



A meta-analysis of in vitro exposures to weak radiofrequency radiation exposure from mobile phones (1990–2015)

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ABSTRACT

To function, mobile phone systems require transmitters that emit and receive radiofrequency signals over an extended geographical area exposing humans in all stages of development ranging from in-utero, early childhood, adolescents and adults. This study evaluates the question of the impact of radiofrequency radiation on living organisms in vitro studies. In this study, we abstract data from 300 peer-reviewed scientific publications (1990–2015) describing 1127 experimental observations in cell-based in vitro models. Our first analysis of these data found that out of 746 human cell experiments, 45.3% indicated cell changes, whereas 54.7% indicated no changes ($p = 0.001$). Realizing that there are profound distinctions between cell types in terms of age, rate of proliferation and apoptosis, and other characteristics and that RF signals can be characterized in terms of polarity, information content, frequency, Specific Absorption Rate (SAR) and power, we further refined our analysis to determine if there were some distinct properties of negative and positive findings associated with these specific characteristics. We further analyzed the data taking into account the cumulative effect ($\text{SAR} \times \text{exposure time}$) to acquire the cumulative energy absorption of experiments due to radiofrequency exposure, which we believe, has not been fully considered previously. When the frequency of signals, length and type of exposure, and maturity, rate of growth (doubling time), apoptosis and other properties of individual cell types are considered, our results identify a number of potential non-thermal effects of radiofrequency fields that are restricted to a subset of specific faster-growing less differentiated cell types such as human spermatozoa (based on 19 reported experiments, $p\text{-value} = 0.002$) and human epithelial cells (based on 89 reported experiments, $p\text{-value} < 0.0001$). In contrast, for mature, differentiated adult cells of Glia ($p = 0.001$) and Glioblastoma ($p < 0.0001$) and adult human blood lymphocytes ($p < 0.0001$) there are no statistically significant differences for these more slowly reproducing cell lines. Thus, we show that RF induces significant changes in human cells (45.3%), and in faster-growing rat/mouse cell dataset (47.3%). In parallel with this finding, further analysis of faster-growing cells from other species (chicken, rabbit, pig, frog, snail) indicates that most undergo significant changes (74.4%) when exposed to RF. This study confirms observations from the REFLEX project, Belyaev and others that cellular response varies with signal properties. We concur that differentiation of cell type thus constitutes a critical piece of information and should be useful as a reference for many researchers planning additional studies. Sponsorship bias is also a factor that we did not take into account in this analysis.

1. Introduction

On May 31, 2011, the World Health Organization (WHO), International Agency for Research on Cancer (IARC) classified radiofrequency electromagnetic fields (RF-EMF) from mobile phones as a “Possible Human Carcinogen” (Group 2 B) (WHO and World Health Organisation, 2011) based on in vitro, in vivo and epidemiological studies; the Interphone Study (INTERPHONE Study, 2010) (some evidence to suggest increased risk of glioma in heavy adult users > 1640 h)

and the Hardell et al. (2006) the study indicates increased risk of malignant brain tumors for users of cellular and cordless phones. The results from these studies have not been without controversy. Others (Swerdlow et al., 2011) suggests that there is no increase in risk, with several reviewing groups advising that mobile phone use is safe for adults as well as children (SCENIHR (SCENIHR, 2015), ICNIRP (International Commission on Non-Ionizing Radiation Protection (ICNIRP), 1998)). Furthermore, there are reports (International Commission on Non-Ionizing Radiation Protection (ICNIRP), 1998) that

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many of the experiments that show effects have not been independently replicated. In addition, in a number of instances when replication of experimental studies has been attempted, the results could not be reproduced. The EMF can have both positive effects as a treatment modality to facilitate wound-healing and cancer treatment, as well as adverse effects (Yu and Peng, 2017), especially on reproductive outcomes and possibly cancer.

To clarify the understanding of EMF impacts, Belyaev has reported (Belyaev, 2005) that signal characteristics play a crucial role in determining biological response, including polarity, frequency, power-density, and information content. They also find that cell properties are of vital importance and that neonatal stem cells appear exquisitely sensitive to RF, in contrast to adult lymphocytes that appear relatively unresponsive. Further complicating the interpretation of in vitro results is the fact that Portelli and Barnes 2013 (Portelli et al., 2013) have shown that poorly controlled laboratory conditions concerning background magnetic field (BMF) exposures from cooling fans, etc., can vary substantially within incubators, resulting in inconsistent conditions and results that may account for differing results. Thus, the lack of consistency in experimental findings may be attributable in part to failures to control for BMF that can influence outcomes importantly and have not typically been measured.

In addition to BMF, there is some evidence to suggest that even low levels of radiofrequency may cause deleterious effects on the functioning of cells. There has been controversy on whether the underlying cause of cellular changes is due to heating or other effects of the RF signal. Hoyto et al. (Höytö et al., 2006) found even small increase in temperature (0.8–0.9°C) affects the ODC (Ornithine Decarboxylase) activity in L929 cells in contrast to low-level radiofrequency fields that did not cause changes. The first large-scale epidemiologic study to investigate this potentially significant association among children reveals weak associations between cell phone use and hearing loss at age 7, however, as is often the case with epidemiological studies, the findings could have been affected by various biases (Sudan et al., 2013).

In considering the possibility of non-thermal biological effects of RF, it is essential to differentiate between the predictive nature of findings produced from experimental studies in whole animals and in vitro, and those resulting from epidemiological or clinical studies. The latter can only indicate the impacts of past exposures and conditions, while the former is intended to predict and ultimately to prevent impacts from arising in the future. There is considerable clinical and epidemiological evidence to suggest that even low levels of radiofrequency may cause deleterious effects on the functioning of cells. Two major types of epidemiological studies are relevant: population-based cohorts followed over time; and case-control studies comparing specific instances of disease with matched controls that do not have this disease.

Conclusions on whether non-thermal RF-EMF might be harmful are usually from extensive epidemiological studies seeking the association of deleterious effects with increased use in large populations. Such population-based studies are epistemologically limited in their capacity to detect important impacts for reasons that others have well-enumerated that include: poor or few measures of direct exposures, difficulty with follow-up, flawed information on uses and users, changing technologies over time, improper or incomplete ascertainment of health status, and ultimately a low statistical power to find an effect. In contrast, case-control studies can provide more accurate information and yield better indications of relative risk.

In light of these limitations of what can be provided from epidemiological studies, when it comes to efforts to prevent disease and promote health, it is essential to consider additional evidence from in vivo and in vitro studies (Leszczynski et al., 2004) as a foundation for predicting and preventing impacts on human populations. A wide-ranging number of experimental investigations of acute and chronic exposure to electromagnetic fields have been reported in animal and cell (human and animal) based models. In several studies, there has been controversy on whether the underlying cause of changes is due to

heating, magnetic fields or other effects of the RF signal. Biological effects due to electromagnetic radiation from mobile communication systems may depend on a number of signal properties including the mean power level, frequency, and modulation of the electromagnetic signal, as well as polarity and underlying nutritional and health status of exposed hosts.

For several decades concerns have been raised about the safety of extended use of mobile phones (Vijayalaxmi et al., 2014; Leszczynski et al., 2012; Marino et al., 2011; Gaestel, 2010; Paffi et al., 2010; McNamee and Chauhan, 2009; Verschaeve, 2001, 2005, 2009; Vijayalakshmi and Prihoda, 2009; Ruediger, 2009; Vijayalaxmi and Prihoda, 2008; Tusch et al., 2006; Moulder et al., 2005; Cotgreave, 2005; Vijayalaxmi and Obe, 2004; Meltz, 2003; Ahlbom et al., 2003; Heynick et al., 2003; Brusick et al., 1998; Verschaeve and Maes, 1998; Hermann and Hossmann, 1997; Leonarda et al., 1983). The recommendations of standard bodies ICNIRP (International Commission on Non-Ionizing Radiation Protection (ICNIRP), 1998), IEEE (IEEE C95.1-2005, 2005), CENELEC (CENELEC, 1995) for exposure limits are based exclusively on measurements of health effects due to elevating tissue temperatures that affect the absorption of energy during exposure and also do not take into account variations in BMF, nor the importance of cell types or signal properties. The specific absorption rate (SAR) is a measure of energy absorption by the body when exposed to radio-frequency electromagnetic fields. The European Union has specified a SAR limit of 2.0 W/kg averaged over a 10 g cube while in the United States this is specified at 1.6 W/kg averaged over a 1 g sphere (International Commission on Non-Ionizing Radiation Protection (ICNIRP), 1998). Besides these standard bodies, there are a group of other reviewing groups (such as, EHFRAN (European health risk assessment network (EHFRAN), 2012) and SCENIHR (SCENIHR, 2015)) that have evaluated the risk assessment due to RF exposure using published data from peer-reviewed scientific publications concluding that current exposures are not and other groups such as the ORSAA (Oceania Radiofrequency Scientific Advisory Association). The International EMF Group (calling for a moratorium on 5G), and International Commission on Electromagnetic Radiation (ICEM) have reached different conclusions and are calling for reductions in exposure and additional research.

In order to clarify biological understanding of RF, we perform a meta-analysis using 1127 in vitro experimental observations in 300 scientific journals (1990–2015) to determine the potential effects on different cell types, from human and rats/mouse, exposed to the non-thermal weak radio-frequency electromagnetic exposure from mobile phones. Our analysis interrogated published experiments that considered the non-thermal radiofrequency electromagnetic exposure effects (cytogenetic, gene and protein expression analysis) on cell types with different doubling times, including lymphocytes, epithelial, endothelial and spermatozoa from rat, mouse, and humans.

2. Material and methods

In our analysis, we included experiments that reported results for exposure to conditions ranging in frequency from 895 to 2450 MHz and specific energy absorption rates (SARs) ranging from 0.001 to 50 W/kg, with exposure durations lasting from 5 min to 6 days in a wide variety of cell types. This study examined frequencies of operation and modulation signal used by (i) Global System for Mobile Communications (GSM), (ii) Time Division Multiple Access (TDMA), (iii) Code Division Multiple Access (CDMA), (iv) Frequency Division Multiple Access (FDMA), (v) Gaussian Minimum Shift Keying (GMSK), (vi) GSM basic, (vii) GSM talk, (viii) GSM Discontinuous Transmission (GSM DTX), (ix) GSM non-Discontinuous Transmission (GSM non-DTX), (x) International Mobile Telecommunication-2000 (IMT-2000), (xi) Enhanced Data rate for GSM Evolution Signal (EDGE), (xii) Wideband CDMA (WCDMA) and (xiii) Universal Mobile Telecommunication System (UMTS).

The raw data presented in Tables 11–42 specifies the variables and experimental protocols, including exposure conditions of the studies we evaluated (please see Appendix). In this paper, cellular response (presence or absence) in human, rat, or mouse cells is defined as changes due to exposure to RF from a mobile phone and are summarized in Tables 11–42, including exposure conditions and experimental protocols. We pooled and analyzed the reported studies based on the physiological variables they measured and the different experimental readouts/endpoints they used for their studies. These studies are shown in Tables 11–29 (human cells), Tables 30–36 (rat/mouse cells), Tables 37–40 (both human and rat/mouse cells) and Tables 41 and 42 (other species), separately. The data specifies the variables that were in the non-thermal radio-frequency electromagnetic field exposure conditions and experimental protocols used in the investigations.

2.1. Collection of the raw data

In our analysis, we excluded experiments that reported results when (i) SAR values are higher than 50 W/kg (ii) exposure durations are higher than seven days (iii) no complete dosimetry is disclosed, and (iv) the publication is not in peer-reviewed scientific journals. Then the cellular response (presence or absence) is observed from 1127 human, rat/mouse, and other species cells. Seventy different tissue/cell types have been used to evaluate the effect of weak radiofrequency radiation from mobile phones. We used peer-reviewed manuscripts for this analysis, which were published in PubMed and IEEE database.

2.2. Analysis of raw data

A meta-analysis combines results from separate studies of common endpoints. Inter-study heterogeneity of in vitro studies of RF is low in our case indicating the plausibility of carrying out a meta-analysis. In experimental protocols that others have considered a few variables such as carrier frequency, specific absorption rate (SAR), modulation method, and exposure time. However, no analysis has evaluated the cumulative effect as measured by SAR $\times$ exposure time) to estimate the cumulative energy absorption of RF exposure for their analysis.

On a worldwide basis, 3G/Universal Mobile Telecommunications System (UMTS) uses 1885–2025 MHz and 2110–2200 MHz while GSM uses 900, 1800 MHz. In UMTS, both the carrier frequency and the modulation method differ greatly from GSM, and thus different biological responses can be expected. As carrier frequency and modulation formats differ greatly across wireless standards, it is possible that different biological responses may be expected or observed. To account for this, we pool the experimental data based on used frequencies and SAR levels. Our analysis considered the effect of several subgroups of frequency and SAR, as follows: (i) all frequencies, (ii) $800 \leq f \leq 1000$ MHz (iii) $1000 \leq f \leq 1500$ MHz (iv) $1500 \leq f \leq 2000$ MHz, (v) $2000 \leq f \leq 2450$ MHz, (vi) all SAR levels, (vii) $0 < SAR \leq 2$ W/kg, (viii) $2 < SAR \leq 5$ W/kg (ix) $5 < SAR \leq 10$ W/kg and (x) $10 < SAR \leq 20$ W/kg and (xi) $20 < SAR \leq 50$ W/kg and (xii) all SAR values. Although there were Wi-Fi and other technologies that use 2450 MHz frequency, we did not consider this. Our study evaluated solely those experiments that simulated mobile phone exposures.

2.3. Statistical analysis

All studies use a measure of statistical significance to analyze their data and to come up with the final analysis of whether the hypothesis of the radiofrequency radiation affects biological cells. In order to detect whether a frequency, modulation format, polarity, and exposure levels may affect the biological impact of RF, we considered all experiments under exposure condition groupings as outlined in the analysis section. We investigated whether the results reported in the literature indicated a potential effect. We tested whether the probability of a positive effect being reported in the literature was statistically different from no effect

being reported. In statistics, the binomial distribution is the base for the standard binomial test of statistical significance. Generally, this method is used to observe the significance of the success-failure experiments (in our case, cellular response: presence or absence). Therefore, in this paper, we used this knowledge to evaluate the overall statistical significance. The null hypothesis in this analysis is that the probability of an experiment showing an effect (cellular response: presence or absence) or not is equal. The alternative hypothesis is that the probabilities are statistically different.

To test the significance, a binomial probability density function was used,

$$p(k) = \binom{n}{k} p^k (1-p)^{n-k},$$

where $p(k)$ is the probability of obtaining k positive experiments (cellular response is present) in n reported experiments. If the probability that a cellular response presence or absence are equal, i.e. ($p_1 = 0.5$). The null hypothesis is rejected if $y < 0.05$, i.e., at confidence level ($p(k) < 0.05$). In this analysis, probability values of $p < 0.05$ were considered to be significant. The MATLAB (MathWorks Inc., Natick, MA, USA) R2013a has been used to carry out analysis on a computer with an Intel Core Intel Core i7 CPU.

3. Results

The raw data presented in Tables 11–42 (please see Appendix) specifies the variables that were in the non-thermal radio-frequency electromagnetic field exposure conditions and experimental protocols used in the investigations. Overview of the year of publication, a number of publications are analyzed in Table 1. Cellular response (presence or absence) is observed in (Table 2), human cells (746 experiments in Table 3), rat or mouse cells (338 experiments in Table 4) and other species, such as chicken, rabbit, pig, frog, snail (43 experiments in Table 5). We grouped different experimental techniques (i) cell structure (cell proliferation, cell differentiation, cell viability, cell morphology, apoptosis), (ii) cell functions (enzyme activity, calcium concentration, signal transductions, membrane potential, membrane stability) and (iii) DNA (Chromosome aberration, micronucleus assay, DNA damage, oxidative stress, DNA single-strand breaks, DNA double-strand breaks, genotoxicity, gene expression, protein expression, ROS production) in Table 6.

We also consider the effects of the different carrier frequency, polarity and modulation formats and specific absorption rate (SAR). In order to do so, we pooled experimental data, based on used frequencies (Table 7), SAR levels (Table 8) and radiation exposure facility (Table 9) used in each experiment of the 300 publications. Cells exposed to RF radiation in vitro experiments that reported results (cellular response (presence or absence)) for different exposure conditions are shown: (i) percentage of cellular response in Figs. 1–3, (ii) classification of experimental techniques in Fig. 4, (iii) frequency of RF fields in Fig. 5, (iv) used SAR levels in Fig. 6, (v) modulation techniques of mobile communication in Fig. 7, and (vi) radiation exposure facility details in Fig. 8.

In our final analysis, we pooled the cells that showed a statistically significant difference for human cells and rat/mouse cells. These analyses showed a statistically significant difference in 7 (out of 16) human cells and 3 (out of 6) rat/mouse cells and 2 (out of 2) cells from other species in Table 10. Our analyses of reported results suggest that substantial studies on faster-growing human cells undergo cell changes due to radiofrequency radiation (45.3%), and this should not be ignored. In contrast, the results obtained from studies on rat/mouse cells indicate that the majority support the no cell changes (52.7%) that occur when exposed to radiofrequency radiation.

Furthermore, when radiofrequency, exposure and individual cell types are all considered, it is clear that potential non-thermal effects of

Table 1

Overview of the published year: Cellular response (presence or absence) for cultured human, rat/mouse and other species cells (1127 in vitro exposures) pooling data from 300 peer-reviewed scientific articles.

Published Year	Number of	Number of	Cellular Response		p - value
	Publications	Exposures	PRESENCE	ABSENCE	
1990	3	3	0 (0%)	3 (100%)	0.125
1991	5	9	7 (77.8%)	2 (22.2%)	0.070
1992	6	20	15 (75%)	5 (25%)	0.015
1993	7	23	20 (86.9%)	3 (13.1%)	2.111e-04
1994	3	12	4 (33.3%)	8 (66.6%)	0.121
1995	4	8	8 (100%)	0 (0%)	0.004
1996	4	7	7 (100%)	0 (0%)	0.008
1997	12	42	11 (26.2%)	31 (73.8%)	9.733e-04
1998	2	16	16 (100%)	0 (0%)	1.526e-05
1999	5	15	10 (66.6%)	5 (33.3%)	0.092
2000	5	20	12 (60%)	8 (40%)	0.121
2001	11	48	15 (31.3%)	33 (68.7%)	0.004
2002	12	59	33 (55.9%)	26 (44.1%)	0.0687
2003	7	29	7 (24.1%)	22 (75.8%)	0.003
2004	13	46	21 (45.7%)	25 (54.3%)	0.098
2005	19	79	27 (34.2%)	52 (65.8%)	0.002
2006	36	163	37 (22.7%)	126 (77.3%)	5.251e-13
2007	18	86	31 (36.1%)	55 (63.9%)	0.003
2008	28	73	44 (60.2%)	29 (39.8%)	0.020
2009	20	86	43 (50%)	43 (50%)	0.085
2010	12	58	28 (48.3%)	30 (51.7%)	0.101
2011	16	45	18 (40%)	27 (60%)	0.048
2012	14	45	27 (60%)	18 (40%)	0.048
2013	13	44	31 (70.5%)	13 (29.5%)	0.003
2014	14	62	42 (67.7%)	20 (32.3%)	0.002
2015	10	29	16 (55.2%)	13 (44.8%)	0.126
Total	300	1127	530 (47.1%)	597 (52.9%)	0.003

Table 2

Cellular response (presence or absence) for cultured human, rat/mouse and other species cells (1127 in vitro exposures) pooling data from 300 peer-reviewed scientific articles published in 1990–2015.

Exposure Details	Number of Experiments	Cellular Response		p - value
		PRESENCE	ABSENCE	
Human	746	338 (45.3%)	408 (54.7%)	0.001
Rat/mouse	338	160 (47.3%)	178 (52.7%)	0.027
Other species	43	32 (74.4%)	11 (25.6%)	6.539e-04
Total Cells	1127	530 (47.1%)	597 (52.9%)	0.003

radio-frequency fields on cell lines/types, such as human spermatozoa (based on 19 reported experiments, p-value = 0.002) and human epithelial cells (based on 89 reported experiments, p-value < 0.0001) may exist whereas for Glia (p = 0.001), Glioblastoma (p < 0.0001) and human blood lymphocytes (p < 0.0001) the evidence suggests that there are no statistically significant effects.

A pattern of cell changes (over the years) due to radiofrequency radiation can be observed from Fig. 1 and Table 1. As shown in Fig. 1, Cluster 1 (Research published between 1991 and 2000) and Cluster 3 (Research published between 2012 and 2015) show the potential cell changes due to radiofrequency radiation. In contrast, the results published between 2001 and 2011 show no cell changes. We also observed this pattern when we consider Human studies (Fig. 2) and animal studies (Fig. 3), separately. This observation should be further analyzed.

In non-ionizing radiation, the acute effects are determined by the intensity of the radiation or fields, and in most cases, cumulative effects (a series of repeated exposure) are not assumed to occur (Halgamuge, 2013). Consequently, in this study, we have further analyzed the data taking into account the cumulative effects (SAR × exposure time) to acquire the cumulative energy absorption of experiments, which we believe, have not been fully considered previously. Cellular response (presence or absence): cells exposed to RF radiation in vitro

experiments that reported results for different exposed cells are shown in Figs. 9–11 (please see Appendix). Our findings from the presently available literature are inconclusive (as we found both negative and positive effects around 50%).

It is emphasized that our statistical test indicates solely the presence or absence of cellular responses reported in the literature and if this difference is statistically significant. A higher number of positive effects will be indicative of potential effect however many confounding factors could bias this analysis, including that it may be more likely for a positive result to be published instead of a negative. Nonetheless, this discrepancy is exciting and warrants further investigation.

4. Discussion

Our results suggest that a large proportion of in vitro studies on human cells experience changes due to radiofrequency radiation (45.3%). If cells are further examined regarding their extent of differentiation, then we find that more differentiated mature cells such as lymphocytes are not responsive to RF, in contrast to less differentiated cells. Results obtained from studies on differentiated rat/mouse cells indicate that the majority undergo no cell changes (52.7%) that occur when exposed to radiofrequency radiation. However, like the human cell dataset, substantial percentages do not comply with this hypothesis. Thus, a substantial subset of the full dataset does not comply with the hypothesis that radiofrequency fields affect living organisms. However, due to the inconsistency of results, it may be safer to look at other possible explanation. One possibility is that, as Portelli and Barnes (2013) (Portelli et al., 2013) have noted, the experiment procedure is not consistently followed throughout the majority of these studies. Lai (2011) (Lai) has shown that sponsorship bias is also involved, with those studies sponsored by industry tending to find few effects, in contrast to studies that are independently supported. As more published studies have been funded through industry or military sponsorship, this could also account for some of these results. Carpenter (2019) (Carpenter, 2019) has extended these findings of sponsorship bias in a

Table 3

Human cells: Cellular response (presence or absence) for cultured human cells (1127 in vitro exposures) pooling data from 300 peer-reviewed scientific articles published in 1990–2015. Statistical significant cell groups are marked in bold italic font.

Cell Line	Number of Experiments	Cellular Response		p - value
		PRESENCE	ABSENCE	
Human Blood Cells	277	121 (43.6%)	156 (56.3%)	0.005
Human peripheral blood mononuclear cells (PBMC) (Liu et al., 2012; Atasoy et al., 2009; Stankiewicz et al., 2006; Capri et al., 2004a, 2004b, 2006)	13	1 (7.6%)	12 (92.3%)	0.002
Human Blood Lymphocytes (Kazemi et al., 2015; Sannino et al., 2014; Vijayalaxmi et al., 2013; Waldmann et al., 2013; Zeni et al., 2012a, 2012b; El-Abd and Eltoweissy, 2012; Lu et al., 2012; Esmekaya et al., 2011; Sannino et al., 2011; Gerner et al., 2010; Zhijian et al., 2010; Hansteen et al., 2009; Sannino et al., 2009a,b; Mazor et al., 2008; Manti et al., 2008; Palumbo et al., 2008; Schwarz et al., 2008; Baohong et al., 2007; Stronati et al., 2006; Vijayalaxmi, 2006; Scarfi et al., 2006; Tusch et al., 2006; Lantow et al., 2006a,b; Remondini et al., 2006; Zotti-Martelli et al., 2005; Baohong et al., 2005; Lim et al., 2005; Markova et al., 2005; Wang et al., 2005a,b; Zeni et al., 2005; Belyaev et al., 2005; Sarimov et al., 2004; Zeni et al., 2003; Mashevich et al., 2003; McNamee et al., 2003; Zhang et al., 2003; Dabrowski et al., 2003; Zhang et al., 2002; D'Ambrosio et al., 2002; Tice et al., 2002; Vijayalaxmi et al., 2001a, 2001b; Vijayalaxmi and Moros, 2001; Maes et al., 2001)	161	61 (37.8%)	100 (62.2%)	5.482e-04
Human Monocytes, monocytic cells (U937), Human Mono Mac 6 cells (MM6) (Stankiewicz et al., 2006; Kazemi et al., 2015; Lantow et al., 2006a, 2006b, 2006c; Remondini et al., 2006; Lim et al., 2005; Dabrowski et al., 2003; Chauhan et al., 2006a, 2007a, 2007b; Gurisik et al., 2006; Simkó et al., 2006)	21	6 (28.5%)	15 (71.5%)	0.026
Human B lymphoblastoid cell (TK6, CCRF-CEM) (Chauhan et al., 2006b, 2007a; Zhijian et al., 2013)	7	2 (28.6%)	5 (71.4%)	0.164
Human T lymphoblastoid cells (Molt-4 T) (Zhijian et al., 2010; Trivino et al., 2012; Hook et al., 2004a; Phillips et al., 1998)	22	13 (59.1%)	9 (40.9%)	0.119
Human Leukocytes, human blood neutrophils, human white blood cells (Gerner et al., 2010; Remondini et al., 2006; Zeni et al., 2005, 2007a, 2008; Tice et al., 2002; Zhijian et al., 2009; Aly et al., 2008; Lee et al., 2006; McNamee et al., 2002a, 2002b)	13	6 (46.2%)	7 (53.8%)	0.209
Human leukemia cells (HL60), human erythroleukemic cells (K562) (Remondini et al., 2006; Chauhan et al., 2006a, 2007a; Lantow et al., 2006c; Koyama et al., 2015; Speit et al., 2013; Jin et al., 2012; Lee et al., 2005)	16	8 (50.0%)	8 (50.0%)	0.196
Human Whole Blood Samples, blood platelets, hemoglobin (HbA), human blood serum (Riazi et al., 2009; Tiwari et al., 2008; Stopczyk et al., 2002; Pashovkina and Akoev, 2001a, 2001b)	24	24 (100%)	0 (0%)	5.961e-08
Human Brain cells	173	51 (29.4%)	122 (70.5%)	2.014e-08
Glial cells: Astroglial (astrocytes) cells, astrocytoma cells and microglial cells (CHME5, N9) (Remondini et al., 2006; Sakurai et al., 2011; Poulietier et al., 2011; Yang et al., 2010; Campisi et al., 2010; Thorlin et al., 2006; French et al., 1997)	17	2 (11.8%)	15 (88.2%)	0.001
Human glioma cells (LN71, MO54, H4, SHG44) (Liu et al., 2012; Cleary, 1995; Sekijima et al., 2010; Ding et al., 2009; Cao et al., 2009; Hoyto et al., 2007; Takashima et al., 2006; Miyakoshi et al., 2005; Tian et al., 2002; Stagg et al., 1997)	37	22 (59.5%)	15 (13.5%)	0.068
Human glioblastoma cells (U87MG, U251MG, A172, T98, U87) (Chauhan et al., 2007b; Poulietier et al., 2011; Thorlin et al., 2006; French et al., 1997; Sekijima et al., 2010; Ding et al., 2009; Liu et al., 2015; Kang et al., 2014; Hirose et al., 2006, 2007; Qutob et al., 2006; Sakuma et al., 2006; Wang et al., 2006; Higashikubo et al., 2001; Malyapa et al., 1997a, 1997b)	72	9 (12.5%)	63 (87.5%)	1.802e-11
Human neuroblastoma cells (NB69, SK-N-SH, SH-SY5Y, NG108-15) (Remondini et al., 2006; Gurisik et al., 2006; Poulietier et al., 2010, 2011; Hoyto et al., 2007; Kang et al., 2014; Calabro et al., 2012; Trillo et al., 2011; Luukkonen et al., 2009, 2010; Billaud et al., 2009a; Höytö et al., 2008a; Buttiglione et al., 2007; Joubert et al., 2006; Merola et al., 2006)	42	18 (42.9%)	24 (57.1%)	0.080
Human lymnaea neurons (Bolshakov and Alekseev, 1992)	5	0 (0%)	5 (100%)	0.031
Human Skin/Fibroblasts Cells	52	14 (26.9%)	38 (73.1%)	8.329e-04
Human primary, epidermal keratinocytes, keratinocytes cells (HaCaT) (Hintzsche et al., 2012; Roux et al., 2011; Sanchez et al., 2006, 2007)	6	1 (16.7%)	5 (83.3%)	0.093
Human fibroblasts, human diploid fibroblasts, human dermal fibroblasts (Schwarz et al., 2008; Sanchez et al., 2006, 2007; Diem et al., 2005; Pacini et al., 2002; Li et al., 1999)	12	5 (41.6%)	7 (58.3%)	0.193
Human skin fibroblasts, human dermal papilla cells (hDPC) (Sanchez et al., 2006; Diem et al., 2005; Xu et al., 2013; Yoon et al., 2011; Sannino et al., 2009b; Speit et al., 2007)	6	3 (50%)	3 (50%)	0.313
Human fibroblast (IMR-90) (Sekijima et al., 2010; Hirose et al., 2006, 2007; Sakuma et al., 2006)	28	5 (17.8%)	23 (92.2%)	3.661e-04
Human Carcinoma Cells	40	19 (47.5%)	21 (52.5%)	0.119
Jurkat Cells, Jurkat human T Lymphoma cells (Gerner et al., 2010; Palumbo et al., 2008; Cranfield et al., 2001; Lee et al., 2006; Brescia et al., 2009; Huang et al., 2008a; Peinnequin et al., 2000)	22	2 (9%)	20 (90.9%)	5.507e-05
Embryonic carcinoma (EC-P19), Epidermoid carcinoma (Caraglia et al., 2005; Cysz et al., 2004)	8	8 (100%)	0 (0%)	0.004
Hepatocarcinoma cell line HepG2 (Trillo et al., 2011; Ozgur et al., 2014)	10	9 (90%)	1 (10%)	0.009
Human Epithelial Cells	89	62 (69.7%)	27 (30.3%)	7.783e-05
Human lens epithelial cells (HLECs), eye lens epithelial cells (Xu et al., 2013; Zhang et al., 2013; Ni et al., 2013; Yao et al., 2008a, 2008b; Wu et al., 2008; Yu et al., 2008; Li et al., 2007; Lixia et al., 2006; Sun et al., 2006a, 2006b)	38	30 (78.9%)	8 (21.1%)	1.779e-04
Human epithelial amnion cells (AMA), bronchial epithelial cells (BEAS-2B), human ovarian surface epithelial cells (OSE-80PC), epithelial carcinoma cells, Human HeLa, HeLa S3 (Yoon et al., 2011; Kim et al., 2015; Friedman et al., 2007; Vanderwaal et al., 2006; Laszlo et al., 2005; Kwee et al., 2001; Velizarov et al., 1999; Kwee and Raskmark, 1998; Cleary et al., 1997)	22	22 (100%)	0 (0%)	2.384e-07
Human amniotic cell, amniotic epithelial cells (FL) (Xu et al., 2013; Bourthoumieu et al., 2010, 2011, 2013; Sun et al., 2012, 2013)	29	10 (34.5%)	19 (65.5%)	0.037
MCF Breast Adenocarcinoma Cells	26	11 (42.3%)	15 (57.7%)	0.115
Human breast carcinoma cells (MCF-7) (Cig and Naziroglu, 2015; Kahya et al., 2014; Stander et al., 2011; Lee et al., 2011; Kim et al., 2010; Zeng et al., 2006)	24	9 (37.5%)	15 (62.5%)	0.077
Human breast epithelial cells (MCF10A), breast fibroblasts (Esmekaya et al., 2013; Hong et al., 2012; Kim et al., 2012)	2	2 (100%)	0 (0%)	0.250
Human Spermatozoa (Zalata et al., 2015; Wang et al., 2015; Gorpichenko et al., 2014; Ahmed and Baig, 2011; Dkhil et al., 2011; Falzone et al., 2008, 2010, 2011; Iulii et al., 2009; Agarwal et al., 2009; Eroglu et al., 2006)	19	16 (84.2%)	3 (15.8%)	0.002

(continued on next page)

Table 3 (continued)

Cell Line	Number of Experiments	Cellular Response		p - value
		PRESENCE	ABSENCE	
Human Endothelial cells (EA.hy926, EA.hy926v1 and EA.hy296) (Leszczynski et al., 2002, 2004; Remondini et al., 2006; Xu et al., 2013; Vanderwaal et al., 2006; Nylund et al., 2009, 2010; Nylund and Leszczynski, 2006; Nylund and Leszczynski, 2004; Leszczynski and Joenväärä, 2001)	16	11 (68.7%)	5 (31.3%)	0.225
Human Trophoblast cells (HTR- 8/SV neo cells)/Human lipid membrane (liposomes) (Cervellati et al., 2009, 2013; Franzellitti et al., 2008, 2010; Valbonesi et al., 2008; Ramundo-Orlando et al., 1993, 2004; Bergqvist et al., 1994; Saalman et al., 1991)	27	13 (48.1%)	14 (51.9%)	0.149
Mast cell lines (HMC-1) - mast cell leukemia (Harvey and French, 1999)	1	1 (100%)	0 (0%)	0.500
FC2 cells, human-hamster hybrid cells (AL) (Hintzsche et al., 2012; Schrader et al., 2008, 2011)	12	6 (50%)	6 (50%)	0.225
Human adipose derived stem cells (Lee et al., 2014)	1	0 (0%)	1 (100%)	0.500
Human dendritic cells (Zhou et al., 2008)	3	3 (100%)	0 (0%)	0.125
Human embryonic kidney cells (HEK 293 T) (Sefidbakht et al., 2014)	5	5 (100%)	0 (0%)	0.031
Human umbilical vein endothelial cells (HUVEC) (Xu et al., 2013)	2	2 (100%)	0 (0%)	0.250
Human hair cell, human scalp hair follicle (Yoon et al., 2011; Cam and Seyhan, 2012)	3	3 (100%)	0 (0%)	0.125
Total	746	338 (45.3%)	408 (54.7%)	0.001

Table 4

Rat/Mouse cells: Cellular response (presence or absence) for cultured rat/mouse cells (1127 in vitro exposures) pooling data from 300 peer-reviewed scientific articles published in 1990–2015. Statistical significant cell groups are marked in bold italic font.

Cell Line	Number of Experiments	Cellular Response		p - value
		PRESENCE	ABSENCE	
Rat blood lymphocytes (Kumar et al., 2011; Gajski and Garaj-Vrhovac, 2009; Zmyslony et al., 2004)	4	3 (75%)	1 (25%)	0.250
Rat Brain Cells	73	45 (61.6%)	28 (38.4%)	0.013
Rat primary microglial cells, mouse microglial cells (N9) (Yang et al., 2010; Lu et al., 2014; Hirose et al., 2010)	9	6 (66.6%)	3 (33.3%)	0.164
Rat glioblastoma cells (C6, C6BU-1) (Liu et al., 2012; Hoyto et al., 2007; Stagg et al., 1997; Dutta et al., 1992)	6	1 (16.7%)	5 (83.3%)	0.094
Rat astrocytes (Liu et al., 2012; Lee et al., 2006; Campisi et al., 2010; Hoyto et al., 2007; Poullietier et al., 2010; Xu et al., 2013; Lu et al., 2014; Terro et al., 2012; Zhao et al., 2007a; Franke et al., 2005a; Schirmacher et al., 2000)	9	2 (22.2%)	7 (77.8%)	0.070
Rat brain capillary endothelial cells (BCEC) (Franke et al., 2005a; Schirmacher et al., 2000)	5	4 (80%)	1 (20%)	0.156
Mouse neuroblastoma cells (N2a, N18TG-2, NG108-15) (Dutta et al., 1992; Moquet et al., 2008)	4	0 (0%)	4 (100%)	0.062
Rat neurons, murine cholinergic neurons (SN56) (Poullietier et al., 2011; Terro et al., 2012; Zhao et al., 2007a, 2007b; Ghazizadeh and Naziroglu, 2014; Moretti et al., 2013; Liu et al., 2011; Vecchio et al., 2009a, 2009b; Joubert et al., 2007, 2008; Platano et al., 2007)	28	23 (82.1%)	5 (17.9%)	3.661e-04
Rat/mouse brain cells (Paparini et al., 2008; Paulraj and Behari, 2006; Takahashi et al., 2002; Morrissey et al., 1999; Lai et al., 1997; Lai and Singh, 1996)	12	9 (75%)	3 (25%)	0.053
Mice retinal ganglion cells (Ghazizadeh and Naziroglu, 2014; Ahlers and Ammermüller, 2014)	12	0 (0%)	12 (100%)	2.441e-04
Rat/mouse bone marrow (Kumar et al., 2011; Rotkowska et al., 1993)	4	3 (75%)	1 (25%)	0.250
Rat bones (femur and tibia) (Kumar et al., 2015)	4	0 (0%)	4 (100%)	0.062
Mouse spermatozoa, Murine spermatocyte-derived cells (GC-2) (Duan et al., 2015; Liu et al., 2013, 2014; Aitken et al., 2005)	10	5 (50%)	5 (50%)	0.246
Embryonic mouse fibroblasts cells (C3H10T1/2, NIH3T3, L929), Mouse embryonic skin cells (M5-S), Rat1 cells (Höytö et al., 2006, 2008a, 2008b; Hoyto et al., 2007; Kang et al., 2014; Higashikubo et al., 2001; Malyapa et al., 1997a, 1997b; Yoon et al., 2011; Friedman et al., 2007; Laszlo et al., 2005; Hou et al., 2015; Yang et al., 2012; Billaudel et al., 2009b; Lee et al., 2008; Zeni et al., 2007b; Whitehead et al., 2005, 2006a, 2006b; Komatsubara et al., 2005; Wang et al., 2005b; LaGroye et al., 2004; Desta et al., 2003; Bisht et al., 2002; Li et al., 2001; Roti et al., 2001; Goswami et al., 1999; Penafiel et al., 1997a, 1997b; Litovitz et al., 1993; Balcer-Kubiczek and Harrison, 1991; Somosy et al., 1991; Krause et al., 1991)	117	30 (25.6%)	87 (74.4%)	4.274e-08
Mouse embryonic carcinoma cells (P19), Mouse embryonic stem cells, Mouse embryonic neural stem cells (BALB/c) (Chen et al., 2014; Rao et al., 2008; Nikolova et al., 2005)	9	8 (88.9%)	1 (11.1%)	0.017
Mouse lymphoma cells (L5178Y Tk +/−), Rat basophilic leukemia cells (RBL-2H3), Murine Cytolytic T lymphocytes (CTLL-2) (Kim et al., 2008; Donnellan et al., 1997; Meltz et al., 1990; Cleary et al., 1996)	4	2 (50%)	2 (50%)	0.375
Rat granulosa cells (GFSH-R17) (Diem et al., 2005)	2	2 (100%)	0 (0%)	0.250
Immortalized mouse auditory hair cells (HEI-OC1) (Huang et al., 2008b)	3	0 (0%)	3 (100%)	0.125
Rat pheochromocytoma cells (PC12) (Kang et al., 2014; Valbonesi et al., 2014; Zeni et al., 2012b; Ivaschuk et al., 1997)	16	10 (62.5%)	6 (37.5%)	0.122
Chinese Hamster Cells (CHO), Ovary (CHO-K1), Chinese hamster lung cells (CHL) (Takashima et al., 2006; Xu et al., 2013; Laszlo et al., 2005; Cleary et al., 1997; Koyama et al., 2003, 2004, 2007; Ciaravino et al., 1991; Kerbacher et al., 1990)	18	3 (16.6%)	15 (83.4%)	0.003
Chinese hamster fibroblast cells (V79) (Speit et al., 2007; Ballard et al., 2011; Trosic and Pavicic, 2009; Pavicic and Trosic, 2008; Pavicic et al., 2006)	21	14 (66.6%)	7 (33.3%)	0.055
Murine macro cells (J774.16) (Hook et al., 2004b)	2	0 (0%)	2 (100%)	0.250
Melanoma cell membrane (B16) (Moiescu et al., 2008; Phelan et al., 1992)	2	2 (100%)	0 (0%)	0.250
Rat myocytes from heart muscle, undifferentiated myoblasts and differentiated myotubes cells (C2C12) (Yoon et al., 2011; Linz et al., 1999)	4	1 (25%)	3 (75%)	0.250
Rat chemoreceptors membranes (Philippova et al., 1994)	5	4 (80%)	1 (20%)	0.156
Hamsters pineal glands cells (Sukhotina et al., 2006)	8	8 (100%)	0 (0%)	0.004
Total	338	160 (47.3%)	178 (52.7%)	0.027

Table 5

Other species cells: Cellular response (presence or absence) for cultured species cells (1127 in vitro exposures) pooling data from 300 peer-reviewed scientific articles published in 1990–2015. Statistical significant cell groups are marked in bold italic font.

Cell Line	Number of Experiments	Cellular Response		p - value
		PRESENCE	ABSENCE	
Chick embryos (Zareen et al., 2009; Shalom et al., 2002; Seaman and DeHaan, 1993)	10	10 (100%)	0 (0%)	9.765e-04
Rabbit lens, Rabbit lens epithelial cells (RLEC) (Wang et al., 2007; Yao et al., 2004)	11	9 (81.8%)	2 (18.2%)	0.027
Guinea pig cardiac myocytes, pig astrocytes (Wolke et al., 1996)	6	3 (50%)	3 (50%)	0.312
Frog Cells	12	6 (50%)	6 (50%)	0.226
Isolated frog auricle (Pakhomov et al., 1995a, 1995b)	4	4 (100%)	0 (0%)	0.063
Frog ventricular muscle (Yee et al., 1994)	3	0 (0%)	3 (100%)	0.125
Frog heart (Schwartz and Mealing, 1993)	3	0 (0%)	3 (100%)	0.125
Isolated frog nerve cord (Pakhomov, 1993)	2	2 (100%)	0 (0%)	0.250
Snail neurons (Field et al., 1993; Ginsburg et al., 1992)	4	4 (100%)	0 (0%)	0.063
Total	43	32 (74.4%)	11 (25.6%)	6.539e-04

recent analysis.

Mostly, the results from studies of the cytogenetic, gene, and protein expression after exposure to mobile phone RF fields are inconsistent to date. Research groups (Hagmar et al., 1994; Bonassi et al., 1995) confirmed that an increased chromosome aberration frequency in human blood lymphocytes connects satisfactorily with increased cancer risk in human populations. Leszczynski argues, Whitehead et al. study (Whitehead et al., 2006a) and Qutob et al. study (Qutob et al., 2006), show experimental studies can be prone to errors in the statistical methodologies concerning false discovery rates (FDR). Some have concluded that radiation of mobile phones does not affect gene expression, however, McNamee et al. among many others (McNamee et al., 2007) rejects this determination.

Schirmacher et al. (2000) (Schirmacher et al., 2000) investigated if GSM 1800, 0.3–0.46 W/kg exposures increased sucrose permeation across the BBB in vitro using rat astrocytes and porcine brain capillary endothelial cells. In contrast, after optimizing cell culture conditions, as in (Franke et al., 1999, 2000) to produce a tight barrier similar to the in vivo barrier tightness, Franke et al. (2005a) failed to reproduce observations by Schirmacher et al. (2000) even with the identical exposure setup (GSM, 1800, 1–5 days at an average SAR of 0.3 W/kg). The in vitro barrier tightness in the experiments of Franke et al. (2005a) (Franke et al., 2005a) is more comparable to that of the in vivo condition. Frank et al. (2005) (Franke et al., 2005b) used the identical optimized in vitro model of the BBB as in (Franke et al., 2005a) to investigate the effects of a generic Universal Mobile Telecommunications System (UMTS) signal on BBB tightness. C-sucrose and serum albumin permeation and by trans-endothelial electrical resistance (TEER) remained unchanged compared to sham-exposed cultures. This in vitro model of the BBB was exposed continuously for up to 84 h at an average SAR maximum of 1.8 W/kg. The BBB area of research remains challenged, and further replication studies are essential.

Many studies of weak radiofrequency electromagnetic fields and radiation have focused on animals, plants (Halgamuge et al., 2015; Sharma et al., 2009; Tkalec et al., 2005, 2007, 2009), human behavioral, and cell cultures. We aim to advance knowledge on the effects of electromagnetic fields on biological tissue by using cell cultures in

Table 6

Different experimental techniques: Cellular response (presence or absence) for cultured human, rat/mouse and other species cells (1127 in vitro exposures) pooling data from 300 peer-reviewed scientific articles.

Technique	Different Methods	Number of Experiments	Cellular Response		p - value
			PRESENCE	ABSENCE	
Cells	Cell proliferation, cell differentiation, cell viability, cell morphology, apoptosis	173	109 (63.1%)	64 (36.9%)	1.684e-04
Cell Functions	Enzyme activity, calcium concentration, signal transductions, membrane potential, membrane stability	48	25 (52.1%)	23 (47.9%)	0.110
DNA	Chromosome aberration, micronucleus assay, DNA damage, oxidative stress, DNA single-strand breaks, DNA double-strand breaks, genotoxicity, gene expression, protein expression, ROS production	348	178 (51.2%)	170 (48.8%)	0.039
Total		569	312 (54.8%)	257 (45.2%)	0.002

Table 7

Meta-analysis: Different frequency levels: Cellular response (presence or absence) for cultured human, rat/mouse and other species cells (1127 in vitro exposures) pooling data from 300 peer-reviewed scientific articles published in 1990–2015.

Exposure Details	Number of Experiments	Cellular Response		p - value
		PRESENCE	ABSENCE	
$800 \leq f \leq 1000$ MHz	464	239 (51.5%)	225 (48.5%)	0.030
$1000 \leq f \leq 1500$ MHz	11	9 (81.8%)	2 (18.2%)	0.027
$1500 \leq f \leq 2000$ MHz	409	233 (56.9%)	176 (43.1%)	7.404e-04
$2000 \leq f \leq 2450$ MHz	243	88 (36.2%)	155 (63.8%)	4.592e-06
All frequencies	1127	569 (50.5%)	558 (49.5%)	0.023

Table 8

Meta-analysis: Different SAR levels: Cellular response (presence or absence) for cultured human, rat/mouse and other species cells (1127 in vitro exposures) pooling data from 300 peer-reviewed scientific articles published in 1990–2015. Please note that SAR values was not given in 29 experiments/exposures.

Exposure Details	Number of Experiments	Cellular Response		p - value
		PRESENCE	ABSENCE	
$0 < SAR \leq 2$ W/kg	689	357 (51.8%)	332 (48.2%)	0.019
$2 < SAR \leq 5$ W/kg	221	111 (50.2%)	110 (49.8%)	0.053
$5 < SAR \leq 10$ W/kg	112	45 (40.2%)	67 (59.8%)	0.008
$10 < SAR \leq 20$ W/kg	36	13 (36.1%)	23 (63.9%)	0.034
$20 < SAR \leq 50$ W/kg	40	16 (40.0%)	24 (60.0%)	9.124e-06
All SAR	1098	542 (49.4%)	556 (50.6%)	0.022

vitro. It cannot be expected that humans similarly respond to EMF as do cell cultures. Nonetheless, studies on simple biological systems can add to our understanding of the fundamental interaction mechanisms and which proteins in living matter are susceptible to electromagnetic radiation and fields. This knowledge is vital for the development of dose-response relationships on which guidelines as required by bodies [such

Table 9

Meta-analysis: Radiation exposure facility used in the experiments Cellular response (presence or absence) for cultured human, rat/mouse and other species cells (1127 in vitro exposures) pooling data from 300 peer-reviewed scientific articles published in 1990–2015. Please note that SAR values was not given in 29 experiments/exposures.

Exposure Chamber Details	Number of Experiments	Cellular Response		p - value
		PRESENCE	ABSENCE	
Waveguide (rectangular, circular, cylindrical)	118	61 (51.6%)	57 (48.3%)	0.068
TEM Cell	39	19 (48.7%)	20 (51.2%)	0.125
GTEM cell	8	7 (87.5%)	1 (12.5%)	0.031
Anechoic chamber anechoic room	17	6 (35.2%)	11 (64.7%)	0.094
Radial transmission line (RTL)	15	1 (6.70%)	14 (93.3%)	4.577e-04
Wire patch cell (WPC)	16	7 (43.7%)	9 (56.2%)	0.174
Others	44	26 (59.1%)	18 (40.9%)	0.058
Not Given	47	36 (76.6%)	11 (23.4%)	1.237e-04
Total	304	163(53.6%)	141 (46.3%)	0.021

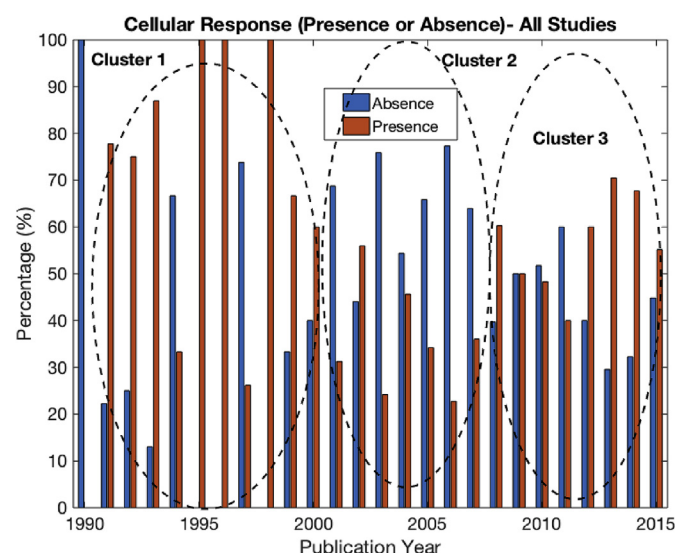


Fig. 1. Overview of the published year - All cells exposed to RF radiation in vitro experiments that reported results published in 1990–2015 (cellular response (presence or absence)) for different exposure conditions (frequency, SAR and exposure durations).

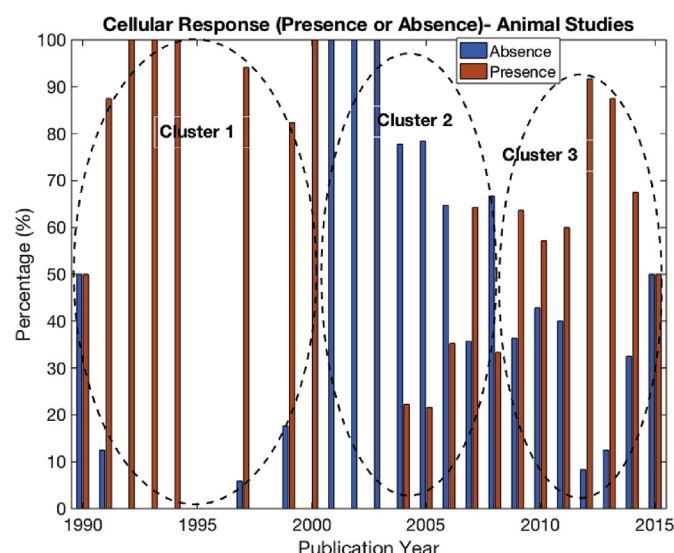


Fig. 3. Overview of the published year - Animal cells exposed to RF radiation in vitro experiments that reported results published in 1990–2015 (cellular response (presence or absence)) for different exposure conditions (frequency, SAR and exposure durations).

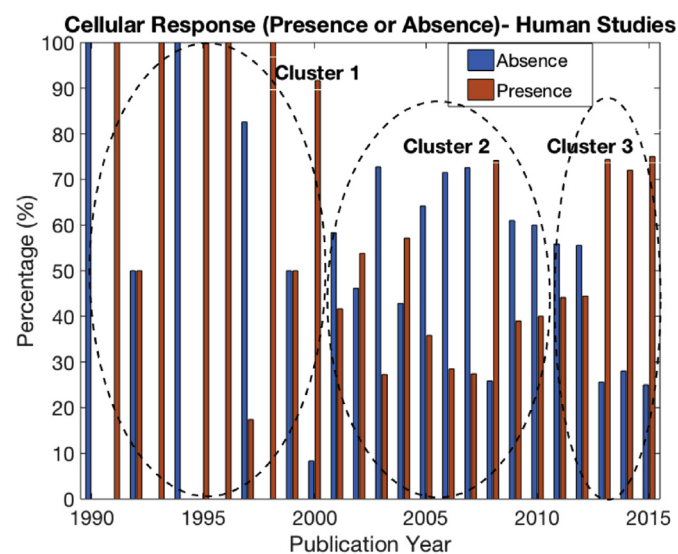


Fig. 2. Overview of the published year - Human cells exposed to RF radiation in vitro experiments that reported results published in 1990–2015 (cellular response (presence or absence)) for different exposure conditions (frequency, SAR and exposure durations).

as (ICNIRP), IEEE, International Agency for Research on Cancer (IARC), and WHO], to have assurance results consequently can be incorporated in the health-risk assessment procedure.

Despite the considerable number of publications, demonstrating biological effects of electromagnetic radiation from mobile communication systems in in-vitro systems, some authors, such as Vijayalaxmi (Vijayalaxmi et al., 1997, 2000, 2001a, 2001b, 2013; Vijayalaxmi, 2006), reject this finding. For example, according to Gurisik et al. there is no substantial evidence to show that the non-thermal radiofrequency fields are used to transmit information in mobile phones, and wireless broadband devices have detrimental effects on human body (Gurisik et al., 2006). In fact, some results published by different research groups even contradict each other, which provide weight to the importance of a conclusive investigation that combines studies as we have done here.

Despite the quite considerable number of publications, demonstrating the biological effects of electromagnetic radiation from mobile communication systems, some authors decline this argument. For example, according to Gurisik et al. there is no substantial evidence to show that the non-thermal radiofrequency fields are used to transmit information in mobile phones, and wireless broadband devices have detrimental effects on the human body (Gurisik et al., 2006). In fact, some results published by different research groups even contradict each other, which provide weight to the importance of a conclusive

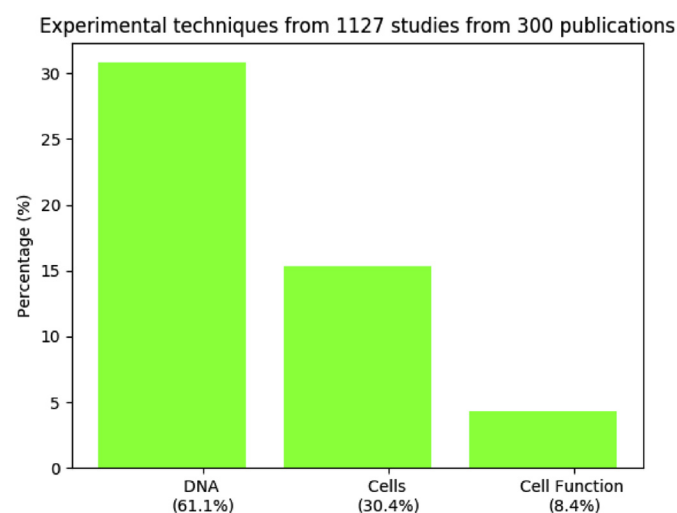


Fig. 4. Classification of experimental techniques observed from 1127 studies from 300 peer-reviewed scientific publications (1990–2015). Cells exposed to RF radiation in vitro experiments that reported results (cellular response (presence or absence)) for different exposure conditions (frequency, SAR and exposure durations). These techniques are classified as (i) cells (cell proliferation, cell differentiation, cell viability, cell morphology, apoptosis), (ii) cell functions (Enzyme activity, calcium concentration, signal transductions, membrane potential, membrane stability), and (iii) DNA (chromosome aberration, micronucleus assay, DNA damage, oxidative stress, DNA single-strand breaks, DNA double-strand breaks, genotoxicity, gene expression, protein expression, ROS production).

investigation. The overall results from the presently available literature are inconclusive (as we found both negative and positive effects around 50%). Hence, uncertainty still exists on the possible biological and health effects of electromagnetic fields from mobile phone RF exposure. Consequently, additional research is required, on top of the replication studies, to broaden the knowledge about the potential health effects of RF-EMFs on humans.

Methodological limitations or shortcomings (Vanderstraeten and Verschaeve, 2008) limit some of the reported positive findings. Even though the variable temperature threshold for the heat shock response, depending on physicochemical parameters such as pH (Coss et al., 2004), the omission of thermal induction of the heat shock response in vitro experiment is challenging (Gaestel, 2010). The sophisticated screening techniques of proteomics (in the investigate for biological and

health effects of electromagnetic fields), is an intensely debated topic (Leszczynski and Meltz, 2006). Additionally, positive in vitro experiments are needed to support appropriate in vivo studies (Meltz, 2003). Some old in vitro studies between 1973 and 1990 significant effects were found (Seaman and Wachtel, 1978; McRee and Wachtel, 1982; Arber and Lin, 1985; Yao, 1976, 1982; Alam et al., 1978; Lloyd et al., 1984, 1986) and some with no significant effects (Meltz et al., 1989, 1990; Kerbacher et al., 1990; McRee and Wachtel, 1980; Hamrick, 1973; Ciaravino et al., 1987; Meltz and Walker, 1987) on mobile phone radiation. Besides this, recent reports reveal inconsistent results: Kim et al. (2012) (Kim et al., 2012) has found no statistically significant alteration in HSP27 and ERK1/2 in MCF10A cells due to CDMA or WCDMA radiation. Oppose to this Sun et al. (2012) (Sun et al., 2012) has found significantly induced EGF receptor clustering and enhanced phosphorylation on the tyrosine-1173 residue of Human amniotic cells.

In some studies, cells are exposed to RF radiation at extremely high SARs of 200 W/kg (Takashima et al., 2006; Wang et al., 2005b, 2006; Koyama et al., 2004), 104–200 W/kg (Lloyd et al., 1984, 1986), 100 W/kg (Tian et al., 2002; Wang et al., 2005b, 2006; Cleary et al., 1997; Komatsubara et al., 2005; Koyama et al., 2003, 2004), 51.75 and 103.5 W/kg (Parker et al., 1988), 90 W/kg (D'Ambrosio et al., 1995), 75–79 W/kg (Cleary, 1995; Koyama et al., 2003; Maes et al., 1993) and 50 W/kg (Cleary, 1995; Tian et al., 2002; Wang et al., 2005b, 2006; Komatsubara et al., 2005; Rao et al., 2008; Koyama et al., 2003, 2004). The reason for using some high SAR values from the experiments is to compare the results with low SAR values. Despite this, there were some poorly controlled experiments in terms of exposure conditions, confirmation of results using Reverse Transcriptase-Polymerase Chain Reaction (RT-PCR) and without inferential statistics (Lee et al., 2005; Pacini et al., 2002; Harvey and French, 1999) and insignificance of using accurate methods to analyze the data (Armitage, 1984). Some experimental studies have not provided sufficient descriptions of their methodology, dosimetry (Erogul et al., 2006; Inoue et al., 2008; Hamann et al., 2006), which limits our ability to interpret the results their results, although many of these are of excellent quality (Marino et al., 2011). Zhao et al. (2007a) experimented by positioning a cell phone on top of a Petri dish that contained cell cultures; nonetheless, they did not measure the SAR values. Nevertheless, in some investigations, no dosimetry was disclosed (Zhao et al., 2007a; Zareen et al., 2009). Biological endpoints and the exposure parameters change the suitable exposure systems for in vitro RF experimental research, (Paffi et al., 2010). Besides, the quality of exposure systems has recently been significantly enhanced, and the use of justifiable experimental protocols (blinded exposure, sham exposure, positive and negative controls) has

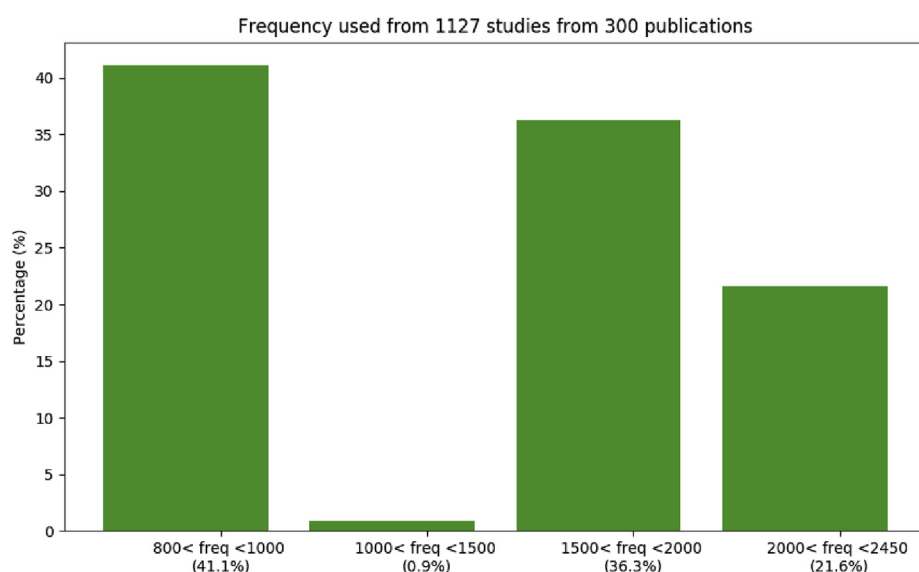


Fig. 5. Frequency range observed from 1127 studies from 300 peer-reviewed scientific publications (1990–2015). Cells exposed to RF radiation in vitro experiments that reported results (cellular response (presence or absence)) for different exposure conditions (frequency, SAR and exposure durations). Frequency values are shown in MHz.

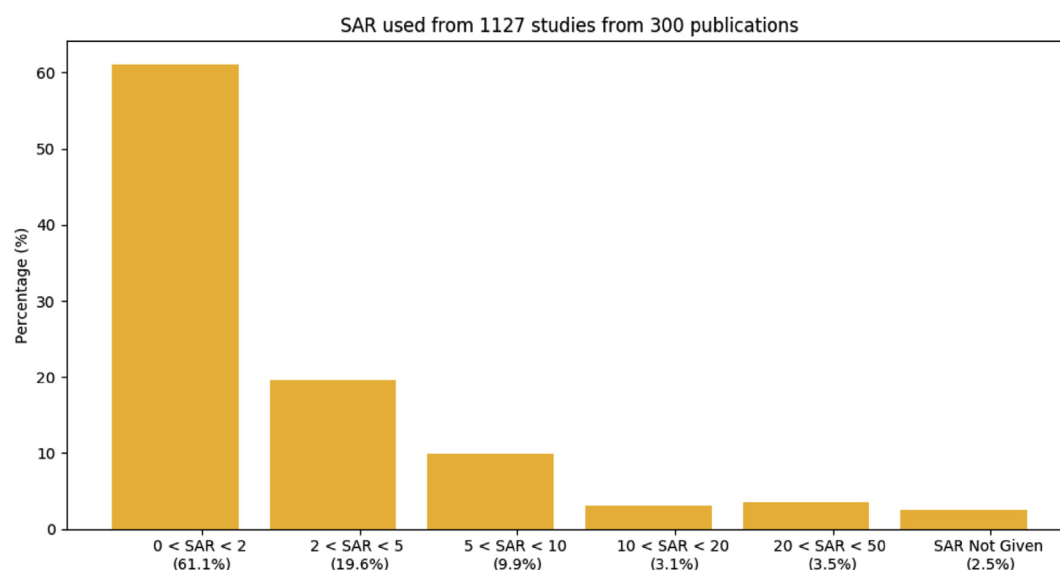


Fig. 6. Specific Absorption Rate (SAR) observed from 1127 studies from 300 peer-reviewed scientific publications (1990–2015). Cells exposed to RF radiation in vitro experiments that reported results (cellular response (presence or absence)) for different exposure conditions (frequency, SAR and exposure durations). SAR values are shown in W/kg.

developed a guide for the scientific community (Paffi et al., 2010).

Regardless of this, some human cell culture groups show the significant effects, for a example, human blood cells (Molt-4 T lymphoblastoid cells, human leukemia cells (HL-60), human whole blood samples), brain cell (neurons, astrocytes, brain capillary endothelial cells), skin/fibroblasts cells (human diploid fibroblasts, human fibroblasts), Chinese hamster cells (V79), carcinoma cells (Embryonic carcinoma), human lens epithelial cells (human epithelial amnion cells), MCF breast adenocarcinoma cells (MCF10A), monocytic (U937), human hair cell, human trophoblast cells (HTR- 8/SVneo cells), human spermatozoa, mast cell lines (HMC-1) and human endothelial cell (EA.hy926).

Lai and Singh (Lai et al., 1997; Lai and Singh, 1995, 1996) have reported, consistently, a significant increase in DNA [single- and double-strand breaks (SSBs and DSBs)], in the rat brain cells at 4 h after exposure to RF radiation. Some other studies confirmed this Cam et al., 2012 (hair root cell) (Cam and Seyhan, 2012), Zhijian et al. (human blood lymphocytes) (Zhijian et al., 2010), Campisi et al. (rat astroglial and astrocytes cells) (Campisi et al., 2010), Iuliis et al. (Human

spermatozoa) (Iuliis et al., 2009), Luukkonen et al. (Human SHSY5Y neuroblastoma cells) (Luukkonen et al., 2009), Agarwal et al. (human semen cell) (Agarwal et al., 2009), Schwarz et al. (Human cultured fibroblasts) (Schwarz et al., 2008), Tiwari et al. (Human whole blood samples) (Tiwari et al., 2008). In contrast, some other studies confirmed that the results are not significant. For an example, Kumar et al. (Rat blood lymphocytes and bone marrow) (Kumar et al., 2011), Falzone et al. (Human spermatozoa) (Falzone et al., 2010), Hansteen et al. (human blood lymphocytes) (Hansteen et al., 2009), Sannino et al. (Human skin fibroblasts) (Sannino et al., 2009b), Kim et al. (L5178Ytk ± mouse lymphoma cells) (Kim et al., 2008), Huang et al. (HEI-OC1 immortalized mouse auditory hair cells) (Huang et al., 2008b), Huang et al. (Jurkat human T-lymphoma cells) (Huang et al., 2008a), Zeni et al. (Human leukocytes) (Zeni et al., 2008), Zhijian et al. (Human leukocytes) (Zhijian et al., 2009) and De Luliis et al. (Human spermatozoa) (Luliis et al., 2009). More recently, the U.S. National Toxicology Program reported multiple sites of DNA damage in their rodent studies of cell phone radiation.

Fundamentally, the purpose of using cells and cell line for in vitro

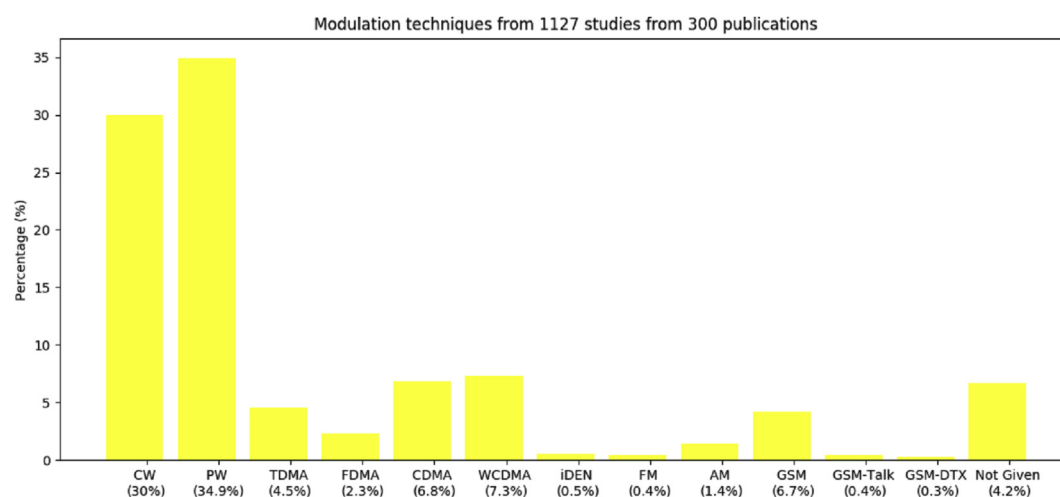


Fig. 7. Modulation techniques of mobile communication observed from 1127 studies from 300 peer-reviewed scientific publications (1990–2015). Cells exposed to RF radiation in vitro experiments that reported results (cellular response (presence or absence)) for different exposure conditions (frequency, SAR and exposure durations).

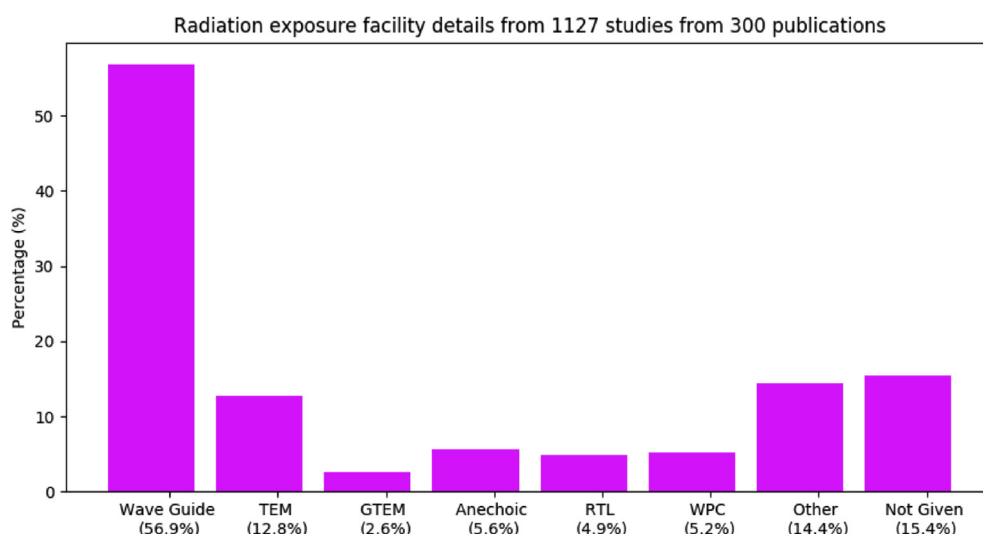


Fig. 8. Radiation exposure facility details observed from 1127 studies from 300 peer-reviewed scientific publications (1990–2015). Cells exposed to RF radiation in vitro experiments that reported results (cellular response (presence or absence)) for different exposure conditions (frequency, SAR and exposure durations).

Table 10

Statistically significant difference cell groups from Tables 3–5.

Exposure Details	Total	Studies with statistical significant cellular response	
		PRESENCE	ABSENCE
Human	16	7 (43.7%)	9 (56.3%)
Rat/mouse	6	3 (50%)	3 (50%)
Other Species	2	2 (100%)	0 (0%)
Total Cells	24	12 (50%)	12 (50%)

studies is to break down the complexity of a whole organism into a better controllable system to tackle mechanistic questions. Each cell type is, hence, a model system of its own which may be suitable for a specific biological aspect depending on its genetic and physiological background. However, none of these findings can be directly related to human welfare and health. This study should be useful as a reference for many researchers supporting epidemiological studies or in vivo experiments using whole organism animal models.

5. Conclusion

In this review, we perform a meta-analysis of data from 300 peer-reviewed scientific publications (1990–2015) with 1127 in vitro experimental observations carried out in the literature that discussed using different experimental techniques (cytogenetic, gene and protein expression analysis) and different cell types (cultured rodent, human cells and human blood lymphocytes) due to non-thermal radio-frequency electromagnetic exposure. In this paper, we directly differentiated the cumulative effect (SAR × exposure time) to acquire the cumulative energy absorption of experiments due to RF exposure, which we believe, has not been fully considered previously. Several studies have reported, based on different experimental techniques that RF exposures comparable to those of a mobile phone induce a range of genetic and other damage including (cytogenetic, gene, and protein expression analysis). Non-thermal radio-frequency electromagnetic exposure in a range of cells/tissues that may not be associated with

potentially harmful health consequences; in contrast, other studies have reported no apparent effects related to radiofrequency radiation. Our observation showed that 45.3% experiments concluded that an increase in such potential effects on cells exposed to radiofrequency radiation, while 54.7% showed no such effects ($p = 0.001$). Specific subtypes of cells show a much clearer cellular response. When radiofrequency, exposure and individual cell types are considered potential non-thermal effects of radio-frequency radiation on cell types, such as human spermatozoa (based on 19 reported experiments, p -value = 0.002) and human epithelial cells (based on 89 reported experiments, p -value < 0.0001) may exist whereas for Glia ($p = 0.001$), Glioblastoma ($p < 0.0001$) and human blood lymphocytes ($p < 0.0001$) the evidence suggests that there are no statistically significant differences.

Fundamentally the validity of any exercise such as this depends on whether studies are carried out with parallel methods and levels of quality assurance and quality control for the biological materials that are employed. The widely varying results we report here could well reflect failures of scientific rigor and consistency, as Portelli and Barnes (2013) (Portelli et al., 2013) have suggested plague in vitro studies. Despite the lack of uniformity in responses, certain patterns are evident. It appears that more mature lymphocytes and glial cells are less reactive to RF, while less mature and less differentiated cells such as epithelium and spermatozoa are more sensitive to RF. In addition, it appears that frequencies that are higher and pulsed have more biological impact than those that are continuous and of lower frequency.

A simple glance at our findings could imply that human cells are less affected by the radiofrequency radiation than rat/mouse cells. However, due to the inconsistency of results, it may be safer to look at other possible explanation. One possibility is that the experimental procedure is not consistently followed throughout the majority of these studies, or it could be due to the experimental design guidelines not being able to account for all the variables we may or may not be aware of. Consequently, it allows an inconsistency set of results due to small fluctuation in different studies. Nevertheless, this study should be useful as a reference for many researchers supporting epidemiological studies and in vivo experiments using whole organism animal models.

Appendix A

List of Abbreviations

4-Nitroquinoline-1-oxide (4NQO), Anomalous viscosity time dependence (AVTD) BCL-2-Associated X Protein (BAX), Computer-assisted sperm

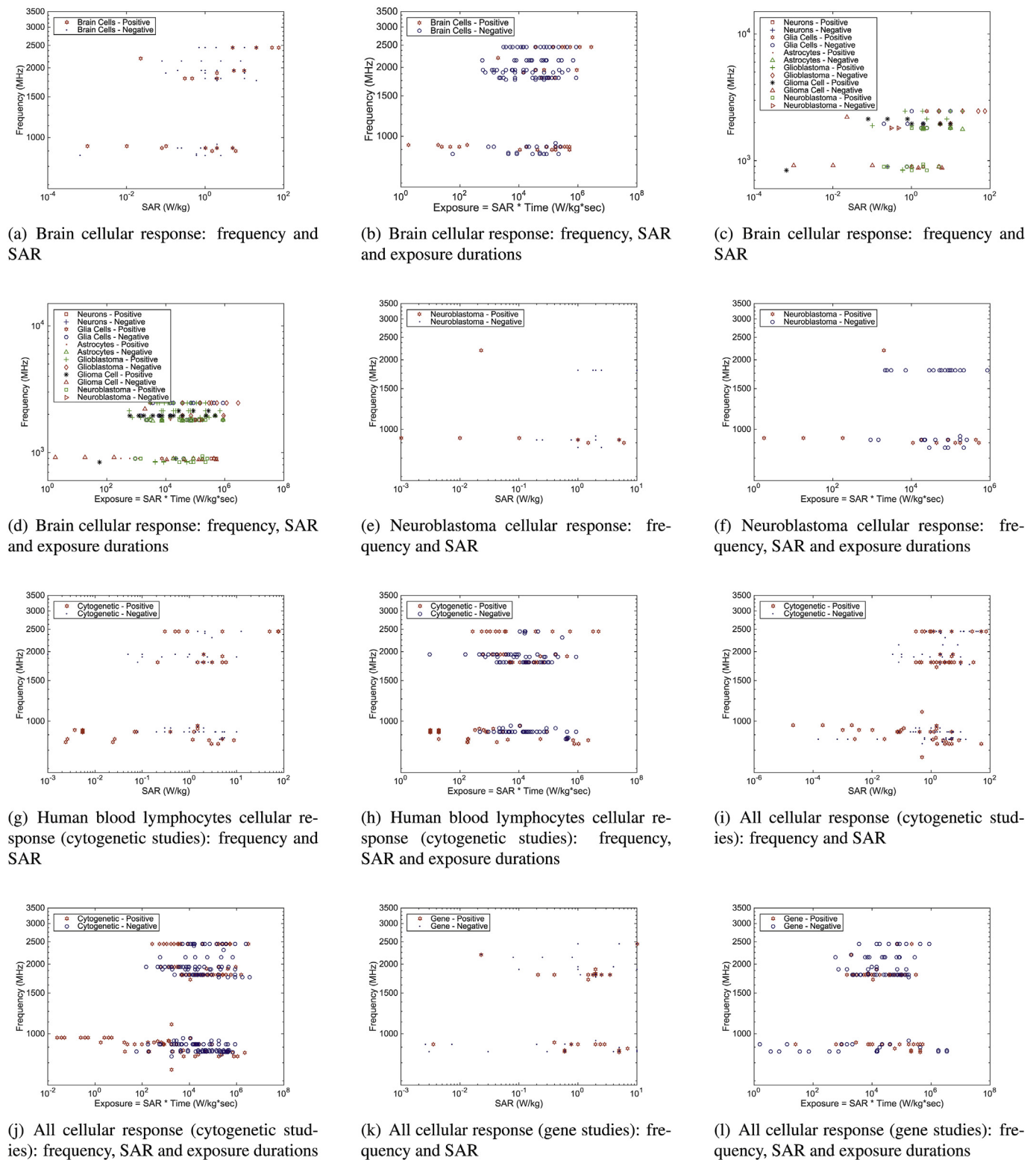


Fig. 9. Cells exposed to RF radiation in vitro experiments that reported results (cellular response (presence or absence)) for different exposure conditions (frequency, SAR and exposure durations). Please note that due to identical exposure conditions there were overlaps of data points.

analysis (CASA), Cytokinesis-blocked micronucleus (CBMN), Chromosome Aberration (CA), Code Division Multiple Access (CDMA), cAMP response element-binding protein (CREB), Continuous Wave (CW), Cytometric bead array (CBA), Digital Advanced Mobile Phone System (D-AMPS), Digital Cellular System (DCS), Deoxyribonucleic acid (DNA), Differential In-Gel Electrophoresis (DIGE), Doxorubicin (DOX), Epidermal Growth Factor (EGF), Frequency Division Multiple Access (FDMA), Fluorescence In Situ Hybridisation (FISH), Fluorescence-modulated Continuous-Wave (FMCW), Gaussian Minimum Shift Keying (GMSK), Global System for Mobile Communications (GSM), GSM-DTX (hearing only), GSM-non DTX (speaking only), GSM-Talk (34% speaking and 66% hearing activity), Histone H2A (H2AX), Human Lens Epithelial Cells (hLEC), Heat Shock Protein (HSP),

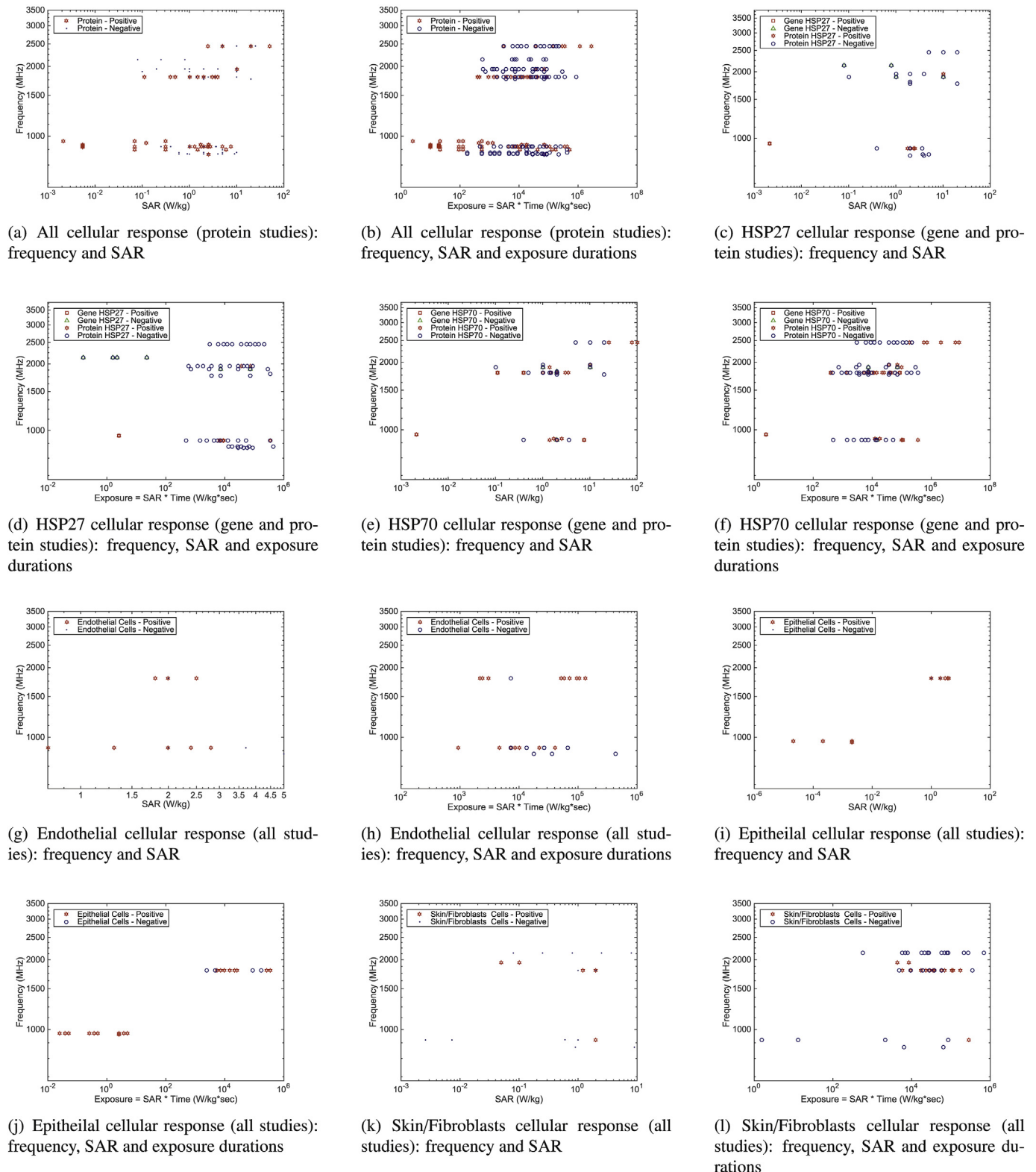
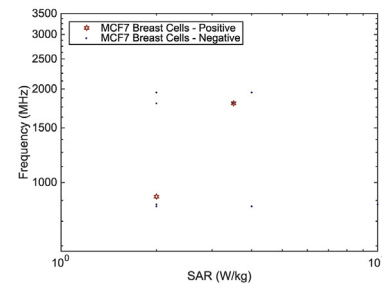
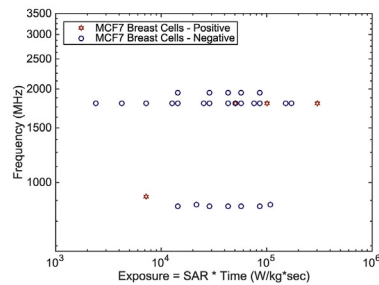


Fig. 10. Cells exposed to RF radiation in vitro experiments that reported results (cellular response (presence or absence)) for different exposure conditions (frequency, SAR and exposure durations). Please note that due to identical exposure conditions there were overlaps of data points.

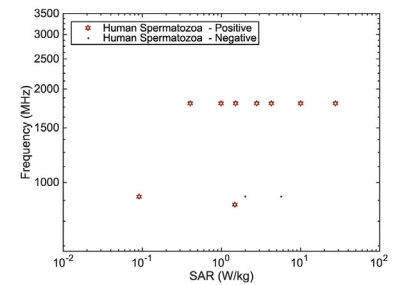
Intermediate-range Nuclear Force (INF), Major Histocompatibility Complex (MHC), Micronuclei (MNI), Messenger Ribonuclear Acid (mRNA), Mutagen Mitomycin C (MMC), Ornithine Decarboxylase (ODC), Peripheral Blood Mononuclear Cell (PBMC), Pulsed-field Gel Electrophoresis (PFGE), Phosphatidylserine (PS), Quantitative Polymerase Chain Reaction (QPCR), Radiofrequency (RF), Radiofrequency radiation (RFR), Ribonuclear Acid (RNA), Reverse Transcriptase-Polymerase Chain Reaction (RT-PCR), RTL - check, Reactive Oxygen Species (ROS), Sequential Analysis of Gene Expression (SAGE), Sister Chromatid Exchange (SCE), Single Cell Gel Electrophoresis (SCGE), Specific Absorption Rate (SAR), Two-dimensional



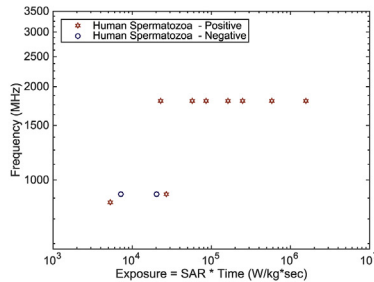
(a) MCF7 Breast cellular response (all studies): frequency and SAR



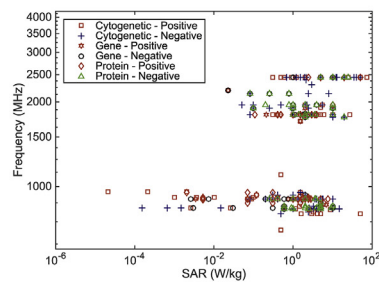
(b) MCF7 Breast cellular response (all studies): frequency, SAR and exposure durations



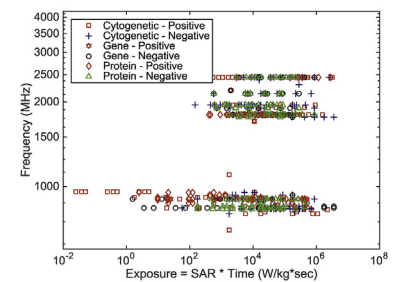
(c) Sperm cell behaviour changes cellular response (all studies): frequency and SAR



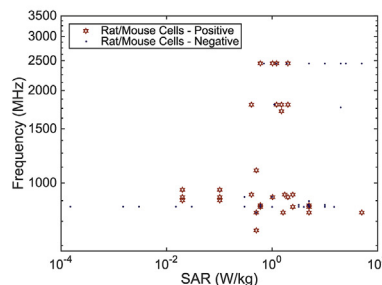
(d) Sperm cellular response (all studies): frequency, SAR and exposure durations



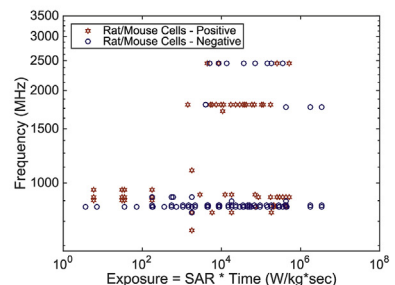
(e) Cytogenetic-gene-protein studies (all studies): frequency and SAR



(f) Cytogenetic-gene-protein studies (all studies): frequency, SAR and exposure durations



(g) Rat/Mouse cellular response (all studies): frequency and SAR



(h) Rat/Mouse cellular response (all studies): frequency, SAR and exposure durations

Fig. 11. Cells exposed to RF radiation in vitro experiments that reported results (cellular response (presence or absence)) for different exposure conditions (frequency, SAR and exposure durations). Please note that due to identical exposure conditions there were overlaps of data points.

Electrophoresis (2-DE), Trinitrotoluene (TNF), Time Division Multiple Access (TDMA), Time Division Synchronous Code Division Multiple Access (TD-SCDMA), TdT-mediated dUTP nick-end labeling (TUNEL), Universal Mobile Telecommunications System (UMTS), Ultraviolet radiation (UVC), Wideband Code Division Multiple Access (WCDMA).

Table 11

Human Cell Studies: Weak RF-radiation exposure conditions used in the investigations that examined cytogenetic studies in mammalian cells exposed in vitro.

No	Cell Line	Exposure System	Analysis	Results	Cellular Response	Authors
01	Human peripheral blood (monocytes and lymphocytes)	900 MHz (PW) for 2 h using waveguide	cell viability/cell division/proliferation: cell viability using reactive oxygen species (dichlorofluorescein stain, flow cytometry)	Observed induce oxidative stress in monocytes	Presence	Kazemi et al. (2015)
02	Human breast cancer cell line (MCF7)	900 (PW), 1800, 2450 MHz (GSM), SAR 0.36, 0.58, 0.18 mW/kg for 1 h using antenna with falcon tube holder	cell viability/cell division/proliferation, oxidative stress, apoptosis, cytosolic Ca ²⁺ concentration, generation of reactive oxygen species	Cell viability was significantly reduced in all 3 groups	Presence	Cig and Naziroglu, (2015)

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Table 11 (continued)

No	Cell Line	Exposure System	Analysis	Results	Cellular Response	Authors
03	Human bronchial epithelial cells (BEAS-2B)	1800 MHz (CW), SAR 1 W/kg for 65 h using dipole antenna	Cell function, cell viability, cell division, proliferation using flow cytometry	No cell viability or cell proliferation, cell cycle distribution or apoptosis were significantly changed. Besides, the healing rate of cells was significantly higher in the exposed cells, hence, this could reduce the wound healing capacity in cell cultures because of to an impaired cell migration	Presence	Kim et al. (2015)
04	Human glioblastoma cell lines (U251MG and U87MG)	1950 MHz (TD-SCDMA, CDMA), SAR 5 W/kg for 12, 24, and 48 h using dipole antenna	(i) Gene and protein expression using real-time PCR and western blotting, immunohistochemical assay (ii) Apoptosis and cell cycle progression using flow cytometry	EMF did not act as a cytotoxic or tumor-promoting agent to affect the proliferation or gene expression profile of glioblastoma cells	Absence	Liu et al. (2015)
05	Human spermatozoa	850 MHz, SAR 1.46 W/kg for 60 min	DNA fragmentation using flow cytometry, gene expression using real-time RT-PCR and gel electrophoresis, protein expression using Western blot, immunohistochemical assay	Gene expression and protein expression and DNA fragmentation were significantly increased	Presence	Zalata et al. (2015)
06	Human sperm cells	1950 MHz (UMTS), SAR 3 W/kg for 3 h	Apoptosis and DNA methylation of sperm, cell viability	Exposed group showed significantly decreased in progressive sperm motility. Progressive motility and viability of human sperm and increases sperm head defects and early apoptosis of sperm cells was identified.	Presence	Wang et al. (2015)
07	Human leukemia cells (HL60)	2450 MHz (CW), SAR 2, 10 W/kg for 4, 24 h using cylindrical waveguide (TM01 mode)	Immune response	Exposure at an SAR under 10 W/kg did not show significant effects on either chemotaxis or phagocytosis in neutrophil-like human HL60 cells	Presence/ Absence	Koyama et al. (2015)
08	Breast cancer cells	900 MHz (GSM), SAR 0.36 W/kg for 1 h using an antenna	Cell viability, intracellular ROS production, mitochondrial membrane depolarization, cell apoptosis, and caspase-3 and caspase-9 values	Observed induce apoptosis effects through oxidative stress and mitochondrial depolarization although incubation of selenium seems to counteract the effects on apoptosis and oxidative stress	Presence	Kahya et al. (2014)
09	Hepatocarcinoma cells (Hep G2)	900, 1800 MHz (GSM), SAR 2 W/kg for intermittent exposure (15 min ON, 15 min OFF) for 1, 2, 3, 4 h using a horn antenna	DNA breaks, cell viability assay using (DAPI) staining using fluorescence microscopy	Observed decrease in the proliferation of the Hep G2 cells	Presence	Ozgur et al. (2014)
10	Human blood lymphocytes	1950 MHz (UMTS), SAR 0.3 W/kg for 20 h using a rectangular waveguide (WR 430)	Genotoxicity/mutation, DNA damage using micronucleus formation	Significant decrease in the number of micronuclei was observed	Presence	Sannino et al. (2014)

Table 12

Human Cell Studies: Weak RF-radiation exposure conditions used in the investigations that examined cytogenetic studies in mammalian cells exposed in vitro (cont.).

No	Cell Line	Exposure System	Analysis	Results	Cellular Response	Authors
11	Human embryonic kidney cells (HEK 293 T)	940 MHz, SAR 0.09 W/kg for 15, 30, 45, 60 and 90 min using waveguide	Luciferase enzyme activity and oxidative stress, cell viability/cell division/proliferation, apoptosis, bioluminescence assay, ROS, flow cytometry	Significant changes have been observed in luciferase enzyme activity and reactive oxygen species content	Presence	Sefidbakht et al. (2014)
12	Human spermatozoa	900, 1800 MHz (PW), for intermittent exposure (outgoing calls every 10 min)	DNA-fragmentation in sperms, cell function: sperm vitality and motility	Significant increase was observed in DNA fragmentation and non-progressive motility, whereas progressive motility was significantly reduced	Presence	Gorpinchenko et al. (2014)
13	Human adipose derived stem cells	2450 MHz (GSM), SAR 0.24 W/kg for 10 h/day for 5 days	Cell proliferation, apoptosis and differentiation, flow cytometry	Cell proliferation was significantly increased	Presence	Lee et al. (2014)
14	Human lymphoblastoid cells (HL60)	1800 MHz (CW), SAR 1.3, 10 W/kg for intermittent exposure (5 min ON, 10 min OFF) for 24 h	DNA single-strand breaks and double-strand breaks using alkaline comet assay, micronucleus assay	Genotoxic effects were not found	Absence	Speit et al. (2013)
15	Human peripheral blood lymphocytes	2450 MHz (WCDMA, CW, PW), SAR: 10.9 W/kg for 2 h using waveguide	Micronuclei formation	No significant differences between WCDMA and CW radiofrequency exposures were found	Absence	Vijayalaxmi et al. (2013)
16	Human peripheral blood lymphocytes	1800 MHz (GSM-217 Hz, PW), SAR 0.2, 2, 10 W/kg for intermittent exposure (5 min ON, 10 min OFF) for 28 h using R18 waveguide	DNA damage, chromosome aberrations, sister chromatid exchange, micronuclei formation, single strand breaks using comet assay	No evidence of a genotoxic effect was observed	Absence	Waldmann et al. (2013)
17	Human breast fibroblasts		Cell viability, apoptosis using flow cytometry, membrane potential	Cell viability was significantly decreased	Presence	Esmekaya et al. (2013)

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Table 12 (continued)

No	Cell Line	Exposure System	Analysis	Results	Cellular Response	Authors
18	Human eye lens epithelial cells	2100 MHz (WCDMA), SAR 0.607 W/kg for 4, 24 h using horn antenna	using fluorescence microscopy and flow cytometry	ROS and the lipid peroxidation were significantly increased and the cell viability, the gene expression and the protein expression were significantly decreased	Presence	Ni et al. (2013)
19	Human trophoblast cells (HTR-8/SVneo)	1800 MHz (GSM, PW), SAR 2, 3 or 4 W/kg for intermittent exposure (5 min ON, 10 min OFF) 0.5, 1 or 1.5 h using waveguide	Oxidative stress, cell viability, reactive oxygen species, gene expression and protein expression	Gene expression has been changed, however, protein expression	Presence	Cervellati et al. (2013)
20	Human B-cell lymphoblastoid cells	1800 MHz (PW), SAR 2 W/kg for 1 h using a waveguide	cell viability (MTT assay), immunofluorescence, fluorescence microscopy	Total of 20 proteins was significantly up-regulated and 7 were down-regulated, significantly	Presence	Zhijian et al. (2013)
21	Human lens epithelial cells (HLECs)	1800 MHz (GSM), SAR 2 W/kg for intermittent exposure (5 min ON, 10 min OFF) for 24 h	Molecular biosynthesis: protein expression using Western blot	VCP and USP35 proteins significantly increased and the expression level of protein SRP68 significantly decreased	Presence	Zhang et al. (2013)
22	Cultured human amniotic cells	1800 MHz (PW), SAR 2, 3, 4 W/kg for 2 h using waveguide	Real-time polymerase chain reaction (qRT-PCR), Western blot assay	No significant changes in the expression and activation of the p53 protein were found	Absence	Bourthoumieu et al. (2013)
23	Human amniotic epithelial cells (FL)	900 MHz (PW), SAR 4, 32 W/kg for 24 h using wire-patch cell	DNA repair, genetic damage, apoptosis, Western blot	SAR 0.5, 1.0, 2.0, or 4.0 W/kg for 15 min induced EGF receptor clustering and enhanced phosphorylation on tyrosine-1173 residue, however, not SAR 0.1 W/kg. Membrane receptors could be one of the main targets by which RFR interacts with cells	Presence	Sun et al. (2013)

Table 13

Human Cell Studies: Weak RF-radiation exposure conditions used in the investigations that examined cytogenetic studies in mammalian cells exposed in vitro (cont.).

No	Cell Line	Exposure System	Analysis	Results	Cellular Response	Authors
24	Human promyelocytic leukemia cells (HL60)	900 MHz (CW), SAR 0.041, 0.025 mW/kg for 1 h/day for 3 days using GTEM cell	Cell viability, apoptosis, mitochondrial membrane potential (MMP), intracellular free calcium (Ca ²⁺)	data showed increased cell proliferation, decreased apoptosis, increased MMP, decreased Ca ²⁺ and increased Ca ²⁺ -Mg ²⁺ -ATPase activity	Presence	Jin et al. (2012)
25	Human breast epithelial cells (MCF10A)	837 MHz (CDMA), 1950 MHz (WCDMA) SAR 2, 4 W/kg for 10, 24 and 48 h using conical antenna	oxidative stress, ROS using flow cytometry, cell morphology and cell growth	Did not observe any changes in cell morphology and growth	Absence	Hong et al. (2012)
26	Human neuroblastoma cells (SH-SY5Y)	1760 MHz (GSM), SAR 0.086 W/kg for 2, 4 h	Cellular stress response - heat shock protein expression (HSP20, HSP27 and HSP70), cell viability and apoptosis using Western blot	No significant changes in cell viability or HSP27 expression or caspase-3 activity, however, a significant decrease in HSP20 expression was observed and HSP70 levels were significantly increased in 4 h exposure	Presence	Calabro et al. (2012)
27	Human hair root cells plucked behind the right ear	900 MHz (GSM), SAR 0.974 W/kg for 15 and 30 min	DNA single-strand breaks using alkaline comet assay	A short-term exposure to REF significantly increased (p<0.05) single-strand DNA breaks in human hair root cells that located around the ear	Presence	(Cam and Seyhan, 2012)
28	Human peripheral blood mononuclear cells (PBMC)	900 Hz (GSM), SAR 0.4 W/kg for 2 h	Reactive oxygen species (ROS), apoptosis and DNA and protein damage using flow cytometry and fluorescence microscopy	Cell apoptosis can be induced in human PBMC by the radiation of 900 MHz	Presence	Lu et al. (2012)
29	Human T-lymphoblastoid leukemia cells (CCRF-CEM)	900 MHz (CW), SAR 3.5 mW/g for 2, 48 h using TEM cell	Cell viability and genes expression profile, double or single-strand DNA repair - Flow cytometry and Western blot analysis	Effect of high-frequency EMF on gene expression was evaluated and identified the functional pathways influenced by 900 MHz (CW) exposure	Presence	Trivino et al. (2012)
30	Human amniotic cells (FL)	1800 MHz (GSM, PW), SAR of 0.5, 1.0, 2, or 4.0 W/kg for 15 min using waveguide	(i) Analyzed using immunofluorescence assessed by confocal microscopy, and phosphorylation of EGF receptors was measured by Western blot technology (ii) different intensities on epidermal growth factor (EGF) receptor clustering and phosphorylation	(i) Significantly induced EGF receptor clustering and enhanced phosphorylation on the tyrosine-1173 residue in FL cells (ii) Membrane receptors could be one of the main targets that radiofrequency radiation interacts with cells, and the dose-rate threshold, in the case of EGF receptors, is between SAR of 0.1–0.5 W/kg	Presence	Sun et al. (2012)

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Table 13 (continued)

No	Cell Line	Exposure System	Analysis	Results	Cellular Response	Authors
31	Human breast epithelial cells (MCF10A)	837 MHz (CDMA) signal alone (4.0 W/kg) or simultaneously to 2 W/kg (CDMA) and 1950 MHz (WCDMA) 2 W/kg signals for 4 h once or 2 h/day for 3 consecutive days using radial transmission line (RTL) with conical antenna	Heat shock proteins (HSPs) and mitogen-activated protein kinases (MAPKs) were analyzed using Western blot	No statistically significant alterations were found in HSP27 level and phosphorylation after either CDMA alone or CDMA and WCDMA combined exposure ($p > 0.05$)	Absence	Kim et al. (2012)
32	Human keratinocytes cells (HaCaT) and human-hamster hybrid cells (AL)	900 MHz (CW, PW), SAR 10.7, 17.2 mW/kg for 30 min (both cell types) or 22 h (AL cells only) using waveguide and μ TEM cell	(i) Genotoxicity/mutation: genomic damage and mitotic disturbances (micronucleus test) (ii) cell viability/cell division/proliferation: cytochalasin B proliferation index	Any genomic damage after exposure was not detected from both cell types did not show	Presence/ Absence	Hintzsche et al. (2012)
33	Human blood lymphocytes	1950 MHz (UMTS, W-CDMA), SAR 0.15, 0.3, 0.6, 1.25 W/kg for 20 h using waveguide	Genotoxicity, mutation: micronucleus formation and cell viability, cell division, proliferation: cytotoxicity	No significant difference was observed in the RF exposed group	Absence	Zeni et al. (2012a)

Table 14

Human Cell Studies: Weak RF-radiation exposure conditions used in the investigations that examined cytogenetic studies in mammalian cells exposed in vitro (cont.).

No	Cell Line	Exposure System	Analysis	Results	Cellular Response	Authors
34	Human blood lymphocyte	1950 MHz (GSM), SAR 2 W/kg for 5, 10, 15, 20, 25 and 30 min	Double strand breaks, single strand breaks of DNA using alkaline comet assay, chromosomal aberrations and the micronucleus	Cytogenetic alterations were observed	Presence	El-Abd et al. (2012)
35	Human amniotic cells	900 MHz (GSM-PW), SAR 0.25, 1, 2, 4 W/kg for 24 h	Aneuploidy of chromosomes was determined by interphase FISH (Fluorescence In Situ Hybridisation)	No aneuploidy of chromosome 11 and 17 was found	Absence	Bourthoumieu et al. (2011)
36	Human peripheral blood lymphocytes (HPBL)	1800 MHz (PW), SAR 0.21 W/kg for 8, 24 and 48 h using horn antenna	Mutagenic and morphologic effects with and without EGb 761	RF radiation induces chromosomal damage in hPBLs - cell morphology, increases SCE and inhibits cell proliferation in SCE frequency ($p < 0.05$) although EGb 761 pre-treatment reduced this. EGb 761 has a protective role against RF induced mutagenicity	Presence	Esmekaya et al. (2011)
37	Human breast carcinoma cells (MCF7)	837 MHz or combined (837 and 1950 MHz - CDMA, W-CDMA), SAR 4 W/kg (mean 0.105, 0.262 W/kg) for 1 h using conical antenna	Cell cycle distribution and its regulatory proteins, levels of cell cycle regulatory proteins, p53, p21, cyclins, and cyclin-dependent kinases	No alterations in DNA synthesis, cell cycle distribution, and levels of cell cycle regulatory proteins	Absence	Lee et al. (2011)
38	Human breast adenocarcinoma cells (MCF7)	900 MHz (GSM-PW), SAR 2 W/kg for 1 h using exposure chamber	Metabolic activity, cell morphology, cell cycle progression, phosphatidylserine (PS) externalisation and the generation of reactive oxygen species and nitrogen species	Experiment was found increase in PS externalisation and an increase in the formation of F-actin stress fibres in MCF-7 cells. A small increase in early and late apoptotic events in irradiated MCF-7 cells was found	Presence	Stander et al. (2011)
39	Human neuroblastoma cells (NB69) and hepatocarcinoma cells (Hep G2)	2200 MHz (PM), SAR 0.023, 1.65 W/kg for 24 h using waveguide	Cell growth and cell viability analyses using flow cytometry	Statistically significant reduction was found in the cell number ($p < 0.001$) in the neuroblastoma NB69 line and in the proportions of cells in phases G0/G1 and G2/M of the cell cycle (6 $p < 0.05$ over controls). However, the hepatocarcinoma cell line HepG2 did not respond to the same RF treatment	Presence	Trillo et al. (2011)
40	Human astroglial cells (SVGp12)	2450 MHz (CW), SAR of 1, 5, and 10 W/kg for 1, 4, and 24 h using waveguide	Gene expression, DNA microarray analysis, RT-PCR	No significant alterations in gene expression were found	Absence	Sakurai et al. (2011)
41	Human epidermal keratinocytes	900 MHz (CW), SAR 2.6, 73 mW/kg for 10 and 30 min using reverberation chamber	Gene expression using microarray screening of over 47 000 human genes, RT-PCR	Not significantly affect was found on cultured keratinocytes by EMF exposure	Absence	Roux et al. (2011)
42	Human spermatozoa	900 MHz (GSM), SAR 1.3 W/kg for 60 min	Separation of seminal plasma, measurement of lipid peroxidation	Increased the lipid peroxidation of sperm membranous polyunsaturated fatty acids through enhanced ROS production	Absence	Ahmed et al. (2011)
43	Human spermatozoa	850 MHz, SAR 1.46 W/kg for 60 min	Sperm vitality and viability as well as sperm motility	Significant decrease in sperm function - decrease in sperm vitality and viability as well as sperm motility	Presence	Dkhil et al. (2011)

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Table 14 (continued)

No	Cell Line	Exposure System	Analysis	Results	Cellular Response	Authors
44	Human blood lymphocytes	900 MHz (GSM), SAR 1.25, 10 W/kg for 20 h using wire patch cell (WPC)	Genotoxicity, mutation: DNA damage, micronucleus formation, cytotoxicity	Adaptive response was identified in human blood lymphocytes exposed to an adaptive dose of RF. Research proposed that the timing of an adaptive dose exposure of RF is important to stimulate an adaptive response.	Presence	Sannino et al. (2011)
45	Human spermatozoa	900 MHz (PW), SAR 2 W/kg for 1 h using exposure chambers	Sperm morphology flow cytometry	Rf field has significant effect on sperm morphometry, however, not in sperm fertilization potential	Presence	Falzone et al. (2011)

Table 15

Human Cell Studies: Weak RF-radiation exposure conditions used in the investigations that examined cytogenetic studies in mammalian cells exposed in vitro (cont.).

No	Cell Line	Exposure System	Analysis	Results	Cellular Response	Authors
46	Human amniotic cells	900 MHz (GSM), SAR 0.25 W/kg for 24 h using wire patch cell (WPC)	Genotoxic effects in cultured human cells. One hundred metaphase cells were analyzed per assay using complete R-banded karyotyping	No direct cytogenetic effects were found	Absence	Bourthoumieu et al. (2010)
47	Human B-cell lymphoblastoid cells	1800 MHz (GSM), SAR 2 W/kg, intermittent exposure (5 min ON, 10 min OFF) for 2 h using rectangular waveguides	DNA damage and repair	DNA repair rate was influenced (increased or decreased) by RF radiation in DOX exposed cells	Presence	Zhijian et al. (2010)
48	Human trophoblast cells (HTR-8/SV neo cells)	1800 MHz (GSM-217, GSM talk, CW) at SAR 2 W/kg for intermittent exposure (5 min ON, 10 min OFF) for 4, 16, 24 h using a waveguide	Alkaline comet assay	Increase in DNA migration (GSM-217, GSM Talk, 16 and 24 h) and No effect of CW	Presence/ Absence	Franzellitti et al. (2010)
49	Human spermatozoa	900 MHz (GSM-PW), SAR 2 or 5.7 W/kg for 1 h using waveguide	DNA strand breaks, ROS formation using flow cytometry, fluorescence microscopy, enzyme activity	No statistically significant effect on externalisation of phosphatidylserine (PS), induction of DNA strand breaks, and generation of reactive oxygen species from mobile phone radiation were found	Absence	Falzone et al. (2010)
50	Human breast cancer cells (MCF7)	849 MHz (CDMA), SAR 2 or 10 W/kg for 1 hr/day for 3 days using monopole antenna	Protein and gene expression profiles using two-dimensional gel electrophoresis, silver stain, RT-PCR, Western blot	No alteration in their mRNA and protein levels were found	Absence	Kim et al. (2010)
51	Human glioblastoma (A172), human neuroglioma cells (H4), and human fibroblasts cells (IMR90) from normal fetal lung	2140 MHz (CW, WCDMA), SAR 80, 250, or 800 mW/kg for 96 h anechoic chamber with horn antenna	Cell proliferation and the gene expression profile	No statistically significant differences in cell growth or viability were found	Absence	Sekijima et al. (2010)
52	Human endothelial cells (EA.hy926)	900 MHz, 1800 MHz (GSM), SAR 2 W/kg for 1 h using exposure chambers	Protein expression patterns, 2D - difference gel electrophoresis based proteomics (2DE-DIGE) (silver stain vs. DIGE)	Statistically significant changes in 900 MHz exposure and less efficient cell proteome in 1800 MHz exposure were observed. It was hypothesized that the endothelial cells, derived from the different vascular beds would respond in a different way to mobile phone radiation exposure	Absence	Nylund et al. (2010)
53	Human lymphoblastoid T cells (Jurkat cells), human fibroblasts and primary human white blood cells	1800 MHz (GSM-PW), SAR 2 W/kg for intermittent exposure (5 min ON, 10 min OFF) for 8 h using waveguide	2D gel spots was used to measure the increased synthesis of individual proteins	8 h exposure caused a significant increase in protein synthesis in Jurkat T-cells and human fibroblasts	Presence	Gerner et al. (2010)
54	Human neuroblastoma cells (SH-SY5Y)	872 MHz (CW, PW), SAR 5 W/kg for 3 h using waveguide	DNA damage, reactive oxygen species production using alkaline comet assay, cell viability	No significant effect was found due to RF exposure	Absence	Luukkonen et al. (2010)

Table 16

Human Cell Studies: Weak RF-radiation exposure conditions used in the investigations that examined cytogenetic studies in mammalian cells exposed in vitro (cont.).

No	Cell Line	Exposure System	Analysis	Results	Cellular Response	Authors
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Presence
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Table 16 (continued)

No	Cell Line	Exposure System	Analysis	Results	Cellular Response	Authors
	Human glioma cells (SHG44)	900 MHz (CW), SAR 1.2 W/kg for 2 h/day on 3 days using GTEM cell	oxidative stress, HSP70 expression using RT-PCR, Western blot, reactive oxygen species, enzyme activity, cell proliferation, cell cycle distribution and apoptosis using flow cytometry	Significant inhibition of cell proliferation was observed		Cao et al. (2009)
56	Cultured human blood lymphocytes	2300 MHz (CW, PW), 10 W/m CW, 10 W/m ² for 53 h using anechoic chamber with horn antenna	DNA damage in cultured human lymphocytes using chromosome aberrations	No statistically significant differences in chromosomal aberrations were found. A weak trend for more chromosomal damage with the interaction of pulsed fields with mitomycin C compared to a constant field was found	Absence	Hansteen et al. (2009a)
57	Peripheral blood mononuclear cells	900 MHz and 1784 MHz (GSM) for 2, 6, 24 h using Biquad antenna	Cell viability, cell proliferation, apoptosis using flow cytometry	Effect was not observed on cell viability, rates of apoptosis and the proliferation index	Absence	Atasoy et al. (2009)
58	Human endothelial cells (EA.hy926)	1800 MHz (GSM-PW), SAR 2 W/kg for 1 h using waveguide	Proteome analysis using two-dimensional electrophoresis, silver stain, PDQuest software, HSP27 expression using Western blot	The 900 GSM and 1800 GSM exposures might affect the expression of some proteins in the EA.hy926 cell line	Presence	Nylund et al. (2009)
59	Human spermatozoa	1800 MHz, SAR 0.4, 1.0 2.8 4.3 10.1 and 27.5 W/kg for 16 h using waveguide	DNA fragmentation using flow cytometry, production of reactive oxygen species and sperm motility	DNA fragmentation were significantly elevated (p<0.001). Observed highly significant relationships between SAR, the oxidative DNA damage bio-marker, 8-OH-dG, and DNA fragmentation after RF-EMR exposure	Presence	Iulius et al. (2009)
60	Human peripheral blood lymphocytes	900 MHz (GSM), SAR 1.25 W/kg for 20 h using wire patch cell (WPC)	DNA damage, micronucleus assay	Lymphocytes that were pre-exposed had a significantly decreased incidence of micronuclei induced by the challenge dose of mitomycin C compared to controls	Presence	Sannino et al. (2009a)
61	Human neuroblastoma cells (SH-SY5Y)	872 MHz (CW, PW), SAR 5 W/kg for 1 h using waveguide	Reactive oxygen species (ROS) production and DNA damage using comet assay	Increased DNA breakage (p<0.01) in comparison to the cells exposed only to menadione. No effects of the GSM signal were found on either ROS production or DNA damage	Presence	Luukkonen et al. (2009)
62	Human lymphoblastoid T cells (Jurkat cells)	1950 MHz (UMTS), SAR 0.5 or 2 W/kg for 5, 15, 30, 45, 60 min, or 24 h using waveguide	oxidative stress (ROS formation), cell viability	No change in ROS production and cell viability was found in Jurkat cells	Absence	Brescia et al. (2009)
63	Human skin fibroblasts	900 MHz (GSM-PW), SAR 1 W/kg for 1, 24 h using wire patch cell (WPC)	DNA damage using micronucleus assay and alkaline comet assay, cell viability and cell viability	No DNA damage (MN) and migration (comet assay) of RF alone or effect of combined treatments were found	Absence	Sannino et al. (2009b)
64	Ejaculated human semen cell/sperm cell	850 MHz (GSM-PW), SAR 1.46 W/kg for 1 h (during talk mode) using omnidirectional antenna	Cell viability, reactive oxygen species (ROS) level, total antioxidant assay (TAC) measurement, DNA damage, sperm motility and concentration	RF EMF may lead to oxidative stress in human semen	Presence	Agarwal et al. (2009)
65	Human leukocytes	1800 MHz (GSM-PW), SAR 2 W/kg for intermittent exposure (5 min ON, 10 min OFF) for 24 h	Alkaline comet assay	No DNA damage to human leukocytes was found	Absence	Zhijian et al. (2009)

Table 17

Human Cell Studies: Weak RF-radiation exposure conditions used in the investigations that examined cytogenetic studies in mammalian cells exposed in vitro (cont.).

No	Cell Line	Exposure System	Analysis	Results	Cellular Response	Authors
66	Human trophoblasts (HTR-8/SV neo cells)	1817 MHz (GSM-PW), SAR 2 W/kg for 1 h using waveguide	Semi-quantitative RT-PCR and protein expression by Western blotting	Increase in Cx40 and Cx43 gene expression without altering protein expression was found. Change in proteins cellular localization	Presence	Cervellati et al. (2009)
67	Human neuroblastoma (SH-SY5Y)	1800 MHz (GSM-PW), 835 MHz (GSM-PW), SAR 1, 2.5 W/kg for 8, 24 h using waveguide	Protein analysis and ODC enzyme activity	No effect on ODC enzyme activity was found	Absence	Billaudel et al. (2009a)
68	Human glioblastoma cells (A172), glioblastoma cells (T98) and human malignant glioma cells (MO54)	1950 MHz (CW), SAR 1 and 10 W/kg for 1 h	Heat shock proteins - HSP27, p-HSP27, and HSP70 were determined by Western blotting	No significant effects was found on HSP70 and HSP27 expression. Slightly decreased protein level was found on phosphorylated HSP27 in MO54 cells at SAR of 10 W/kg for 1 hr	Absence	Ding et al. (2009)
69	Human adult hemoglobin (HbA)	910 MHz and 940 MHz (CW) for 15, 30, 60, 90 and 120 min using spiral antenna setup	Protein secondary structure, circular dichroism and fluorescence spectroscopy, Oxygen affinity, fluorescence spectroscopy	RF radiation altered oxygen affinity and tertiary structure of HbA	Presence	Mousavy et al. (2009)
70		1950 MHz (UMTS), SAR 0.05, 0.1, 1, 2 W/kg for 24 h Continuous and		RF radiation exposure increased DNA damage and micronuclei (MNI) in	Presence	Riazi et al., (2009)

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Table 17 (continued)

No	Cell Line	Exposure System	Analysis	Results	Cellular Response	Authors
	Human cultured di-ploid fibroblasts and lymphocytes	intermittent exposure (5 min ON, 10 or 20 min OFF and 10 min ON, 10 or 20 min OFF) using rectangular wave-guide (R18)	DNA damage, Genotoxic effects: formation of micronuclei, alkaline comet assay	fibroblasts. No effects were found on lymphocytes		Schwarz et al. (2008)
71	Human whole blood samples	835 MHz (CDMA), SAR 1.17 W/kg for 1, 2 h	DNA damage using alkaline comet assay, cell viability	DNA damage increased and DNA repair efficiency increased or decreased in co-exposure RF signals induces reversible DNA damage in synergism with aphidicolin (APC)	Presence 2/2	Tiwari et al. (2008)
72	Human peripheral blood lymphocytes	800 MHz (CW), SAR 2.9 or 4.1 W/kg for 72 h using cavity resonator	Chromosome aberrations - Aneuploidy rate of aberrations 1, 10, 11, 17 determined by interphase FISH, cell proliferation	Aneuploidy was increased in chromosomes 1 and 10 (4.1 W/kg), and in chromosomes 11 and 17 (2.9 W/kg)	Presence	Mazor et al. (2008)
73	Human peripheral blood lymphocytes (HPBL)	1950 MHz (UMTS, CDMA), SAR 0.5, 2 W/kg for 24 h using rectangular waveguide (WR 430)	Genotoxicity, chromosome aberrations	Frequencies of exchanges per cell were increased by the 2 W/kg exposure	Presence	Manti et al. (2008)
74	Human lymphoblastoid T cells (Jurkat cells)	1760 MHz (CDMA), SAR 2 W/kg or 10 W/kg for 1, 4, 24 h using cavity resonator with monopole antenna	Cell proliferation, cell cycle progression using flow cytometry, DNA damage using omet assay, ethidium bromide staining, fluorescence microscopy and gene expression	No statistically significant effects of RF radiation were found in cell numbers, cell cycle distributions, or DNA damage	Absence	Huang et al. (2008b)
75	Human leukocytes	1950 MHz (UMTS), 2.2 W/kg for intermittent exposure (6 min ON, 2 h OFF) for 24, 44, 68 h using TEM cell	Genotoxic effects using alkaline single cell gel electrophoresis (SCG)/comet assay, micronucleus	No effects was found in micronucleated cells, change in cell cycle kinetics or DNA damage	Absence	Zeni et al. (2008)
76	Human lens epithelial cells (HLEC)	1800 MHz (GSM), SAR 1, 2, 3 or 4 W/kg, for intermittent exposure (5 min ON, 10 min OFF) for 2 h rectangular wave-guide	DNA damage was examined using alkaline comet assay	DNA damage was increased at 3 and 4 W/kg with comet assay. No effects found with the H2AX assay was found	Presence	Yao et al., 2008a

Table 18

Human Cell Studies: Weak RF-radiation exposure conditions used in the investigations that examined cytogenetic studies in mammalian cells exposed in vitro (cont.).

No	Cell Line	Exposure System	Analysis	Results	Cellular Response	Authors
77	Human lymphoblastoid T cells (Jurkat cells) and human peripheral blood lymphocytes (PBL)	900 MHz (GSM), SAR 1.35, 10.8 W/kg for 1 h using wire patch cell (WPC)	Cell viability using Western blot analysis and in both cell types by flow cytometry, apoptosis	No difference was found except dose-response increase in caspase 3 activity after exposure to radiofrequency radiation	Absence	Palumbo et al. (2008)
78	Human eye lens epithelial cells (HLEC)	1800 MHz, SAR 1, 2, 3 and 4 W/kg intermittent exposure (5 min ON, 10 min OFF) for 24 h using rectangular waveguide	DNA damage, intracellular reactive oxygen species (ROS) formation, cell cycle, and apoptosis using alkaline comet assay	DNA damage examined by alkaline comet assay was significantly increased after 3 W/kg and 4 W/kg radiation ($P < 0.05$), however, no detectable difference in cell apoptosis was found ($p > 0.05$)	Presence	Yao et al. (2008b)
79	FC2 cells, human-hamster hybrid cells (AL)	835 MHz (CW), SAR 60 mW/kg for 10, 30, 60 and 120 min using TEM cell	Assay for spindle disturbances, numerical chromosome aberrations	Sub-thermal effects were found	Presence/Absence	Schrader et al. (2008)
80	Human trophoblasts cells (HTR-8/SV neo cells)	1800 MHz (CW, GSM-PW), SAR 2, 16, 22.77 W/kg for intermittent exposure (5 min ON, 10 min OFF) for 4, 16, 24 h using waveguide with cavity resonator	HSP70 gene and protein expression and cell viability using Western blot, RT-PCR	Changes in one (HSP70C) over 4 transcript isoforms with different effect of GSM signals were found	Presence	Franzellitti et al. (2008)
81	Human trophoblast (HTR-8/SV neo cells)	1817 MHz (CW, GSM-PW), SAR of 2 W/kg for 60 min waveguide with cavity resonator	Expression of proteins (HSP70 and HSC70) and genes (HSP70A, B, C and HSC70) of the HSP70 family and the primary DNA damage response using comet assay	No evidence was found that HSP70 or HSC70 protein or gene expression - HSP70-mediated stress response or primary DNA damage in HTR-8/SVneo cells	Absence	Valbonesi et al. (2008)
82	Human lens epithelial cells (HLECs)	1800 MHz, SAR 4 W/kg for 24 h	Intracellular ROS and DNA damage - DCFH-DA method and comet assay	Intracellular ROS and DNA damage was significantly increased ($p < 0.05$)	Presence	Wu et al. (2008)
83	Human lymphoblastoid T cells (Jurkat cells)	1763 MHz (CDMA), SAR 2, 10 W/kg for 1, 4, 24 h using cavity resonator with monopole antenna	Cell proliferation, cell cycle progression using flow cytometry, DNA damage using comet assay, ethidium bromide staining, fluorescence microscopy and gene expression	Alterations in cell proliferation, cell cycle progression, DNA integrity or global gene expression was not found	Absence	Huang et al. (2008b)
84	Chinese hamster fibroblast cells (V79)	935 MHz (CW), SAR 0.12 W/kg for 1, 2, and 3 h using GTEM cell	Cell proliferation, cell morphology, structure of microtubule proteins using the immunocytochemical assay	Microtubule structure significantly altered after 3 h of irradiation ($p < 0.05$), therefore, may obstruct cell growth	Presence	Pavicic et al. (2008)
85	Human lens epithelial cells (HLEC)	1800 MHz (GSM), SAR 1, 2, 3, and 4 W/kg for 2 h	Protein expression - HSPs and the activation of mitogen-activated protein	Induce expression of HSP27 and HSP70 and the activation of signal transduction	Presence	Yu et al. (2008)

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Table 18 (continued)

No	Cell Line	Exposure System	Analysis	Results	Cellular Response	Authors
			kinases (MAPKs) - HSP90, HSP70, and HSP60, and the small HSP, such as HSP10, HSP27 using Western blot analysis	pathways (ERK1/2 and JNK1/2) in human LECs were observed after 5 min of exposure		

Table 19

Human Cell Studies: Weak RF-radiation exposure conditions used in the investigations that examined cytogenetic studies in mammalian cells exposed in vitro (cont.).

No	Cell Line	Exposure System	Analysis	Results	Cellular Response	Authors
86	Human spermatozoa	900 MHz (PW), SAR 2.0 and 5.7 W/kg for 60 min using a waveguide (TE10 mode) with cavity resonator and monopole antenna	Sperm mitochondrial membrane potential using flow cytometry and sperm motility using CASA	No effect on mitochondrial membrane potential or sperm motility at SAR of 2.0 W/kg was observed, however, two kinematic parameters straight line velocity (VSL) and beat-cross frequency (BCF) were significantly impaired ($P < 0.05$) after the exposure at SAR 5.7 W/kg	Presence/Absence	Falzone et al. (2008)
87	Human dendritic cells	1800 MHz, SAR 4 W/kg for 1, 12, 24 h	Enzyme linked immunosorbent assay (ELISA)	Down-regulate the surface molecules and stimulation ability of human dendritic cells	Presence	Zhou et al. (2008)
88	Human blood neutrophils (leukocyte - white blood cells)	900 MHz, field strength 0.392 V/m for 15 min using microstrip transmission line	Using C-AMP gradient	Human neutrophils were affected by RF fields	Presence	Aly et al. (2008)
89	Human lymphocytes	1800 MHz (GSM), SAR 3 W/kg for 1.5 or 4 h using TEM cell and waveguide	DNA damage using alkaline comet assay and fluorescence microscopy	Exposure for 1.5 and 4 h did not increase significantly human lymphocyte DNA damage, however, could reduce and increase DNA damage that induced by ultraviolet radiation-C	Absence	Baohong et al. (2007)
90	Human acute myeloid leukemia cells (HL60), human monocytes cells (Mono Mac 6), human lymphoblastoma cells (TK6)	1900 MHz (PW), SAR 0.1, 1 and 10 W/kg for intermittent exposure (5 min ON, 10 min OFF) for 6 h using circular waveguide	Cell viability, apoptosis and alterations in cell cycle progression using flow cytometry	No evidence was found in three human-derived cell lines. Nonetheless, the positive (heat-shock) control samples demonstrated a remarkable decrease in cell viability, increase in apoptosis, and alteration in cell cycle kinetics	Absence	Chauhan et al. (2007b)
91	Human primary epidermis keratinocytes and human dermal fibroblasts	1800 MHz (GSM-PW), SAR 2 W/kg for 48 h using rectangular waveguide (R18)	Heat shock protein HSP27, HSP70 and HSC70 using immunohistochemistry and apoptosis using flow cytometry	No effect was found as a stress factor on human primary skin cells	Absence	Sanchez et al. (2007)
92	Human glioblastoma cells (A172) and human fibroblasts (IMR90) from fetal lungs	2140 MHz (CW, WCDMA), SAR 80, 250 800 mW/kg for 2 and 28 h and CW, SAR 80 mW/kg for 28 h using anechoic chamber with horn antenna	Protein expression, Heat-shock proteins - HSP27 using immunofluorescence	No evidence of altered HSP27 phosphorylation or increased expression of mRNA for a different of HSPs was found in both cell lines	Absence	Hirose et al. (2007)
93	Human neuroblastoma cells (SH-SY5Y)	900 MHz (GSM-PW), SAR 1.0 W/kg for 5, 15, 30 min or 6, 24 h using wire-patch cell (WPC)	Cell viability, gene expression using RT-PCR, enzyme activity of MAPK using Western blot, apoptosis using RT-PCR, cell viability using MTT assay and cell cycle progression using flow cytometry	Significant reduction was observed in cell viability and cell proliferation, gene expression. Evidence of apoptosis after 24 h RFR exposure and possible confounding could be due to environmental factors was confirm	Presence	Buttiglione et al. (2007)
94	Human monocyte cells (MM6) and human glioblastoma cells (U87MG)	1900 MHz (PM), SAR 0.1, 1 and 10 W/kg for intermittent exposure (5 min ON, 10 min OFF) for 6 h (MM6) and 24 h (U87MG) using circular waveguide	Gene expression using semiquantitative RT-PCR and cell viability	No evidence of altered HSP transcriptional activation of HSP27, HSP40, HSP70, HSP90 and HSP105 was found	Absence	Chauhan et al. (2007a)

Table 20

Human Cell Studies: Weak RF-radiation exposure conditions used in the investigations that examined cytogenetic studies in mammalian cells exposed in vitro (cont.).

No	Cell Line	Exposure System	Analysis	Results	Cellular Response	Authors
95	Human lens epithelial cells (HLEC)	1800 MHz (GSM-PW), SAR 1, 2, or 3.5 W/kg for 2 h using rectangular waveguide (R18)	Proteome changes, protein expression using two-dimensional polyacrylamide gel electrophoresis (2-DE; silver staining), PDQuest software	Four proteins were detected as up-regulated. Heat-shock protein HSP70 and heterogeneous nuclear ribonucleoprotein K were up-regulated in the exposed cells	Presence	Li et al. (2007)

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Table 20 (continued)

No	Cell Line	Exposure System	Analysis	Results	Cellular Response	Authors
96	Human leukocytes	1950 MHz (UMTS), 2.2 W/kg for 24 and 68 h using TEM cell	Genotoxic effects using micronucleus assay, primary DNA damage using alkaline comet assay and cell proliferation	Intermittent exposures of human lymphocytes in different stages of cell cycle do not induce either an increase in micronucleated cells, or change in cell cycle kinetics	Absence	Zeni et al. (2007b)
97	Human glioblastoma cells (A172) and Human fibroblast (IMR90) from fetal lungs	2140 MHz (CW, WCDMA), SAR at 80 mW/kg (CW, WCDMA), SAR 250 mW/kg and 800 mW/kg (WCDMA) for 2 and 24 h using anechoic chamber using horn antenna	DNA Strand breakage using SCGE, alkaline comet assays	No significant differences in the DNA migration (comet assay) were found	Absence	Sakuma et al. (2006)
98	Human blood lymphocytes	935 MHz (GSM-PW), SAR 1 and 2 W/kg for 24 h using waveguide	Genotoxicity using chromosome aberrations, alkaline comet assay, micronuclei formation and sister chromatid exchange and cell viability using nuclear division index	No effect was found of RFR alone from any assay endpoints	Absence	Stronati et al. (2006)
99	Human peripheral blood lymphocytes	2450 MHz (PW), SAR 2.13 W/kg for 2 h using anechoic chamber with horn antenna	Cytogenetic damage assessed, genotoxic effect (chromosome aberrations, micronuclei formation), cell viability using mitotic index	No statistically significant difference was found	Absence	Vijayalaxmi (2006)
100	Human peripheral blood lymphocytes	900 MHz (GSM), SAR 1, 5 and 10 W/kg for 24 h using wire-patch cell (WPC)	Micronucleus frequency and cell proliferation	No evidence was found for the existence of genotoxic or cytotoxic effects	Absence	Scarf et al. (2006)
101	Human monocytes cells (Mono Mac 6)	1800 MHz (PW), SAR 2 W/kg for 12 h using waveguide with cavity resonator	Cell viability and apoptosis using flow cytometry	Cell cycle alterations or changes in BrdU incorporation or induce apoptosis and necrosis in Mono Mac 6 cells were not found	Absence	Lantow et al. (2006c)
102	Human blood lymphocytes cells	1950 MHz (GSM-PW), SAR 1 mW/kg for intermittent exposure (5 min ON, 10 min OFF) for 8 h using rectangular waveguides (R18) with cavity resonator	Cytotoxicity using flow cytometry, activity of immune-relevant genes using RT-PCR	No statistically significant effects were found on the human immune system due to radiofrequency radiation	Absence	Tuschl et al. (2006)
103	Human endothelial cells (EA.hy926 and EA.hy926v1)	900 MHz (GSM-PW), SAR 2.8 W/kg for 1 h using waveguide with resonator (TE10 mode)	Gene and protein expression analysis using DNA microarray, two-dimensional electrophoresis, silver stain and PDQuest software	Obtained results show that gene and protein expression were altered in both examined cell lines. The study suggests the cell responses might be genome- and proteome-dependent	Presence	Nylund et al. (2006)

Table 21

Human Cell Studies: Weak RF-radiation exposure conditions used in the investigations that examined gene expression in mammalian cells exposed in vitro.

No	Cell Line	Exposure System	Analysis	Results	Cellular Response	Authors
104	Human neuroblastoma cells (SK-N-SH) and Monocyte cells (U937)	900 MHz (GSM-PW), SAR 0.2 W/kg for 1, 2 h using TEM cell	Cell viability and cell cycle distribution using flow cytometry and gene expression (heat shock protein) using Western blot and RT-PCR	Gene expression, cell viability and cell cycle distribution were not changed significantly	Absence	Gurisik et al. (2006)
105	Human glioblastoma cells (A172) and human fibroblasts cells (IMR90) from fetal lungs	2142 MHz (CW, WCDMA), SAR 80, 250 and 800 mW/kg for 24, 28 h and CW, SAR 80 mW/kg for 28 h using anechoic chamber with horn antenna	Cell viability using apoptosis, flow cytometry and gene expression using RT-PCR	No significant differences were found in the expression of these p53-related apoptosis	Absence	Hirose et al. (2006)
106	Human neuroblastoma cells (NB69), T lymphocytes, human microglial cells (CHME5), human endothelial cells (EA.hy926), monocytic lymphoblastoma cells (U937) and human acute myeloid leukemia cells (HL60)	900 MHz (GSM) 1800 MHz (GSM), SAR 0.77 W/kg and SAR 1.8–2.5 W/kg for intermittent exposure (5 min ON, 10 min OFF) for 1, 24 h and (10 min ON, 20 min OFF) for 44 h using waveguide with cavity resonator	Gene expression using DNA microarray	No significant changes in gene expression was found in NB69 neuroblastoma cells, T lymphocytes, and CHME5 microglial cells. In EA.hy926 endothelial cells, U937 lymphoblastoma cells, and HL60 leukemia cells were found between 12 and 34 up- or down-regulated genes	Presence/ Absence	Remondini et al. (2006)
107	Human breast cancer cells (MCF7)	1800 MHz (GSM-PW), SAR 2 and 3.5 W/kg, continuous or intermittent exposure (5 min ON, 10 min OFF) 1, 3, 6, 12 and 24 h using rectangular waveguide	Gene and protein expression using DNA microarray, RT-PCR and two-dimensional gel electrophoresis	No effect at 2 W/kg was found, however, 5 genes up-regulated at 3.5 W/kg	Presence/ Absence	Zeng et al. (2006a)
108	Human leukemia cells (HL60) and human monocytes Mono-Mac-6 cells (MM6)	1900 MHz (PM), SAR 1 and 10 W/kg for Intermittent exposure (5 min ON, 10 min OFF) for 6 h using circular waveguide	Gene expression (heat shock proteins (HSP27, HSP70)), proto-oncogenes (c-jun, c-myc	No significant effects were found in mRNA expression of HSP27, HSP70, c-jun, c-myc or c-fos between the sham and RF-exposed groups	Absence	Chauhan et al. (2006a)

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Table 21 (continued)

No	Cell Line	Exposure System	Analysis	Results	Cellular Response	Authors
109	Human cultured glioblastoma cells (U87MG)	1900 MHz (PM), SAR 0.1, 1.0 and 10 W/kg for 4 h using circular waveguide	and c-fos) using RT-PCR and cell viability Gene expression, RNA microarray, heat shock proteins using semiquantitative RT-PCR	No effects was found in gene expressions	Absence	Qutob et al. (2006)
110	Human lymphoblastoma cells (TK6)	1900 MHz (PM), SAR 1 and 10 W/kg for Intermittent exposure (5 min ON, 10 min OFF) for 6 h using circular waveguide	Gene expression- mRNA expression and heat shock protein genes (HSP27, HSP70) using RT-PCR	No alterations in HSP27, HSP70 genes were found, however, concurrent positive (heat-shock) control samples displayed a significant elevation in the expression of HSP27, HSP70, FOS and JUN	Absence	Chauhan et al. (2006b)
111	Human neuroblastoma cells (SH-SY5Y)	900 MHz (CW, GSM-PW), SAR 0.25 W/kg (PW), SAR 2 W/kg (CW) for 24 h using wire-patch cell (WPC)	Apoptosis rate using DAPI staining, flow cytometry and double staining (TUNEL assay)	No apoptosis	Absence	Joubert et al. (2006)

Table 22

Human Cell Studies: Weak RF-radiation exposure conditions used in the investigations that examined gene expression in mammalian cells exposed in vitro.

No	Cell Line	Exposure System	Analysis	Results	Cellular Response	Authors
112	Human lens epithelial cells	1800 MHz (GSM, PW), SAR 1, 2, or 3 W/kg for 30, 60, 120 and 240 min using waveguide	DNA damage, expression of heat shock protein 70 (HSP70) and cell proliferation using comment assay and BudR incorporation, Western blot and RT-PCR	SARs 2 and 3 W/kg for 2 h showed significantly increased HSP70 protein expression ($p < 0.05$), no change in HSP70 mRNA expression, no difference of the cell proliferation rate	Presence/ Absence	Lixia et al. (2006)
113	Human glioblastoma cells (A172)	2450 MHz (CW), SAR <5, 10, 20, 50 W/kg for 10, 30, 60, 120 and 180 min using rectangular waveguide (TE10)	Protein expression using Western blotting	No alterations in HSP27, HSP70 or phosphorylated-HSP27 protein expression in human glioblastoma-derived A172 cells were found	Absence	Wang et al. (2006)
114	Human neuroblastoma cells (LAN-5)	900 MHz (GSM-PW), SAR 1 W/kg for 24, 48, 72 h using wire patch cells (WPC)	Protein expression using Western blots, cell proliferation using apoptosis	No significant effect of RF alone on proliferation, apoptosis and differentiation or co-exposures were found	Absence	Merola et al. (2006)
115	Human monocytes Mono Mac 6 cells (MM6) and human erythroleukemic cells (K562)	1800 MHz (CW, GSM-DTX, GSM-non DTX, GSM-talk), SAR 0.5, 1.0, 1.5, and 2 W/kg for 45 min (continuous and intermittent exposure for 5 min ON, 10 min OFF) using rectangular waveguides (R18) with cavity resonator	Protein HSP70, heat shock proteins using flow cytometry	GSM-DTX signal at 2 W/kg produced a significant difference, no changes in HSP70 and no effects of co-exposures were found	Presence/ Absence	Lantow et al. (2006a)
116	Primary human monocytes and lymphocytes	1800 MHz (CW, GSM-DTX, GSM talk), SAR 2 W/kg for 30 or 45 min continuous or intermittent (5 min ON, 5 min OFF) using rectangular waveguides (R18) with cavity resonator	ROS formation - apoptosis detection, HSP70 expression using flow cytometry	HSP70 expression after exposure to continuous or intermittent GSM-DTX signal increased ROS production in human monocytes (interpreted as a negative study as a decreased sham value)	Presence/ Absence	Lantow et al. (2006b)
117	Human skin cells, human reconstructed epidermis (hRE) using human keratinocytes and human dermal fibroblast	900 MHz (GSM-PW), SAR at 2 W/kg for 48 h using wire-patch antenna (WPC)	HSC70, HSP27 and HSP70 expression using immunohistochemistry and fluorescence microscopy, cell proliferation using flow cytometry, apoptosis	No immediate effect, however significant increase in HSP70 expression was found	Presence/ Absence	Sanchez et al. (2006)
118	Human cervical carcinoma cells (HeLa S3) and human endothelium cells (EA.hy296)	847 MHz (TDMA), SAR of 5 W/kg for 1, 2 or 24 h or 900 MHz (GSM-PW), SAR of 3.7 W/kg for 1, 2 or 5 h using radial waveguide	Heat shock protein using two-dimensional gel electrophoresis, immunoblotting	No significant differences in the levels of HSP27 phosphorylation was found	Absence	Vanderwaal et al. (2006)
119	Human monocyte Mono Mac 6 cells (MM6)	1800 MHz (CW, GSM-PW, GSM-nonDTX), SAR 2 W/kg for 60 min using cavity resonator	Free radical levels and the stress protein heat-shock protein (HSP70) using flow cytometry and Western blot	RF exposure cannot influence stress-related responses	Absence	Simkó et al. (2006)

Table 23

Human Cell Studies: Weak RF-radiation exposure conditions used in the investigations that examined gene expression in mammalian cells exposed in vitro (cont.).

No	Cell Line	Exposure System	Analysis	Results	Cellular Response	Authors
120	Peripheral blood				Presence	Stankiewicz et al. (2006)

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Table 23 (continued)

No	Cell Line	Exposure System	Analysis	Results	Cellular Response	Authors
121	mononuclear cells (PBMC) Peripheral blood cells (PBMCs)	900 MHz (GSM-PW), SAR 0.024, 0.18 W/kg for 15 min/day for 3 days using anechoic chamber 1800 MHz (PW), SAR 2 W/kg, intermittent exposure (10 min ON, 20 min OFF) for 44 h using cavity resonator	Cell viability, influence on mitogenic response, cell function, T cell and monocyte activity Cellular functions and molecular pathways - apoptosis induction, percentage of cell subsets using flow cytometry	Immune activity of responding lymphocytes and monocytes can be additionally intensified by 900 MHz fields No significant changes were found between exposed and sham-exposed lymphocytes, RF exposure we observed a slight, but significant, down-regulation of CD95 expression in stimulated CD4 ⁺ T lymphocytes from elderly, however, not from young donors	Presence	Capri et al. (2006)
122	Glial cells: Astroglial (astrocytes) cells and microglial cells	900 MHz (CW, GSM-PW), SAR 3 W/kg (PW), 27 W/kg (CW) for 4, 8 and 24 h using waveguide with cavity resonator (TE103 mode)	Microglial reactivity marker using Western blot, cell reactivity, cell damage, cell morphology using light microscopy	No significant differences found in any of the parameters	Absence	Thorlin et al. (2006)
123	Human lens epithelial cells (HLECs)	1800 MHz (PW), SAR 1, 2, 3 and 4 W/kg for 2 h	DNA-breaks, DNA single strand breaks using comet assay, single-cell gel electrophoresis, cell proliferation rate	No effective DNA damage was observed using comet assay after 2 h irradiation of 1800 MHz microwave for SAR was ≤ 3 W/kg	Presence/ Absence	Sun et al. (2006a)
124	Human lens epithelial cells (HLECs)	1800 MHz (GSM-PW), SAR 1, 2, 3 and 4 W/kg for 2 h	DNA single strand breaks using comet assay	SAR 1 and 2 W/kg irradiation was not significant, however, 3 and 4 W/kg there was difference in both group immediately after irradiation	Presence/ Absence	Sun et al. (2006b)
125	Human sperm	900 MHz (GSM-PW), power density 0.02 mW/cm ² for 5 min	Sperm motility, sperm concentration	Significant difference in sperm motility were observed in the rapid progressive, however, sperm concentration difference was not observed	Presence	Erogul et al. (2006)
126	Peripheral blood lymphocytes	1800 MHz (CW), power flux density 5, 10 and 20 mW/cm ² for 60, 120, 180 min using trumpet-like aerial	Genotoxicity using micronuclei frequency and cell viability using lymphocyte proliferation index, chromosomes	A statistically significant increase of micronuclei was observed and decrease in spontaneous and induced micronuclei frequencies was found	Presence	Zotti-Martelli et al. (2005)
127	Human peripheral blood leukocytes	900 MHz (GSM-PW), SAR 0.3, 1 W/kg for 2 h using rectangular waveguide	DNA damage using the alkaline SCGE/comet assay and structural chromosome aberrations and sister chromatid exchanges (SCE) were evaluated in lymphocytes stimulated with phytohemagglutinin	No statistically significant differences were detected	Absence	Zeni et al. (2005)
128	Human blood lymphocytes	915 MHz (PW), SAR 37 mW/kg for 24 and 48 h using TEM cell	DNA breaks and apoptosis using immunostaining and pulsed-field gel electrophoresis	Decrease was found in background levels of 53BP1 foci and this may indicate decrease in accessibility of 53BP1 to antibodies as stress-induced chromatin condensation	Presence	Belyaev et al. (2005)
129	Human blood lymphocytes	1800 MHz, SAR 3 W/kg for 2 and 3 h	DNA damage effects using comet assay	No DNA damage effects 1800 MHz RFR for 2 h, but could enhance the human lymphocyte DNA damage effects induced by MMC and 4NQO	Absence	Wang et al. (2005b)
130	Human acute myeloid leukemia cells (HL60)	2450 MHz (PW), SAR 10 W/kg for 2 and 6 h using waveguide)	Gene expression using SAGE and apoptosis	2.45 GHz can change gene expression - 221 genes altered at 2 h exposure and 759 genes altered at 6 h exposure. Apoptosis-related gene are upregulated. Cell cycle gene are down-regulated. Heat shock gene stay unaltered	Presence	Lee et al. (2005)

Table 24

Human Cell Studies: Weak RF-radiation exposure conditions used in the investigations that examined gene expression in mammalian cells exposed in vitro (cont.).

No	Cell Line	Exposure System	Analysis	Results	Cellular Response	Authors
131	Human glioma cells (MO54)	1950 MHz (CW), SAR 1, 2 and 10 W/kg for 10, 30 min 1 and 2 h using waveguide with cavity resonator (R18 mode)	Protein expression, HSP70 and HSP27 using Western blotting and immunofluorescent staining and cell morphology using phase contrast microscopy	Exposure to RF field at a SAR of 10 W/kg for 1 and 2 h decreased the protein level of phosphorylated HSP27	Presence/ Absence	Miyakoshi et al. (2005)
132	Human blood lymphocytes and monocytes	900 MHz (GSM, CW, PW), SAR at 0.4, 2 and 3.6 W/kg for 20 min, 1 and 4 h using TEM cell	Protein expression, HSP27 and HSP70 using flow cytometry)	No statistically significant difference was observed in the number of cells expressing stress proteins after RF-field exposure	Absence	Lim et al. (2005)
133	Human blood Lymphocytes	905, 915 MHz (GSM) SAR 37 mW/kg for 1 h using TEM cell	Cell viability, 53BP1/ γ -H2AX foci Immunostaining-Trypan blue exclusion assay, AVTD assay, DNA double-strand breaks, stress response	Observed a significant reduction in the 53BP1 level and the effect depends on the carrier frequency. These effects show stress responses and DNA damage	Presence	Markova et al. (2005)
134	Human oropharyngeal epidermoid carcinoma	1950 MHz, SAR 3.6 mW/g for 1, 2, 3, 48 h using waveguide	DNA damage, Apoptosis, protein expression of HSP90, HSP27 and HSP70 by Western blot assay	EMF induced apoptosis through the inactivation of the ras- ζ Erk survival signalling due to enhanced degradation of raf-1	Presence	Caraglia et al. (2005)

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Table 24 (continued)

No	Cell Line	Exposure System	Analysis	Results	Cellular Response	Authors
135	KB cancer cell line Human blood lymphocytes	1800 MHz (GSM), SAR 3 W/kg for 2 and 3 h using rectangular waveguide chambers (R18)	DNA damage using Alkaline comet assay	No human lymphocyte DNA damage effects was found in vitro, however could enhance the human lymphocyte DNA damage effects induced by MMC and 4NQO	Absence	Baohong et al. (2005)
136	Peripheral blood mononuclear cells (PBMCs)	(i) 900 MHz (GSM-PW), SAR 76 mW/kg for 1 h/day for 2 days (ii) 900 MHz (CW), SAR 70 mW/kg for 1 h/day for 2 days (iii) 900 MHz (CW), SAR 70 mW/kg for intermittent exposure (30 min ON, 30 min OFF) for a day using TEM cell	Apoptosis and Mitochondrial Membrane Potential - (i) mitogen-induced proliferation; (ii) cell cycle progression; (iii) spontaneous and 2-deoxy-D-ribose (dRib)-induced apoptosis; (iv) mitochondrial membrane potential modifications during spontaneous and dRib-induced-apoptosis, flow cytometry	Shown a slight decrease in cell proliferation when PBMCs were stimulated with the lowest mitogen concentration and a slight increase in the number of cells with altered distribution of phosphatidylserine across the membrane. No significant modifications were found in CW RF field	Absence	Capri et al. (2004a)
137	Human lymphoblastoid cells (Molt-4 T)	813.56 MHz (iDEN, PW), 836.55 MHz (TDMA, PW), 847.74 MHz (CDMA) and 835.62 MHz (FDMA), SAR 3.2 W/kg (CDMA and FDMA), 2.4 W/kg (iDEN) and 2.6 W/kg (TDMA) for 24 h using Radial Transmission Line (RTL)	DNA single-strand break using SCGE, comet assay and cell proliferation using apoptosis	No DNA damage or induce apoptosis were found exposure of Molt-4 cells to CDMA, FDMA, iDEN or TDMA modulated RF radiation	Absence	Hook et al. (2004b)
138	Human endothelial cells (EA.hy926)	900 MHz (GSM-PW), SAR 2.4 W/kg for 1 h using exposure chamber	Protein expression using two-dimensional electrophoresis (2-DE), silver stain, PDQuest software, Western blot, immunofluorescence, flow cytometry	The expression level of this protein was somewhat down-regulated in the exposed samples having a ratio exposed vs. control 0.72 with a p-value of 0.03. Confirmed the hypothesis that indicated that the mobile phone radiation might affect the cytoskeleton, might have an impact on the physiological functions that are regulated by the cytoskeleton	Presence	Nylund and Leszczynski, (2004)

Table 25

Human Cell Studies: Weak RF-radiation exposure conditions used in the investigations that examined gene expression in mammalian cells exposed in vitro (cont.).

No	Cell Line	Exposure System	Analysis	Results	Cellular Response	Authors
139	Human endothelial cells (EA.hy926)	900 MHz (GSM), SAR 2.4 W/kg for 1 h	Gene expression, protein expression, apoptosis using 2-DE and Western blot	HSP27 protein was affected	Presence	Leszczynski et al. (2004)
140	Human blood lymphocytes	895, 900, 905, 910, and 915 MHz (GSM-PW), 5.4 mW/kg for 30, 60 min using TEM cell	Heat shock expression, DNA damage, cell viability using AVTD, SCGE	Observed the significant effect and this is different at different GSM frequencies and varied between individuals	Presence	Sarimov et al. (2004)
141	Human peripheral blood mononuclear cells (PBMC)	1800 MHz, (GSM-PW) - GSM Basic (SAR 2 W/kg), GSM-DTX (SAR 1.4 W/kg), GSM-Talk (SAR 2 W/kg), for intermittent exposure (10 min ON, 2 min OFF) for 44 h using waveguide with cavity resonator	Protein expression using flow cytometry, apoptosis using Single cell gel electrophoresis, flow cytometry and halo assay	No significant difference was found. 1800 MHz RF could not induce apoptosis by itself or affect the apoptotic phenomenon when induced by an apoptotic agent. RF did not modify the mitochondrial functionality and the expression of HSP70	Absence	Capri et al. (2004b)
142	Human lipid membrane (liposomes)	2450 MHz, 1.4, 2.8, 4.2, and 5.6 W/kg for 3 min using TEM cell	Enzyme activity using spectrophotometry	No response was observed for SAR below 5.6 W/kg and the difference is not statistically significant when used SAR is 5.6 W/kg	Absence	Ramundo-Orlando et al., (2004)
143	Embryonic stem cells (EC-P19)	1710 MHz (GSM-217 Hz), 1.5, 2 W/kg (GSM-217 Hz) and 0.4 W/kg (GSM-Talk) for intermittent exposure (5 min ON, 30 min OFF) for 6 and 48 h using waveguide (R14)	Gene expression, RT-PCR analysis and apoptosis detection of cell cycle phases using flow cytometric	GSM-217 EMF induced a significant up-regulation of mRNA levels of the heat shock protein, HSP70 of p53-deficient ES cells differentiating in vitro, however, no effect on egr-1 or bcl-2 was found	Presence	Czyz et al. (2004)
144	Human blood lymphocytes simulated with phytohemagglutinin	900 MHz (CW, GSM), SAR 1.6 W/kg (GSM and CW) at 14 cycles of intermittent exposure (6 min ON, 3 h OFF) and SAR at 0.2 W/kg (GSM) at 1hr/day exposure for 3 days using TEM cell	Micronucleus frequency and cell cycle kinetics	No significant differences in either micronucleus frequency or cell cycle kinetics were found	Absence	Zeni et al. (2003)
145	Human peripheral blood lymphocytes (PBL)	830 MHz (CW), SAR 2, 2.9, 4.3, 8.2 W/kg for 72 h	DNA replication, Chromosomal aberration analysis using FISH	Genotoxic effect and epigenetic alterations are found. Genotoxic effect of the EMF radiation is obtained via a non-thermal pathway	Presence	Mashevich et al. (2003)
146	Human blood lymphocytes	1900 MHz (CW and PM) generated using a series of 6 circularly polarized cylindrical waveguide, SAR ranging from 0.1, 0.26, 0.92, 2.4, 10 W/kg for 24 h using waveguide (TE11)	Micronucleus, DNA Strand breakage using the alkaline comet assay	No significant difference in the binucleated cell frequency, incidence of micronucleated binucleated cells or total incidence of micronuclei were found	Absence	McNamee et al. (2003)

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Table 25 (continued)

No	Cell Line	Exposure System	Analysis	Results	Cellular Response	Authors
147	Human blood lymphocyte	2450 MHz, SAR 1.5 W/kg for 2 and 3 h	DNA damage using comet assay	DNA damage was not directly found, however, could enhance the DNA damage effects induced by MMC	Presence/Absence	Zhang et al. (2003)
148	T-lymphocytes and monocytes - Human peripheral blood mononuclear cells	1300 MHz (PM), SAR 0.18 W/kg for 1 h using anechoic chamber with horn antenna	Activation of immunogenic and proinflammatory functions	The potential of immunotropic influence, stimulating the immunogenic and proinflammatory activity of monocytes at low levels of exposure was observed	Presence	Dabrowski et al. (2003)

Table 26

Human Cell Studies: Weak RF-radiation exposure conditions used in the investigations that examined gene expression in mammalian cells exposed in vitro (cont.).

No	Cell Line	Exposure System	Analysis	Results	Cellular Response	Authors
149	Human blood leukocytes	1900 MHz (CW), SAR 0.1, 0.26, 0.92, 2.4, 10 W/kg for 2 h using circularly polarized cylindrical waveguide with monopole antenna (T11 mode)	Micronucleus assay, DNA Strand breakage using the alkaline comet assay and tail ratio, tail moment, comet length and tail length were used to assess DNA damage for each comet	No significant difference in the binucleated cell frequency, incidence of micronucleated binucleated cells or total incidence of micronuclei were found	Absence	McNamee et al. (2002a)
150	Human blood leukocytes	1900 MHz (PM), SAR 0.1, 0.26, 0.92, 2.4, 10 W/kg for 2 h using circularly polarized cylindrical waveguide with monopole antenna (T11 mode)	Micronucleus assay, DNA Strand breakage using the alkaline comet	No significant difference in the binucleated cell frequency, incidence of micronucleated binucleated cells or total incidence of micronuclei were found	Absence	McNamee et al. (2002b)
151	Human blood lymphocytes	2450 MHz (CW), power flux density 5 mW/cm ² (1.5 W/kg) for 2 h using magnetron	DNA damage, chromosome change using single cell gel electrophoresis (SCGE) (comet assay) and formation of micronuclei	No induce DNA and chromosome damage, however DNA damage effect induced by MMC in comet assay increased were found	Absence	Zhang et al. (2002)
152	Human blood leukocytes and lymphocytes	837 MHz (TDMA, voice modulated), 837 MHz (CDMA, not voice modulated), and voice modulated 1909.8 MHz (GSM), SAR 1, 2.5, 5, 10 W/kg for 3 or 24 h using TEM cell	DNA and chromosomal damage, DNA damage (strand breaks/alkali labile sites) leukocytes using the alkaline single cell gel electrophoresis (SCG) assay, Micronucleus assay	SAR of 5.0 W/kg is capable of inducing chromosomal damage in human lymphocytes were found	Presence/Absence	Tice et al. (2002)
153	Human peripheral blood cultures, lymphocytes	1748 MHz (GSM) both phase (GMSK) and amplitude (TDMA) modulate, SAR 5 W/kg for 15 min using waveguide	Cell proliferation kinetics and/or genotoxic effects using the cytokinesis block proliferation index and the micronucleus frequency	A statistically significant micronucleus effect was found to phase modulated field but not with CW or GMSK field, this result would show a genotoxic effect of phase modulation	Presence/Absence	D'Ambrosio et al. (2002)
154	Human skin fibroblasts	902.4 MHz (GSM-PW), SAR 0.6 W/kg for 1 h	Gene expression changes using Atlas array, DNA synthesis and controlling apoptosis, cell morphology	Genes of mitotic signal transduction up-regulated, data showed the morphological and functional changes due to RF exposure	Presence	Pacini et al. (2002)
155	Human glioma cells (MO54)	2450 MHz (CW), SAR 5, 20, 50 W/kg for 2, 4, 8, 16 h using circular waveguide with cavity resonator	Protein expression using Western blots, HSP70	Increased expression of HSP70 at SAR is greater than 20 W/kg was observed	Presence	Tian et al. (2002)
156	Human endothelial cells (EA.hy926)	900 MHz (GSM-PW), SAR 1.8–2.5 W/kg, 1 h using waveguide	Protein expression and detection of HSP27 expression using Western blot, PDQuest software, silver-stained 2D-gels, apoptosis detection	Mobile phone exposure made transient changes in the protein expression levels of HSP27 and p38MAPK	Presence	Leszczynski et al. (2002)
157	Human blood platelets	900 MHz for 1, 3, 5, and 7 min	superoxide dismutase (SOD-1) and the level of malonyldialdehyde (MDA)	significantly depleted SOD-1 activity after 1, 5, and 7 min of exposure and increased after 3 min in comparison with the control test	Presence	Stopczyk et al. (2002)
158	Human blood lymphocytes (T-75 tissue)	835.62 MHz (FDMA, CW), SAR 4.4 and 5 W/kg for 24 h using radial transmission lines (RTL)	Genotoxic damage and carcinogenic effects using chromosomal aberrations and micronuclei	No evidence for the induction of chromosomal aberrations and micronuclei in human blood lymphocytes were found	Absence	Vijayalaxmi et al. (2001a)
159	Human blood lymphocytes (T-75 tissue)	847.7 MHz (CDMA, CW), SAR 4.9 and 5.5 W/kg for 24 h using radial transmission lines (RTL)	Genetic damage using chromosomal aberrations and micronuclei	No evidence for the induction of chromosomal aberrations and micronuclei in human blood lymphocytes were found	Absence	Vijayalaxmi et al. (2001b)
160	Human blood lymphocytes	900 MHz (GSM, CW, PW), SAR 0.4, 2, 3.5, 5.5, and 10 W/kg for 2 h using TEM cell	Chromosome aberration and sister chromatid exchange and cell proliferation	No indication was found of a mutagenic, and/or co-mutagenic/synergistic effect	Absence 15/15	Maes et al. (2001)

Table 27

Human Cell Studies: Weak RF-radiation exposure conditions used in the investigations that examined protein expression in mammalian cells exposed in vitro.

No	Cell Line	Exposure System	Analysis	Results	Cellular Response	Authors
161					Presence	

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Table 27 (continued)

No	Cell Line	Exposure System	Analysis	Results	Cellular Response	Authors
	Human epithelial amnion (AMA) cells	960 MHz (GSM-217 Hz), SAR 2.1 mW/kg for 20 min using TEM cell	Protein expression, heat-shock proteins HSP70 and HSP27 using immunofluorescence	Higher amounts of HSP70 were present however, no significant response in the case of HSP27		Kwee et al. (2001)
162	Human T-lymphocyte hybridoma cells, Jurkat cells (E6-1)	915 MHz (GSM, CW and PW), SAR 1.5 W/kg for 20 min using transmission lines	Cell calcium concentration using fluorescence microscope	No evidences found in calcium levels or calcium signalling in lymphocytes due to RF exposure	Absence	Cranfield et al. (2001)
163	Human blood serum	2375 MHz (PW), 0.8, 8, 40 $\mu\text{W}/\text{cm}^2$ for 1–3 min	Alkaline phosphatase activity	Change in alkaline phosphatase activity in vitro was observed	Presence	Pashovkina and Akoev, (2001a)
164	Human blood	2375 MHz (PW), 2, 8 $\mu\text{W}/\text{cm}^2$ for 5 min	Aspartate amino transferase activity	Maximum activity was found at 390 Hz and 8 $\mu\text{W}/\text{cm}^2$	Presence	Pashovkina and Akoev, (2001b)
165	Human blood lymphocytes	2450 MHz (CW), power flux density 10, 20 and 30 mW/cm^2 for 15, 30, 60 min using anechoic chamber with horn antenna	Cytogenetic damage and cell proliferation using micronucleus (MN) assay	Cytogenetic damage in human lymphocytes was found at a power density of 30 mW/cm^2 after an exposure of 30 and 60 min (increased the lymphocyte MN frequencies without affecting cell cycle progression)	Presence	Zotti-Martelli et al. (2000)
166	Human blood lymphocytes	2400 MHz (PW), SAR 2.135 W/kg for 2 h using anechoic room with horn antenna	DNA damage using single-strand breaks, alkaline comet assay (tail length, tail intensity, tail moment)	No damage was found in DNA single-strand breaks and alkali-labile lesions	Absence	Vijayalaxmi et al. (2000)
167	Human Jurkat T-cell line	2450 MHz (CW), SAR 4 W/kg for 48 h using horn antenna chamber	Cell viability using the trypan dye exclusion method and Apoptosis detection	Statistically significant non-thermal in vitro effects on immune system was observed	Presence	Peinnequin et al. (2000)
168	Human mast cell line (HMC-1)	864.3 MHz, SAR 7 W/kg for 20-min/day for 7 days using resonant chamber	Protein expression using Western blot and gene expression changes using Atlas array	Effects were found on localization of protein kinase C, and expression of three genes of 588 screened	Presence	Harvey and French, (1999)
169	Human epithelial amnion cells (AMA)	960 MHz (GSM, AM, 217 Hz), SAR 2.1 $\mu\text{W}/\text{g}$ for 30 min using TEM cell	Cell proliferation	A significant change in cell proliferation in the exposed cells in comparison to the non-exposed control cells were found	Presence	Velizarov et al. (1999)
170	Human fibroblasts	837 MHz (CW), SAR 0.9 or 9.0 W/kg for 2 h using TEM cell	TP53 protein expression using Western blot	No evidence was found of altered TP53 protein expression	Absence	Li et al. (1999)
171	Human lymphoblastoid cells (Molt-4 T)	813.5 MHz (iDEN) and 836.5 MHz (TDMA), SAR 3.2 W/kg for CDMA and FDMA, 2.4 or 24 mW/kg for iDEN, and 2.6 or 26 mW/kg for TDMA for 2 and 21 h using TEM cell	DNA Strand breakage using alkaline comet and single cell gel electrophoresis (SCGE)	DNA damage altered due to difference in signal, SAR, exposure duration	Presence	Phillips et al. (1998)
172	Human epithelial amnion cells	960 MHz (GSM, PW), SAR 0.021, 0.21 and 2.1 mW/kg for 20, 30, 40 min, respectively using TEM cell	Changes in cell proliferation	Decrease in cell growth	Presence	Kwee and Raskmark, (1998)
173	Human blood lymphocytes	935.2 MHz (CW), SAR 0.3, 0.4 W/kg for 2 h using TEM cell	DNA damage, Chromosomal aberrations, sister chromatid exchanges and the alkaline comet assay	No cytogenetic damage on RF-radiation exposure alone was found	Absence	Maes et al. (1997)

Table 28

Human Cell Studies: Weak RF-radiation exposure conditions used in the investigations that examined protein expression in mammalian cells exposed in vitro (cont.).

No	Cell Line	Exposure System	Analysis	Results	Cellular Response	Authors
174	Human blood lymphocytes	2450 MHz (CW), SAR 12.5 W/kg for intermittent exposure (30 min ON, 30 min OFF) for 1.5 h using antenna horn	Cell proliferation, mitotic indices, chromosome damage, exchange aberrations, micronuclei	No differences were found for an effect on mitogen-stimulated proliferation kinetics or for excess genotoxicity	Absence	Vijayalaxmi et al. (1997)
175	Human blood lymphocytes	900 (PM), 1800 MHz (GSM, 217 Hz PM), SAR 208 mW/kg (900 MHz) and 1700 mW/kg (1800 MHz) for 4 h using wave-guide	Cell cycle progression and the frequencies of sister chromatid exchanges, SCE	No changes between exposed and control cultures were identified	Absence	Antonopoulos et al., (1997a, b))
176	Human astrocytoma cells, primary glioblastoma cells (U87MG)	835 MHz, 8.1, 40 mW/cm^2 for 3 $\times$ 20 min/day for 7 days using cavity resonator	Cell viability, alteration in cell morphology, rate of DNA synthesis, signal transduction pathway	At the 8 mW/cm^2 - the rate of DNA synthesis reduced, and that the cells flattened and spread out. At 40 mW/cm^2 , no effects seen on cell proliferation, nevertheless changes in cell morphology included also increased cell spreading	Presence	French et al. (1997)

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Table 28 (continued)

No	Cell Line	Exposure System	Analysis	Results	Cellular Response	Authors
177	Human blood lymphocytes	954 MHz (GSM-PW), 1.5 W/kg for 2 h	DNA damage, Cell proliferation, Chemical mutagen mitomycin C (MMC), sister chromatid exchange (SCE) analysis	and the appearance of actin-containing blebs at localized places on the membrane Synergistic effect was found with the chemical mutagen mitomycin C (MMC)	Presence	Maes et al. (1996)
178	Human blood lymphocytes	954 MHz (GSM-PW), SAR 1.5 W/kg for 1, 2 h	Chromosome aberrations	Insignificant increase was found in chromosome aberration frequency after exposure	Absence	Maes et al. (1995)
179	Human glioma cells (LN71) and Human blood lymphocytes	2450 MHz (CW), SAR 50 W/kg for 2 h	Changes in nucleic acid	Increased incorporation of radiolabelled nucleic acid at SARs of 50 W/kg or less	Presence	Cleary, (1995)
180	Human phosphatidylcholine liposome	2450 MHz (CW), SAR 38 W/kg for 5, 10, 15 and 20 min using horn antenna	Fluorescence emission assessed of the carboxyfluorescein dye	No permeability of liposome was detected and the overall observed microwave-induced membrane permeability, is not significant	Absence	Bergqvist et al. (1994)
181	Human lipid membrane (liposomes)	2450 MHz (AM), SAR 2.8, 5.6 mW/g for 3 min using TEM cell	DNA synthesis, enzyme-activity	The enzyme loaded into liposomes exhibits a significant decrease of 13% ($p < 0.005$, $n = 42$) at SAR 5.6 mW/g, however, no significant decrease was found in SAR 2.8 mW/g	Presence	Ramundo-Orlando et al., (1993)
182	Human peripheral lymphocytes	2450 MHz (CW, PM), SAR 0.5 and 5 W/kg for 2 h	Cell proliferation	Caused statistically significant increased $^3\text{H-TdR}$ incorporation in both PHA-activated and unactivated lymphocytes	Presence	Cleary et al. (1992)
183	Human lymnaea neurons	900 MHz (CW, PM), SAR 0.5, 15 W/kg (CW) and SAR 0.5, 2, 4 W/kg (PM) for 6 min using waveguide	Bursting response of neurons to RF fields	A CW exposure when SAR 0.5–15 W/kg was not shown the bursting effect	Absence	Bolshakov and Alekseev, (1992)
184	Human blood lymphocytes	2450 MHz (CW, PW), SAR 12.3 W/kg using waveguide	Chromosome A, Spontaneous lymphoblastoid transformation	PW exposure increased transformation at non-heating levels. With the same SAR values, PW 2450-MHz radiation acts differently on the process of lymphoblastoid transformation in vitro compared with CW 2450-MHz radiation.	Presence	Czerska et al. (1992)
185	Melanoma cell membrane (B16)	2450 MHz (PW), SAR 0.2 W/kg for 60 min using anechoic chamber	Estimation of membrane fluidity, spectral parameter	A significant, specific alteration of cell-membrane was observed and this alteration was distinctive to melanotic membranes (due to the generation of oxygen radicals)	Presence	Phelan et al. (1992)

Table 29

Human Cell Studies: Weak RF-radiation exposure conditions used in the investigations that examined protein expression in mammalian cells exposed in vitro (cont.).

No	Cell Line	Exposure System	Analysis	Results	Cellular Response	Authors
186	Unilamellar liposome	2450 MHz, SAR 38 W/kg for 10 min using waveguide with horn antenna	Fluorescence: permeability of carboxy fluorescein through the membrane	Observed a significant increase in leakage of liposomes above their phase transition temperature upon exposure to RF fields	Presence	Saalmann et al. (1991)
187	Human blood lymphocyte	2450 MHz (CW), SAR 5, 50 W/kg for 2 h using exposure chamber	Cell proliferation - lymphocyte morphology or viability	No detectable effects of RF radiation on lymphocyte morphology or viability was observed	Absence	Cleary et al. (1990)

Table 30

Rat/Mouse Cell Studies: Weak RF-radiation exposure conditions used in the investigations that examined protein expression in mammalian cells exposed in vitro (cont.).

No	Cell Line	Exposure System	Analysis	Results	Cellular Response	Authors
188	Murine spermatocyte-derived cells (GC-2)	1800 MHz (GSM-talk), SAR 1, 2, 4 W/kg for intermittent exposure (5 min ON, 10 min OFF) for 24 h using waveguide	Genotoxicity, mutation, DNA damage and cell viability/cell division/proliferation using comet assay, immunofluorescence staining, spectrophotometry	No significant differences were observed in cell viability	Absence	Duan et al. (2015)
189	Mouse embryonic fibroblast cells (NIH3T3)	1800 MHz (PW), SAR 2 W/kg for intermittent exposure (5 min ON, 10 min OFF) for 0.5, 1, 1.5, 2, 4, 6, 8 h using waveguide	Genotoxicity or mutation - DNA damage using fluorescence microscopy and cell viability using apoptosis and oxidative stress using reactive oxygen species, dichlorofluorescein stain, flow cytometry	No significant differences in the amount of DNA damages were observed, however, this could promote oxidative stress and apoptosis	Presence	Hou et al. (2015)
190	Rat bones (femur and tibia)	900 Hz (CW) and 1800 MHz (PM), SAR 2, 2.5 W/kg (CW) and SAR 10, 12.4 W/kg (PW) using (i) a	comet assay; hematopoietic cells; proliferation	No significant changes were found	Absence	Kumar et al. (2015)

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Table 30 (continued)

No	Cell Line	Exposure System	Analysis	Results	Cellular Response	Authors
191	Mouse embryonic neural stem cells (BALB/c)	Transverse Electromagnetic (TEM) cell or (ii) waveguide 1800 MHz (GSM-talk), SAR 1, 2, 4 W/kg for intermittent exposure (5 min ON, 10 min OFF) for 1–3 days using rectangular waveguide (R18)	gene expression using RT-PCR, protein expression using Western blot, cell viability/cell division/proliferation: apoptosis, immunofluorescence, fluorescence microscopy, immunocytochemistry, fluorescence microscopy and flow cytometry	GSM field impairs the neurite outgrowth in differentiated neurons with SAR 4 W/kg	Presence	Chen et al. (2014)
192	Murine spermatocyte-derived cells (GC-2)	1800 MHz (GSM-talk), SAR 1, 2, 4 W/kg for intermittent exposure (5 min ON, 10 min OFF) for 24 h using waveguides	ROS levels, apoptotic cells	Extracellular-signal-regulated kinase (ERK) significantly increased and did not increase the percentage of apoptotic cells	Presence	Liu et al., (2014)
193	Mouse microglial cells (N9) and mouse astrocyte cells (C8-D1A)	1800 MHz (PW), SAR 2 W/kg for intermittent exposure (5 min ON, 10 min OFF) for 1, 3, 6, 12, or 24 h using waveguide	Protein expression using Western blot, gene expression using real-time RT-PCR, cell activation using immunofluorescence and flow cytometry	Protein expression of microglia was significantly increased and in astrocytes, the protein expression of glial also was significantly increased	Presence	Lu et al., (2014b)
194	Mice retinal ganglion cells	900 MHz (GSM), 1750 MHz (GSM), 1966 MHz (UMTS), SAR 0.02, 0.2, 2, 20 W/kg for 30 min using waveguide	Spikes of action potentials, cell function, responses to light stimuli	results	Absence	Ahlers and Ammermüller, (2014)
195	Pheochromocytoma cells from rat adrenal gland (PC-12)	1800 MHz (CW, GSM-217 Hz), SAR 2 W/kg for intermittent exposure (5min ON, 10 min OFF) for 4, 16, and 24 h using waveguide	Gene expression using RT-PCR and protein expression using Western blot and cell viability/cell division/proliferation: cell viability (MTT assay)	Gene expression of HSP70 was significantly increased	Presence	Valbonesi et al. (2014)
196	Murine spermatocyte-derived cells (GC-2)	1800 MHz (PW), SAR 1, 2, 4 W/kg for intermittent exposure (5 min on, 10 min off) for 24 h using waveguide	Genotoxicity/mutation, DNA damage, oxidative stress using alkaline comet assay, flow cytometry and level of reactive oxygen species	Significant DNA damage in the 4 W/kg was observed, however, not in 1 W/kg and 2 W/kg)	Presence	Liu et al. (2013)

Table 31

Rat/Mouse Cell Studies: Weak RF-radiation exposure conditions used in the investigations that examined protein expression in mammalian cells exposed in vitro (cont.).

No	Cell Line	Exposure System	Analysis	Results	Cellular Response	Authors
197	Primary cortical neurons (of rat embryos)	1800 MHz (PW), SAR: 3.2 W/kg for 3 min using TEM cell	Electrical activity of neurons (firing rate, bursting rate); microelectrode array and temperature of cell cultures	No differences in the electrical activity were observed the firing rate and the bursting rate were significantly decreased	Absence	Moretti et al. (2013)
198	Rat pheochromocytoma cells (PC12)	1950 MHz (UMTS, WCDMA), SAR 10 W/kg for 24 h using waveguide	analysis	Cell viability, DNA damage, DNA strand breaks using alkaline comet assay and apoptosis using flow cytometry)	Absence	Zeni et al. (2012b)
199	Primary cerebral cortical cells (neurons and astrocytes) of rat embryos	900 MHz (GSM, PW), SAR 0.25 W/kg for 24 h using wire-patch cell	Cell viability/cell division/proliferation using apoptosis	Hsc70 was significantly increased and HSP90 was significantly decreased	Presence	Terro et al. (2012)
200	Mouse fibroblasts cells (NIH3T3)	916 MHz (CW), 10, 50, 90 W/m ² for 2 h/day up to 8 weeks using chamber with monopole antenna	Cell viability/cell division/proliferation, cell morphology	Observed 916 Hz (CW) exposure can promote neoplastic transformation of NIH3T3 cells	Presence	Yang et al. (2012)
201	Rat astrocytes and rat glioma cells (C6)	1950 MHz (TD-SCDMA), SAR 5.36 W/kg for 12, 24 and 48 h using a dipole antenna	Apoptosis detection using Immuno-fluorescence staining, flow cytometric analysis, RT-PCR, Western Blotting analysis	A 48 h of exposure damaged the mitochondria and induced significant apoptosis of astrocytes, however, no differences were observed in C6 cells	Presence/ Absence	Liu et al. (2012)
202	Cultured rat cortical neurons	1800 MHz (TD-SCDMA), 6 × 2 h/day on 2 days	Cell viability using TUNEL assay and DAPI staining, cell morphology, protein expression using Western blot	Neuronal cell death in the TUNEL assay and a decreased cell viability was observed	Presence	Liu et al. (2011)
203	Rat blood lymphocytes and bone marrow	900 MHz (CW), SAR 2 W/kg for 30 min using TEM cell	DNA damage, proliferation rate of whole bone marrow cells, maturation rate of erythrocytes, proliferation rate of lymphocytes	No statistically significant effect change was found in the proliferation rate of bone marrow cells and lymphocytes, erythrocyte maturation rate and DNA damage of lymphocytes	Absence	Kumar et al. (2011)
204	Chinese hamster fibroblast cells (V79)	2450 MHz (CW), SAR 0.04, 0.51 W/kg for 15 min using GTEM cell	(i) genotoxicity/mutation: mitotic spindle apparatus alterations (immunocytochemistry, fluorescence microscopy) (ii) cell viability/cell division/proliferation: apoptosis (apoptotic chromatin condensation), cell growth (mitotic index, immunocytochemistry, fluorescence microscopy)	Alterations of the mitotic spindle apparatus in V79 cells were observed	Presence	Ballardin et al. (2011)
205	Rat primary microglial cells	1950 MHz (IMT-2000, WCDMA), SAR 0.2, 0.8, 2 W/kg for 2 h using horn	Immunocytochemistry, Cells positive for major histocompatibility complex (MHC) class II,	No activation of microglial cells. No production of TNF-α, IL-1β, IL-6 was found	Absence	Hirose et al. (2010)

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Table 31 (continued)

No	Cell Line	Exposure System	Analysis	Results	Cellular Response	Authors
206	Mouse microglial cells (N9)	antenna with anechoic chamber 2450 MHz (PW), SAR 6 W/kg for 20 min using anechoic chamber with rectangular horn antenna	Gene expression, protein expression (activation of JAKs and STAT3 proteins) using Western blotting, immunofluorescence, Flow cytometry	EMF exposure directly responses initial activation of microglia and produces a significant pro-inflammatory response, also confirm that the JAK2-STAT3 pathway may not mediate this initial microglial activation, however, does promote pro-inflammatory responses in EMF-stimulated microglial cells	Presence	Yang et al. (2010)

Table 32

Rat/Mouse Cell Studies: Weak RF-radiation exposure conditions used in the investigations that examined protein expression in mammalian cells exposed in vitro (cont.).

No	Cell Line	Exposure System	Analysis	Results	Cellular Response	Authors
207	Rat neocortical astroglial cell cultures - neocortical astrocytes	900 MHz (CW), power 0.26 W/m ² for 5, 10, or 20 min using horn antenna	ROS production and DNA fragmentation, comet assay in astrocytes	Acute exposure to low intensity EMF increases ROS production and DNA fragmentation in astrocytes in primary cultures (p < 0.001)	Presence	Campisi et al. (2010)
208	Chinese hamster cells (V79)	935 MHz (CW), SAR 0.12 W/kg for 1, 2 and 3 h using GTEM cell	Cell proliferation, protein expression using specific immunocytochemical methods	Cell proliferation declined in cells exposed for 3 h of irradiation (p<0.05) and microtubule structure was clearly altered and cell proliferation kinetics may depend on microtubule impairment	Presence	Trosic and Pavicic, (2009)
209	Rat primary cortical neurons, Murine cholinergic neurons (SN56)	900 MHz (GSM), SAR 1 W/kg 24, 72 h (primary neurons) using TEM cells	Gene expression (mRNA analysis, neurite analysis) using RT-PCR on mRNA	Decrease in neurite number, increase in b-thymosine gene expression in both cell types were found	Presence	Vecchio et al. (2009a)
210	Rat primary cortical neurons, Murine cholinergic neurons (SN56)	900 MHz (GSM, AM), SAR 1 W/kg for 24, 48, 72, 96, 120, 144 h using TEM cells	Gene expression, cell proliferation and viability, apoptosis, oxidative stress, nuclear morphological analysis, beta-amyloid toxicity and glutamate toxicity	Increased hydrogen peroxide-induced oxidative stress in SN56 cells, however, no effect of RF alone on viability, proliferation, apoptosis, oxidative stress and signal act as a co-stressor for oxidative damage of neural cells	Presence	Vecchio et al. (2009b)
211	Murine fibroblasts (L929)	1800, 900, 835 MHz (GSM-PW), SAR 0.5, 1, 2.5 W/g for 1, 2, 8, 24 h using TEM cell, waveguide, wire patch antenna	Protein expression, ODC activity	No significant alteration in ODC activity was found	Absence	Billaudel et al. (2009b)
212	Rat blood lymphocytes	915 MHz (GSM, PW), SAR 0.6 W/kg for 30 min using GTEM cell	DNA damage and oxidative stress using alkaline comet assay	Exposure increased the DNA damage in rat lymphocytes	Presence	(Gajski and Garaj-Vrhovac, (2009)
213	Immortalized mouse auditory hair cells (HEI-OC1)	1763 MHz (CDMA), SAR 20 W/kg for 6, 24 or 48 h using chamber	Cell cycle distribution, DNA damage, stress response, and gene expression using comet assay, microarrays	No effect was found of RFR alone from any assay endpoints	Absence	Huang et al. (2008a)
214	Mouse lymphoma cells (L5178Y Tk ^{+/+})	835 MHz (CDMA), SAR 4 W/kg for 24 h using TEM cells	DNA damage, genetic damage, cytogenetic endpoints: Alkaline comet assay and chromosome aberration (CA) test	No direct cytogenetic effect was found in the CA test and damage DNA were nearly negative. However, the applied RF-EMF had potentiation effect in comet assay when administered in combination with model clastogens (cyclophosphamide or 4-nitroquinoline 1-oxide)	Absence	Kim et al. (2008)
215	Mouse embryonic carcinoma cells (P19)	1100 MHz, SAR 0.5 W/kg for 60 min and 800 MHz - SAR 0.5, 1.1, 5, 50 W/kg for 60 min using custom-built frequency-tunable exposure applicator	Ca (2+) spiking in cells, Immunofluorescence analysis	No effects were found on cell viability. Increased Ca (2+) spiking in cells as a function of frequency 800 MHz, SAR 0.5 W/kg	Presence/ Absence	Rao et al. (2008)
216	Murine neuroblastoma (N2a)	935 MHz (CW, GSM basic -GSM talk), SAR 2 W/kg for 24 h using rectangular waveguide	Cell proliferation, apoptosis under a fluorescence microscope using three independent assays: Annexin V, caspase activation and in situ end-labeling	No significant differences in apoptosis levels were found	Absence	Moquet et al. (2008)

Table 33

Rat/Mouse Cell Studies: Weak RF-radiation exposure conditions used in the investigations that examined protein expression in mammalian cells exposed in vitro (cont.).

No	Cell Line	Exposure System	Analysis	Results	Cellular Response	Authors
217	Mouse brain cell	1800 MHz (GSM), SAR 1.1 W/kg for 1 h using GTEM cell	Gene expression using RT-PCR	No consistent indication of gene expression changed were found. However, Forty-two probes showed fold changes ranging from 1.5 to 2.8, whereas 33 were down-regulated from 0.67- to 0.29-fold changes.	Absence	Papirini et al. (2008)
218	Rat primary cortical neurons	900 MHz (CW), SAR 2 W/kg for 24 h using wire-patch cell (WPC)	Protein expression using Apoptosis, flow cytometry analysis,	Significant increase of apoptosis, no caspase-3 activation and increase in AIF-positive cells were found	Presence	Joubert et al. (2008)
219	Murine fibroblasts cells (L929)	872 MHz (CW, GSM-217), SAR 5.0 W/kg for 1 or 24 h using waveguide	ODC activity, cell proliferation, caspase-3 activity	No statistically significant effects of RF radiation were found	Absence	Höytö et al. (2008b)
220	Mouse fibroblasts (NIH3T3)	849 MHz (CDMA), SAR 2 or 10 W/kg for 3 h using waveguide (TE102 mode) with a cavity resonator	Cell cycle distribution using flow cytometry	No statistically significant differences identified in cell cycle distribution, cellular migration, or invasion at average SAR values of 2 or 10 W/kg	Absence	Lee et al. (2008)
221	Murine melanoma cells	900 MHz (GSM PW-217 Hz), SAR 3.2 W/kg for 2 h using wire patch cell (WPC)	Proliferation assay, Clathrin-mediated endocytosis pathway - Lucifer Yellow (LY) uptake	Clathrin-dependent endocytosis is stimulated by the GSM-EMF, suggesting that the cellular mechanism affected by the modulated EMF involves vesicles that detach from the cell membrane-clathrin-coated vesicles	Presence	Moisesescu et al. (2008)
222	Chinese hamster ovary cells (CHO-K1)	2450 MHz (CW), SAR 5, 50 W/kg for 2 h min using rectangular waveguide (TE10 mode)	Genotoxicity/mutation, transferase gene mutations	No significant difference was observed except the higher SAR values	Absence	Koyama et al. (2007)
223	Rat primary cortical neurons	900 MHz (GSM, PW-217), SAR 0.25 W/kg for 24 h using wire-patch cell (WPC)	DAPI staining, apoptosis, flow cytometry using double staining with TdT-mediated dUTP nick-end labeling (TUNEL) and propidium iodide (PI) and measurement of caspase-3 activity by fluorimetry	No apoptosis was induced	Absence	Joubert et al. (2007)
224	Murine fibrosarcoma cells (L929)	900 MHz (CW, GSM), SAR 0.3 or 1 W/kg for 10 or 30 min using waveguide	Protein expression using ROS formation	No significant induced formation of reactive oxygen species were found	Absence	Zeni et al. (2007)
225	Rats neurons	1800 MHz (GSM-PW), SAR at 2 W/kg for intermittent exposure (5 min ON, 10 min OFF) for 24 h using rectangular waveguides	Gene expression, RT-PCR	Between 1200 candidate genes, 24 up-regulated genes and 10 down-regulated genes were recognized after 24 h intermittent exposure at an average SAR of 2 W/kg, which are associated with multiple cellular functions (signal transduction pathway, cytoskeleton, metabolism, etc.) after functional classification	Presence	Zhao et al. (2007a)
226	Rat primary neurons and astrocytes	1800 MHz (GSM-PW), SAR at 2 W/kg for 2 h	Gene expression, apoptosis using RT-PCR	Up-regulation of caspases gene expression and specific up-regulation of Bax in astrocytes	Presence	Zhao et al. (2007b)
227	Rat cortical neurons	900 MHz (CW and GSM-PM), 2 W/kg for 4.5 min using waveguide	Voltage-gated calcium channels (VGCC) patch-clamp technique	Cells were not significantly altered by RF-EMFs	Absence	Platano et al. (2007)
228	Embryonic mouse fibroblasts cells (C3H10T1/2)	847.74 MHz (CDMA) and 835.2 MHz (FDMA), SAR 5 W/kg for 24 h using TEM cell	DNA damage, Expression of Proto-oncogenes	One third of genes altered between exposed-sham comparison	Absence	Whitehead et al. (2006a)

Table 34

Rat/Mouse Cell Studies: Weak RF-radiation exposure conditions used in the investigations that examined protein expression in mammalian cells exposed in vitro (cont.).

No	Cell Line	Exposure System	Analysis	Results	Cellular Response	Authors
229	Embryonic mouse fibroblasts cells (C3H10T1/2)	847.74 MHz (CDMA and 835.2 MHz FDMA), SAR 5 W/kg for 24 h using radial transmission line	Gene expression, expression of Proto-oncogenes	Genes altered between exposed-sham comparison, however, was not higher than the number of false positives expected based on a sham versus sham comparison	Absence	Whitehead et al. (2006b)
230	Pineal glands of Djungarian hamsters	1800 MHz (CW, PW), SAR of 8, 80, 800, and 2700 mW/kg for 7 h using radial waveguide	Radioimmunoassay	Significantly enhanced melatonin release at 800 mW/kg SAR, while at 2700 mW/kg SAR	Presence/Absence	Sukhotina et al. (2006)
231	Murine fibroblasts cells (L929)	900 MHz (GSM-PW, CW), SAR 0.2, 0.4 W/kg for 2, 8, 24 h using waveguide	Ornithine decarboxylase (ODC) activity	RF radiation did not affect cellular ODC activity	Absence	Höytö et al. (2006)
232	Chinese hamster fibroblast cells (V79)	864 MHz, SAR 0.08 W/kg and 935 MHz SAR 0.12 W/kg for 2 h and 3 h using TEM cell	Cell culture growth, colony-forming ability and viability	935 MHz microwaves for 3 h showed a significant growth	Presence	Pavicic et al. (2006)

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Table 34 (continued)

No	Cell Line	Exposure System	Analysis	Results	Cellular Response	Authors
233	Mouse embryonic stem cells	1710 MHz (GSM-PW), SAR 1.5 W/kg for intermittent exposure (5 min ON, 30 min OFF) for 6 h using waveguide	Cytogenetic effects - chromosomal aberrations, sister chromatid exchanges, DNA double-strand breaks using comet assay, RT-PCR	Increase of DNA double-strand breaks	Presence	Nikolova et al. (2005)
234	Mouse embryonic skin cells (M5-S)	2450 MHz (CW, PW), SAR 5, 10, 20, 50 W/kg for 2 h using waveguide (TE10 mode)	Chromosomal aberrations	No increase in chromosomal aberrations was found	Absence	Komatsubara et al. (2005)
235	Mouse spermatozoa	900 MHz, SAR 0.09 W/kg for 12 h/day for 7 days using rectangular waveguide	DNA damage to caudal epididymal spermatozoa using quantitative PCR and comet assay	Detailed analysis of DNA integrity using QPCR revealed statistically significant damage to both the mitochondrial genome ($p < 0.05$) and the nuclear b-globin locus ($p < 0.01$)	Presence	Aitken et al. (2005)
236	Embryonic mouse fibroblasts cells (C3H10T1/2)	2450 MHz (CW), SAR 5, 10, 20, 50 W/kg for 2 h using rectangular waveguide	Comet assay	No effect of RF alone up to 200 W/kg was found, however, increase in cell transformation after co-exposure at SAR 100 W/kg	Absence	Wang et al. (2005a)
237	Embryonic mouse fibroblasts cells (C3H10T1/2)	847.7 MHz (CDMA), 835.6 MHz (FDMA), 836.6 MHz (TDMA) SAR 5 and 10 W/kg for 4 days using waveguide	DNA damage, expression proto-oncogenes (mRNA c-fos) using the RT-PCR	Insignificant effects on c-fos expression	Absence	Whitehead et al. (2005)
238	Embryonic mouse fibroblasts cells (C3H10T1/2)	2450 MHz (CW), SAR at 1.9 W/kg for 2 h using radial transmission line	DNA Strand breakage using SCGE, Alkaline comet assay	No evidence for alkali-labile DNA damage or DNA-DNA or DNA-protein cross-links	Absence	LaGroye et al. (2004)
239	Chinese hamster ovary cells (CHO-K1)	2450 MHz (CW), SAR of 5, 10, 20 and 50 W/kg for 2 h using rectangular waveguide	Assessed the frequency of micronucleus (MN) formation induced by chromosomal breakage	SAR of up to 50 W/kg was not different, however SAR of 100 and 200 W/kg found statistically significant increases to that in sham-exposed cells	Absence	Koyama et al. (2004)
240	Rat blood lymphocytes	930 MHz (CW), SAR 1.5 W/kg for 5 and 15 min using GTEM cell	Intracellular reactive oxygen species (ROS) level	ROS level during the experiment may effect in the exposed lymphocytes	Presence	Zmyslony et al. (2004)
241	Murine macro cells (J774.16)	847.74 MHz (CDMA) and 835.62 MHz (FMCW), 0.8 W/kg for 20–22 h using radial transmission line (RTL)	Oxidative stress analysis, cytotoxicity Assay	FMCW and CDMA modulated fields did not alter the intracellular oxidants levels, accumulation of GSSG or induction of antioxidant defenses in IFN/LPS-stimulated cells	Absence	Hook et al. (2004a)
242	Chinese hamster ovary cells (CHO-K1)	2450 MHz (CW), SARs 13, 39 and 50 W/kg for 18 h using waveguide	Assessed the frequency of micronucleus (MN) formation induced by chromosomal breakage	SAR of up to 50 W/kg was not different, however SAR of 100 and 78 W/kg found statistically significant increases to that in sham-exposed cells	Absence	Koyama et al. (2003)

Table 35

Rat/Mouse Cell Studies: Weak RF-radiation exposure conditions used in the investigations that examined protein expression in mammalian cells exposed in vitro (cont.).

No	Cell Line	Exposure System	Analysis	Results	Cellular Response	Authors
243	Murine fibroblast cells (L929)	835 MHz (TDMA-PW), SAR 1, 5, 10, 15 W/kg for 8 h using Crawford cell	ODC assay, enzyme activity	No statistically significant difference in ODC activity was found	Absence	Desta et al. (2003)
244	Embryonic mouse fibroblasts cells (C3H10T1/2)	835.62 MHz (FDMA), SAR 3.2, 5.1 W/kg for 3, 8, 16, 24 h and 847.74 MHz (CDMA), SAR 3.2, 4.8 W/kg for 3, 8, 16, 24 h using radial transmission line (RTL)	Micronuclei assay using CBMA treated with cytochalasin	No significant differences for either plateau-phase cells or exponentially growing cells were found	Absence	Bisht et al. (2002)
245	Brain tissue of Big Blue mice	1500 MHz (TDMA), SAR 0.67, 2.0 W/kg for 90 min/day, 5 days/week, for 4 weeks using aluminum exposure box with monopole antenna	DNA damage, cell Proliferation and apoptosis, mutation induction using histopathological and immunohistochemistry	No gliosis or degenerative lesions, no differences in Ki-67 labeling and apoptotic indices of glial cells and no significant variation in the lacI transgene in the brains were observed	Absence	Takahashi et al. (2002)
246	Embryonic mouse fibroblasts cells (C3H10T1/2)	835.62 MHz (FDMA), SAR 3.2, 5.1 W/kg for 2, 4, 24 h and 847.74 MHz (CDMA), SAR 3.2, 4.8 W/kg for 2, 4, 24 h using radial transmission line (RTL)	DNA damage using Alkaline comet assay	No DNA damage was found	Absence	Li et al. (2001)
247	Embryonic mouse fibroblasts cells (C3H10T1/2)	835.62 MHz (FDMA), 847.74 MHz (CDMA), 0.6 W/kg for 7 days using radial transmission line (RTL)	Gene expression	No neoplastic cell transformation was found	Absence	Roti et al. (2001)
248	Rat astrocytes and porcine brain capillary endothelial cells (BCEC)	1800 MHz (GSM, PM 217 Hz), SAR 0.3, 0.46 W/kg for 2 and 4 days using rectangular waveguide	Immunocytochemistry	Permeability for ^{14}C -sucrose significantly increased compared to unexposed samples	Presence	Schirmacher et al. (2000)
249	Mouse embryo fibroblasts cells (C3H10T1/2)	847.74 MHz (CDMA) and 835.62 MHz (FMCW), SAR 0.6 W/kg for 4 days using radial transmission line (RTL)	DNA damage, proto-oncogene expression using RT-PCR assay	Statistically significant increases ($P = 0.001$) in Fos mRNA levels were detected in exponential cells in transit to the plateau phase and in plateau-phase cells exposed to	Presence	Goswami et al. (1999)

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Table 35 (continued)

No	Cell Line	Exposure System	Analysis	Results	Cellular Response	Authors
250	Rat myocytes from heart muscle	(i) 1800 MHz (GSM-PW) at SAR 600, 720, and 880 mW/kg for 3 min using rectangular waveguides or TEM cell	Membrane potential	835.62 MHz FMCW microwaves. For 847.74 MHz CDMA exposure, the increase was ($P = 0.04$). RF fields do not interfere with a number of electrical membrane parameters, like resting membrane potential and action potential	Absence	Linz et al. (1999)
251	Mouse brain cells	1600 MHz (CW, PW), SAR 0.23, 0.48, 1.19, 2.99 and 6.42, 11.21 W/kg for 1 h using dipole antenna	C-fos gene expression	C-fos elevation in limbic cortex and subcortex was observed in the mouse brain	Presence	Morrissey et al. (1999)
252	Rat brain cells	2450 MHz (PW), SAR 1.2 W/kg for 2 h using cylindrical waveguide (T11 mode)	DNA double strand breaks using comet assay	RFR exposure significantly increased DNA double strand breaks in brain cells of the rat, and the effect was partially blocked by treatment with naltrexone	Presence	Lai et al. (1997)
253	Rat pheochromocytoma cells (PC12)	836.55 MHz (TDMA), SAR 0.09, 0.9, 9.0 mW/cm ² for intermittent exposure (20 min ON, 20 min OFF) for 20, 40 and 60 min using TEM cell	Expression of Proto-oncogenes (c-jun and c-fos) using Northern blot analysis	No effect on c-fos, however, decrease in c-jun expression after 20 min exposure to 9 mW/cm ² was found	Absence	Ivaschuk et al. (1997)
254	Murine fibroblast cells (L929)	835 MHz (TDMA, CW, AM, FM, PW), SAR 2.5 W/kg for 8 h using TEM cells	ODC activity (enzyme activity)	No significant change in ODC activity (TDMA), however, statistically significant enhancement in ODC activity after 6 h of exposure (CW)	Presence/ Absence	(Penafiel et al., 1997)

Table 36

Rat/Mouse Cell Studies: Weak RF-radiation exposure conditions used in the investigations that examined protein expression in mammalian cells exposed in vitro (cont.).

No	Cell Line	Exposure System	Analysis	Results	Cellular Response	Authors
255	rat glioma and primary glial cells (C6)	836.55 MHz (TDMA modulated), SAR 0.59, 5.9, 59 mW/kg for 24 h using TEM cells	DNA synthesis rates and cell proliferation	No significant differences that could be attributed to altered DNA synthesis rates. Increased uptake of nucleic acid precursors was found in glioma cells at 6 mW/kg	Absence	Stagg et al. (1997)
256	Rat basophilic leukemia cells (RBL-2H3)	835 MHz (PW), 8.1 mW/cm ² for 3 × 20 min/day at 4-h intervals, for 7 days using aluminium exposure chamber with aluminium box and cavity resonator	Cell proliferation, Protein proliferation, Signal transduction pathway	DNA synthesis and cell replication were increased and no effects were observed on cytoskeletal protein synthesis or of beta-actin mRNA. Bioeffects could be via a signal transduction pathway	Presence	Donnellan et al. (1997)
257	Murine Cytolytic T lymphocytes (CTLL-2)	2450 MHz (CW), SAR 25 W/kg for 2 h using waveguide	Protein expression, CTLL-2 proliferation	Statistically significant reduction in CTLL-2 proliferation was found	Presence	Cleary et al. (1996)
258	Rat brain cells	2450 MHz (CW and PW), SAR 1.2 W/kg for 2 h using circular waveguide (TE11 mode)	genotoxicity/mutation - Single and double-strand DNA breaks using a microgel electrophoresis assay	An increase in both types of DNA strand breaks was found for both pulsed or continuous-wave radiation	Presence	Lai and Singh, (1996)
259	Rat chemoreceptors membranes	900 MHz (CW, PM), SAR 0.5, 4, 12, 18 W/kg for 15 min using waveguide (TE ₀₁ mode)	Protein shedding	RF fields was influenced diverse types of receptors and the function of peroxidation of lipids on receptor-protein shedding	Presence	Philippova et al. (1994)
260	Mouse fibroblasts cells (L929)	915 MHz (CW, TDMA), SAR 2.5 W/kg for 8 h using exposure chamber with a Crawford cell	ODC activities	ODC activities are altered	Presence	Litovitz et al. (1993)
261	Murine bone marrow cells	2450 MHz (CW), SAR 12 W/kg for 5, 10, 15 min using waveguide	Spectrofluorometric method, fluorescence intensity	The possibility of affecting stimulatory and inhibitory effects of RF radiation using a blocker of cell receptors was indicated	Presence	Rotkovska et al. (1993)
262	Mouse neuroblastoma U937 cells (N18TG-2) with rat glioma cells (C6BU-1)	915 MHz (AM), SAR 0.001, 0.005, 0.01, 0.02, 0.05, or 0.1 W/kg for 30 min using TEM cell	Protein expression, activity of acetylcholinesterase and calcium-ion release, enzyme activity	RFR affects both calcium-ion release and AChE activity - Increase in acetylcholinesterase activity at 0.02 and 0.05 W/kg, but not at higher or lower SAR, therefore, exposure to modulated RFR at different SARs affects differentially AChE activity of neuroblastoma NG108-15 cells	Presence	Dutta et al. (1992)
263	Chinese hamster ovary cells (CHO)	2450 MHz (PW), SAR 33.8 W/kg for 2 h using anechoic chamber	Cell cycle progression and sister chromatid exchanges (SCE)	No differences were found on SCE with or without mitomycin C (MMC)	Absence	Ciaravino et al. (1991)
264	Mouse embryo fibroblast cells (C3H/10T1/2)	2450 MHz (PW), SAR 0.1, 1, or 4.4 W/kg for 24 h using magnetron	Cell survival and neoplastic transformation	Increment of cell transformation was found with RF energy alone, however only in the presence of a chemical promoter	Presence	Balcer-Kubiczek and Harrison. (1991)
265	Murine L929 cells	2450 MHz (CW), SAR 130 mW/g for 4 h using rectangular waveguide	Cell viability	No detectable differences in cell viability was detected nor plating efficiency when the	Absence	Krause et al. (1991)

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Table 36 (continued)

No	Cell Line	Exposure System	Analysis	Results	Cellular Response	Authors
266	Mouse embryo fibroblasts cells (3T3)	2450 MHz (PM, CW), SAR 0.024 mW/g for PM and 0.24, 2.4 mW/g for CW	Cationized ferritin binding on cell surfaces	temperature was simultaneously increased to above normal physiological limits Modulated RF irradiation yielded more morphological cell changes than the continuous RF fields of the same intensity	Presence	Somosy et al. (1991)
267	Chinese hamster ovary cells (CHO)	2450 MHz (PW), SAR 33.8 W/kg for 2 h using anechoic chamber	DNA-damaging, chromosome aberrations	No differences were found on chromosomal aberrations with or without mitomycin C (MMC)	Absence	Kerbacher et al. (1990)

Table 37

Both human and Rat/Mouse Cell Studies: Weak RF-radiation exposure conditions used in the investigations that examined protein expression in mammalian cells exposed in vitro (cont.).

No	Cell Line	Exposure System	Analysis	Results	Cellular Response	Authors
268	Mouse leukemic cells (L5178Y)	2450 MHz (PW), SAR 40 W/kg for 4hrs using anechoic chamber	Genotoxic damage induced by chemical mutagens interaction	No indication of any change in the mutant colonies or any mutagenic action by the RF field exposure alone were observed	Absence	Meltz et al. (1990)
269	Mouse fibroblasts cells (NIH3T3), human glioma cells (U87), rat pheochromocytoma cells (PC12), human neuroblastoma cells (SH-SY5Y)	837–1950 MHz (CDMA, WCDMA), SAR 2 W/kg for 2 h using radial transmission line (RTL)	cell viability/cell division/proliferation, oxidative stress using ROS, flow cytometry	No consistent significant differences observed in CDMA or WCDMA	Absence	Kang et al. (2014)
270	Hippocampal neurons and dorsal root ganglion neurons of rats	2450 MHz (PW), SAR 0.52 mW/kg for 1 h using antenna	Ion channel activity, oxidative stress and apoptosis	Induced a calcium influx in cells through TRPV1 ion channels, oxidative stress and apoptosis and that capsazepine might attenuate these effects	Presence	Ghazizadeh and Naziroglu. (2014)
271	Chinese hamster lung cells (CHL), human umbilical vein endothelial cells (HUVEC), primary newborn rat astrocytes, human amniotic epithelial cells (FL), human lens epithelial cells (HLEC), human skin fibroblasts	1800 MHz (GSM-PW), SAR 3 W/kg for intermittent exposure (5 min ON, 10 min OFF) for 1, 24 h using waveguide	Genotoxicity/mutation: DNA damage, DNA double strand breaks using reactive oxygen species, flow cytometry, alkaline and neutral comet assay	Exposure to RF-EMF for 24 h significantly induced γ H2AX foci formation in Chinese hamster lung cells and Human skin fibroblasts (HSFs), however, not the other cells	Presence	Xu et al. (2013)
272	Human neuroblastoma cells neurons (SH-SY5Y), human astrocytes (U87), microglia (CHME5) and rat primary cortical neurons	1800 MHz (PW, EDGE), SAR 2 or 10 W/kg for 1 or 24 h using waveguide	Oxidative stress, ROS formation, flow cytometry	EDGE signal does not induce oxidative stress, therefore, no effects was found in increasing ROS production	Absence	Poulette et al. (2011)
273	FC2 cells (human-hamster hybrid) (AL) cells	900 MHz (GSM), SAR 10.7, 17.2 mW/kg for 30 min using coaxial TEM cell	Genotoxicity/mutation: spindle disturbance at metaphases or at anaphases and telophases (aceto-orcein stain) cell viability/cell division/proliferation: cell proliferation (mitotic index)	The spindle-acting potential of a RF exposure at 835 MHz in human-hamster hybrid cells	Presence	Schrader et al. (2011)

Table 38

Both human and Rat/Mouse Cell Studies: Weak RF-radiation exposure conditions used in the investigations that examined protein expression in mammalian cells exposed in vitro (cont.).

No	Cell Line	Exposure System	Analysis	Results	Cellular Response	Authors
274	Human scalp hair follicle preparations, human dermal papilla cells (hDPC), mouse fibroblasts cells (NIH3T3), undifferentiated myoblasts and differentiated myotubes cells (C2C12), human adenocarcinoma cells (HeLa), human ovarian surface epithelial cells (OSE-80PC)	1763 MHz (CDMA), SAR 2, 10 W/kg for 1, 3 h and continuous for 1 h/day for 7 days using rectangular cavity-type chamber (TE102 mode)	gene expression using RT-PCR, protein expression using Western blot and flow cytometry, cell proliferation using immunofluorescence staining and flow cytometry	Human dermal papilla cells was significantly induced, 1 h per day for 7 days exposure was significantly enhanced the hair shaft elongation, hence, 1763 MHz fields stimulates hair growth in vitro through the induction of IGF-1 in human dermal papilla cells	Presence	Yoon et al. (2011)
275	Human neuroblastoma cells (SH-SY5Y) and mouse fibroblast cells (L929)	872 MHz (CW, GSM-217), SAR 5 W/kg for 1 or 24 h using chamber with monopole antenna	DNA fragmentation, cell viability, Apoptosis	GSM-modulated signal: (i) Lipid peroxidation induced by t-BOOH was increased in SH-SY5Y (but not in L929) cells, (ii) menadione-induced caspase 3 activity was increased in L929 (but not in SH-SY5Y) cells. No effects were observed from exposure to RF radiation alone and GSM-modulated signal produced statistically significant differences	Presence/ Absence	Höytdö et al. (2008a)

(continued on next page)

Table 38 (continued)

No	Cell Line	Exposure System	Analysis	Results	Cellular Response	Authors
276	Murine fibroblasts cells (L929), rat glioblastoma cells (C6), human neuroblastoma cells (SH-SY5Y), and rat primary astrocytes	872 MHz (CW, GSM-PM), SAR 1.5, 2.5, 6 W/kg for 2, 8, 24 h using waveguide exposure chamber	Protein expression	ODC activity in rat primary astrocytes was decreased statistically significantly and consistently in all experiments performed at two exposure levels (1.5 and 6.0 W/kg) and using GSM modulated or CW radiation. In the secondary cell lines, ODC activity was generally not affected	Presence/Absence	Hoyto et al. (2007)
277	Rat1 and human epithelial cells (HeLa)	875, 900 and 950 MHz, SAR 0.005, 0.03, 0.110 and 0.31 mW/cm ² 5, 10, 15, 20, 30 min	Phosphorylation p38MAPK, ERK1/2, JNK1/2 using ROS activity and Western blotting	(i) increase in ERK1/2 phosphorylation/activation, no effect on p38MAPK or JNK1/2 (ii) insufficient details on RFR exposure system, temperature control and Absence control conditions and (iii) no inferential statistics	Presence	Friedman et al. (2007)
278	Human diploid fibroblasts (ES1) and Chinese hamster fibroblast cells (V79)	1800 MHz (CW, GSM-PW), SAR 1, 2 W/kg for intermittent exposure (5 min ON, 10 min OFF) for 4, 18, 22, 24 h using rectangular waveguide (R18)	DNA single-strand breaks and DNA double-strand breaks using alkaline comet assay and micronucleus assay	No increase in DNA migration and micronucleus formation were found	Absence	Speit et al. (2007)

Table 39

Both human and Rat/Mouse Cell Studies: Weak RF-radiation exposure conditions used in the investigations that examined protein expression in mammalian cells exposed in vitro (cont.).

No	Cell Line	Exposure System	Analysis	Results	Cellular Response	Authors
279	Jurkat cells (human T lymphocyte) and rat primary astrocytes	1763 MHz (CDMA), SAR 2 or 20 W/kg for 30 min or 1 h using waveguide (TE ₁₀₂ mode)	Protein phosphorylation status, p38MAPK, ERK1/2, JNK1/2, HSP Expression using Western Blotting	No effect in the presence or absence of TPA and properly controlled exposure conditions/temperature was found. No detectable difference was found in the expression levels of HSP90, HSP70, and HSP27	Absence	Lee et al. (2006)
280	Chinese hamster ovary cell line (CHO-K1), human glioma cells (MO54)	2450 MHz (CW), SAR 5, 50 W/g for 2 h using rectangular waveguide	Cell proliferation - cell growth, survival, and cell cycle distribution using flow cytometry	No increases or decreases in cell proliferation were observed. Temperature increased up to 39.1°C for SAR 50 W/kg and suggested that the proliferation disorder is caused by the thermal effect	Absence	Takashima et al. (2006)
281	Embryonic mouse fibroblasts (C3H10T1/2), Hamster ovary fibroblasts (HA-1) and Human HeLa cells (HeLa S3) (Human epithelial carcinoma cell line)	835.62 MHz (FDMA) 847.74 MHz (CDMA), SAR 0.6 W/kg 5 W/kg for 5, 15, 30, 60 min and 24 h using radial transmission line (RTL)	Protein expression, DNA damage, Heat shock protein - gel shift assay	No increase was detected in the DNA-binding ability of transcription of HSPs	Absence	Laszlo et al. (2005)
282	Human diploid fibroblasts and rat granulosa cells (GFSH-R17)	1800 MHz (CW, PW), SAR 1.2 or 2 W/kg, different modulations for intermittent exposure (5 min ON, 10 min OFF) or CW for 4, 16 and 24 h using hollow rectangular waveguide (R18 mode)	DNA strand breaks - alkaline and neutral comet assay	A stronger effect of the comet assay was found in the intermittent exposure than continuous exposure after 16 h	Presence	Diem et al. (2005)
283	Blood-brain barrier cells cultures (rat astrocytes and capillary endothelial cells, brain capillary endothelial cells)	1800 MHz (PM-217 Hz), SAR 0.3 W/kg for 24*5 h using rectangular waveguides	Permeability Assay - sucrose permeation across the blood-brain barrier (BBB)	Could not confirm enhanced permeability of the BBB in vitro after EMF exposure	Absence	Franke et al. (2005a)
284	Murine fibroblast (C3H10T1/2) and human glioblastoma (U87MG cells)	835.62 MHz (FMCW) and 847.74 MHz (CDMA), SAR 0.6 W/kg for 3 h using radial transmission line (RTL)	Cell viability using flow cytometry	No alterations in cell cycle progression were found	Absence	Higashikubo et al. (2001)
285	Human glioblastoma cells (U87MG) and rodent fibroblasts cells (C3H10T1/2)	2450 MHz (CW), SAR 0.7 and 1.9 W/kg for 2, 4 and 24 h using radial transmission line (RTL)	DNA Strand breakage using alkaline comet assay (single-cell gel electrophoresis - SCGE)	No significant differences were found	Absence	Malyapa et al. (1997a)

Table 40

Both human and Rat/Mouse Cell Studies: Weak RF-radiation exposure conditions used in the investigations that examined protein expression in mammalian cells exposed in vitro (cont.).

No	Cell Line	Exposure System	Analysis	Results	Cellular Response	Authors
286	Human glioblastoma cells (U87MG) and mouse fibroblasts cells (C3H10T1/2)	835.62 MHz (FMCW) and 847.74 MHz (CDMA), SAR at 0.6 W/kg for 2, 4 and 24 h using radial transmission line (RTL)	DNA Strand breakage using alkaline comet assay (single-cell gel electrophoresis)	No significant differences were found in both FMCW or CDMA radiation	Absence	Malyapa et al. (1997b)
287	Human HeLa S3 and Chinese hamster ovary cells (CHO)	for 2450 MHz (CW), SAR 25 W/kg for 2 h using exposure chamber	Protein expression	No detectable effect was found on stress protein induction	Absence	Cleary et al. (1997)

Table 41

Other Species Cell Studies: Weak RF-radiation exposure conditions used in the investigations that examined protein expression in mammalian cells exposed in vitro (cont.).

No	Cell Line	Exposure System	Analysis	Results	Cellular Response	Authors
288	Cultured rabbit lens	2450 MHz (CW), 0.25, 0.5, 1, 2, 5 mW/cm ² for 8 h	Proteins metabolism, transparency of lens using SDS-PAGE electrophoresis and coomassie-blue staining	Lens sonicated protein decreased when the power of RF fields was 5 mW/cm ² and higher than 1 mW/cm ² can affect the proportion of water-soluble protein and urea soluble protein in cultured rabbit lens	Absence	Wang et al. (2007)
289	Pig astrocytes in co-culture with porcine brain microvascular endothelial cells (PBECS)	1966 MHz (UMTS), SAR 0.02, 0.05, 1.64 W/kg for 84 h using radial waveguide	Transendothelial electrical resistance (TEER) to determine the tightness of the BBB, Immunocytochemistry, Western blot analysis	CTransendothelial electrical resistance (TEER) to determine the tightness of the BBB. Could not confirm enhanced permeability of the BBB in vitro after EMF exposure	Absence	Franke et al. (2005b)
290	Rabbit lens epithelial cells (RLEC)	2450 MHz (CW), 0.1, 0.25, 0.5, 1, and 2 mW/cm ² for 8 h	Cell morphologic changes - using phase-contrast microscopy, cell viability - using the MTT assay and cell cycle analysis - using flow cytometry. Levels of P21WAF1 and P27Kip1 mRNA were analyzed by reverse transcription-polymerase chain reaction (RT-PCR), Gel electrophoresis and western blot analysis	RF fields higher than 0.50 mW/cm ² can hinder lens epithelial cell proliferation, and increase the expression of P27Kip1	Presence	Yao et al. (2004)
291	Chick embryo	915 MHz, SAR 1.75 or 2.5 W/kg for 2 h using TEM cell	Heat shock protein - HSP70	RF exposures activate the stress protein response pathway and enhance survivability lethal stress	Presence	Shallom et al. (2002)
292	Cardiac myocytes of the guinea pig	900, 1300, and 1800 MHz (PM), SAR 1 mW/kg for 8 min using TEM cell	Digital image analysis - fura-2 fluorescence, Ca ²⁺ concentration	Chemical stimulation [K ⁺ -depolarization] indicated the viability of the cells and the K ⁺ depolarization yielded a significant increase in [Ca (2 ⁺)]	Presence	Wolke et al. (1996)
293	Isolated frog auricle	915 or 885 MHz (PM), SAR 10 W/kg for 2 min using complanar stripline slot irradiator	The rhythm of spontaneous twitches of the isolated frog auricle - Saline temperature-rise	Provided evidence that the spontaneous activity of the frog auricle was not affected by the short-term exposure to pulsed microwaves except the thermal effect. Established no specific dependence on exposure parameters such as frequency or power windows	Presence	Pakhomov et al. (1995)
294	Isolated frog auricle	915 MHz (PM) SAR 8–10 W/kg for 40 min using complanar stripline slot irradiator	Ca ²⁺ -dependent adenosine triphosphatase (ATPase)	Observed the nonthermal microwave effect	Presence	Pakhomov et al. (1995b)
295	Frog ventricular muscle	2450 MHz (PW), SAR 0.003, 2, and 6 W/kg for 2 h using waveguide (WR-284)	Conduction velocity was measured - between two action potentials	No significant difference was observed in conduction velocity between the control and the exposed groups	Absence	Yee et al. (1994)
296	Snail neurons	2450 MHz (PM), SAR 85 W/kg for 30, 45 min using waveguide	Action potential (AP) firing rate and analysis of interspike intervals (ISIs)	PW showed a clear increase in membrane input resistance. Represented evidence of a direct interaction between neurons and pulsed waves RF fields	Presence	Field et al. (1993)
297	Frog heart	1000 MHz (PW), SAR 3.2 μW/kg to 1.6 W/kg for 32 min (CW, AM) using exposure chamber	Calcium efflux ratio of preloaded atrial strips of the frog heart	No changes were found in neither unmodulated nor modulated RF fields	Absence	Schwartz et al. (1993)

Table 42

Other Species Cell Studies: Weak RF-radiation exposure conditions used in the investigations that examined protein expression in mammalian cells exposed in vitro (cont.).

No	Cell Line	Exposure System	Analysis	Results	Cellular Response	Authors
298	Cardiac cells from chicken embryos	2450 MHz, SAR 1.2, 8.4, 42.6 W/kg (CW) and 1.2, 8.4 W/kg (PW) for 3 min using coaxial device	Inter-beat intervals	RF fields affected the beat rate of aggregates of cardiac cells from chicken embryo by both athermal as well as thermal effects of exposure	Presence	Seaman and DeHaan. (1993)
299	Isolated frog nerve cord	915 MHz (PW), SAR 20–30 W/g	Significant decrease of action potential amplitude and peak latency	Nerve irradiation and its stimulation lead to significant decrease of action potential amplitude and peak latency	Presence	Pakhomov. (1993)
300	Neurons in ganglia of snails (<i>Helix aspersa</i>)	2450 MHz (CW), SAR 12.5 or 125 mW/g for 45 min using waveguide (TE10 mode)	Action potential firing	RF fields may enhance degenerative effects (metabolic rundown or loss of ion channel patency)	Presence	Ginsburg et al. (1992)

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