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Results. There was no significant difference for audiological abnormalities between users and controls. But, within the users, degree of hearing loss increased with increase in duration of mobile phone use. In addition, users who had some complaints during mobile phone use had more abnormalities in DPOAE, ABR and MLR.

Conclusions. Long term mobile phone use may cause inner ear damage. Presence of ear symptoms like fullness or ear warmth may be an early warning sign.

Audiological disturbances in long term mobile phone users.

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Introduction

There is a general concern on the possible hazardous health effects of radiofrequency electromagnetic radiation (RFR) emitted from wireless communication devices, especially following the enormous increase in the use of wireless mobile technology throughout the world.. The biological electrical activities that are vulnerable to interference from GSM radiation include highly organized electrical activities at a cellular level whose frequency happens to lie in the microwaves region, and which are a consequence of metabolism. Furthermore, the discontinuous transmission mode (DTX) pulse frequency at 5Hz and the time division multiple access (TDMA) frequency of 8.34 Hz correspond to frequency of electrical oscillations found in the human brain , specifically the delta and alpha brain waves respectively. It is thus possible that living organism have two-fold sensitivity to the pulsed GSM signal i.e. to both the microwave carrier and the lower frequency pulsing of the TDMA and DTX signals.

Anatomically, the ear is in closest proximity to mobile telephones during use. So, theoretically its use should affect the ear most, although it is well covered inside a bony cage. However, there is only limited medical literature available on hearing loss due to long term mobile telephone use. Few workers have studied the short term effects of acute exposure to mobile phone use.[1.2.3.] There is paucity of complete audiological assessment studies to assess the effects of chronic exposure of electromagnetic waves from mobile phones on the hearing in human beings. Only few studies have been undertaken so far. [4.5.6.7] Oktay et al [6] reported a higher degree of hearing loss associated with long term exposure to electro magnetic field generated by cellular phones. Davidson et al [8] investigated the possible chronic effects of use of mobile phones on hearing, tinnitus and balance with the help of questionnaires. They reported no harmful effects of mobile usage on audiovestibular system detected by the self report method. Sievert et al[9] based on their studies did not report any ABR abnormality in chronic mobile phone users.

The present study was conducted to assess the potential changes in hearing function at the level of inner ear and central auditory pathway due to chronic exposure to electromagnetic waves from GSM mobile phones.

Patients and methods

This was a prospective study which was conducted in 100 adult subjects, in the age range of 18-45 yrs, who were chronic users (taken as persons using mobile phones for more than one year) of GSM mobile phones (hereinafter called USERS) and 50 adult subjects with healthy ear and normal hearing who have never used GSM mobile phones who acted as controls. Persons with history of ear discharge, prior hearing loss, ear surgery, ototoxic medication, prolonged noise exposure, head trauma or any systemic disease affecting hearing were excluded. Also excluded were persons using CDMA type of mobile phones or headphones while talking over mobile phones. The proposed study was conducted for the period between July 2005 and November 2006 in the Department of Otolaryngology Head and Neck Surgery, Postgraduate Institute of

Medical Education and Research, Chandigarh India. A prior clearance from the Institute Ethics committee was taken before starting the study. The users were categorized into three groups according to total duration of GSM mobile phone use, group A (1-2 yrs use. n=35), group B (2-4 yrs use. n=35), group C (>4 yrs use. n=30).

A detailed history was taken and a complete clinical examination was undertaken in all the subjects. After exclusion of external and middle ear pathology, the patients were taken up for a battery of audiological investigations which included pure tone audiometry (from 250 Hz to 12,000Hz), speech discrimination score, speech reception threshold, impedance audiometry, distortion product otoacoustic emission (DPOAE), Auditory Brain Responses (ABR) and middle latency responses (MLR). The air and bone conduction thresholds were recorded for pure tones with frequencies ranging from 250 Hz to 4000Hz. The thresholds were averaged at 500Hz, 1 kHz and 2 KHz. Similarly, high frequency thresholds were taken at 4000 Hz to 12000Hz. They were considered to have hearing loss if the thresholds exceeded 25 dB.

In each category, the users were further divided into two groups according to daily use of mobile phones, as follows:

- Group I: Users using mobile phones for less than 60 minutes per day.
- Group II: Users using mobile phones for more than 60 minutes per day

The changes in high frequency pure tone audiometry, DPOAE, ABR and MLR were studied in each ear (right and left) to ascertain the effect of electromagnetic force exposure due to chronic mobile phone use.

The data obtained for each audiological parameter on either side was compared using Chi-square test and Independent t-test as applicable. A p value of less than 0.05 was considered significant.

Results

The mean age among users was 28.19 +/- 7.65 yrs and among controls were 31.7 +/- 7.76 yrs. Males predominated over females amongst both the users and controls. (3:1). 90% of the users used the right ear for mobile phone use.

The comparison of high frequency audiogram between the users and controls on the right side in shown in **Table 1**. There was no statistically significant difference between the controls and users.

Similarly there was no statistically significant difference between the users and controls on the left side.

Comparing the mean high frequency thresholds between the users and controls, it was found that among the users, the mean HF loss was 19.6 dB in the right ear and 19.4 dB in the left ear. Among the controls (non users) it was 22.5 dB and 24.76 dB in the right and left ears respectively. This was statistically significant. (p=0.024). **Table 2.**

The ABR parameters i.e. I-III, III-V and I-V interpeak latencies did not have significant difference between the controls and the users.

The analysis of DPOAE also did not reveal a significant difference. In addition, 6 users and 2 non users were found to have absent DPOAE on the right side. Similarly, 5 users and 2 non users had absent DPOAE on the left side. This difference was not significant. Notably users with absent DPOAE in either ear were using mobile phone for at least 30 minutes a day.

The Pa wave amplitude in MLR between the users and controls based on daily duration of use was analyzed. A statistically significant difference was noted on the left side. (P=0.012). **Table 3.** None of the subjects among the controls had abnormal Pa wave amplitude.

Comparing the parameters within the different categories, it was seen that the high frequency hearing loss was found to increase with increase in duration of use of the mobile phone among different categories of users. This was statistically significant on the right side between category A (1-2 yrs) users and category C (>4 years) users. **(Table 4).** There was no statistically significant difference for any of the audiological parameters between group I (<60 minutes daily use) and group II (>60 minutes daily use) users.

Comparing the parameters among the users with and without complaints, it was seen that there was significant difference between III-V inter peak latency on the left side. (**Table 5)**

Discussion

A limited number of studies have been conducted to have an insight into hazardous health effects of mobile phone use, if any. The widespread use of mobile telephones has also given rise to concern about the potential influence of electromagnetic field on hearing of users, as ear is in closest proximity to mobile telephones during their use. Szyjkowska et al[10] studied the subjective symptoms related to mobile phone use using a pilot study and found that the most prevalent symptom among users was the thermal sensation around the ear. Our study too had patients who had symptoms of ear fullness, sensation of warmth around the ear and tinnitus while using mobile phones.

On comparing the hearing thresholds in the high frequencies, we encountered some interesting findings. There was no statistically significant difference for number of subjects with high frequency hearing loss between users and non-users on either side. In fact, there was negative correlation for high frequency hearing loss between users and controls with statistically significant difference on the left side. The possible explanation for presence of high frequency hearing loss amongst the control group is a matter of conjecture. It can probably be speculated that these control subjects may be residing in the vicinity of base stations or TV towers.[7] In addition; environmental influences prevalent in our country may also be playing a role.

Comparing the high frequency hearing thresholds within the categories (A, B, C) it was found that the degree of high frequency hearing loss increased with increase in the duration of mobile phone use, with statistically significant difference for degree of hearing loss ($p <0.05$) between category A (1-2 yrs) and category C (>4 yrs) users on the dominant side. Similar results were reported by Oktay et al.[6] The detection thresholds in those who talked approximately 2 hours per day were found to be higher than those in either moderate users or controls.

Comparing the high frequency audiogram between users who were using mobile phones for >60 minutes per day (group II) with users using mobile phones for </=60 minutes per day (group I), we did not see any statistically significant difference, although group II users had more degree of hearing loss on both the sides than group I users.

Thus it can be concluded that increase in the duration of use as well as use of more than 60 minutes per day of mobile phones can lead to hearing loss at high frequencies. This is in accordance with observations made by Kerekhanjanarong et al [5], found that subjects who used mobile phones for more than 60 minutes per day had worse hearing threshold in the dominant ear than the non-dominant ear.Oktay et al [6] also had similar observations.

Among the users, subjects with some sorts of ear complaints (viz. ear warmth, ear fullness, and tinnitus) during mobile phone use were found to have more hearing loss than the users who had no complaints. The difference was not statistically significant, but users who had complaints had 10.54dB HL and 6.79dB HL more hearing thresholds on the right and left sides respectively than users without complaints. Another interesting observation was that the dominant ear often was worst affected in the users with ear complaints. This is a novel finding and to the best of our knowledge has not been reported earlier.

Analyzing the Distortion product emission (DPOAE) for right and left ears, no statistically significant difference was observed between the users and the controls (non-users). But it was surprising to note that all the users who had absent DPOAE in either ear, were using mobile phones for at least 30 minutes per day. Thus it can be said that use of mobile phones for more than 30 minutes per day can have deleterious effects on inner ear leading to abnormal DPOAE. This is in contrast to the observations made by Kizilay et al [4] in rats. They did not find any measurable electromagnetic field associated changes in the DPOAE either in the adults or developing rats when exposed to mobile phones for more than one hour per day for 30 days. Kerekhanjanarong et al [5] also did not find any difference for OAE in chronic mobile phone users between the dominant and non-dominant sides. Mora et al[11] studied TEOAE and ABR before and after 3 sessions of exposure to electromagnetic field by cellular phones. The sessions ranged from 15 to 30 minutes in length. They did not note changes in either measurement. However, DPOAE changes have not been reported so far.

Studying the ABR waves, we did not find any any statistically significant difference for waves I-III, III-V, and I-V interpeak latencies between the users and the controls (non-users). When compared between different categories among users, there was no significant difference seen on ABR. Comparing the various parameters in users using the mobile phones for more than 60 minutes and less than 60 minutes, no significant difference was noted. These findings were in accordance with the findings of previous researchers. Oktay et al [6] did not find any differences in the BERA results among intensive and moderate mobile phone users and controls. Similarly Kerekhanjanarong et al [5] and Sievert et al [9.12] also did not find any difference between the dominant and non-dominant side in chronic mobile phone users on ABR measurements.

However, on comparing the ABR parameters (I-III, III-V, and I-V inter peak latencies) between the users who had complaints while using mobile phones and the users who did not have any complaint, there was statistically significant difference for wave III-V inter peak latency on the left side.

Thus it can be said that subtle ABR abnormalities might be seen in subjects who have complaints of ear warmth, fullness or tinnitus during mobile phone use. Presence of ear complaints may thus be a warning for central auditory abnormalities in mobile phone users.

On analyzing the Middle Latency Responses (MLR), a statistically significant difference was noted for the Pa wave amplitude on the left side (non-dominant side) between the users and the controls (non-users). (P=0.015). Again comparing the controls and the users on the basis of daily duration of use, statistically significant difference (p =0.12) was seen for Pa wave amplitude on the left (non-dominant) side. This abnormality of Pa wave amplitude on MLR studies has not been reported earlier. It can thus be suggested that analysis of MLR waves (Na and Pa waves) may have some role in assessing the damage to the auditory cortical areas in the brain. Arai et al[1] studied the short term effects of pulsed EM field by mobile phones after a 30 minute exposure in 15 normally hearing volunteers. The ABR and MLR did not show any abnormality. The changes in middle latency responses in long term mobile phone users has not been reported earlier and is a novel finding.

Another important point that needs to be highlighted is the fact that many controls had abnormal audiological parameters but they did not have MLR abnormalities. It can be postulated that the environmental factors which might have caused hearing abnormalities in the controls had not affected the auditory cortex region as yet. However, abnormal MLR responses in the mobile phone users due to long standing exposure to electromagnetic waves could be due to cortical changes in these subjects. Thus it can be postulated that EMF exposure leading to hearing changes in subjects residing close to mobile phone base stations is not severe enough to result in cortical damage.

Another interesting finding noted during the course of analysis is varied changes in various auditory parameters on the non-dominant side. There is no definite explanation for this but it can be speculated that the auditory fibers crossing at the level of superior olive may have been affected. This may be responsible for abnormal changes occurring in the central auditory pathway affecting the non-dominant side.

It can thus be concluded that long term use of mobile phone is associated with high frequency hearing loss. This loss increases with increase in duration of exposure, with more loss on the dominant side than the non-dominant side. Presence of ear symptoms during mobile phone use viz. ear warmth, fullness or tinnitus may be a warning sign for impending hearing loss. Further follow up studies are required to see if changes seen in ABR and MLR studies are reversible after modification of mobile use habits.

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Table 1. Showing the comparison of high frequency audiogram between the users and controls (non users) on the right side.

HFPTA ®	Users	Non users	Total
<25dB (normal hearing)	76	37	113
>25 dB (hearing loss)	24	13	37
Total	100	50	150

P value =0.923.

Table 2: Showing the comparison of audiological parameters between users and controls (non-users).

	EARS	N	Mean	Std. Deviation	p-value
HFPTAR	CONTROL	50	22.05	11.62	0.304
	USERS	100	19.6	14.65	
HFPTAL	CONTROL	50	24.76	12.13	**0.024**
	USERS	100	19.44	14.14	
I-III lat r	CONTROL	48	2.1177	0.2263	0.455
	USERS	94	2.1494	0.2437	
III-Vlat r	CONTROL	48	1.8602	0.1882	0.73
	USERS	94	1.8719	0.192	
I-Vlat r	CONTROL	48	3.9352	0.3869	0.109
	USERS	94	4.0223	0.2535	
I-III lat l	CONTROL	48	2.1379	0.3087	0.966
	USERS	94	2.1361	0.2058	
III-V lat l	CONTROL	48	1.9213	0.2208	0.095
	USERS	94	1.8614	0.1896	
I-V lat l	CONTROL	48	4.0604	0.2981	0.259
	USERS	94	4.0065	0.1922	
NAAMPR	CONTROL	44	1.352	0.5158	0.818
	USERS	86	1.3727	0.4656	
PAAMP_R	CONTROL	44	1.2427	0.4563	0.577
	USERS	87	1.1928	0.4953	
NAAMPL	CONTROL	42	1.485	0.7185	0.086
	USERS	84	1.2745	0.4343	
PAAMPL	CONTROL	42	1.2821	0.4801	**0.015**
	USERS	84	1.0714	0.3697	

TABLE 3: Showing the comparison of Pa wave amplitude on left side between controls and subjects on the basis of daily duration.

USERS (IN DAILY MINUTES)	Pa WAVE AMP (L) (microV)		TOTAL	p-value
	> 0.5 normal	<=0.5 abnormal		
CONTROL	42	0	42	**0.012**
GROUP I (<= 60 MIN)	63	2	65	
GROUP II (> 60 min)	16	3	19	
TOTAL	121	5	126	

Table 4: Showing the comparison of high frequency audiogram between category A (1-2yrs users) and category C (>4 yrs users).

		N	Mean (dB HL)	Std. Deviation	p- value
HFPTAR	1-2 YRS	35	16.48	14.02	**0.040**
	>4 YRS	30	24.54	17.03	
HFPTAL	1-2 YRS	35	16.54	15.45	0.077
	>4 YRS	30	23.24	14.43	

Table 5: Showing the comparison of audiological parameters between users who had complaints while using mobile phones and users who had no complaints using t-test

	Complaints	**N**	**Mean**	**Std. Deviation**	**p-value**
HFPTAR	Yes	6	29.5	14.79	0.088
	No	94	18.96	14.49	
HFPTAL	Yes	6	25.83	17.02	0.256
	No	94	19.04	13.94	
I-III lat r	Yes	6	2.10	0.14	0.263
	No	88	2.15	0.24	
III-Vlat r	Yes	6	1.78	0.20	0.263
	No	88	1.87	0.19	
I-Vlat r	Yes	6	3.89	0.24	0.193
	No	88	3-87	0.19	
I-III lat l	Yes	6	2.14	0.11	0.945
	No	88	2.13	0.21	
III-V lat l	**Yes**	**6**	**1.90**	**0.26**	**0.04**
	No	**88**	**1.65**	**0.18**	
I-V lat l	Yes	6	3.84	0.31	0.244
	No	88	4.01	0.17	
NAAMPR	Yes	5	1.144	0.17	0.26
	No	81	1.3868	0.4747	
PAAMP_R	Yes	5	1.118	0.1066	0.73
	No	82	1.1973	0.5095	
NAAMPL	Yes	5	1.182	0.3604	0.626
	No	79	1.2804	0.4399	
PAAMPL	Yes	5	0.888	0.2986	0.255
	No	79	1.083	0.3722	

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