Background. The effects of radio frequency (RF) and microwave radiation on humans have been the subject of continuous investigation. Clinical investigations related to occupational RF/microwave exposure have been reported by investigators (1). Since one of the major groups occupationally exposed to RF and microwave radiation includes those working in radio broadcasting and TV transmitter stations, this study investigates whether RF affects auditory systems of people exposed to RF.

Methods. The study is carried out with people working in radio broadcasting stations and living in employee residential houses close to the broadcasting stations. All subjects in the control group were similar in age, work regime, socioeconomic status, and lack of experience in working with RF sources.

Brainstem Evoked Response Audiometer (BERA) and Pure Tone Audiometry (PTA) were used to measure the effects of RF under investigation on hearing functions of the subjects. In BERA measurements, I-III, III-V and I-V interpeak latencies were evaluated. In pure tone audiometric measurements, 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz and 8000 Hz frequencies of hearing threshold were measured in subjects of experimental and control groups. Interpeak latencies and bone conduction hearing thresholds of subjects in the experimental group were compared with those of the control group.

Results. BERA results showed that I-III, I-V and III-V interpeak latencies of people occupationally exposed to RF were not higher than subjects in control groups (p < 0.05).

Results of BERA indicated no statistically significant differences between exposure and control subjects.

In audiometric evaluation, hearing threshold of people occupationally exposed to RF were found higher than the control group subjects for frequencies of 4000 Hz and 8000 Hz in terms of bone and air conduction of right and left ear (p < 0.01).

Conclusions. The results of traditional audiometer indicated that RF promotes sensorineural hearing loss and affects cochlea parts related to 4000 Hz and 8000 Hz. These findings may have immediate implications and considerations for workplace safety in order to provide an occupationally safe environment to employees working in such settings. © 2004 IMSS. Published by Elsevier Inc.

Key Words: Occupational safety, Radio frequencies (RF), Radio broadcasting, Brainstem Evoked Response Audiometer (BERA), Pure Tone Audiometry (PTA), Hearing loss.

Introduction

Research related to RF/microwave exposure has generally focused on brain tumors and cancer. However, research
should also be focused on hearing functions of persons working or living in RF/microwave fields such as radio broadcasting, TV transmitting stations, and radar because some people may perceive individual pulses of RF as audible clicks, chirping, or buzzing sounds, depending on the pulsing regime and intensity of the frequency. Frey was the first to investigate this phenomenon (1,2). Since then, there have been numerous studies on the auditory responses of volunteers. Other radiation parameters (peak power density, energy density per pulse, and pulse width) are also important in determining human threshold. Most experimental results indicate that the auditory perception of RF pulses is due to the induction of thermoelastic waves in the head rather than direct brain stimulation by the RF (3).

At high power levels, RF/microwave energy can rapidly heat biological tissue and cause damage, such as burns (4). However, the RF/microwave health issue has generally focused on whether there are any adverse biological effects from long-term or frequent exposure to low-level radio frequency emissions that are not caused by heating (nonthermal effects). While most workers in the field of communication and radar are exposed only to low strength fields, in a few situations workers can potentially be exposed to high levels of RF radiation. Power density is usually very low (1 microwatt/cm²) in radio transmitter rooms, near the bases, and surrounding areas (5,12–15).

Employees who have both been working at and living in the surrounding areas of broadcasting stations constitute one of the major groups occupationally exposed to RF and microwave. Clinical investigations on occupational RF and/or microwave exposure on humans have been the subject of continuous investigation (5–11). Consequently, since the RF auditory phenomenon has been widely recognized as one of the most interesting biological effects of RF, this study presents an extensive analysis of the effects of radiation emitted from antenna of the radio broadcasting stations on hearing functions in humans working at and residing near these stations. Hearing levels of the subjects were evaluated by using pure tone audiometry and BERA in this study. BERA has made assessment of the brainstem and level of hearing. It is a non-invasive test not requiring patient cooperation. The study is designed to investigate possible effects of chronic exposure to radio frequency radiation in people working and living in the residency area of media broadcasting stations.

Materials and Methods

Twenty eight male subjects working in media broadcasting stations and living in the employee residential houses near these stations and 28 age-matched male subjects—a total of 56—were selected for this study. After obtaining the subjects’ consents an otolaryngologist examined their ears and excluded the cases that had ear diseases such as otitis media, otosclerosis, a history of any ear and/or neurologic diseases, and noise-induced hearing loss, which may affect neurologic pathway. Three cases with chronic otitis media and two cases with history of noise-induced hearing loss were excluded from the exposed group. All employees of the same RF station volunteered to participate in the study.

Further consideration has been given to the possibility of cellular phone usage and its consequent effects of hearing function of the participants. The subjects were asked whether they possessed a cellular phone and, if they did, how much they used the device on average per day. Based on their responses, usage of cellular phone was not commonplace and only a few of the subjects possessed the device and rarely used it, approximately less than 15 min per day on average.

Bone conduction hearing threshold of frequencies (500, 1000, 2000, 4000, 8000 Hz) was recorded by means of pure tone audiometry (OB-822, Madsen electronics, Copenhagen, Denmark) in the exposed and control groups. A comparison was made between two groups in each frequency.

Later, BERA was performed by Sapphire 2A EP System (Medelec®, Old Woking, UK) device after all subjects lay supine on a bed in a sound-isolated and electrically shielded room. Subjects in the experimental group have been working and living at 1062 KHz medium wave radio broadcasting stations for at least 10 years, thus indicating that they were generally exposed to RF 24 h/day from various distances in respect to the transmitting antenna of the broadcasting stations as they were also residing close to the antenna.

Recording of BERA

Three silver-silver chloride disk electrodes were placed, respectively, at the forehead in the midline (ground), at the mastoid ipsilateral to the acoustic stimuli (negative), at the vertex (positive). Inter-electrode resistance was maintained at 4 kΩ or less; 100-μsec duration of rarefaction clicks were used as acoustic stimuli. Brainstem responses to 2048 clicks were recorded for each run. The recording signals were bandpass-filtered between 100 and 2000 Hz and processed by an averaging computer. An automatic artifact rejection was used to reduce the inclusion of high-amplitude muscular activity in the averaged responses. Sampling was discontinued whenever there were excessive muscle artifacts on the monitoring oscilloscope. In repeating records, sound waves with stable duration and shape were recorded at 90 dB sound pressure level (SPL) delivered monaurally through TDH 39 earphones used for comparisons. The contralateral ear was masked with white noise 40 dB below the ipsilateral click stimuli. All subjects were tested at a click rate of 10/sec.

Power density and E field of radio frequency inside and around the employee residential houses as well as other nearby locations were measured by EMR 300 (NARDA, Pfullingen, Germany).
Statistical analysis of t-test for independent groups was performed for pure tone audiometry results in all frequencies and BERA values of 90 dBSPL.

Results

Distance between the antennas of the radio broadcasting stations to the employees’ workplace was approximately 250 meters. However, the distance of the antennas to the employee residential houses was between 300 and 350 meters. Exposure level of RF in the room where the control desk was placed was measured as 4.87 V/m in maximum and 4.04 V/m in average (Max Power Density: 0.0063 mW/cm², Average Power Density: 0.0042 mW/cm²). E field and power density inside the buildings in which the control desk and other equipment were placed was measured as 36.23 V/m in maximum and 31.88 V/m in average (Max Power Density: 0.3482 mW/cm², Average Power Density: 0.2717 mW/cm²). E field and power density inside houses provided to employees measured between 0.48 V/m and 0.0073 mW/cm², respectively, depending on the distance from the antenna. However, average E field and power density in children’s playgrounds were measured as 12.75 V/m and 0.0436 mW/cm², respectively, depending on the distance from the antenna. Average E field and power density outside the playgrounds and employee residential houses were measured as 18.64 V/m and 0.0971 mW/cm². E field and power density inside and around these houses where the subjects in the control group normally work and reside were measured as between 0.74 V/m and 2.00 V/m and 0.0001 mW/cm² and 0.0023 mW/cm², respectively, depending on the distance from the antenna. However, average E field and power density in children’s playgrounds were measured as 12.75 V/m and 0.0436 mW/cm², respectively. Average E field and power density outside the playgrounds and employee residential houses were measured as 18.64 V/m and 0.0971 mW/cm². E field and power density inside and around these houses where the subjects in the control group normally work and reside were measured as between 0.74 V/m and 2.00 V/m and 0.0001 mW/cm² and 0.0023 mW/cm², respectively. In addition, the average noise level in the participating radio broadcasting stations was about 70 dB.

Statistical analysis of patient’s BERA findings indicate that there was no difference in the I-III, III-V, or I-V interpeak intervals between the two groups (p > 0.05). On the basis of t-test results, the findings of interpeak intervals are illustrated in Table 1. Pure tone audiometry results showed sensorineural hearing loss in high frequencies after 4000 Hz in those persons working at the broadcasting stations. There were no statistically significant differences in 250, 500, 1000, 2000 Hz frequencies between the two groups. However, significant differences were observed in 4000 and 8000 Hz frequencies between these two groups after the statistical evaluation of subjects’ pure tone audiograms (p = 0.000; p = 0.007) were conducted. Although pure tone audiometry showed 26.4 dBHL in 4000 Hz and 28.8 dBHL in 8000 Hz in those working at the broadcasting stations, they were 13.2 dBHL in 4000 Hz and 20 dBHL in 8000 Hz for the control group. Mean values of the frequencies in two groups were shown in Table 2. It should be noted that although every precaution was taken to minimize potential risks for subjects, they suffered from minor dizziness, fatigue, headache and stress.

Discussion

Microwave auditory phenomenon has been widely recognized as one of the biological effects of RF (16). Some animal studies have shown that exposure to electromagnetic field may alter the endocrine and nervous system (17,18). There is no published data in the existing literature for the long-term effects of electromagnetic field to the hearing of those working at radio broadcasting stations using BERA and PTA together.

It has been shown that radiation-induced pressure changes result from the absorption of RF pulses and could produce significant acoustic energy in solution (19). It is well documented that when the human head is in a pulsed RF field, an audible sound described as a click, buzz, chirp, or a knocking sensation is perceived by some individuals (19,20). Audible sound is produced by rapid thermoelastic expansion, resulting from a rate of $5 \times 10^{-6}$ °C in a short period of time (10 μsec) (19,21). However, Lin stated that when human subjects are exposed to rectangular pulses of microwave radiation, an audible sound occurs which appears to originate from within or behind the head. Lin also stated that thermoelastic theory is adequate for describing microwave-induced sound frequency, threshold of sensation, the influence of pulse width and frequency of the impinging microwave radiation (20). In order for sound exposure to result in hearing damage, the intensity has to be high. Because RF exposure from the radio station does not cause vibrations that give rise to sound perception, a damaging mechanism similar to the one causing damage by acoustic exposure is not possible. Available data support the conclusion that the RF auditory effect is evoked by a possibly different mechanism from the conventional acoustic stimuli; however, the primary site of interaction seems to be the same as the cochlea.

The earliest report on the auditory perception of pulsed microwaves appeared in 1956 as an advertisement by the airborne instruments laboratory (19). Hearing a transient buzzing sound on exposure to the intermittent rotating beam was reported in subjects who are in RF field. The apparent location of the sound was described as a short distance behind the head and was independent of orientation (21).

Auditory brainstem response techniques are of value in evaluation of hearing and identification of site of lesion from cochlear nucleus to inferior colliculus in auditory pathway. Comparison of interpeak intervals after stimulation of each ear separately is of value in distinguishing cochlear

### Table 1. Results of BERA interpeak intervals for subjects

<table>
<thead>
<tr>
<th>Interpeak intervals</th>
<th>I-III* (msec)</th>
<th>III-V* (msec)</th>
<th>I-V* (msec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Study subjects (n = 28)</td>
<td>2.26 ± 0.21</td>
<td>1.97 ± 0.31</td>
<td>4.20 ± 0.25</td>
</tr>
<tr>
<td>Control subjects (n = 28)</td>
<td>2.23 ± 0.28</td>
<td>1.97 ± 0.23</td>
<td>4.23 ± 0.27</td>
</tr>
</tbody>
</table>

*There is no difference between the two groups (p > 0.05).
pathology from retrocochlear pathology. In this study, there was no difference in the I-III, III-V, or I-V interpeak intervals between two groups. These results obviously showed that chronic exposure of the electromagnetic field did not cause any damage in the brainstem, which was detectable by BERA. The detected sensorineural hearing losses in two frequencies (4000–8000 Hz) indicated involvement of the basal turn of cochlea in those subjects who chronically were exposed to electromagnetic field.

These findings undoubtedly have immediate implications for workplace safety and employee well being. Employees who are exposed to such occupational hazards must be provided with additional protective equipment as well as continuous monitoring of their hearing functions. Numerous opportunities to reduce risks of death, injury, and disease are available to government officials, industrial managers, and individual citizens (22). Therefore, it would be appropriate to develop and implement protective mechanisms and systems so as to prevent any potential hearing loss in such workplace environment. This also impacts employees’ performance and long-term organizational commitment. Human resource development contains activities that are undertaken to build a safer and healthier workforce, including the paramount need of the participation of workers in safety activities, training (in both general safety matters and those particular to the job) and exercising their right to refuse dangerous work (23). Being aware of such risks, employees unsurprisingly may be less inclined to work in such settings or may be less willing to thoroughly fulfill their everyday tasks. Organizations of this nature should take every necessary precaution to eliminate these risks and incorporate more technology to improve their equipment. The importance of comprehending both workplace safety and job satisfaction is crucial (24). Consequently, productive and high-performance achieving organizations may only be achieved through protected workplace and healthy employees.

Although cellular phone usage, which may cause bias in the results, was not common among the subjects, it was impossible not to include this in the study. This study has shown that there are significant differences in 4 KHz and 8 KHz frequencies in pure tone audiometry results between two groups. However, in BERA findings, we could not find any difference between these two groups. These findings suggest the primary site of interaction to be the cochlea. In particular, basal turn of cochlea, corresponding to 4000 Hz and 8000 Hz frequencies, has been significantly effected in those who work and reside in the broadcasting stations.

### Table 2. Bone conduction hearing thresholds of subjects for six frequencies

<table>
<thead>
<tr>
<th>Frequencies (Hz)</th>
<th>250</th>
<th>500</th>
<th>1000</th>
<th>2000</th>
<th>4000</th>
<th>8000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Workers (n = 28)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>13.4 ± 6.8a</td>
<td>10.6 ± 6.6</td>
<td>9.6 ± 7.0</td>
<td>10.6 ± 8.2</td>
<td>25.2 ± 12.5a</td>
<td>28.6 ± 13.0b</td>
</tr>
<tr>
<td>Left</td>
<td>14.6 ± 7.62</td>
<td>12.8 ± 8.0</td>
<td>11.8 ± 7.8</td>
<td>12.8 ± 9.4</td>
<td>27.6 ± 12.8a</td>
<td>29.0 ± 12.9b</td>
</tr>
<tr>
<td>Controls (n = 28)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>13.8 ± 5.8</td>
<td>8.0 ± 4.4</td>
<td>6.9 ± 3.1</td>
<td>7.3 ± 6.2</td>
<td>11.9 ± 9.4</td>
<td>20.0 ± 8.4</td>
</tr>
<tr>
<td>Left</td>
<td>13.8 ± 5.8</td>
<td>11.5 ± 5.0</td>
<td>10.5 ± 4.0</td>
<td>10.0 ± 6.4</td>
<td>14.4 ± 9.4</td>
<td>20.0 ± 8.4</td>
</tr>
</tbody>
</table>

*a*BHL; *b*p <0.01.

References

8. Celik F, Dasdag S, Toksoz P. The nutritional status of people occupationally exposed to radio frequency and microwave. Proc 5th Int Symp on Recent Advances in Microwave Technology (ISRAMT’ 1995); part 2, 742-745, Sept. 11-16, Kiev, Ukraine.