Genotoxic Potential of Radiofrequency Exposures

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ABSTRACT

In genetics, the term genotoxicity describes the action of physical agents, such as chemicals and ionising radiation, which result in damage to genetic material encoded in deoxyribonucleic acid (DNA), and can take many forms. Markers of genetic damage include single strand and double strand DNA breaks, DNA base damage, chromosome aberrations and micronuclei induction. It is well-known that genetic damage is a major pathway to carcinogenesis.

There has been much debate over the last 30 years as to whether man-made radiofrequency (RF) radiation is genotoxic. Ruediger's review in 2009 found 49 studies reporting a genotoxic effect while 42 did not, and a more recent 2021 review by Lai found 237 or 66% of studies investigating genetic effects had a significant finding while 124 or 34% did not. Both papers provide a summary of the current state of the science with a "balance of evidence" finding. Further, both suggest some possible reasons for the discrepancies. However, such reviews can best be described as superficial, as neither of these papers investigated in depth (using meta-analysis techniques) how experimental methodology and parameters used may affect outcomes.

A search of the ORSAA database identified over 370 papers investigating RF exposures and genotoxicity. A comprehensive data set was then constructed by capturing important comparable parameters from the collection of identified studies. Example parameters include: experiment type (in vivo, in vitro, epidemiological); funding source; cell type (primary vs cell line); species; RF generation source; carrier wave frequency and signal modulation used; number of sequential exposures; duration of exposures; intensity of the signal; DNA damage assay type; sacrificial method (animal studies); time between exposure cessation and commencement of assay. These parameters and their inter-relationships were methodically analysed.

The resulting comprehensive data set provides valuable insights into how some of these parameters can significantly influence study results, and identifies the main drivers contributing to the mixed findings. The data set also shines a light on methodological limitations and issues that need to be addressed in future studies in order to further clarify the genotoxic potential of radiofrequency exposures. The preliminary findings to be presented are likely to have far-reaching implications for our understanding of radiofrequency exposure in relation to health and safety. The findings also bring into question the applicability of the current RF Standard (ARPANSA 2021) and RF Guidelines (ICNIRP 2020) for providing suitable protection to all species, not just humans.

Keywords

Electromagnetic Radiation, EMR, EME, EMF, RF, Microwaves, Wi-Fi, Mobile phones, Health, Cancer, Genotoxicity, DNA Damage, DNA Breaks, Chromosomal Aberrations, Micronuclei Induction.

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INTRODUCTION

The International Agency for Research on Cancer (IARC) classified all types of radiofrequency radiation exposure (not just limited to mobile phones) as a group 2B possible carcinogen [1]. The classification was based on the available evidence at the time covering both epidemiological and experimental animal studies. The evidence was deemed to be credible, although bias and confounding could not be completely ruled out. Another limitation that prevented a more stringent classification was the inability to describe the underlying mechanism(s) by which radiofrequency (RF) could initiate carcinogenesis [1].

The 2B classification was very controversial at the time, and even more recently, some scientists do not appear to be in agreement with IARC [2]. The 2B pronouncement also resulted in industry supporters trivialising the importance of the group 2B classification by comparing it to other 2B carcinogens like pickled vegetables [3]. Of course, those who have concerns about the deployment of base stations [4] are keen to point out that DDT and lead are also group 2B carcinogens. The level of toxicity of these different group 2B agents is a separate issue and not to be confused with their potential to cause cancer.

Evidence for RF carcinogenicity has further developed since the original 2B classification in May 2011. Two important life span exposure studies conducted on rats found clear evidence of carcinogenicity. The US National Toxicology Program (NTP) initiated by the National Institutes of Health (NIH) conducted a 25-million-dollar (US) experiment on rats and mice [5]. There was clear evidence of tumours in male rats in the form of heart schwannomas (a rare nerve tumour) that were seen only in the exposed rats. There was also some evidence of glioma, which is a rare, but aggressive brain tumour. Exposure levels in the NTP near-field study were equivalent to some mobile phone emissions when used close to the head and higher. The International Commission on Non-Ionizing Radiation Protection (ICNIRP) raised a number of criticisms against the study findings, although most of the points of concern were dismissed as unfounded or incorrect by the NTP study project designer [6]. The NTP study also found statistically significant increases in DNA damage in various organs including the brain [7].

At the same time as the NTP study results were published, another research group from the Ramazzini Institute (Italy) also found evidence for the same rare heart tumour in their rat study. However, the exposure levels were considerably lower than those use in the NTP study, approximating far-field RF exposures from mobile phone base stations [8]. It is worth noting that the rare heart schwannomas found in both rat studies are similar in nature to benign brain tumours, also known as acoustic neuromas (a type of schwannoma) found in heavy users of mobile phones [9].

There have also been additional epidemiological studies investigating mobile usage and brain tumours published by Hardell [10] along with the French case control CERENAT study [11] that further strengthen the evidence supporting carcinogenesis. In view of these recent study findings, RF exposure and cancer was declared by IARC in 2019 as a priority for re-review in the next five years.

A recent systematic review and meta-analysis [12] provides further in-depth analysis of RF carcinogenicity, particularly in relation to mobile phone usage and brain tumours.

Worldwide Cancers

Cancer incidence data from IARC world cancer reports are published every 2-6 years. Taking the incidence data from a number of these reports and plotting the change over time in Figure 1 below shows this increase clearly. The world is faced with a cancer pandemic with many cancers seeing exponential growth. An aging population and increased population growth has a role to play and yet cannot fully explain the rapid rise of many of the top twenty cancers. Some other factor(s) in our environment or lifestyle choices are possibly contributing to this increase.

It is also worth noting that at the same time cancer incidence is increasing, the EMF

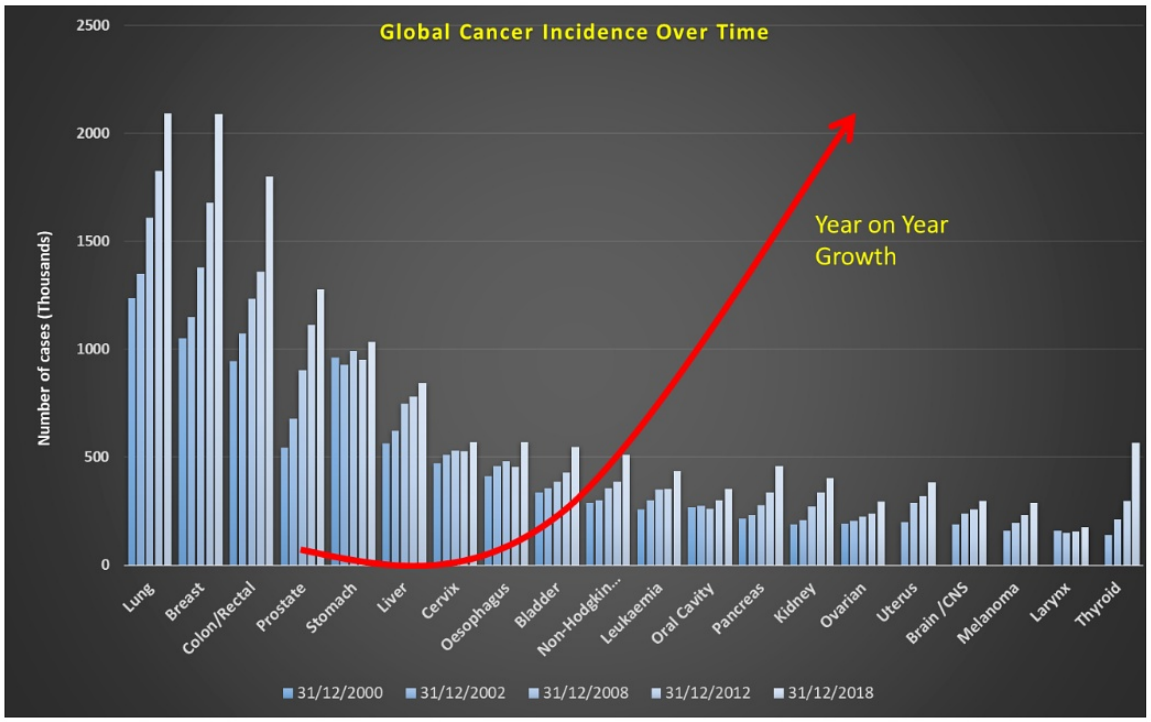

Figure 1. Rising incidence of cancers

background has also dramatically changed since the end of WW2, with a quintillion fold [13] increase, which is 10^18 greater than natural background.

Rationale for RF Genotoxicity review

Genetic damage is a recognised pathway to cancer [14]. IARC and ICNIRP require details of the mechanism by which cancer can occur as a result of RF exposure, before they can confirm RF exposure as an "established" carcinogenic agent.

There are more than 370 scientific publications investigating RF exposure and genotoxicity covering animals, plants and humans across different experimental types as follows:

- in vitro - (in glass) outside normal biological context;
- in vivo – complete organism animal study;
- epidemiological – disease statistical association studies of human populations.

At a superficial level, the evidence for genotoxicity appears to be inconsistent with some types of DNA damage, showing a balance of evidence that is close to 50-50.

A number of reviews have previously been conducted investigating many of the genotoxicity papers. However, some of these reviews suffer from limitations and/or biases. The most recent review in 2021 was conducted by Henry Lai who has extensive research experience in this field. Lai's narrative review highlights many of the problems observed in RF genotoxicity research, but also suggests genotoxicity is plausible [15].

The REFLEX in-vitro study 2000-2004 [16] provided clear evidence of single strand breaks (SSB) and double stand breaks (DSB) as shown in Figure 2.

Chromosome aberrations were also detected:

- Structural changes occur as a result of chromosome breakage and abnormal reunion of broken chromosomes.

Micronuclei induction was also detected:

- Extra-nuclear bodies containing whole or fragmented chromosomes;
- Induced by defects in cell repair or accumulation of DNA damage or

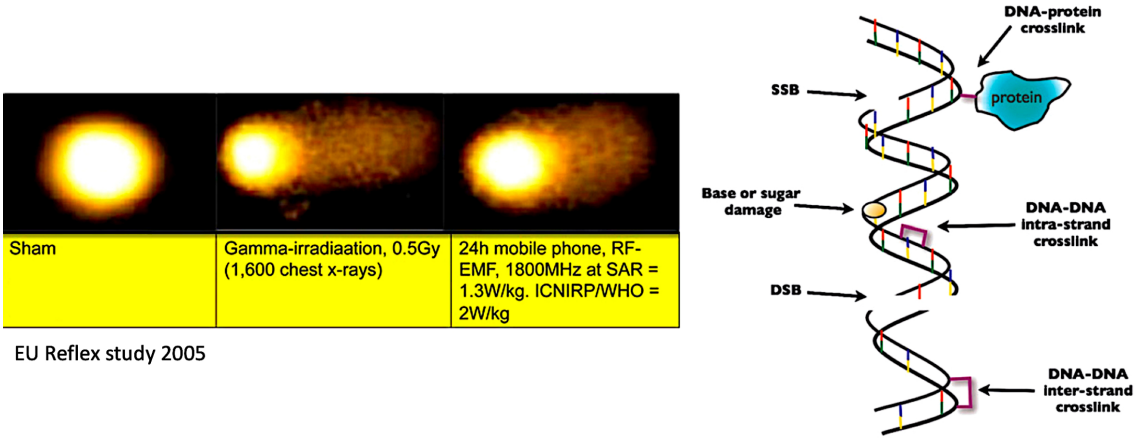

Figure 2. DNA damage - Breaks and Fragmentation (Source: https://doi.org/10.1089/ars.2012.5151)

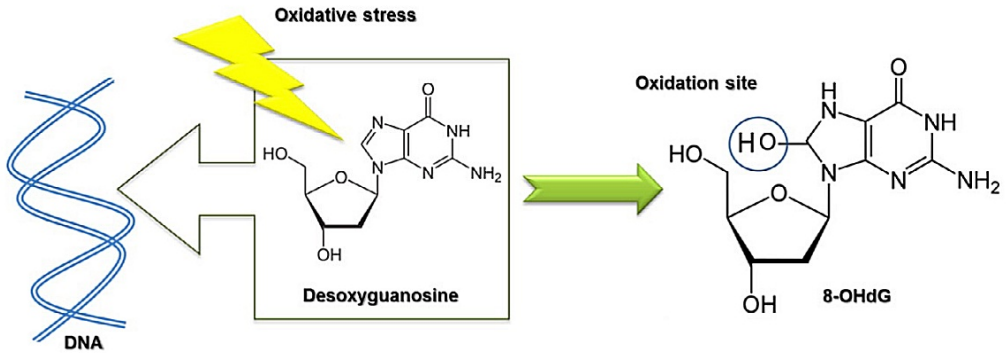

Figure 3. DNA damage – Base damage (Source: https://doi.org/10.1016/B978-0-444-63406-1.00005-2)

chromosomal aberrations.

DNA base damage was also found as shown in Figure 3.

- DNA base damage can occur from exposure to reactive oxygen species;
- Guanine has the lowest redox potential of the four DNA bases and is therefore the most easily oxidized.

A review of Radiofrequency DNA damage literature

Aim

To provide a preview of the results from a comprehensive review of 370 scientific papers investigating Radiofrequency (RF) exposure & DNA damage.

Method

Relevant publications (1970s to 2022) were collected using a complex keyword search on international research databases such as Pubmed/ Medline, EMF-Portal. The selected papers have been loaded directly into the ORSAA Database on Electromagnetic Bioeffects (ODEB) and categorised (17). The number of papers identified for each type of DNA damage has been provided, noting that some research papers cover more than one type of damage. In total, 370 papers were thoroughly investigated and the breakdown by DNA damage type is as follows:

DNA breaks (Single stranded and/or double stranded breaks) – 199 papers;
Micronuclei induction – 113 Papers;
Chromosome aberrations – 89 Papers;
DNA Base damage – 37 Papers.

Assumptions

A number of assumptions were made when analysing each research publication. It was assumed that the data contained within each paper was accurate and not fabricated. Published corrections were also taken into consideration, for example, a correction to a paper authored by Vijayalaxmi, Frei et al. 1998 [18] was included. Another assumption made was that all relevant experimental data were published, including null results and positive findings. Finally, funding sources were assumed to be accurate and fully disclosed when a declaration was made. It is however important to note that a large proportion of the research publications did not make any funding source declaration (127 of the 370 papers (34%) provided no funding declaration).

Data capture – Exposure duration as a factor for DNA damage

A heat map in relation to the number and percentage of effect papers for each of the main types of DNA damage over accumulated exposure time is shown as Figure 4. The number of papers that were evaluated for some time intervals are very low and so it is not possible to infer much from a statistical perspective for these specific time intervals. However, what does become quite apparent with each of the different types of DNA damage is that acute exposures (minutes in duration) have a high propensity to cause statistically significant DNA damage. As time progresses, the DNA damage effects become less obvious, as repair mechanisms may be starting to have an effect. This is particularly obvious for DNA breaks and micronuclei induction, especially for exposures up to 48 hours and 24 hours respectively. Exposure durations beyond 48 hours show robust evidence of DNA damage. It is important to recognise this time-based exposure phenomenon.

Cell adaptive response may have a role to play as cells attempt to establish homeostasis [19]. Cells have various mechanisms to protect themselves, including the ability to upregulate genes relating to DNA repair, heat shock proteins (which act as chaperones), and expression of proteins (enzymes) involved in oxidative stress mitigation [20]. Gene expression is not an instantaneous action and takes time to progress, starting with the signalling pathway activation for the transcription factor to bind to the DNA and for transcription to initiate. Then there is process of exporting the mRNA to the cytosol where it will be processed by the endoplasmic reticulum and translated on a ribosome to synthesize the requisite proteins. This whole process can take many minutes to complete [21]. There are some papers suggesting that RF exposure may also have an effect on the DNA repair process [22], but this needs to be confirmed and replicated.

If an adaptive response has a role to play, it appears to be limited in the level of protection it

	DNA Breaks		Micronuclei Induction		Chromosome Aberrations		DNA Base Damage	
	# Papers		#Papers		# Papers		#Papers	
Exposure Time	Effect	%	Effect	%	Effect	%	Effect	%
<1 Minute	1	100.0	1	100.0	3	60.0	0	0.0
1 - 5 Min	2	100.0	1	100.0	2	40.0	0	0.0
6 -15 Min	5	100.0	8	80.0	7	53.8	0	0.0
16 -30 Min	7	35.0	9	60.0	11	55.0	1	50.0
31 - 40 Min	4	80.0	2	66.7	0	0.0	0	0.0
41- 60 Min	12	46.2	8	66.7	9	50.0	2	66.7
61 min - 2 Hours	17	34.0	5	27.8	11	52.4	6	85.7
3 - 4 Hours	9	40.9	7	46.7	13	76.5	3	75.0
5 - 8 Hours	8	38.1	2	28.6	6	75.0	6	85.7
9 - 16 Hours	8	61.5	4	33.3	3	60.0	1	50.0
17 - 24 Hours	10	28.3	8	30.8	5	38.5	3	100.0
25 -48 Hours	4	33.3	8	57.1	3	75.0	2	66.7
49 - 96 Hours	12	70.6	10	58.8	4	66.7	4	100.0
97 Hours - 7 Days	8	80.0	3	100.0	1	100.0	3	100.0
7 Days - 2 Weeks	4	80.0	2	100.0	1	50.0	1	50.0
2 Weeks - 4 Weeks	5	100.0	1	33.3	0	0.0	5	83.3
4 Weeks - 8 Weeks	3	75.0	4	100.0	2	66.7	2	66.7
8 Weeks - 3 Months	3	100.0	1	100.0	1	50.0	1	100.0
3 Months - 1 Year	3	100.0	1	50.0	2	66.7	1	100.0
>1 Year	12	100.0	13	86.7	7	77.8	1	100.0

Key

No papers

70% > Effect

55 - 69% Effect

45 - 54% Effect

30 - 44% Effect

< 29 % Effect

Figure 4. Data capture – Multiple dimensions - Exposure duration - A factor for DNA damage

offers, because DNA damage begins to become a dominant feature as the exposure duration increases. It is also very likely that some of the observed inconsistencies in the results for short exposure durations may be in part due to the underlying study design methodology, such as the type of signals being applied and cell types exposed. Some cells are more radiosensitive than others [23]. This will be discussed further on in this conference paper.

Of all the different types of DNA damage that were investigated, DNA oxidative base damage shows no specific time interval where the number of effect papers are exceeded by those showing no effects.

Balance of evidence – Paper level

A number of charts shown on Figure 5 illustrate the overall balance of evidence for each type of DNA damage reviewed. It is important to note that the classification of effect for the various pie charts presented are based on findings at the paper level and an effect is identified where statistical significance of a given end-point is p <0.05 or better is found. If a publication conducted several experiments and one of the experiments found a statistically significant effect, it is classified as an effect paper. Experimental level data have also been analysed and will be published in a separate paper. The experimental data do not significantly change the heat map pictures. A trend is identified when an increase in DNA damage was observed in a study that is at least 10% higher than the sham/control, or in the case where multiple exposures are performed at different intensities, the amount of damage is seen to be increasing with intensity. In both scenarios the changes recorded were not seen to be statistically significant.

What is of particular interest is the number of papers finding a positive trend that did not reach statistical significance is fairly consistent for three types of DNA damage (DNA breaks, Micronuclei and Chromosome aberrations) in approximately 18% of papers. Also, the proportion of statistically significant effect papers is fairly similar for DNA breaks and micronuclei induction. The standout observation in Figure 5 (89%) however is the clear evidence linking RF exposure to DNA oxidative base damage. DNA oxidative base damage can lead to point mutations [24], DNA strand breaks, and genomic instability [25].

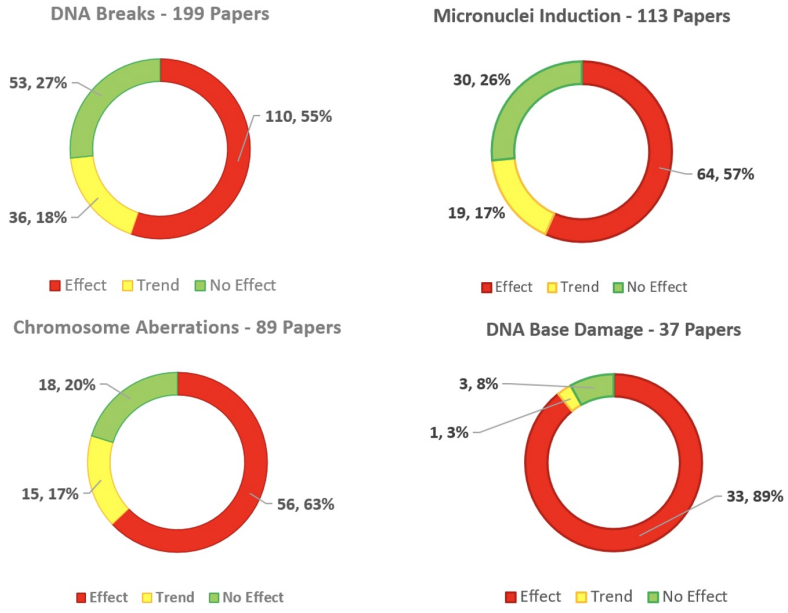

Figure 5. Balance of evidence

Findings by experimental Type – DNA breaks

The breakdown of findings present in this conference paper is based on experiments conducted for DNA breaks only. Micronuclei, chromosome aberrations and DNA base damage are not discussed further in this specific review but results will be presented in a future paper. Figure 6 presents the results from different types of experimental studies. What becomes clear is that studies showing the most uncertainty for genotoxicity are related to in vitro experiments, which usually involve the testing of a specific cell in culture media contained in a petri dish or test tube.

In vitro studies can suffer from limitations as they cannot fully replicate the conditions of cells in living organisms, and so are less relevant when trying to predict cell behaviours in their natural environment [26]. Of course, this does not mean that in vitro model is not useful, as they do have some advantages such as providing a cheap and relatively quick way to conduct biological tests. There are ethical considerations for in vitro studies to be considered when using primary cells (such as blood lymphocytes) but are not important in cases where cell lines are used from tissue banks. It is worth noting that industry funded studies predominantly performed genotoxicity studies using in vitro methods.

In vivo studies (Latin for "within the living"), are considered to be more reliable than in vitro methods when it comes to simulating biological conditions within a living subject. Of course, in vivo studies do bring with them ethical challenges, and are more expensive to conduct. The evidence presented clearly indicates RF induced genotoxicity within living entities, as demonstrated by the in vivo study results.

All epidemiological studies found evidence for RF genotoxicity. However, the sample size, in terms of the number of publications, is relatively small (14 papers) compared with in vitro (199 papers) and in vivo studies (68 papers). Another problem that can hamper epidemiological studies is that they may be subject to confounding factors and biases (such as population selection). However, a quality research project can manage these potential issues.

Real vs Simulated signals

Real world devices such as mobile phones, Wi-Fi routers and access points have output signals that are complex and variable in intensities, duty cycle (how frequently the signal is active), and even the amount of data being sent, which results in modulations of the carrier wave. Some older mobile phone technologies emit radiofrequency transmissions that can include extremely low frequency components i.e., 217 MHz pulses in GSM/TDMA signals, while Wi-Fi has a 10 Hz beacon signal. On the other hand, simulated signals from a signal generator are often missing these components, as the experiments try to fix the different variables. It is worth noting that 5G modulations involving orthogonal frequency-division multiplexing (OFDM) will also use TDMA to separate signals so it's important to use real signals in experiments to confirm

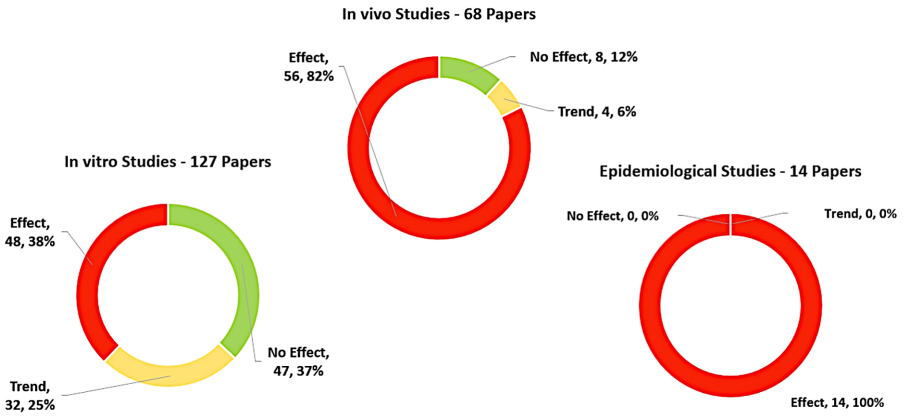

Figure 6. Findings by experimental type – DNA breaks

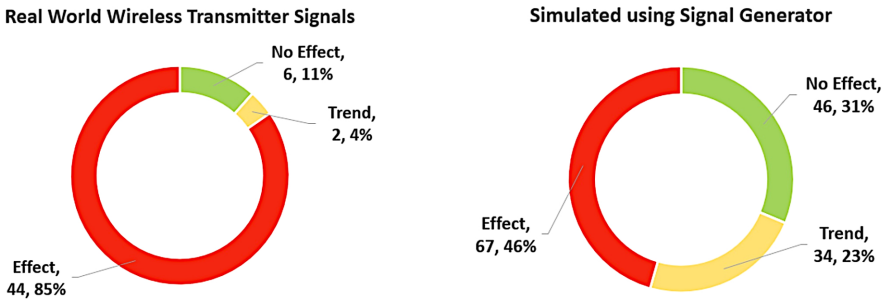

Figure 7. Real vs Simulated signals

biocompatibility. This biocompatibility check of OFDM 5G signals is yet to be performed.

Some experiments use test phones and turn off/ on features before conducting the experiment. Others experiments use simulated signals where the output power is fixed and don't transmit any data, and thus the emitted waves are unmodulated. Simulated signals may not always include low frequency pulsing. Those that do, such as replaying real world communication signals between a laptop and a router through a signal generator, are doing so at a constant boosted intensity, which does not accurately reflect real life exposure scenarios.

In laboratory experimental work, signal generators are often used with intensity fixed over a known exposure duration for a specific frequency, making it easy to calculate dosimetry. However, fixing the different variables can make it very difficult to determine if interaction effects between these variables occurs simultaneously. This variability in power density is one component missing from experiments conducted with signal generators, and so does not mimic real world signals produced by commercial wireless devices.

Contrastingly, using real world devices can make calculating dosimetry very difficult. However, most of these devices are expected to operate within the ICNIRP public limits, with some operating well below public limits. Modern measurement instruments are used, and typically measure power density levels (Watts/m2). Because of the variability in power density levels, maximum and average exposure levels are typically quoted.

Dosimetry is important when trying to establish a safe threshold for public exposures, considering both duration of exposures and the intensity of the field. However, real world wireless devices are expected to comply with current public limits advised by ICNIRP. Calculating dosimetry for a study using real world devices becomes quite complex given the variable nature of the signals being emitted. The "poor dosimetry" argument is then used by some scientists to question the quality of a study in order to dismiss the findings [27]. To some degree, because these unmodified real-world devices are operating below (well below in some cases) ICNIRP RF Guideline for member of the public limits, the poor dosimetry argument becomes irrelevant when testing the validity of current public limits.

The evidence presented in Figure 7 suggests current guidelines are not fit for purpose because genetic damage is being observed at exposures well below public limits and therefore represents a real risk for carcinogenicity. Overall, the results suggest that the use of real-world devices provides strong evidence (85% of papers) of RF exposures increasing DNA damage, whereas the evidence for simulated signals is inconsistent and far less convincing.

Cell types – RF induced DNA breaks assessment

The data presented in Figure 8 relates to cell type responses to RF exposure, and the propensity to show signs of DNA damage. Brain tissue that is not cancerous and cells related to fertility are especially vulnerable to RF induced genotoxic

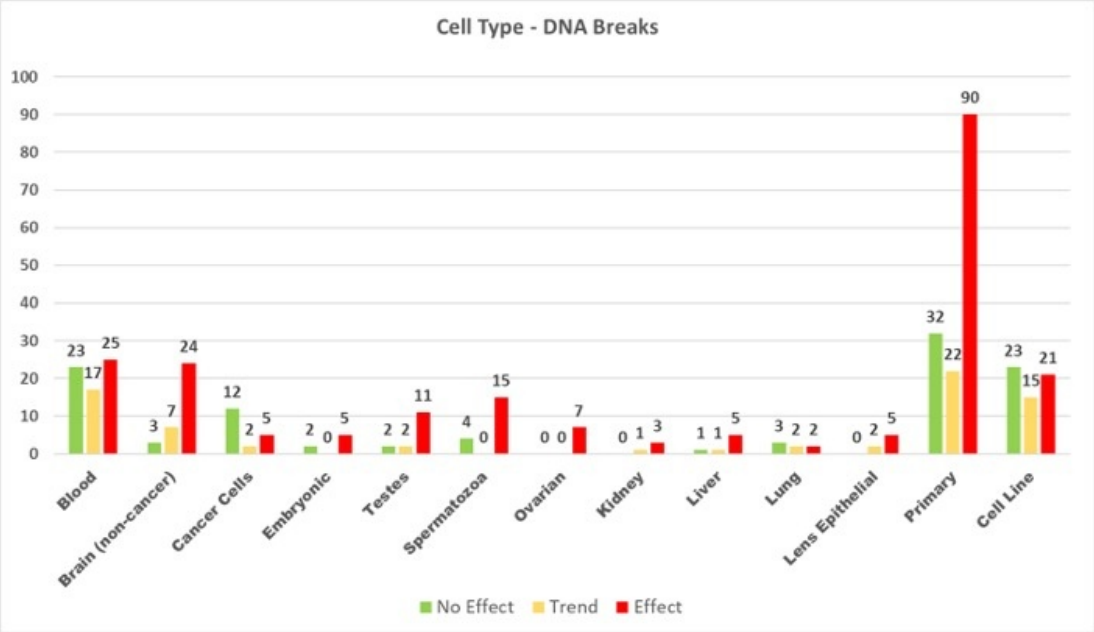

Figure 8. Cell types – RF induced DNA breaks assessment

effects. This evidence can be used to support claims of increased risk for rare brain tumours, testicular cancer and infertility found in epidemiological studies. Blood on the other hand has quite mixed results. It is only on close inspection of the data that one finds study methodology may have an important role to play in influencing outcomes. Single short exposures from signal generators are less likely to show genetic damage when compared with multiple exposures from real devices/wireless infrastructure over a longer exposure duration.

Some studies do show cell types having sensitivity for RF genotoxicity, such as embryos, eyes, liver and kidney cells, however, the number of experiments investigating these particular cell types are quite low, so drawing conclusions is problematic. What is clear from the summary results is that cancer cells and cell lines appear to be more resistant to genotoxic effects from RF exposure. Cell lines are often used because they do not require ethical considerations, whereas ethical clearance is required for usage of primary cells. Cell lines are also cheap and easy to use [28]. However, cell lines are genetically manipulated so their function and responsiveness can change. Therefore, they may not adequately represent the primary cell they were originally derived from. Cell lines may not be as sensitive as primary cultures and because they are immortal (proliferate indefinitely), they intrinsically are different from primary cells. The heritage of cell lines cannot always be determined and may change genotypically and phenotypically with each serial passage they undertake [28]. Prior exposures to RF/other agents or cell contamination could also affect cell behaviour (i.e., radio-resistance).

Species - RF induced DNA breaks assessment

All species are affected to varying degrees. Some species such as mice and humans appear to have very mixed results. However, the conflicting findings require further exploration and much like cell type responses, the applied study methodology may be a deciding factor. Factors that influence outcomes include specific cell type exposed, source of signal, and duration and number of exposures. What is also very apparent, from Figure 9 is that industry funded studies typically involve research on humans and mice, which is further discussed under funding influence below.

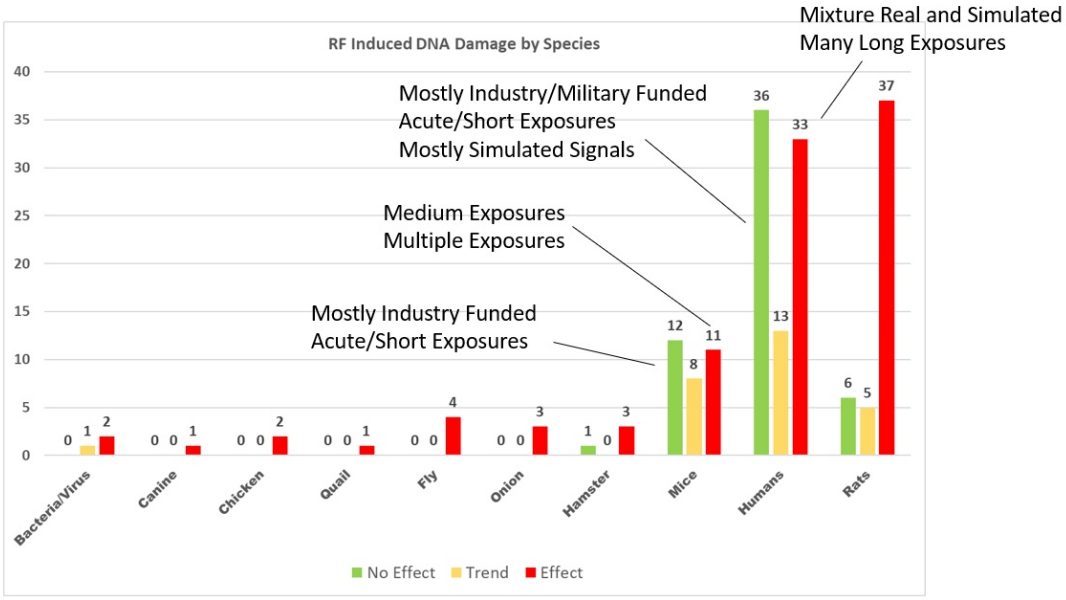

Figure 9. Species - RF induced DNA breaks assessment

Funding effects and experimental outcomes

1. Industry funded with partners

Figure 10 below covers industry funded research along with partners, which can include government/military, public trusts, private foundations and institutions. Industry and partners funded research tend not to conduct long-term studies, epidemiological studies, and multiple exposures, instead there is a preference for using simulated signals rather than real world signals. Figure 10 shows the relatively low presence of “Effect” outcomes compared with “No Effect” outcomes.

2. Institutionally with partners

Figure 11 shows the outcomes for institutionally (university) funded studies with their partners. The difference between outcomes shown in Figure 10 and 11 it is quite obvious with experiments funded by institutions has "Effect" studies dominating the outcomes, in contrast with “No effect” studies dominating industry funded results.

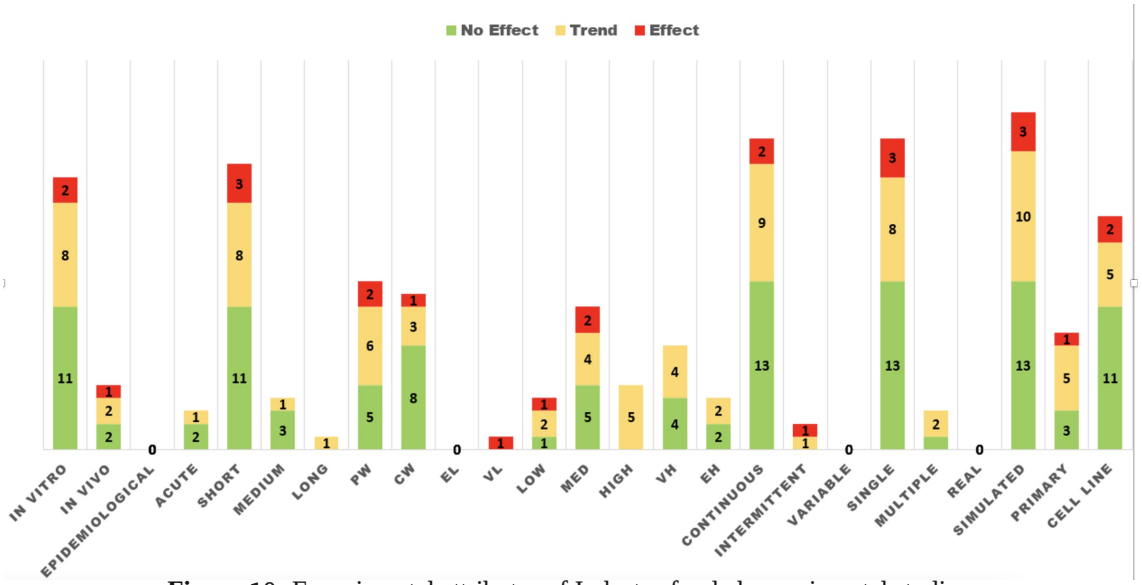

Figure 10. Experimental attributes of Industry funded experimental studies

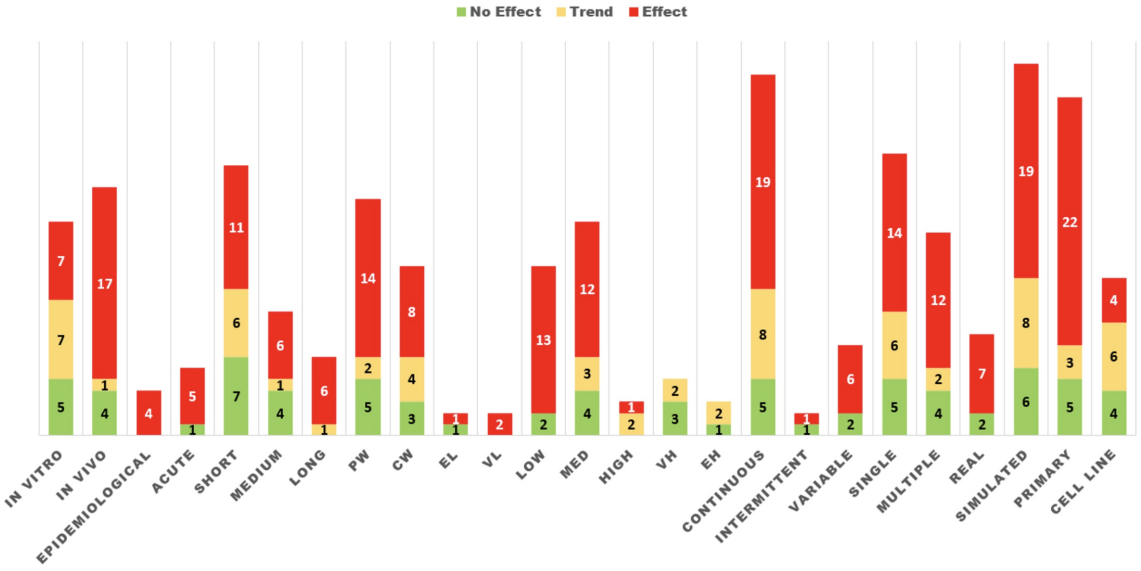

Figure 11. Institutionally with partners

Each funding source is the primary filter that is applied to the data in each instance. What becomes quite clear via the colour codes, green being "No Effect", yellow being "Trend" and red being "Significant Effect" is that industry funded research is predominantly finding no effect (green) which is quite dissimilar to other funding sources findings which are dominated by significant effects (red). It is also worth noting that a proportion of the "No Effect" studies observed in the other funding groups is partly due to industry being a funding partner.

3. Government funded research (excluding military and communication agency funding)

Figure 12 shows that "Effect" studies dominate the overall outcomes.

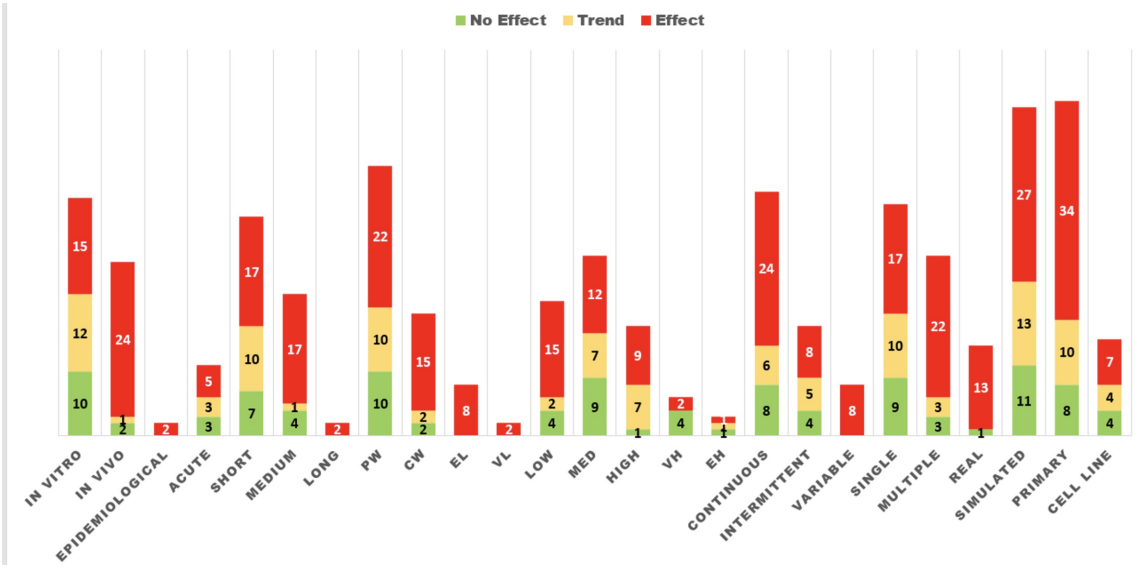

Figure 12. Outcomes for government funded research (excluding military and communication agency funding)

Summary of funding outcomes for experimental research

What is noticeable is the ratio of “No Effect" and "Trend Effect" studies for each attribute is very similar across each funding group. Are industry under-reporting significant effects, or is something else happening here?

It was suggested by an attendee at the March 2022 ARPS conference that industry studies have a lot more money available to them and therefore allows them to conduct studies of a high quality. However, this claim remains unconfirmed without a peer reviewed publication to verify this statement. What has been previously demonstrated with Tobacco science is that industry undertakes actions designed to protect its revenue and products, including paying scientists to write papers to support the industry position and to generate uncertainty [29]. This is also occurring with the telecommunications industry as evidenced by Motorola stating in a memo it is war gaming the science [30].

Result summary - Industry focussed experiments

Industry focuses on in vitro studies, which are cheaper, while tending to avoid in vivo and epidemiological studies. The majority of their studies are conducted with an exposure duration set in a narrow window of 1 to 24 hours, which in this paper have been classified as “short” exposures. This is where adaptive responses are likely to be effective. When it comes to intensity of the exposures, industry funded studies focus on the higher intensities between medium (public limits) and higher. DNA damage is occurring at non-thermal levels, so higher intensity may not help find these effects if the underlying mechanism is non-thermal. The exposure regime employed by industry is dominated by continuous exposures with few intermittent patterns applied and no variable exposures. This is because industry funded researchers only use signal generators and not real wireless devices. The exposure type is mostly limited to a single short duration exposure, and cell types used are dominated by cell lines which are not as sensitive to RF radiation.

In summary:

A typical industry funded study is an in vitro study that exposes a cell line to a single short exposure from a signal generator at a moderately high intensity in a continuous manner.

- Studies that show genotoxicity are typically in vivo studies (or in vitro), exposing a primary cell or animal or plant to a variable signal from a real-world wireless device, at a low to moderate intensity. This is for an extended period of time (total accumulated exposure) with multiple exposures.

- The first scenario (industry study) is designed to support current international guidelines to protect people from thermal-based health effects from acute exposures, while the second scenario is more reflective of real-life usage and exposure scenarios.

Note that when it comes to exposure intensity, a mobile phone would typically fit in the medium category. ICNIRP public limits are equivalent to the upper boundary of medium level exposure and lower. ICNIRP occupational limits sit between Medium and Very High exposures. Extremely High exposures are above occupational limits and can include levels where thermal injury can occur.

Mechanism for genetic damage

A plausible mechanism for radiofrequency exposure to lead to genetic damage is via the generation of free radicals which can create a cellular oxidative stress state in the organism. Many RF exposure experiments investigating oxidative stress find that radiofrequencies can change redox status by increasing free radical production [31]. Experiments demonstrate this directly by using probes, measuring enzyme levels and activity associated with free radical removal (antioxidant enzymes catalase, glutathione peroxidase, superoxide dismutase), measuring glutathione levels or measuring evidence of direct damage such as DNA base damage (8-oxoG, 8-OHdG etc.), lipid peroxidization (Malondialdehyde levels) and protein carbonyls.

A number of RF genotoxicity studies that were reviewed investigated whether there were

increased free radicals and evidence of oxidative stress. Some of the studies also investigated DNA base damage. As can be seen on the bar chart in Figure 13, the clear majority of the papers did find evidence of increased free radical production/ damage.

The ODEB database [17] contains a large collection of peer reviewed papers investigating RF exposures and oxidative stress. Figure 14 shows a recent search (April 2022) of the ODEB database, which found 90%, or 297 papers out of 330, showing radiofrequency exposures associated with increased free radicals.

Current view of WHO, ICNIRP and ARPANSA illustrated in misleading statements

Some misleading statements are as follows:

> From WHO/IARC: “Non-ionizing radiation is a general term for that part of the electromagnetic spectrum which has photon energies too weak to break chemical bonds” [32].

This statement is misleading, as UV (A/B) radiation is also non-ionising, damages DNA and is a recognised Group 1 carcinogen. Both RF and UV generate free radicals. Free radicals are known to be capable of damaging DNA as

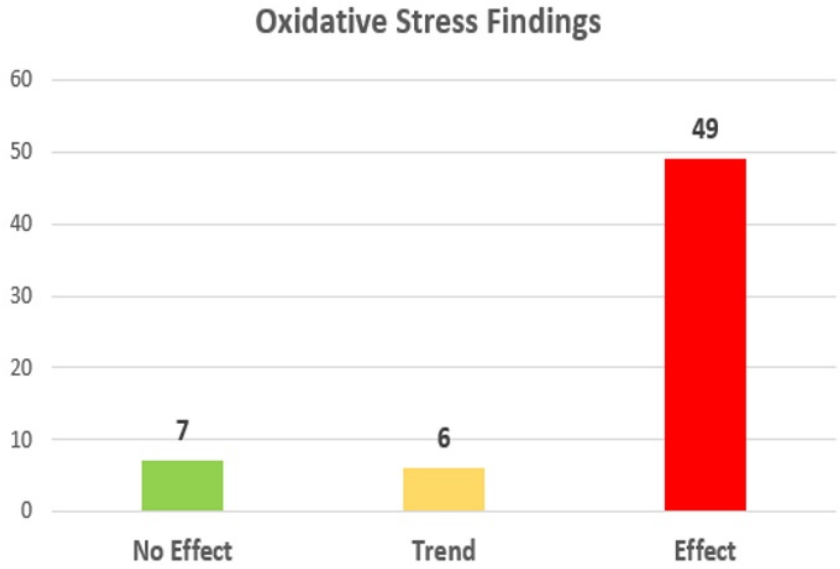

Figure 13. DNA damage papers also investigating free radical production/oxidative stress

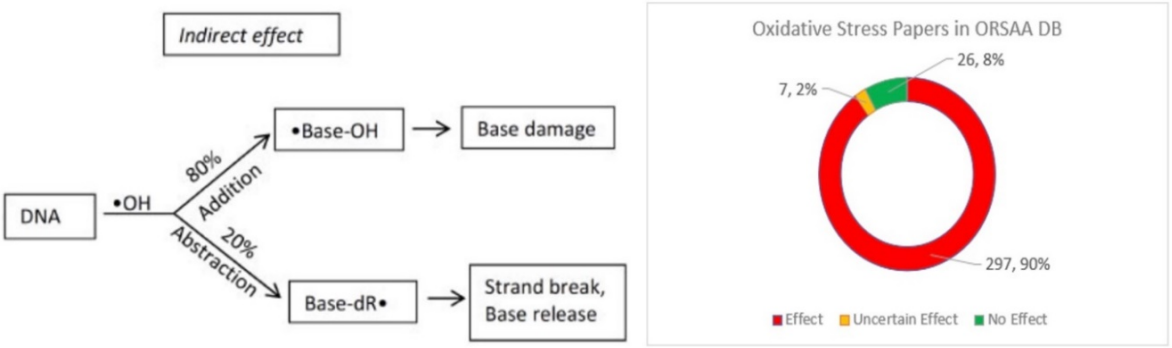

Figure 14. Free radicals can damage DNA

evidenced in 8-oxoG and 8-OHdG assays.

- From WHO/IARC: "Despite considerable research efforts, no mechanism relevant for carcinogenesis of radiofrequency electromagnetic fields has been consistently identified to date" [33].

This is incorrect – free radical production provides a plausible mechanism, with 90% of papers showing RF exposures generating increased levels of free radicals, which can damage DNA. Accumulated DNA damage is a recognised pathway for carcinogenesis.

- From WHO/IARC: “Most of the epidemiological research does not indicate carcinogenicity of radiofrequency electromagnetic fields” [33].

This statement is challenged by epidemiological evidence for brain tumours which shows an association [10, 12], being the principal reason for the IARC classifying RF as a Group 2B carcinogen in May 2011. Animal evidence was seen to be limited at the time; however, clear evidence has since been found [5, 7, 8] reinforcing the need to revisit the original IARC classification. What is most surprising is the most recent World Cancer Report 2020 [33] from IARC made no reference to these important and recent animal studies when discussing RF carcinogenicity. Of interest, one of the contributing authors of this particular section of the World Cancer Report is an ICNIRP member. ICNIRP’s position on the carcinogenic potential of RF exposure is to say the least, controversial, as seen by its manoeuvring to downplay the NTP findings (6).

Closing Statements

The original abstract associated with this work captures much more detail than what was presented at the ARPS conference 2021. The allotted time of 20 minutes for the presentation was a limiting factor, and did not allow for deeper exploration of the data that have been analysed. A future review paper will be published in a peer-reviewed scientific journal that will give further insight into this very important topic.

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