hopfe		X	X	
Kjell Hansson Mild		X		
Mats Olof Mattsson		X		X
Hannu Norppa		X		
James Rubin	X	X		
Joachim Schüz		X		
Zenon Sienkiewicz	X	X		X
Olga Zeni	X	X		
Anke Huss			X	X ^c
Clemens Dasenbrock			X	X
Lars Klæboe			X	
Martin Rösli	X		X	X
Aslak Harbo Poulsen			X	

^aWHO Observer in the main commission (95); ^b2002-2011; ^c2020-2024. The table is based on members of WHO, SCENIHR and SSM during the defined time period(s). No other individuals among those within WHO or SCENIHR were found in the list of SSM participants. A total of 15 additional experts in WHO were not members of SCENIHR, SSM or ICNIRP. SCENIHR, Scientific Committee on Emerging and Newly Identified Health Risks; SSM, Swedish Radiation Safety Authority; WHO, World Health Organization; EU, European Union; ICNIRP, International Commission on Non-Ionizing Radiation Protection.

opinion of the majority of the scientific community involved in research on health effects from RF radiation. Independent international EMF scientists in this research area have declared that: *'In 2009, the ICNIRP released a statement saying that it was reaffirming its 1998 guidelines, as in their opinion, the scientific literature published since that time has provided no evidence of any adverse effects below the basic restrictions and does not necessitate an immediate revision of its guidance on limiting exposure to high frequency electromagnetic fields. ICNIRP continues to the present day to make these assertions, in spite of growing scientific evidence to the contrary. It is our opinion that, because the ICNIRP guidelines do not cover long-term exposure and low-intensity effects, they are insufficient to protect public health'* (30).

ICNIRP only acknowledges thermal effects from RF radiation. Therefore, the large body of research on detrimental non-thermal effects is ignored. This was further discussed in a peer-reviewed scientific comment article (3).

In 2018, ICNIRP published *'ICNIRP Note: Critical Evaluation of Two Radiofrequency Electromagnetic Field Animal Carcinogenicity Studies Published in 2018'* (36). It is

surprising that this note claims that the histopathological evaluation in the US National Toxicology Program (NTP) study on animals exposed to RF radiation was not blinded (12,13). In fact, unfounded critique of the NTP study had already been rebutted (37); however, this seems to have had little or no impact on this ICNIRP note casting doubt on the findings of the animal study: *'This commentary addresses several unfounded criticisms about the design and results of the NTP study that have been promoted to minimize the utility of the experimental data on RFR [radiofrequency radiation] for assessing human health risks. In contrast to those criticisms, an expert peer-review panel recently concluded that the NTP studies were well designed, and that the results demonstrated that both GSM- and CDMA-modulated RFR were carcinogenic to the heart (schwannomas) and brain (gliomas) of male rats'* (37).

In contrast to the opinion of the 13 ICNIRP commission members, the IARC advisory group of 29 scientists from 18 countries has recently stated that the cancer bioassay in experimental animals and mechanistic evidence warrants high priority re-evaluation of the RF radiation-induced carcinogenesis (38).

ICNIRP draft. On July 11, 2018, ICNIRP released a draft on guidelines (39) for limiting exposure to time-varying electric, magnetic and electromagnetic fields (100 kHz to 300 GHz). It was open for public consultations until October 9, 2018. Appendix B was based on assessment of health risks based on a literature survey (39).

Surprisingly, the IARC classification of RF-EMF exposure as Group 2B ('possibly' carcinogenic to humans) from 2011 was concealed in the background material to the new ICNIRP draft on guidelines. Notably, one of the ICNIRP commission members, Martin Rösli (40), was also one of the IARC experts evaluating the scientific RF carcinogenicity in May 2011 (41). He should be well aware of the IARC classification. The IARC classification contradicts the scientific basis for the ICNIRP guidelines, making novel guidelines necessary and providing a basis to halt the rollout of 5G technology.

Therefore, the ICNIRP provides scientifically inaccurate reviews for various governments. One issue is that only thermal (heating) effects from RF radiation are considered, and all non-thermal effects are dismissed. An analysis from the UK demonstrates these inaccuracies (4), also discussed in another article (5). All members of the ICNIRP commission are responsible for these biased statements that are not based on solid scientific evidence.

ICNIRP release of novel guidelines for RF radiation. On March 11, 2020, ICNIRP published their novel guidelines for exposure to EMFs in the range of 100 kHz to 300 GHz, thus including 5G (8). The experimental studies demonstrating a variety of non-thermal biological/health effects (9,10) are not considered, as in their previous guidelines (6,7). Additionally, the ICNIRP increased the reference levels for the general public averaged over 6 min for RF frequencies >2-6 GHz (those that will be used for 5G in this frequency range), from 10 W/m² (Tables 5 and 7 in ref. no. 6) to 40 W/m² (Table 6 in ref. no. 8), which paves the way for even higher exposure levels to 5G than the already extremely high ones.

Background dosimetry is discussed in Appendix A of the ICNIRP 2020 guidelines (8). The discussion on 'Relevant Biophysical Mechanisms' should be criticized. The only mechanism considered by ICNIRP is temperature rise, which may also occur with 5G exposure, apart from the established non-thermal biological/health effects (42,43). It is well known among experts in the EMF-bioeffects field that the recorded cellular effects, such as DNA damage, protein damage, chromosome damage and reproductive declines, and the vast majority of biological/health effects are not accompanied by any significant temperature rise in tissues (44-47). The ion forced-oscillation mechanism (48) should be referred to as a plausible non-thermal mechanism of irregular gating of electrosensitive ion channels on cell membranes, resulting in disruption of the cell electrochemical balance and initiating free radical release and oxidative stress in the cells, which in turn causes genetic damage (15,49). The irregular gating of ion channels on cell membranes is associated with changes in permeability of the cell membranes, which ICNIRP admits in its summary (8).

Health risks are discussed in Appendix B of the ICNIRP 2020 guidelines (8). Again, only thermal effects are considered, whereas literature on non-thermal health consequences

is disregarded (9,10,50). In spite of public consultations on the draft, the final published version on health effects is virtually identical to the draft version, and comments seem to have been neglected (19). In the following section, Appendix B on health effects (8) is discussed.

Appendix B starts with: '*The World Health Organization (WHO) has undertaken an in-depth review of the literature on radiofrequency electromagnetic fields (EMFs) and health, which was released as a Public Consultation Environmental Health Criteria Document in 2014... Further, the Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR), a European Commission initiative, also produced a report on potential health effects of exposure to electromagnetic fields (SCENIHR 2015), and the Swedish Radiation Safety Authority (SSM) have produced several international reports regarding this issue (SSM 2015, 2016, 2018). Accordingly, the present guidelines have used these literature reviews as the basis for the health risk assessment associated with exposure to radiofrequency EMFs rather than providing another review of the individual studies*'.

In the last 11 years since its previous ICNIRP 2009 statement (7), ICNIRP has not managed to conduct a novel evaluation of health effects from RF radiation. However, as shown in Table I, several of the present ICNIRP members are also members of other committees, such as the EU Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR), the Swedish Radiation Safety Authority (SSM) and the WHO, thus creating a cartel of individuals known to propagate the ICNIRP paradigm on RF radiation (4,5,22,51). In fact, six of the seven expert members of the WHO, including Emelie van Deventer, were also included in ICNIRP (5,7). Therefore, Emelie van Deventer, the team leader of the Radiation Programme at WHO (the International EMF Project), is an observer on the main ICNIRP commission, and SSM seems to be influenced by ICNIRP. Among the current seven external experts (Danker-Hopfe, Dasenbrock, Huss, Harbo Polusen, van Rongen, Rösli and Scarfi), five are also members of ICNIRP, and van Deventer used to be part of SSM.

As discussed elsewhere (5), it is unlikely that a person's evaluation of health risks associated with exposure to RF radiation would differ depending on what group the person belongs to. Therefore, by selecting group members, the final outcome of the evaluation may already be predicted (no-risk paradigm). Additionally, we believe that this may compromise sound scientific code of conduct.

The SCENIHR report from 2015 (52) has been used to legitimate the further expansion of the wireless technology and has been the basis for its deployment in a number of countries. One method, applied in the SCENIHR report, to dismiss cancer risks involves the selective inclusion of studies, excluding studies reporting cancer risks and including some investigations with inferior epidemiological quality. The report has been heavily criticized by researchers with no COI (53): '*In January of 2015, the Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) published its final opinion on (P)otential health effects of exposure to electromagnetic fields... SCENIHR has not answered the question it was appointed to investigate. The Committee has answered a*

different question, limiting its conclusions to whether certainty or causal effect is established, instead of possibility of health risks... Overall, SCENIHR has not conducted a scientific review process for judging possible health risks. This results in erroneous and deceptive conclusions by failing to conclude such possible health risks do exist. Evidence that SCENIHR has presented clearly and conclusively demonstrates that EMF health risks are possible, and in some cases are established. The Committee is obligated to draw to the attention of the European Commission that EMF is a new and emerging problem that may pose an actual or potential threat'.

Regarding the SSM, only yearly updates are available and no overall evaluations are made. Therefore, no thorough review is presented. Over the years, the ICNIRP has dominated this committee (Table I). Therefore, it is unlikely that the opinion of the SSM will differ from that of the ICNIRP.

In 2014, the WHO launched a draft of a Monograph on RF fields and health for public comments (54). It should be noted that the WHO issued the following statement: *'This is a draft document for public consultation. Please do not quote or cite'*. ICNIRP completely ignored that request and used the aforementioned document. The public consultations on the draft document were dismissed and never published.

In addition to van Deventer, five of the six members (Mann, Feychting, Oftedal, van Rongen, and Scarfi) of the Core Group in charge of the WHO draft were also affiliated with ICNIRP, which constitutes a COI (Table I). Scarfi is a former member of ICNIRP (5). Several individuals and groups sent critical comments to the WHO on the numerous shortcomings in the draft of the Monograph on RF radiation. In general, the WHO never responded to these comments and it is unclear to what extent, if any, they were even considered. Nevertheless, the final version of the WHO 'in-depth review' has never been published. Instead, WHO made a call on October 8, 2019 (Emelie van Deventer), for systematic reviews to analyze and synthesize the available evidence: *'Through this Call, WHO invites eligible teams to indicate their interest in undertaking a systematic review on one (or more) of the following topics: SR1 - Effect of exposure to RF on cancer (human observational studies); SR2 - Effect of exposure to RF on cancer (animal studies); SR3 - Effect of exposure to RF on adverse reproductive outcomes (human observational studies); SR4 - Effect of exposure to RF on adverse reproductive outcomes (animal and in vitro studies); SR5 - Effect of exposure to RF on cognitive impairment (human observational studies); SR6 - Effect of exposure to RF on cognitive impairment (human experimental studies); SR7 - Effect of exposure to RF on symptoms (human observational studies); SR8 - Effect of exposure to RF on symptoms (human experimental studies); SR9 - Effect of exposure to RF on biomarkers of oxidative stress; SR10 - Effect of exposure to heat from any source and pain, burns, cataract and heat-related illness'.*

The authors of the present article were part of a team that applied to review SR1- human cancer. On December 20, 2019, the following reply was received from the WHO Radiation Programme: *'After careful review, we have decided to choose another team for this systematic review'*.

Transparency is of importance for the whole process. Therefore, a query was sent to the WHO requesting informa-

tion regarding the following points: *'Who did the evaluation of the groups that answered the call? What criteria were applied? How many groups had submitted and who were these? Which groups were finally chosen for the different packages?'*. In spite of sending the request four times, January 2, January 3, April 7 and April 30, 2020, there has been no reply from WHO. This appears to be a secret process behind closed doors. These circumstances have also been reported in Microwave News (55).

It is important to comment on the current ICNIRP evaluation. Notably, on February 27, 2020, two weeks before the ICNIRP publication, the WHO Team on Public Health, Environmental and Social Determinants of Health issued a statement on 5G mobile networks and health: *'To date, and after much research performed, no adverse health effect has been causally linked with exposure to wireless technologies'* (56). This statement is not correct based on current knowledge (4,5,9-11,17,19) and was without a personal signature. The lack of research on 5G safety has been previously discussed (19). Furthermore, there is no evidence that can 'causally link' an adverse effect to an exposure. Causality is no empirical fact, it is an interpretation.

In the following section, only one (cancer) of the eight different end points in the ICNIRP publication (8) is discussed, since it deals with our main research area.

viii) Cancer.

'In summary, no effects of radiofrequency EMFs on the induction or development of cancer have been substantiated.'

Summary

The only substantiated adverse health effects caused by exposure to radiofrequency EMFs are nerve stimulation, changes in the permeability of cell membranes, and effects due to temperature elevation. There is no evidence of adverse health effects at exposure levels below the restriction levels in the ICNIRP (1998) guidelines and no evidence of an interaction mechanism that would predict that adverse health effects could occur due to radiofrequency EMF exposure below those restriction levels'.

Comments

The ICNIRP draft (39) has been previously described to some extent (19). The published final version on health effects is virtually similar to the draft. It cannot be taken at face value as scientific evidence of no risk from RF radiation. One example is the following statement (p. 41): *'...a set of case-control studies from the Hardell group in Sweden report significantly increased risks of both acoustic neuroma and malignant brain tumors already after less than five years since the start of mobile phone use, and at quite low levels of cumulative call time'*.

This allegation is not correct according to our publication for glioma (11). In the shortest latency group >1-5 years, the risk of glioma was not increased (odds ratio (OR), 1.1; 95% CI, 0.9-1.4) for use of wireless phones (mobile phone and/or cordless phone). There was a statistically significant increased risk of glioma per 100 h of cumulative use (OR, 1.011; 95% CI, 1.008-1.014) and per year of latency (OR, 1.032; 95% CI,

1.019-1.046) (11). These published results are in contrast to the ICNIRP claims.

Regarding acoustic neuroma, the corresponding detailed results are reported in our previous study (57). The shortest latency period >1-5 years yielded an OR of 1.2 (95% CI, 0.8-1.6) for use of wireless phones; the risk increased per 100 h of cumulative use (OR, 1.008; 95% CI, 1.002-1.014) and per year of latency (OR, 1.056; 95% CI, 1.029-1.085) (57). Therefore, the allegation by ICNIRP is false.

It is remarkable that ICNIRP is uninformed and that their writing is based on a misunderstanding of the peer-reviewed published articles as exemplified above. Additionally, our studies (11,57) and another study by Coureau *et al* (58), as well as the IARC evaluation from 2011 (1,2), are not included among the references. Several statements by ICNIRP are made without any scientific references. On the other hand, the Danish cohort study on mobile phone use (59) is included, in spite of the fact that it was judged by IARC (1,2), as well as in our review (60), to be uninformative. A biased article written by authors including ICNIRP members, used to 'prove' the no-risk paradigm for RF radiation carcinogenesis (23), is cited by ICNIRP. Notably, the article has not undergone relevant peer-review and we believe that it should not have been published in its current version. The shortcomings in the aforementioned article are discussed in the following sections. As discussed below, another claim (23) is incorrect regarding increased risk of brain tumors associated with use of wireless phones: *'However, they are not consistent with trends in brain cancer incidence rates from a large number of countries or regions, which have not found any increase in the incidence since mobile phones were introduced'*.

The criticism of the ICNIRP draft guidelines from 2018 by the EMF call (61) can also be applied to the current ICNIRP publication. The call has been signed by 164 scientists and medical doctors, as well as 95 NGOs: *'The International Commission on Non-Ionizing Radiation Protection (ICNIRP) issued draft Guidelines on 11th July 2018 for limiting exposure to electric, magnetic and electromagnetic fields (100 kHz to 300 GHz).1 These guidelines are unscientific, obsolete and do not represent an objective evaluation of the available science on effects from this form of radiation. They ignore the vast amount of scientific findings that clearly and convincingly show harmful effects at intensities well below ICNIRP guidelines.2 The guidelines are inadequate to protect humans and the environment. ICNIRP guidelines only protect against acute thermal effects from very short and intense exposure. The guidelines do not protect against harmful effects from low-intensity and long-term exposure, such as cancer, reproductive harm, or effects on the nervous system, although these effects are convincingly shown to appear from chronic exposure at intensities below ICNIRP limits.2,3*

ICNIRP's mandate to issue exposure guidelines needs to be seriously questioned. ICNIRP is not independent of industry ties as it claims.12,13 Its opinions are not objective, not representative of the body of scientific evidence, but are biased in favor of industry. It is obvious from their reluctance to consider scientific findings of harm that ICNIRP protects industry, not the public health, nor the environment.

We ask the United Nations, the World Health Organization, and all governments to support the development and consideration of medical guidelines16, that are independent of conflict of interests in terms of direct or indirect ties to industry, that represent the state of medical science, and that are truly protective'.

In the recent report on ICNIRP published by two Members of the European Parliament it is concluded: *'That is the most important conclusion of this report: For really independent scientific advice we cannot rely on ICNIRP. The European Commission and national governments, from countries like Germany, should stop funding ICNIRP. It is high time that the European Commission creates a new, public and fully independent advisory council on non-ionizing radiation'* (22).

Other examples of scientific misrepresentation

Published article. This section discusses an article with conclusions not substantiated by scientific evidence, representing a biased evaluation of cancer risks from mobile phone use and is an example of lack of objectivity and impartiality (23). The aforementioned report was used by ICNIRP 2020 (8) to validate that no risks have been found for brain and head tumors. Therefore, the article should be discussed in further detail.

The aforementioned article has numerous severe scientific deficiencies. One is that the results on use of cordless phones as a risk factor for brain tumors are not discussed. In fact, detailed results on cordless phones in studies by Hardell *et al* (11,57) are omitted.

When discussing glioma risk, all results on cumulative use of mobile phones, as well as ipsilateral or contralateral use associated with tumor localization in the brain, are omitted from the figures in the main text. Some results in the article by Rösli *et al* (23), such as cumulative use, can be found in the Supplementary Material, although the increased risk among heavy users is disregarded (11,57,58,62). In Supplementary Figure 4, all odds ratios regarding long-term (≥ 10 years) use of mobile phones are above unity (>1.0) for glioma and neuroma (23). No results are provided for ipsilateral mobile phone use (same side of tumor localization and mobile phone use), which is of large biological importance. Results on cumulative use, latency and ipsilateral use are especially important for risk assessment and have shown a consistent pattern of increased risk for brain and head tumors (11,57).

In the aforementioned article, recall bias is discussed as the reason for increased risk (23). The studies by Hardell *et al* (11,57) included all types of brain tumors. In one analysis, meningioma cases in the same study were used as the 'control' entity (11), and still a statistically significant increased risk of glioma was identified for mobile phone use (ipsilateral OR, 1.4; 95% CI, 1.1-1.8; contralateral OR, 1.0; 95% CI, 0.7-1.4) and for cordless phone use (ipsilateral OR, 1.4; 95% CI, 1.1-1.9; contralateral OR, 1.1; 95% CI, 0.8-1.6). If the results were 'explained' by recall bias, similar results would have been obtained for both glioma and meningioma. Thus, this type of analyses would not have yielded an increased glioma risk. Also, for acoustic neuroma a statistically significant increased risk was found using meningioma cases as 'controls' (57). Therefore, the results in the studies by Hardell *et al* (11,57) cannot be explained by a systematic difference in assessment

of exposure between cases and controls. These important methodological findings were disregarded by Rösli *et al* (23).

In the analyses of long-term use of mobile phones, a Danish cohort study on mobile phone use is included (59), which was concluded to be uninformative in the 2011 IARC evaluation (1,2). A methodological shortcoming of the aforementioned study was that only private mobile phone subscribers in Denmark between 1982 and 1995 were included in the exposure group (59). The most exposed group, comprising 200,507 corporate users of mobile phones, were excluded and instead included in the unexposed control group consisting of the rest of the Danish population. Users with mobile phone subscription after 1995 were not included in the exposed group and were thus treated as unexposed at the time of cut-off of the follow up. No analysis of laterality of mobile phone use in relation to tumor localization was performed. Notably, this cohort study is now included in the risk calculations, although Martin Rösli was a member of the IARC evaluation group and should have been aware of the IARC decision. The numerous shortcomings in the Danish cohort study, discussed in detail in a peer-reviewed article (60), are omitted in the article by Rösli *et al* (23).

Regarding animal studies, a study by Falcioni *et al* (14) at the Ramazzini Institute on RF radiation carcinogenesis is only mentioned as a reference, but the results are not discussed. In fact, these findings (14) provide supportive evidence on the risk found in human epidemiology studies (3), as well as the results in the NTP study (12,13).

Furthermore, for incidence studies on brain tumors, the results are not presented in an adequate way. There is a lot of emphasis on the Swedish Cancer Register data (63,64), but the numerous shortcomings in the reporting of brain tumor cases to the register are not discussed. These shortcomings have been presented in detail in a previous study (63), but are disregarded by Rösli *et al* (23).

There is clear evidence from several countries regarding increasing numbers of patients with brain tumors, such as in Sweden (63,64), England (65), Denmark (66) and France (67).

The article by Rösli *et al* (23), does not represent an objective scientific evaluation of brain and head tumor risk associated with the use of wireless phones, and should thus be disregarded. By omitting results of biological relevance and including studies that have been judged to be uninformative, the authors come to the conclusion that there are no risks: *'In summary, current evidence from all available studies including in vitro, in vivo, and epidemiological studies does not indicate an association between MP [mobile phone] use and tumors developing from the most exposed organs and tissues'*.

Rösli *et al* (23), disregard the concordance of increased cancer risk in human epidemiology studies (11,57,58,62) animal studies (12-14,68,69) and laboratory studies (15,16,37). It is unfortunate that the review process of the aforementioned article has not been of adequate quality. Finally, there is no statement in the article of specific funding of this particular work, which is not acceptable. Only a limited number of comments on general funding are provided. It is not plausible that there was no funding for the study. We believe that, due to its numerous limitations, the aforementioned article should not have been published.

CEFALO. In 2011, a case-control study on mobile phone use and brain tumor risk among children and adolescents termed *CEFALO* was published (70). The study appears to have been designed to misrepresent the true risk, since the following question regarding cordless phone use was asked: *'How often did [child] speak on the cordless phone in the first 3 years he/she used it regularly?'*.

There are no scientific valid reasons to limit the investigation to the first 3 years. The result is a misrepresentation and a wrong exposure classification, since Aydin *et al* (70) willingly omitted any increase in the child's use of and exposure from cordless phone radiation after the first 3 years of use. This unscientific treatment of cordless phone exposure was not mentioned in the article other than in a footnote of a table and in the methods section (70); however, no explanation was provided: *'Specifically, we analyzed whether subjects ever used baby monitors near the head, ever used cordless phones, and the cumulative duration and number of calls with cordless phones in the first 3 years of use'*.

Since previous studies have demonstrated that these phone types, in addition to mobile phones, increase brain tumor risk (11,57), we believe that the exclusion of a complete exposure history on the use of cordless phones represents scientific misconduct.

In a critical comment the authors of the present study wrote: *'Further support of a true association was found in the results based on operator-recorded use for 62 cases and 101 controls, which for time since first subscription >2.8 years yielded OR 2.15 (95% CI 1.07-4.29) with a statistically significant trend (P = 0.001). The results based on such records would be judged to be more objective than face-to-face interviews, as in the study that clearly disclosed to the interviewer who was a case or a control. The authors disregarded these results on the grounds that there was no significant trend for operator data for the other variables - cumulative duration of subscriptions, cumulative duration of calls and cumulative number of calls. However, the statistical power in all the latter groups was lower since data was missing for about half of the cases and controls with operator-recorded use, which could very well explain the difference in the results'* (71).

Our conclusion was that: *'We consider that the data contain several indications of increased risk, despite low exposure, short latency period, and limitations in the study design, analyses and interpretation. The information certainly cannot be used as reassuring evidence against an association, for reasons that we discuss in this commentary'* (71).

This is in contrast to the authors that claimed that the study was reassuring of no risk in a press release from Martin Rösli, July 28, 2011: *'Kein erhöhtes Hirntumorrisiko bei Kindern und Jugendlichen wegen Handys... Die Resultate sind beruhigend'* [*'No increased brain tumour risk in children and adolescents for mobile phone users... The results are reassuring'*] (72).

A similar press release was issued by Maria Feychting at the Karolinska Institute in Stockholm stating: *'Reassuring results from first study on young mobile users and cancer risk... The so called CEFALO study does not show an increased brain tumor risk for young mobile users'* (73). Considering the results and the numerous scientific shortcomings in the study (70), the statements in these press releases are not correct.

Discussion

There is no doubt that several individuals included in Table I are influential, being members, as well as having consulting assignments, in several organizations, such as ICNIRP, BERENIS, the SSM, the Program Electromagnetic Fields and Health from ZonMw in the Netherlands, and the Rapid Response Group for the Japan EMF Information Center (74).

In fact, there appears to be a cartel of individuals working on this issue (75). Associate Professor Martin Rööslé has had the chance to provide his view on the content of the present article relating to him. The only message from him was in an e-mail dated January 16, 2020: *'Just to be clear, all my research is funded by public money or not-for-profit foundations [foundations]. I think you will not help an important debate if you spread fake news'*. Obviously, as described in the present article, his comment is not correct considering his funding from the telecom industry (76,77).

As shown in Table I, few individuals, and mostly the same ones, are involved in different evaluations of health risks from RF radiation and will thus propagate the same views on the risks in agencies of different countries associated with the ICNIRP views (4,5). Therefore, it is unlikely that they will change their opinions when participating in different organizations. Furthermore, their competence in natural sciences, such as medicine, is often low or non-existent due to a lack of education in these disciplines (2). Therefore, any chance for solid evaluations of medical issues is hampered. Additionally, it must be concluded that if the 'thermal only' dogma is dismissed, this will have wide consequences for the whole wireless community, including permissions for base stations, regulations of the wireless technology and marketing, plans to roll out 5G, and it would therefore have a large impact on the industry. This may explain the resistance to acknowledge the risk by ICNIRP, EU, WHO, SSM and other agencies. However, the most important aspects to consider are human wellbeing and a healthy environment. Telecoms can make profit in a variety of ways, and wireless is just one of them. They have the capacity to maintain profits by using different techniques, such as optical fiber, that will provide more data with less RF radiation exposure. Particularly when considering the liability, they are incurring in their misguided insistence of wireless expansion that may ultimately catch up to them in the form of lawsuits, such as those previously experienced by asbestos and tobacco companies (78,79).

A recent book describes how deception is used to capture agencies and hijack science (80). There are certain tools that can be used for this. One is to re-analyze existing data using methods that are biased towards predetermined results (23). For example, this can be performed by hiring 'independent experts' to question scientific results and create doubt (81,82). As clearly discussed in a number of chapters of the books (80-82), front groups may be created to gain access to politicians and to influence the public with biased opinions. Other methods may involve intimidating and harassing independent scientists that report health risks based on sound science, or removing all funding from scientists who do not adhere to the no-risk pro-industry paradigm. Another tool would be economic support and courting decision makers with special information sessions that mislead them on science and mask bribery (3,5,19,80-82).

An industry with precise marketing goals has a big advantage over a loose scientific community with little funding. Furthermore, access to regulatory agencies and overwhelming them with comments on proposed regulations is crucial (3). To counteract all these actions is time consuming and not always successful (19). Nevertheless, it is important that these circumstances are explored and published in the peer-reviewed literature as historical notes for future use.

Based on the Swiss and ICNIRP experiences, some recommendations can be made. One is to include only unbiased and experienced experts without COIs for evaluation of health risks from RF radiation. All countries should declare a moratorium on 5G until independent research, performed by scientists without any ties to the industry, confirms its safety or not. 2G, 3G, 4G and WiFi are also considered not to be safe, but 5G will be worse regarding harmful biological effects (42,83,84). The authors of the present article recommend an educational campaign to educate the public about the health risks of RF radiation exposure, and safe use of the technology, such as the deployment of wired internet in schools (85), as previously recommended by the European Council resolution 1815 in 2011 (86) and The EMF Scientist Appeal (87). Additionally, it is recommended that the government takes steps to markedly decrease the current exposure of the public to RF radiation, (88,89). Notably, DNA damage has been identified in peripheral blood lymphocytes using the comet assay technique, and in buccal cells using the micronucleus assay, in individuals exposed to RF radiation from base stations (90).

Finally, an alternative approach to the flawed ICNIRP safety standards may be the comprehensive work of the European Academy for Environmental Medicine (EUROPAEM) EMF working group that has resulted in safety recommendations, which are free from the ICNIRP shortcomings (50). Recently, the International Guidelines on Non-Ionising Radiation (IGNIR) have accepted EUROPAEM safety recommendations (91). The Bioinitiative group has recommended similar safety standards based on non-thermal EMF effects (92). WHO and all nations should adopt the EUROPAEM/Bioinitiative/IGNIR safety recommendations, supported by the majority of the scientific community, instead of the obsolete ICNIRP standards.

In conclusion, it is important that all experts evaluating scientific evidence and assessing health risks from RF radiation do not have COIs or bias. Being a member of ICNIRP and being funded by the industry directly, or through an industry-funded foundation, constitute clear COIs. Furthermore, it is recommended that the interpretation of results from studies on health effects of RF radiation should take sponsorship from the telecom or other industry into account. It is concluded that the ICNIRP has failed to conduct a comprehensive evaluation of health risks associated with RF radiation. The latest ICNIRP publication cannot be used for guidelines on this exposure.

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Authors' contributions

LH and MC contributed to the conception, design and writing of the manuscript. Both authors read and approved the final manuscript.

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Not applicable.

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Competing interests

The authors declare that they have no competing interests.

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Review Article

Lennart Hardell* and Tarmo Koppel

Electromagnetic hypersensitivity close to mobile phone base stations – a case study in Stockholm, Sweden

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Abstract: A previously healthy worker developed symptoms assigned to electromagnetic hypersensitivity (EHS) after moving to an office with exposure to high levels of anthropogenic electromagnetic fields (EMFs). These symptoms consisted of e.g. headache, arthralgia, tinnitus, dizziness, memory loss, fatigue, insomnia, transitory cardiovascular abnormalities, and skin lesions. Most of the symptoms were alleviated after 2 weeks sick leave. The highest radiofrequency (RF) field level at the working place was 1.72 V/m (7,852 $\mu\text{W}/\text{m}^2$). Maximum value for extremely low frequency electromagnetic field (ELF-EMF) from electric power at 50 Hz was measured to 285 nT (mean 241 nT). For electric train ELF-EMF at 16.7 Hz was measured to 383 nT (mean 76 nT). Exposure to EMFs at the working place could be the cause for developing EHS related symptoms. The association was strengthened by the symptom reduction outside the working place.

Keywords: electromagnetic hypersensitivity; EMF; radio-frequency radiation; symptoms.

Introduction

Exposure to extremely low frequency (ELF) electromagnetic fields (EMF) and radiofrequency (RF) EMF is in most cases involuntary and unknown to people. Both ELF-EMF and RF-EMF have been evaluated by IARC to be possible human carcinogens, Group 2B [1–3]. In fact EMFs should be regarded to be environmental pollutants that do not smell, have no taste and are invisible.

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Already in the 1970s the ‘microwave syndrome’ was described in the former Soviet Union [4]. Persons working with radar or radio equipment reported symptoms of fatigue, headache, dizziness, disturbed sleep, concentration and memory problems.

In the 1980s similar symptoms were reported among Swedish persons working in front of cathode ray tube monitors [5]. In Finns such symptoms were attributed to exposure to EMF [6]. This syndrome was termed electromagnetic hypersensitivity (EHS), although still without an International Classification of Diseases (ICD-code) [7].

EHS consists of a wide range of different symptoms that may vary from person to person. EMF sensitivity varies among individuals from mild to severe. The prevalence has been reported to be 1.5% in Sweden [8], 3.2% in California [9], 5% in Switzerland [10], and 13% in Taiwan [11].

We report here on a person who developed symptoms consistent with those described among EHS subjects. The symptoms developed at a work place with exposure to EMFs. Our hypothesis is that the symptoms may be attributed to that exposure. We obtained informed consent by the person to publish the symptoms and work history anonymously.

Methods

The subject attributed the development of EHS symptoms to her office room where she had been working one year since April 2018 for a total of 183 working days. As the source of the adverse health effects was unknown, the investigators devised a broad spectrum approach for EMF measurements, to include all possible sources of EMFs.

The room was thoroughly measured encompassing different types of electromagnetic fields, including:

- Extremely low frequency (ELF) magnetic field (MF)
- Intermediate frequency (IF) magnetic field (MF)
- Radiofrequency (RF) electromagnetic field.

Three types of measurements approaches were utilized characterizing:

- Spatial field distribution
- Temporal field dynamics
- Spectrum analysis of EMF

Spatial field distribution was done by conducting spot measurements across the room at evenly distributed locations. At each location the field was scanned in circular movements encompassing a one square meter area at the height of 0.7–2 m. Broadband field meter was used for spot measurements to account for any frequency in the monitored electromagnetic field type.

Spot measurement data, were fed to the contour map software 3DFIELD ver. 4.5.2.0 (by Vladimir Galouchko) and spatial field distribution maps were drawn.

Temporal field dynamics were investigated by using exposimeters. The meters were positioned at the location of the subject at the workstation and logging commenced for 40 min period. Electromagnetic fields spectrum was also measured using the same exposimeters with the frequency band discriminating function.

Measurement devices

Extremely low frequencies were investigated using broadband frequency selective electromagnetic field meter NFA400 by Gigahertz Solutions (Langenzenn, Germany). This meter is capable of simultaneous measurements of 6 frequency bands: (1) 16.7 Hz, (2) 50 Hz, (3) 100 Hz, (4) 150 Hz, (5) <2 kHz excluding the aforementioned, 6) >2 kHz. The frequency range covered: 5 Hz to 400 kHz. Measurement range for magnetic flux density is 1 nanoTesla (nT) to 20 microTesla (μ T) and for electrical field strength 0.1–1999 Volt per meter ($V\ m^{-1}$).

Both magnetic and electric fields can be measured by the meter. The meter is a three-axial meter for magnetic field, capable of measuring all three axes separately and calculating the resultant field. The measurements are taken in tRMS (true Root Mean Square) mode. In exposimeter setting, logging 3D magnetic field was done at 0.1 s sampling rate.

Radiofrequency spatial mapping was done using RF broadband meter Narda NBM-520, with an E-field probe E0391 (Narda-Safety-Test-Solutions GmbH, Pfullingen, Germany). This Narda NBM-series meter is capable of time and spatial averaging and determining the maximum level during the period monitored. Narda EF0391 probe is produced by the manufacturer for base station measurements and has a frequency range from 100 kHz to 3 GHz, measurement range of 0.2–320 $V\ m^{-1}$.

Radiofrequency temporal dynamics and dominant frequencies were determined by using exposimeter EME SPY200 by Satimo. This exposimeter measures 20 predefined frequencies covering the frequencies of most public RF radiation emitting devices. The exposimeter covers frequencies from 87 to 5,850 MHz and measures different telecommunication protocols: FM radio broadcasting; TV broadcasting; TETRA emergency services (police, rescue, etc.); GSM second generation mobile communications; UMTS third generation mobile communications, 3G; long-term evolution (LTE) fourth generation mobile communications standard, 4G; digital European cordless telecommunications (DECT) cordless telephone systems standard; Wi-Fi 2.4 GHz and 5 GHz wireless local area network protocol; worldwide interoperability for microwave access (WiMAX) wireless communication standard for high-speed voice, data and Internet

For frequency modulation (FM), TV3, TETRA, TV4&5, Wi-Fi 2.4 GHz and Wi-Fi 5 GHz, the lower detection limit is 0.01 $V\ m^{-1}$ (0.27 $\mu W/m^2$). For all other bands, the lower detection limit is 0.005 $V\ m^{-1}$ (0.066 $\mu W/m^2$). For all bands, the upper detection limit is 6 $V\ m^{-1}$ (95,544 $\mu W/m^2$). The sampling time used in this study was 4 s which is the fastest for the given exposimeter.

Next to measurements visual observations were conducted to identify openly detectable EMF sources near the investigated premises. Also the distance to the EMF sources was determined by visual assessments.

Conversion from V/m to W/m²

In most of our earlier studies [12–17] we have used the EME Spy 200 from Satimo and preferred to show our results in power flux density in W/m^2 and $\mu W/m^2$ for RF radiation. In the current measurements the broadband analyzer Narda NBM-520 measures in V/m and the contour map software 3DFIELD is also constructed for measurements in V/m .

To convert from electric field strength, E , in $V\ m^{-1}$ to power flux density in W/m^2 , S , use the formula: $S = 0.002654 \cdot E^2$.

To convert from power flux density in W/m^2 , S , to electric field strength, E , in $V\ m^{-1}$, use the formula: $E = 19.41 \cdot \sqrt{S}$.

The aim of the study was to assess the EMF levels at this work place and if they could be related to the symptoms of EHS in this individual.

Results

Case report

A 55 year old previously healthy female office worker changed her work place in April 2018. She had worked in the same building for almost 10 years but at another location. After 3 months job in another place she returned to this building, but this time to another office at the 6th floor close to base stations on the roof. In the surrounding 4G was installed a couple of years before her return. She had full time work in the office. At the previous working place she had no health problems.

During the following months after she had changed office she experienced increasing health problems. She attributed the symptoms to the working place, as the symptoms diminished while being away from the premises and reappeared and increased when back.

She experienced continuous heavy headache during the week, pain in the chest, shortness of breath, cough, fatigue, dizziness, uncontrolled movements of the body, low blood pressure (e.g. 86/57 mmHg), palpitations with rapid heart rate (e.g. 140–145) including fainting at one occasion. She had sensations of ‘fever’ in the head but not in the body. All these symptoms initially started at work and were aggravated over time including nose bleeding at the work place. She noticed loss of hair on the head and on eyebrows.

This person had never had skin problems, her skin was visually extremely healthy. Now she felt tenderness, burning and itching on the scalp, face and the body. She noticed leathery, exfoliating skin in the face; the skin

Table 1: Clinical symptoms graded 0–10; 0=no symptoms, 1=mild, 10=unbearable pain and/or discomfort. Percentages in parentheses represent frequencies in a survey on 100 patients by Belpomme et al. [18].

Symptoms	Office	After 2 weeks sick leave
Headache	8 (88%)	3
Dysesthesia	0 (82%)	0
Myalgia	3 (48%)	1
Arthralgia	7 (30%)	5
Ear heat/otalgia	2 (70%)	0
Tinnitus	9 (60%)	1
Hyperacusis	0 (40%)	0
Dizziness	8 (70%)	3
Balance disorder	10 (42%)	4
Concentration/attention deficiency	5 (76%)	2
Loss of immediate memory	9 (70%)	7
Confusion	2 (4%)	1
Fatigue	9 (88%)	5
Insomnia	8 (74%)	7
Depression tendency	1 (60%)	1
Suicidal ideation	0 (20%)	0
Transitory cardiovascular abnormalities	10 (50%)	3
Ocular deficiency	2 (48%)	2
Anxiety/panic	0 (38%)	0
Emotivity	2 (20%)	1
Irritability (irritabel)	1 (24%)	0
Skin lesions	10 (16%)	5
Global body dysthermia	0 (14%)	0
Lungs	5	1
Stomach	7	2
-Diarrehea (involuntary)	3	0
-Pricking, burning inside body	9	0
Skin (face, arms, legs)	10	6
-Burning, lancinating skin on hands and arms	7	0
Nose bleeding	7	0
Blood pressure	10	3
Anemia	8	Not evaluated
Hair loss	3	3
Mouth infection	4	3
-Tongue, fungus	10	3

seemed to have grown older in short time becoming aged and wrinkled, and had also burning sensations on the arms and hands. She used to wake up around 3 o'clock in the morning with stomach pain, nausea and sudden vomiting.

She noticed 'vibrating and pulsing' eardrums with tinnitus and pain in the ears. The short-term memory was impaired and she felt restless like being hyperactive with shaky hands, and in addition concentration difficulties.

It is also noteworthy that she had pain in her joints that tended to swell. Anemia was recorded at a health check by a general practitioner.

In Table 1 the different symptoms while at office in April 2019 and after 2 weeks of sick leave are described.

This table is based with some additions on a publication by Belpomme et al. [18] on symptoms in the first 100 patients in their case series. It is noteworthy that for this presented person almost all symptoms declined during sick leave, most notably the most serious health problems. Thus headache, tinnitus, dizziness, balance disorder, cardiovascular problems including low blood pressure and mouth infection improved. Also skin lesions and sensations improved.

All these symptoms have been described in persons with EHS [6, 7, 19]. This person contacted our research team and we judged it to be pertinent to make EMF measurements at her work place. The contact was initiated by her observation of the proximity to the base stations.

The work environment

This person does a regular office job, working with a desktop computer. She is using an ergonomic desk, the height of which can be adjusted by a fitted lifting motor. Hence, the worker can choose to work at the desk either on foot or by sitting on a chair.

The lighting in the room was determined to meet the minimum requirement for office work stations (500 lux). There was no noise in the room, nor other detectable occupational health risks.

The building is fairly new so that noise, vibrations, or impaired air quality would not be expected. Also exposure to e.g. asbestos and radon was excluded. Furthermore, since she had worked in the same building, but at another place, for several years detrimental health effects from such working conditions would already have occurred. All health problems appeared after moving to the current office at the 6th floor of the building close to the base stations.

Measurements

Measurements were conducted on a business day afternoon in April 2019.

Visual observations

The working room where the subject had developed EHS symptoms was located on the 6th floor of a 6-floor office building. The closest mobile phone base station mast with several antennas was positioned right above the subjects workstation, distanced about 4 m away on the roof (see Figure 1).

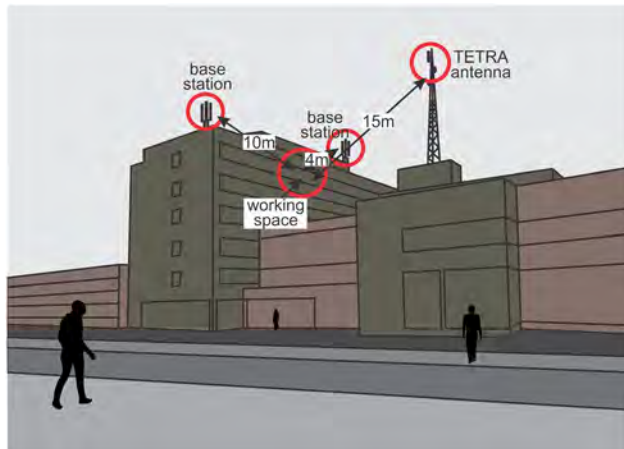


Figure 1: Location of the person's working space with respect to the RF sources indicated by circles.



Figure 2: The case study location – several mobile phone base station antennas and TETRA antennas on the roof.

Another mobile phone base station antenna array was positioned 10 m further away on top of the same building. Additionally, a lower radiofrequency communications antenna array (TETRA) was positioned some 15 m away positioned on adjacent wing of the building (see Figure 2).

Radiofrequency spatial mapping

Radiofrequency spatial mapping revealed a strong influence from above installed mobile phone base station. Radiofrequency mobile communications were the highest level type of electromagnetic field in the premises. Field distribution is pictured in Figure 3. The field is not notably higher close to the windows, which indicates that much of the radiofrequency field is penetrating into the room also

from other directions, including paths through the walls and ceiling. The RF field level at subjects working position was 1.72 Vm^{-1} ($7,852 \mu\text{W}/\text{m}^2$) which happens to be also the highest in the room. The minimum field level in the room was 1.06 Vm^{-1} ($2,982 \mu\text{W}/\text{m}^2$) and mean 1.21 Vm^{-1} ($3,886 \mu\text{W}/\text{m}^2$). This illustrates a uniformly exposed room to a high level of radiofrequency fields.

Radiofrequency temporal changes

Radiofrequency temporal changes were assessed based on the exposimeter placed on the subject's workstation (Table 2). The location was at her typical working position. Highest levels were found for LTE 800 DL, GSM + UMTS 900 down load, GSM 800 down load and LTE 2600 DL. These results represent RF electromagnetic radiation from the nearby base stations. Besides base station exposure, other RF sources were quite low and constituted a total mean value of $34.9 \mu\text{W}/\text{m}^2$ (excluding down link; DL).

Extremely low frequency magnetic field exposure

Table 3 presents extremely low frequency magnetic field measurements at the subject's work station. 'Edges per hour' column present sharp rise of the measured field intensity. This indicator is used to analyze the number of sudden rising edges in field that can be due to spikes or high frequency transients of the corresponding field. The main frequencies in the room are (1) 50 Hz from electrical power grid and appliances and (2) 16.7 Hz electric train power frequency.

Extremely low and intermediate frequency temporal changes

The main frequency components of magnetic field were assessed with exposimeter total logging time 40 min. The results depict an MF exposure with high amplitude temporal variation. The main fluctuation was because of changing power drain in the railroad power cable due to electric train traffic. MF from power frequency 50 Hz is at stable level with little amplitude variation, indicating a stable consumption of electrical power in the area. MF at frequencies above 2 kHz are at negligent levels and show no abrupt changes over time.

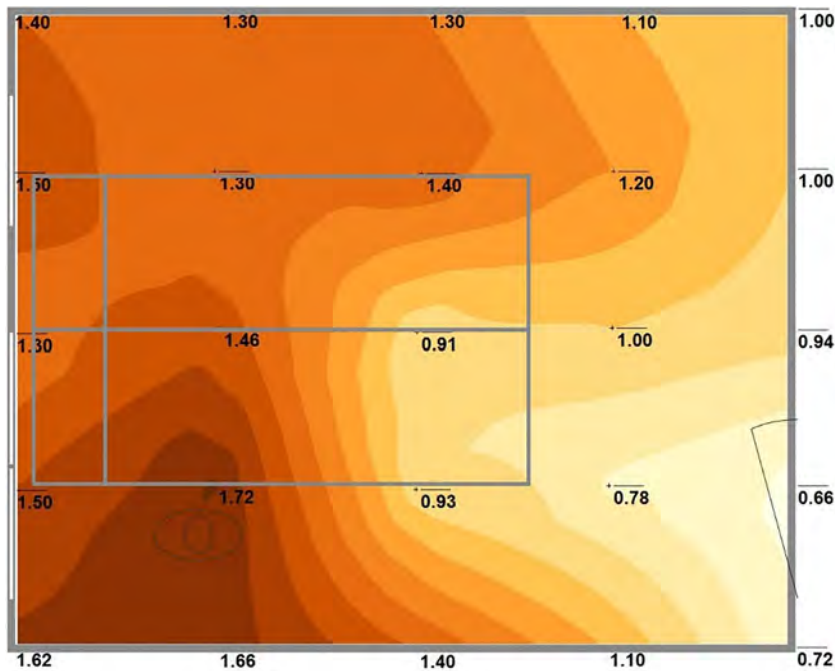


Figure 3: Radiofrequency field distribution in $V\ m^{-1}$ in the work area; typical position of the person at marked with wireframe at the bottom left of the figure.

Table 2: Analysis of exposimeter data ($\mu W/m^2$) treating values at detection limit as 0. Total (n=891).

	Mean	Median	Min	Max
FM	0.8	0.0	0.0	45.5
TV3	0.0	0.0	0.0	0.0
TETRA I	16.3	6.9	0.0	1,520.0
TETRA II	0.0	0.0	0.0	0.4
TETRA III	0.0	0.0	0.0	0.0
TV4&5	1.0	0.0	0.0	40.8
LTE 800 (DL)	132.1	91.8	18.3	1,480.1
LTE 800 (UL)	0.0	0.0	0.0	0.2
GSM + UMTS 900 (UL)	0.0	0.0	0.0	0.4
GSM + UMTS 900 (DL)	269.6	224.6	38.8	1,340.9
GSM 1800 (UL)	16.5	11.9	2.7	175.2
GSM 1800 (DL)	447.6	340.0	114.8	2,506.1
DECT	0.1	0.0	0.0	25.0
UMTS 2100 (UL)	0.0	0.0	0.0	0.4
UMTS 2100 (DL)	32.6	30.9	9.2	113.7
WIFI 2G	0.1	0.0	0.0	4.7
LTE 2600 (UL)	0.1	0.0	0.0	7.7
LTE 2600 (DL)	181.9	136.7	26.0	2,077.5
WiMax	0.0	0.0	0.0	0.0
WIFI 5G	0.0	0.0	0.0	0.0
Total	1,098.7	968.3	423.5	4,183.8
Total excluding DL	34.9	23.2	5.0	1,585.4

Discussion

Within a couple of months, this person developed a series of health problems, after moving to an office with high EMF

Table 3: Magnetic field at work station, time logged exposure over 40 min.

Frequency band	Min	Max	Mean	95th percentile	Edges per hour
5 Hz–400 kHz	135 nT	497 nT	284 nT	319 nT	275/h
16.7 Hz	0 nT	383 nT	76 nT	167 nT	169/h
50 Hz	0 nT	285 nT	241 nT	274 nT	0/h
>2 kHz	0 nT	3.5 nT	1.8 nT	2.8 nT	50/h

exposure. These symptoms are typical for persons with EHS [20]. This syndrome has been characterized by fatigue, chronic pain and impaired cognitive function, see the Paris Appeal (<http://appel-deparis.com/?lang=4en>). This person has all these symptoms in addition to a large number of other health problems as discussed by Belyaev et al. [19].

We will here take some of the symptoms this office worker presented and compare these with published scientific studies showing detrimental effects from ELF-EMF and RF radiation on humans, animals and biological material.

The symptoms may vary from person to person. There are no reliable biomarkers for EHS. In a case series by Belpomme et al. [18] a number of biomarkers were described. The 24 h urine 6-hydroxymelatonin sulfate (6-OHMS)/creatinin ratio was found to be decreased (<0.8) in all investigated cases which might be of interest. It may indicate one reason for the sleep problems in 74% of the

participants, see Table 1. Our case person graded her sleep problems as 8 on the 0–10 scale during her work time in the office and still as 7 during sick-leave and afterwards while working in another office at floor 2. Earlier she had had no sleeping problems at all.

Electroencephalographic (EEG) activity in the brain can be altered by RF radiation. Especially the second non-rapid eye movement (NREM) sleep after 2–3 h sleep was effected when 30 young healthy men were exposed to two different 900 MHz pulse modulated signal 30 min directly before sleep. The 14 Hz pulse modulated condition had a stronger influence on EEG than 217 Hz [21]. Also during the day when awake, RF radiation can have considerable influence on EEG [22, 23]. Pulsed extremely low frequency magnetic field (ELF MF) has been shown to lower the alpha frequency activity over the parietal-occipital regions of the brain [24]. Decreased β -trace protein, which is a key enzyme in the synthesis of a sleep-promoting neurohormone, has been seen in young adults with high-cumulative amounts of hours of mobile phone use [25]. RF radiation showed disturbed glucose metabolism in the brain after 50 min exposure from a mobile phone [26].

Our case person noticed loss of hair on her head and on her eyebrows and was severely affected by a burning sensation from her skin. A study on healthy human subjects showed DNA damage in hair root cells after 30 min of mobile phone talk [27]. A Finnish study showed that proteins in the skin could be affected after RF radiation exposure on the skin [28]. Dermatitis has also been seen near electronic wireless devices like lap tops [29].

Two studies from India have shown how long term, high users of mobile phones can get more micronuclei in oral mucosal cells from the same side as they hold their mobile phone, compared to low users. This indicates a genotoxic effect of RF radiation [30, 31]. Salivary oxidative stress has been seen in mobile phone users with decrease in salivary flow, total protein, albumin and amylase activity [32, 33]. It should be noted that Arbabi-Kalati et al. [33] did not provide details if the study groups were controlled for age and dietary intakes, which are crucial determinants of the antioxidant status. Salivary cortisol can increase after 50 min of RF radiation of GSM 900 MHz [34]. Also thyroid hormones have been effected for people living near mobile phone base stations [35]. A study in Germany showed that the neurotransmitters adrenaline, noradrenaline, dopamine and phenylethylamine increased or decreased after a 900 MHz base station was activated in 2004. The neurotransmitters were not normalized after 18 months especially not in children and chronically ill adults. Several of the 60 participants had got new symptoms like sleep disturbances, headache, dizziness, concentration problems and allergies [36].

In India 40 healthy people living <80 meter from a base station had lowered antioxidant levels and higher frequency of micronuclei in their blood lymphocytes compared to a control group living >300 m from a base station [37].

A study on mice showed that 900 MHz RF radiation exposure delayed wound healing several days in experimentally induced cutaneous candidiasis. The mortality rate also increased in the RF radiation exposed group, probably due to higher yeast loads in skin lesions and systemic infection [38].

Our case person had long lasting problems with candidiasis on her tongue. According to the above studies RF radiation may decrease her immune system defense, increase stress reactions and oxidative stress. Decreased production of melatonin can give sleep problems and has an important role on the antioxidant system and wound healing [39]. Reduced immune functions, such as natural killer lymphocytes, as well as higher stress levels were reported in women in residencies with high levels of RF EMFs from radio-television broadcasting stations [40].

This case person had severe problems with tinnitus during her work in the office. After two weeks of sick-leave it had almost disappeared. Prolonged use of mobile phones can increase the risk of tinnitus on the same side as the mobile phone is used [41, 42]. There is also a higher degree of hearing loss in high amount users with over 2 h mobile phone talk per day [43, 44]. A study from Turkey showed that DNA damage of hair follicle cells in human ear canal increased with the daily duration of exposure from mobile phones. It was highest in the group that talked more than 60 min per day in their mobile phone [45].

An association between chemicals and EHS is not well studied. Regarding persistent organic pollutants a small study indicated increases concentration of the flame retardant PBDE #47 in EHS persons. This might be of interest since flame retardants have been used in electronic devices such as computer screens [46]. However, we had not information on chemical exposure to the study person.

In this case report certainly the decline or even disappearance of some symptoms during sick leave avoiding EMF exposure in the office might be a diagnostic criteria. The most promising treatment must be avoiding high EMF exposure. Today it is almost impossible to find any environment without any EMF exposure at all.

Although all the measured field levels are within the current safety limits, the working premises were demonstrating elevated exposure levels both to the radiofrequency electromagnetic field and the extremely low frequency magnetic field.

In our paper on long term glioma risk from occupational exposure to ELF MF [47] all the workers were divided

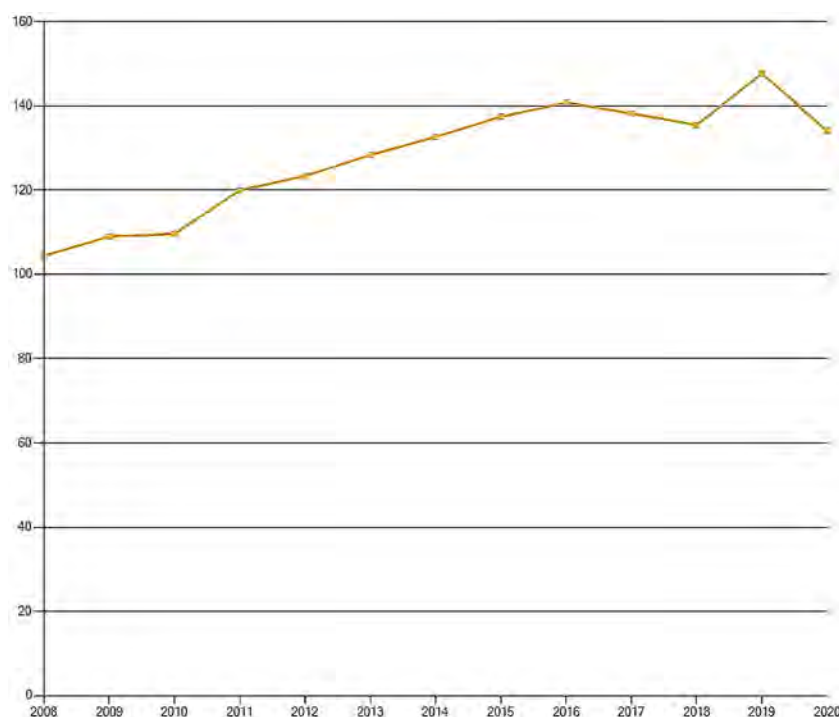


Figure 4: Number of patients per 100,000, both genders combined, diagnosed with myelin damage in CNS, ICD-codes G35-37, according to registers for in-patients and out-patients in Sweden during 2008–2020 (Statistikdatabaser – Diagnoser – Val (socialstyrelsen.se)).

into five groups based on the average exposure level: (1) low exposure group ($<0.11 \mu\text{T}$); (2) low-medium exposure group (0.11 to $<0.13 \mu\text{T}$); (3) medium exposure group (0.13 to $<0.18 \mu\text{T}$); (4) medium-high exposure group (0.18 to $<0.27 \mu\text{T}$) and (5) highly exposed workers group ($\geq 0.27 \mu\text{T}$). Odds ratio (OR) 1.3, 95% confidence interval (CI) = 1.003–1.6 for glioma risk was found for average exposure $\geq 0.27 \mu\text{T}$.

In the current study, the mean exposure level to extremely low frequency magnetic field at the subject's workstation was determined to be $= 0.284 \mu\text{T}$, which places the person into highly exposed workers' group in our study [47].

This person was in December 2021, much improved and is working full time at another office in the same building. The visible properties are similar to her previous office. There are no known problems with mold, dust or fabrics and the cleaning is similar in the whole building. However, she experiences some numbness, tremor and tingling in her extremities, especially fingers and toes, almost on a daily basis. The reason for those symptoms is unclear. RF radiation has been associated with neuron damage [48] including myelin damage [49].

Register data without personal identification is available in Sweden for hospital discharges and out-ward specialists (Statistikdatabaser – Diagnoser – Val (socialstyrelsen.se)). We report numbers per 100,000 inhabitants for both genders combined. Age-standardized rates are not available in the registre. We found a clearly increasing number of patients per

100,000 diagnosed with myelin damage, ICD codes G35-37, during 2008–2020, Figure 4. Also for diseases of basal ganglia and movement disorders, G20-26, the numbers increased during the same time period, Figure 5. Note that data for 2020 are less reliable due to lag time for reporting to the register. The register started in 2008 and it should be considered that registration has improved over the years. Thus, the trends must be evaluated with caution, but indicate anyhow increasing rates.

Conclusions

This investigation established three possible reasons for developing health symptoms associated with the EMF exposure, including the following.

- (1) The working room was right below the mobile phone base station antenna, located on the roof of the building. The close proximity to these antennas caused significantly high RF radiation exposure in the working area.
- (2) The working room is also positioned close to lower radiofrequency transmitter (TETRA emergency services), located on the neighboring roof of the same building.
- (3) The working room was positioned within 20 m from the electric train railroad. 16 Hz magnetic field from the railroad power cable was on some instances the

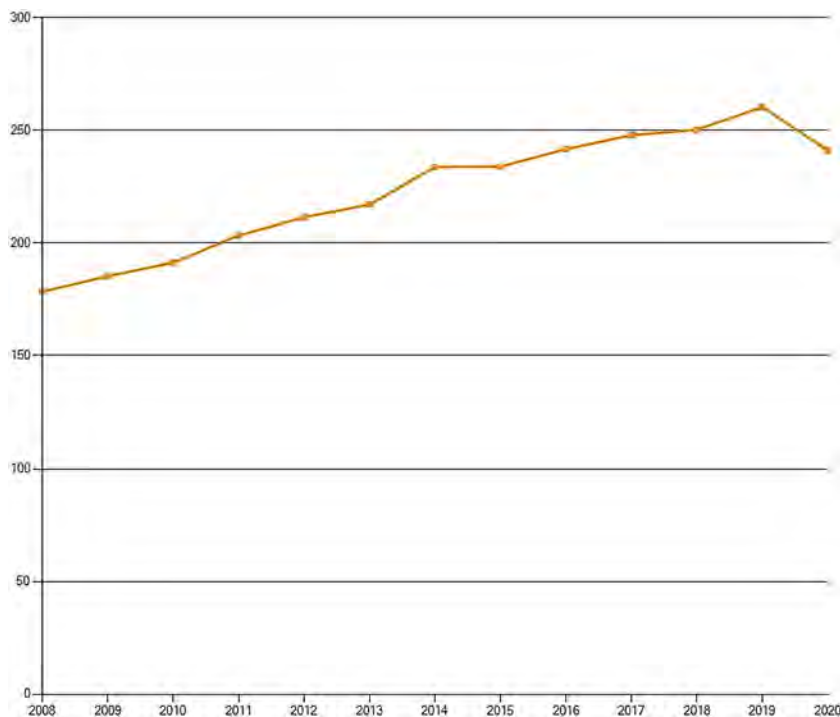


Figure 5: Number of patients per 100,000, both genders combined, diagnosed with diseases of basal ganglia and movement disorders, G20-26, according to the in-patient and out-patient registers during 2008–2020 (Statistikdatabaser – Diagnoser – Val (socialstyrelsen.se).

highest ELF MF component in the room, exceeding even the power grid 50 Hz MFs. Also, railroad power cable induced a fluctuating magnetic field in the office due to the coming and passing electric trains. As trains come and go, this introduces a change in the electric power supplied by the railroad electric cable. Consequently the magnetic field also changes in great amplitude.

In conclusion, there are at least three types of electromagnetic fields present in the working room, which cause a long term exposure to the workers. Exposure to multiple source electromagnetic fields could be the cause for developing EHS related symptoms. However, the person had been exposed to ELF-EMF also at other locations in the building, so exposure to RF-EMF seems to be the most probable cause to her developed health problems.

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Informed consent: Informed consent was obtained by the study person for anonymous publication.

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World Health Organization, radiofrequency radiation and health - a hard nut to crack (Review)

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Abstract. In May 2011 the International Agency for Research on Cancer (IARC) evaluated cancer risks from radiofrequency (RF) radiation. Human epidemiological studies gave evidence of increased risk for glioma and acoustic neuroma. RF radiation was classified as Group 2B, a possible human carcinogen. Further epidemiological, animal and mechanistic studies have strengthened the association. In spite of this, in most countries little or nothing has been done to reduce exposure and educate people on health hazards from RF radiation. On the contrary ambient levels have increased. In 2014 the WHO launched a draft of a Monograph on RF fields and health for public comments. It turned out that five of the six members of the Core Group in charge of the draft are affiliated with International Commission on Non-Ionizing Radiation Protection (ICNIRP), an industry loyal NGO, and thus have a serious conflict of interest. Just as by ICNIRP, evaluation of non-thermal biological effects from RF radiation are dismissed as scientific evidence of adverse health effects in the Monograph. This has provoked many comments sent to the WHO. However, at a meeting on March 3, 2017 at the WHO Geneva office it was stated that the WHO has no intention to change the Core Group.

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Key words: electromagnetic fields, EMF, radiofrequency radiation, public exposure, cancer, WHO, monograph, conflict of interest, ICNIRP, non-thermal effects, health risks

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1. Introduction

The use of wireless digital technology has grown rapidly during the last couple of decades (<http://www.itu.int/en/ITU-D/Statistics/Documents/facts/ICTFactsFigures2016.pdf>). During use, mobile phones and cordless phones emit radiofrequency (RF) radiation. The brain is the main target organ for RF emissions from the handheld wireless phone (1,2). An evaluation of the scientific evidence on the brain tumour risk was made in May 2011 by the International Agency for Research on Cancer (IARC) at the World Health Organization (WHO). IARC is independently financed and has its own governing and scientific councils, which WHO staff only attend as observers (http://www.who.int/ionizing_radiation/research/iarc/en/).

Epidemiological studies provided supportive evidence of increased risk for head and brain tumours, i.e., acoustic neuroma and glioma. The working group reached the conclusion that RF radiation from devices that emit non-ionizing RF radiation in the frequency range 30 kHz-300 GHz, is a Group 2B, i.e. a 'possible', human carcinogen (3,4). Later studies have corroborated these findings and have thus strengthened the evidence (5-8).

Several laboratory studies have indicated mechanisms of action for RF radiation carcinogenesis such as on DNA repair, oxidative stress, down regulation of mRNA and DNA damage with single strand breaks (9-13). A report was released from The National Toxicology Program (NTP) under the National Institutes of Health (NIH) in USA on the largest ever animal study on cell phone RF radiation and cancer (14). An increased incidence of glioma in the brain and malignant schwannoma in the heart was found in rats. Acoustic neuroma or vestibular schwannoma is a similar type of tumour as the one found in the heart, although benign. Thus, this animal study supported human epidemiological findings on RF radiation and brain tumour risk (8).

The IARC cancer classification includes all sources of RF radiation. The exposure from mobile phone base stations, Wi-Fi access points, smart phones, laptops and tablets can be long-term, sometimes around the clock, both at home and at

school. For children this risk may be accentuated because of a cumulative effect during a long lifetime use (15). Developing and immature cells can also be more sensitive to exposure to RF radiation (9).

In spite of the IARC evaluation little has happened to reduce exposure to RF fields in most countries. On the contrary, with new technology increasing environmental exposure levels are found as in measurements of ambient RF radiation at e.g. Stockholm Central Station and Stockholm Old Town in Sweden (16,17). The exposure guideline used by many agencies was established in 1998 by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and was based only on established short-term thermal (heating) effects from RF radiation neglecting non-thermal biological effects (18). The heating effects arise when radiation is so high that it warms up the whole body by 1°C or more after 30 min exposure at 4 W/kg specific absorption rate. The guidelines are set with a safety factor of 50 for the general public (<http://www.who.int/peh-emf/about/WhatisEMF/en/index4.html>).

Basis for limiting exposure according to ICNIRP: 'Only established effects were used as the basis for the proposed exposure restrictions. Induction of cancer from long-term EMF exposure was not considered to be established, and so these guidelines are based on short-term, immediate health effects such as stimulation of peripheral nerves and muscles, shocks and burns caused by touching conducting objects, and elevated tissue temperatures resulting from absorption of energy during exposure to EMF. In the case of potential long-term effects of exposure, such as an increased risk of cancer, ICNIRP concluded that available data are insufficient to provide a basis for setting exposure restrictions, although epidemiological research has provided suggestive, but unconvincing, evidence of an association between possible carcinogenic effects.' (<http://www.icnirp.org/cms/upload/publications/ICNIRPemfgdl.pdf>).

This is an exceptional statement by ICNIRP, and found in many statements of groups following the ICNIRP philosophy like the AGNIR and on the WHO EMF Project's homepage as well, that epidemiology found 'suggestive, but unconvincing' evidence. What is convincing or not is so decidedly subjective that no scientific body will ever make this as a basis for a decision. There might be gaps in knowledge that make it difficult to decide about the mechanisms that underlie an observation and even an observation could be considered unreliable but the conviction must not enter a rational discourse about a scientific issue.

The guidelines were updated in 2009 but still do not cover cancer and other long-term or non-thermal health effects. ICNIRP gives the guideline 2 to 10 W/m² for RF radiation depending on frequency, thus only based on a short-term immediate thermal effect (19). ICNIRP is a private organisation (NGO) based in Germany. New expert members can only be elected by members of ICNIRP. Many of ICNIRP members have ties to the industry that is dependent on the ICNIRP guidelines. The guidelines are of huge economic and strategic importance to the military, telecom/IT and power industry.

In contrast to ICNIRP, the BioInitiative Reports from 2007 and updated in 2012, based the evaluation also on non-thermal health effects from RF radiation (20,21). The scientific

benchmark for possible health risks was defined to be 30 to 60 $\mu\text{W}/\text{m}^2$. Thus, using the significantly higher guideline by ICNIRP gives a 'green card' to roll out the wireless digital technology thereby not considering non-thermal health effects from RF radiation. Numerous health hazards are disregarded such as cancer (8), effects on neurotransmitters and neuroprotection (22,23), blood-brain-barrier (24,25), cognition (26-29), psychological addiction (30-32), sleep (33-36), behavioral problems (37-41) and sperm quality (13,42,43).

No doubt the IARC decision started a world-wide spinning machine to question the evaluation. It was similar to the one launched by the tobacco industry when IARC was studying and evaluating passive smoking as a carcinogen in the 1990s (44). Sowing confusion and manufacturing doubt about scientific facts is a well-known strategy used by the tobacco and other industries (8,45-48).

2. The WHO fact sheet

A Fact Sheet from WHO issued in June 2011 shortly after the IARC cancer classification in May 2011 stated that 'To date, no adverse health effects have been established as being caused by mobile phone use' (<http://www.who.int/mediacentre/factsheets/fs193/en/>). This statement was not based on scientific evidence at that time on a carcinogenic effect from RF radiation. It was certainly a remarkable conclusion by WHO since IARC is part of WHO although seemingly independent, see above.

However, it is also important to note that the statement in the Fact Sheet does not fully contradict the IARC statement. A Group 2B carcinogen is considered by IARC as an agent where an association with cancer has been detected that can be causally interpreted but for which chance, bias and confounding cannot be ruled out with sufficient scientific certainty. Hence, the statement in the Fact Sheet is in line with IARC's classification although, of course, it will rather be understood as a full dismissal of claims of harm.

In the WHO Fact Sheet it was also stated that 'WHO will conduct a formal risk assessment of all studied health outcomes from radiofrequency fields exposure by 2012.' The pertinent question is why WHO was so keen to make a new risk evaluation shortly after the IARC evaluation. It was hardly expected that new studies would be published in short time changing the classification of RF radiation as a possible, Group 2B, human carcinogen. Considering the WHO statement of 'no adverse health effects' the aim might have been to undermine the IARC decision and give the telecom industry a 'clean bill' of health (8). It might, however, be argued that as a result of the IARC classification, it was necessary for WHO to also look at other effects, and not just tumours.

3. The WHO EMF project

The biophysicist Michael Repacholi from Australia was the first chairman of ICNIRP in 1992. His own research within this field is scanty, although a study on lymphoma incidence in mice exposed to RF radiation published in 1997 has attracted interest (49). Repacholi suggested in 1995 that WHO should start the EMF project. This was adopted by WHO in 1996, see WHO Press office: WHO launches new international project

to assess health effects of electric and magnetic fields; 4 June 1996 (50). Repacholi was during 1996-2006 the leader of the WHO department of electromagnetic radiation, the WHO EMF project.

The WHO EMF project is supposed to: 1) provide information on the management of EMF protection programs for national and other authorities, including monographs on EMF risk perception, communication and management; 2) provide advice to national authorities, other institutions, the general public and workers, about any hazards resulting from EMF exposure and any needed mitigation measures. (http://www.who.int/peh-emf/project/EMF_Project/en/index1.html).

Michael Repacholi immediately set up a close collaboration between WHO and ICNIRP (being head of both organizations) inviting the electric, telecom and military industries to meetings. He also arranged for large part of the WHO EMF project to be financed by the telecommunication industry's lobbying organisations; GSM Association and Mobile Manufacturers Forum, now called Mobile & Wireless Forum (MWF) (51) in addition to WHO, see the International EMF Project, Progress Report June 2005-2006 (http://www.who.int/peh-emf/publications/reports/IAC_Progress_Report_2005-2006.pdf).

Repacholi acted like a representative for the telecom industry while responsible for the EMF health effects department at the WHO (<http://microwavenews.com/news/time-stop-who-charade>). Since he left WHO in 2006 he has been involved in industry propaganda video interviews with GSM Association and Hydro Quebec (<https://www.youtube.com/watch?v=fDZx7MphDjQ>; https://www.youtube.com/watch?v=1MI_fa5YsgY) where he clearly speaks in favor of the telecommunications and the power industries, respectively.

Michael Repacholi is still the Chairman emeritus at ICNIRP (<http://www.icnirp.org/en/about-icnirp/emeritus-members/index.html>) and has propagated during almost 20 years worldwide the 'only thermal effect' paradigm of health risks from RF-EMF exposure, ignoring the abundant evidence for non-thermal effects or cancer risks.

Repacholi recruited Emilie van Deventer to the WHO EMF Project in 2000. She is the current project manager at WHO for the EMF project. She has been a long time member of the industry dominated organization Institute of Electrical and Electronics Engineers (IEEE). IEEE is the world's most powerful federation of engineers. The members are or have been employed in companies or organizations that are producers or users of technologies that depend on radiation frequencies, such as power companies, the telecom and the military industry. IEEE has prioritized international lobbying efforts for decades especially aimed at the WHO, for more information see (http://www.ices-emfsafety.org/wp-content/uploads/2016/10/Approved-Minutes-TC95-Jan_16.pdf).

Van Deventer is an electrical engineer. She has no formal or earlier knowledge in medicine, epidemiology or biology, so it is surprising that she was selected for such an important position at the WHO (http://www.waves.utoronto.ca/people_vandeventer.htm) (<http://www.itu.int/ITU-T/worksem/emc-emf/201107/bios.html>).

The very same year she was recruited to the WHO EMF Project Toronto University Magazine wrote about Emilie van Deventer's work stating that it was 'invaluable' to industry:

'The software modelling done by teams like van Deventer's is invaluable.' 'The industrial community is very interested in our research capabilities,' says van Deventer. 'It always needs to be working on the next generation of products, so it turns to universities to get the research done.' (<http://www.research.utoronto.ca/edge/fall2000/content2b.html>).

The importance of this work is reflected in the research funding van Deventer and her team received from the Natural Sciences & Engineering Research Council of Canada (NSERC), Communications & Information Technology Ontario (CITO), and their major industrial partner, Nortel. 'We are fulfilling a very real need in the industry today, which will only increase as technology creates more opportunity. In the process, consumers will continue to enjoy faster computers, lighter cell phones, smaller electronic organizers and the vast array of other electronic gadgets the high-tech world has to offer.' (<http://www.research.utoronto.ca/edge/edgenet/fall2000/a-clear-signal/>).

4. WHO radio frequency fields: Environmental health criteria monograph

Two years after the anticipated 'formal risk assessment' by WHO in 2012 a draft was launched in 2014 (http://www.who.int/peh-emf/research/rf_ehc_page/en/). It was open for public consultation until December 31, 2014, but is now closed according to the WHO home page.

It was stated that: 'The process used in developing the chapters is described in Appendix X. Note that the chapters 1, 13 and 14 which will provide a summary, health risk assessment and protective measures are not available for this consultation. The drawing of conclusions from the literature and the drafting of these chapters is the remit of a formal Task Group that will be convened by WHO at a later stage in the process.'

It must be regarded to be unusual and scientifically inadequate not to provide for review the health risk assessment and protective measures which would be most important parts of the Monograph. Furthermore, it turned out that of the six members in the WHO Core Group four are active members of ICNIRP and one is a former member. This was published in 2016 (52) and also discussed more recently (8). Only one person seems to be independent of ICNIRP, see Table I. Several persons have also affiliation(s) to other advisory groups, authorities and/or committees. Six of the 20 additional experts are affiliated with ICNIRP.

Being a member of ICNIRP is a conflict of interest in the scientific evaluation of health hazards from RF radiation through ties to military and industry. This is particularly true since the ICNIRP guidelines are of huge importance to the influential telecommunications, military and power industries. Another conflict of interest is for members officially assessing possible health effects below their own set ICNIRP guidelines, which they have already stated as being safe, see also discussion in (52). Such persons would hardly have different opinions than those stated by ICNIRP. Critical views are not heard and a balanced scientific evaluation is not obtained.

It should be noted that the Ethical Board at the Karolinska Institute in Stockholm, Sweden concluded already in 2008 that being a member of ICNIRP may be a conflict of interest that

Table I. Members of WHO Monograph core group and their involvement in different other groups (8).

Name	WHO	ICNIRP	UK/AGNIR	SSM	SCENIHR
Simon Mann	X	X	X		
Maria Feychting	X	X	X	X ^a	
Gunnhild Oftedal	X	X			
Eric van Rongen	X	X		X	
Maria Rosaria Scarfi	X	X ^a		X	X
Denis Zmirou	X				

^aFormer. WHO, World Health Organization; ICNIRP, International Commission on Non-Ionizing Radiation Protection; AGNIR, Advisory Group on Non-Ionising Radiation; SSM, Strålsäkerhetsmyndigheten (Swedish Radiation Safety Authority); SCENIHR, Scientific Committee on Emerging and Newly Identified Health Risks.

should be stated officially whenever a member from ICNIRP makes opinions on health risks from EMF (Karolinska Institute diary number: 3753-2008-609). No statement of such conflict of interest can be found in the WHO draft of the Monograph on RF radiation.

Several persons and groups have sent critical comments to WHO on the many shortcomings in the draft of the Monograph on RF fields. In general WHO has not responded to these comments and it is unclear to what extent, if any, they are considered. Due to the short time for submission our (Lennart Hardell, Michael Carlberg) comments related only to section 12.1 Cancer Epidemiology. Our concluding remarks dated December 15, 2014 were: 'In conclusion the WHO draft is biased towards the null results. Findings on an association between use of wireless phones (mobile phones and cordless phones) and increased risk for brain tumours are misinterpreted, selectively reported and/or omitted in total. The draft cannot be used as science-based evaluation of increased risk. It needs to be re-written in a balanced way by scientists trained in epidemiology and oncology, not the least in medicine, and without conflicts of interest.'

Moreover, after the formal closing date for comments on the Monograph several additional submissions have been made to WHO. Professor Michael Kundi at Center for Public Health, Institute of Environmental Health, Vienna, Austria stated in his summary dated January 12, 2015: 'I was only able to check chapter 12 about cancer and only the epidemiological studies. While the EHC (Environmental Health Criteria) team did a great job in allocating the relevant literature with only few more recent papers missing, I'm not fully satisfied with the assessment of the evidence. There is a striking imbalance in the comments made on studies that were positive in contrast to those that were negative. Only the most obvious shortcomings of studies that didn't report an effect of exposure are mentioned while positive findings are often discussed at length, sometimes with very far-fetched assumptions about potential sources of bias. This is in marked contrast to other EHC monographs that are discussing the evidence in a way not to overlook a potential harmful effect. My comments, giving reference to the lines of the draft are detailed on the following pages.'

The BioInitiative Working Group issued December 19, 2016 a 'No Confidence' Letter to the WHO EMF Program

Manager: 'The BioInitiative Working Group urges the World Health Organization to make changes to the WHO RF EHC Core Group membership to more fairly reflect membership and expertise of the 2011 IARC RF Working Group. At present, the WHO RF EHC Core Group is indistinguishable from ICNIRP... undermining credibility of the process and ensuring doubt about conclusions... Even if schedule delays occur as a result, an acceptable outcome depends on public confidence. There [are] now many thousands of high quality scientific papers indicating possible non-thermal RF risks to health and those experts most competent by virtue of their research contributions are absent from this process... Both human and animal results are now available to incorporate in the RF EHC risk assessment. This important effort can only be assured with a more balanced composition of core participants in the process. As well, the membership needs to be inclusive of under-represented countries such as Russia, China, India, Turkey, and Iran whose research communities have produced the majority of studies on non-thermal effects of RF in recent years.' (<http://www.bioinitiative.org/report/wp-content/uploads/2016/12/BIWG-final-draft-WHO-RF-EHC-Monograph-team-composition.pdf>).

This letter was followed by another from the BioInitiative Working Group on January 24, 2017 including suggestion of experts to replace present persons in the Core Group and Additional Experts: 'We have not yet received a reply acknowledging our letter... It is important that the most knowledgeable panel of experts be appointed to prepare the RF EHC Monograph. At present, the EHC Core Group members uniformly represent attitudes and scientific positions of ICNIRP, an organization whose membership has steadfastly refused to accept new scientific evidence of potential health risks from non-thermal, low-intensity radiofrequency radiation despite recent scientific advances in knowledge on the subject. We are recommending substitutions for membership as indicated on the attached page. Please note that we are suggesting a complete replacement for those persons currently holding positions.' (<http://www.bioinitiative.org/report/wp-content/uploads/2017/01/BIWG-EHC-substitution-letter.pdf>).

Call for Protection from Non-ionizing Electromagnetic Field Exposure was made by the International Electromagnetic Field Scientist Appeal, initial release date May 11, 2015, latest version's date January 29, 2017 with 222 signatures

from 41 nations: 'We are scientists engaged in the study of biological and health effects of non-ionizing electromagnetic fields (EMF)... Effects include increased cancer risk, cellular stress, increase in harmful free radicals, genetic damages, structural and functional changes of the reproductive system, learning and memory deficits, neurological disorders, and negative impacts on general well-being in humans. Damage goes well beyond the human race, as there is growing evidence of harmful effects to both plant and animal life. These findings justify our appeal to the United Nations (UN) and, all member States in the world, to encourage the World Health Organization (WHO) to exert strong leadership in fostering the development of more protective EMF guidelines, encouraging precautionary measures, and educating the public about health risks, particularly risk to children and fetal development. By not taking action, the WHO is failing to fulfil its role as the preeminent international public health agency.' (<https://www.emfscientist.org/index.php/emf-scientist-appeal>).

A press release was issued on February 24, 2017 by the European coordination of organizations for an EMF exposure regulation which truly protects public health. The European citizens' organizations failed, however, to include in their letter the conflict of interest associated with ICNIRP members assessing possible effects below set ICNIRP guidelines, see discussion above. They stated that: 'The Conflict of Interest Scandal is repeating itself in the WHO: European citizens' organizations uncover conflicts of interest between the health and radiofrequency WHO expert group and telecommunications or electric companies. Almost 40 organizations and European Platforms (which in turn include many regional, national or local social organizations), supported by the International EMF Alliance (IEMFA), denounce the flagrant conflict of interest of the Core Group of experts for drafting, in the current year, of a WHO Environmental Health Criteria Monograph on Radio-Frequency Fields...

The preponderant presence of members of the International Commission on Non-Ionizing Radiation Protection (ICNIRP) reminds us that this organization (and other institutions with the same criteria) refused to accept new scientific evidence of potential health risks from non-thermal, low-intensity radiofrequency radiation despite recent scientific advances in knowledge on the subject. The ICNIRP not only does not guarantee transparency or independence but conflicts of interest of its members are well known and reported, due to their relationships with telecommunications or electric companies, thereby undermining the impartiality that should govern the regulation of Public Exposure Standards for non-ionizing radiation... By not taking action, the WHO is failing to fulfill its role as the preeminent international public health agency...' (<http://www.peccem.org/DocumentacionDescarga/Plataforma-Estatal/notasprensa/European.coordination.press.release-february-2017.pdf>).

Letter dated March 1, 2017 from Russian National Committee on Non-Ionizing Radiation Protection to Maria Neira, Director, Public Health and Environment with copy to Dr. E. van Deventer, Public Health and Environment, WHO: 'It has just come to our attention that the WHO RF Working group consists mainly from present and past ICNIRP members. In general, the WG is not balanced and... the private self-elected

organization ICNIRP, similar as majority of the current WHO RF WG members, does not recognize the non-thermal RF effects,... Thus, the guidelines of ICNIRP are irrelevant to present situation when majority of population over the world is chronically exposed to non-thermal RF from mobile communication.' (<http://www.radiationresearch.org/articles/rusncnirp-letter-to-who/>), letter available at (http://www.mast-victims.org/resources/docs/RNCNIRP-letter-WHO/2017_03_01.pdf).

5. Human Health Effects of Non-Ionizing Radiation - Informal meeting at WHO March 3, 2017

It is quite obvious that it would be of utmost value to learn what is on-going at WHO regarding the Monograph on RF radiation, especially since formal responses to submissions with comments are virtually absent. Thus, some 9 months after initial contact Dr Maria Neira accepted to organize a meeting, relating to the effects of electromagnetic fields on health, in her office at WHO in Geneva. The request for a meeting was made by independent researchers from different universities. An informal meeting was organized on March 3, 2017. (http://eceri-institute.org/fichiers/1490952497_news-letter_ECERI_5.pdf).

Dr Maria Neira is Director of the Public Health and the Environment Department at WHO. Present at the meeting was also Dr Emilie van Deventer, the Team Leader of the Radiation Programme at WHO which deals with non-ionizing and ionizing radiation topics related to human health. She has been working at WHO since 2000 where she heads the International EMF Project, the Ultraviolet INTERSUN Programme and the International Radon Project. Dr van Deventer received a Ph.D. in Electrical Engineering from the University of Michigan, USA. She was adjunct professor of Electrical and Computer Engineering, financed by the telecom industry, at the University of Toronto in Canada from 1992 to 2000. She is the WHO Observer on the Main Commission of ICNIRP, e.g. participating in ICNIRP meetings. (<http://www.itu.int/en/ITU-T/Workshops-and-Seminars/emf/201307/Pages/vanDeVENTERTaheraEmilie.aspx>). She is also one of 8 members of the Swedish Radiation Safety Authority (SSM).

The allocated time at the WHO office was 1.5 h. Dr Maria Neira opened the meeting stressing that it was not official but informal. She told that her department is very much interested in challenging science. In addition to myself, four additional experts were also present. The experts gave short presentations on health effects of RF radiation, biological effects from exposure to non-thermal RF radiation, overview of epidemiological studies on brain tumour risk, RF radiation and electromagnetic hypersensitivity (EHS), and finally epigenetic mechanisms by which children are especially-vulnerable to RF radiation. Obviously the five presentations were very short in order to give time for discussions, the most important part of the meeting.

The participating team of five experts with considerable knowledge and own research within this area offered to collaborate with WHO, especially to finalize the WHO Monograph on RF radiation. Maria Neira stated clearly that no collaboration with WHO is to be considered, and further that she does not intend to have another meeting with the group. However,

Table II. World Health Organization (Geneva, Switzerland) levels of RF-radiation March 3, 2017 ($\mu\text{W}/\text{m}^2$) treating values at detection limit as 0.^a

	n	Mean	Median	Min	Max
FM	1,813	2.0	1.2	0.0	128.4
TV3	1,813	0.0	0.0	0.0	1.7
TETRA I	1,813	0.1	0.0	0.0	136.7
TETRA II	1,813	0.0	0.0	0.0	0.0
TETRA III	1,813	0.0	0.0	0.0	3.2
TV4&5	1,813	0.1	0.0	0.0	11.9
LTE 800 (DL)	1,813	1.3	0.4	0.0	101.9
LTE 800 (UL)	1,813	0.0	0.0	0.0	0.0
GSM + UMTS 900 (UL)	1,813	0.0	0.0	0.0	4.7
GSM + UMTS 900 (DL)	1,813	8.6	4.9	0.3	268.2
GSM 1800 (UL)	1,813	0.3	0.0	0.0	182.1
GSM 1800 (DL)	1,813	4.2	1.7	0.3	268.2
DECT	1,813	0.3	0.1	0.0	38.2
UMTS 2100 (UL)	1,813	0.0	0.0	0.0	0.4
UMTS 2100 (DL)	1,813	4.5	2.5	0.4	199.1
WIFI 2G	1,813	0.0	0.0	0.0	1.3
LTE 2600 (UL)	1,813	0.0	0.0	0.0	0.0
LTE 2600 (DL)	1,813	0.0	0.0	0.0	0.6
WiMax	1,813	0.0	0.0	0.0	0.0
WIFI 5G	1,813	0.0	0.0	0.0	4.0
Total	1,813	21.5	13.3	4.8	432.3

^aFrequency bands and number (n) of readings are given.

she added that she is open to new data. She also said that there is no conflict of interest with ICNIRP since ICNIRP is a WHO collaborative organization. The scientific group, as above, was instead invited to send to WHO peer-reviewed publications, especially meta-analyses that would be the 'best gift'.

It was stated by the WHO officials that ICNIRP is an NGO with an official relationship with WHO that 'helps us a lot in our analyses' and their members work as WHO's experts. Thus, in spite of five of six persons in the Core Group for the Monograph being affiliated with ICNIRP, WHO seems to have no intention to change these members. On the other hand, the Task Group is not finalized. According to the meeting all experts are selected on individual basis and not as members of ICNIRP. Further, it was stated that the WHO guideline documents are in full WHO's responsibility. It is not known when the Monograph on RF radiation will be published. WHO still 'keeps looking at the evidence' and is still adding new documents to the Monograph.

The decision by the Ethical Board at the Karolinska Institute in Stockholm, Sweden from 2008 that being a member of ICNIRP may be a conflict of interest that should be stated in scientific publications was brought into attention during the meeting. WHO was unaware of that document and promised to 'look into it'. Obviously that conflict of interest applies to almost the whole Core Group of the Monograph, several members of additional experts, not to say Emilie van Deventer and thus the whole WHO EMF project and the Monograph on RF radiation.

6. Exposure to RF radiation within the WHO building in Geneva

In our on-going project on measurements of ambient RF radiation in some cities Geneva is part of the study. Results of parts of Stockholm, Sweden have been published (16,17) and will be used e.g. for comparison with levels in the future due to further development of this technology. In Geneva also measurements within the WHO building; main entrance, some corridors and the meeting room were included. These previously unpublished results have been communicated to the representatives at WHO including that they will be published. There has been no reaction from the WHO.

An EME Spy 200 exposimeter with a valid calibration was used to collect the exposure data. The exposimeter measures 20 predefined frequency bands that cover frequencies from 88-5,850 MHz. The sampling time was every 4th sec which is the fastest for the given exposimeter, for further details see our publications. For frequency modulation (FM), TV3, TETRA, TV4&5, Wi-Fi 2G and Wi-Fi 5G, the lower detection limit is 0.01 V/m (0.27 $\mu\text{W}/\text{m}^2$); for all other bands, the lower detection limit is 0.005 V/m (0.066 $\mu\text{W}/\text{m}^2$) (16,17).

The results, presented in Table II, show low mean total exposure level, 21.5 $\mu\text{W}/\text{m}^2$, thus below the scientific benchmark of 30 to 60 $\mu\text{W}/\text{m}^2$ that has been proposed to be the 'lowest observed effect level' (LOEL) for RF radiation, see Chapter 24

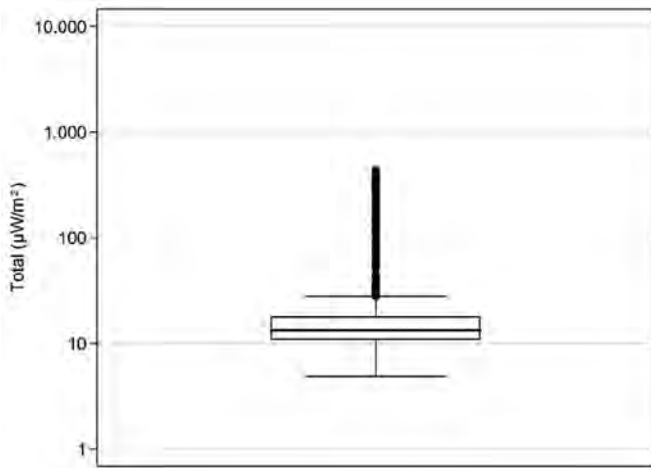


Figure 1. World Health Organization, 20 Avenue Appia, CH-1211 Geneva 27, Switzerland. Box plot for total exposure in $\mu\text{W}/\text{m}^2$, logarithmic scale. The median is indicated by a black line inside the box; the bottom and top of the boxes show first and third quartiles; the end of the whisker is calculated as $1.5 \times \text{IQR}$ (interquartile range). Points represent outliers.

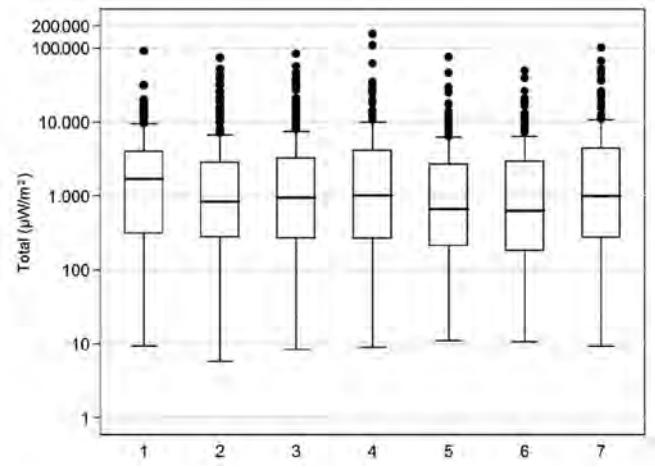


Figure 3. Box plot for total exposure in $\mu\text{W}/\text{m}^2$ for the seven measurement rounds in the Stockholm Central Railway Station (16). The median is indicated by a black line inside each box; the bottom and top of the boxes show first and third quartiles; the end of the whiskers are calculated as $1.5 \times \text{IQR}$ (interquartile range). Points represent outliers.

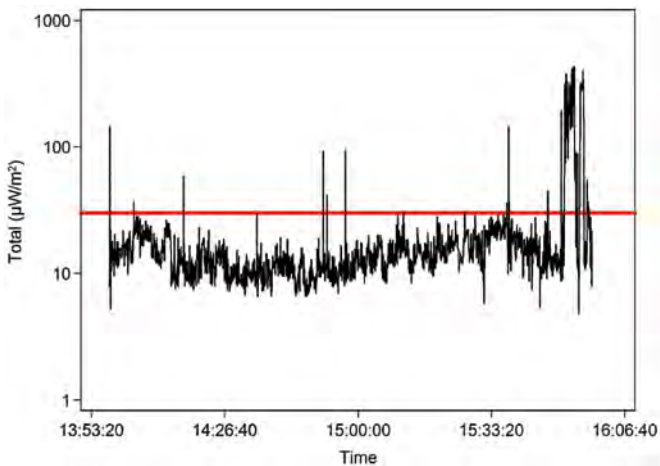


Figure 2. World Health Organization, Geneva, Switzerland. Total RF field exposure ($\mu\text{W}/\text{m}^2$, mean exposure= $21.5 \mu\text{W}/\text{m}^2$, logarithmic scale) over time of one exposure round, March 3, 2017 time 13:57:53-15:58:31. The horizontal line represents the LOEL exposure limit of $30 \mu\text{W}/\text{m}^2$ suggested by the Bioinitiative Report (21).

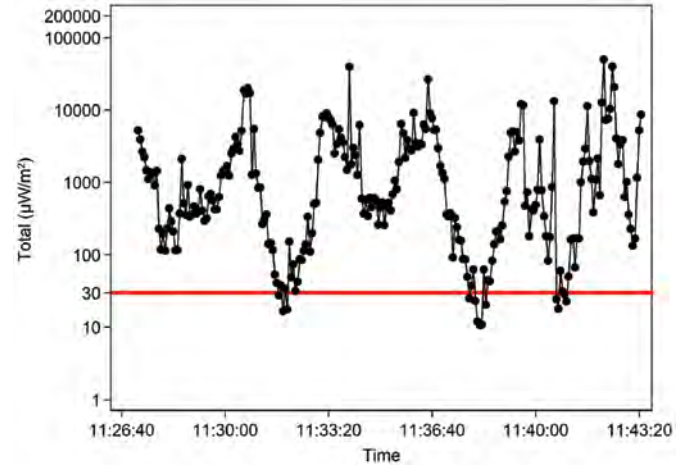


Figure 4. Total radiofrequency field exposure ($\mu\text{W}/\text{m}^2$) of the lowest exposure round (November 9, 2015; mean exposure $2,817.0 \mu\text{W}/\text{m}^2$) by walking across the Stockholm Central Station (16). The line represents the exposure limit of $30 \mu\text{W}/\text{m}^2$ suggested by the Bioinitiative Report (21).

of the BioInitiative Report (21). Note that only for the mean it is possible to calculate the total as the sum of means of the individual frequency bands, mathematically this is not possible for median, min and max in Table II. The major sources were GSM + UMTS 900 DL (3G), GSM 1800 DL (2G) and UMTS 2100 DL (3G), i.e. downlink (DL) of RF radiation from outside base stations. The results for total exposure are also presented as box plot in Fig. 1. In Fig. 2 total exposure over time is presented. Almost all RF radiation was below $30 \mu\text{W}/\text{m}^2$, the LOEL of RF radiation for possible health risks as shown with the horizontal line. The highest peak level, $432.3 \mu\text{W}/\text{m}^2$, was measured at 15:54:07. Most contribution was from GSM 1800 (DL), $268.2 \mu\text{W}/\text{m}^2$, and UMTS 2100 (DL), $110.4 \mu\text{W}/\text{m}^2$. This was measured just inside the building at the entrance and represent RF radiation from base stations in the vicinity.

The exposure to RF radiation within the WHO building is very low compared to other measurements, for example our

measurements inside the Stockholm Central station where people both are passing through but also are there for hours each day such as security and police staff, cafe workers, shop workers, janitors, information counter people, etc., see Figs 3 and 4. Here, the mean total exposure for the lowest exposure round was $2,817 \mu\text{W}/\text{m}^2$, mostly from down loading from GSM, 3G and 4G base stations (16). Thus, the measured mean level in the WHO building is more than 130 times lower than in the Stockholm Central Station.

7. Concluding remarks

The meeting at WHO was an obvious disappointment. During the discussion the two WHO officials showed little interest to collaborate with the scientists convened at the meeting in spite of the scientific evidence on adverse health effects. Their in-house experts seem to be members of ICNIRP,

although not exclusively. This may explain why only short-term thermal effects from RF radiation are accepted as proofs of harm, and why non-thermal biological effects are ignored. In the draft of the Monograph a large bulk of peer-reviewed scientific publications on non-thermal effects are dismissed, c.f. as also by ICNIRP (19). Most remarkable is that WHO has no intention to replace the Core Group of experts affiliated with ICNIRP. Thereby ICNIRP is given full access to and exclusive possibilities to influence the Monograph. In view of the huge economic interests built into the ICNIRP guidelines, and several of its expert members' ties to industry, no doubt this is a large conflict of interest that will seriously undermine not only the credibility of the Monograph on RF radiation but also the credibility of WHO as a protector of world health. Seriously enough, the Monograph will be the hallmark for years to come on evaluation of health hazards from RF radiation and pave the way for increasing exposure to RF radiation to people and environment, e.g. the fifth generation (5G), internet of things, etc.

Children and adolescents may be more sensitive to RF radiation than adults (2). Thus as an authoritative agency, WHO has an obligation to reference all the scientific research results and call the experts from all the related fields like engineering, health and medicine to engage in the re-evaluation of all health effects including non-thermal of RF radiation. Related agencies should launch an objective and transparent project for this assessment. The EMF project was started many years ago and many new wireless digital technologies are developed and new devices are popularizing with a very fast speed.

Protests and comments by scientific experts and several organizations seem to be ignored. The Monograph might be political and industry supportive more than scientific and health promoting. For a definitive conclusion a more thorough review of the whole draft document would be needed. By now it is time for laymen, NGOs and scientists to exert pressure on politicians to change the WHO agenda on RF radiation and health hazards and decide that WHO's purpose is to support world health instead of industry interests. It is also time to evaluate the competence of the persons making the evaluations and decisions before publishing the Monograph. Of note, evidence has been published (52) which indicated that members of ICNIRP have written scientifically incorrect and misleading information. It is unknown if WHO has responded to this evidence of suggested scientific misconduct.

To evaluate cancer risks it is necessary to include scientists with competence in medicine, especially oncology. Furthermore, what are the personal advantages, at least in the short time, for those refusing to accept peer-reviewed scientific publications on adverse effects on health and environment from RF radiation? Ironically enough, whether knowingly or not, the WHO staff seems to protect themselves from high involuntary RF radiation levels at least in the measured areas within the Geneva building.

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High radiofrequency radiation at Stockholm Old Town: An exposimeter study including the Royal Castle, Supreme Court, three major squares and the Swedish Parliament

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Abstract. Exposure to radiofrequency (RF) radiation was classified as a possible human carcinogen, Group 2B, by the International Agency for Research on Cancer at WHO in 2011. The exposure pattern is changing due to the rapid development of technology. Outdoor RF radiation level was measured during five tours in Stockholm Old Town in April, 2016 using the EME Spy 200 exposimeter with 20 predefined frequencies. The results were based on 10,437 samples in total. The mean level of the total RF radiation was $4,293 \mu\text{W}/\text{m}^2$ ($0.4293 \mu\text{W}/\text{cm}^2$). The highest mean levels were obtained for global system for mobile communications (GSM) + universal mobile telecommunications system (UMTS) 900 downlink and long-term evolution (LTE) 2600 downlink ($1,558$ and $1,265 \mu\text{W}/\text{m}^2$, respectively). The town squares displayed highest total mean levels, with the example of Järntorget square with $24,277 \mu\text{W}/\text{m}^2$ (min 257 , max $173,302 \mu\text{W}/\text{m}^2$). These results were in large contrast to areas with lowest total exposure, such as the Supreme Court, with a mean level of $404 \mu\text{W}/\text{m}^2$ (min 20.4 , max $4,088 \mu\text{W}/\text{m}^2$). In addition, measurements in the streets surrounding the Royal Castle were lower than the total for the Old Town, with a mean of $756 \mu\text{W}/\text{m}^2$ (min 0.3 , max $50,967 \mu\text{W}/\text{m}^2$). The BioInitiative 2012 Report defined the scientific benchmark for possible health risks as $30\text{--}60 \mu\text{W}/\text{m}^2$. Our results of outdoor RF radiation exposure at Stockholm Old Town are significantly above that level. The mean exposure level at Järntorget square was 405-fold higher than $60 \mu\text{W}/\text{m}^2$. Our results were below the reference level on $10,000,000 \mu\text{W}/\text{m}^2$ established by the International Commission on Non-Ionizing

Radiation Protection (ICNIRP), which, however, are less credible, as they do not take non-thermal effects into consideration and are not based on sound scientific evaluation. Our highest measured mean level at Järntorget was 0.24% of the ICNIRP level. A number of studies have found adverse, non-thermal (no measurable temperature increase) health effects far below the ICNIRP guidelines.

Introduction

The results of a study on public exposure to radiofrequency (RF) radiation at the Stockholm Central Railway Station in Sweden were recently published (1). The exposimeter EME Spy 200 that covers 20 different radiofrequency bands from 87 to $5,850$ MHz was used. The results were based on 1,669 data points recorded in November, 2015. The median value for total exposure was $921 \mu\text{W}/\text{m}^2$ ($0.092 \mu\text{W}/\text{cm}^2$), with certain outliers $>95,544 \mu\text{W}/\text{m}^2$ (6 V/m, which is the upper detection limit). One example of such very high measured power density was from a global system for mobile communications (GSM) + universal mobile telecommunications system (UMTS) 900 downlink band from a base station located at the Stockholm Central Station lower level (1). People standing at that area or passing by are involuntarily exposed to high RF radiation without their knowledge. It was concluded that this represented an improper location of a base station with an unnecessary high downlink level.

In European countries, the Old Town is a point of a national heritage, a place and source of cultural and historical development throughout centuries. Stockholm Old Town has already been retrofitted with several existing antennas to accommodate voice and data transmission. The aim of the present study was to characterize RF radiation already in place and its effect on the public. The antenna grid is expected to be further expanded to accommodate the rollout of 5G mobile networking as the next wave of mobile technology is implemented. As mobile base station antennas are placed on rooftops, outer walls of buildings and other places, visual perturbations appear in the form of antenna casings, cables and other peripheral devices. Not only does this damage the aesthetic appearance of the historic districts of the Old Town,

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but it is associated with exposure of the public to invisible RF radiation. Even where hidden antennas have been architecturally camouflaged (stealth installations), the RF radiation exposure is still present and remains a growing concern for environmental health.

The most drastic change brought about by the mobile telephony network is the change in the electromagnetic climate. The streets of old towns are filled with visually imperceptible RF radiation. As modern mobile telephony and data networking provide services at several different bands, there are different frequencies that also require band-specific antennas, therefore multiplying the number of antennas.

One major concern regarding RF radiation exposure in Sweden, as well as in a number of other countries, is that various authorities base their guidelines for exposure on the International Commission on Non-Ionizing Radiation Protection's (ICNIRP) guidelines that are based on short-term (acute) exposure. Chronic, low-intensity cumulative exposure, possible long-term health risks and non-thermal biological effects are not taken into consideration. The ICNIRP safety limit was established in 1998 (2) and updated in 2009 (3), without any further changes, and it still recommends 10 W/m^2 ($10,000,000 \mu\text{W/m}^2$) as the reference level for limiting the public's exposure to RF radiation (2–300 GHz) (2). The Swedish Radiation Safety Authority (SSM) has adopted the ICNIRP guidelines. Several members of the SSM expert panel are also members of ICNIRP, which may entail a conflict of interest, since these members would rarely compromise the ICNIRP view so that critical opinions are not heard.

Our results on public RF radiation exposure at the Stockholm Central Station are orders of magnitude lower than the ICNIRP guidelines, where the median level of exposure was $\sim 10,000$ times lower. Wireless internet access in schools is also a concern (4), although measurements of levels are scanty.

In contrast to ICNIRP, the BioInitiative Reports from 2007 (5), updated in 2012 (6), also based their evaluation on the non-thermal effects of RF radiation. The BioInitiative 2012 Report assessed $\sim 1,800$ new peer-reviewed studies published between 2006 and 2012 that documented the new and lower scientific benchmark for health harm to be $30\text{--}60 \mu\text{W/m}^2$ ($0.003\text{--}0.006 \mu\text{W/cm}^2$), which is $0.0003\text{--}0.0006\%$ below ICNIRP's guidelines. Also considering chronic exposure and sensitivity among children, the precautionary target level was proposed to be one-tenth of this value, namely $3\text{--}6 \mu\text{W/m}^2$ (6). This exposure target level is not acknowledged by SSM, thus making it possible to overlook results on exposure, such as those at the Stockholm Central Station, and not providing precautions against potential detrimental effects on public health.

Interestingly, scientific evidence on the carcinogenic potential of RF radiation in laboratory studies has long been accumulating, but has mostly been ignored or entirely overlooked by decision-makers.

In 1982, Szmigielski *et al* published a study on the co-carcinogenic effects of RF radiation exposure and benzopyrene in mice (7) and demonstrated that 2,450 MHz of RF radiation at either 50 or 150 W/m^2 promoted carcinogenesis. The authors concluded that the resulting acceleration of development of spontaneous and chemically induced cancers indicated the carcinogenic potential of RF radiation.

Two studies published in 1990 demonstrated that non-thermal 2,450 MHz continuous-wave RF radiation exerted a biphasic effect on glioma cells (8) and lymphocytes (9). Cell proliferation was found at a specific absorption rate (SAR) of $\leq 50 \text{ W/kg}$, whereas a higher SAR suppressed DNA and RNA synthesis. These effects were reported to be non-thermal.

In 1992, Chou *et al* published a study on 200 rats exposed to 2,450 MHz pulsed RF radiation for 21.5 h/day for 25 months and 200 controls (10). SAR ranged between 0.144 and 0.4 W/kg , depending on the rat's weight. A statistically significantly increased incidence of primary malignant diseases was found in exposed animals compared with sham exposure. It should be noted that malignant lymphoma and thyroid cancer were among the malignancies found in exposed rats. These findings are interesting in view of the low SAR values in that study compared with the ICNIRP safety limit of 2 W/kg in the brain for use of mobile phones (2).

In 1997, a study on mice carrying a lymphomagenic oncogene exposed to RF radiation was published (11). A total of 100 mice were sham-exposed and 101 were exposed for two 30-min periods per day for up to 18 months to 900 MHz pulsed RF radiation with power densities of $2.6\text{--}13 \text{ W/m}^2$ (SAR $0.008\text{--}4.2 \text{ W/kg}$; mean, $0.13\text{--}1.4 \text{ W/kg}$). The lymphoma risk was found to be statistically significantly higher in the exposed mice compared with that in the controls.

Those results were not confirmed in the study by Utteridge *et al* (12), which has been criticized for not being a replication study. However, the findings on lymphoma risk by Repacholi *et al* (11) and Chou *et al* (10) are of relevance in terms of increased non-Hodgkin lymphoma (NHL) risk in epidemiological studies on humans associated with the use of wireless phones. Thus, a statistically significantly increased risk of T-cell NHL was found in a previous study [odds ratio (OR)=8.75] (13) and in a second study for all NHL cases among subjects with >6 years of mobile phone use (OR=4.4 in men) (14), although based on limited numbers. Furthermore, the finding of thyroid cancer risk in the Chou *et al* study (10) is interesting in view of the sharp increase in the incidence of thyroid cancer during recent years (15). The thyroid gland is among the organs with highest exposure to RF radiation during use of handheld wireless phones, particularly smartphones (16,17).

The effects on tumour susceptibility in mice exposed to a UMTS test signal from the fetal period for up to 24 months was studied by Tillman *et al* (18). Animals were exposed to UMTS fields with intensities of 0, 4.8 and 48 W/m^2 . The low-dose group (4.8 W/m^2) was subjected to additional prenatal ethylnitrosourea (ENU) treatment. The group that was ENU-treated and UMTS-exposed at 4.8 W/m^2 exhibited an increased rate of lung tumours and an increased incidence of lung carcinomas as compared with the controls treated with ENU alone. The authors concluded that the study demonstrated a co-carcinogenic effect of lifelong UMTS exposure in female mice subjected to pretreatment with ENU (18).

A follow-up study of the Tillman *et al* investigation was published in 2015 (19). The exposure levels were 0 (sham), 0.04, 0.4 and 2 W/kg SAR. The numbers of lung and liver tumours in exposed animals were statistically significantly higher compared with those in sham-exposed controls, as were the numbers of malignant lymphoma. A tumour-promoting

effect of RF radiation was found at low to moderate levels (0.04 and 0.4 W/kg SAR), which were well below the exposure limits for users of mobile phones (19).

A report was released from The National Toxicology Program (NTP) under the National Institutes of Health (NIH) in USA on the largest ever animal study on cell phone RF radiation and cancer (20). An increased incidence of glioma in the brain and malignant schwannoma in the heart was found. Acoustic neuroma or vestibular schwannoma is a similar type of tumour as the one found in the heart, although benign. The use of mobile as well as cordless phones has been associated with increased risk for glioma and acoustic neuroma in humans, as described below.

The same RF radiation that led male rats to develop brain tumours in the NTP study also caused DNA breaks in their brains. Female rats, which did not have statistically significantly elevated tumour counts, had fewer DNA breaks (<http://microwavenews.com/news-center/ntp-comet-assay>). According to Ron Melnick, who led the team that designed the NTP study, the results provide 'strong evidence for the genotoxicity of cell phone radiation' and this 'should put to rest the old argument that RF radiation cannot cause DNA damage'. The study is currently under peer review.

These new NTP study results appear to corroborate the findings of the 1995 study by Lai and Singh regarding increased levels of DNA single-strand breaks in brain cells from rats acutely exposed to low-intensity 2,450 MHz microwaves (21). A dose-rate-dependent increase in DNA single-strand breaks was found in brain cells of rats at 4 h post-exposure to 0.6 and 1.2 W/kg whole-body SAR. In rats exposed for 2 h to continuous-wave 2,450 MHz microwaves (SAR 1.2 W/kg), increases in brain cell DNA single-strand breaks were observed immediately as well as at 4 h post-exposure (21).

Our research group published the first results on the increased risk for brain tumours associated with the use of mobile and cordless phones ~15 years ago (22-25). More results have been obtained from our subsequent studies, as well as from studies conducted in other countries. The International Agency for Research on Cancer (IARC) at WHO concluded in 2011 that RF radiation is a possible human carcinogen, Group 2B (26,27). The IARC decision was based on human Swedish studies by our group (28-30) and the IARC Interphone Study (31-33) giving evidence of increased risk for brain tumours, mainly glioma, and acoustic neuroma in subjects using mobile phones. These results have been replicated in our subsequent studies (34-37) and the French CERENAT study on glioma and meningioma (38). IARC concluded that there is limited evidence from experimental animal studies supporting the carcinogenicity of RF radiation. However, later published human and animal studies reported that there is sufficient evidence of the carcinogenicity of RF radiation. That conclusion is supported by our review (39) using the Bradford Hill viewpoints (40) on the association or causation on environment and disease. Mechanistic studies that support a causal inference are also currently available and discussed below.

As areas with high RF radiation were previously recorded at the Stockholm Central Station in Sweden (1), the aim of the present study was to continue with outdoor measurements in locations visited by numerous individuals in Stockholm. Stockholm Old Town is a popular place for tourists that is

located in Stockholm City within walking distance from the Central Railway Station. Several people reside in the Old Town and a number of shops and restaurants are located within this area. In addition, certain government buildings, such as the Supreme Court and the Royal Castle and the nearby Swedish Parliament, are located in that region as well.

As this was a measurement study with no involvement of test subjects, no ethical permission was required.

Materials and methods

EME Spy 200 exposimeter. In this study, an EME Spy 200 exposimeter (Satimo, MVG Industries, Brest, France) with a valid calibration was used to collect the exposure data. The exposimeter measures 20 predefined frequency bands, as presented in Table I. These cover the frequencies of most public RF radiation emitting devices currently used in Sweden. The exposimeter covers frequencies of 87-5,850 MHz. For frequency modulation (FM), TV3, TETRA, TV4&5, Wi-Fi 2G and Wi-Fi 5G, the lower detection limit is 0.01 V/m ($0.27 \mu\text{W}/\text{m}^2$); for all other bands, the lower detection limit is 0.005 V/m ($0.066 \mu\text{W}/\text{m}^2$). For all bands, the upper detection limit is 6 V/m ($95,544 \mu\text{W}/\text{m}^2$; $9.5544 \mu\text{W}/\text{cm}^2$). The sampling time used in this study was every 4th sec, which is the fastest for the given exposimeter.

The exposimeter measures different telecommunications protocols: FM radio broadcasting; TV broadcasting; TETRA emergency services (police, rescue, etc.); GSM second-generation mobile communications; UMTS third-generation mobile communications, 3G; long-term evolution (LTE) fourth-generation mobile communications standard, 4G; digital European cordless telecommunications (DECT) cordless telephone systems standard; Wi-Fi wireless local area network protocol; worldwide interoperability for microwave access (WiMAX) wireless communication standard for high-speed voice, data and internet.

EME SPY 200 utilizes 3-axis antennas to capture RF radiation from all possible directions. The exposimeter was held at a distance of ~0.4 m from the body. The unit reports the exposure in a conservative manner, since each reported value is the sampling outcome, where many samples are collected and statistically processed including minimum, mean, median and maximum values.

Study design. The study was performed during daytime in April 8, 9, 10, 11, 13 and 22, 2016. These were all business days, except for April 9 and 10 (Saturday and Sunday). The length of the measurement route was up to 2.5 h, depending on the investigation. All major streets were covered during the investigation rounds. A few very short and narrow streets were not included. In addition, special measurement rounds were made using the streets surrounding the Supreme Court and the Royal Castle. The Swedish Parliament was also measured using the streets surrounding the Parliament as well as the central street, Riksgatan. Special measurement rounds were made at three squares, Stortorget, Kornhamnstorg and Järntorget. All measurements were included in the total result for the Old Town, except for the Swedish Parliament, which is located on the island of Helgeandsholmen and is reported separately. The buildings were selected as they are important sites

for decision-makers in Sweden. The squares were included as they are frequented by numerous visitors sitting outdoors at the restaurants and cafés. The selected locations as major streets, squares and buildings were measured several times, whereas small streets were measured only once. It should be noted that the Old Town is located on an island surrounded by water and, thus, is geographically well-defined (Fig. 1).

Statistical methods. Means, medians, minimum and maximum values in $\mu\text{W}/\text{m}^2$ were calculated for all measured frequency bands and for total exposure, and box plots were constructed to illustrate the distribution of total exposure for all measurement rounds. Values below the lower detection limit were treated as null (0). Total exposure was calculated as the sum of all measured frequency bands at each measured data point. Stata/SE 12.1 for Windows (StataCorp., College Station, TX, USA) was used for all calculations.

Results

The results of the Old Town measurements were based on 10,437 measurements in total during five separate measurement rounds, with a total of 696 min of measurements (~12 h). The results are displayed in Table II. The mean total level of RF radiation was $4,292.7 \mu\text{W}/\text{m}^2$. The highest mean values were obtained for GSM + UMTS 900 downlink and LTE 2600 downlink ($1,558.2$ and $1,264.9 \mu\text{W}/\text{m}^2$, respectively). It should be noted that the highest maximum levels were from base stations (5 bands) varying from $24,384.7$ (LTE 800 downlink) to $95,522.5$ (LTE 2600 downlink) $\mu\text{W}/\text{m}^2$. The highest maximum uplink (from a mobile phone) was found for GSM 1800, yielding $19,136.9 \mu\text{W}/\text{m}^2$.

In Fig. 2, the box plot shows the results for five old town measurements and all exposure (total). The total median level was $534.0 \mu\text{W}/\text{m}^2$ with several outliers of $>100,000 \mu\text{W}/\text{m}^2$.

In Fig. 3, the RF exposure variation over time is displayed for one of the measurement rounds. There was a large variation over time during these >2 h measurements covering major parts of the Old Town (streets and squares). The mean level was $5,371.4 \mu\text{W}/\text{m}^2$ (median, $701.8 \mu\text{W}/\text{m}^2$; range, 4.2 – $83,348.8 \mu\text{W}/\text{m}^2$). Only for few moments the exposure was $<100 \mu\text{W}/\text{m}^2$, whereas several measurements were $>10,000 \mu\text{W}/\text{m}^2$.

Royal castle. The Swedish Royal Castle was covered by measurement rounds on the surrounding streets and also the Castle Square (Yttre Borggården) during ~4 h measurement time in total. These measurements represent an area with among the lowest RF radiation in the Old Town. The results were also included in the total measurement of the Old Town. Rather low mean values were found for most downlink bands (Table III). The highest mean level was measured for UMTS 2100 downlink ($306.2 \mu\text{W}/\text{m}^2$). The total mean RF radiation level for the Royal Castle area was $755.6 \mu\text{W}/\text{m}^2$, representing only 17.6 % of the total mean level for the Old Town. In addition, the total highest level (maximum) was lower than all ($50,967.1 \mu\text{W}/\text{m}^2$, or 29.4% of the total).

The box plot in Fig. 4 of the six measurement tours to the Royal Castle area and total clearly shows lower levels compared with those for all the Old Town. The total median

Table I. Frequency ranges of predefined measurement frequency bands of EME Spy 200 exposimeter.

Frequency band	Frequency min (MHz)	Frequency max (MHz)
FM	87	107
TV3	174	223
TETRA I	380	400
TETRA II	410	430
TETRA III	450	470
TV4&5	470	770
LTE 800, 4G (DL)	791	821
LTE 800, 4G (UL)	832	862
GSM 900 + UMTS 900, 3G (UL)	880	915
GSM 900 + UMTS 900, 3G (DL)	925	960
GSM 1800 (UL)	1,710	1,785
GSM 1800 (DL)	1,805	1,880
DECT	1,880	1,900
UMTS 2100, 3G (UL)	1,920	1,980
UMTS 2100, 3G (DL)	2,110	2,170
Wi-Fi 2 GHz	2,400	2,483.5
LTE 2600, 4G (UL)	2,500	2,570
LTE 2600, 4G (DL)	2,620	2,690
WiMAX	3,300	3,900
Wi-Fi 5 GHz	5,150	5,850

FM, frequency modulation; TV, television; LTE, long-term evolution; DL, downlink (transmission from base station to mobile phone); UL, uplink (transmission from mobile phone to base station); GSM, global system for mobile communications; UMTS, universal mobile telecommunications system; DECT, digital European cordless telecommunications; WiMAX, worldwide interoperability for microwave access.

level was $387.8 \mu\text{W}/\text{m}^2$, without any significant variation between different tours.

Fig. 5 shows the RF exposure variation over time during one of the measurement rounds around the Royal Castle, clearly indicating that most measurements were $<1,000 \mu\text{W}/\text{m}^2$, with few spikes exceeding $10,000 \mu\text{W}/\text{m}^2$.

Supreme court. The results for the Supreme Court are displayed in Table IV. These measurements represent the lowest levels of RF radiation among all measurements. The total mean level was $403.6 \mu\text{W}/\text{m}^2$ and the maximum level was $4,088.1 \mu\text{W}/\text{m}^2$. Almost all exposure represented downlink bands from mobile telephony base stations.

Fig. 6 displays the box plot for the measurement tours around the Supreme Court and all exposure (total). The total median level was $274.5 \mu\text{W}/\text{m}^2$. Total exposure over time during the tours exhibited little difference over time, mostly $<1,000 \mu\text{W}/\text{m}^2$. The time variation for one tour is shown in Fig. 7.

Old town squares. The mean values for three major squares in the Old Town are shown in Table V. Several shops, restaurants and cafés are located in this region, including outdoor sitting



Figure 1. Map of Stockholm Old Town and Helgeandsholmen. Specific measurement locations are shown as follows: 1, Royal Castle; 2, Supreme Court; 3, Stortorget; 4, Kornhamnstorg; 5, Järntorget and 6, Swedish Parliament. Map from Lantmäteriet, Sweden.

areas. The results represent the highest measurements in the Old Town.

The highest levels were measured at the Järntorget square, as presented in Table VI. Only at Järntorget some levels for FM radio were detected, which were comparatively low in other parts of the Old Town. Very high mean and maximum levels were found for all downlinks from mobile telephony base stations, except for GSM 1800. The mean level for GSM + UMTS 900 downlink was noteworthy ($10,272.7 \mu\text{W}/\text{m}^2$). An exceptionally high total maximum level of $95,522.5 \mu\text{W}/\text{m}^2$ was measured for LTE 2600 downlink.

The box plot for the measurements in Järntorget is shown in Fig. 8 and variation over time during one tour is shown in Fig. 9. High levels were measured, with a total median of $19,990.0 \mu\text{W}/\text{m}^2$.

Swedish parliament. The Swedish Parliament is located on a separate island, Helgeandsholmen, just outside the Old Town. The results of four measurement rounds of ~ 1.5 h measurement time in total are shown in Table VII. Significantly lower levels were found compared with total measurements for the Old Town. RF level dynamics for one measurement tour are seen in Fig. 10.

Old town summary. The box plot in Fig. 11 shows a large variation in total exposure across measured sites in Stockholm Old Town. Relatively low RF levels were measured at the Royal Castle and the Supreme Court, whereas the Stortorget, Kornhamnstorg and Järntorget squares had exposure levels of at least an order of magnitude higher.

Discussion

The Stockholm Old Town RF radiation levels were measured on five occasions, yielding a total of 10,437 readings for the

Old Town. This study showed a large variation in outdoor RF radiation level in the Stockholm Old Town. Furthermore, it should be noted that the measurements mainly characterize downlink exposure, without considering personal use of wireless devices, such as mobile phones. Indoor RF levels are likely to be somewhat lower with respect to inbound radiation, since the walls and windows of buildings attenuate the signals. On the other hand, on the premises on the opposite side of the transmitter antennas, the exposure levels may be even an order of magnitude higher if the beam happens to be directed towards these premises. For accurate information it would be necessary to make measurements inside buildings such as the Royal Castle, the Supreme Court, restaurants, apartments and the Swedish Parliament. Several buildings contain Wi-Fi routers for wireless communication, which would increase exposure at Wi-Fi bands. Furthermore, personal use of wireless phones (mobile as well as cordless), use of tablets and wireless internet via computers, add to RF radiation exposure.

This study provides information on the passive RF radiation exposure in a popular area of Stockholm, which is a destination for a number of visitors, such as tourists, citizens contacting different authorities, employees and residents. The study determined low levels at the surroundings of the Royal Castle, with a mean level of $755.6 \mu\text{W}/\text{m}^2$, which is 17.6% of the total mean level in the Old Town ($4,292.7 \mu\text{W}/\text{m}^2$). An even lower mean level was measured for the Supreme Court ($403.6 \mu\text{W}/\text{m}^2$), representing 9.4% of the total mean level for the Old Town. It should also be noted that certain hotspots had somewhat higher RF radiation levels, both for the Royal Castle and the Supreme Court (Figs. 5 and 7). This is also illustrated by the box plots (Figs. 4 and 6) with third quartiles of $<1,000 \mu\text{W}/\text{m}^2$, with the exception of one of the Royal Castle measurements.

The abovementioned results are in large contrast to the squares of the Old Town. The three major squares were

Table II. Stockholm Old Town levels of radiofrequency radiation in total for five different tours on 8, 9, 11, 13 and 22 April, 2016.

Frequency band	No. of readings	Mean	Median	Min	Max
FM	10,437	11.1	0.0	0.0	3,674.6
TV3	10,437	1.5	0.0	0.0	273.3
TETRA I	10,437	18.6	0.0	0.0	2,913.3
TETRA II	10,437	0.2	0.0	0.0	253.3
TETRA III	10,437	0.6	0.0	0.0	790.8
TV4&5	10,437	4.0	0.0	0.0	2,775.9
LTE 800 (DL)	10,437	473.6	9.5	0.0	24,384.7
LTE 800 (UL)	10,437	0.0	0.0	0.0	1.7
GSM + UMTS 900 (UL)	10,437	4.3	0.0	0.0	9,972.7
GSM + UMTS 900 (DL)	10,437	1,558.2	38.2	0.0	84,495.3
GSM 1800 (UL)	10,437	10.3	1.0	0.0	19,136.9
GSM 1800 (DL)	10,437	215.2	37.6	0.0	73,221.5
DECT	10,437	5.0	0.0	0.0	1,127.6
UMTS 2100 (UL)	10,437	0.0	0.0	0.0	51.2
UMTS 2100 (DL)	10,437	720.4	152.8	0.0	71,228.5
Wi-Fi 2G	10,437	0.4	0.0	0.0	288.9
LTE 2600 (UL)	10,437	4.6	0.0	0.0	3,832.4
LTE 2600 (DL)	10,437	1,264.9	84.0	0.0	95,522.5
WiMAX	10,437	0.0	0.0	0.0	3.1
Wi-Fi 5G	10,437	0.0	0.0	0.0	62.1
Total	10,437	4,292.7	534.0	0.0	173,301.8

Analysis of all data ($\mu\text{W}/\text{m}^2$) treating values at detection limit as 0. FM, frequency modulation; TV, television; LTE, long-term evolution; DL, downlink (transmission from base station to mobile phone); UL, uplink (transmission from mobile phone to base station); GSM, global system for mobile communications; UMTS, universal mobile telecommunications system; DECT, digital European cordless telecommunications; WiMAX, worldwide interoperability for microwave access.

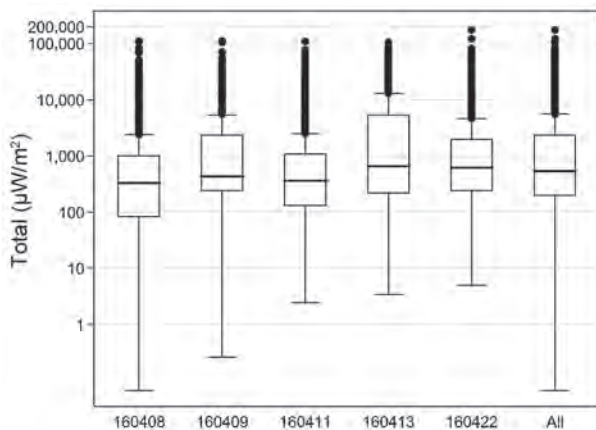


Figure 2. Stockholm Old Town. Box plot for exposure in $\mu\text{W}/\text{m}^2$, logarithmic scale, for the five measurement rounds and total exposure. The median is indicated by the black line inside each box; the bottom and top of the boxes represent the first and third quartiles; the end of the whiskers are calculated as 1.5 x interquartile range. The points represent the outliers.

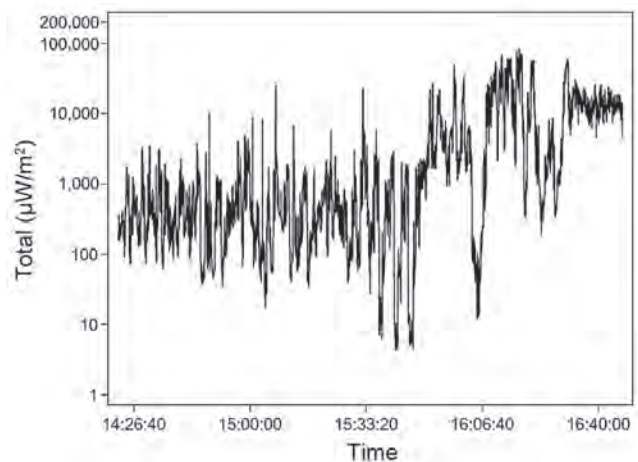


Figure 3. Stockholm Old Town. Total radiofrequency field exposure (mean exposure, 5,371.4 $\mu\text{W}/\text{m}^2$, logarithmic scale) over time of one typical exposure round (13 April, 2016; time, 14:22:14–16:46:58).

measured, namely Stortorget in the area of the Royal Castle, Kornhamnstorg and Järntorget at the other end of the Old Town. Particularly striking is the RF radiation level at Järntorget, although high mean levels were measured in all squares.

The mean RF radiation level at Järntorget was 24,277.1 $\mu\text{W}/\text{m}^2$, which is 60 times higher compared with that for the Supreme Court. It should also be noted that the maximum level for Järntorget was 173,301.8 $\mu\text{W}/\text{m}^2$, compared with 4,088.1 $\mu\text{W}/\text{m}^2$ for the Supreme Court, which is 42 times higher.

Table III. Stockholm Royal Castle levels of radiofrequency radiation in total as measured on 9, 11, 13 and 22 April, 2016.

Frequency band	No. of readings	Mean	Median	Min	Max
FM	3,385	3.7	0.9	0.0	140.3
TV3	3,385	1.8	0.0	0.0	85.9
TETRA I	3,385	51.6	1.7	0.0	2,913.3
TETRA II	3,385	0.3	0.0	0.0	74.9
TETRA III	3,385	0.8	0.0	0.0	655.2
TV4&5	3,385	1.4	0.0	0.0	133.1
LTE 800 (DL)	3,385	19.3	2.4	0.0	492.7
LTE 800 (UL)	3,385	0.0	0.0	0.0	0.3
GSM + UMTS 900 (UL)	3,385	9.7	0.0	0.0	9,972.7
GSM + UMTS 900 (DL)	3,385	51.2	6.6	0.0	3,961.0
GSM 1800 (UL)	3,385	14.4	1.2	0.0	19,136.9
GSM 1800 (DL)	3,385	172.4	42.1	0.0	44,198.2
DECT	3,385	1.4	0.0	0.0	234.0
UMTS 2100 (UL)	3,385	0.0	0.0	0.0	51.2
UMTS 2100 (DL)	3,385	306.2	126.1	0.1	32,530.5
Wi-Fi 2G	3,385	0.1	0.0	0.0	26.0
LTE 2600 (UL)	3,385	0.7	0.0	0.0	60.5
LTE 2600 (DL)	3,385	120.6	40.8	0.0	6,909.8
WiMAX	3,385	0.0	0.0	0.0	0.0
Wi-Fi 5G	3,385	0.0	0.0	0.0	1.4
Total	3,385	755.6	387.8	0.3	50,967.1

Analysis of all data ($\mu\text{W}/\text{m}^2$) treating values at detection limit as 0. FM, frequency modulation; TV, television; LTE, long-term evolution; DL, downlink (transmission from base station to mobile phone); UL, uplink (transmission from mobile phone to base station); GSM, global system for mobile communications; UMTS, universal mobile telecommunications system; DECT, digital European cordless telecommunications; WiMAX, worldwide interoperability for microwave access.

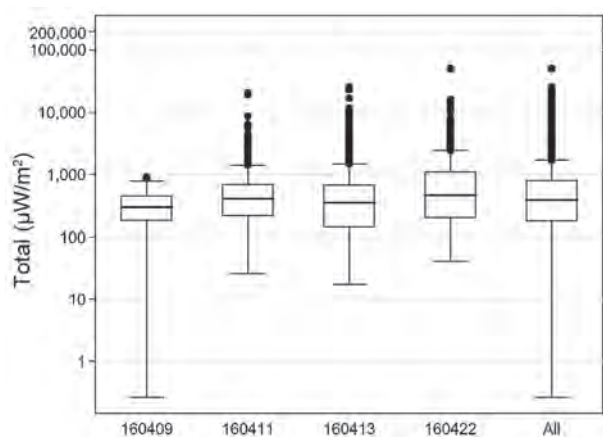


Figure 4. Stockholm Royal Castle. Box plot for exposure in $\mu\text{W}/\text{m}^2$, logarithmic scale, for four measurement rounds and total exposure. The median is indicated by the black line inside each box; the bottom and top of the boxes represent the first and third quartiles; the end of the whiskers are calculated as 1.5 x interquartile range. The points represent the outliers.

The high RF radiation exposure at the squares is of major concern due to the numerous shops, outdoor restaurants and cafés. The measured RF radiation is almost exclusively from mobile telephony base stations (e.g., see Table VI for Järntorget). Some of the base stations appear to be located

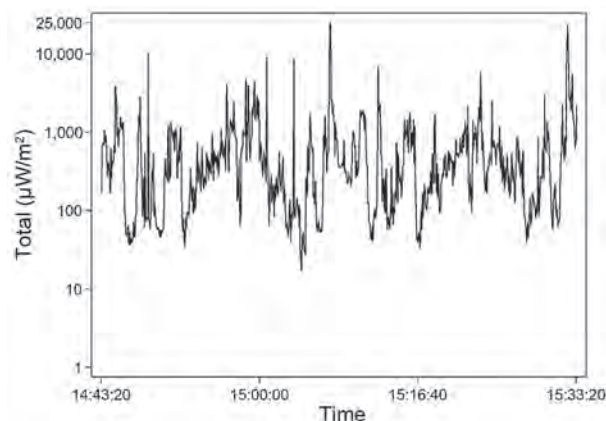


Figure 5. Stockholm Royal Castle. Total radiofrequency field exposure (mean exposure, $721.2 \mu\text{W}/\text{m}^2$, logarithmic scale) over time of one typical exposure round (13 April, 2016; time, 14:43:22-15:33:26).

in buildings of rather low height, with the radiation directed towards the sitting area of restaurants and coffee shops. The location of a base station at one of the measured squares is shown in Fig. 12; it was placed rather low, with the main emission directed towards an outdoor restaurant at a short distance.

Our results are significantly lower compared with the ICNIRP exposure guideline of $10,000,000 \mu\text{W}/\text{m}^2$. However,

Table IV. Stockholm Supreme Court levels of radiofrequency radiation in total, as measured on 13 and 22 April, 2016.

Frequency band	No. of readings	Mean	Median	Min	Max
FM	715	0.6	0.0	0.0	29.2
TV3	715	1.2	0.0	0.0	35.7
TETRA I	715	0.3	0.0	0.0	58.9
TETRA II	715	0.3	0.0	0.0	12.6
TETRA III	715	0.1	0.0	0.0	26.0
TV4&5	715	0.1	0.0	0.0	19.2
LTE 800 (DL)	715	18.4	4.7	0.1	898.5
LTE 800 (UL)	715	0.0	0.0	0.0	0.0
GSM + UMTS 900 (UL)	715	6.1	0.0	0.0	2,874.5
GSM + UMTS 900 (DL)	715	32.7	11.2	0.2	578.5
GSM 1800 (UL)	715	4.7	2.5	0.0	65.4
GSM 1800 (DL)	715	104.6	54.2	3.4	2,196.6
DECT	715	0.0	0.0	0.0	1.1
UMTS 2100 (UL)	715	0.0	0.0	0.0	0.3
UMTS 2100 (DL)	715	82.0	46.2	0.4	1,966.4
Wi-Fi 2G	715	0.1	0.0	0.0	8.3
LTE 2600 (UL)	715	0.1	0.0	0.0	4.5
LTE 2600 (DL)	715	152.3	87.9	3.8	3,674.6
WiMAX	715	0.0	0.0	0.0	0.0
Wi-Fi 5G	715	0.0	0.0	0.0	0.9
Total	715	403.6	274.5	20.4	4,088.1

Analysis of all data ($\mu\text{W}/\text{m}^2$) treating values at detection limit as 0. FM, frequency modulation; TV, television; LTE, long-term evolution; DL, downlink (transmission from base station to mobile phone); UL, uplink (transmission from mobile phone to base station); GSM, global system for mobile communications; UMTS, universal mobile telecommunications system; DECT, digital European cordless telecommunications; WiMAX, worldwide interoperability for microwave access.

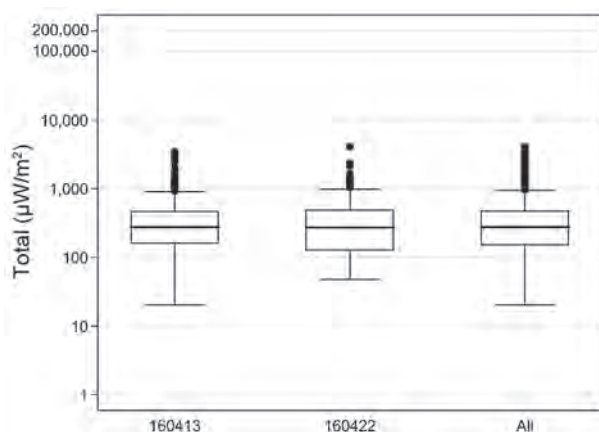


Figure 6. Stockholm Supreme Court. Box plot for exposure in $\mu\text{W}/\text{m}^2$, logarithmic scale, for two measurement rounds and total exposure. The median is indicated by the black line inside each box; the bottom and top of the boxes represent the first and third quartiles; the end of the whiskers are calculated as 1.5 x interquartile range. The points represent the outliers.

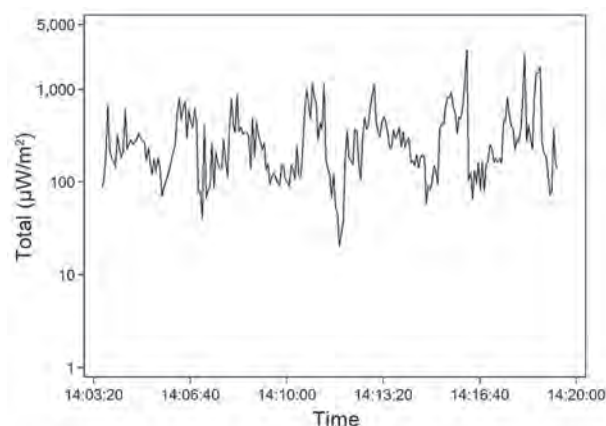


Figure 7. Stockholm Supreme Court. Total radiofrequency field exposure (mean exposure, $335.6 \mu\text{W}/\text{m}^2$, logarithmic scale) over time of one typical exposure round (13 April, 2016; time, 14:03:37-14:19:21).

that guideline is outdated, since it does not include current scientific findings in humans and laboratory studies on RF radiation exposure. On the other hand, most measurements were higher than the scientific benchmark of $30\text{--}60 \mu\text{W}/\text{m}^2$ that has been proposed to be the lowest observed effect level

for RF radiation in Chapter 24 of the BioInitiative Report (6). Furthermore, our result on a total mean RF radiation level of $4,292.7 \mu\text{W}/\text{m}^2$ in the Old Town (Table II) is of major concern, considering the oxidative effects on living cells from exposure to a level of RF radiation as low as $2,500 \mu\text{W}/\text{m}^2$, as described by Yakymenko *et al* (41). This is also of

Table V. Stockholm Old Town mean levels of radiofrequency radiation ($\mu\text{W}/\text{m}^2$) for three squares, treating values at detection limit as 0.

Frequency band	Stortorget, April 13 and 22, 2016		Kornhamnstorg, April 13 and 22, 2016		Järntorget, April 11, 13 and 22, 2016	
	No. ^a	Mean	No. ^a	Mean	No. ^a	Mean
FM	527	2.8	1,191	24.4	574	67.9
TV3	527	0.0	1,191	0.4	574	0.7
TETRA I	527	0.6	1,191	0.0	574	0.9
TETRA II	527	0.0	1,191	0.3	574	0.0
TETRA III	527	0.1	1,191	0.0	574	0.4
TV4&5	527	4.3	1,191	3.4	574	30.8
LTE 800 (DL)	527	863.0	1,191	1,762.6	574	2,917.6
LTE 800 (UL)	527	0.0	1,191	0.0	574	0.0
GSM + UMTS 900 (UL)	527	0.0	1,191	0.0	574	0.0
GSM + UMTS 900 (DL)	527	2,721.9	1,191	5,222.3	574	10,272.7
GSM 1800 (UL)	527	10.8	1,191	7.5	574	0.1
GSM 1800 (DL)	527	194.4	1,191	590.8	574	12.1
DECT	527	0.0	1,191	39.2	574	0.0
UMTS 2100 (UL)	527	0.0	1,191	0.0	574	0.0
UMTS 2100 (DL)	527	1,811.0	1,191	672.2	574	4,049.7
Wi-Fi 2G	527	0.1	1,191	2.2	574	0.3
LTE 2600 (UL)	527	2.7	1,191	0.0	574	0.8
LTE 2600 (DL)	527	3,441.8	1,191	3,677.1	574	6,923.0
WiMAX	527	0.0	1,191	0.0	574	0.0
Wi-Fi 5G	527	0.0	1,191	0.1	574	0.0
Total	527	9,053.7	1,191	12,002.6	574	24,277.1

^a Number of readings. FM, frequency modulation; TV, television; LTE, long-term evolution; DL, downlink (transmission from base station to mobile phone); UL, uplink (transmission from mobile phone to base station); GSM, global system for mobile communications; UMTS, universal mobile telecommunications system; DECT, digital European cordless telecommunications; WiMAX, worldwide interoperability for microwave access.

concern, since reactive oxidative species are crucial in carcinogenesis.

In Sweden, the dominating sources are currently exposure from mobile communication with UMTS, 3G and LTE, 4G with addition of Wi-Fi indoors, but also in certain outdoors locations. Our study from Stockholm Central Railway Station in 2015 yielded a mean total radiation level of 2,817-4,891 $\mu\text{W}/\text{m}^2$ for each measurement round and a median value of 921 $\mu\text{W}/\text{m}^2$ for all rounds. The mean for all rounds was 3,860 $\mu\text{W}/\text{m}^2$. In addition, hotspots were registered yielding >95,544 $\mu\text{W}/\text{m}^2$, which exceeded the exposimeter EME-Spy 200's upper detection limit. GSM+UMTS 900 downlink and UMTS 2100 downlink contributed the most, but LTE 800 downlink, GSM 1800 downlink and LTE 2600 downlink were also in the higher range of measurements (1). Thus, these results are similar to those of the present study.

The results of the present study show a large variation in passive outdoor RF radiation exposure in Stockholm Old Town. One explanation may be that there are no outdoor places with sitting areas to accommodate people during lunch or coffee breaks around the Royal Castle or the Supreme Court.

This also applies to the Swedish Parliament, which is located on a separate island close to the Old Town. Thus, base stations are located around the squares to enable good network access. However, a lower level of radiation would still enable good network access (6). Comparatively low levels of RF radiation were measured for the Swedish Parliament compared with Järntorget. However, no indoor measurements were performed at the Swedish Parliament, where the RF radiation level would be quite different due to wireless internet access within the Parliament.

Unlike in other city districts, where mobile phone base station antennas are placed at a certain height, in the Old Town some antennas are located significantly closer to humans, sometimes only a few meters from the ground level. This creates areas of significantly high RF radiation, particularly in the immediate vicinity of such antennas. The exposure situation is worsened by the narrow streets and tall walls, which tend to trap the radio waves, hence creating reflections and increasing the exposure. The highest radiation zones may be proposed at buildings with windows facing the mobile base station antenna just across the street at the same height. The

Table VI. Järntorget mean levels of radiofrequency radiation ($\mu\text{W}/\text{m}^2$) on 11, 13 and 22 April, 2016, treating values at detection limit as 0.

Frequency band	No. of readings	Mean	Median	Min	Max
FM	574	67.9	0.4	0.0	3,674.6
TV3	574	0.7	0.0	0.0	69.6
TETRA I	574	0.9	0.0	0.0	41.4
TETRA II	574	0.0	0.0	0.0	0.7
TETRA III	574	0.4	0.0	0.0	27.1
TV4&5	574	30.8	0.0	0.0	2,775.9
LTE 800 (DL)	574	2,917.6	1,504.0	3.8	20,367.2
LTE 800 (UL)	574	0.0	0.0	0.0	0.0
GSM + UMTS 900 (UL)	574	0.0	0.0	0.0	4.9
GSM + UMTS 900 (DL)	574	10,272.7	6,140.5	29.8	65,440.6
GSM 1800 (UL)	574	0.1	0.0	0.0	8.9
GSM 1800 (DL)	574	12.1	4.5	0.6	590.9
DECT	574	0.0	0.0	0.0	0.0
UMTS 2100 (UL)	574	0.0	0.0	0.0	2.5
UMTS 2100 (DL)	574	4,049.7	2,716.7	38.2	21,078.9
WIFI 2G	574	0.3	0.0	0.0	25.5
LTE 2600 (UL)	574	0.8	0.0	0.0	35.1
LTE 2600 (DL)	574	6,923.0	4,157.8	30.4	95,522.5
WiMAX	574	0.0	0.0	0.0	3.1
Wi-Fi 5G	574	0.0	0.0	0.0	1.7
Total	574	24,277.1	19,990.0	257.0	173,301.8

FM, frequency modulation; TV, television; LTE, long-term evolution; DL, downlink (transmission from base station to mobile phone); UL, uplink (transmission from mobile phone to base station); GSM, global system for mobile communications; UMTS, universal mobile telecommunications system; DECT, digital European cordless telecommunications; WiMAX, worldwide interoperability for microwave access.

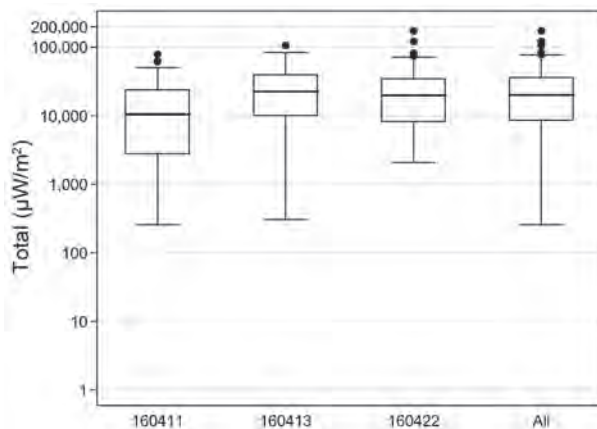


Figure 8. Stockholm Old Town, Järntorget. Box plot for exposure in $\mu\text{W}/\text{m}^2$, logarithmic scale, for three measurement rounds and total exposure. The median is indicated by the black line inside each box; the bottom and top of the boxes represent the first and third quartiles; the end of the whiskers are calculated as 1.5 x interquartile range. The points represent the outliers.

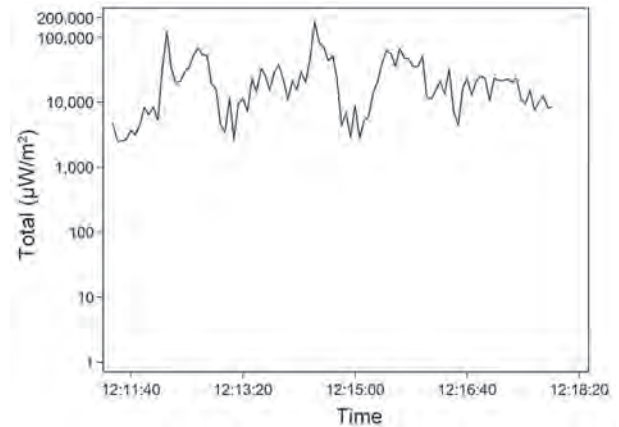


Figure 9. Stockholm Old Town, Järntorget. Total radiofrequency field exposure (mean exposure, $24,766.2 \mu\text{W}/\text{m}^2$, logarithmic scale) over time of one typical exposure round (22 April, 2016; time, 12:11:24-12:17:56).

most affected are the individuals that have to stay longer in such places, also referred to as hotspots. Individuals whose living quarters, workstation or work area happen to be located in hotspots, are exposed to the heaviest RF load, whereas those

who walk by hotspots only undergo momentary exposure and are less affected.

As the mobile telephony network is currently under development, the base station antennas are positioned following the current legal safety limits. However, the current limits only provide protection from short-term health effects (heating), but

Table VII. Stockholm Swedish Parliament mean levels of radiofrequency radiation ($\mu\text{W}/\text{m}^2$) on 8, 10, 11 and 22 April, 2016, treating values at detection limit as 0.

Frequency band	No. of readings	Mean	Median	Min	Max
FM	1,196	1.7	0.0	0.0	129.6
TV3	1,196	6.7	0.0	0.0	485.9
TETRA I	1,196	62.8	0.4	0.0	3,157.2
TETRA II	1,196	2.0	0.3	0.0	52.0
TETRA III	1,196	1.5	0.0	0.0	208.0
TV4&5	1,196	0.3	0.0	0.0	50.5
LTE 800 (DL)	1,196	99.7	5.9	0.0	5,623.2
LTE 800 (UL)	1,196	0.0	0.0	0.0	0.1
GSM + UMTS 900 (UL)	1,196	0.0	0.0	0.0	16.1
GSM + UMTS 900 (DL)	1,196	240.7	99.8	1.0	5,176.7
GSM 1800 (UL)	1,196	8.6	3.4	0.0	426.5
GSM 1800 (DL)	1,196	322.6	137.9	6.1	9,395.0
DECT	1,196	5.5	0.0	0.0	347.6
UMTS 2100 (UL)	1,196	0.0	0.0	0.0	1.5
UMTS 2100 (DL)	1,196	450.7	163.1	6.4	9,717.2
Wi-Fi 2G	1,196	0.1	0.0	0.0	8.9
LTE 2600 (UL)	1,196	7.1	1.1	0.0	313.9
LTE 2600 (DL)	1,196	293.9	129.6	5.1	9,385.0
WiMAX	1,196	0.0	0.0	0.0	0.0
Wi-Fi 5G	1,196	0.0	0.0	0.0	8.9
Total	1,196	1,503.9	957.4	99.6	16,781.9

FM, frequency modulation; TV, television; LTE, long-term evolution; DL, downlink (transmission from base station to mobile phone); UL, uplink (transmission from mobile phone to base station); GSM, global system for mobile communications; UMTS, universal mobile telecommunications system; DECT, digital European cordless telecommunications; WiMAX, worldwide interoperability for microwave access.

do not exclude possible long-term effects, which are currently under investigation. To grant better service coverage, the base station antennas are continuously placed in new locations, and the mobile telephony network becomes denser annually. Thus, the RF exposure of the population is increasing, particularly in densely populated areas.

As the research on long-term health hazards is ongoing, it is mostly focused on clearly identifiable biological effects. Knowledge on the effect of RF fields on mental health is of utmost importance, as in chronic exposure to RF radiation levels, such as those measured in hotspots in the Old Town. It should also be noted that long-term health effects, such as cancer, have not been investigated for this type of environmental contamination.

EME Spy 200 is a band-specific exposimeter and it enables identification and measurement of the majority of RF radiation bands currently used in Sweden. This study describes measurements mostly from far-field RF radiation and the exposure that the citizens may undergo without using personal wireless devices. Near-field exposure from personal mobile phones held near the ear or in the hand when on the internet will likely contribute considerably to an individual's total exposure.

The shielding effect from the body of a person carrying an exposimeter may be considerable, as shown by Bolte *et al* (42) when comparing a body-worn exposimeter with an exposimeter

mounted on the roof of a car. This was partly compensated in our study by holding the exposimeter at a certain distance from the body.

Other studies have measured the exposure of RF radiation in public places. In 2012, Estenberg and Augustsson (43) used a car-mounted device to measure the frequency range 30-3,000 MHz in public places (rural, urban and large cities). The arithmetic mean measured exposure was $6,700 \mu\text{W}/\text{m}^2$ in Stockholm, $1,500 \mu\text{W}/\text{m}^2$ in 4 urban towns and $230 \mu\text{W}/\text{m}^2$ in 2 rural areas. Similar to our study, the major sources were GSM and UMTS downlinks.

Earlier studies, prior to the use of smartphones, when 3G and 4G protocols became more common, reported lower exposure. Joseph *et al* (44) performed measurements with a personal exposimeter (EME-Spy 120-121) in different urban areas across Europe during 2007-2009. They found mean values for outdoor areas of $372\text{-}569 \mu\text{W}/\text{m}^2$, mostly from mobile communications. In 2010, Bolte and Eikelboom (45) also performed measurements in The Netherlands with a personal exposimeter (EME-Spy 121) and found a mean value in outdoor activities of $208 \mu\text{W}/\text{m}^2$. Visits to pubs, cafés, discos and snack bars yielded the highest mean value in their study ($526 \mu\text{W}/\text{m}^2$), mostly from mobile uplink at 1,800 MHz. Urbinello *et al* (46) used the same exposimeter in three different European cities (Basel, Ghent and Brussels), every month for 1 year (April, 2011-March, 2012). The

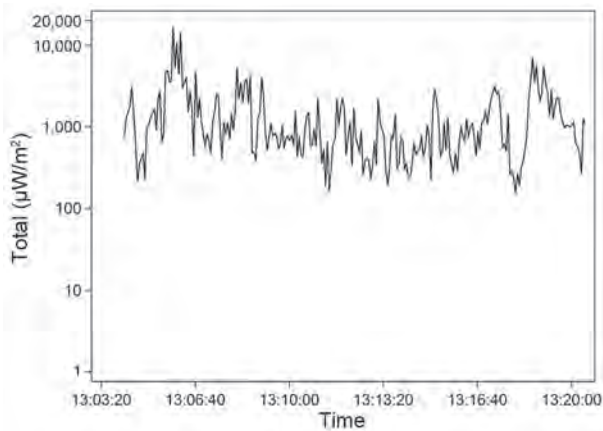


Figure 10. Stockholm, Swedish Parliament. Total radiofrequency field exposure (mean exposure, $1,460.2 \mu\text{W}/\text{m}^2$, logarithmic scale) over time of one typical exposure round (11 April, 2016; time, 13:04:09-13:20:29).

total from all sources of RF radiation in downtown outdoor areas increased by 56% in Basel, 27% in Ghent and 25% in Brussels. The mean levels were 0.32-0.58 V/m ($271\text{-}892 \mu\text{W}/\text{m}^2$). In 2012, Aerts *et al* (47) conducted measurements in an urban/suburban area of Ghent, Belgium covering an area of 1 km². They selected 0.7 V/m ($1,300 \mu\text{W}/\text{m}^2$) as a threshold for a hotspot and found five hotspots in the area. GSM 900 base station signals contributed the most to all five hotspots with 45-100%, with GSM 1800 and 3G present in two of the hotspots.

Verlock *et al* (48) used a Narda NBM-550 in public places in Belgium during 2012-2013. The total average from all RF radiation sources between 100 kHz and 3 GHz was 0.62 V/m ($1,020 \mu\text{W}/\text{m}^2$), with a maximum of 2.4 V/m ($15,287 \mu\text{W}/\text{m}^2$).

Calvente *et al* (49) conducted measurements outside the homes of 123 families in Granada, Spain during 2012-2013. The arithmetic mean root square (RMS) for power density was $799 \mu\text{W}/\text{m}^2$ and the median value was $285 \mu\text{W}/\text{m}^2$. For the different homes, the median RMS ranged from 5 to $11,559 \mu\text{W}/\text{m}^2$. In 2015, Gonzalez-Rubio *et al* (50) used an EME-Spy 140 located inside the plastic basket of a bicycle. With this bicycle they covered all 110 regions in the city of Albacete, Spain, performing measurements. The average for the 3 bands of mobile telephone antennas (GSM, Digital Combat Simulator and UMTS) in the different regions varied from 0.04 V/m ($4.2 \mu\text{W}/\text{m}^2$) to 0.89 V/m ($2,102 \mu\text{W}/\text{m}^2$).

The mean values for exposure to RF radiation from the earlier studies indicate a clear increase in the more recent exposure studies. It is clear from our present and previous (1) studies that the level of ambient RF radiation exposure is increasing. With the development of mobile communications technologies and the widespread use of wireless services, the exposure will continue to increase with higher exposure levels and also other frequency bands, despite the already proven adverse health effects.

Long-term studies with laboratory animals at or below the levels in the present study have shown the effects of RF radiation on several physiological parameters in the body of mammals. These are non-thermal effects and are discussed briefly below, including a few human studies.

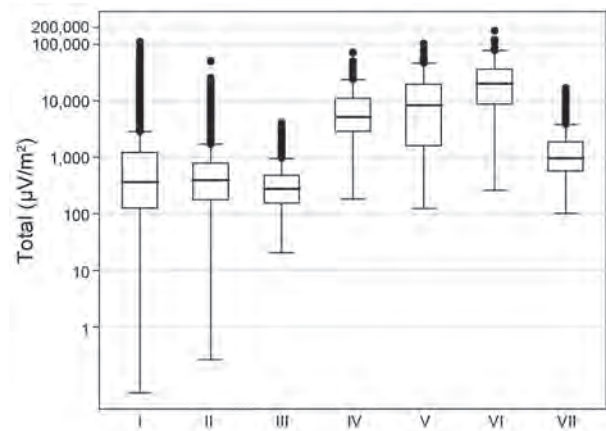


Figure 11. Box plot, total exposure ($\mu\text{W}/\text{m}^2$), all locations, logarithmic scale for the measurement rounds. The median is indicated by the black line inside each box; the bottom and top of the boxes represent the first and third quartiles; the end of the whiskers are calculated as 1.5 x interquartile range. The points represent the outliers. I=Stockholm Old Town; II=Royal Castle; III=Supreme Court; IV=Stortorget; V=Kornhamnstorg; VI=Järntorget; VII=Swedish Parliament.



Figure 12. Stockholm Old Town measurement location with a relatively high radiofrequency radiation level, due to a mobile telephony base station antenna positioned at a low height and targeted towards the square.

Several studies on rats have demonstrated that the blood-brain barrier (BBB) may open when exposed to RF radiation, resulting in pathological leakage of large molecules that may be toxic to the brain, with condensed dark neurons in the brain representing a sign of damage (51-54). The hippocampus, a center for memory and learning in the brain, appears to be particularly sensitive to neuronal damage from RF radiation and an opened BBB. Long-term exposure to 900 MHz RF radiation has been associated with extravasation of albumin in the hippocampus and cortex and impaired spatial memory in exposed rats (55-57).

A long-term study with exposure from GSM 900 MHz 3 h/day or DECT base station 8 h/day during 8 months reported a statistically significant downregulation or an overexpression for one-third of the 432 analyzed proteins from the brains of the RF-irradiated mice. Several neural function-related proteins, such as apolipoprotein E, heat shock proteins and cytoskeletal proteins, as well as proteins involved in brain metabolism, were altered (58).

Up to 12 months of exposure to Wi-Fi exerted an effect on microRNA in the brain (59) and in the testes, with head defects and DNA damage in sperm cells (60-62).

Yakymenko *et al* (41) published a review of 100 studies investigating the oxidative effects of low-intensity RF radiation in living cells, and demonstrated that exposure down to 2,500 $\mu\text{W}/\text{m}^2$ (63) with SAR values as low as 600 $\mu\text{W}/\text{kg}$ (64,65) may increase oxidative stress in the cells. Long-term, low-intensity RF radiation exposure has also been associated with reduced levels of neurotransmitters, downregulation of microRNA, increase in pro-inflammatory cytokines and DNA damage with single-strand breaks in the hippocampus and cognitive impairments in learning and memory in exposed rats (65-67). An increase in frequency appears to exert more deleterious effect on several of the parameters (66).

Exposure levels in rats down to a SAR of 85 $\mu\text{W}/\text{kg}$, for 900 MHz during 2 h/day, 5 days/week for 30 days, increased the oxidative stress parameters in lipid peroxidation and protein oxidation. In addition, there was a statistically significant impairment in cognitive function in terms of spatial memory in the rats (68).

RF radiation has been shown to increase protein synthesis in proliferating human cells after 8 h of exposure, but not in quiescent white blood cells. This indicates a higher sensitivity of growing organisms (69). Furthermore, the capacity to repair DNA double-strand breaks was more affected by RF radiation in stem cells compared with differentiated cells, such as fibroblasts (70).

Epidemiological studies of mobile phone base stations have indicated health risks for humans. In particular, increased prevalence of adverse neurobehavioral symptoms or cancer in populations living at a distance of <500 m from base stations was found in 80% of the available studies in a review by Khurana *et al* (71). In another review, Levitt and Lai (72) included 56 studies. Exposure from base stations and other antenna arrays brought about changes in the immunological and reproductive systems of animals and humans, changes in biological material, DNA double-strand breaks, changes in calcium movement in the heart and increased proliferation rates in human astrocytoma cancer cells.

Long-term studies on low exposure to RF radiation of humans have demonstrated an effect on the neurotransmitters adrenaline, noradrenaline, dopamine and phenylethylamine when a GSM 900 MHz base station was installed in the village of Rimbach in Germany (73), as well as on cortisol and thyroid gland hormones in individuals living near base stations (74,75). Chronic dysregulation of psychobiological stress markers may contribute to health problems and chronic illnesses.

The results from these studies report levels of environmental exposure to RF radiation below the ICNIRP target level (2,3), but far above the BioInitiative Report level for

biological effects (5,6). It has been argued that the BioInitiative Reports are not peer-reviewed. However, peer-reviewed and published studies also document health effects at low RF radiation levels (76,77). A recent article highlights the need for accurate information on the safety of exposure to RF radiation (78).

In conclusion, the aim of our study was to assess outdoor exposure to RF radiation at the Old Town and the nearby Parliament in Stockholm, Sweden. The Old Town is a part of Stockholm that is very popular among tourists, but also a destination for locals visiting the official buildings located in the area. In this study, real-time band-specific exposure measurements showed the highest contributors to the exposure to be download frequencies from the base stations of GSM + UMTS 900, UMTS 2100, LTE 800, LTE 2600 and GSM 1800 bands. The highest mean levels were found for GSM + UMTS 900 (3G) downlink and LTE 2600 (4G) downlink. The differences in exposure levels between the Supreme Court and Järntorget were striking, with the mean level 60 times higher at Järntorget. Unfortunately, studies on human risk from long-term environmental RF radiation based on personal exposure monitoring do not exist to the best of our knowledge. Future studies on cancer risk and other health effects from such exposure are imperative. The results of this study revealed unnecessarily high RF radiation areas in several parts of Stockholm Old Town. Using unnecessarily high power levels and placing mobile phone base station antennas too close to the ground and in heavily frequented areas pose an excess health risk to a significant part of the population.

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Radiofrequency radiation at Stockholm Central Railway Station in Sweden and some medical aspects on public exposure to RF fields

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Abstract. The Stockholm Central Railway Station in Sweden was investigated for public radiofrequency (RF) radiation exposure. The exposimeter EME Spy 200 was used to collect the RF exposure data across the railway station. The exposimeter covers 20 different radiofrequency bands from 88 to 5,850 MHz. In total 1,669 data points were recorded. The median value for total exposure was $921 \mu\text{W}/\text{m}^2$ (or $0.092 \mu\text{W}/\text{cm}^2$; $1 \mu\text{W}/\text{m}^2 = 0.0001 \mu\text{W}/\text{cm}^2$) with some outliers over $95,544 \mu\text{W}/\text{m}^2$ (6 V/m, upper detection limit). The mean total RF radiation level varied between 2,817 to $4,891 \mu\text{W}/\text{m}^2$ for each walking round. High mean measurements were obtained for GSM + UMTS 900 downlink varying between 1,165 and $2,075 \mu\text{W}/\text{m}^2$. High levels were also obtained for UMTS 2100 downlink; 442 to $1,632 \mu\text{W}/\text{m}^2$. Also LTE 800 downlink, GSM 1800 downlink, and LTE 2600 downlink were in the higher range of measurements. Hot spots were identified, for example close to a wall mounted base station yielding over $95,544 \mu\text{W}/\text{m}^2$ and thus exceeding the exposimeter's detection limit. Almost all of the total measured levels were above the precautionary target level of $3\text{--}6 \mu\text{W}/\text{m}^2$ as proposed by the BioInitiative Working Group in 2012. That target level was one-tenth of the scientific benchmark providing a safety margin either for children, or chronic exposure conditions. We compare the levels of RF radiation exposures identified in the present study to published scientific results reporting adverse biological effects and health harm at levels equivalent to, or below those measured in this Stockholm Central Railway Station project. It should be noted that these RF radiation levels give transient exposure, since people are generally passing through the areas

tested, except for subsets of people who are there for hours each day of work.

Introduction

On 31 May 2011 the WHO International Agency for Research on Cancer (IARC) categorized the radiation fields from mobile phones, and from other devices that emit similar non-ionizing electromagnetic field (EMF) radiation in the frequency range 30 kHz to 300 GHz, as a Group 2B, i.e. a 'possible', human carcinogen (1,2). Nine years earlier IARC had also classified the electromagnetic fields from overhead electric power lines as a Group 2B carcinogen (3).

The IARC decision on mobile phones was based mainly on two sets of case-control human studies: the Hardell group of studies from Sweden (4-6) and the IARC Interphone study (7-9). Both provided complementary and generally mutually supportive evidence of increased risk for brain tumours, i.e. glioma and acoustic neuroma. Later published studies by us (10-13) and the French CERENAT study on glioma and meningioma published in 2014 (14) supported an increased risk for brain tumours and use of mobile phones. These results were further supported by a study on mice showing tumour-promoting effect from radiofrequency (RF) radiation at low to moderate levels (0.04 and 0.4 W/kg SAR), radiation well below exposure limits for users of mobile phones (15). Thus, implications of the study by Tillman *et al* (16) were successfully tested. It should be added that a long-term animal toxicity study at 900 MHz published in 1997 resulted in statistically significant increased lymphoma risk in mice (17).

Recently, a report was released from The National Toxicology Program (NTP) under the National Institutes of Health (NIH) in USA on the largest ever animal study on cell phone RF radiation and cancer (18). An increased incidence of glioma and malignant Schwannoma in the heart was found. Acoustic neuroma or vestibular Schwannoma is the same type of tumour as the one found in the heart, although benign.

The carcinogenicity findings evaluated by IARC in 2011 were related to personal wireless phone use, including mobile phones and DECT phones. The overall exposure including

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mobile phone base stations, radio- and TV-transmitters, DECT base stations and wireless local area networks (WLAN) is not very well known. Epidemiological studies of mobile phone base stations indicated health risks for humans, see a review of Khurana *et al* (19), but did not contain enough exposure information.

The exposure guideline by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) was established in 1998 (20) and was based on thermal (heating) effects from RF radiation neglecting non-thermal biological effects. It was updated in 2009 (21) and stated that: 'it is the opinion of ICNIRP that the scientific literature published since the 1998 guidelines has provided no evidence of any adverse effects below the basic restrictions and does not necessitate an immediate revision of its guidance on limiting exposure to high frequency electromagnetic fields. Therefore, ICNIRP reconfirms the 1998 basic restrictions in the frequency range 100 kHz to 300 GHz until further notice'. The guideline provided by ICNIRP still recommends 10 W/m² as a reference level for limiting public's exposure to the RF-EMFs (2-300 GHz) (20).

It should be noted that the ICNIRP guideline, although only a recommendation, is nevertheless used in most European countries as well as in many other countries. The guideline is based on short-term (acute) exposures but not chronic, low-intensity cumulative exposures, nor possible health effects. ICNIRP safety limits do not acknowledge effects from long-term exposure and non-thermal biological effects from RF-EMF exposure. According to the philosophy document of ICNIRP (22): 'Some guidelines may still not provide adequate protection for certain sensitive individuals nor for normal individuals exposed concomitantly to other agents'. In practice this means, that if simultaneously exposed to chemicals and RF radiation (15,16), the ICNIRP guideline does not protect. The philosophy document of ICNIRP (22) also states: 'Different groups in a population may have differences in their ability to tolerate a particular NIR (Non-Ionizing Radiation) exposure. For example, children, the elderly, and some chronically ill people might have a lower tolerance for one or more forms of NIR exposure than the rest of the population'. However, this is not considered in existing ICNIRP (1998) guideline document (20) and for example Gandhi *et al* (23) provide a historical overview how ICNIRP and the Federal Communications Commission (FCC) standard setting is based on (adult) military recruit head and body models, not children's.

ICNIRP's goal has been to harmonize guidelines worldwide and most countries have adopted the ICNIRP's guidelines into their national legislation. Using wireless internet access is compatible with ICNIRP's guidelines, but may exceed the BioInitiative Report recommendation (24). There is a vast body of literature that shows non-thermal adverse health effects from RF radiation. These, as well as thermal effects, have been evaluated in several reports, e.g. the BioInitiative report from 2007 (25) and in the 2012 update (26). The 2007 BioInitiative report suggested a precautionary target level of 1,000 $\mu\text{W}/\text{m}^2$ for outdoor pulsed RF radiation that could be applied to sources from cell tower antennas, Wi-Fi, WiMAX and other similar sources (25). The BioInitiative 2012 Report defined the scientific benchmark for possible risks as 30-60 $\mu\text{W}/\text{m}^2$, based in part on post-2007 studies by

Thomas *et al* (27,28), Heinrich *et al* (29) and Buchner and Eger (30). Considering also chronic exposure and sensitivity among children the precautionary target level was proposed to one tenth of this, 3-6 $\mu\text{W}/\text{m}^2$, see Chapter 24 of the BioInitiative Report (26). However, the studies by Thomas *et al* (27,28) and Heinrich *et al* (29) used personal dosimetry without differentiating up-and downlink and without presenting actual measurements, but only percentages of the reference levels. Also shielding by the body may preclude any statement about actual exposure.

The BioInitiative report guideline obviously differs from the one proposed by ICNIRP, largely because ICNIRP protects only against acute, thermal injury while the BioInitiative recommendations address chronic exposures to non-thermal, low-intensity exposures for which mounting evidence shows adverse health effects. The ICNIRP level has been vigorously propagated by that organisation in order to harmonize guidelines worldwide. With few exceptions it has been a successful story and most countries have adopted the ICNIRP guideline. This gives a 'green card' to roll out the technology, for example using wireless internet access in schools (24), since the high exposure level by ICNIRP is rarely compromised.

There are few studies in this area on public exposure, other than for example outdoor exposure in urban and rural areas in Sweden (31), in a workplace (32), the metro in Warsaw (33) and a study with body-worn exposimeters in The Netherlands (34).

The aim of the present study was to assess RF radiation exposure in a public transportation hub, Stockholm Central Railway Station in Sweden. Many shops, restaurants and offices are located within this area. The Central Station contains many people, those working there and those commuting, thus, both short- and long-term exposure occurs. There is a lack of exposure studies in public places in Sweden. The previous measurement studies are outdated due to the rapid technology shift (35,36). We selected a place visited by many persons that are exposed to RF radiation. This was a measurement study with no involvement of test persons. Thus, no ethical permission was needed. We discuss also some laboratory studies on RF-radiation that will help the reader to understand the context of the exposer logger measurements. Especially interesting are non-thermal levels of RF radiation and biological effects.

Materials and methods

EME Spy 200 exposimeter. In the present study an EME Spy 200 exposimeter with a valid calibration was used to collect the exposure data. The 20 predefined measured frequency bands are presented in Table I. They cover the frequencies of most public RF-EMF emitting devices currently used in Sweden. This band selective exposimeter covers 88 to 5,850 MHz. For FM, TV3, TETRA, TV4&5, Wi-Fi and 5G the lower detection limit is 0.01 V/m (0.27 $\mu\text{W}/\text{m}^2$); for all other exposures the lower detection limit is 0.005 V/m (0.066 $\mu\text{W}/\text{m}^2$). The upper detection limit is 6 V/m (95,544 $\mu\text{W}/\text{m}^2$). The sampling time used in this study was 4 sec which is the fastest for the given exposimeter. The exposimeter measures different telecommunication protocols: FM (frequency modulation) radio broadcasting; TV (television) broadcasting; TETRA emergency services (police, rescue, etc.); GSM (global system for mobile communications) second generation mobile communications; UMTS (universal

Table I. Predefined measurement frequency bands of EME Spy 200 exposimeter and frequency ranges.

Frequency band	Frequency Min (MHz)	Frequency Max (MHz)
FM	87	107
TV3	174	223
TETRA I	380	400
TETRA II	410	430
TETRA III	450	470
TV4&5	470	770
LTE 800 (DL ^a), 4G	791	821
LTE 800 (UL ^b), 4G	832	862
GSM 900+ UMTS 900 (UL), 3G	880	915
GSM 900 + UMTS 900 (DL), 3G	925	960
GSM 1800 (UL)	1,710	1,785
GSM 1800 (DL)	1,805	1,880
DECT	1,880	1,900
UMTS 2100 (UL), 3G	1,920	1,980
UMTS 2100 (DL), 3G	2,110	2,170
Wi-Fi, 2G	2,400	2,483.5
LTE 2600 (UL), 4G	2,500	2,570
LTE 2600 (DL), 4G	2,620	2,690
WiMax	3,300	3,900
Wi-Fi 5G	5,150	5,850

^aDL, down link: transmission from base station to mobile phone; ^bUL, up link: transmission from mobile phone to base station.

mobile telecommunications systems) third generation mobile communications, 3G; LTE (long-term evolution) fourth generation mobile communications standard, 4G; DECT (digital European cordless telecommunications) cordless telephone systems standard; Wi-Fi wireless local area network protocol; WiMAX (worldwide interoperability for microwave access) wireless communication standard for high speed voice, data and internet.

EME SPY 200 is a sophisticated exposimeter, preferred by the majority of the EMF measurement's community. The unit utilizes 3-axis antennas to capture EMF radiation from all possible directions. The unit reports the exposure in a conservative manner since each reported value is the sampling outcome, where many samples are taken and statistically processed. The amount of the samples is dependent on the measurement band and could reach several hundreds. These samples are analyzed and minimum, mean, median and maximum values are calculated. For each band the sampling period is longer than the pulse length characteristic to that band and signal. This ensures that all the pulses are accounted for in the sampling period. The analysis method of EME SPY 200 allows differentiation of low and high wireless traffic, whereas the peak value might remain the same in both cases. Multiple antennas are of importance to reduce body shielding (37) as well as holding the exposimeter at some distance from the body.

Study design. The present study was performed during daytime November 7, (Saturday; 1 round), November 8 (Sunday; 3



Figure 1. Stockholm Central Station main level (ground floor).

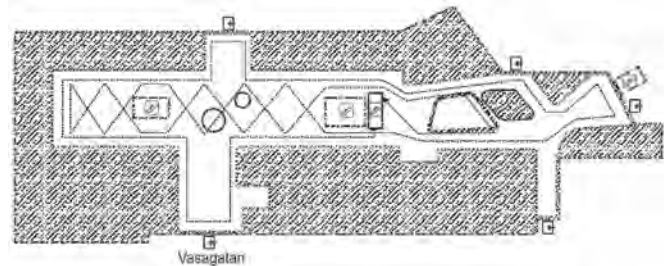


Figure 2. Stockholm Central Station ground floor measurement path.

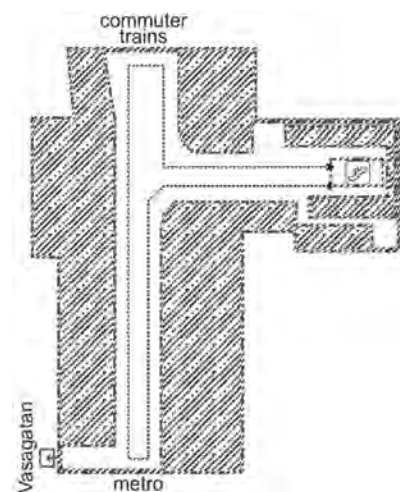


Figure 3. Stockholm Central Station lower level measurement path.

rounds) and November 9, 2015 (Monday; 3 rounds) at the Stockholm Central Station in Sweden. The upper level of the station is displayed in Fig. 1. To the left is the access to the street (Vasagatan) and to the right to commuter trains.

On each measurement round the main and lower floor were walked through with the exposimeter; the same path was always followed. The path was developed to make a clockwise tour of the station's main floor, followed by a zig-zag pattern across the main floor. Due to the narrow area of the lower floor, it was scanned only by a clockwise tour. The walking

Table II. Mean values ($\mu\text{W}/\text{m}^2$) for the seven measurement rounds.

Date	151107 (Saturday)	151108 (Sunday)	151108 (Sunday)	151108 (Sunday)	151109 (Monday)	151109 (Monday)	151109 (Monday)
Time (start)	21:18	11:00	14:45	18:50	9:45	10:50	15:50
No. of readings	195	258	250	235	225	244	262
FM	5.8	9.6	6.7	78.0	10.1	2.0	50.1
TV3	0.0	1.0	0.5	0.3	0.0	0.0	0.1
TETRA I	8.1	2.5	0.4	2.7	1.1	2.7	5.1
TETRA II	0.0	0.0	0.0	0.0	0.0	0.0	1.0
TETRA III	1.3	0.5	0.4	1.3	0.8	1.1	0.8
TV4&5	0.7	0.3	0.2	0.2	0.2	0.3	0.3
LTE 800 (DL ^a)	556.8	472.9	421.3	482.9	250.1	363.6	864.4
LTE 800 (UL ^b)	0.1	0.7	0.6	0.1	0.3	0.1	0.1
GSM+UMTS 900 (UL)	5.4	4.1	4.3	14.3	8.0	4.8	4.1
GSM+UMTS 900 (DL)	1,561.6	1,453.5	1,409.5	2,074.6	1,337.0	1,165.1	1,314.0
GSM 1800 (UL)	0.4	0.9	1.1	4.1	1.0	0.6	1.1
GSM 1800 (DL)	102.5	354.4	390.0	840.2	495.5	370.5	344.8
DECT	20.8	8.6	19.6	11.2	8.5	12.0	35.4
UMTS 2100 (UL)	0.0	0.1	0.5	0.3	0.5	0.1	0.2
UMTS 2100 (DL)	864.3	964.2	1,631.9	893.3	441.5	557.1	1,239.6
Wi-Fi 2G	1.6	0.9	1.2	2.6	1.2	1.9	2.0
LTE 2600 (UL)	0.1	0.1	0.1	0.2	0.1	0.1	0.1
LTE 2600 (DL)	404.7	309.3	674.5	483.3	372.4	331.0	683.6
WiMax	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wi-Fi 5G	0.7	0.9	1.5	1.6	1.7	3.9	1.4
Total	3,535.0	3,584.4	4,564.2	4,891.2	2,929.9	2,817.0	4,548.1

^aDL, down link: transmission from base station to mobile phone; ^bUL, up link: transmission from mobile phone to base station.

path is schematically shown in Figs. 2 and 3. The lower level contains businesses and access to the metro, commuter trains and Vasagatan; the main floor has also businesses, access to the trains and exits to the street.

In order to minimize the body's shielding effect to the exposimeter, the unit was held ahead within ~0.4 m from the investigator's body.

Statistical methods. Means in $\mu\text{W}/\text{m}^2$ were calculated for all measured frequency bands and a box plot was constructed to illustrate the distribution of total exposure for all measurement rounds. Values at lower detection limit were treated as no (0) exposure. Total exposure was calculated as the sum of all measured frequency bands. Stata/SE 12.1 (Stata/SE 12.1 for Windows; StataCorp., College Station, TX, USA) was used for all calculations.

Results

In total 1,669 readings were collected varying from 195 to 262 during each round (median 244). Thus, the time varied between 13.0 and 17.5 min for different rounds.

The results for each round are displayed in Table II, and for all rounds in Table III. The mean total exposure level varied between 2,817 to 4,891 $\mu\text{W}/\text{m}^2$ (or 0.28 to 0.49 $\mu\text{W}/\text{cm}^2$; 1 $\mu\text{W}/\text{m}^2=0.0001 \mu\text{W}/\text{cm}^2$) and the median value for total

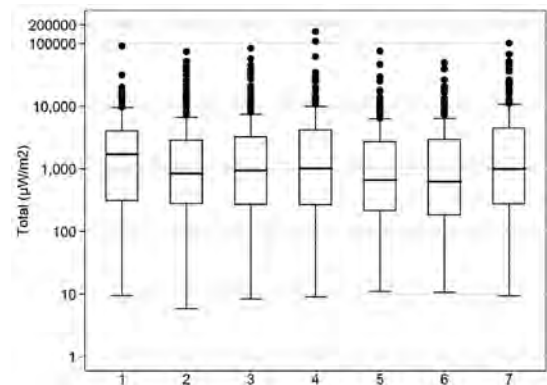


Figure 4. Box plot for total exposure in $\mu\text{W}/\text{m}^2$ for the seven measurement rounds. The median is indicated by a black line inside each box; the bottom and top of the boxes show first and third quartiles; the end of the whiskers are calculated as 1.5xIQR (interquartile range). Points represent outliers.

exposure (all measurement rounds) was 921 $\mu\text{W}/\text{m}^2$. High mean measurements were obtained for GSM and UMTS 900 downlink varying between 1,165 and 2,075 $\mu\text{W}/\text{m}^2$. High mean levels were also obtained for UMTS 2100 downlink; 442 to 1,632 $\mu\text{W}/\text{m}^2$. Also LTE 800 downlink, GSM 1800 downlink, and LTE 2600 downlink were in the higher range of measurements. Notably lower mean levels were seen for DECT varying between 8.5 to 35.4 $\mu\text{W}/\text{m}^2$. The mean level results for FM

Table III. Mean, median, minimum and maximum values ($\mu\text{W}/\text{m}^2$) for all measurement rounds ($n=1,669$ measurement points).

Frequency band	Mean	Median	Min	Max
FM	23.7	0.0	0.0	9,206.3
TV3	0.3	0.0	0.0	176.6
TETRA I	3.1	0.0	0.0	834.8
TETRA II	0.2	0.0	0.0	78.5
TETRA III	0.9	0.0	0.0	100.9
TV4&5	0.3	0.0	0.0	41.4
LTE 800 (DL ^a)	491.8	55.8	0.0	41,281.2
LTE 800 (UL ^b)	0.3	0.0	0.0	142.8
GSM+UMTS 900 (UL)	6.3	0.6	0.0	561.3
GSM+UMTS 900 (DL)	1,467.2	254.9	0.0	95,522.5
GSM 1800 (UL)	1.3	0.1	0.0	243.5
GSM 1800 (DL)	418.6	22.9	0.0	58,843.8
DECT	16.7	0.3	0.0	3,637.2
UMTS 2100 (UL)	0.2	0.0	0.0	94.8
UMTS 2100 (DL)	955.8	127.2	0.9	59,847.5
Wi-Fi 2G	1.6	0.2	0.0	186.3
LTE 2600 (UL)	0.1	0.0	0.0	13.4
LTE 2600 (DL)	470.1	64.6	0.0	40,158.8
WiMax	0.0	0.0	0.0	1.3
Wi-Fi 5G	1.7	0.4	0.0	301.2
Total	3,860.2	920.6	5.8	155,263.4

^aDL, down link: transmission from base station to mobile phone; ^bUL, up link: transmission from mobile phone to base station.

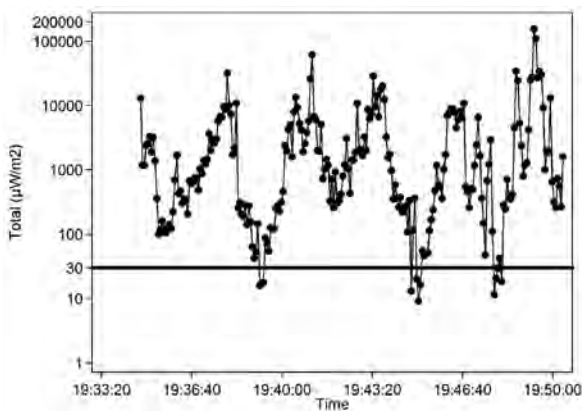


Figure 5. Total radiofrequency field exposure ($\mu\text{W}/\text{m}^2$) of the highest exposure round (151108, 18:50; mean exposure 4,891.2 $\mu\text{W}/\text{m}^2$) by walking across the station. The horizontal line represents the exposure limit of 30 $\mu\text{W}/\text{m}^2$ suggested by the BioInitiative Report (29).

radio varied between 2.0 to 78.0 $\mu\text{W}/\text{m}^2$. Some of the results showed 0.0 $\mu\text{W}/\text{m}^2$ since readings registered as lower detection limit were considered as 0 in the analysis.

In Fig. 4 the box plot shows total exposure in $\mu\text{W}/\text{m}^2$ for the seven measurement rounds. The overall median value was 921 $\mu\text{W}/\text{m}^2$ with some outliers of >150,000 $\mu\text{W}/\text{m}^2$. Fig. 5 displays the variation over time for the highest exposure round.

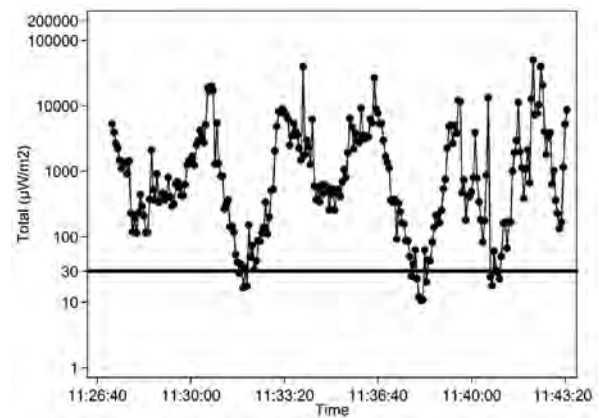


Figure 6. Total radiofrequency field exposure ($\mu\text{W}/\text{m}^2$) of the lowest exposure round (151109, 10:50; mean exposure 2,817.0 $\mu\text{W}/\text{m}^2$) by walking across the station. The horizontal line represents the exposure limit of 30 $\mu\text{W}/\text{m}^2$ suggested by the BioInitiative Report (29).

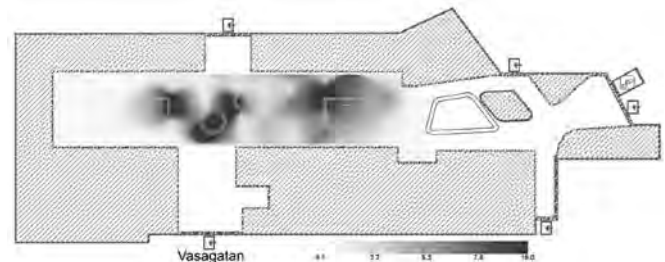


Figure 7. Stockholm Central Station ground floor with total field intensity map (151108, 19:20) scale in mW/m^2 .



Figure 8. An example of highest exposure area. A man is standing with his smartphone just a couple of meters below a base station (see arrow). In that area maximum measured power density in the GSM +UMTS 900 downlink band was 95,544 $\mu\text{W}/\text{m}^2$, which is the upper limit of measurement for EME Spy 200.

It should be noted that most measurements were >100 $\mu\text{W}/\text{m}^2$. In Fig. 6 similar results as in Fig. 5 are shown for lowest exposure round.

Fig. 7 shows total field intensity map on the Central Station main level. Clearly there were several hot spots, for example at

places where people use to sit or stand waiting for their train or meeting with other persons.

One example of highest exposure area is shown in Fig. 8. In that area maximum measured power density in the GSM + UMTS 900 downlink band was $95,544 \mu\text{W}/\text{m}^2$, which is the upper limit of measurement in each frequency band for EME Spy 200. Note that the photo was not taken simultaneously with the measurement rounds.

Discussion

EME Spy 200 is a band specific exposimeter and gives the possibility to identify and measure most RF radiation bands currently used in Sweden. We selected Stockholm Central Station in Sweden since it is a place for communication with lots of daily visiting persons. It may be persons that transfer between the metro and train (or opposite), but also people that meet each other or are waiting during a considerable time for a transfer train. There are also lots of shops in that area with employees. We did not make any measurements in shops since the aim was to restrict the study to transfer areas. Anyhow, there is a possibility for many persons to be exposed to high RF radiation for shorter or longer time periods.

Major results. The major finding of the present study was that total RF radiation mean exposure for a walking round, see Figs. 2 and 3, varied between $2,817$ to $4,891 \mu\text{W}/\text{m}^2$. GSM and UMTS 900 downlink contributed to most of the radiation dose. In fact, this together with UMTS 2100 downlink contributed to almost half of total exposure. Other major sources were LTE 800 downlink, GSM 1800 downlink and LTE 2600 downlink. Other sources were comparatively low. According to Table II, the vast majority of the mobile telephone exposure is from the downlink bands, i.e. the sources are the base station antennas placed around the railway station. Exposure from uplink levels was an insignificant percentage of the downlink exposure: LTE 800 0.06%, GSM 900 0.44%, GSM 1800 0.32%, UMTS 2100 0.03% and LTE 2600 0.21%.

All measured mean and median levels were well below ICNIRP's exposure guidelines at $2\text{--}10 \text{ W}/\text{m}^2$ (see below), but most of the measured levels were above the scientific benchmark of $30\text{--}60 \mu\text{W}/\text{m}^2$ as proposed by the BioInitiative Report (26). Obviously few total measurements were below $30 \mu\text{W}/\text{m}^2$, see Figs. 5 and 6.

There were also some hot spots for exposure. This is exemplified in Fig. 8 with a man standing close to a base station on the wall just below the roof. The measured exposure was $95,544 \mu\text{W}/\text{m}^2$, which is the upper detection limit for each frequency band for the exposimeter. Thus, it was not possible to get the exact value. People in general are not aware of this kind of exposure that may be considerable. Moreover, this is an example of an inappropriate placement of a base station with high downlink exposure. Note that the photo was taken separate from measurement rounds.

The exposure guidelines by ICNIRP. The reference values for radiofrequency electromagnetic fields were recommended in 1998 by ICNIRP to $2\text{--}10 \text{ W}/\text{m}^2$ for frequencies between 10 MHz to 300 GHz. Up to 400 MHz the recommendation is $2 \text{ W}/\text{m}^2$. The formula: $\text{frequency}/(2 \times 10^8)$ is used for frequen-

cies between 400 and 2,000 MHz. Above 2,000 MHz up to 300 GHz the recommended reference value is $10 \text{ W}/\text{m}^2$ (20).

The basic restrictions for time varying electric and magnetic fields for frequencies from 10 MHz up to 10 GHz for the specific energy absorption rate (SAR) is over 10 g of tissue for whole-body average set to $80 \text{ mW}/\text{kg}$, for localized head and trunk $2 \text{ W}/\text{kg}$ and for localized limbs $4 \text{ W}/\text{kg}$. FCC/Institute of Electrical and Electronics Engineers (IEEE) public safety limits use a 1 g rather than 10 g volume of tissue and the SAR limit for ICNIRP is $2 \text{ W}/\text{kg}$ in comparison to the FCC/IEEE $1.6 \text{ W}/\text{kg}$ SAR allowance.

These reference values and basic restrictions protect against injuries caused by a heating effect over 1°C after an exposure of 30 min, and with a safety factor of 50 for general public (20). Injuries caused by other biological mechanisms than heating or from chronic effects are not considered in the above mentioned limit values.

Limitations due to method of measurements. The present study describes measurements mostly from far-field RF radiation. It describes the exposure that the citizen may be exposed to without himself/herself using personal wireless devices. Near-field exposure from people's own mobile phones held near the ear or in the hand when surfing on the internet may be a considerable contribution to the individual's total exposure.

We measured during seven rounds during three days yielding 1,669 readings in total. The exposure levels did somewhat vary between the different walking rounds but did not exceed 2-fold. However, the data does not show that either weekends or weekdays would exhibit higher exposure level. Many people pass through the station in rush hours, but also in weekends when traveling away and into the city. It should be noted that this is a conservative estimate of exposure. The results do not reflect personal wireless devices being carried around or used by individuals, just the 'ambient' RF levels of people not using devices.

The present study used an exposimeter for measurements. Because samples were taken every 4 sec, technologies with large differences between average and peak might not have been exactly evaluated, an inherent limitation of the exposimeter. For example the DECT-base stations and Wi-Fi router exposures may have been undervalued with the used exposimeter. Generally, peak signal level measurement data is interesting when discussing the non-thermal effects of radio-frequency radiation.

The shielding effect from the body of a person carrying an exposimeter can be considerable as shown by Bolte *et al* (38) when comparing a body worn exposimeter with an exposimeter mounted on a car roof. This was partly compensated in the present study by holding the exposimeter at some distance from the body. Bhatt *et al* (37) concluded that using an exposimeter with three antennas, as in the present study, may minimize body shielding.

Laboratory studies and medical aspects. The mean measurements in the Stockholm Central Station showed a total RF radiation between $2,817$ to $4,891 \mu\text{W}/\text{m}^2$. Studies with laboratory animals exposed to RF radiation at or below these levels have shown influence on several physiological parameters in

the body of mammals. Influence on the blood-brain barrier, proteins and microRNA in the brain, testicular function, oxidative stress in the cells and DNA damage have been shown. Also neurotransmitters in people living in a village were changed after activation of a GSM mobile phone base station. These are non-thermal effects and are discussed briefly in the following.

The blood brain barrier (BBB) may open by exposure to RF radiation and lead to leakage into the brain of large molecules, like albumin and different toxins. As a result of opening of the protective BBB layer that separates the brain from the blood, this pathological leakage of the BBB has been shown to be toxic to brain tissues and can cause damage to, and death of neurons (39,40). Condensed dark neurons in the rats' brains are a sign of damage, and have been seen after 2 h of exposure to a GSM mobile phone both at 28 and 50 days after exposure (39,40). Several studies on rats have shown opened BBB after RF radiation from a GSM mobile phone with peak power output down to 1,000 μW and with an average whole body SAR-value down to 120 $\mu\text{W/kg}$ (41). A U-shaped response curve has also been seen with stronger health effects by RF radiation at lower exposure levels than at higher exposure (39,41).

Difference between genders after exposure to RF radiation has been found, where male rats got an increased BBB permeability for both GSM 900 and 1,800 MHz pulsed modulated RF radiation while female rats only got increased BBB permeability for the 900 MHz frequency (42).

The hippocampus is a center for memory and learning in the brain, and in particular appears to be a primary target for neuronal damage from RF radiation and opened BBB. Exposure to 900 MHz RF radiation during 3 h per day for 28 days showed extravasation of albumin in the hippocampus and cortex and impaired spatial memory in exposed rats (43). Also exposure for 2 h per day for 55 weeks showed impaired memory in GSM 900 MHz exposed rats, but no statistically significant alterations of histopathological parameters (44,45).

RF radiation has been shown to increase protein synthesis in proliferating human cells after 8 h of exposure, but not in quiescent white blood cells. This indicates a higher sensitivity of growing organisms (46). Also the capacity to repair DNA double-strand breaks was more effected by RF radiation in stem cells compared to differentiated cells like fibroblasts (47).

In a long-term study mice were exposed to a GSM 900 MHz mobile phone at SAR-level 370,000 $\mu\text{W/kg}$ for 3 h a day or to a DECT base station at a SAR-level of 12,000-28,000 $\mu\text{W/kg}$ for 8 h a day. After 8 months of exposure the two exposed groups of mice were compared with a sham exposed control group regarding 432 proteins from the cerebellum, hippocampus and frontal lobes of the brains. Comparative proteomics analyses revealed that 143 of the proteins had a statistically significant downregulation or an overexpression. Several neural function related proteins, like apolipoprotein E, heat shock proteins and cytoskeletal proteins as well as proteins of the brain metabolism were altered (48).

In two long-term studies rats were exposed to RF radiation emitted from a Wi-Fi system of 2.4 GHz for 24 h a day for 12 months. The peak power from the Wi-Fi was 100,000 μW with the antenna 50 cm above the cage. The SAR value over 10 g of brain tissue was 1,030 $\mu\text{W/kg}$. In one of the studies

micro-RNAs (miRNA) in the rat brains were examined. Two of the five examined miRNA, 107 and 106b-5p, decreased 3.3 and 3.6 times, respectively. miRNA plays an important role in the proliferation, differentiation, function and maintenance of neuronal cells. Dysfunction of miRNA pathways may be a potential contribution to pathogenesis of neurodegenerative disorders and also a key indicator of epigenetic changes and cancer risk (49).

In the other study the rat testes and prostate were examined. The SAR value in the exposed rat testes and prostate was 1,020 $\mu\text{W/kg}$ over 10 gram tissue. Compared to the sham exposed rats the Wi-Fi exposed rats showed statistically significant more head defects of the sperms and effects on testicular function and histology (50). Other Wi-Fi exposure studies have indicated damage to DNA in sperms (51-53).

Yakymenko *et al* (54) showed in a review of 100 studies investigating oxidative effects of low-intensity RF radiation in living cells, that exposure down to 2,500 $\mu\text{W/m}^2$ (55) and with SAR values down to 600 $\mu\text{W/kg}$ (56,57) could increase oxidative stress in the cells. Long-term RF radiation exposure at the frequencies 900, 1,800 and 2,450 MHz for 2 h per day 5 days per week for 30-180 days at SAR 595-667 $\mu\text{W/kg}$ have shown induced oxidative stress, reduced levels of neurotransmitters and downregulation of mRNA, increase in pro-inflammatory cytokines and DNA damage with single strand breaks in the hippocampus in the brain in the exposed rats (57-59). Cognitive impairments in learning and memory were also shown (59). Increase in frequency seems to have more deleterious effect on several of the parameters; 1,800 and 2,450 MHz had a statistically significant effect not only compared to sham exposed animals but also in some cases compared to 900 MHz exposure.

Even lower exposure levels in rats, down to SAR 85 $\mu\text{W/kg}$, for 900 MHz during 2 h/day, 5 days/week for 30 days showed increase in oxidative stress parameters in lipid peroxidation and protein oxidation. Also cognitive function showed a statistically significant impairment in spatial memory in the rats (60).

Buchner and Eger (30) performed a study with 60 participants out of the 2,000 inhabitants, who lived in the village Rimbach in Germany, when a GSM mobile base station was built in the spring of 2004. The neurotransmitters adrenaline, noradrenaline, dopamine and phenylethylamine (PEA) were measured in second morning urine samples before the base station was activated and 6, 12 and 18 months after. The RF radiation was measured outside each participant's house in peak value of the power density after the activation of the base station. The 60 study participants were divided into three exposure groups, <60, 60-100 and >100 $\mu\text{W/m}^2$.

After the activation of the GSM base station the levels of the stress hormones adrenaline and noradrenaline showed a statistically significant increase during the first six months and then decreased but were not restored to initial level after 18 months. This was seen especially for the children and the chronically ill adults. A statistically significant decrease was seen for dopamine levels during the first six months ($P < 0.0002$), then dopamine levels increased but were not restored to the initial level. These three neurotransmitters showed a dose-response relationship with highest influence for the participants with exposure >100 $\mu\text{W/m}^2$ at home. PEA levels decreased for the

highest exposed group first, but after 18 months all three exposure groups had a statistically significant decrease ($P < 0.0001$). Wireless devices like DECT, Wi-Fi and bluetooth at home seemed to amplify the effect of GSM radiation. Even the lowest exposed group, $<60 \mu\text{W}/\text{m}^2$, had decreased dopamine and PEA levels after 18 months. Chronic dysregulation of the catecholamine system and PEA may contribute to health problems and chronic illnesses (30).

The NTP animal study (18) confirms findings in epidemiological studies of an increased risk for glioma and acoustic neuroma among people that use wireless phones, both mobile phones and cordless phones (DECT). In 2013, accumulating evidence from brain cancer studies resulted in a recommendation to upgrade IARC's 2011 classification of RF from a Group 2B - Possible Human Carcinogen to Group 1 - Known Carcinogen (61). The NTP study has greatly strengthened the evidence of risk, and reaffirms that it is sufficient to reclassify wireless phone radiation as a known cancer causing agent, and confirms the inadequacy of existing public safety limits.

Environmental RF radiation exposure. There are no other published studies in Sweden on RF radiation exposure in public places like this one at the Stockholm Central Station. The study by Hamnerius *et al* (35) from 2000 has merit as an RF radiation baseline, and may establish how much exposure has changed over time. Estenberg and Augustsson (31) measured with a car-mounted device the frequency range 30-3,000 MHz in some public places; rural, urban and city. The arithmetic mean measured exposure was in Stockholm city $6,700 \mu\text{W}/\text{m}^2$, in urban areas (4 towns) $1,500 \mu\text{W}/\text{m}^2$, and in rural areas (2 places) $230 \mu\text{W}/\text{m}^2$. Similarly as in present study the major sources were GSM and UMTS downlinks.

Within one year, from 2011 to 2012, total RF radiation levels in all studied European outdoor city areas in combination increased by 57.1% (62). Over the past decade or so, RF radiation levels have significantly increased in our environment. Frei *et al* (63) estimated that the introduction of mobile phone technology has resulted in a 10-fold increase of RF radiation at outdoor areas compared to the time period before when broadcast transmitting was the most relevant source. Urbinello *et al* (62) measured 3 European cities, including train stations. The RF radiation measurement values in train stations ranged from 0.32 ($272 \mu\text{W}/\text{m}^2$) to 0.57 V/m ($862 \mu\text{W}/\text{m}^2$). Authors comment: 'Interestingly, across all indoor areas in all cities, mobile phone base station exposure showed a stronger temporal increase than mobile phone handset exposure' (62).

In a study by Bolte *et al* (64) 98 persons in The Netherlands carried a body-worn EME-Spy 121 for 24 h. Passing time at a railway station or going by train and metro showed high exposure, mean power density 304-354 $\mu\text{W}/\text{m}^2$, although visiting pubs or cafés showed even higher exposure, mean 526 $\mu\text{W}/\text{m}^2$. These are places where many people gather together and use mobile phones and laptops. During 2010 and 2011 when the study was done exposure from UMTS, both downlink and uplink, was low and few owned and used smartphones.

Grytz and Karpowicz (33) measured RF radiation inside the metro in Warsaw. The major source of exposure was the 900 GSM system. In another publication the mean exposure based on 173,323 measurements in 23 countries

worldwide was reported to be $730 \mu\text{W}/\text{m}^2$ (65). However, these measurements covered a different time period and not the same frequency range as in this study. Furthermore, the study methods were not clearly described. Markakis and Samaras (66) made a measurement campaign in Greece from 2010 to 2012 and concluded that signals from mobile base stations were dominant in workplaces and schools, whereas in home environment the dominant exposure was from wireless phones and computer networks. Viel *et al* (67) used exposimeters to investigate the participants' exposure budget across the week. They concluded the highest exposure to reside during Sundays, with main contributions from UMTS Tx (transmitting, upload) and DECT.

The present study is unique and different from those published previously since it covers 20 different frequency bands including most currently used frequency bands. Thus, in addition to the changing technology, our results are not comparable with previous ones such as the one from 2010 by Joseph *et al* (68) or even the results by Tell and Kavet (69) from 2014 stating that the FM band was a major contributor to overall power density. These results are less reliable comparing with our findings. Mean values for the FM band was orders of magnitude lower than e.g. for GSM+UMTS 900 (DL) and UMTS 2100 (DL) in this study, see Table II.

In conclusion, the aim of the present study was to assess the exposure to RF radiation in a public place in Sweden visited daily by many persons. We compare our results with non-thermal effects in laboratory investigations and also discuss results in animal studies on the carcinogenic risk. In epidemiological studies an increased risk of glioma and acoustic neuroma has been found in persons exposed to RF radiation from wireless phones. In animal studies RF radiation has been shown to promote tumours but also cause glioma and acoustic neuroma. There are also by now mechanistic studies such as oxidative effects from low-intensity RF radiation. We call for upgrading the carcinogenic potential to IARC Group 1, the agent causes cancer in humans.

In this study, real-time band specific exposure measurements at a public place showed comparatively high exposure from all mobile telephone and networking bands. The highest contributors to the exposure were download frequencies from the base stations at GSM+UMTS 900, UMTS 2100, LTE800, LTE 2600 and GSM 1800 bands. However, these RF exposure levels in this study are transient, since people are generally passing through the areas tested, except for subsets of people, i.e., security and police staff, cafe workers, shop workers, janitors, information counter people, who are there for hours each day of work.

Due to the rapid development of the telecommunications technology and the evolution of the wireless infrastructure, it is imperative to measure public's exposure. Yearly monitoring measurements would allow an overview of the public's exposure budget, since nowadays, rapid deployment of new RF radiation sources take place. The information obtained by the exposure studies allows assessing public's exposure to RF radiation today and in the years to come, when future epidemiologic studies seek for information in assessing the historic exposure levels to which the public was commonly exposed. Unfortunately studies on human risk from long-term environmental RF radiation based on personal exposure monitoring

do not exist to our knowledge. Given the lack of good historic RF radiation exposure information to date, it is imperative that better efforts be directed to periodic collection of RF radiation exposures in daily life for use in epidemiological studies of cancer as well as of neurological diseases and other adverse health effects attributed to RF radiation exposures.

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Commentary

Aspects on the International Commission on Non-Ionizing Radiation Protection (ICNIRP) 2020 Guidelines on Radiofrequency Radiation

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Abstract

The International Commission on Non-Ionizing Radiation Protection (ICNIRP) published 2020 updated guidelines on radiofrequency (RF) radiation in the frequency range 100 kHz to 300 GHz. Harmful effects on human health and the environment at levels below the guidelines are downplayed although evidence is steadily increasing. Only thermal (heating) effects are acknowledged and therefore form the basis for the guidelines. Despite the increasing scientific evidence of non-thermal effects, the new ICNIRP guidelines

are not lower compared with the previous levels. Expert groups from the WHO, the EU Commission and Sweden are to a large extent made up of members from ICNIRP, with no representative from the many scientists who are critical of the ICNIRP standpoint.

Keywords: EU; WHO; ICNIRP; 5G; Microwave radiation

1. Introduction

Wireless technologies, such as mobile phones, cordless phones, base stations, WiFi, 2G, 3G, 4G and 5G emit radiofrequency (RF) radiation, also called microwave radiation. For a long time there has been concern among laymen and a large part of the scientific community that such radiation may be a health hazard and also have a negative effect on the environment including birds [1], insects [2] and plants [3,4].

The seminal first early warning on brain tumor risk associated with exposure to RF radiation from mobile phones was published some 20 years ago [5, 6]. In the following case-control studies by the Hardell group, in addition to mobile phones, also use of cordless phones (DECT) was assessed. These studies confirmed an increased risk for brain tumors, i.e. glioma, for both types of wireless phones [7]. Similar findings were reported for acoustic neuroma [8].

In May 2011 the International Agency for Research on Cancer (IARC) at the World Health Organization (WHO) evaluated RF radiation in the frequency range 30 kHz–300 GHz to be a possible human carcinogen, Group 2B [9, 10]. The IARC decision on mobile phones was based mainly on two sets of case-control human studies: the Hardell group studies from Sweden [11-13] and the IARC Interphone study [14, 15]. Both provided supportive evidence of increased risk for brain and head tumors, i.e. glioma and acoustic neuroma. Later published studies by the Hardell group [7, 8] and the French CERENAT (CEREbral tumors: a NATional study) study on glioma and meningioma [16] supported an increased risk for brain tumors and use of mobile and cordless phones. However, risks associated with the use of

cordless phones was assessed only by the Hardell group, although cordless phones emit RF radiation of similar type as mobile phones.

The increasing scientific evidence on cancer risks from RF radiation, as well as other health effects, has had little or mostly no effect on preventive measurements. This is due to scientific disagreements and controversies. Some influential organizations are downplaying the health risks, i.e. the International Commission on Non-Ionizing Radiation Protection (ICNIRP), the World Health Organization (WHO), the European Union (EU) and the Swedish Radiation Safety Authority (SSM), see next section. It has been discussed that by now such exposure might be classified as carcinogenic to humans, Group 1, according to the IARC classification [17-19]. However, only an IARC evaluation can make that classification.

Because of the controversies and the lobbying by influential organizations, including the telecom industry, precautionary measures are not taken and the public is not informed about health risks [20, 21]. People in general are, as a consequence, not taking preventive measures when using the handheld wireless phone, WiFi, or when exposed to RF radiation from base stations. Increasing ambient RF radiation gives higher total human exposure [22, 23] in addition to the widespread use of mobile and cordless phones.

During the last decades, the scientific evidence on other health effects than cancer has also increased. By January 2021, 255 scientists from 44 nations and 15 supporting scientists from 11 nations concluded that these effects occur well below most international and national guidelines recommended by ICNIRP, (see next section).

“Effects include increased cancer risk, cellular stress, increase in harmful free radicals, genetic damages, structural and functional changes of the reproductive system, learning and memory deficits, neurological disorders, and negative impacts on general well-being in humans. Damage goes well beyond the human race, as there is growing evidence of harmful effects to both plant and animal life.” [24].

The scientific evidence on the carcinogenic potential of RF radiation in laboratory studies has long been accumulating, but has mostly been ignored or dismissed by e.g., ICNIRP, the WHO, the EU and the SSM. The increased cancer risk in humans for RF radiation is clearly supported by recent animal studies [25-27] and mechanistic studies, both induction of reactive oxygen species (ROS) [28], and DNA damage [29-31]. The history on carcinogenic effects in laboratory studies started several decades ago.

Co-carcinogenic effects of RF radiation exposure and benzopyrene in mice were published already in 1982 [32]. The study showed that 2,450 MHz of RF radiation at either 50 or 150 W/m² promoted carcinogenesis. These levels exceed the ICNIRP guidelines, see below. The authors concluded that the resulting acceleration of development of spontaneous and chemically induced cancers indicated the carcinogenic potential of RF radiation.

Two studies published in 1990 demonstrated that 2,450 MHz continuous-wave RF radiation exerted a biphasic effect on glioma cells [33] and lymphocytes [34]. Cell proliferation was found at a specific absorption rate (SAR) of ≤ 50 W/kg, whereas a higher SAR suppressed DNA and RNA synthesis. These effects were reported to be non-thermal, i.e. not caused by heating.

A statistically significant increased incidence of primary malignant diseases was found in exposed animals compared with sham exposure in a study on 200 rats exposed to 2,450 MHz pulsed RF radiation for 21.5 h/day for 25 months compared with 200 controls. SAR ranged between 0.144 and 0.4 W/kg, depending on the rat's weight [35]. This was one of the first large scale studies to be conducted. Consequently the results in the U.S. National Toxicology Program (NTP) [25-26] and the Ramazzini Institute [27] studies are in line with these findings.

A study on mice carrying a lymphomagenic oncogene exposed to RF radiation showed a statistically significant increased risk for malignant lymphoma [36]. A total of 100 mice were sham-exposed and 101 were exposed for two 30-min periods per day for up to eighteen months to 900 MHz pulsed RF radiation with power densities of 2.6-13 W/m² (SAR 0.008-4.2 W/kg; mean, 0.13-1.4 W/kg). These results were not confirmed in the study by Utteridge et al. [37] which has been noted not to be a replication study [10, 38].

A co-carcinogenic effect was found in a study on mice exposed to a Universal Mobile Telecommunications System (UMTS) test signal from the fetal period for up to 24 months [39]. Animals were exposed to UMTS fields with intensities of 0 (sham), 4.8 and 48 W/m². The low-dose group was subjected to additional prenatal ethylnitrosourea (ENU) treatment. The group that was ENU-treated and UMTS-exposed at 4.8 W/m² exhibited an increased rate of lung tumors and an increased incidence of lung carcinomas as compared with the controls treated with ENU alone. A tumor promoting effect was studied in another study on ENU-treated mice. The exposure levels were 0 (sham), 0.04, 0.4 and 2 W/kg SAR. The numbers of lung and liver tumors

in exposed animals were statistically significant higher compared with those in sham-exposed controls, as were the numbers of malignant lymphoma. A tumor-promoting effect of RF radiation was found at low to moderate levels (0.04 and 0.4 W/kg SAR), which were well below the exposure limits for users of mobile phones, 2 W/kg (of tissue) to the head [40].

Numerous published studies report effects or damage in terms of oxidative stress, damage to DNA, gene and protein expression, breakdown of the blood-brain barrier and damage to the brain and other organs of the body [41, 42]. There is also increasing evidence of adverse (chronic) health effects from long-term exposure. This was already reported as the “microwave syndrome” or “radiofrequency sickness” some fifty years ago. Reported health effects in scientific studies during the last decades from exposure to mobile phone towers, WiFi and mobile phones are consistent with the reported effects from RF radiation (microwaves) half a century ago [43, 44]. Furthermore, repeated studies show harmful effects from prenatal exposure, both in animal studies and in humans [45, 46].

Many countries around the world rely on guidelines for maximum allowed exposure from ICNIRP, supported and recommended by the WHO [47]. In Europe, most countries also follow the recommendations from the EU Commission that are based on ICNIRP and the EU expert group Scientific Committee on Emerging and Newly Identified Health Risk (SCENIHR). In 2020 ICNIRP published updated guidelines [48] based on the reviews and opinions from the WHO 2014 environmental health criteria public consultation report, SCENIHR 2015 [49] and the Scientific Council on Electromagnetic Fields at the Swedish Radiation Safety Authority (SSM) 2015, 2016, 2018 [50-52].

In this article we discuss how these organizations have evaluated the increasing evidence of harmful effects of RF radiation at levels below most national guidelines and limits for RF radiation exposure. The same individuals reappear in several of these organizations’ expert groups, see Table 1, and there are no representatives in these groups from the many scientists that disagree with their conclusions [24]. We discuss primarily cancer risks in Appendix B of the ICNIRP updated guidelines [48].

WHO 2014 core group	ICNIRP	IEEE	EU	SSM	EMF Scientist Appeal	The 5G Appeal EU
Emilie van Deventer, project leader	X	X	-	X	-	-
Simon Mann	X	-	-	-	-	-
Maria Feychting	X	-	-	X	-	-
Gunnhild Oftedal	X	-	-	-	-	-
Eric van Rongen	X	X	X	X	-	-
Maria Rosaria Scarfi	X	-	X	X	-	-
Denis Zmirou	-	-	-	-	-	

SCENIHR 2015	ICNIRP	IEEE	WHO	SSM	EMF Scientist	5G Appeal EU
Theodoros Samaras	-	X	-	-	-	-
Norbert Leitgeb	-	-	-	-	-	-
Anssi Auvinen	X	-	-	-	-	-
Heidi Danker Hopfe	-	-	-	X	-	-
Kjell Hansson Mild	-	-	-	-	-	-
Mats Olof Mattsson	X	X	-	-	-	-
Hannu Norppa	-	-	-	-	-	-
James Rubin	-	-	X	-	-	-
Maria Rosaria Scarfi	X	-	X	X	-	-
Joachim Schüz	-	-	-	-	-	-
Zenon Sienkiewicz	X	-	-	-	-	-
Olga Zeni	-	-	X	-	-	-
SSM 2016	ICNIRP	IEEE	WHO	EU	EMF Scientist	5G Appeal EU
Anke Huss	From 2020	-	-	-	-	-
Clemens Dasenbrock	X	-	-	-	-	-
Emilie van Deventer	X	X	X	-	-	-
Eric van Rongen	X	X	X	X	-	-
Heidi Danker-Hopfe	-	-	-	X	-	-
Lars Klæboe	-	-	-	-	-	-
Maria Rosaria Scarfi	X	-	X	X	-	-
Martin Rösli	X	-	X	-	-	-

Table 1: Many persons in expert groups at the WHO, the EU commission and in Sweden are current or former members in ICNIRP, and other expert groups, with no representative from the scientific community with opinions as expressed in EMF Scientist Appeal or 5G Appeal. For further details see ICNIRP [72,135,136,140,141,143-146], IEEE [137,145], EU [86,138,145], SSM [71,142], EMF Scientist Appeal [24], the 5G Appeal EU [139].

2. Evaluating Organizations

2.1. ICNIRP

ICNIRP is a non-governmental organization (NGO) based in Germany that has obtained major influence world-wide on health risks from RF radiation through its recommended guidelines for limiting RF radiation exposure [48, 53, 54]. These guidelines are recommended by the EU Commission, the WHO and are adopted by the majority of the countries around the globe.

ICNIRP was started in 1992 as an “independent commission”. It is registered in Germany and located in Munich at the same address as the German Federal Office for Radiation Protection [55].

ICNIRP maintains the same attitude to health effects from RF-radiation as the Institute of Electrical and Electronics Engineers (IEEE) and its standards setting committee, the International Committee on Electromagnetic Safety (ICES). This committee and ICNIRP, are both standard setting organizations for frequencies between 0 Hz to 300 GHz.

ICES have many industry and military representatives among its members [56]. ICES within IEEE also sets limits for RF exposure which are in line with the ICNIRP opinion that there are only immediate thermal effects and no effects below those that cause immediate effects due to increased temperature. This perception was established in the 1950's and a decade later used when the first thermal based standard for radiofrequency radiation was set in the USA in 1966 [57]. Several members of ICNIRP are also present or former members of IEEE/ICES [58].

The biophysicist Michael Repacholi from Australia was ICNIRP's first chairman and he is since 1996 an emeritus member [59]. Experts from various countries constitute the “main commission” of ICNIRP; a chair, a vice chair and 11 other members. Further scientists are elected by this commission to the scientific expert group (SEG). New and continuing members to the commission are elected by the members of the main commission. Nominations can be submitted by the members of the Commission itself, the Executive Council of IRPA (the International Radiation Protection Association) or the IRPA Associate Societies. It seems as if no scientist that is critical to the thermal paradigm on RF radiation risks, advocated by ICNIRP, is elected as a member of the Commission.

ICNIRP published its first guidelines on RF radiation in 1998 [53]. These were updated in 2009 with no changes [54]. Only short-term thermal (heating) effects were acknowledged to form the basis for the exposure guidelines. Long-term exposure and non-thermal effects were considered not to be established, thus excluding a large number of peer-reviewed scientific studies on negative health and biological effects from RF-radiation below the ICNIRP guidelines. In 2020 ICNIRP [48] published new guidelines on health risks based on documents from: the WHO 2014 draft, the EU SCENIHR 2015 report and the Swedish SSM reports 2015, 2016 and 2018.

It should be noted that not one of these five reviews has been published after peer-review in a scientific journal. Critique from the scientific community has been expressed against several of these reviews but has been ignored. Furthermore, these older documents do not cover the most recent research. In the following comments are given to these three reviews

since the ICNIRP 2020 is based on these older evaluations with no new and further evaluation of its own [48].

2.2 The WHO Public Consultation Environmental Health Criteria Document, 2014

The WHO EMF Project, responsible for the 2014 document, was established in 1996. ICNIRP's chairman Michael Repacholi suggested in 1995 that WHO should start the EMF Project [60]. In 1995, while Repacholi still was chairman of ICNIRP, he became the head of the WHO International Electromagnetic Fields Project, and then head of the WHO EMF Project in 1996 [61], where he remained until 2006 [62]. A close collaboration between WHO and ICNIRP was initiated. In November 1998 the WHO EMF Project commenced a process aimed at the harmonization of EMF standards worldwide according to the ICNIRP guidelines [63]. Benefits to trade was given as one main argument to this specific project. The 100 times lower limits (compared to ICNIRP) in Eastern Europe were described as problematic [63].

The possibility of industry funding to the project was arranged already before the start of the project: "In 1995 WHO reached agreement consistent with these policies with Royal Adelaide Hospital (RAH), Australia to collect funds on behalf of the EMF Project. A memorandum of understanding allowed RAH to collect funds from government, professional associations and industry." [64]. This financial situation was ended in 2006 after disclosure by investigating journalists that showed that approximately half of the funding for the WHO EMF Project came from telecom industry organizations; GSM Association, Mobile Manufacturers Forum (MMF) and Forschungsgemeinschaft Funk e.V. (FGF) [65, 66].

Since 2006 the project leader of the WHO EMF project is Emilie van Deventer, an electrical engineer and longtime member of the industry organization IEEE [67]. She is the founder and former chairperson of the IEEE Joint Chapter on Electromagnetics and Radiation [68]. Her background is in "electromagnetic characterization of high-speed circuits for telecommunications applications, computational electromagnetics (RF frequency and time domain techniques), electromagnetic compatibility, antenna modelling and design" and does not include medical training [69, 70]. She is the WHO EMF Project observer at the ICNIRP's main commission as well as a member of the SSM expert group from 2010 to 2017 [60, 71, 72].

The WHO EMF Project is in principle synonymous with ICNIRP. The same individuals that propose the ICNIRP guidelines are also acting as experts evaluating hazards from RF radiation on behalf of the WHO. This kind of double position situation is a potential conflict of interest according to the Ethical Board of the Karolinska Institute, Stockholm, Sweden 2008 (Dnr 3753-2008-609).

In 2005-2006 the personnel at the WHO EMF Project were Michael Repacholi, Emilie van Deventer, Chiyoi Ohkubo [62], Richard Saunders [73], Eric van Rongen and Lisa Ravenscroft [60]. All except Ravenscroft are current or former members of ICNIRP. In fact, at a meeting at WHO, Geneva in March 2017, Dr Maria Neira, at that time Director for Public Health and Environment at WHO, stated that ICNIRP is an Non-Governmental organization (NGO) with an official relationship with WHO that "helps us a lot in our analyses" and their members work as WHO's experts [74]. The WHO EMF Project has for many years been criticized for its collaboration with the industry; electrical, military and telecom [75].

A draft of a Monograph on health effects of electromagnetic field (EMF) exposure was released by WHO in 2014 [76]. It was open for public consultation until December 31, 2014, but has never been published as a final version and it is unclear why it was never finalized.

Out of the six experts in the WHO core group responsible for the draft, four were active members and one was a former member of ICNIRP [74], a fact that illustrates that WHO continues to be almost identical with ICNIRP, see Table 1. Many critical comments were sent to the WHO. One example is the “No confidence” letter sent by The BioInitiative Working Group in December 2016 to the WHO EMF Program Manager that concluded that the experts writing the WHO draft were to a large extent ICNIRP members.

“The BioInitiative Working Group urges the World Health Organization to make changes to the WHO RF EHC [Environmental Health Criteria] Core Group membership to more fairly reflect membership and expertise of the 2011 IARC RF Working Group. At present the WHO RF EHC Core Group is indistinguishable from ICNIRP (1, 2) undermining credibility of the process and ensuring doubt about conclusions.” [77].

This letter was followed by another letter from the BioInitiative Working Group in January 2017 including suggestion of experts to replace present persons in the Core Group as well as Additional Experts [78].

A call for Protection from Non-ionizing Electromagnetic Field Exposure was made by the International EMF Scientist Appeal.

“By not taking action, the WHO is failing to fulfil its role as the preeminent international public health agency.... The WHO is calling for all nations to adopt the ICNIRP guidelines to encourage international harmonization of standards... It is our opinion that, because the ICNIRP guidelines do not cover long-term exposure and low-intensity effects, they are insufficient to protect public health.” [24].

In total forty-seven NGOs also submitted a critical statement regarding the WHO draft on December 15, 2014. The WHO draft was criticized for the absence of pluralism among the selected experts, for biased reporting of scientific results and the “promiscuity between the WHO and ICNIRP.” [79].

A press release was furthermore issued on February 24, 2017 by the European coordination of organizations for an EMF exposure regulation which truly protects public health. They stated that “The Conflict of Interest Scandal is repeating itself in the WHO” [80].

In a letter of concern dated March 1, 2017 the Russian National Committee on Non-Ionizing Radiation Protection wrote to the WHO: “It has just come to our attention that the WHO RF Working group consists mainly from present and past ICNIRP members.....the private self-elected organization ICNIRP, similar as majority of the current WHO RF WG [Working Group] members, does not recognize the non-thermal RF effects,...” [81].

In 2016 at a seminar at SSM in Stockholm Emilie van Deventer said that they had received 700 comments on the draft including references to “at least 300 papers that we had missed” [82].

It is unclear how WHO reacted to the critique. The Monograph is still unfinished. Instead the WHO has called for a new systematic review of this topic.

It should be noted that WHO in 2014 issued the following statement: “THIS IS A DRAFT DOCUMENT FOR PUBLIC CONSULTATION. PLEASE DO NOT QUOTE OR CITE.” Nevertheless, this WHO Monograph draft from 2014, issued by a group dominated by ICNIRP members, was used as a basis for the ICNIRP guidelines 2020.

2.3. The European Commission SCENIHR opinion 2015

In 2015 the European Commission’s expert group on electromagnetic fields, SCENIHR, released its report “Opinion on potential health effects of exposure to electromagnetic fields (EMF)” [49]. It was an update of the previous SCENIHR Opinions of 19 January 2009 “Health effects of exposure to EMF” and 6 July 2009 “Research needs and methodology to address the remaining knowledge gaps on the potential health effects of EMF” [83].

SCENIHR is one of three “Independent Scientific Committees” that provide the EU Commission, and through the Commission the other European institutions, with scientific advice regarding consumer safety, public health and the environment [84]. The Committee is also supposed to “...draw the Commission's attention to the new or emerging problems which may pose an actual or potential threat”.

According to the Commission decision 2008, article 15 [85], the experts “...shall undertake to act independently of any external influence” and “shall make a declaration of commitment to act in the public interest and a declaration of interests indicating either the absence or existence of any

direct or indirect interest which might be considered prejudicial to their independence”. However, this committee has a history of being unbalanced in terms of representation from both sides of the scientific controversy on RF radiation. No representatives from the scientific community that are of the opinion that there is increasing evidence of harmful effects have participated; at least no person has declared other opinion than the ICNIRP view.

The 2007 SCENIHR [86] working group’s chair was Anders Ahlbom from Sweden, ICNIRP commission member 1996-2008 and contributing to the ICNIRP guidelines 1998. Mats-Olof Mattsson, from Sweden, was one of the groups’ three experts.

The 2009 SCENIHR [87] working group was identical to the 2007 group, but Mats-Olof Mattsson, from 2013 member of ICNIRP SEG, replaced Ahlbom as chair [88]. Eric van Rongen, member of ICNIRP and ICES as well as working with the WHO EMF Project, was now among the external experts [87].

The 2015 SCENIHR working group was made up of Theodoros Samaras and Norbert Leitgeb (retired) and ten additional external experts [89]. Of the ten external experts, four are former or present members of ICNIRP main commission or SEG (Anssi Auvinen, Mats-Olof Mattsson, Maria Rosaria Scarfi and Zenon Sienkiewicz). Both Mattsson and Samaras are members of ICES/ IEEE [56].

2.3.1 Main conclusions 2015

The quotes in this section are from the SCENIHR report 2015 [49]:

“Overall, the epidemiological studies on mobile phone RF EMF exposure do not show an increased risk of brain tumours. Furthermore, they do not indicate an increased risk for other cancers of the head and neck region....The results of cohort and incidence time trend studies do not support an increased risk for glioma while the possibility of an association with acoustic neuroma remains open.”

Other effects from RF-radiation such as different health symptoms, also known as the microwave syndrome [43], neurological diseases and other health outcomes, were also dismissed with various arguments. The conclusion of no brain tumor risks from RF radiation relied upon several studies with methodological shortcomings resulting in underestimated risks, for instance the Danish cohort study [90, 91], the UK Benson study [92] as well as the Cefalo study [93], see below. Joachim Schüz, who was a member of SCENIHR 2015 working group that drafted SCENIHR 2015, was also coauthor of these three studies [94].

Increased cancer risks in other epidemiological studies [7, 8, 14, 15, 16] were downplayed by SCENIHR [49] with reference to a few brain tumor incidence trend reports, the Danish cohort and a UK cohort:

“The fact that incidence rates of glioma and meningioma do not rise in the age groups of highest mobile phone prevalence provides evidence that common use of mobile phones is unlikely to be associated with an increased risk of those brain tumours. This is confirmed by the Danish cohort study that rules out risks that would affect large segments of the population. Evidence against an association also arises from the large-scale UK million women study.”

2.3.2. Methodological issues

2.3.2.1. The Danish Cohort (2001, 2006, 2011): This study, funded by Danish telecom operators, first published in 2001 [90] and last updated in 2011 [91], reported no increased risks of tumors in the central nervous system. It was based on 420,095 mobile phone private subscribers. This group's incidence of brain tumors was compared with the incidence within the rest of the Danish population (control group). However, there are severe methodological faults that led to erroneous results:

- Inclusion only of mobile phone private subscribers in Denmark between 1982 and 1995 in the exposure group.
- Exclusion of the most exposed group, consisting of 200,507 corporate users of mobile phones [90]. They were instead included in the unexposed control group if not private subscribers.
- Users with mobile phone subscription after 1995 were not included in the exposed group and were thus treated as unexposed: “individuals with a subscription in 1996 or later were classified as non-users” [91].
- Actual exposure data is unknown and no analysis by laterality (the side where the phone is held in relation to the position of the tumor) was performed.
- All users of cordless (DECT) phones were treated as unexposed for that exposure although they were also exposed to the same kind of RF radiation as from mobile phone use. The Hardell group has shown that use of cordless phones increases risk of glioma and acoustic neuroma tumors [7, 8].

Professor Michael Kundi of the Medical University of Vienna expressed the opinion that the Danish study is “the

most severely biased study among all studies published so far” [95]. Certainly, there were severe methodological flaws. The study [90, 91, 96] was regarded by IARC in the 2011 evaluation [9, 10] to be uninformative regarding cancer risks due to serious exposure misclassification. However, it is included by SCENIHR [49], WHO [76], SSM [97] and ICNIRP as evidence of no risk [98, 99]. The statement by SSM 2013 [97] that: “The Danish cohort studies make an important contribution to the total assessment in the field.” is remarkable taking the critique of the study that should have been well known to the SSM expert panel. The many shortcomings in the study were discussed in a peer-reviewed article [100] concluding that: “After reviewing the four publications on the Danish cohort study, one might rightly wonder whether this cohort was initially set up to show no increased risk.”

2.3.2.2. The Benson UK study (2013): This cohort study of 791,710 women in the Million Women Study was started during 1996-2001 [92]. Data on mobile phone use was collected at one time between 1999 and 2005, without questions separating heavy users from light users. Mobile phone use was based on the answers to a few questions posed at the time when the women were recruited to the study: “About how often do you use a mobile phone?”, “Never, less than once a day, or every day?” Those who did use a mobile phone were also asked “for how long?”. At the end of the study in 2009, a random sample of participants were asked two more questions about their mobile phone use, but these answers were never used in the analyses. Use of cordless (DECT) phone was not assessed. Due to limitations in the study design, such as no comprehensive assessment of life-time mobile phone use, the study is uninformative and should not be used as scientific evidence of lack of cancer risk. In fact the authors concluded that:

“The main limitation of the study is that mobile phone use was reported at baseline and may have changed subsequently. Almost all women who reported daily use of mobile phones at baseline were still using a mobile phone at least once a week when asked again 8.8 years later. However, some women who reported not using a mobile phone at baseline began use subsequently; and this might dilute our estimates of relative risk towards the null” [92].

2.3.2.3. The CEFALO Study (2011): The CEFALO study on brain tumor risk for children aged 7-19 using mobile phones [93] is claimed in the SCENIHR 2015 report [49] to have found no increased risk. The children in the study were diagnosed with a brain tumor during 2004-2008. The study showed several statistically non-significant increased odds ratios (ORs). However, a press release issued by one of the authors, Maria Feychting at the Karolinska Institute in Stockholm, stated that “Reassuring results from first study on young mobile users and cancer risk...The so called CEFALO study does not show an increased brain tumor risk for young mobile users.” [101]. She was vice chair of ICNIRP 2012-2020, member of ICNIRP SEG 2000-2012, and is currently SEG member since 2020. Maria Feychting was also member of the WHO core group responsible for the WHO 2014 draft. Martin Röösli, member of ICNIRP Commission since 2016, the SSM expert group since 2010, as well as member of the WHO 2014 external expert group, was also coauthor of this study (corresponding author). Martin Röösli also claimed in a press-release that the results were reassuring of no risk [102].

The study has several shortcomings and one major shortcoming is the assessment of RF exposure from cordless phones that was not included in the total RF radiation exposure. Furthermore, the scientists did not assess total

exposure from cordless phones (DECT). Instead the authors analyzed "...ever used cordless phones, and the cumulative duration and number of calls with cordless phones in the first 3 years of use." This is a scientifically invalid method to study risk associated with an agent [103]. Thereby four to sixteen years of potential exposure were disregarded in the study age group 7-19 years. It is most questionable since use of the cordless phone increases by age.

This is more startling since no such time limit was made in the questionnaire sent to the Ethical Board at Karolinska Institute, Stockholm (DNR2005/1562-3). There were four questions on use of a cordless phone (summary): 1. When did you first start using a cordless phone? 2. How often did [child] answer the cordless phone? 3. How often does [child] speak on the cordless phone? 4. When [child] talks on the cordless phone, which phrase fits the best? (about 1 min, about 3 min, about 6 min, about 10 min or more).

No doubt even with these few questions it would have been possible to assess lifetime cumulative use of the cordless phones. According to the questions there is no reason or possibility to limit to only the first three years of use. Furthermore, it is not probable that a child would only use the cordless phone for three years and then stop the habit. To note is also an e-mail (personal communication) from Martin Rösli to one of the authors (MN) on August 17, 2011 in which he regarding cordless phones stated that "We also asked about ever using it and we requested the age range that they have used the phone". No doubt with that information, which was not given in the article, it would have been possible to calculate whole lifetime cumulative exposure. Thus, it is evident that limiting use to only first three years would bias the results towards unity, particularly as children tend to increase their phone use with increasing age, which

is also shown in the CEFALO study. In spite of this, SCENIHR [49] gave the impression that all cordless phone use was included by claiming that "Use of cordless phones showed no increased OR (1.09; CI 0.81-1.45), not even in the group of highest cumulative use." This claim is most misleading. Highest group for cumulative use available in the study was only 70+ hours. Further, the authors intentionally omitted the real highest users by limiting the exposure to the first three years of use. It is remarkable that this misleading claim in the SCENIHR report was written by one of the authors of CEFALO (Joachim Schüz), who also was coauthor of the Danish cohort and the Benson study.

In a comment, the Hardell group wrote [103]:

"Further support of a true association was found in the results based on operator-recorded use [of mobile phones] for 62 cases and 101 controls, which for time since first subscription > 2.8 years yielded [odds ratio] OR 2.15 (95% [confidence interval] CI 1.07-4.29) with a statistically significant trend (P = 0.001).... We consider that the data contain several indications of increased risk, despite low exposure, short latency period, and limitations in the study design, analyses and interpretation".

In fact, all ORs on mobile phone use were >1.0 according to Table 2 in the article [93]. For both ipsilateral and contralateral mobile phone use statistically significant increased risks were obtained for highest group of cumulative numbers of calls; OR = 2.91, 95% CI = 1.09-7.76 and OR = 4.82, 95 % CI = 1.21-19.24, respectively. For central or unknown location a statistically significant decreased risk was found based on low numbers. It should be noted that there are missing numbers of cases and controls in different strata in e.g. Table 5 in the article [93], no

explanation is given as we have discussed [103]. The anatomical distribution for brain tumors in children differs from adults [104]. Thus, there are more central and brain stem tumors, facts not considered by Aydin et al. [93] In children the distribution of RF radiation differs from adults with larger part of the brain more exposed due to e.g. smaller head and thinner bone [105]. Thus, the laterality analysis should be interpreted with caution.

2.3.3. Critical comments on SCENIHR [49]

There were in total 186 critical comments submitted to EU by different persons and organizations [106]. Less than 30 percent of these comments were taken into account, a few yielding minor clarifications in the text but without changes of the SCENIHR major conclusions. The BioInitiative Group was among many others that expressed critical comments to the SCENIHR: “In summary, the preliminary SCENIHR conclusion that glioma risk is weaker now is not scientifically justified. The only way that conclusion could be reached by SCENIHR is to exclude critical studies that present evidence to the contrary, i.e. studies that report the risk of glioma (and acoustic neuroma) is stronger now than in 2009” [107].

2.4. The reports from the Swedish Radiation Safety Authority (SSM) 2015, 2016 and 2018 [50-52]

The expert group on electromagnetic fields at SSM was created in June 2002. Between 2003 and 2010 it was called the “Independent Expert Group on Electromagnetic Fields”. During that period Anders Ahlbom, member of ICNIRP main commission 1996-2008, and SCENIHR member 2007-2009, was the head of the expert group and his colleague Maria Feychting, longtime member of ICNIRP and member of the WHO 2014 core group, was the group’s secretary.

From 2013 and until today, the expert group was renamed as the “Scientific Council on Electromagnetic Fields”.

Between 2003 and 2019 the SSM group has published thirteen reports in English on its webpage [71]. All reports since 2003 have consistently refuted or ignored evidence of health risks from non-thermal exposure in line with the views by ICNIRP, the WHO and the SCENIHR.

Since the first report in 2003 until today around half of the group’s members have also been present or previous ICNIRP members. In consequence the conclusions have generally been that there are no health risks below the limits recommended by ICNIRP. No scientist critical to the ICNIRP view has ever been part of this group. Here are some examples of conclusions from the SSM reports (2015 – 2018) that are included as basis for the present ICNIRP guidelines.

2.4.1. SSM 2015

“In terms of exposure from mobile phone base stations or other RF-EMF transmitters, no new evidence has become available indicating a causal link between exposure and symptoms or Electromagnetic Hypersensitivity (EHS).... New studies on mobile phone use and tumours in the brain using retrospective exposure assessment are in line with previous research, which means that increased risks were observed in some of the most extreme exposure categories. However, it is not clear to what extent these risk estimates are affected by recall bias... New studies on associations between sperm quality and mobile phone use are of low quality and cannot be used to evaluate a potential association with RF-EMF exposure” [50].

The 2015 SSM report raised the issue that recall bias might have affected brain cancer risk estimates. However the study by Momoli et al. [108] showed that recall bias did not affect the risk of glioma in the Canadian component of the Interphone study [14]. In addition, it should be noted that the 2020 ICNIRP guidelines [48] refer to recall bias in the case-control studies of the Interphone study but do not mention the analysis by Momoli et al. Also, as displayed below, recall bias cannot explain the results in the Hardell group studies.

2.4.2. SSM 2016

“Most research in the past decade has been done into a possible relation between mobile phone use and brain tumours. Epidemiological studies have provided weak indications for an association between frequent and long-term use of a mobile phone and gliomas (malign tumours of the brain tissue) and vestibular schwannomas (also called acoustic neuromas, a benign tumour of the vestibulocochlear

nerve that connects the ear to the inner brain). The evidence is not very clear and unequivocal, however. Altogether it provides no or at most little indications for a risk for up to approximately 15 years of mobile phone use” [51].

In a press release, at the time of the publication of the 2016 report, this Swedish authority claimed that the suspicion that mobile phones or wireless networks could be a health risk to humans or to the environment had become weaker during the past 13 years since the first of the group’s report [109]. This contrasted with the increasing scientific evidence of the opposite [24]. In Table 2 results for meta-analysis of highest cumulative use in hours of mobile phone use in case-control studies is given and the results for acoustic neuroma are given in Table 3. Clearly these results from the different studies available in 2016 are in contrast to the statement by SSM.

	All			Ipsilateral		
	Ca/Co	OR	95 % CI	Ca/Co	OR	95 % CI
Interphone 2010 [14]						
Cumulative use $\geq 1,640$ h	210/154	1.40	1.03 – 1.89	100/62	1.96	1.22 – 3.16
Coureau et al 2014 [16]						
Cumulative use ≥ 896 h	24/22	2.89	1.41 – 5.93	9/7	2.11	0.73 – 6.08
Hardell, Carlberg 2015 [7]						
Cumulative use $\geq 1,640$ h	211/301	2.13	1.61 – 2.82	138/133	3.11	2.18 – 4.44
Meta-analysis						
Cumulative use $\geq 1,640$ h*	445/477	1.90	1.31 – 2.76	247/202	2.54	1.83 – 3.52

* ≥ 896 h used for Coureau et al.

Table 2: Numbers of exposed cases (Ca) and controls (Co) and odds ratio (OR) with 95 % confidence interval (CI) for glioma in case-control studies in the highest category of cumulative use in hours for mobile phone use, for further details see [42].

	All			Ipsilateral		
	Ca/Co	OR	95 % CI	Ca/Co	OR	95 % CI
Interphone 2010 [15]						
Cumulative use $\geq 1,640$ h	77/107	1.32	0.88 – 1.97	47/46	2.33	1.23 – 4.40
Hardell et al. 2013 [8]						
Cumulative use $\geq 1,640$ h	27/301	2.40	1.39 – 4.16	19/133	3.18	1.65 – 6.12
Meta-analysis						
Cumulative use $\geq 1,640$ h	104/408	1.73	0.96 – 3.09	66/179	2.71	1.72 – 4.28

Table 3: Numbers of exposed cases (Ca) and controls (Co) and odds ratio (OR) with 95 % confidence interval (CI) for acoustic neuroma in case-control studies in the highest category of cumulative use in hours for mobile phone use, for further details see [42].

2.4.3. SSM 2018

This annual report was the twelfth in this series and covered studies published from October 2015 up to and including March 2017. Oxidative stress effects reported below ICNIRP guidelines was discussed but the relevance for human “direct health effects” was claimed to be “unclear”. The conclusion was that “No new health risks have been identified.” [52].

It is clear that the SSM expert group has not made a sound and objective scientific evaluation of health risks associated with RF radiation exposure. We note that SSM in April 2020 published a new report from the SSM expert group which concluded: “The results of the research review give no reason to change any reference levels [ICNIRP’s] or recommendations in the field”. Of the ten members in the scientific group five were present or past members of ICNIRP [110].

3. ICNIRP 2020 Evaluation

Eric van Rongen, chair of the ICNIRP Commission 2016-2020, claimed in a press release regarding the new ICNIRP

guidelines 2020 that the 1998 version was “conservative in most cases” and “still provide adequate protection for current technologies”. He also argued that: “The most important thing for people to remember is that 5G technologies will not be able to cause harm when these new guidelines are adhered to” [111].

Many other incorrect statements were made in the recent ICNIRP paper [48] contrary to an objective evaluation of the available scientific evidence. In the following the section on cancer is reviewed. That section claims:

“There is a large body of literature concerning cellular and molecular processes that are of particular relevance to cancer. Although there are reports of effects of radiofrequency EMFs on a number of these endpoints, there is no substantiated evidence of health-relevant effects (Vijayalaxmi and Prihoda 2019)”.

Already in the first paragraph in the report evidence on biological effects from RF radiation is dismissed without

scientific foundation. This continues regarding cancer risks. Mostly not even references are given to the discussed studies, or with erroneous references. The uninformed reader may take the statements at face value and not understand that they are, in fact, not correct.

3.1. Animal studies

Regarding animal studies yielding a promoting effect from RF radiation [39, 40] ICNIRP states that "...interpretation of these results and their applicability to human health [is] difficult, and, therefore, there is a need for further research to better understand these results". In the next paragraph the recent animal NTP studies [25, 26] and Ramazzini Institute results [27] are disregarded, stating that "...no consistency was seen across these two studies" and "within the context of other animal and human carcinogenicity research (HCN 2014, 2016), their findings do not provide evidence that radiofrequency EMFs are carcinogenic".

On the contrary, as discussed above, animal studies indicate that RF radiation may both promote and initiate cancer. In a review, the Hardell group concluded that:

"There is clear evidence that RF radiation causes cancer/tumor at multiple sites, primarily in the brain (glioma) and head (acoustic neuroma). There is also evidence of an increased risk of developing other tumor types. The results are similar in both the NTP studies (19, 20) and the Ramazzini Institute findings (34). Based on the IARC preamble to the monographs, RF radiation should be classified as Group 1: The agent is carcinogenic to humans" [19].

In a note published by ICNIRP in 2018 it was claimed that

the histopathological evaluation in the NTP study was not blinded as to exposure status [112]. This was rebutted by one of those responsible for the NTP study [113]. However, it seems to have had no impact on the ICNIRP evaluation [48]. ICNIRP claims that the animal studies "do not provide evidence that radiofrequency EMFs are carcinogenic," while an independent peer review of the NTP data concluded that this study provided 'clear evidence of carcinogenic activity', see Table 4 in a comment on the NTP study [19]. A comprehensive discussion of the ICNIRP evaluation was published by Melnick as a correspondence with "focuses on ICNIRP's false claims about the methodology, interpretation, and relevance of the National Toxicology Program studies on cell phone radiation" [114]. This included misleading statements by ICNIRP on e.g., the pathology review procedure, rat survival rates, multiple comparisons, but also excluding discussion of other end points such as DNA strand breaks in the brain cells, and increased incidence of cardiomyopathy. Melnick concluded that "ICNIRP should promote precautionary advice for the general public rather than trying to justify their decision to dismiss findings of adverse health effects caused by RF-EMFs and thereby retain their 20+ y-old exposure guidelines that are based on protection against thermal effects from acute exposure". In the response, ICNIRP seemed not to make a serious scientific rebuttal of the statements by Melnick "except for one minor issue", i.e., the description of the NTP study as "whole of life" rather than "most of life" [115].

3.2. Brain tumor risks from mobile phone use

Regarding epidemiological studies first a study by Martin Röösli et al. [116] is cited by ICNIRP. Röösli is, as mentioned earlier, both member of the ICNIRP commission, the WHO 2014 external experts and the SSM experts. The

article has several limitations. The results on use of cordless phones as risk factor for brain tumors are not discussed. Regarding glioma risk all results on cumulative use of wireless phones were not discussed and ipsilateral or contralateral use in relation to tumor localization in the brain were omitted from the meta-analyses. These results are important and have shown a consistent pattern of increased risk.

There were several other limitations in the article [116], such as including the Danish cohort study [90] in the meta-analyses. As discussed above, the study has severe errors of exposure classification and was therefore evaluated to be uninformative regarding carcinogenesis in the IARC 2011 evaluation [10] including Martin Röösli as one participating member.

Regarding the thirteen country Interphone study on glioma [14] and acoustic neuroma [15] ICNIRP concludes that the studies do "...not provide evidence of an increased risk", which is not correct [48]. On the contrary regarding glioma cumulative call-time of mobile phones $\geq 1,640$ h resulted in OR = 1.40, 95 % CI = 1.03–1.89, increasing to OR = 1.87, 95% CI = 1.09–3.22 for glioma in the temporal lobe, the most exposed part of the brain. Ipsilateral mobile phone use yielded OR = 1.96, 95% CI = 1.22–3.16 for all glioma, cumulative use $\geq 1,640$ h. Furthermore, a statistically significant increased risk for glioma was seen in the group 2–4 years for regular use, with 1–1.9 years use as reference category, OR = 1.68, 95% CI = 1.16–2.41, see Appendix 2 [14]. The highest OR was seen in the 10+ years category for regular use, OR = 2.18, 95% CI = 1.43–3.31.

In parts of Interphone, RF radiation dose was estimated as total cumulative specific energy (TCSE; J/kg) absorbed at

the tumor's estimated center [117]. The risk increased with increasing TCSE 7+ years before diagnosis, OR = 1.91, 95% CI = 1.05 - 3.47 (p-trend = 0.01) in the highest quintile. Comparing with glioma in other parts of the brain, increased ORs were found for tumors in the most exposed part of the brain in those with 10+ years of mobile phone use, OR = 2.80, 95% CI = 1.13 - 6.94.

Similar results were reported by Grell et al. [118]:

"we found a statistically significant association between the intracranial distribution of gliomas and the self-reported location of the phone...Taken together, our results suggest that ever using a mobile phone regularly is associated with glioma localization in the sense that more gliomas occurred closer to the ear on the side of the head where the mobile phone was reported to have been used the most".

Canadian data from the Interphone Study were evaluated separately [108]. For glioma, when comparing those in the highest quartile of use (>558 lifetime hours) to those who were no regular users, the OR was 2.0, 95% CI = 1.2 - 3.4. After adjustment for selection and recall biases somewhat higher OR was found, 2.2, 95 % CI = 95% CI = 1.3 - 4.1, indicating that such bias did not cause the results.

Also for acoustic neuroma, the Interphone study yielded statistically significant increased risk. Thus, ipsilateral cumulative mobile phone use > 1,640 hours gave OR = 2.33, 95 % CI = 1.23-4.40 [15].

Regarding the Hardell group studies ICNIRP [48] writes: "...a set of case-control studies from the Hardell group in Sweden report significantly increased risks of both acoustic neuroma and malignant brain tumors already after less than

five years since the start of mobile phone use, and at quite low levels of cumulative call time.” No reference is given to the studies, indicating they have not been seriously evaluated. ICNIRP’s writing is not consistent with what the studies reported. In the shortest latency time >1- 5 years period overall mobile phone use yielded for glioma OR = 1.2, 95 % CI = 0.98-1.5 increasing to OR = 2.3, 95 % CI = 1.6-3.4 in the latency period > 20 years (p trend = 0.01). Similar results were found for cordless phones although based on low numbers in the longest latency period. The lowest quartile of cumulative wireless phone use gave OR = 1.2, 95 % CI = 0.9-1.4 increasing to OR = 2.0, 95 % CI = 1.6-2.6 in the fourth quartile (p trend < 0.0001) [7]. Thus, as the published results show no statistically significant increased risk was found in total in the shortest latency group contrary to what ICNIRP stated, although somewhat higher risk was found for ipsilateral use.

For acoustic neuroma, the Hardell group reported use of wireless phone (mobile and/or cordless phone) with latency time >1-5 years in total OR = 1.2, 95 % CI = 0.8-1.6 increasing to OR = 4.4, 95 % CI = 2.2-9.0 (p trend = 0.003) for latency > 20 years [8]. The risk increased with cumulative use of wireless phone; first quartile OR = 1.2, 95 % CI = 0.8-1.7 and fourth quartile OR = 2.2, 95 % CI = 1.5 – 3.4, p trend = 0.03. Thus, the results were similar as for glioma. These results were dismissed by ICNIRP.

In addition, ICNIRP claims that the Hardell group results may be caused by recall bias. For meningioma no statistically significant increased risk was found in the same study. Using meningioma cases as “controls” (the comparison entity) still yielded statistically significant increased risk for glioma and mobile phone use; ipsilateral use OR = 1.4, 95 % CI = 1.1-1.8, contralateral OR = 1.0, 94 % CI = 0.7-1.4 and for

cordless phone use ipsilateral OR = 1.4, 95 % CI = 1.1-1.9, contralateral OR = 1.1, 95 % CI = 0.8-1.6 [7]. Similar results were found for acoustic neuroma using meningioma cases as the comparison group [8]. These results clearly show that the increased risks for glioma and acoustic neuroma were not caused by recall bias.

The CERENAT study by Coureau et al. [16] was omitted by ICNIRP. The study strengthened the evidence of increased risk for glioma associated with mobile phone use. Life-long cumulative duration ≥ 896 h gave OR=2.89, 95% CI 1.41 - 5.93 for glioma. Number of calls $\geq 18,360$ gave OR=2.10, 95% CI 1.03 - 4.31. Higher risks were obtained for the highest exposed area, (temporal tumor), as well as occupational and urban mobile phone use. The Danish cohort study on mobile phone use with serious methodological limitations was however discussed in ICNIRP 2020, adding to the no-risk paradigm.

Furthermore, ICNIRP claims that “Studies of other types of tumors have also not provided evidence of an increased tumor risk in relation to mobile phone use. Only one study is available on mobile phone use in children and brain tumor risk. No increased risk of brain tumors was observed.” This is yet another incorrect statement [93]. The CEFALO study, as discussed previously, showed increased risks in spite of methodological shortcomings.

3.3. Thyroid cancer

In 2016 the Hardell group published increasing incidence of thyroid cancer in the Nordic countries especially during the last two decades [119]. The thyroid gland is a target organ for RF radiation from smartphones, which was discussed as an etiologic factor. A case-control study on mobile phone use suggested an increased risk for thyroid cancer associated

with long-term use [120]. The same material was used to study genotype-environment interaction between single nucleotide polymorphism (SNPs) and mobile phone use [121]. The study showed that mobile phone use increased the risk for thyroid cancer when genetic variants were present within some genes. It was concluded that pathways related to DNA repair may be involved in the increased risk. The study was published online 6 December 2019, that is well before the ICNIRP 2020 publication. ICNIRP omitted completely to discuss the increasing incidence of thyroid cancer and the association with mobile phone use. The statement by ICNIRP of no risk for other tumor types is not correct. The increasing incidence of thyroid cancer in the Nordic countries is confirmed in our recent publication [122].

3.4. Brain tumor incidence

Another example by ICNIRP that misguides the reader is the statement “trends in brain cancer incidence rates from a large number of countries or regions...have not found any increase in the incidence since mobile phones were introduced.” This is not correct. Philips et al. [123] reported a statistically significant increasing incidence of glioblastoma multiforme in UK during 1995-2015. Similar results were published from USA [124]. In Sweden, the Hardell group published increasing rates of brain tumors based on the Swedish National Inpatient Register and the Causes of Death Register [125]. The same group also published an increasing incidence of brain tumors in the Swedish Cancer Register [126]. ICNIRP seems to have overlooked facts that would contradict their claim that the results showing brain tumor risk are “not consistent with trends in brain cancer trends”.

3.5. Transmitters, base stations and cancer

According to ICNIRP, studies on exposure to environmental RF radiation “have not provided evidence of an increased cancer risk either in children or in adults”. No references to that statement are given. In a review by Khurana et al. [127] two of three studies reported increased incidence of cancer at a distance < 350 m [128] or < 400 m [129] from a base station. Dode et al. [130] reported increased cancer mortality in an area within 500 m from a base station in Belo Horizonte, Brazil. A study from Taiwan found a statistically significant increased risk of all neoplasms in children with higher-than-median RF radiation exposure to mobile phone base stations [131]. A cause-effect relationship between RF radiation in occupational and military settings, mainly communication equipment and radar, and hematolymphatic malignancies was reported by Peleg et al. [18]. They concluded that available research “make a coherent case for a cause-effect relationship and classifying RFR exposure as a human carcinogen (IARC group 1)”. DNA damage and oxidative stress were associated with living in a vicinity of base stations in a study from India which is also of interest in this context [132]. It would have been pertinent for ICNIRP to review the literature.

There are also studies showing increased risk for childhood leukemia from RF transmitters. One of the authors of the ICNIRP 2020 guidelines, commission member Martin Rösli, stated at a seminar organized by SSM in 2016 that until 2003 all but one results on transmitters had shown increased risk for childhood leukemia: “it was quite impressive that [for] almost all the studies for different type of leukemias basically they reported significantly increased risk. So it was not a random sample of risk estimates. All but one risk estimates were above 1” [133]. This is in obvious contrast to the claim in ICNIRP 2020.

4. Conflicts of Interests

The conclusion by ICNIRP is not objective and lacks scientific credibility according to a research report that investigated ICNIRP commissioned by two European Parliament Members published in June 2020 [58]. Industry funding has been found to influence the results on research on RF radiation and health effects. However, ICNIRP does not take this into account although ICNIRP members themselves have reported that industry-funded scientific research seems to influence the results by reporting less findings showing adverse health effects of EMF compared to independent research [134].

The composition of ICNIRP is very one-sided according to the EU report [58]:

“ICNIRP has been, and is still, dominated by physical scientists... ..As one can read in the 45 portraits of the members of the ICNIRP commission and of the Scientific Expert Group (SEG), they all share the same position on the safety issues: non-ionising radiation poses no health threats and the only effects it has are thermal”.

The EU report [58] pointed to the fact that ICNIRP’s chairman Eric van Rongen, in 2016 invited the industry organization ICES to comment and thereby influence the upcoming ICNIRP 2020 guidelines [48]. The report concludes that it is:

“clear from ICES minutes that ICNIRP worked very closely with IEEE/ICES on the creation of the new RF safety guidelines that were published in March 2020. And this implies that large telecom-companies such as Motorola and others, as well as US military, had a direct influence on the

ICNIRP guidelines, which are still the basis for EU-policies in this domain”.

The EU report [58] also highlights several ICNIRP experts’ financial ties to the industry. As described in that report, it should be noted that for example the European Food and Safety Authority (EFSA) considers conflict of interests as “any situation where an individual has an interest that may compromise or be reasonably perceived to compromise his or her capacity to act independently and in the public interest in relation to the subject of the work performed at EFSA”. Apart from the telecom industry funding of the WHO EMF project, while it was led by ICNIRP’s first chairman Michael Repacholi [74] (1996-2006), the EU report documents that “the majority of ICNIRP-scientists did perform research partly funded by industry”.

As cited in the EU Report [58], Professor David Carpenter, Environmental Health Sciences at the University of Albany, USA, considers the “perversion that can result due to conflicts of interests” to be “one of the greatest problems in scientific discovery...When funding for scientists comes from an organization or corporation with desires to present a clean bill of health to the public, there is strong motivation to give the funder what they want, if only to continue receipt of funding.”

To act both on behalf of ICNIRP to set guidelines supposed to protect against harmful health effects of RF radiation, and at the same time evaluate the health risks representing other organizations, may constitute a conflict of interest, i.e. according to the opinion of the Ethical board of the Karolinska Institute, Stockholm, Sweden. Many of the ICNIRP commission and SEG members act on behalf of several organizations thereby evaluating their own ICNIRP

guidelines validity on behalf of other organizations. This kind of conflict of interest adds to those in terms of telecom funding and connection to ICES, see Table 1 [24, 71, 72, 86, 135-146].

5. Guidelines for RF Radiation Exposure

The new ICNIRP 2020 guidelines were developed with 5G in mind, especially considering frequencies that are higher to the presently used mobile phone communications. ICNIRP recognizes citizens' concerns regarding safety of 5G, however the new guidelines show no reduction of safety limits. The premise for safeguarding human health has remained the same – to avoid thermal effects. ICNIRP's 2020 guidelines [48] are based, like in 1998 [53], only on thermal effects, i.e. the RF radiation from mobile communications devices can be high as long as it causes no tissue heating. This may be problematic for mm waves as the radiation can cause heating effects on the surface of the skin. A systematic review on 5G safety limits based on thermal dose concluded that: "The results also show that the peak-to-average ratio of 1,000 tolerated by the International Council on Non-Ionizing Radiation Protection guidelines may lead to permanent tissue damage after even short exposures, highlighting the importance of revisiting existing exposure guidelines" [147]. Furthermore, some organs are more susceptible to RF radiation damage so local dosimetry is more appropriate for characterizing organ-specific risk [10].

Currently the mobile communications reside on frequencies up to 2,600 MHz band, with some minor exceptions beyond that frequency. 5G frequencies are expected to be using bands all over the higher radiofrequency spectrum, including

previous 2G and 3G bands. Main 5G frequencies, however, will be at 3.4 to 4.2 GHz. Later, millimeter waves will also be deployed to provide 5G services, these are expected to reside at frequencies of 24-28 and 39 GHz. Millimeter wave base stations are expected to cover mainly high public density areas, such as city squares, transportation hubs, business and shopping centers and other public areas.

With the new reference levels [48] ICNIRP differentiates whole body exposure and exposure to small areas of the body introducing two separate classes of reference levels. ICNIRP grants higher exposure when assessing compliance by reference values; basic restrictions however have remained the same. ICNIRP claims, that this is because of better scientific understanding with respect to the 1998 guidelines. In Table 4 we compare ICNIRP reference levels between the 1998 [53] and the 2020 guidelines [48]. The calculated values are for arbitrary frequencies per each designated band; mobile communications frequency bands differ from region to region. Table 4 characterizes bands used in most European countries.

In their 1998 guidelines, at frequencies over 10 MHz, the reference levels are based on electric and magnetic field strengths for the whole-body SAR basic restrictions, derived by computer simulations and experimental data [53]. The 2020 guidelines introduce reference levels for local exposure [48]. In 2020 whole body reference levels, the averaging time has been increased from 6 min to 30 min, which ICNIRP argues is to better match the time taken for body core temperature to rise [48].

Frequency (MHz)	Example usage	ICNIRP 1998 [53] reference level, 6 min	ICNIRP 2020 [48] reference levels, whole body exposure, 30 min	ICNIRP 2020 [48] reference levels, local exposure, 6 min
800	LTE	4	4	18.2
900	GSM, UMTS	4.5	4.5	20.1
1,800	GSM	9	9	36.6
1,900	DECT	9.5	9.5	38.3
2,100	UMTS	10	10	40
2,400	WiFi 2G	10	10	40
2,600	LTE	10	10	40
3,500	5G, WiMax	10	10	40
5,500	WiFi 5G	10	10	40
26,000	5G	10	10	30.9

Table 4: Comparison of ICNIRP 1998 and 2020 reference levels across common mobile communication frequencies, time averaged (W/m^2).

The ICNIRP 2020 [48] reference levels are based on time averaged exposure over 6 min or 30 min, see Table 4. However, supra-additive effects between pulses from different RF radiation sources may give much higher peak

radiation from short time pulses than the power density average. Using time averaging in reference values, as in the ICNIRP guidelines, definitely underestimates the risk.

Year	Power Density Limit ($\mu\text{W}/\text{m}^2$)	Name	Description
1966	100,000,000	ANSI C95.1 [149]	Based on thermal effects and 0.1-hour (or 6 minute) averaging time.
1991	10,000,000	ANSI/IEEE C95.1-1991 [150]	Based on thermal effects.
1996	10,000,000 5,800,000	FCC [151]	USA: 5,800,000 averaged over a 30-minute period (869 MHz), previously recommended in 1986 by NCRP; 10,000,000 for PCS frequencies (1.85-1.99 GHz).
1998	10,000,000 9,000,000 4,500,000	ICNIRP [53]	10,000,000 for 2–300 GHz 9,000,000 for 1800 MHz and 4,500,000 for 900 MHz averaged over 6 min.

2001	1,000	Salzburg Resolution [152]	
2001	100	EU Parliament STOA 2001 [153]	
2002	1	New Salzburg Precautionary Exposure Limit Indoor [154]	Maximum indoor exposure recommendation for GSM base stations proposed by the Public Health Office of the Government of Salzburg.
2009	See 1998	ICNIRP [54]	Confirmation of ICNIRP 1998.
2012	3-6	Bioinitiative 2012 Recommendation [44]	
2016	0,1-100	Europa EM EMF Guidelines [41]	For frequencies between GSM 900 to WiFi 5,6 GHz depending on sensitivity, night time or daytime exposure.
2020	400 MHz: 10,000,000 800 MHz: 18,200,000 1,800 MHz: 36,600,000 2,000 MHz: 40,000,000 6 GHz: 40,000,000 60 GHz: 26,600,000 300 GHz: 20,000,000	ICNIRP 2020 [48]	General public, local exposure, averaged over 6 min. For whole body exposure see Table 4.

Table 5: Guidelines by different organizations for radiofrequency radiation in $\mu\text{W}/\text{m}^2$.

In a recent review, average exposure limit was suggested to be considerably lower, 0.1 V/m; 26.5 $\mu\text{W}/\text{m}^2$ [148]. This guideline is comparable with the BioInitiative Report from 2012 [44] with a scientific benchmark of 30-60 $\mu\text{W}/\text{m}^2$, and for chronic exposure to sensitive persons and children 3-6 $\mu\text{W}/\text{m}^2$. The EUROPAEM EMF guidelines published daytime RF radiation exposure to be 10-1,000 $\mu\text{W}/\text{m}^2$, nighttime 1-100 $\mu\text{W}/\text{m}^2$, and for sensitive persons 0.1-10 $\mu\text{W}/\text{m}^2$ [41]. All these guidelines by independent research groups without conflicts of interest are very much lower than the ICNIRP guidelines. These lower guidelines are aimed at preventing health effects and hazards, Table 5 [41, 44, 48, 53, 54, 149-154].

6. Discussion

As a general rule ICNIRP, WHO, SCENIHR and SSM have for many years dismissed available studies showing harmful effects from non-thermal RF exposure and have based their conclusions mainly on studies showing no effects. Results showing risk are criticized, disregarded or not even cited while studies showing no risks are accepted as evidence of no risk in spite of severe methodological problems. Many statements by these agencies are misleading and not correct. They are easily rebutted by reading the relevant publications.

In fact, these activities are not in line with prevention of health hazards. Previously the precautionary principle in

cancer prevention was discussed exemplified by e.g. asbestos, certain pesticides and RF radiation [155, 156]. It was noted that cancer prevention is usually very cost-effective. In a recent article we gave historical examples on lost opportunities based on early warnings with RF radiation as one more recent example [157].

In 2018 there was a call to dismantle ICNIRP and replace the organization with independent scientists [158]: “ICNIRP’s mandate to issue exposure guidelines needs to be seriously questioned. ICNIRP is not independent of industry ties as it claims... Its opinions are not objective, not representative of the body of scientific evidence, but are biased in favor of industry.”

The EU report investigating ICNIRP concluded in June 2020 that “for really independent scientific advice we cannot rely on ICNIRP.” [58].

Our review reveals, with focus on cancer risks, an almost systematic downplaying of health risks from RF radiation by a group of persons that dominate the expert evaluations, see Table 1. Many of them reappear in several of these organizations’ expert groups and also in other groups not described in this paper. One striking example is ICNIRP’s chairman Eric van Rongen who also appeared in the WHO core group of six experts 2014 as well as one of SSM’s eight experts and SCENIHR’s nine experts in 2009 as well as secretary of the Health Council of the Netherlands expert group [159]. Another example is Maria Feychting, ICNIRP member since 2000, who was one of WHO’s six core group experts behind the WHO 2014 draft, secretary of the SSM expert group evaluations 2003-2010, on the AGNIR (UK) expert group from 2009 and a Norwegian expert group in 2012 [160]. A third example is Martin Rösli, member of

ICNIRP, the WHO external experts for the WHO draft 2014, the SSM expert group since 2010 and a Swiss expert group [99].

Our review also notes that there is a clear relationship between ICNIRP and ICES, which is dominated by industry representatives. Eric van Rongen, has been a member of ICES since 2000, ICNIRP member since 2001 and elected chair of ICNIRP in 2016, vice chair since 2020. From ICES annual report 2016 it was reported that:

“The new ICNIRP Chairman and one of the new members of the 14 member committee are also ICES members and ICNIRP is now willing to discuss harmonization of the exposure limits found in IEEE Stds C95.1TM-2005 and C95.6TM-2002 and the ICNIRP Guidelines. At a June 2016 Mobile Manufacturers Forum Workshop in Ghent, Belgium, the new ICNIRP Chairman, Dr. van Rongen, presented “ICNIRP’s proposed HF guidelines” and extended an invitation to ICES to comment on the proposed guidelines. TC95 formed a 19 member task group to draft a document to comment on the ICNIRP proposed guidelines. The document was circulated to the TC95 membership for comment and a final document submitted to ICNIRP in time for discussion at the ICNIRP September meeting.” [56].

The TC 95 committee’s objective is “Development of standards for the safe use of electromagnetic energy in the range of 0 Hz to 300 GHz”. These standards are based on the same scientifically invalid approach as the ICNIRP guidelines. In this TC95 committee, in which many members come from the military or the telecom industry, or are consultants to them, ICNIRP’s chairman Eric van Rongen, Michael Repacholi, ICNIRP’s first chairman and leader of the WHO EMF project 1996-2006, Theodoros Samaras

(chairman SCENIHR) and Mats-Olof Mattson, Chairman SCENIHR 2009 and member of ICNIRP, are also found.

All these expert groups dominated by ICNIRP consequently reach similar conclusions that there are no health effects below ICNIRP guidelines. No representative from the scientific community that is of the opinion that there is increasing evidence of health risks below the ICNIRP guidelines, e.g. as expressed in the EMF Scientists Appeal [24], has ever been a member of the expert groups at the WHO, the EU, the SSM or ICNIRP. Certainly scientists who do not discount evidence of health effects from exposure to RF radiation that are observed at exposures below guideline levels should be represented.

The resistance to the abundant and growing scientific evidence on health risks is remarkable and not within the realm of public health. This behavior, due to the ICNIRP influence and dominant role in several other expert groups, is detrimental to human health and leads to suffering and even premature death that could have been prevented. Furthermore, it must be stressed that in general there is lack of persons with medical education and competence not only in the evaluating bodies but also in several research teams producing questionable results as exemplified in this text.

ICNIRP is not representative of the scientific community since it does not include representatives from scientists that agree there is evidence of harmful effects at levels well below ICNIRPs limits although these scientists are in majority in the scientific community [24].

7. Conclusion

ICNIRP's conclusion [48] on cancer risks is: "In summary, no effects of radiofrequency EMFs on the induction or development of cancer have been substantiated." This conclusion is not correct and is contradicted by scientific evidence. Abundant and convincing evidence of increased cancer risks and other negative health effects are today available. The ICNIRP 2020 guidelines allow exposure at levels known to be harmful. In the interest of public health, the ICNIRP 2020 guidelines should be immediately replaced by truly protective guidelines produced by independent scientists.

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Radiofrequency radiation from nearby base stations gives high levels in an apartment in Stockholm, Sweden: A case report

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Abstract. Exposure to radiofrequency (RF) radiation was classified in 2011 as a possible human carcinogen, Group 2B, by the International Agency for Research on Cancer of the World Health Organisation. Evidence of the risk of cancer risk has since strengthened. Exposure is changing due to the rapid development of technology resulting in increased ambient radiation. RF radiation of sufficient intensity heats tissues, but the energy is insufficient to cause ionization, hence it is called non-ionizing radiation. These non-thermal exposure levels have resulted in biological effects in humans, animals and cells, including an increased cancer risk. In the present study, the levels of RF radiation were measured in an apartment close to two groups of mobile phone base stations on the roof. A total of 74,531 measurements were made corresponding to ~83 h of recording. The total mean RF radiation level was 3,811 $\mu\text{W}/\text{m}^2$ (range 15.2–112,318 $\mu\text{W}/\text{m}^2$) for the measurement of the whole apartment, including balconies. Particularly high levels were measured on three balconies and 3 of 4 bedrooms. The total mean RF radiation level decreased by 98% when the measured down-links from the base stations for 2, 3 and 4 G were disregarded. The results are discussed in relation to the detrimental health effects of non-thermal RF radiation. Due to the current high RF radiation, the apartment is not suitable for long-term living, particularly for children who may be more sensitive than adults. For a definitive conclusion regarding the effect of RF radiation from nearby base stations, one option would be to turn them off and repeat the measurements. However,

the simplest and safest solution would be to turn them off and dismantle them.

Introduction

The use of wireless digital technology has grown rapidly during the last couple of decades. While in use, mobile and cordless phones emit radiofrequency (RF) radiation. The brain is the main target of exposure to RF radiation with handheld wireless phones (mobile and cordless) (1,2). An increased risk for brain tumors has been of concern for a long time. In May 2011, RF radiation in the range 30–300 GHz could be categorized in Group 2B, i.e., a 'possible' human carcinogen, by the International Agency for Research on Cancer (IARC) of WHO (3,4). The decision was based mainly on case-control human studies on the use of wireless phones by the Hardell group in Sweden (mobile and cordless phones; DECT) and the IARC Interphone study (mobile phones), which showed an increased risk for brain and head tumours, i.e., glioma and acoustic neuroma (3–6), which has since been confirmed (7–10), resulting in a recommendation to upgrade IARC's 2011 classification of RF radiation to Group 1, a human carcinogen. This conclusion was published in our up-dated review in 2013 (11) using the so-called Hill viewpoints on the association or causation put forward at the height of the tobacco and lung cancer controversy (12).

Due to the increasing use of the wireless technology, environmental exposure to RF radiation has been increasing, but there has been no systematic study of ambient exposure. We have measured RF radiation at Stockholm Central Station (13) and the Stockholm Old Town in Sweden (14). The results generally exceeded the levels known to have adverse biological effects. By contrast, low levels were measured at certain places in the WHO building in Geneva (15).

We have measured RF radiation in an apartment with a central location at Östermalm in Stockholm. The apartment is located on the 6th floor, with a tower including a bedroom on the first floor of the tower (7th floor) and a conference room on the second and highest floor (8th) of the tower, at the same level as the roof of the building. The measurements did not involve any human subjects, and therefore no ethical permission was needed. We also discuss laboratory studies on RF-radiation and biological effects relative to the levels of RF in question. Of particular interest are the non-thermal levels of RF radiation and

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biological effects. For comparison, radiation was also measured in another apartment located on the 3rd floor in a high building of 9 floors at Gärdet in central part of Stockholm.

Materials and methods

EME-Spy 200 exposimeter. To measure RF radiation, a calibrated exposimeter EME-Spy 200 (Satimo, MVG Industries, Brest, France) was used. The instrument measures 20 predefined frequency bands (Table I), which cover the frequencies of most public RF radiation emitting devices now in use in Sweden. These frequencies are from 87 to 5,850 MHz. For frequency modulation (FM), TV3, TETRA, TV4&5, Wi-Fi 2.4 GHz and Wi-Fi 5 GHz, the lower detection limit is 0.01 V/m (0.27 $\mu\text{W}/\text{m}^2$). For all other bands, the lower detection limit is 0.005 V/m (0.066 $\mu\text{W}/\text{m}^2$). For all bands, the upper detection limit is 6 V/m (95,544 $\mu\text{W}/\text{m}^2$). Samples were taken every 4th second.

The exposimeter measures different telecommunications protocols: FM radio broadcasting; TV broadcasting; TETRA emergency services (police and rescue); GSM second generation mobile communications, 2G; UMTS third generation mobile communications, 3G; long-term evolution (LTE) fourth generation mobile communications standard, 4G; digital European cordless telecommunications (DECT) cordless telephone systems standard; Wi-Fi 2.4 GHz and 5 GHz wireless local area network protocol; worldwide interoperability for microwave access (WiMAX) wireless communication standard for high-speed voice, data and Internet.

EME-Spy 200 has a 3-axis antenna to capture RF radiation from every direction. The unit reports the exposure after statistical processing, since each value is a sampling outcome of many readings after statistical analysis, including minimum, mean, median and maximum values.

Study design. Measurements were taken on June 5, 6, and August 21, 22, 30, 31, 2017. Some measurements were made during the night to assess variation of RF exposure from daytime readings. While walking through all the rooms and balconies, the effect of body shielding was minimized by the exposimeter being held about 0.4 m in front of the investigator. More extended measurements were then taken in places judged to be of interest—bedrooms and the living room. The exposimeter was placed where people tend to occupy, e.g., corresponding to the upper part of the body, including the head of a bed. Three of the five balconies were located close to the 2 groups of base stations located on the roofs. The closest base stations were only 6 m from the balcony outside the tower.

Measurements in another apartment for comparison at Gärdet, Stockholm were taken on October 27–29 and November 6, 2017. This was a smaller apartment with a balcony and no visible surrounding base stations. A group of base stations are located at the top of another 9 floor building, but in the opposite direction to this apartment.

Statistical methods. Means, medians, minimum, and maximum values in $\mu\text{W}/\text{m}^2$ were calculated for all measured frequency bands, and box plots and bar graphs were constructed to illustrate the distribution of total exposure for all measurement rounds. Values at the lower detection limit were treated as

zero exposure. Total exposure was calculated as the sum of all measured frequency bands. Stata/SE 12.1 (Stata/SE 12.1 for Windows; StataCorp., College Station, TX, USA) was used for all calculations.

Results

Whole apartment. The total of measurements made at the apartment in Östermalm was 74,531 readings (~83 h of recording). The daily data were consistent; therefore, totals are presented for the whole apartment including different locations. Some places of interest will be discussed in greater detail. The results are given as numbers of readings (measurements), and as mean, median, minimum and maximum values in $\mu\text{W}/\text{m}^2$.

Table II shows mean level 3,810.8 $\mu\text{W}/\text{m}^2$ for the total measurement of the whole apartment, including balconies, a high maximum level of 112,318 $\mu\text{W}/\text{m}^2$ being recorded. Over 55% of the mean level was caused by the 4 G down link from base stations (LTE 800 and LTE 2600). The 3G down link (GSM+UMTS 900 and UMTS 2100) yielded >40% of the total mean exposure. About 96% of the total mean value was caused by the 3G and 4G down links, with the 2G down link accounting for only 2% (GSM 1800). The results were calculated excluding all RF radiation from base stations, which gave a mean level 78.8 $\mu\text{W}/\text{m}^2$ and maximum 4,616.2 $\mu\text{W}/\text{m}^2$, Table II. Thus 3,732.0 $\mu\text{W}/\text{m}^2$, 97.9% of the mean RF radiation was caused by down link from the 2G, 3G and 4G base stations.

The measurements in the apartment, excluding the 5 balconies, were based on 64,070 readings (71 h of measurements). The mean level was 1,766 $\mu\text{W}/\text{m}^2$; median 1,051 $\mu\text{W}/\text{m}^2$ (range min 15.2 $\mu\text{W}/\text{m}^2$, max 50,431.0 $\mu\text{W}/\text{m}^2$; data not shown). These results nevertheless represent high levels of RF radiation.

Table III gives the levels for different locations within the apartment, and Table IV shows the results where the contribution from base stations is excluded at each location; thereby substantially lower values were generally obtained.

Balconies. The highest results were inevitably found on the balconies, especially the 3 facing at short distance the visible base stations. The highest mean value (24,885.9 $\mu\text{W}/\text{m}^2$) was measured on the balcony outside the living room (Table V), at which the highest maximum exposure was found (112,317.7 $\mu\text{W}/\text{m}^2$). The results were based on 5,251 entries corresponding to ~6 h of measurements. If the down link of RF radiation from the base stations was disregarded, the total mean on that balcony fell to 229.6 $\mu\text{W}/\text{m}^2$ (~0.9% of the total; Table V). The balconies outside the boy's bedroom and outside the tower gave similar results with high RF radiation from nearby base stations (Tables III and IV). Thus the mean RF radiation value outside the boy's bedroom was reduced from 6,803.3 $\mu\text{W}/\text{m}^2$ to 90.2 $\mu\text{W}/\text{m}^2$ when disregarding down links from base stations. For the balcony outside the tower, the RF radiation fell from 8,989.4 to 331.2 $\mu\text{W}/\text{m}^2$ excluding down links.

Bedrooms. Most of the time is usually spent in bedroom. The master bedroom showed lower RF radiation values compared with the other bedrooms, mean 569.7, and 32.4 $\mu\text{W}/\text{m}^2$ excluding down links (Tables III and IV). Especially high levels were recorded in the two children's bedrooms and the

Table I. Predefined measurement frequency bands of EME-Spy 200 Exposimeter. Frequency ranges.

Frequency band	Frequency Min (MHz)	Frequency Max (MHz)
FM	87	107
TV3	174	223
TETRA I	380	400
TETRA II	410	430
TETRA III	450	470
TV4&5	470	770
LTE 800, 4G (DL)	791	821
LTE 800, 4G (UL)	832	862
GSM 900 + UMTS 900, 3G (UL)	880	915
GSM 900 + UMTS 900, 3G (DL)	925	960
GSM 1800, 2G (UL)	1,710	1,785
GSM 1800, 2G (DL)	1,805	1,880
DECT	1,880	1,900
UMTS 2100, 3G (UL)	1,920	1,980
UMTS 2100, 3G (DL)	2,110	2,170
Wi-Fi, 2GHz	2,400	2,483.5
LTE 2600, 4G (UL)	2,500	2,570
LTE 2600, 4G (DL)	2,620	2,690
WiMax	3,300	3,900
Wi-Fi 5GHz	5,150	5,850

FM, frequency modulation; TV, television; LTE, long-term evolution; DL, downlink (transmission from base station to mobile phone); UL, uplink (transmission from mobile phone to base station); GSM, global system for mobile communications; UMTS, universal mobile telecommunications system; DECT, digital European cordless telecommunications; WiMAX, worldwide interoperability for microwave access.

one located in the tower (Tables VI-VIII). In the girl's bedroom, the mean level was $2,531.0 \mu\text{W}/\text{m}^2$ (Table VI), whereas in the boy's bedroom it was $1,471.1 \mu\text{W}/\text{m}^2$ (Table VII). The highest RF radiation level in the bedrooms was recorded in the tower bedroom, mean value $5,954.3 \mu\text{W}/\text{m}^2$, Table VIII. Most of the RF radiation came from down links from the base stations, whereas excluding them gave a mean level in the girl's bedroom of $34.1 \mu\text{W}/\text{m}^2$, $13.4 \mu\text{W}/\text{m}^2$ in the boy's bedroom, and $205.4 \mu\text{W}/\text{m}^2$ in the tower bedroom. Thus, RF radiation in the children's bedrooms was reduced ~99%, and by 97% in the tower bedroom by excluding down links from the base stations.

Fig. 1 shows box plots of median levels for all 18 measured areas, with the results in increasing median levels of RF radiation. The bottom and top of the boxes represent first and third quartiles of the levels, with outliers shown as points. Without doubt the balconies had the highest levels, especially the 3 visibly near the surrounding base stations. Fig. 2 shows a bar graph of the mean levels.

There was little variation of the levels in the day and night. Some fall in the measurements were noted from midnight until

Table II. Levels of RF-radiation in total based on 74,531 entries for 6 different tours (Östermalm, Stockholm).

Variable	Mean	Median	Min	Max
FM	38.3	3.4	0.0	3,441.2
TV3	4.7	0.0	0.0	308.4
TETRA I	1.2	0.0	0.0	229.3
TETRA II	0.2	0.0	0.0	33.9
TETRA III	0.1	0.0	0.0	26.5
TV4&5	3.0	0.0	0.0	2,206.2
LTE 800 (DL)	977.5	299.5	1.1	52,526.5
LTE 800 (UL)	0.0	0.0	0.0	2.5
GSM + UMTS 900 (UL)	0.0	0.0	0.0	4.5
GSM + UMTS 900 (DL)	1,236.2	459.0	2.5	44,241.5
GSM 1800 (UL)	0.0	0.0	0.0	7.5
GSM 1800 (DL)	78.9	17.8	0.3	8,442.1
DECT	27.3	5.1	0.0	4,614.8
UMTS 2100 (UL)	0.0	0.0	0.0	5.6
UMTS 2100 (DL)	301.8	92.8	0.2	18,445.0
WIFI 2G	0.0	0.0	0.0	203.5
LTE 2600 (UL)	3.9	0.0	0.0	904.7
LTE 2600 (DL)	1,137.5	70.5	0.5	95,522.5
WiMax	0.0	0.0	0.0	2.7
WIFI 5G	0.1	0.0	0.0	105.0
Total	3,810.8	1,312.9	15.2	112,317.7
Total excluding down link	78.8	27.0	0.0	4,616.2

Data is based on 74,531 entries for 6 different tours, June 5, 6 and August 21, 22, 30, 31, 2017 (apartment at Östermalm, Stockholm). Analysis of all data ($\mu\text{W}/\text{m}^2$) treating values at detection limit as 0. Frequency bands are given. FM, frequency modulation; TV, television; LTE, long-term evolution; DL, downlink (transmission from base station to mobile phone); UL, uplink (transmission from mobile phone to base station); GSM, global system for mobile communications; UMTS, universal mobile telecommunications system; DECT, digital European cordless telecommunications; WiMAX, worldwide interoperability for microwave access.

early morning in the boy's bedroom (Fig. 3), but there was still a high level of RF radiation.

Apartment at Gärdet for comparison. Data for the apartment at Gärdet, Stockholm, based on 36,799 entries corresponding to ~40 h of measurements are given in (Table IX). The highest RF radiation was measured on the balcony, but the total mean remained low, $15.6 \mu\text{W}/\text{m}^2$ (min 2.2, max $195.1 \mu\text{W}/\text{m}^2$). About 50% of the RF radiation was caused by the GSM + UMTS 900 (3G) down link.

Discussion

The results were based on a large sample of measurements in the apartment at Östermalm, Stockholm representing about 83 h

Table III. Levels of RF-radiation in total for different locations in the apartment (Östermalm, Stockholm).

Location	Total				
	No.	Mean	Median	Min	Max
1. Balcony outside kitchen ^a	166	1,083.2	895.6	226.5	5,026.6
2. Kitchen	1,973	256.4	194.0	70.4	2,091.7
3. Dining room	4,272	1,480.6	854.1	93.6	12,068.7
4. Master bedroom	12,920	569.7	370.5	36.1	6,280.8
5. Balcony outside bathroom ^a	506	1,912.8	1,684.4	31.8	6,475.8
6. Living room	4,415	321.7	236.1	15.2	8,782.6
7. Balcony outside living room	5,251	24,885.9	22,256.1	72.0	112,317.7
8. Main hall ^a	59	185.2	154.2	59.6	512.7
9. Workroom close to kitchen ^a	599	266.9	235.3	123.6	2,135.6
10. Workroom close to laundry	3,899	1,310.1	1,044.6	266.0	7,999.8
11. Laundry ^a	388	1,561.6	1,416.0	193.2	7,843.2
12. Girl's bedroom	11,440	2,531.0	2,270.5	79.1	11,802.6
13. Boy's bedroom	14,161	1,471.1	1,122.3	58.5	13,739.1
14. Balcony outside boy's room ^a	777	6,803.3	3,254.9	65.3	107,992.5
15. Hall outside elevator ^a	90	251.3	197.6	24.3	1,590.1
16. Bedroom in tower	6,797	5,954.3	4,503.5	96.8	50,431.0
17. Conference room in tower	3,057	432.5	229.3	89.9	12,840.7
18. Balcony outside tower	3,761	8,989.4	7,848.8	43.5	56,191.3
Whole apartment	74,531	3,810.8	1,312.9	15.2	112,317.7

^aOnly measured June 2017. Levels of RF-radiation in total for different locations in the apartment (Östermalm, Stockholm) based on measurements in June 5, 6 and August 21, 22, 30, 31, 2017. Analysis of all data ($\mu\text{W}/\text{m}^2$) treating values at detection limit as 0. Numbers of entries are given for the different locations.

of recording. High levels of RF radiation were clearly measured throughout the apartment, but especially on the 3 balconies. Most of the RF radiation came from the outside base stations. The total mean level in the apartment fell from 3,810.8 to 78.8 $\mu\text{W}/\text{m}^2$, a reduction of ~98% occurring if the down links from base stations were excluded.

Table II shows that TV and radio communications contributed only to a minor extent. The contribution was more pronounced at the balcony outside the kitchen in the direction of the transmitting tower (mean level of 276.4 $\mu\text{W}/\text{m}^2$ for all TV and radio communications; data not in the Table). Most of the RF radiation in the tower bedroom was also caused by radio/TV towers when down links from base stations were excluded (see Table VIII). A minor contribution was from the DECT frequency (Table II). The source of radiation was probably from a neighboring apartment, since no DECT phone was used in the present apartment.

The highest RF radiation levels were measured on the balconies (Figs. 1 and 2 give median and mean values). Fig. 4 shows the group of base stations located only 12 m from the balcony outside the living room. It is questionable whether these balconies are suitable for any longer stay due to the high radiation; the balcony outside the living room (with mean level 24,885.9 $\mu\text{W}/\text{m}^2$, median 22,256.1 $\mu\text{W}/\text{m}^2$, and maximum level 112,317.7 $\mu\text{W}/\text{m}^2$) gave the highest of all recorded measurements (Table V). Regarding all 5 balconies, the results were based on 10,461 readings (>11 h of measurements). The mean level

was 16,338.7 $\mu\text{W}/\text{m}^2$, with a median of 13,775 $\mu\text{W}/\text{m}^2$ (range min 31.8, max 112,318 $\mu\text{W}/\text{m}^2$). Usually balconies in Sweden are used only briefly due to the climate, but nevertheless these results far exceed levels known to be detrimental to health from RF radiation.

The use of balconies with decent views can be used for pleasure, a part of comfortable living, but most of the day and night is spent in the apartment. Thus, the level of RF radiation inside is of more concern, especially for a family with children. Notably there was high RF radiation in the bedrooms occupied by children, as also in the tower bedroom. There was little variation with time, although the level declining during night (Fig. 3) still exceeded what is known to give non-thermal biological effects from long-term RF radiation. In the boy's bedroom there seemed to be 2 steps in the reduction of radiation during night, one from approximately 7:00 p.m. and another from midnight, indicating less use of wireless communication after business hours and during late leisure time.

Interestingly measurements recorded in another centrally located apartment in Gärdet were considerably lower in RF radiation. Thus, the mean level was only 0.4% of that found in the apartment at Östermalm. The mean RF radiation on the balcony in Gärdet was much lower; only 0.3% of that on the balcony outside the living room in Östermalm. These results show extreme variation of RF radiation in 2 residential apartments in Stockholm.

Table IV. Levels of RF-radiation in total excluding down links in the apartment (Östermalm, Stockholm).

Location	Total excluding down links				
	No.	Mean	Median	Min	Max
1. Balcony outside kitchen ^a	166	288.2	310.3	68.1	565.1
2. Kitchen	1,973	87.4	44.5	15.0	440.7
3. Dining room	4,272	70.8	68.4	20.0	461.0
4. Master bedroom	12,920	32.4	22.5	4.8	606.5
5. Balcony outside bathroom ^a	506	77.3	56.8	5.8	687.1
6. Living room	4,415	26.8	25.5	2.0	383.8
7. Balcony outside living room	5,251	229.6	146.5	0.0	4,155.6
8. Main hall ^a	59	41.3	28.4	5.7	282.9
9. Workroom close to kitchen ^a	599	40.6	31.5	14.0	2,004.3
10. Workroom close to laundry	3,899	25.3	19.4	6.7	2,199.0
11. Laundry ^a	388	38.4	26.0	3.2	343.6
12. Girl's bedroom	11,440	34.1	23.1	7.2	1,069.8
13. Boy's bedroom	14,161	13.4	6.8	0.0	427.8
14. Balcony outside boy's room ^a	777	90.2	52.6	0.0	4,616.2
15. Hall outside elevator ^a	90	28.3	22.0	0.2	157.8
16. Bedroom in tower	6,797	205.4	158.4	13.5	3,457.8
17. Conference room in tower	3,057	44.5	36.7	9.4	743.4
18. Balcony outside tower	3,761	331.2	363.8	3.8	1,618.4
Whole apartment	74,531	78.8	27.0	0.0	4,616.2

^aOnly measured June 2017. Levels of RF-radiation in total excluding down links for different locations in the apartment (Östermalm, Stockholm) based on measurements in June 5, 6 and August 21, 22, 30, 31, 2017. Analysis of all data ($\mu\text{W}/\text{m}^2$) treating values at detection limit as 0. Numbers of entries are given for the different locations. Down links from base stations are excluded.

The guideline for RF radiation in Sweden is set on the false assumption that adverse health effects are caused only by heating. However, human, animal and cell studies show biological effects at non-thermal exposure levels that are often exceeded during the life-time of most people, especially as shown from the measurements in the Östermalm apartment during this study. Exposure to RF radiation levels in the current study may clearly increase the risk for adverse health effects in the long run, since levels giving non-thermal biological effects are generally exceeded. Our findings will now be related to other measurements of RF radiation exposure, guidelines and studies regarding health issues.

Levels of RF radiation have increased considerably in recent years, both outdoor and indoor, due to new telecommunication technologies and protocols. In 2013, Estenberg and Augustsson (16) measured outdoor exposure with a car-based measuring system in Sweden. The median power-density for RF fields between 30 MHz and 3 GHz was measured in rural areas at $16 \mu\text{W}/\text{m}^2$, urban areas $270 \mu\text{W}/\text{m}^2$, and city areas $2,400 \mu\text{W}/\text{m}^2$. The EME-Spy 200 exposimeter was used to measure 2 areas of high exposure to RF radiation in Stockholm. At the Central Railway Station, the mean total RF radiation level varied between $2,817$ and $4,891 \mu\text{W}/\text{m}^2$ (min 5.8 , max $155,263 \mu\text{W}/\text{m}^2$) when walking around (13). The total RF radiation in the Stockholm Old Town varied between a mean of $404 \mu\text{W}/\text{m}^2$ (min 20.4 , max $4,088 \mu\text{W}/\text{m}^2$) on the streets around the Supreme Court, $756 \mu\text{W}/\text{m}^2$ (min 0.3 , max

$50,967 \mu\text{W}/\text{m}^2$) around the Royal Castle, and $24,277 \mu\text{W}/\text{m}^2$ (min 257 , max $173,302 \mu\text{W}/\text{m}^2$) at Järntorget, which is a popular square with shops and outdoor restaurants (14).

Calvente *et al* in Spain (17) measured outside the homes of 123 boys aged 10 years. For all houses, the root mean-square of power density (S_{RMS}) was $286 \mu\text{W}/\text{m}^2$ and the maximum power density (S_{RMS}) was $2,760 \mu\text{W}/\text{m}^2$ for frequencies between 100 kHz and 6 GHz. The range between highest and lowest measured mean was large, ranging from 5.5 to $11,560 \mu\text{W}/\text{m}^2$. The 10-year old boys with higher exposure of RF radiation in their immediate surroundings of their dwellings showed statistically significant lower scores in expression and comprehension, and higher behavioral and emotional problems, including anxiety and depressed behavior in different tests.

Usually much lower RF radiation exposure inside homes is measured since the walls can act as a shield against RF radiation. Frei *et al* (18) got 166 volunteers measure the frequencies 88-2,500 MHz with a body-born exposimeter (EME-Spy 120) in Switzerland. In the homes, the total mean value was $100 \mu\text{W}/\text{m}^2$, and total median $44 \mu\text{W}/\text{m}^2$. The maximum level in the homes was $1,212 \mu\text{W}/\text{m}^2$.

Roser *et al* (19) got 90 adolescents to carry a body-born exposimeter (Expo-RF) for 3 consecutive days to measure frequencies from 620 to 2,450 MHz. The total mean for these measurements was $63.2 \mu\text{W}/\text{m}^2$, and the total mean measured in the homes was $32.1 \mu\text{W}/\text{m}^2$.

Table V. Levels of RF-radiation at the balcony outside the living room (Östermalm, Stockholm).

Variable	Mean	Median	Min	Max
FM	6.3	1.2	0.0	2,139.0
TV3	0.7	0.0	0.0	66.2
TETRA I	0.0	0.0	0.0	3.4
TETRA II	0.0	0.0	0.0	0.9
TETRA III	0.0	0.0	0.0	2.7
TV4&5	9.3	0.0	0.0	828.9
LTE 800 (DL)	1,280.2	706.2	4.9	17,533.3
LTE 800 (UL)	0.0	0.0	0.0	0.2
GSM + UMTS 900 (UL)	0.0	0.0	0.0	0.3
GSM + UMTS 900 (DL)	8,731.6	11,977.8	16.1	44,241.5
GSM 1800 (UL)	0.0	0.0	0.0	1.8
GSM 1800 (DL)	584.3	409.7	0.7	6,193.1
DECT	212.9	137.9	0.0	4,124.7
UMTS 2100 (UL)	0.0	0.0	0.0	5.6
UMTS 2100 (DL)	1,421.6	1,270.2	1.1	18,445.0
WIFI 2G	0.0	0.0	0.0	7.2
LTE 2600 (UL)	0.4	0.0	0.0	95.8
LTE 2600 (DL)	12,638.7	8,394.8	1.1	95,522.5
WiMax	0.0	0.0	0.0	0.8
WIFI 5G	0.0	0.0	0.0	1.8
Total	24,885.9	22,256.1	72.0	112,317.7
Total excluding down link	229.6	146.5	0.0	4,155.6

Levels of RF-radiation at the balcony outside the living room based on measurements in June 5, 6 and August 21, 22, 30, 31, 2017 (apartment at Östermalm, Stockholm). Analysis of all data ($\mu\text{W}/\text{m}^2$) treating values at detection limit as 0. In total 5,251 entries corresponding to almost 6 h of measurements. FM, frequency modulation; TV, television; LTE, long-term evolution; DL, downlink (transmission from base station to mobile phone); UL, uplink (transmission from mobile phone to base station); GSM, global system for mobile communications; UMTS, universal mobile telecommunications system; DECT, digital European cordless telecommunications; WiMAX, worldwide interoperability for microwave access.

Vermeeren *et al* (20) measured levels using exposimeters EME-Spy 121 and 140 in schools, kindergartens, offices and homes in Belgium and Greece. In homes, the total average was 0.32 V/m ($272 \mu\text{W}/\text{m}^2$) in Belgium and 0.42 V/m ($468 \mu\text{W}/\text{m}^2$) in Greece. The maximum levels were 0.77 V/m ($1,574 \mu\text{W}/\text{m}^2$) in Belgium and 2.08 V/m ($11,482 \mu\text{W}/\text{m}^2$) in Greece. In Belgium, FM-radio, GSM 900 down link from bases stations, and DECT telephones contributed most of the radiation, and in Greece DECT and Wi-Fi 2.45 GHz contributed most.

Verlock *et al* (21) measured schools, homes and public places in Belgium with a Narda NBM-550 in the frequency range 100 kHz-6 GHz. Total means for the measurements was 0.45 V/m ($537 \mu\text{W}/\text{m}^2$), for homes 0.08 V/m ($16.9 \mu\text{W}/\text{m}^2$), and maximum value in homes was 1.08 V/m ($3,096 \mu\text{W}/\text{m}^2$).

Table VI. Levels of RF-radiation in the girls's bedroom (Östermalm, Stockholm).

Variable	Mean	Median	Min	Max
FM	1.2	0.5	0.0	1,056.1
TV3	0.1	0.0	0.0	28.7
TETRA I	0.0	0.0	0.0	0.0
TETRA II	0.0	0.0	0.0	1.0
TETRA III	0.0	0.0	0.0	1.4
TV4&5	0.2	0.0	0.0	44.8
LTE 800 (DL)	327.0	156.6	12.6	3,980.4
LTE 800 (UL)	0.0	0.0	0.0	0.3
GSM + UMTS 900 (UL)	0.0	0.0	0.0	0.1
GSM + UMTS 900 (DL)	774.9	590.9	18.7	5,561.5
GSM 1800 (UL)	0.0	0.0	0.0	0.3
GSM 1800 (DL)	29.4	18.3	1.2	243.5
DECT	8.1	4.0	0.0	167.1
UMTS 2100 (UL)	0.0	0.0	0.0	0.1
UMTS 2100 (DL)	808.5	706.2	2.9	3,806.9
WIFI 2G	0.0	0.0	0.0	0.5
LTE 2600 (UL)	24.5	15.7	0.0	904.7
LTE 2600 (DL)	557.1	420.2	1.4	7,584.8
WiMax	0.0	0.0	0.0	0.0
WIFI 5G	0.0	0.0	0.0	0.5
Total	2,531.0	2,270.5	79.1	11,802.6
Total excluding down link	34.1	23.1	7.2	1,069.8

Levels of RF-radiation in the girls's bedroom based on measurements in June 5, 6 and August 21, 22, 30, 31, 2017 (apartment at Östermalm, Stockholm). Analysis of all data ($\mu\text{W}/\text{m}^2$) treating values at detection limit as 0. In total 11,440 entries corresponding to almost 13 h of measurements. FM, frequency modulation; TV, television; LTE, long-term evolution; DL, downlink (transmission from base station to mobile phone); UL, uplink (transmission from mobile phone to base station); GSM, global system for mobile communications; UMTS, universal mobile telecommunications system; DECT, digital European cordless telecommunications; WiMAX, worldwide interoperability for microwave access.

These studies, published from 2009 to 2017, show a large variation in the levels of RF radiation, with highest levels measured in Stockholm.

One obstacle to those concerned with RF radiation exposure in Sweden, as in many other countries, is that different authorities base their guideline for exposure on the International Commission on Non-Ionizing Radiation Protection (ICNIRP). This guideline is based on short-term (acute) exposure. Chronic, low-intensity cumulative exposures, possible long term health effects, and non-thermal biological effects have been ignored. The ICNIRP safety limit established in 1998 (22) was updated in 2009 (23) without change. The guideline from the ICNIRP for RF radiation is 2 to 10 W/m^2 (2,000,000 to 10,000,000 $\mu\text{W}/\text{m}^2$) depending

Table VII. Levels of RF-radiation in the boy's bedroom (Östermalm, Stockholm).

Variable	Mean	Median	Min	Max
FM	0.5	0.4	0.0	407.6
TV3	0.0	0.0	0.0	6.1
TETRA I	0.0	0.0	0.0	16.6
TETRA II	0.0	0.0	0.0	1.2
TETRA III	0.0	0.0	0.0	0.6
TV4&5	2.2	0.0	0.0	304.8
LTE 800 (DL)	448.2	292.4	2.4	8,651.6
LTE 800 (UL)	0.0	0.0	0.0	0.0
GSM + UMTS 900 (UL)	0.0	0.0	0.0	0.2
GSM + UMTS 900 (DL)	756.1	558.8	6.4	7,056.1
GSM 1800 (UL)	0.0	0.0	0.0	0.1
GSM 1800 (DL)	29.4	18.7	0.7	474.6
DECT	10.5	5.9	0.0	353.4
UMTS 2100 (UL)	0.0	0.0	0.0	0.1
UMTS 2100 (DL)	124.3	114.8	1.5	1,158.9
WIFI 2G	0.0	0.0	0.0	1.2
LTE 2600 (UL)	0.2	0.1	0.0	14.1
LTE 2600 (DL)	99.7	57.3	0.5	1,352.2
WiMax	0.0	0.0	0.0	0.0
WIFI 5G	0.0	0.0	0.0	0.9
Total	1,471.1	1,122.3	58.5	13,739.1
Total excluding down link	13.4	6.8	0.0	427.8

Levels of RF-radiation in the boy's bedroom based on measurements in June 5, 6 and August 21, 22, 30, 31, 2017 (apartment at Östermalm, Stockholm). Analysis of all data ($\mu\text{W}/\text{m}^2$) treating values at detection limit as 0. In total 14,161 entries corresponding to almost 16 h of measurements. FM, frequency modulation; TV, television; LTE, long-term evolution; DL, downlink (transmission from base station to mobile phone); UL, uplink (transmission from mobile phone to base station); GSM, global system for mobile communications; UMTS, universal mobile telecommunications system; DECT, digital European cordless telecommunications; WiMAX, worldwide interoperability for microwave access.

Table VIII. Levels of RF-radiation in the tower bedroom (Östermalm, Stockholm).

Variable	Mean	Median	Min	Max
FM	155.0	127.2	4.0	3,441.2
TV3	6.2	4.9	0.0	193.4
TETRA I	9.1	0.0	0.0	59.7
TETRA II	1.6	1.8	0.0	33.9
TETRA III	0.6	0.0	0.0	11.9
TV4&5	14.0	0.0	0.0	2,206.2
LTE 800 (DL)	3,712.1	2,333.8	8.6	48,136.9
LTE 800 (UL)	0.0	0.0	0.0	0.1
GSM + UMTS 900 (UL)	0.0	0.0	0.0	4.5
GSM + UMTS 900 (DL)	1,785.4	1,689.1	13.8	11,775.7
GSM 1800 (UL)	0.0	0.0	0.0	0.1
GSM 1800 (DL)	59.0	47.6	0.9	657.8
DECT	18.8	13.8	0.0	593.4
UMTS 2100 (UL)	0.0	0.0	0.0	0.7
UMTS 2100 (DL)	77.7	65.4	1.0	495.0
WIFI 2G	0.0	0.0	0.0	0.7
LTE 2600 (UL)	0.0	0.0	0.0	6.4
LTE 2600 (DL)	114.8	75.8	2.7	3,321.4
WiMax	0.0	0.0	0.0	0.0
WIFI 5G	0.0	0.0	0.0	1.5
Total	5,954.3	4,503.5	96.8	50,431.0
Total excluding down link	205.4	158.4	13.5	3,457.8

Levels of RF-radiation in the tower bedroom based on measurements in June 5, 6 and August 21, 22, 30, 31, 2017 (apartment at Östermalm, Stockholm). Analysis of all data ($\mu\text{W}/\text{m}^2$) treating values at detection limit as 0. In total 6,797 entries corresponding to almost 7.5 h of measurements. FM, frequency modulation; TV, television; LTE, long-term evolution; DL, downlink (transmission from base station to mobile phone); UL, uplink (transmission from mobile phone to base station); GSM, global system for mobile communications; UMTS, universal mobile telecommunications system; DECT, digital European cordless telecommunications; WiMAX, worldwide interoperability for microwave access.

on frequency (22). The Swedish Radiation Safety Authority (SSM) has adopted the ICNIRP guideline. Many experts at the SSM panel are also members of ICNIRP, which suggests a conflict of interest, since they would rarely compromise the ICNIRP view by expressing critical opinions (15).

Our results on RF radiation exposure in Östermalm are orders of magnitude lower than the ICNIRP guideline, with the median level of exposure being ~10,000 times lower. Using the ICNIRP guideline gives a 'green card' to roll out the technology, and position mobile phone base stations on roofs on apartment houses, in close to those living in the surrounding houses, since the high exposure level by ICNIRP is rarely compromised.

In contrast to ICNIRP, the BioInitiative Reports from 2007 and updated in 2012, based the evaluation on non-thermal

health effects of RF radiation (24,25). A summary of the BioInitiative Report (2007) was published in a peer-reviewed article (26). Furthermore in both reports, all chapters were based on peer-review published articles, many of them by the authors of the different chapters. Thus, it is incorrect to suggest that the reports represent views and results that are not supported by the scientific literature.

The BioInitiative Report (2012) with updated references defined the scientific benchmark for possible health risks as 30-60 $\mu\text{W}/\text{m}^2$. Considering also chronic exposure and the sensitivity of children, the precautionary target level was proposed at 1/10th of this, i.e., 3-6 $\mu\text{W}/\text{m}^2$ (25). This exposure target level has not been acknowledged by SSM in Sweden, thus making it possible to neglect results on exposure, such as

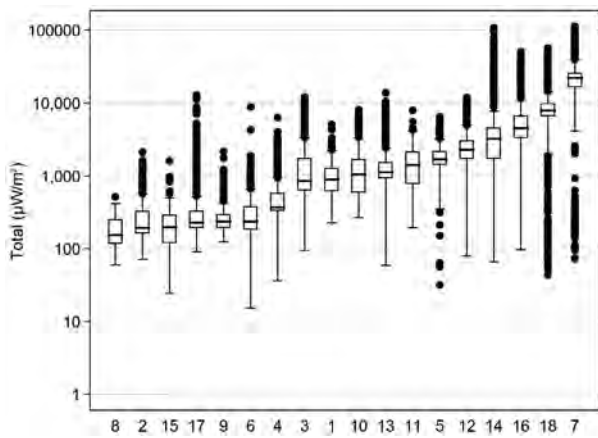


Figure 1. Box plot of exposure in $\mu\text{W}/\text{m}^2$, logarithmic scale, for the 6 measurement rounds and total exposure (apartment in Östermalm, Stockholm). The median is indicated by a black line inside each box; the bottom and top of the boxes show first and third quartiles; the end of the whiskers are calculated as $1.5 \times \text{IQR}$ (interquartile range). Points represent outliers. Results are displayed according to increasing median level. 1, Balcony outside kitchen; 2, Kitchen; 3, Dining room; 4, Master bedroom; 5, Balcony outside bathroom; 6, Living room; 7, Balcony outside living room; 8, Main hall; 9, Workroom close to kitchen; 10, Workroom close to laundry; 11, Laundry; 12, Girl's bedroom; 13, Boy's bedroom; 14, Balcony outside boy's bedroom; 15, Hall outside elevator; 16, Bedroom in tower; 17, Conference room in tower; 18, Balcony outside tower.

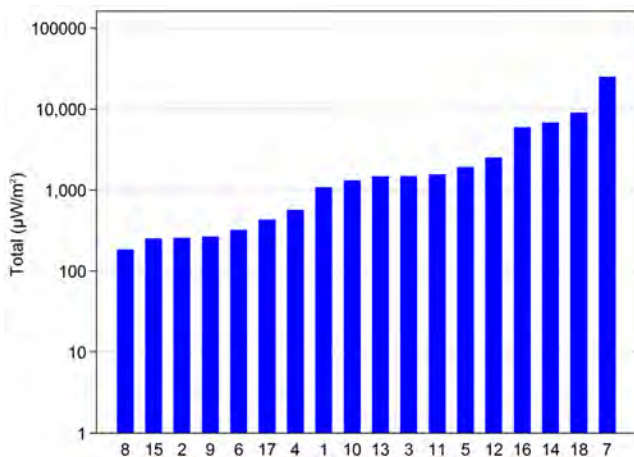


Figure 2. Bar graph on mean levels of total exposure in $\mu\text{W}/\text{m}^2$ displayed with a logarithmic scale and ranked according to increasing mean level in the different locations (apartment in Östermalm, Stockholm). 1, Balcony outside kitchen; 2, Kitchen; 3, Dining room; 4, Master bedroom; 5, Balcony outside bathroom; 6, Living room; 7, Balcony outside living room; 8, Main hall; 9, Workroom close to kitchen; 10, Workroom close to laundry; 11, Laundry; 12, Girl's bedroom; 13, Boy's bedroom; 14, Balcony outside boy's bedroom; 15, Hall outside elevator; 16, Bedroom in tower; 17, Conference room in tower; 18, Balcony outside tower.

in the apartment we measured, and not in providing precaution for the potential detrimental effects on health for those living therein.

We used the same exposimeter in the Geneva WHO building on March 3, 2017. The results show a low mean total exposure level of $21.5 \mu\text{W}/\text{m}^2$, median $13.3 \mu\text{W}/\text{m}^2$ (range min 4.8, max $433 \mu\text{W}/\text{m}^2$), i.e., a mean level below the scientific benchmark of $30\text{--}60 \mu\text{W}/\text{m}^2$ that has been proposed as the 'lowest observed effect level' (LOEL) for RF radiation,

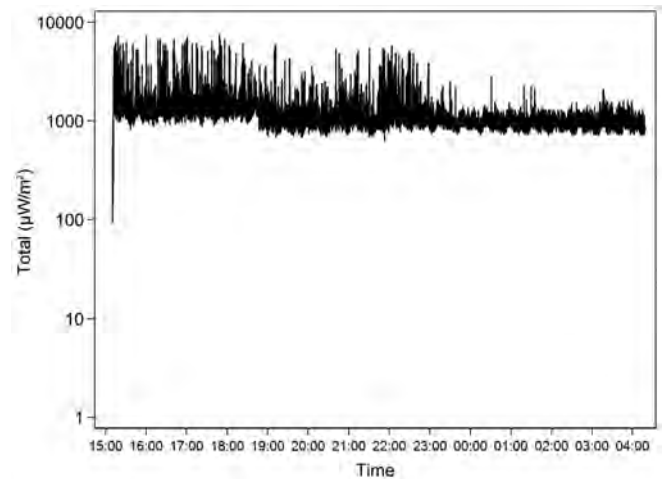


Figure 3. Time variation of measurements in boy's bedroom (apartment in Östermalm, Stockholm) from the afternoon until early next morning ($\mu\text{W}/\text{m}^2$ on a logarithmic scale). The spikes represent measurements taken every 4th sec.

[see Chapter 24 in the BioInitiative Report (25)]. The major sources were GSM + UMTS 900 DL (3G), GSM 1800 DL (2G) and UMTS 2100 DL (3G), i.e., down link (DL) of RF radiation from base stations. Thus these results indicate that, whether known or unknown, the WHO staff seems to protect themselves from high involuntary RF radiation levels at least within the measured areas of the Geneva building (15).

In the present study, for the whole apartment including the balconies, the measurements of RF radiation had a total mean of $3,811 \mu\text{W}/\text{m}^2$ and a total median of $1,313 \mu\text{W}/\text{m}^2$. For rooms inside the apartment, the tower bedroom had the highest mean ($5,954 \mu\text{W}/\text{m}^2$) and median ($4,504 \mu\text{W}/\text{m}^2$). Also the girl's bedroom with mean $2,531 \mu\text{W}/\text{m}^2$ and median $2,271 \mu\text{W}/\text{m}^2$ and the boy's bedroom with a mean of $1,471 \mu\text{W}/\text{m}^2$ and median $1,122 \mu\text{W}/\text{m}^2$ were high values. Time spent in a bedroom is usually many hours per night, which means long term exposure when relatively high levels of RF radiation are still present.

RF radiation exposure at or below these levels indicated above have influenced several physiological parameters in the body of mammals in laboratory studies. Effects on oxidative cell stress and DNA damage in cells, opening of the blood-brain barrier, up or down regulated proteins and microRNA in the brain, and testicular dysfunction, have been found. For people living near mobile phone base stations, effects have been seen on neurotransmitters, peripheral blood lymphocytes with DNA damage, lower antioxidant levels, decreased salivary secretion, adverse neuro-behavioral symptoms, and an increased incidence of cancer. People residing near mobile phone base stations have more often complained of sleep disturbances, headaches, dizziness, irritability, concentration difficulties and hypertension. Exposures to RF radiation were all below the reference levels in the ICNIRP guidelines. The effects were caused by non-thermal RF radiation exposure and will now be briefly discussed.

In rats exposed to RF radiation, the blood brain barrier (BBB) has opened up, leading to leakage into the brain tissues of large molecules, e.g., albumin and toxins that can

Table IX. Levels of RF-radiation in total for different locations in the apartment (Gärdet, Stockholm).

Location	No.	Mean	Median	Min	Max
Kitchen	6,815	9.2	7.8	4.2	55.6
Dining room	5,970	16.2	15.4	6.2	60.6
Bedroom	8,163	10.7	8.6	3.9	58.2
Living room	8,229	18.4	17.0	7.5	97.8
Hall	5,809	4.2	3.9	2.2	20.6
Balcony	1,813	82.4	73.1	9.1	195.1
Whole apartment	36,799	15.6	12.8	2.2	195.1
Whole apartment-excluding down link	36,799	1.1	0.7	0.0	124.6

Levels of RF-radiation in total for different locations in the apartment based on measurements in October 27-29 and November 6, 2017 (Gärdet, Stockholm). Analysis of all data ($\mu\text{W}/\text{m}^2$) treating values at detection limit as 0. Numbers of entries are given for the different locations.



Figure 4. Image taken from the balcony outside the living room where the highest mean and median were measured (24,885.9 and 22,256.1 $\mu\text{W}/\text{m}^2$). One group of base stations is located only 12 m from the balcony.

damage the brain tissue. The BBB is supposed to protect and prevent pathological leakage of toxins from the blood vessels (27). Several studies have shown that the BBB can open after RF radiation from a GSM mobile phone with a peak power output of only 1,000 μW , and with an average whole body specific energy absorption rate (SAR) of down to 120 $\mu\text{W}/\text{kg}$ (28). Stronger effects on health due to RF radiation at lower exposure levels than at higher exposure indicate a U-shaped response curve (28,29).

Difference between sexes exposed to different RF radiation frequencies has been reported, where only female rats showed increased BBB permeability at 900 MHz

frequency, whereas male rats had increased BBB permeability at both GSM 900 and 1,800 MHz pulse-modulated RF radiation (30).

Exposure to 900 MHz for 3 h per day for 28 days caused extravasation of albumin in the hippocampus and cortex, and impaired spatial memory in rats. The hippocampus, a center for co-ordination of memory and learning in the brain, seems in particular to be a primary target for neuronal damage from RF radiation and opening of the BBB (31). Exposure for 2 h each week for 55 weeks impaired the memory in rats exposed to GSM 900 MHz, but histopathological parameters did not seem to be statistically significantly affected (32,33).

Higher sensitivity to RF radiation has been reported in growing organisms. An increase in protein synthesis in proliferating human cells has been seen after 8 h of RF radiation exposure, but not in quiescent white blood cells (34). In stems cells, the capacity to repair DNA double-strand breaks was more affected by RF radiation compared to differentiated cells (fibroblasts) (35).

Mice exposed to RF radiation from a GSM 900 MHz mobile phone for 3 h/day or to DECT base station for 8 h/day over 8 months showed an up or down regulation of 143 out of 432 proteins analyzed from the cerebellum, hippocampus and frontal lobes of the brain. Several proteins involved in the brain metabolism and different neural functions were altered (36).

Two long-term studies have exposed rats for 24 h a day for 12 months to RF radiation emitted from a Wi-Fi system at 2.4 GHz. The peak power was 100,000 μW , with the antenna 50 cm above the cage. The SAR value over 10 g of brain tissue was 1,030 $\mu\text{W}/\text{kg}$. One study examined 5 different microRNAs (miRNA) in the rat brains, 2 of which decreased at least 70%. miRNA is important in the proliferation, differentiation, function and maintenance of all cells, including neurons; and dysfunction of their pathways can contribute to pathogenesis of neurodegenerative disorders, as well as being a key indicator of epigenetic changes and cancer risk (37).

Rat testes and prostate were examined in another study, where the SAR value was 1,020 W/kg over 10 gram tissue. The Wi-Fi exposed rats showed statistically significant greater effects on testicular function and histology, and increased defects in the heads of sperms (38). DNA damage in sperms has been reported in several other Wi-Fi exposure investigations (39-41).

In a review of 100 studies, Yakymenko *et al* (42) showed oxidative effects of low-intensity RF radiation on living cells, with exposure down to 2,500 $\mu\text{W}/\text{m}^2$ (43). SAR values down to 600 $\mu\text{W}/\text{kg}$ increased oxidative stress in the cells (44,45). Embryos of Japanese quails were exposed to RF radiation using GSM 900 MHz (46). The average intensity of RF radiation on the surface of hatching eggs was 2,500 $\mu\text{W}/\text{m}^2$ (0.25 $\mu\text{W}/\text{cm}^2$). SAR was calculated to be 3 $\mu\text{W}/\text{kg}$. A statistically significant overproduction of reactive oxygen species (ROS) and oxidative damage of DNA in living cells was reported compared with the control group given no exposure. The exposure was far below the guideline of the ICNIRP for RF radiation at 2 to 10 W/m² depending on frequency and 2 W/kg to the brain. The results showed that the ICNIRP guidelines are outdated. Moreover, using a safety factor of 10 would give 250 $\mu\text{W}/\text{m}^2$ as a guideline, a level easily exceeded in many places, e.g., our measurements taken at the Stockholm Central Railway

Station (13), in the Old Town (14) and in most rooms in the present apartment at Östermalm.

Long-term RF radiation exposure for 2 h per day 5 days per week for 30–180 days at SAR values of 595–667 $\mu\text{W/kg}$ and at the frequencies 900, 1,800 and 2,450 MHz resulted in oxidative stress, increase in pro-inflammatory cytokines, DNA damage with single-strand breaks, reduced levels of neurotransmitters and downregulation of mRNA in the hippocampus in the brain of rats (45,47,48), with memory and learning also being affected (47). More deleterious effects on several of the parameters were seen with an increase in frequency; 1,800 MHz and 2,450 MHz had a statistically significant effect, not only compared with sham exposed animals, but in some cases compared with 900 MHz exposure.

Even a SAR value down to 85 $\mu\text{W/kg}$ exposure from 900 MHz during 2 h/day, 5 days/week for 30 days, increased oxidative stress parameters in lipid peroxidation and protein oxidation, and resulted in a statistically significant impairment in spatial memory in rats (49).

The pancreas was examined in young rats of 6 weeks of age exposed for 3 h/day for 30 days to 2.45 MHz, pulsed 217 Hz, from a RF test generator, with similar exposure to Wi-Fi 2.45 GHz. Compared to the control group, these rats had statistically significant increased levels of glucose, lipase and amylase in the blood, degenerative changes in both endocrine and exocrine cells, increased inflammatory cells and immune-positive markers, especially in the islets of Langerhans. These findings point to a deleterious effect on both endocrine and exocrine functioning of the pancreas. Langerhans islets secrete hormones like insulin, glucagon and somatostatin, which regulate blood glucose levels; insufficient secretion can lead to diabetes, which have seen a big increase during the last few decades in parallel with the fast increasing use of wireless techniques (50).

The National Toxicology Program (NTP) under the National Institutes of Health (NIH) in the USA released a report in 2016 which showed an increased incidence of glioma in the brain and malignant schwannoma in the heart in up to 2 years in RF irradiated rats. These findings support human epidemiological studies on brain tumor risk and strengthen the association between RF radiation and cancer (51). Recent results from the NTP study showed genotoxicity of RF radiation in rats and mice (52). This result supports several previous findings of DNA strand-breaks in rat brain cells exposed to RF radiation, as first published by Lai and Singh (53). RF radiation leads to oxidative stress in biological systems, including the brain, due to an increase in free radicals and changes in antioxidant defence systems.

The NTP study has greatly strengthened the evidence of cancer risk, and reaffirms that there is sufficient scientific evidence to reclassify wireless phone radiation as a carcinogenic agent in Group 1, according to the IARC classification. It confirms that the current public safety limits based only on the thermal effects are inadequate and do not protect us against the associated detrimental health effects (10,11).

In the village of Rimbach in Germany, a GSM mobile base station was built in 2004. Buchner and Eger (54) studied 60 inhabitants (aged 0–69 years), measuring the neurotransmitters adrenaline, noradrenaline, dopamine and phenylethylamine (PEA) in second morning urine samples before the base station

was activated, and at 6, 12 and 18 months after activation. RF radiation was measured in peak value of the power density after the activation of the base station outside each participant's houses. The participants were divided into 3 groups based on exposure: less than 60, 60–100 or $>100 \mu\text{W/m}^2$. The stress hormones adrenaline and noradrenaline were significantly increased over the first 6 months after the activation of the GSM base station. The levels decreased, but were not restored to initial level, after 18 months. This was especially evident in the children and the chronically ill adults. A statistically significant decrease was seen for dopamine levels over the first 6 months, after which dopamine levels increased, but did not return to their initial level. For the participants with RF radiation exposure over $100 \mu\text{W/m}^2$ at home, the 3 neurotransmitters showed a clear dose-response relationship. PEA levels decreased first for the highest exposed group, but after 18 months the 3 groups were all statistically significantly decreased. DECT, Wi-Fi and other wireless devices at home seemed to amplify the effect of GSM radiation. After 18 months, even the lowest exposed group (RF radiation $<60 \mu\text{W/m}^2$) had decreased dopamine and PEA levels.

PEA is often low in patients with depression, and in adults and children with attention deficit hyperactivity disorder (ADHD). Chronic dysregulation of the catecholamine system and PEA may contribute to chronic illnesses and health problems in the long term. Several of the 60 participants had new symptoms, including headache, dizziness, concentration problems, sleep disturbances and allergies (54).

Khurana *et al* (55) reviewed epidemiological studies on populations living near mobile phone base stations for indications of any health risks for humans. In 80% of the studies, people living <500 m from base stations had an increased prevalence in particular of adverse neuro-behavioral symptoms and cancer. In another review of 56 studies, Levitt and Lai (56) found that exposure from base stations and other antenna arrays induced changes in immunological and reproductive systems, DNA double-strand breaks, influence on calcium movement in the heart, and increased proliferation of astrocytoma cancer cells in humans and laboratory animals. Cortisol and thyroid hormones were also affected in people living near base stations (57,58).

A study with 40 healthy persons in India living <80 m from a mobile phone base station showed that RF radiation definitely induced DNA damage, a lowering of antioxidants levels, and a higher frequency of micronuclei in peripheral blood lymphocytes compared with a control group living >300 m from the base station. Those exposed were between 20 and 40 years old, 18 being male and 22 female. All but 3 used a mobile phone every day. None of the participants had occupational exposure to RF radiation and none lived near a high tension electric power line or electric transformer station (59).

Sleep disturbances, burned-out syndromes, depressions, pain problems and sick leaves are being increasingly reported in our daily papers. Scientific studies on humans, animals and biological material show adverse effects on physiological parameters due to RF radiation. The complex picture relates to wellbeing within the stress of working life and at home, and the rapid technological development leading to more sedentary behavior, with both children and adults watching the screen of a smart phone, laptop or television for many hours each day.

RF radiation may contribute to deterioration in physical and mental wellbeing and health. There seems also to be a large difference in sensitivity to RF radiation between individuals, both in humans and animals (28,60). One example is the findings of downregulation of a sleep-inducing neurohormone in the age group of 18-30 years. Its level decreased with increasing number of years in use of a wireless phone (61), whereas no effect was seen among older persons (62). Since tumors take several decades to develop, and chronic illnesses, like neurological and cardiac diseases, come in older ages, we will only know in the future if and to what degree RF radiation may influence on the incidence of these illnesses and disorders.

Children are probably more sensitive to RF radiation because of their growing bodies and more immature cells, and also because they will be exposed for probably a whole lifetime in contrast to present generation (34,35,63). High mean exposure levels in the bedrooms of growing children (one at 2,531 $\mu\text{W}/\text{m}^2$ and the other at 1,471 $\mu\text{W}/\text{m}^2$) may have deleterious effects on their physical and mental health, based on data already obtained from humans and animals. Cognitive effects have also been found in such studies (17,32,48,49), which might affect a child's future work and memory function in older age.

This study shows high RF radiation levels in an apartment with 2 groups of base stations in the near vicinity. Of special concern is the levels in bedrooms, especially those two used by children, since they seem to be more vulnerable to adverse health effects than grown-ups. They have also a longer expected life in which illnesses may later become manifest. The results indicate that this apartment is unsuitable for long-term living based on current knowledge of the potential adverse effects on health of RF radiation. For definitive conclusions regarding the effects of RF radiation levels from the base stations, one option would be to turn off all nearby base stations and make new measurements; some exposure from more distant located base stations cannot be excluded. However, the present results show that the safest solution is to turn off permanently and dismantle the base stations.

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Availability of data and materials

The datasets generated and analyzed during the current study are not publicly available due to measurements performed in a private apartment, but are available from the corresponding author on reasonable request.

Authors' contributions

LHa made all measurements and drafted the article. MC made all statistical analyses, tables and figures. LHe was

responsible for the literature review of other measurement studies in homes and studies about the biological effects from non-thermal levels of RF radiation. All authors contributed to the final article and approved the submitted version.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Comments on the US National Toxicology Program technical reports on toxicology and carcinogenesis study in rats exposed to whole-body radiofrequency radiation at 900 MHz and in mice exposed to whole-body radiofrequency radiation at 1,900 MHz

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Abstract. During the use of handheld mobile and cordless phones, the brain is the main target of radiofrequency (RF) radiation. An increased risk of developing glioma and acoustic neuroma has been found in human epidemiological studies. Primarily based on these findings, the International Agency for Research on Cancer (IARC) at the World Health Organization (WHO) classified in May, 2011 RF radiation at the frequency range of 30 kHz-300 GHz as a 'possible' human carcinogen, Group 2B. A carcinogenic potential for RF radiation in animal studies was already published in 1982. This has been confirmed over the years, more recently in the Ramazzini Institute rat study. An increased incidence of glioma in the brain and malignant schwannoma in the heart was found in the US National Toxicology Program (NTP) study on rats and mice. The NTP final report is to be published; however, the extended reports are published on the internet for evaluation and are reviewed herein in more detail in relation to human epidemiological studies. Thus, the main aim of this study was to compare earlier human epidemiological studies with NTP findings, including a short review of animal studies. We conclude that there is clear evidence that RF radiation is a human carcinogen, causing glioma and vestibular schwannoma (acoustic neuroma). There is some evidence of an increased risk of developing thyroid cancer, and clear evidence that RF radiation is a multi-site carcinogen. Based on the Preamble to the IARC Monographs, RF radiation should be classified as carcinogenic to humans, Group 1.

Introduction

Recently, the US National Toxicology Program (NTP) released results on the toxicology and carcinogenicity of radiofrequency (RF) radiation in rats and mice, as further discussed below. This initiated this article for the comparison of earlier human epidemiological studies with the NTP the findings, including a short review of animal studies.

NTP is an interagency program established in 1978 to coordinate toxicology research and testing across the Department of Health and Human Services. The program was also created to strengthen the science base in toxicology, develop and validate improved testing methods, and provide information about potentially toxic chemicals to health regulatory and research agencies, scientific and medical communities, and the public. NTP is headquartered at the National Institute of Environmental Health Sciences (NIEHS) (<https://ntp.niehs.nih.gov/about/org/index.html>).

The brain is the main target of the exposure to RF radiation during the use of handheld wireless phones; both mobile and cordless phones (1,2). Thus, an increased risk of developing brain tumors has long been a cause for concern.

Our study group has since the end of the 1990s published results from case-control studies on use of wireless phones and brain tumor risk (3). A statistically significant increased risk for ipsilateral use of mobile phones, the same side of the brain as the phone was used, was published for malignant brain tumors (4) and vestibular schwannoma (5). Further scientific evidence on the association has more recently been discussed by Carlberg and Hardell (6).

In May, 2011 the International Agency for Research on Cancer (IARC) concluded that radiofrequency (RF) radiation in the frequency range 30 kHz-300 GHz is a 'possible' human carcinogen Group 2B (7,8). The classification was based primarily on evidence that long-term users of wireless phones (mobile and cordless phones) have an increased risk for glioma and acoustic neuroma. One major reason that the rating was not a 'probable' or a 'known' risk was the lack of clear evidence from animal studies. IARC at the World Health Organization (WHO) is independently financed and has its own governing and scientific councils, which WHO staff

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only attend as observers (http://www.who.int/ionizing_radiation/research/iarc/en/).

Unfortunately, WHO itself has constantly refused to acknowledge the carcinogenicity of RF radiation. In fact, WHO seems to rely on the conclusion of the non-governmental organization International Commission on Non-ionizing Radiation Protection (ICNIRP) instead of the IARC evaluation. That organization is even declared to be their in-house experts (9,10). ICNIRP is a private non-governmental organisation (NGO) based in Germany. New expert members can only be elected by members of the organization. Many of the ICNIRP members have ties to the industry that are dependent on the ICNIRP guidelines (11). This creates a conflict of interest, since the former leader of the WHO International Electromagnetic Field (EMF) Project is also the founder and honorary member of the ICNIRP (11). The guidelines are of huge economic and strategic importance to the military, telecom/IT and power industry. These circumstances are further discussed in a recent publication (12).

The IARC cancer classification includes all sources of RF radiation. The exposure from mobile phone base stations, DECT base stations, Wi-Fi access points, smart phones, laptops and tablets can be long-term, sometimes around the clock, at home, at the work place, at school and in the environment. For children, this risk may be accentuated due to a cumulative effect during a long lifetime use (13).

The exposure guidelines used by many agencies and countries were established in 1998 by the ICNIRP and were based only on established short-term thermal (heating) effects from RF radiation neglecting non-thermal biological effects (14). ICNIRP provides the guideline of 2 to 10 W/m² for RF radiation, depending on the frequency. The ICNIRP guidelines were updated in 2009; however, they still do not cover cancer and other long-term or non-thermal effects (15) [see also Hardell (10)].

In contrast to the ICNIRP, the BioInitiative Reports from 2007 and 2012 based the evaluation also on the non-thermal health effects from RF radiation (16,17). The scientific benchmark for possible health risks was defined to be 30 to 60 μ W/m². In 2012, the Bioinitiative Working Group proposed a precautionary target level of 3–6 μ W/m², using a safety factor of 10. Using the significantly higher guideline by ICNIRP gives a 'green card' to roll out the wireless digital technology, thereby not considering non-thermal health effects from RF radiation.

The evidence of RF radiation as a carcinogen was confirmed when NTP released preliminary results of a study of long-term exposure of rats and mice to cell phone radiation (18). An increased incidence of glioma in the brain and malignant schwannoma in the heart was found. The NTP study has now been published online for public consultations (19,20) and is discussed below in relation to human epidemiological studies.

Background: Evidence from previous animal studies

There are several earlier animal studies that demonstrate the carcinogenic potential of RF radiation. Szmigielski *et al* already in 1982 published a study on the co-carcinogenic effects of RF radiation exposure and benzopyrene in mice (21). Cancer promotion was found for 2,450 MHz RF radiation at either 50 or 150 W/m². The results revealed an acceleration of spontaneous and chemically-induced cancers.

Non-thermal 2,450 MHz continuous-wave RF radiation has been shown to cause a biphasic effect on glioma cells (22) and lymphocytes (23). Cell proliferation was found at a specific absorption rate (SAR) of ≤ 50 W/kg, whereas a higher SAR suppressed DNA and RNA synthesis.

SAR ranged from 0.144 to 0.4 W/kg depending on the rats' weight in a study from 1992 on 200 rats exposed to 2,450 MHz pulsed RF radiation 21.5 h per day for 25 months (24). Compared with 200 sham-exposed rats, a statistically significant increased incidence of primary malignant diseases was found in exposed animals. Among the malignancies found in the exposed rats were malignant lymphoma and thyroid cancer. These findings are of interest since SAR values in the study were rather low compared to the ICNIRP guideline on SAR 2 W/kg to the brain for use of mobile phones (14).

A total of 100 mice were sham-exposed and 101 were exposed for two 30-min periods per day for up to 18 months to 900 MHz pulsed RF radiation with power densities 2.6–13 W/m² (SAR 0.008–4.2 W/kg, averaging 0.13–1.4 W/kg). The mice carried a lymphomagenic oncogene and their risk of developing lymphoma was found to be statistically significantly higher in the exposed mice than in the controls (25).

The same results were not found in the study by Utteridge *et al* (26) that has been criticized as it was not a replication study. However, the findings on lymphoma risk by Repacholi *et al* (25) and Chou *et al* (24) are of relevance in relation to the indications of an increased risk of non-Hodgkin lymphoma (NHL) in human epidemiological studies on the use of wireless phones. Thus, a statistically significant increased risk of T-Cell NHL was found in one study (27). In another study, NHL not otherwise specified was statistically significantly increased among subjects with ≥ 6 years duration [odds ratio (OR) = 4.4 in men] for mobile phone use (28), although based on low numbers (n=7).

The thyroid gland is among the organs with the highest exposure to RF radiation during the use of the handheld wireless phone, particularly smartphones (29,30). The finding of thyroid cancer risk in the study by Chou *et al* (24), and the sharp increase in the incidence of thyroid cancer in humans during recent years (31) are of interest in that context.

In another study, mice were exposed to universal mobile telecommunications system (UMTS) fields with intensities of 0 (sham), 4.8 and 48 W/m² up to 24 months (32). The low-dose group, exposed to 4.8 W/m², was subjected to additional prenatal ethylnitrosourea (ENU) treatment. That group showed an increased lung tumor rate and an increased incidence of lung carcinomas as compared to the controls treated with ENU only. This indicated a cocarcinogenic effect of a lifelong UMTS exposure in female mice pretreated with ENU (32).

In a follow-up study, mice were exposed to RF radiation: 0 (sham), 0.04, 0.4 and 2 W/kg SAR (33). The numbers of tumors of the lungs and livers in exposed animals were statistically significantly higher than in sham-exposed controls, and the numbers of malignant lymphoma were also higher. A tumor-promoting effect of RF radiation was found at low to moderate levels (0.04 and 0.4 W/kg SAR), well below the ICNIRP exposure limits for users of mobile phones (33).

The study by the Ramazzini Institute is the largest long-term study ever performed on the health effects of RF radiation,

including 2,448 rats (34). Male and female Sprague-Dawley rats were exposed from prenatal life until natural death to a 1.8 GHz global system for mobile communication (GSM) far field of 0, 5, 25, 50 V/m with a whole-body exposure for 19 h/day. A statistically significant increase in the incidence of malignant Schwannoma in the heart was found in male rats at the highest dose, 50 V/m, corresponding to 0.66 mW/cm² and whole-body SAR of 0.1 W/Kg. An increased incidence of heart Schwann cell hyperplasia was observed in treated male and female rats at the highest dose (50 V/m), but was not statistically significant. In treated female rats at the highest dose (50 V/m), the incidence of malignant glial tumors was increased, although this was not statistically significant. The study revealed an increased incidence of tumor types similar to those associated with the use of wireless phones, glioma and acoustic neuroma, in human epidemiological studies.

The NTP study provides additional confirmation of the carcinogenicity of RF radiation (19,20). They showed an increased incidence of malignant schwannoma in the heart and brain glioma in male rats exposed either to GSM-modulated or code division multiple access (CDMA)-modulated cell phone RF radiation for two years. There are also increased incidences of some other tumor types and diseases. Below we discuss some of the major findings.

The results on schwannoma and glioma are of particular concern since they corroborate human epidemiological findings. Thus, it is noteworthy that similar tumors were found in the NTP study as in epidemiological studies on the human use of wireless phones; mobile phones or cordless phones (DECT). Malignant schwannoma in the heart is a similar type of tumor as vestibular schwannoma in humans, also known as acoustic neuroma, although acoustic neuroma is usually benign and rarely undergoes malignant transformation.

Below, we provide an updated evaluation of the scientific evidence of an increased risk of developing glioma and vestibular schwannoma (acoustic neuroma) associated with the use of wireless phones. It is pertinent to provide an updated presentation of the NTP reports on current evidence on cancer risks associated with the use of wireless phones.

Since the IARC evaluation in 2011, more human epidemiological studies have been published that support a causal association between RF radiation and brain and head tumors. A Danish cohort study on 'mobile phone users' (35,36) is not included herein due to serious methodological shortcomings in the study design [see Söderqvist *et al* (37)]. The study by Benson *et al* (38) is of limited value since the use of cordless phones was not included, mobile phone use was assessed only at baseline and no information on tumor laterality, including ipsilateral versus contralateral use was given. In spite of the many shortcomings, an increased risk of developing acoustic neuroma was reported. The study will not be further discussed below.

In the following, first, human epidemiological studies on specific tumor types are discussed. The NTP study findings are then presented and finally, an evaluation of the combined evidence from human and animal studies is presented.

Glioma

Human studies. Glioma is the most common malignant brain tumor and represents approximately 60% of all central

nervous system (CNS) tumors. Most of these are astrocytic tumors divided into low-grade (WHO grades I-II) and high-grade (WHO grades III-IV). The most common glioma type is glioblastoma multiforme (WHO grade IV) with a peak incidence in the age group of 45-75 years and a median survival less than one year (39). No substantial increasing survival has been obtained in recent years. Three research groups have provided results in case-control studies on glioma, Interphone (40), Coureau *et al* (41) and the Hardell group in Sweden (42-46).

The random effects model was used for a meta-analysis of published studies, based on the test for heterogeneity in the overall group ('all mobile'), see also http://www.bioinitiative.org/report/wp-content/uploads/2017/11/Hardell-2017-Sec11-Update-Use_of_Wireless_Phones.pdf. Note that only our group also assessed the use of cordless phones. Thus, the reference category in our studies included cases and controls with no use of wireless phones, in contrast to the other studies investigating only mobile phone use. Including cordless phone use in the 'unexposed' group would bias the risk estimates towards unity (45).

In Table I, results of the highest cumulative use in hours of mobile phones are presented. All studies reported a statistically significantly increased risk of developing glioma and the meta-analysis yielded OR =1.90 and 95% confidence interval (CI) =1.31-2.76. For ipsilateral mobile phone use, the risk increased further to OR =2.54, 95% CI =1.83-3.52 in the meta-analysis based on 247 exposed cases and 202 exposed controls. Further support of the increased risk of glioma associated with mobile phone use has been obtained in additional analyses of parts of the Interphone study (47-49).

We previously analyzed the survival of the patients in our studies and found a shorter survival in patients with glioblastoma multiforme associated with the use of wireless phones compared with patients with no use (50). Interestingly, the mutation of the p53 gene involved in disease progression has been reported in glioblastoma multiforme in patients using mobile phones for ≥3 h per day. The mutation was statistically significantly associated with a shorter overall survival time (51).

NTP study. No increased incidence of glioma was reported in the mouse study (20).

In male rats (19), malignant glioma and glia cell hyperplasia occurred in all groups exposed to GSM-modulated cell phone RF radiation for two years. No lesions were observed in the sham controls. In female rats, glial cell hyperplasia occurred in one rat (3 W/kg), but none in the sham controls. One malignant glioma occurred in one rat in the 6 W/kg group but none in the sham controls.

In male rats exposed to CDMA-modulated cell phone RF radiation for two years, there was an increased incidence of malignant glioma with a statistically significant trend, $P=0.044$. In females, three malignant glioma occurred in the 1.5 W/kg group, but none in the other exposed groups or the sham control (P -value for trend =0.384). Glial cell hyperplasia was observed in most exposed groups, although this was not statistically significant (noted in text; P -value for trend not presented in NTP table).

Evaluation. Based on human epidemiological studies supported by the NTP animal study, there is clear evidence that RF radiation causes glioma in humans. There is also

Table I. Numbers of exposed cases (Ca) and controls (Co) and odds ratio (OR) with 95% confidence interval (CI) for glioma in case-control studies in the highest category of cumulative use in hours for mobile phone use.

Study (ref.)	All			Ipsilateral		
	Ca/Co	OR	95% CI	Ca/Co	OR	95% CI
Interphone, 2010 (40)						
Cumulative use $\geq 1,640$ h	210/154	1.40	1.03-1.89	100/62	1.96	1.22-3.16
Coureau <i>et al</i> , 2014 (41)						
Cumulative use >896 h	24/22	2.89	1.41-5.93	9/7	2.11	0.73-6.08
Hardell and Carlberg, 2015 (43)						
Cumulative use $\geq 1,640$ h	211/301	2.13	1.61-2.82	138/133	3.11	2.18-4.44
Meta-analysis (40,41,43)						
Cumulative use $\geq 1,640$ h ^a	445/477	1.90	1.31-2.76	247/202	2.54	1.83-3.52

^a ≥ 896 h used for Coureau *et al*.

Table II. Numbers of exposed cases (Ca) and controls (Co) and odds ratio (OR) with 95% confidence interval (CI) for meningioma in case-control studies in the highest category of cumulative use in hours for mobile phone use.

Study (ref.)	All			Ipsilateral		
	Ca/Co	OR	95% CI	Ca/Co	OR	95% CI
Interphone, 2010 (40)						
Cumulative use $\geq 1,640$ h	130/107	1.15	0.81-1.62	46/35	1.45	0.80-2.61
Coureau <i>et al</i> , 2014 (41)						
Cumulative use >896 h	13/9	2.57	1.02-6.44	6/4	2.29	0.58-8.97
Carlberg and Hardell, 2015 (56)						
Cumulative use $\geq 1,640$ h	141/301	1.24	0.93-1.66	67/133	1.46	0.98-2.17
Meta-analysis (40,41,56)						
Cumulative use $\geq 1,640$ h ^a	284/417	1.27	0.98-1.66	119/172	1.49	1.08-2.06

^a ≥ 896 h used for Coureau *et al*.

evidence of an increased glioma risk in occupational studies on exposure to EMF (52-54).

Meningioma

Human studies. Meningioma is an encapsulated, well-demarcated and rarely malignant tumor. It is the most common non-malignant brain tumor that accounts for approximately 30% of intracranial neoplasms. It develops from the pia and arachnoid membranes that cover the CNS. It is slow-growing and presents neurological symptoms by the compression of adjacent structures. Most common are headaches and seizures. The incidence is greater than two-fold higher in women than in men and meningioma develops mostly among middle-aged and older individuals (55). The same research groups as for glioma also included meningioma in their case-control studies with a separate publication on meningioma by Carlberg and Hardell (56). The results of the meta-analyses for cumulative exposure in highest exposure category are presented in Table II. A statistically significant

increased risk was obtained for ipsilateral mobile phone use with OR =1.49, 95% CI =1.08-2.06.

NTP study. No increased incidence of meningioma was reported in rats or mice (19,20).

Granular cell tumors (GCTs)

Human studies. GCTs are uncommon tumors. They are believed to be of neuronal origin (57). They are soft tissue tumors, which are thought to be derived from Schwann cells (58). The immunoprofile of granular cell tumors has revealed nerve sheath differentiation, lending support to their neuronal origin (59). GCTs can affect any organ in the body, although approximately 50% are found in the head and neck region (60). In our case-control studies on brain tumors, all diagnoses were based on a histopathological examination; no one was diagnosed with a granular cell tumor (42-46).

NTP study. In the rat study (19), increased incidence of malignant or non-malignant granular cell tumors in the meninges, likely derived from Schwann cells, occurred in the

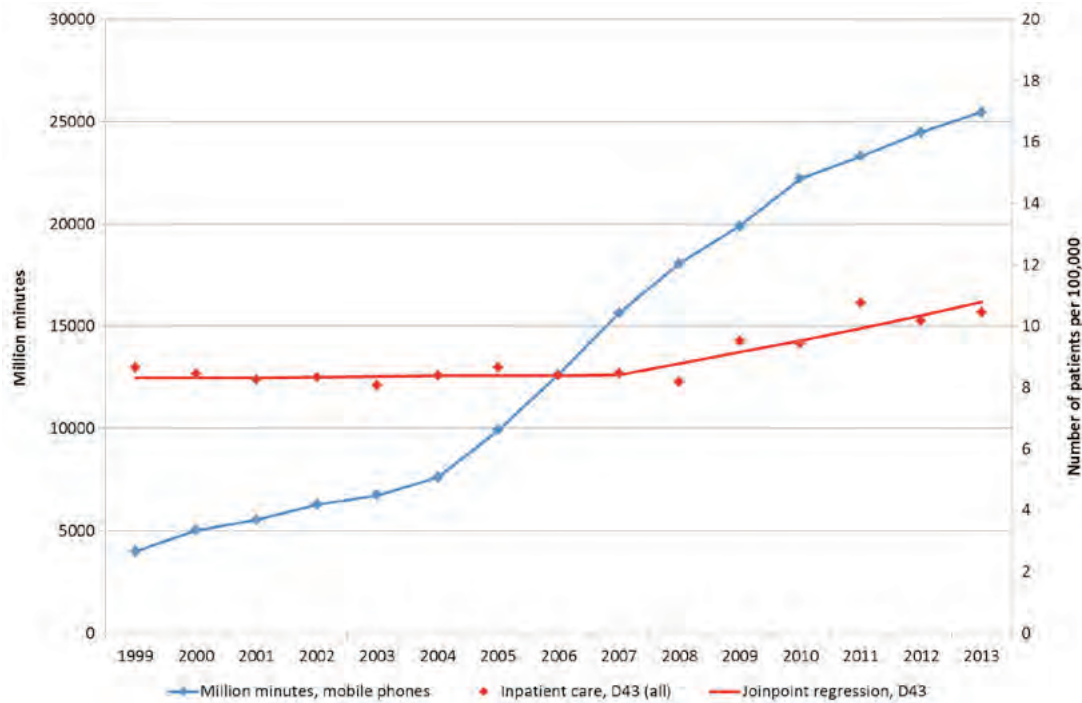


Figure 1. Number of out-going mobile phone minutes in millions during the period between 1999-2013 (<http://statistik.pts.se/pts2013/download/Svensk%20Telemarknad%202013.pdf>; accessed on April 1, 2015) and joinpoint regression analysis of number of patients per 100,000 inhabitants according to the Swedish National Inpatient Register for all ages during the period between 1999-2013 diagnosed with D43 = tumor of unknown type in the brain or CNS (<http://www.socialstyrelsen.se/statistik/statistikdatabas/diagnoserislutenvard>; accessed on April 1, 2015).

males exposed to GSM-modulated cell phone RF radiation for two years. This was not statistically significant (P-value for trend =0.343). In female rats, granular cell tumors, either malignant or non-malignant were not associated with RF radiation (P-value for trend =0.594). Since GCT is neuronal in origin, the NTP study findings in male rats add to the evidence that exposure to RF radiation damage nerve sheaths.

Evaluation. Based on human epidemiological studies and the NTP animal study, there is equivocal evidence that RF radiation causes meningeal tumors in humans (may be related to exposure).

Rate/incidence of brain tumors. The Swedish Cancer Register has not shown increasing incidence of brain tumors in a study for the time period between 1979-2008, and has been used to dismissing epidemiological evidence on risk associated with use of wireless phones (61). We have previously demonstrated that descriptive studies cannot be used to dismiss results in analytical epidemiology with individual exposure histories, such as in case-control studies. We have also published the deficiencies in the reporting of brain tumors to the Swedish Cancer Register (62). The results for more recent time periods have now been published. These articles also discuss results from studies in other countries.

We used the Swedish National Inpatient Register (IPR) and Causes of Death Register (CDR) to study the incidence of brain tumors comparing with the Swedish Cancer Register data for the time period between 1998-2013 using joinpoint regression analysis (62). In the IPR, we found a joinpoint in 2007 with Annual Percentage Change (APC) +4.25%, 95% CI +1.98, +6.57% during the period between 2007-2013 for tumors of unknown type in the brain or CNS. Fig. 1 shows time trends

in IPR for brain tumors of unknown type (D43), red line, and mobile phone communication; number of out-going mobile phone minutes in millions per year (blue line). The figure shows increasing rates of brain tumors with some latency in relation to the increasing use of mobile phones.

In the CDR joinpoint regression, we found one joinpoint in 2008 with APC during the period between 2008-2013, +22.60%, 95% CI +9.68, +37.03%. These tumor diagnoses would be based on clinical examination, mainly CT and/or MRI, but without histopathology or cytology. No statistically significant increasing incidence was found in the Swedish Cancer Register during these years. We postulated that a large part of brain tumors of unknown type are never reported in the Cancer Register. Furthermore, the frequency of diagnoses based on autopsy has declined substantially due to a general decline of autopsies in Sweden, further adding to missing cases. We concluded that the Swedish Cancer Register is not reliable to be used to dismiss results in epidemiological studies on the use of wireless phones and brain tumor risk.

In Fig. 2, we present the rates per 100,000 of deaths in unknown type of brain tumor (D43), red line, and number of out-going mobile phone minutes in millions (blue line) during the period between 1999-2013. We postulate that the increasing rate of patients deceased with brain tumor may be associated with the increasing use of mobile phones.

In an updated further analysis, we used the Swedish IPR to analyze rates of brain tumors of unknown type (D43) during the period between 1998-2015 in different age groups (63). The Average Annual Percentage Change (AAPC) per 100,000 increased with +2.06%, 95% CI +1.27, +2.86% in both sexes combined. A joinpoint was found in 2007 with APC 1998-2007 of +0.16%, 95% CI -0.94, +1.28%, and 2007-2015 of +4.24%,

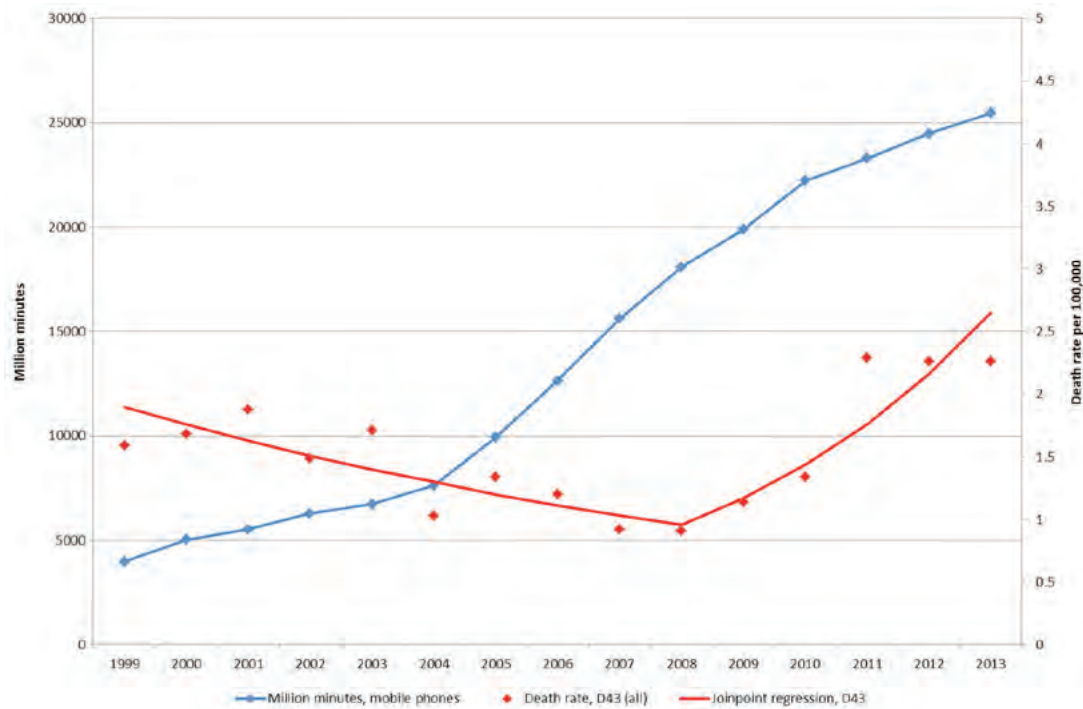


Figure 2. Number of out-going mobile phone minutes in millions during the period between 1999-2013 (<http://statistik.pts.se/pts2013/download/Svensk%20Telemarknad%202013.pdf>; accessed on April 1, 2015) and joinpoint regression analysis of age-standardized death rates per 100,000 inhabitants according to the Swedish Causes of Death Register for all ages during the period between 1999-2013 diagnosed with D43 = tumor of unknown type in the brain or CNS (<http://www.socialstyrelsen.se/statistik/statistikdatabas/dodsorsaker>).

95% CI +2.87, +5.63%. The highest AAPC was found in the age group of 20-39 years.

In the Swedish Cancer Register, the age-standardized incidence rate per 100,000 increased for brain tumors, ICD-code 193.0, during 1998-2015 with AAPC in men +0.49%, 95% CI +0.05, +0.94%, and in women +0.33%, 95% CI -0.29, +0.45% (63). The cases with brain tumor of unknown type lack morphological examination. Brain tumor diagnoses in the Cancer Register were based on cytology/histopathology in 83% for men and in 87% for women in 1980. This frequency increased to 90% in men and 88% in women in 2015. During the same time period, CT and MRI imaging techniques were introduced and morphology is not always necessary for diagnosis. If all brain tumors based on clinical diagnosis with CT or MRI had been reported to the Cancer Register the frequency of diagnoses based on cytology/histology would have decreased in the register. The results indicate underreporting of brain tumor cases to the Cancer Register. The real incidence would be higher. Thus, incidence trends based on the Cancer Register should be used with caution. Our results support mobile and cordless phones as risk factors for brain tumors with a reasonable latency period.

Fig. 3 shows joinpoint regression analyses of age-standardized incidence rates per 100,000 in men aged 60-79 years with astrocytoma grade III or IV in the Swedish Cancer Register during the period between 1998-2015, and Fig. 4 shows results in women (63).

Interestingly, a recent study demonstrated a similar increase in glioblastoma multiforme in England as in Sweden (64), 'We report a sustained and highly statistically significant ASR [age-standardized incidence rates] rise in glioblastoma multiforme (GBM) across all ages. The ASR for GBM more

than doubled from 2.4 to 5.0, with annual case numbers rising from 983 to 2531. Overall, this rise is mostly hidden in the overall data by a reduced incidence of lower-grade tumours.'

Evaluation. Increasing rates/incidences of brain tumors in Sweden, a country with among the earliest use of wireless phones in the world, have been published. Similar findings have been reported from other countries, see above and reviewed by us (62). The results have strengthened the evidence that RF radiation causes brain tumors in humans.

Acoustic neuroma (vestibular schwannoma)

Human studies. Acoustic neuroma, also known as vestibular schwannoma, is a non-malignant tumor located on the eighth cranial nerve from the inner ear to the brain. It is usually encapsulated and grows in relation to the auditory and vestibular portions of the nerve. It grows slowly and due to the narrow anatomical space, may lead to the compression of vital brain stem structures. The first symptoms of acoustic neuroma are usually tinnitus and hearing problems. The results for the use of mobile phones in the Interphone (65) and Hardell *et al* (66) studies are presented in Table III. A statistically significant increased risk was found for cumulative ipsilateral use >1,640 h yielding an OR of 2.71, 95% CI of 1.72-4.28.

The study by Moon *et al* (67) was not included in the meta-analysis, since the data on cumulative mobile phone use with numbers of cases and controls were not given. Support of an increased risk was found in the case-case part of the study (67), as also reported by Sato *et al* (68) in their case-case analysis. Pettersson *et al* made a case-control study on acoustic neuroma in Sweden not overlapping our study (69). An increased risk for the highest category of cumulative use

Table III. Numbers of exposed cases (Ca) and controls (Co) and odds ratio (OR) with 95% confidence interval (CI) for acoustic neuroma in case-control studies in the highest category of cumulative use in hours for mobile phone use.

Study (ref.)	All			Ipsilateral		
	Ca/Co	OR	95% CI	Ca/Co	OR	95% CI
Interphone, 2011 (65)						
Cumulative use $\geq 1,640$ h	77/107	1.32	0.88-1.97	47/46	2.33	1.23-4.40
Hardell <i>et al</i> , 2013 (66)						
Cumulative use $\geq 1,640$ h	27/301	2.40	1.39-4.16	19/133	3.18	1.65-6.12
Meta-analysis (65,66)						
Cumulative use $\geq 1,640$ h	104/408	1.73	0.96-3.09	66/179	2.71	1.72-4.28

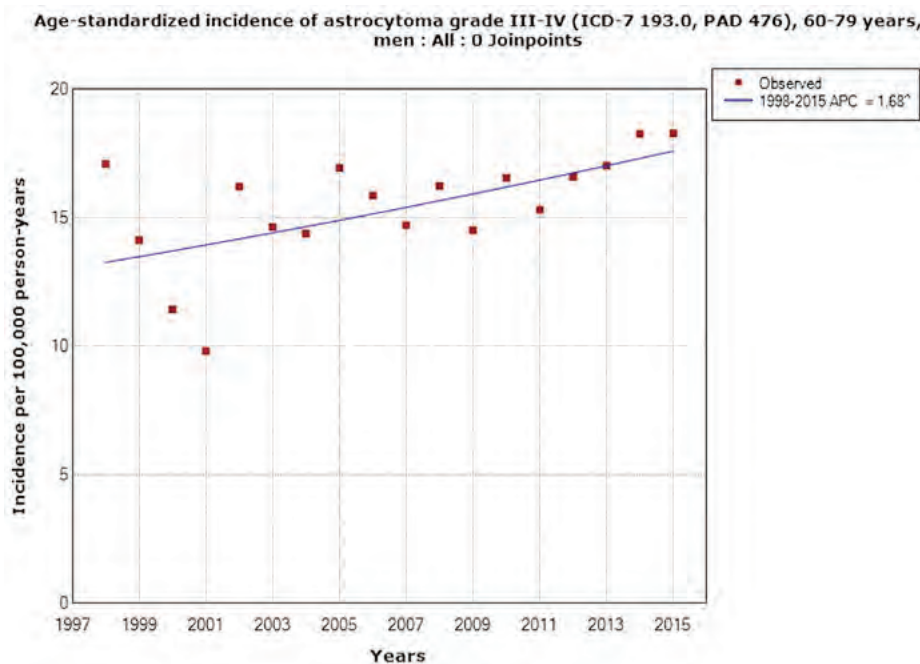


Figure 3. Joinpoint regression analysis of age-standardized incidence rates per 100,000 in men aged 60-79 years with astrocytoma grade III or IV in the Swedish Cancer Register during the period between 1998-2015. APC/AAPC +1.68%, 95% CI +0.39, +2.99% (<http://www.socialstyrelsen.se/statistik/statistik-databas/cancer>).

of both mobile phone (≥ 680 h OR =1.46, 95% CI =0.98-2.17) and cordless phone (≥ 900 h OR =1.67, 95% CI =1.13-2.49) was found. We did not include that study in our meta-analysis due to the many scientific shortcomings in the study, e.g., laterality analysis was not made for cordless phone and the numbers in the laterality analysis for mobile phone are not consistent in text and tables and obviously not correct, and the 'unexposed' reference category included subjects using either mobile or cordless phone (70).

The Danish part of the Interphone study reported a mean tumor volume of 1.66 cm³ among regular mobile phone users and 1.39 cm³ for non-users ($P=0.03$) (71). We analyzed the percentage change in tumor volume per year of latency and 100 h of cumulative use (66). For all types of wireless phones, the percentage of tumor volume increased, and was statistically significant for analogue mobile phones per year of latency ($P=0.02$) and per 100 h of cumulative use ($P=0.01$). Moon *et al* (67) reported a statistically significant larger mean

tumor volume for heavy users (11.32 ± 15.43 cm³) compared with light users (4.88 ± 5.60 cm³) based on the daily amount of mobile phone use ($P=0.026$). Similar results were found for cumulative hours of use. Taken together, these results support tumor promotion by RF radiation.

NTP study. No malignant schwannoma was reported in the mouse study (20).

In the rat study (19), there was a statistically significant increased incidence of malignant schwannoma in the heart of males exposed to GSM modulated cell phone RF radiation for 2 years; P -value for trend =0.041. The tumor was found in all exposure categories for male rats, whereas no malignant schwannoma was found in the sham controls. Endocardial hyperplastic Schwann cell lesions, that are preneoplastic, were found in one 1.5 W/kg and in two 6 W/kg males, but not in the sham control. A statistically significant trend was found in CDMA-modulated exposed males, $P=0.011$. Two female rats were diagnosed with malignant schwannoma in the heart

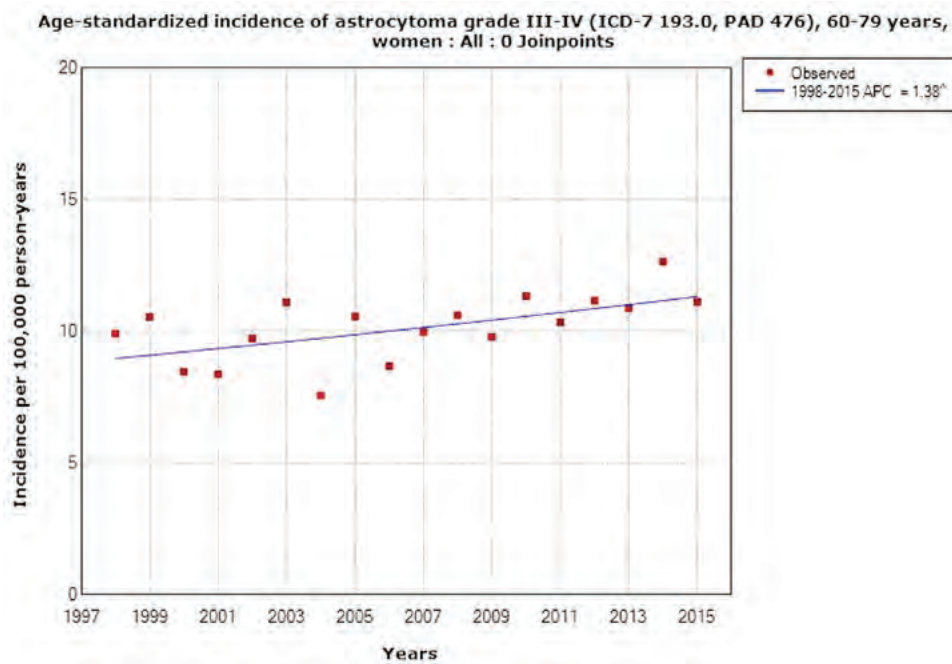


Figure 4. Joinpoint regression analysis of age-standardized incidence rates per 100,000 in women aged 60-79 years with astrocytoma grade III or IV in the Swedish Cancer Register during the period between 1998-2015. APC/AAPC +1.38%, 95% CI +0.32, +2.45% (<http://www.socialstyrelsen.se/statistik/statistik-databas/cancer>).

in the 3 W/kg group, but no malignant schwannomas were found in the two other exposure groups or in the sham control, P -value for trend =0.640.

Evaluation. Based on human epidemiological studies and the NTP animal study, there is clear evidence that RF radiation causes vestibular schwannoma (acoustic neuroma) in humans.

Pituitary tumors

Human studies. In a case-control study from Japan, no statistically significant increased risks were found for the use of mobile phone (72). A somewhat increased risk was found in the highest cumulative call time in hours, OR =1.33, 95% CI =0.58-3.09. The cases were aged 30-69 years and diagnosed during the period between 2000-2004.

In a UK case-control study with patients diagnosed during the period between 2001-2005, overall no statistically significant increased risks were found (73). In the group with ≥ 10 years of use a somewhat increased risk was found for analog mobile phone use: OR =1.2, 95% CI =0.6-2.4, and digital mobile phone use with OR =2.5, 95% CI =0.7-9.1.

In a case-control study from China with cases diagnosed between 2006-2010, mobile phone use yielded an increased risk for pituitary tumor: OR =7.6, 95% CI =2.6-21.4 and a duration of use yielded OR =8.5, 95% CI =2.8-24.4 (74). However, no more data were provided.

The incidence of pituitary tumors increased during the time period between 2004-2009 in the USA (75). The incidence is increasing in Sweden, particularly since 2000, as shown in Fig. 5. There seems to be a decrease during the latest year, but this may be explained by a time lag in the reporting to the Swedish Cancer Register.

NTP study. In male mice (20) exposed to CDMA-modulated RF radiation for two years, two adenoma and one carcinoma

occurred in the pars distalis of the pituitary gland. No carcinoma or adenoma occurred in the sham control or the other two exposure groups. No increased incidence was found in female mice.

In male rats exposed to GSM-modulated cell phone RF radiation for two years (19), an increased incidence of pituitary adenoma was found in all exposed groups, although no statistically significance was found (P -value for trend =0.301). In females, the incidence of adenoma in 1.5 and 6 W/kg was statistically significantly decreased (1.5 W/kg P =0.049; 6 W/kg P =0.038).

In male rats exposed to CDMA-modulated RF radiation for two years, an increased incidence of pituitary adenoma was found in the 1.5 W/kg (P =0.208) and 3 W/kg (P =0.030). In females there was a statistically significantly decreased incidence of adenoma or carcinoma in the 3 W/kg group (P =0.030).

Evaluation. Based on human epidemiological studies and the NTP animal study, there is equivocal evidence that RF radiation causes pituitary tumors in humans (may be related to exposure).

Thyroid cancer

Human studies. The incidence of thyroid cancer is increasing in many countries, particularly the papillary type that is the most radiosensitive type. We used the Swedish Cancer Register to study the incidence of thyroid cancer during the period between 1970-2013 using joinpoint regression analysis (31). In women, the incidence increased statistically significantly during the whole study period; AAPC +1.19% (95% CI +0.56, +1.83%). Two joinpoints were detected, 1979 and 2001, with a high increase of the incidence during the last period between 2001-2013 with an APC of +5.34% (95% CI +3.93, +6.77%).

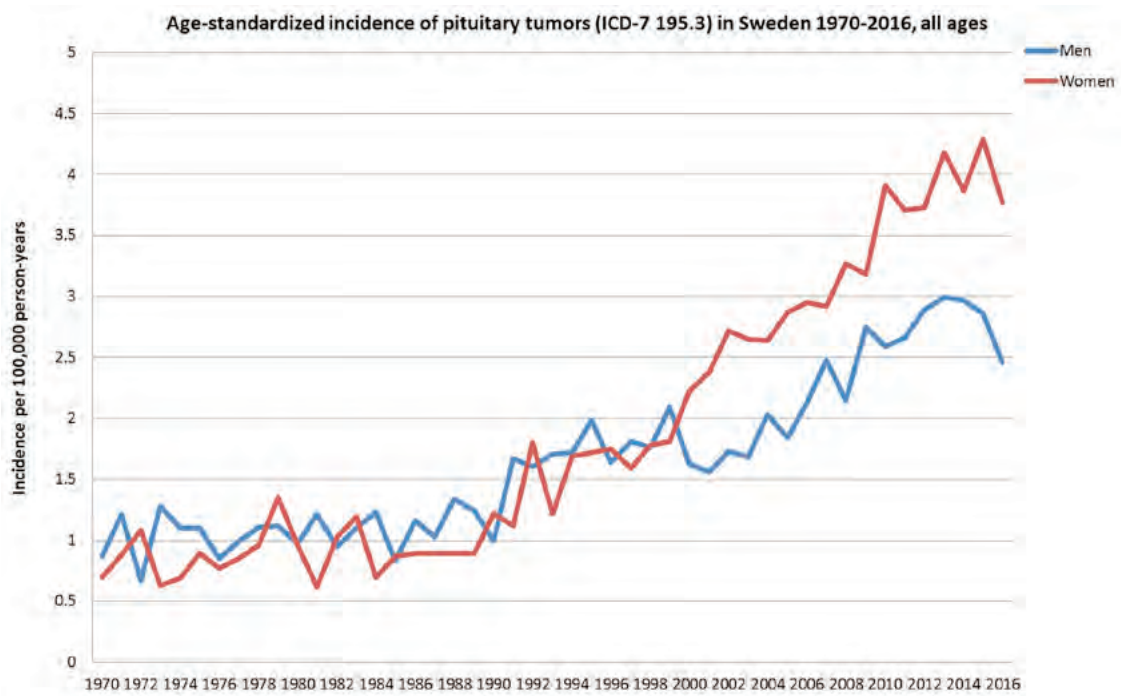


Figure 5. Age-standardized incidence of pituitary tumors (ICD-7 195.3) in Sweden between 1970-2016 for men and women, all ages, according to the Swedish Cancer Register (<http://www.socialstyrelsen.se/statistik/statistikdatabas/cancer>).

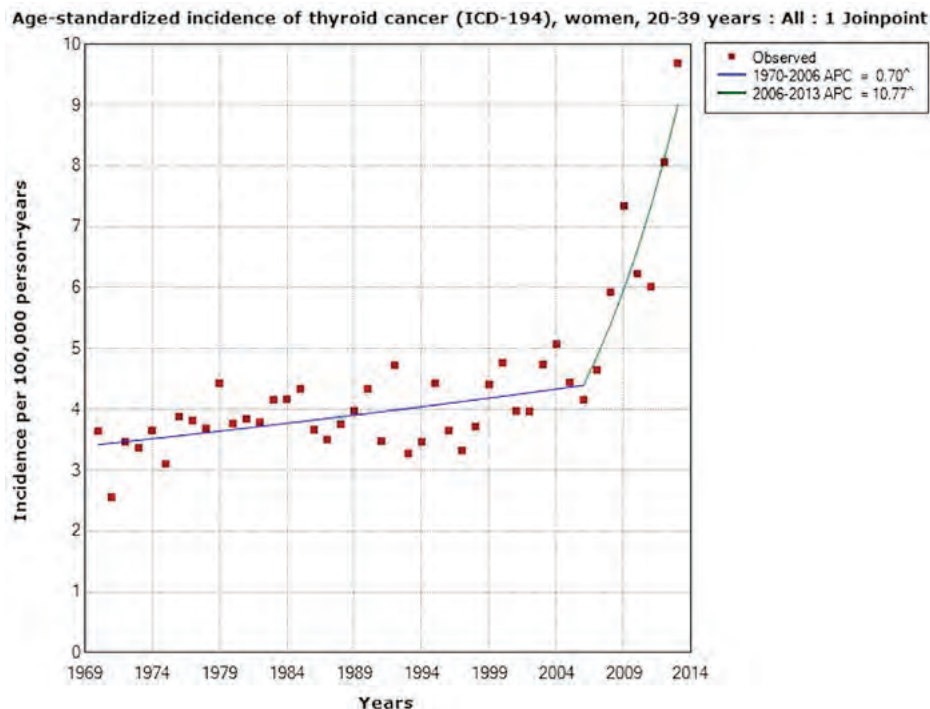


Figure 6. Jointpoint regression analysis of age-standardized incidence of thyroid cancer for women, aged 20-39 years, 1970-2013. Incidence per 100,000 inhabitants for ICD-7 code 194 according to the Swedish Cancer Register (<http://www.socialstyrelsen.se/statistik/statistikdatabas/cancer>).

In the age group of 20-39 years, jointpoint regression analysis of age-standardized incidence of thyroid cancer in women, aged 20-39 years, APC increased with +10.77% (95% CI +5.75, +16.04%) during the time period between 2006-2013 (Fig. 6).

Analyses based on data from the Cancer Register indicated that the increasing trend in Sweden was mainly caused by thyroid cancer of the papillary type. The incidence

increased statistically significantly in women with an AAPC of +4.38% (95% CI +2.95, +5.84%) during the period between 1993-2013 (Fig. 7). One jointpoint was detected in 2006; 1993-2006 APC +1.69% (95% CI +0.32, +3.08%), 2006-2013 APC +9.58% (95% CI +5.85, +13.44%). The incidence of papillary cancer increased in men during the period between 1993-2013 with an AAPC of +3.95% (95% CI +2.20, +5.73%).

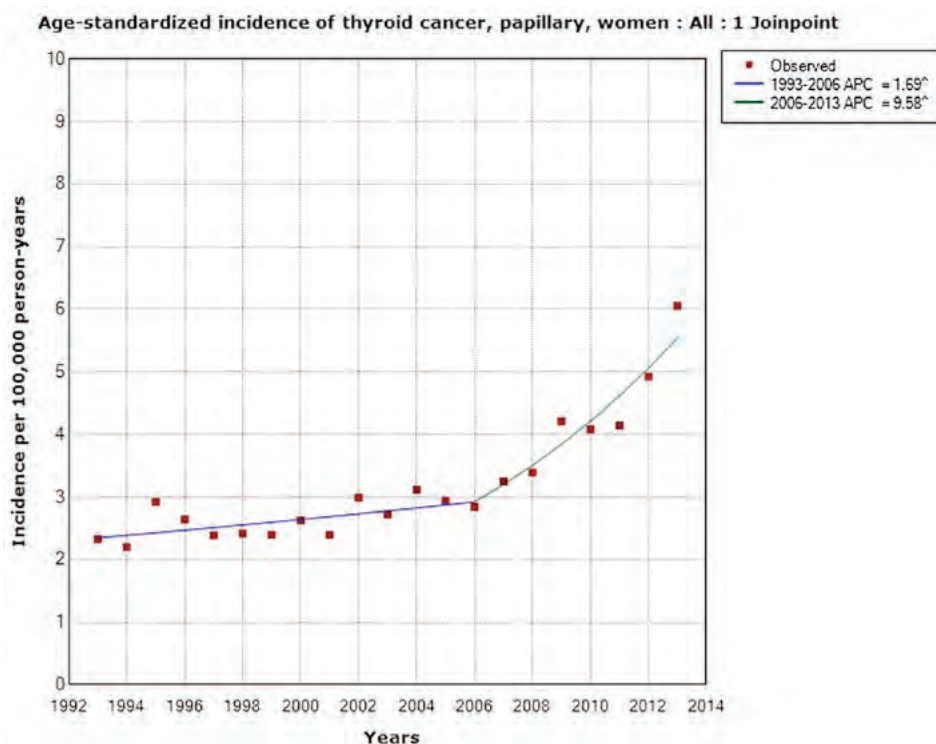


Figure 7. Joinpoint regression analysis of age-standardized incidence of papillary thyroid cancer for women, all ages, 1993-2013. Incidence per 100,000 inhabitants for ICD-7 code 194; data obtained from the Swedish Cancer Register.

AAPC for thyroid cancer in all men during the period between 1970-2013 was +0.77% (95% CI -0.03, +1.58%). One joinpoint was detected in 2005 with a statistically significant increase in incidence during the period between 2005-2013; APC +7.56% (95% CI +3.34, +11.96%). Based on the NORDCAN data, there was a statistically significant increase in the incidence of thyroid cancer in the Nordic countries during the same time period. In both women and men a joinpoint was detected in 2006. The incidence increased during 2006-2013 in women; APC +6.16% (95% CI +3.94, +8.42%) and in men; APC +6.84% (95% CI +3.69, +10.08%), thus showing similar results as in the Swedish Cancer Register (31).

We postulate that the whole increase cannot be attributed to better diagnostic procedures. In Fig. 8 data from the Nordic countries are shown on number of out-going mobile phone minutes during the period between 2001-2013 and the incidence of thyroid cancer in men (green line) and in women (red line). Clearly, with a lag time of some years after the increasing number of out-going calls, the thyroid cancer incidence is increasing.

Increasing exposure to ionizing radiation, e.g., medical CT scans, and to RF radiation should be further studied as causative factors to this emerging thyroid cancer health problem.

Fig. 9 presents three developments in the antenna design in mobile phones that may be of relevance in thyroid carcinogenesis. The second generation (2G) mobile phones appeared in the 1990s with the external retractable monopole or helical antennas. The 2G GSM band operated at a 800/900 MHz frequency band, later accompanied by a 1,800 MHz band. Around the turn of the millennium, the external antennas began to disappear, replaced with new phone models with

internal planar or microstrip antennas. The first internal antenna was introduced in 1998 and the first dual-band mobile phone, with the internal antenna, was introduced on the market in 1999 (76). The internal antennas were positioned at the top of the telephone. With the emergence of the smartphones in the mid- and late 2000s, the internal antenna location started to shift from the top of the phone to the bottom. Currently, the majority of smartphone models have their antenna positioned at the bottom of the phone, thus closer to the thyroid gland (shown by grey color in Fig. 9). This would have a major impact on increasing radiation to the thyroid gland from smartphones.

Some published laboratory studies are of interest. Radiofrequency radiation at 2.45 GHz at a non-thermal level modified the morphology of the thyroid gland in a study on rats. The central and peripheral follicles presented increased in size and the thickness of peripheral septa decreased. Peripheral follicles increased in size with repeated exposure at 3 W power (77).

In another study on rats, whole body exposure to 900 MHz pulse-modulated RF radiation that was similar to that emitted by the global system for mobile communications (GSM) mobile phones caused pathological changes in the thyroid gland. The gland structure was altered and caspase-dependent pathways of apoptosis were enhanced (78).

NTP study. In mice (20) no increased incidence was reported.

In female rats (19) a statistically significant increased incidence of C-cell hyperplasia was found in the two years of GSM-exposed groups (1.5, 3 and 6 W/kg, respectively). In males, a statistically non-significant increased incidence was observed in the 1.5 W/kg exposure group (noted in text; P-value not given in NTP table).

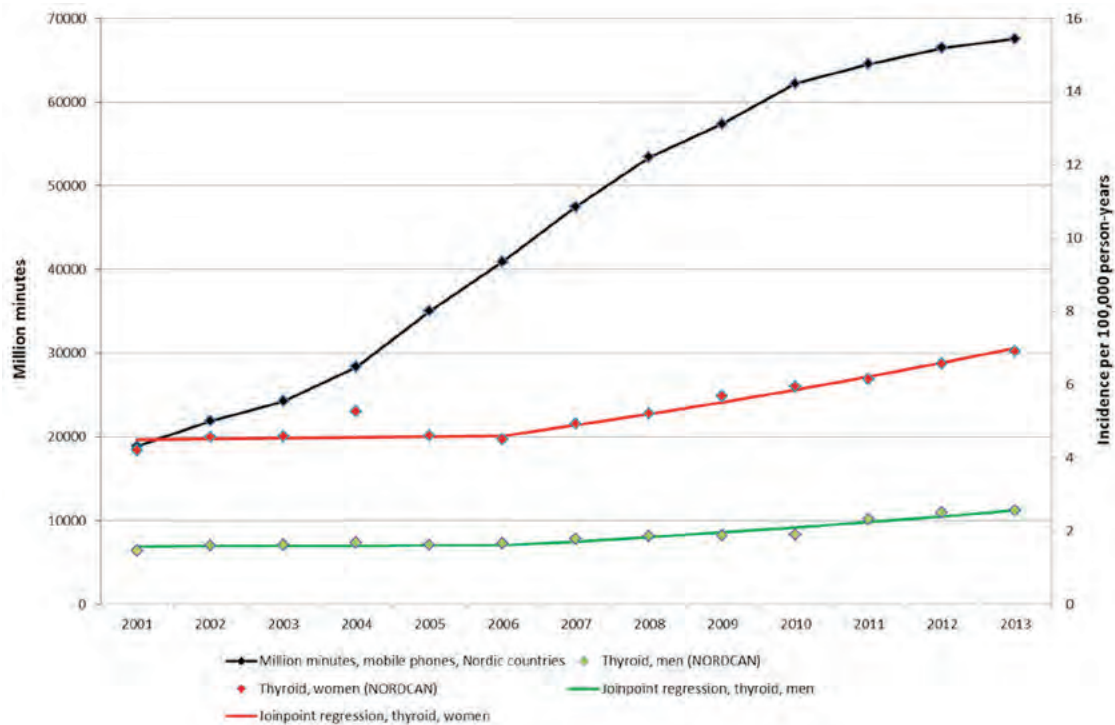


Figure 8. Number of out-going mobile phone minutes and incidence of thyroid cancer 2001-2013. Mobile phone minutes in millions in the Nordic countries (<http://statistik.pts.se/PTSnordic/NordicBaltic2014/>) and incidence per 100,000 person-years for all ages 2001-2013 according to NORDCAN (<http://www-dep.iarc.fr/NORDCAN/english/frame.asp>). Joinpoint regression analyses based on the time period between 1970-2013.

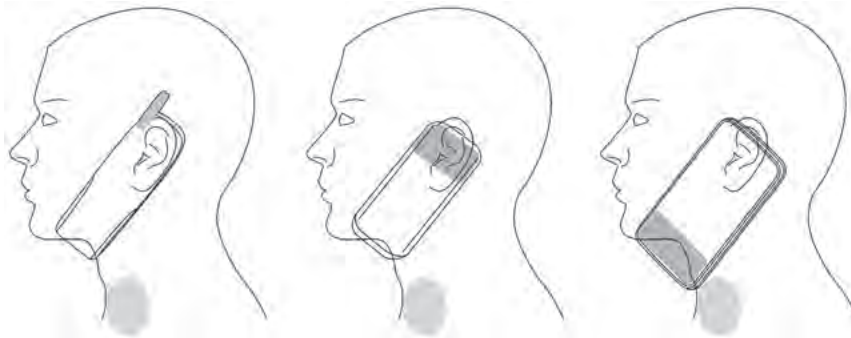


Figure 9. Mobile phone antenna placements in regard to the thyroid gland (grey). Different localizations of the antenna depending on new generations of mobile phones are shown in the panels from left to right.

Evaluation. C-cell hyperplasia as a precursor to familial medullary thyroid cancer in humans is well established. C-cell hyperplasia may be a precursor to other types of thyroid cancer but its role is not well established. Based on human cancer statistics and the NTP animal study, there is some evidence that thyroid cancer is caused by RF radiation in humans.

Malignant lymphoma

Human studies. Few studies exist on malignant lymphoma and exposure to RF radiation. In a case-control study male and female subjects aged 18-74 years living in Sweden were included during a period from December 1, 1999 to April 30, 2002 (27). Controls were selected from the national population registry. Exposure to different agents was assessed by a questionnaire. In total, 910 (91%) cases and 1,016 (92%) controls participated. NHL of the B-cell type was not associated with

the use of cellular or cordless telephones. As regards T-cell NHL and the >5 year latency period, the use of analogue cellular phones yielded: OR =1.46, 95% CI =0.58-3.70; digital: OR =1.92, 95% CI =0.77-4.80; and cordless phones: OR =2.47; 95% CI =1.09-5.60. The corresponding results for certain lymphoma, e.g., of the cutaneous and leukemia types, were for analogue phones: OR =3.41, 95% CI =0.78-15.0; digital: OR =6.12, 95% CI =1.26-29.7; and cordless phones: OR =5.48, 95% CI =1.26-23.9. The results indicate an association between T-cell NHL and the use of cellular and cordless telephones; however, the study was based on low numbers and must be interpreted with caution. As regards B-cell NHL, no association was found.

A case-control study in USA used a questionnaire to assess cellular telephone use in 551 NHL cases and 462 frequency-matched population controls (28). Compared to persons who had never used cellular telephones, risks

were not increased among individuals whose lifetime use was >100 times (e.g., regular users, OR =0.9, 95% CI =0.6-1.4). Among regular users compared to those who had never used hand-held cellular telephones, risks of NHL were not statistically significantly associated with minutes per week, duration, cumulative lifetime or year of first use, although NHL was non-significantly higher in men who used cellular telephones for >8 years; OR =2.4, 95% CI =0.8-7.0. NHL not otherwise specified was statistically significantly increased in men for mobile phone use among subjects with ≥ 6 years duration, OR =4.4, 95% CI =1.3-14.6. There was little evidence to link the use of cellular telephones with total, diffuse large B-cell lymphoma or follicular NHL. No results were presented for T-cell lymphoma.

In the USA, primary central nervous system lymphoma (PCNSL) rates in immunocompetent men and women aged 65+ years increased statistically significantly (1.7 and 1.6% per year, respectively), but remained stable in other age groups during the period between 1992-2011 (79). Thus, the increasing rates could not be related to HIV or immune suppression in organ transplant patients.

In Sweden, the increasing incidence of PCNSL was reported for the time period between 2000-2013 in immunocompetent persons (80). With 359 identified PCNSL cases (median age, 66 years), the overall incidence was 0.26 (95% CI =0.24-0.29) per 100,000 person-years and the average annual increase 4% ($P=0.002$). The increasing trend was primarily observed among elderly individuals (70+ years). Similarly, an increase in incidence of all brain tumors was noted only among the elderly.

No etiological factor has clearly been defined to explain the increasing incidence of brain lymphoma. However, it has occurred during a time period when RF radiation to the brain from wireless phones has increased.

It should be noted that in transgenic mice, an increased incidence of lymphoma exposed to 900 MHz GSM RF radiation was reported; $P=0.006$ versus the sham group (25). No increased risk of malignant lymphoma was found in mice exposed to GSM 900 MHz in another study (26). However, the incidence in the sham exposed group was higher in the study by Utteridge *et al* (26) compared with the study by Repacholi *et al* (25) which might have influenced the results.

NTP study. In female mice exposed to GSM-modulated cell phone RF radiation for two years, there were increased incidences of malignant lymphoma in all exposed groups compared to the controls (20). The increase was statistically significant in the 2.5 W/kg ($P=0.004$) and 5 W/kg groups ($P=0.035$). In the CDMA-modulated cell phone RF radiation for two years, the incidence increased in female mice in all exposed groups compared to the controls, and was statistically significant in the 2.5 W/kg group ($P=0.035$).

No conclusive evidence of increased incidence of malignant lymphoma was reported in female rats (19); P -value for trend =0.537 for GSM-modulated cell phone RF radiation and P -value for trend =0.339 for CDMA-modulated cell phone RF radiation.

Evaluation. Based on human epidemiological studies and the NTP study, there is equivocal evidence that malignant lymphoma is caused by RF radiation in humans (may be related to exposure).

Skin (cutaneous tissue)

Human studies. Few studies exist on RF radiation and the risk of developing skin tumors. In a Danish cohort on mobile phone subscribers from the period between 1987-1995 followed to 2007, no increased risks of skin cancer were observed (81). The same cohort has also been used for studying brain tumor risk. Due to serious methodological problems, including the misclassification of exposure the study has been evaluated to be uninformative (8,37).

In a Swedish study on cutaneous malignant melanoma diagnosed during the period between 2000-2003, no increased risk was observed overall (82). In the shortest latency period of >1-5 years and highest cumulative use of >365 h, wireless phone use (mobile phone and/or cordless phone) yielded OR =1.6, 95% CI =0.96-2.9. For melanoma in the most exposed anatomical area during use of the handheld phone, temporal, ear, cheek, the risk increased to OR =2.1, 95% CI =1.1-3.8. The risk was overall highest for cases with first use of a wireless phone before 20 years of age, OR =2.7, 95% CI =0.6-12, although based on low numbers. No interaction was observed with known risk factors for malignant melanoma, such as hair and eye color, skin type or sunburns as a teenager.

Fig. 10 displays the rapidly increasing incidence of malignant melanoma in Sweden in both sexes. The increase is most marked from early 2000.

NTP study. The incidences of malignant fibrous histiocytoma in the skin were higher in 5 and 10 W/kg male mice exposed to GSM-modulated cell phone RF radiation for two years (20). The results were not statistically significant (5 W/kg $P=0.124$; 10 W/kg $P=0.321$). The incidences of fibrosarcoma, sarcoma or malignant fibrous histiocytoma were higher in exposed male mice compared with sham control, although border-line significant, P -value for trend =0.093. No increased incidence was observed in female mice.

Male rats exposed to GSM-modulated cell phone RF radiation for two years (19) exhibited higher incidences of fibroma, fibrosarcoma, myxosarcoma, or malignant fibrous histiocytoma in the skin (subcutaneous tissue) in all exposed groups. The increased rates were not statistically significant (P -value for =0.428). No statistically significant results were found in female rats (P -value for trend =0.551).

Evaluation. Based on human epidemiological studies and NTP animal studies there is equivocal evidence that RF radiation causes skin cancer in humans (may be related to exposure).

Concluding remarks. Based on case-control studies, as discussed above, there is a consistent finding of an increased risk of developing glioma and acoustic neuroma associated with the use of mobile phones. Similar results are found for cordless phones in the Hardell group studies. These results are supported by the results of the NTP animal studies (19,20). Malignant vestibular schwannoma is a similar tumor type as acoustic neuroma, also known as vestibular schwannoma.

The findings are less consistent for meningioma although somewhat an increased risk was observed in the meta-analysis of ipsilateral mobile phone use. A longer follow-up time is necessary for this type of slow-growing tumor.

The results on glioma and acoustic neuroma are supported by results from other animal studies showing

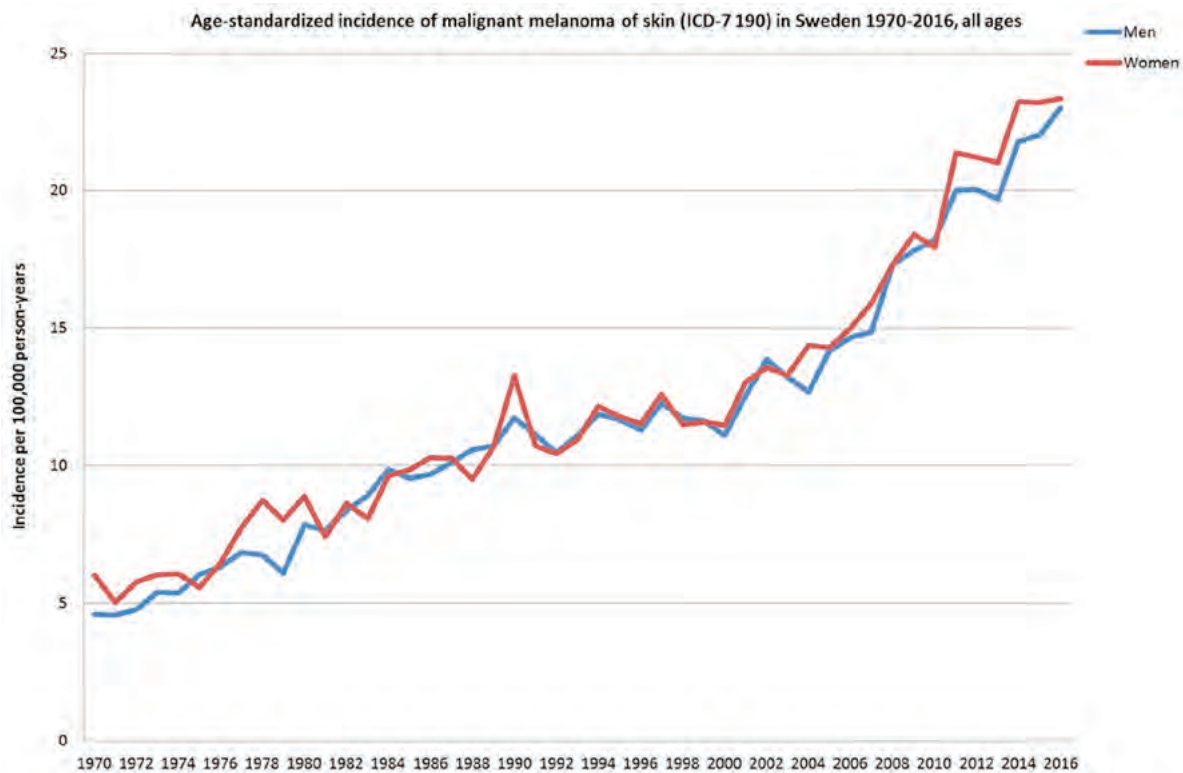


Figure 10. Age-standardized incidence of malignant melanoma (ICD-7 190) in Sweden between 1970-2016 for men and women, all ages, according to the Swedish Cancer Register (<http://www.socialstyrelsen.se/statistik/statistikdatabas/cancer>).

carcinogenic and/or tumor promoting effects from RF radiation (21-25,32-34). The NTP study showed genotoxicity of RF radiation in rats and mice exposed to RF radiation (83). That result supports previous findings of DNA strand breaks in rat brain cells exposed to RF radiation (84).

One mechanism in carcinogenesis may be oxidative stress with the production of reactive oxygen species (ROS), as summarized by Yakymenko *et al* (85). This could be an indirect mechanism for the increased brain and head tumor risk since ROS may lead to DNA damage (86).

By now carcinogenicity has been shown in human epidemiological studies, which has been replicated in animal studies. Laboratory studies on RF radiation have shown increased ROS production that can cause DNA damage. In 2013, we published the conclusion that RF radiation should be regarded as a human carcinogen, Group 1 according to the IARC definition, fulfilling Bradford Hill causality criteria (87). This was further supported in our updated article (6). That conclusion is reinforced by the current evaluation.

The evidence that RF radiation exposure is a risk factor for cancer is particularly worrying, taking the present deployment of the fifth generation (5G) for wireless communication. More than 200 scientists and medical doctors have asked for a moratorium until studies have been performed by independent researchers on hazards to human health and the environment (88). These millimeter waves have primarily effects on the skin and eye (89). Sweat ducts in the skin may act as helical antennas and boost RF radiation exposure (90). These findings are worrying, taking the present evaluation that present RF radiation may increase the risk of developing skin cancer.

Discussion

The NTP report uses five categories for the evaluation of RF radiation carcinogenicity as follows:

Clear evidence. Clear evidence of carcinogenic activity is demonstrated by studies that are interpreted as showing a dose-related i) increase of malignant neoplasms; ii) increase of a combination of malignant and benign neoplasms; or iii) marked increase of benign neoplasms if there is an indication from this or other studies of the ability of such tumors to progress to malignancy.

Some evidence. Some evidence of carcinogenic activity is demonstrated by studies that are interpreted as showing a test agent-related increased incidence of neoplasms (malignant, benign, or combined) in which the strength of the response is less than that required for clear evidence.

Equivocal evidence. Equivocal evidence of carcinogenic activity is demonstrated by studies that are interpreted as showing a marginal increase of neoplasms that may be test agent related.

No evidence. No evidence of carcinogenic activity is demonstrated by studies that are interpreted as showing no test agent-related increases in malignant or benign neoplasms.

Inadequate study. Inadequate evidence of carcinogenic activity is demonstrated by studies that, due to major qualitative or quantitative limitations, cannot be interpreted as valid

Table IV. National Toxicology Program (NTP) Cell Phone Radiation 2-Year Study Evaluation of Carcinogenicity of Cell Phone Radiation: NTP Draft Technical Reports (TR 595, TR 596) vs. Expert Panel Vote.^a

Animal	Sex	Cell phone modulation	Tumor types and/or location	Evidence of carcinogenicity	
				NTP draft report	Expert panel (vote yes-no-abstention)
Rat	Male	GSM ^b	Heart: Schwannoma	Some evidence	Clear evidence (8-3)
Rat	Male	CDMA ^c	Heart: Schwannoma	Some evidence	Clear evidence (8-3)
Rat	Male	GSM	Brain: Glioma	Equivocal	Some evidence (7-4)
Rat	Male	CDMA	Brain: Glioma	Equivocal	Some evidence (6-4-1)
Rat	Male	GSM	Brain: Granular cell	Equivocal	Equivocal (11-0)
Rat	Male	GSM	Prostate gland	Equivocal	Equivocal (11-0)
Rat	Male	GSM	Pituitary gland	Equivocal	Equivocal (10-1)
Rat	Male	CDMA	Pituitary gland	Equivocal	Equivocal (11-0)
Rat	Male	GSM	Adrenal medulla	Equivocal	Some evidence (6-4-1)
Rat	Male	GSM	Pancreas	Equivocal	Equivocal (11-0)
Rat	Male	CDMA	Liver	Equivocal	Equivocal (11-0)
Rat	Female	GSM	Heart: Schwannoma	No evidence	Equivocal (9-2)
Rat	Female	CDMA	Heart: Schwannoma	No evidence	Equivocal (9-2)
Rat	Female	CDMA	Brain: Glioma	Equivocal	Equivocal (8-3) (4 voted earlier for 'some evidence')
Rat	Female	CDMA	Adrenal medulla	Equivocal	Equivocal (10-0-1)
Mouse	Male	GSM	Skin	Equivocal	Equivocal (8-3)
Mouse	Male	GSM	Lung	Equivocal	Equivocal (11-0)
Mouse	Male	CDMA	Liver	Equivocal	Equivocal (10-1)
Mouse	Female	GSM	Lymphoma	Equivocal	Equivocal (9-2)
Mouse	Female	CDMA	Lymphoma	Equivocal	Equivocal (11-0)

^aJoel M. Moskowitz, School of Public Health, University of California, Berkeley, March 30, 2018 Electromagnetic Radiation Safety (<https://www.saferemr.com/2018/01/national-toxicology-program-peer-public.html>) with courtesy; ^bGSM, global system for mobile communications; ^cCDMA, code-division multiple access.

for showing either the presence or absence of carcinogenic activity.

On March 26-28, 2018, a panel of 11 external scientific experts met to evaluate carcinogenicity of the NTP carcinogenicity studies (<https://factor.niehs.nih.gov/2018/4/feature/feature-2-cell-phone/index.htm>). As shown in Table IV, the carcinogenicity was upgraded for seven tumor types and/or location. Thus for glioma the vote was 'some evidence' in male rats exposed to GSM or CDMA cell modulation. Evidence for heart Schwannoma was found in male rats and was equivocal in female rats, as shown in Table IV. Note that we have herein discussed carcinogenesis only for tumor types with human epidemiological data. It is of interest that animal data indicate also increased incidence for other tumor types and/or locations such as prostate gland, adrenal medulla, pancreas, liver and lung, see also https://ntp.niehs.nih.gov/ntp/about_ntp/trpanel/2018/march/actions20180328_508.pdf.

In contrast to the NTP panel, ICNIRP has made its own evaluation (<https://www.icnirp.org/cms/upload/publications/ICNIRPnote2018.pdf>). They discuss mainly the Schwannoma findings and ignore glial tumors. ICNIRP does not recognize the pattern of increased risk for Schwannoma and glioma in

both animal studies and human epidemiology on RF radiation. They conclude that '*ICNIRP considers that the NTP (2018a, b) and Falcioni et al (2018) studies do not provide a consistent, reliable and generalizable body of evidence that can be used as a basis for revising current human exposure guidelines.*' That conclusion is not based on scientific evidence, but is rather an ad hoc statement.

A recent commentary discussed '*several unfounded criticisms about the design and results of the NTP study that have been promoted to minimize the utility of the experimental data on RFR for assessing human health risks. In contrast to those criticisms, an expert peer-review panel recently concluded that the NTP studies were well designed, and that the results demonstrated that both GSM- and CDMA-modulated RFR were carcinogenic to the heart (schwannomas) and brain (gliomas) of male rats.*' (91).

Our conclusion on RF radiation carcinogenicity is the following based on human epidemiology and supported by animal results in the NTP reports: Glioma, clear evidence; meningioma, equivocal evidence; vestibular schwannoma (acoustic neuroma), clear evidence; pituitary tumor (adenoma), equivocal evidence; thyroid cancer, some evidence; malignant lymphoma, equivocal evidence; skin

(cutaneous tissue), equivocal evidence; multi-site carcinogen, clear evidence.

There is clear evidence that RF radiation causes cancer/tumor at multiple sites, primarily in the brain (glioma) and head (acoustic neuroma). There is also evidence of an increased risk of developing other tumor types. The results are similar in both the NTP studies (19,20) and the Ramazzini Institute findings (34). Based on the IARC preamble to the monographs, RF radiation should be classified as Group 1: The agent is carcinogenic to humans.

'This category is used when there is sufficient evidence of carcinogenicity in humans. Exceptionally, an agent may be placed in this category when evidence of carcinogenicity in humans is less than sufficient but there is sufficient evidence of carcinogenicity in experimental animals and strong evidence in exposed humans that the agent acts through a relevant mechanism of carcinogenicity.' (<http://monographs.iarc.fr/ENG/Preamble/currentb6evalrationale0706.php>)

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Availability of data and materials

The datasets generated and analyzed during the current study are available from the corresponding author on reasonable request.

Authors' contributions

Both LH and MC participated in the conception, design and writing of the manuscript LH supervised the study. MC made all statistical calculations. Both authors have read and approved the final version.

Ethics approval and consent to participate

Not applicable.

Patient consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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