Original Communication

Genetic damage in mobile phone users: some preliminary findings

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BACKGROUND : The impact of microwave (MW)/radio frequency radiation (RFR) on important biological parameters is probably more than a simply thermal one. Exposure to radio frequency (RF) signals generated by the use of cellular telephones have increased dramatically and reported to affect physiological, neurological, cognitive and behavioural changes and to induce, initiate and promote carcinogenesis. Genotoxicity of RFR has also been reported in various test systems after *in vitro* and/or *in vivo* exposure but none in mobile phone users.
AIMS : In the present study, DNA and chromosomal damage investigations were carried out on the peripheral blood lymphocytes of individuals using mobile phones, being exposed to MW frequency ranging from 800 to 2000 MHz.
METHODS : DNA damage was assessed using the single cell gel electrophoresis assay and aneugenic and clastogenic damage by the *in vivo* capillary blood micronucleus test (MNT) in a total of 24 mobile phone users.
RESULTS : Mean comet tail length (26.76 ± 0.054 μm; 39.75% of cells damaged) in mobile phone users was highly significant from that in the control group. The *in vivo* capillary blood MNT also revealed highly significant (0.25) frequency of micronucleated (MNd) cells.
CONCLUSIONS : These results highlight a correlation between mobile phone use (exposure to RFR) and genetic damage and require interim public health actions in the wake of widespread use of mobile telephony.

Key words: DNA damage; micronuclei; microwaves;

The continued spread of mobile telephony is of serious concerns since a relationship between electromagnetic fields radio frequency (RF) and microwave (MW) radiation and adverse health effects at low intensity exposures exists. The cell (mobile) phone is an appliance that requires that it be held close to or touching the head, which is the most sensitive organ of the body. This has initiated a spate of studies to enquire for effects on user health and explore mechanisms of interaction responsible for reported biological sequel on humans, animals and organic cells from acute and chronic exposures from mobile phone frequencies. Generally, the higher the frequency the less able electromagnetic radiation is to penetrate materials. However, even millimetre waves penetrate irradiated skin to a depth of 1 mm, while the microcirculatory system of the skin functions at 150 μm and so is fully accessible to EHF exposure. Lower frequencies can however penetrate further. The mode of interaction between nonionising electromagnetic radiation and tissue is also highly dependent on the dielectric behaviour of water and dissolved ions at RF and MW frequencies.

Wireless communication systems operate in the 400–2000 MHz range, differing in respect to frequency usage in different countries and on different continents. In fact, the use of the digital communication system that transmits radio frequency radiations (RFR) at higher frequencies in this range has increased dramatically. The Indian mobile phone market has also shown dramatic ascent and has 40.6 million users with the global system of mobile communication (GSM) service having 32.02 million registered users and the code division multiple access (CDMA) subscribers with 8.6 million (www.Indianews.com, October 2004). The potential for health effects from low intensity RF/MW

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radiation from the 'weight of the scientific evidence' points to a relationship between RF/MW and illness.

Some of the biological effects associated with RF radiation include RF sickness, electroencephalographic changes, cell proliferation[1] and blood pressure changes, blood–brain barrier leakage,[2] altered EEG patterns[3] and decreased fertility in mice.[4] Cancer risks and genotoxicity from exposure to RF fields *in vivo* and *in vitro* have rather been points of cynosure since equivocal evidences exist.[5–8]Apparently no studies have documented genotoxicity in mobile phone users. The present investigation reports DNA and chromosomal damage in peripheral blood lymphocytes of mobile phone users by the single cell gel electrophoresis (SCGE/Comet) assay and the capillary blood *in vivo* micronucleus test (MNT). The study was cleared by the institutional ethical committee.

Methods

The subjects were selected on the basis of period of mobile phone use. Voluntary written informed consent was obtained and details on their diet, life style and health status were recorded. Age- and sex-matched healthy individuals who had never used the mobile phone formed the control group. Finger-prick blood samples were collected in heparinised eppendorf tubes, transported in an ice-box to the laboratory and processed for the comet assay[9],[10] and the MNT[11] within 3–4 h of collection. Peripheral blood cells were embedded in agarose on agar-coated slides, lysed under alkaline conditions to partially unwind DNA, electrophorosed followed by silver staining. Both the normal cells and comets (100/sample) were scored and DNA migration lengths were measured less than under 40x using an ocular micrometer calibrated with the help of a stage micrometer.

The MNT is based on the observation that when cells with chromatid breaks or exchanges undergo mitosis, a sizeable portion of chromatin that is not included in the daughter nuclei, forms a single micronucleus or multiple micronuclei. The *in vivo* MNT in lymphocytes of human capillary blood is a simpler, convenient, informative *in vivo* cytogenetic technique and its precision makes it more suitable to large-scale investigations and human biomonitoring studies. To 0.06 - 1.00 ml blood obtained through finger puncture, 0.3% methyl cellulose was added to blood in a v/v ratio of 1: 3 and kept in a water bath (37°C for 40–60 min).The lymphocyte suspension was then centrifuged at 1000 rpm for 6 min and the pellet, suspended in 43 μl of remaining supernatant, was used to make smears on glass slides. Air-dried smears were fixed in 100% methanol for 1 min and stained in buffered Giemsa (pH 6.4, 1:10, 20 min). Coded preparations were scored (2000 cells/sample at 40x) for MN [small, spherical and separated chromatin masses in small (T) lymphocytes]. The presence of micronuclei (as per the given criteria)[12] in the cells was confirmed at 100 x under oil immersion and randomly by another observer. The main nucleus and MN show dark blue against the light blue cytoplasm.

Results

Peripheral blood lymphocytes of individuals ($n = 24$) using mobile phones were processed in order to assess whether mobile phone usage induces chromosomal and DNA damage. All those evaluated for the MN test ($n = 20$) were also investigated for DNA damage and so are included among those ($n = 24$) for which the SCGE assay was performed [Table 1]. Samples from age-, sex- and socioeconomic status-matched controls ($n = 11$) were also processed for DNA damage ($n = 10$) and the MN test ($n = 8$). There were only three females among mobile phone users; very few smokers ($n = 2$) and those taking alcohol ($n = 2$). None of the subjects had any family history of any genetic anomaly or major illness nor had they undergone irradiation examination or been exposed to organic solvents and for the last 6 months none have been on medication or on drugs and no one did any regular exercise. The reproductive performance of married individuals ($n = 7$) was known to be normal. However, some of the selected individuals ($n = 4$) complained about sleeplessness, memory loss, less attentivity and heart pain, which they felt was associated with mobile phone vibrations. The usage of phone varied from one to 5 years with most persons ($n = 20$) using it from 2 to 3 years. The specific absorption rate (SAR) gives estimates of the radiated energy given out by the cell phone and being absorbed

Subject code	Brand & Model No.	Saw W/kg.	Duration of use year	Daily frequency of calls (No.) In	Daily frequency of calls (No.) Out	Duration of calls (min) In	Duration of calls (min) Out	Kept on On mode hour	Phone attend-ence (ear)	Placement of phone on move	Placement of phone at Home	Placement of phone In Hand	Placement of phone Shirt Pocket	Placement of phone In Office	Occupation	Health effect	MN test Mnd cells/ 2000 cells scored (%)	SCGE assay Damaged cells average DNA (%)	SCGE assay Migration Length (μm)
A 1f	Nokia 3310	1.27	3	20	5	20	10	24	R	Bag	Bedside	L	–	–	Student	–	–	27	26.14
A 2f	Ericssion LX-588	1.51	5	6–8	5–6	20–25	20–25	24	R	Bag	Table	L	–	–	Student	–	7 (0.35)	46	29.09
A 3f	Samsung 210	1.56	2.5	6–7	5–6	15	5	24	R	Bag	Table	R	–	Table	Research fellow	–	–	24	30.33
A 4	Panasonic GD 70	0.99	3	4	10–12	2–3	2–3	24	R	Pocket	Table	R	Yes	Drawer	Sales executive	Heart pain	5 (0.25)	56	20.14
A 5	Nokia C 131	0.87	2.5	6	10–15	2–3	1	24	L	W. pouch	Table	R	–	Belt	Mechanic	Heart pain	3 (0.15)	32	31.12
A 6	Panasonic	0.99	3	30–35	20–25	7–8	4–5	24	R	T. pocket	Belt	R	Yes	B. pocket	Business	–	7 (0.35)	48	16.91
A 7	Nokia 6210	1.45	4	70–75	60–65	1–2	1–2	24	R	B. pocket	Table	R	Yes	B. pocket	Sales executive	–	9 (0.45)	58	19.83
A 8	Samsung 220	0.59	2	5–6	5–6	3	2	18	R	W. pouch	Belt	L	No	Belt	Business	–	2 (0.10)	63	27.74
A 9	Nokia 3310	1.24	2	15–17	10–12	30	15	24	L	T. pocket	Table	R	Yes	Trousers	Customer care service	–	10 (0.50)	49	28.89
A 10	Nokia 3315	1.47	3	10–15	5–6	1–2	1–2	24	L	Pocket	Table	R	Yes	Table	Business	Sleeplessness, memory loss	6 (0.30)	33	25.09
A 11	Nokia 3310	1.24	2.5	16–20	4	20–30	10	24	R	Pocket	Table	R	Yes	–	Unemployed	–	–	28	28.50
A 12	Nokia 3310	1.24	4	6–7	3–4	20	10	24	R	Pocket	Bedside	R	Yes	Table	Business	–	4 (0.20)	43	31.86
A 13	Nokia 3315	1.47	2	5–6	2–3	25–30	2–3	18	L	T. pocket	Table	R	No	Pocket	Field work	–	3 (0.15)	57	26.87
A 14	Nokia 3315	1.47	2.5	4–5	2–3	5–10	5–7	16	R	Pocket	TV	R	Yes	Drawer	Software analyst	–	2 (0.10)	26	26.61
A 15	Nokia 3310	1.24	2.5	20–22	13–15	1–2	1–2	24	L	Pocket	Pocket	R	No	Pocket	Marketing	–	3 (0.15)	47	26.08
A 16	Motorola C 350	1.36	3.5	15–20	4–5	10–15	2	24	R	Pocket	Pocket	L	No	Table	Business	–	5 (0.25)	53	24.30
A 17	Nokia 3610	1.42	2.5	10–11	4–5	2–3	1–2	24	L	Pocket	Pocket	R	Yes	Pocket	Surveyor	–	7 (0.35)	26	28.46
A 18	Ericsson T 100	1.66	2.5	5–6	3–4	10	10–15	24	L	B. pocket	Table	R	No	–	Student	–	6 (0.30)	23	30.60
A 19	Samsung R 20	0.59	2	10–12	6–7	3	2	18	R	Pocket	Hand/pocket	R	Yes	Pocket	Medical representative	–	7 (0.35)	39	26.82
A 20	Nokia 3315	1.47	1	10–15	10–15	5–10	3–4	24	R	T. pocket	Hand	R	No	Table	Unemployed	–	3 (0.15)	42	24.47
A 21	Nokia 3310	1.24	2	10–15	4–5	2.25	0.5–1	24	R	T. pocket	Hand	L	No	Trousers	Hardware and networking engineer	–	–	58	28.06
A 22	Panasonic EB-GD 70	0.99	3	10–12	5–10	11.5	1.5	24	L	Pocket	Table	R	No	Pocket	Supervisor	–	4 (0.20)	18	29.77
A 23	Nokia 3310	1.24	3	10–20	10–12	10–15	5–10	24	R	Pocket	Shelf	R	No	Table	Business	–	–	21	28.33
A 24	Nokia 3110	1.27	3	15–20	10–12	10	5–7	24	R	Pocket	Table	R	No	Table	Business	–	–	39	26.17
A 25f	Samsung 220	0.59	1.5	10–20	4–5	45	10	24	L	Pocket	Table	R	No	–	Student	–	4 (0.20)	–	–
A 26f	LG 2030	1.55	2.5	8–10	3–4	2–3	1–2	24	R	W. pouch	Bedside	R	No	–	Student Less attentivity	Memory loss/	3 (0.15)	–	–
Total (n=20 for MNT; n=24 for SCGE)																	100/40,000 (0.25*** ±0.0006)	954/2400 (39.75***)	26.76*** ±0.054
Control (n=8 for MNT; n=10 for SCGE)																	8/16,000 (0.0005)	104/1,000 (10.40)	8.1 ±0.028

[a] L-left ear, R-right ear, B-both ears; f-female; B./T.pocket- breast/trousers pocket;W-waist

* - Significant when compared to total control group (P<0.05 and P<0.01; Student's 't' test)

into the body tissues in terms of Watts per kilogram (W/kg) or milliWatts per gram (μW/g) of body weight. The popular phone brands were Nokia (SAR = 0.87–1.47 W/kg) with 15 users, Samsung (SAR = 0.59 and 1.56 W/kg) with four, and Panasonic (SAR = 0.99 W/kg) with three users. The daily use of phone ranged from 1 to 15 h, which actually contributes to the daily direct exposure in the real sense though the mobile was kept on 'On' mode for 24 h by 22 subjects. There were 17 individuals attending phones from the right ears whereas nine attended from left ears. None subjects used any protective cases for mobile phones and no one among them availed of any special offer (s).

The SCGE assay results demonstrated DNA migration in ~40% (39.75) of mobile phone users with a mean tail length of 26.76 ± 0.054 μm (range 16.91 ± 0.192 to 31.86 ± 0.252 μm) which was significantly increased from the control value (8.11 ± 0.028 μm with 10.40% of cell damage). The maximum tail length was observed in the blood sample (with 43% cell damage) of a 28-year-old male who was dealing in automobile spare parts and was using Nokia 3310 (SAR = 1.27 W/kg) for the past 4 years. At the time of sample collection his daily communication on mobile phone was from 1.5 to 2.0 h. The higher value of comet tail length may be due to longer duration of mobile phone use as he is a nonsmoker, nonalcoholic, and nonvegetarian. Similarly in peripheral blood lymphocytes of another male aged 21 years (a two-wheeler mechanic), a long-tail length (31.12 μm, with 32% damaged cells) was observed. He had been using Nokia C131 (SAR = 0.87 W/kg) for 2.5 years with daily use of 1.5–2 h and probably with some exposure at his work place also contributing towards the genetic damage observed in his PBLs. The maximum number of damaged cells (63%) was observed in a male (24 years) using Samsung 220 (SAR = 0.59 W/kg) for 2 years with 1–1.5 h daily mobile phone usage. Among the control individuals, comet tail lengths ranged from 6.03 ± 0.130 to 10.3 ± 0.090 μm.

Chromosomal damage (aneugenic/clastogenic) was also scored for in 20 individuals and in eight controls. There was a marked difference in the frequencies of micronucleated (MNd) cells among subjects (av. 0.25 MNd cells) and the control group (av. 0.05 MNd cells; only 3.8% had MN). The maximum MNd cell frequency of 0.50 was observed in a male (24 years) who had been using Nokia 3310 (SAR = 1.24 W/kg) for 2 years with a daily use of 8–9 h and working in the customer-care department of a mobile phone company. The minimum frequency of MNd cells (0.10 each) was observed in two males aged 24 and 28 years, a businessman and software analyst, respectively. Both were using mobile phones for 2 years with SAR of 0.59 and 1.47 W/kg and with a daily use of 1–1.5 and 3–4 h, respectively.

Discussion

Both the MNT and SCGE assay were employed for assessing any genetic damage in mobile phone users being exposed to mobile phone MW frequency ranging from 800 to 2000 MHz. Significant increases in DNA tail lengths, of cells with DNA damage and in MNd cells of mobile phone users were observed. Data for DNA and chromosomal damage of female subjects were clubbed with that of male subjects, as there were no differences in the values. No significant influence of sex on MN frequency has been also reported in the *in vivo* capillary blood MN test.[11] More DNA damage than micronuclei induction in the same PBL samples was noted. This is because the MN test detects injuries that survive at least one mitotic cycle, while the comet assay identifies repairable injuries or alkali-labile sites, which cause an increased intensity of comet tail length but do not cause MN induction. It has been reported that when the exposure to genotoxic agents is small, even though there may be positive results in the comet assay, correspondingly positive results in the MN test may not occur.[13]

The presence of MNd cells was observed in only ~4% of control individuals. This low frequency may be due to good dietary patterns in the absence of smoking and drinking habits. Punjabi people have a fairly good intake of fruits and vegetables, which are associated with reduced risks for cancers. The carotenoids and carotenoid-rich foods can influence DNA damage and repair by modulating discrete stages in the DNA repair mechanisms.[14] The effects of mobile use can be curbed depending upon the availability of dietary antioxidants,[15] consumption of ethanol,[16] conditions like psychological stress[17] and strenuous physical exercise.[18] This emphasizes the speculation that some individuals may

be more susceptible to the effects of RFR exposure.[19]

The results of the present study are in tune with some reports in the literature. Chromosome aberrations and micronuclei were significantly higher than the controls, in a group of workers exposed to 10 to 50 μW/cm^2 of radar producing MWs and/or also exposed to about 5 ppm of vinyl chloride monomer, a known carcinogen.[20] Human lymphocytes exposed to MW radiation produced a dose response increase in chromosome aberrations.[21]

Occupational exposure to MWs in 12 workers had significantly increased chromosome damage as well as disturbances in the distribution of cells over the first-, second- and third-mitotic divisions.[22] In rat brain cells exposure of both continuous wave (CW) and pulsed microwaves (PW) caused significant increase in single- and double-strand DNA breakage with PW causing more damage than CW.[6] Neither direct chromosomal damage (chromosome aberrations and SCEs) nor tail moment and tail lengths increased in comet assay when human whole blood cells were exposed to continuous 935.2 MHz (SAR 0.3–0.4 W/kg) but a synergistic effect after RFR exposure followed by mitomycin-C was reported in the form of an increase in SCEs.[23] *In vitro* exposure of human peripheral blood lymphocytes to continuous 830 MHz EMF (SAR 1.65–8.8 W/kg) for 72 h caused losses and gains of chromosomes. A linear increase in Chr # 17 aneuploidy was observed as a function of SAR value at 34.5–37.5°C indicating that the genotoxic effect of the EMF is elicited via a nonthermal pathway.[24]

Some contrary reports include: absence of primary DNA damage in human glioblastoma and mouse fibroblast cells exposed to 835.62 MHz (FDMA) and 847.74 MHz (CDMA) RFR, respectively, at SAR 0.6 W/kg.[8] Equal number of DNA breaks in rat lymphocytes were reported in both controls and animals exposed to 945 MHz RFR for 1–5 weeks.[25]Human blood lymphocytes exposed to 837 MHz (TDMA), 837 MHz (CDMA) and 1900 MHz (PCS) showed no increase in primary DNA damage or of MNd binucleated human blood lymphocytes.[26] PBL cultures of 20 healthy donors exposed to CW intermittent exposure and GSM signals did not increase MN frequency in the cytokinesis – block MN assay.[27] PBL cultures exposed to both CW and PW 1.9 GHz RFR at SAR 0–10 W/kg for 24 h revealed no significant increase in DNA damage or MN frequency.[28] No statistically significant differences in the level of DNA damage or apoptosis by SCGE assay and annexin V affinity assay, respectively were observed between sham-treated and RF- exposed Molt-4T lymphoblastoid cells.[29]

In the light of this literature it can be observed that the studies documenting positive genotoxicity are those where there is mostly *in vivo* occupational exposure to RFR of mobile phone range. The present study clearly demonstrates the same, albeit the exposure is directly through mobile phone use. There is a potential for a very large worldwide public health impact in the wake of the results of this study and calls for interim public health protective measures.

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