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EFFECTS OF RADIOFREQUENCY RADIATION FROM MOBILE PHONES ON HEALTH: A REVIEW

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Cancer, electromagnetic radiation, health, microwave, mobile phone, network operation, radiofrequency, specific absorption rate, technology, tumor.

ABSTRACT

Research on the possible health effects associated with the usage of mobile phones has become a subject of interest in recent years owing to a large number of mobile phone users. Incidence of headache, stress, cancer, memory loss, and sleep problems have been linked to the frequency and duration of usage by some studies. However, there is no conclusive view on the effects of microwave electromagnetic radiation from mobile phones on health which has ignited more research into this area. This work aims to review the health effects of electromagnetic radiations from mobile phones on databases published till 2020. Emphasis is given to circumstances that have the potential to affect the quality of future research conducted on both long-term use and short-term use of mobile phones and health. Safety measures to protect users have also been highlighted. Future research should therefore factor measures to overcome the potential challenge of accurate data interpretation.

1.0 INTRODUCTION

In the telecommunication industry, the mobile phone has gained popularity because it is easily accessible, affordable, and convenient. There are about 3.5 billion mobile phone users according to a recent statistic [1]. The number of mobile phone subscribers in some countries is more than the country population [2]. Concerns on the health implications of radiofrequency radiation emitted from the mobile phone have been on a rise recently. Some studies [3]–[5] have indicated the likelihood of an adverse health effect associated with mobile phone use, however, there is no conclusive scientific evidence [6]. Further scientific research is geared towards searching for mechanisms by which microwave electromagnetic radiations affect biological systems, the association between radiations from mobile phones and cancer, and indirect effects other than radiofrequency radiations [7], [8].

Communication with a mobile phone is through electromagnetic radiation in the radio frequency range of 100 to 2000MHz and therefore has no ionization effect. The electrical and magnetic component of the EM radiation propagates perpendicular to one another in-phase and the same direction. Design specification, geographical location, duration of mobile phone use, and proximity between user and cell phone tower influences the amount of radiofrequency energy absorbed by a user [2], [9].

Interaction of radiofrequency radiation with the body results in thermal and non-thermal effects. In thermal effect, there is heating at the surface of the head resulting in a fractional change in temperature. The thermoregulatory mechanism of the brain is capable of conducting the heat away from the head. The orientation of the head, the duration of mobile phone use, and the frequency of the radiation affect the quantity of heat accumulated. Knowledge of the type of tissue, the wave frequency, the penetrating depth of the wave, and the optimum range of thermal effect can be determined [10]. Kisangiri [11] noted that even though the temperature increase is small to pose any physiological effect, it is theoretically possible that unknown non-thermal mechanisms may disturb the normal function of the cell by the electric field. Biological processes such as biological field patterns, accumulation of information and energy inside the fluid of the body, and alteration in the functional activity of the cell resulting in some disease can be initiated by the electrical field component [12].

Specific absorption ratio (SAR) measures the rate of absorption of radiofrequency energy in the body and is measured in W/kg [13]. SAR depends on the size of the averaging volume of tissue or the whole body. Different mobile handsets emit different SAR values with different exposure patterns [7]. Manufacturers publish the SAR values of their products normally on the internet for general consumption. The mathematical expression of SAR through simulation is given by

$$SAR = \frac{\sigma|E|^2}{2\rho}$$

Where (σ) represents tissue conductivity, (E) represents the root mean square electric field and (ρ) represents tissue density. The magnetic and electric field polarization concerning the body position, the wavelength, the strength of the field, and the dielectric properties of the tissue affects SAR [7]. A decrease in permeability with a subsequent increase in conductivity results in an increment of SAR [14], [15].

To avoid biological damage to human health, regulatory bodies have set standards for SAR values. These standards protect against occupational hazards and general hazards hence categorized into occupational exposure and general exposure.

Table 1. Basic restrictions for electromagnetic field exposure from 100 kHz to 300 GHz, for averaging intervals ≥6 min[a]. [16]

Exposure scenario	Frequency range	Whole-body average SAR(W/kg)	Local Head/Torso SAR(W/kg)	Local Limb SAR(W/kg)	Local S_{ab}(W/m^2)
Occupational	100 kHz to 6 GHz	0.4	10	20	NA
	>6 to 300 GHz	0.4	NA	NA	100
General public	100 KHz to 6 GHz	0.08	2	4	NA
	>6 to 300 GHz	0.08	NA	NA	20

[a]**Note:**

- "NA" signifies "not applicable" and does not need to be taken into account when determining compliance.
- Whole-body average SAR is to be averaged over 30 min.
- Local SAR and S_{ab} exposures are to be averaged over 6 min.

- Local SAR is to be averaged over a 10g cubic mass.
- Local S_{ab} is to be averaged over a 4 cm^2 surface area of the body. Above 30 GHz, an additional constraint is imposed, such that exposure averaged over a 1cm^2 surface area of the body is restricted to two times that of the 4cm^2 restriction.

Below the limit of exposure, it is generally considered safe by regulatory bodies to use a mobile handset.
After a review by a team of experts on the effects of mobile phone radiation on human health by the International Agency for Research on Cancer (IARC), the WHO in 2011 classified them as possibly carcinogenic to humans (Group 2B). Before this, a lot of researchers had found links between mobile phone use and adverse health effect however, the scale of evidence to date is not definite. This work reviews various studies on the health effect of electromagnetic radiations from mobile phones on databases published till 2020. Circumstances that could affect the quality of future research conducted on both long-term use and short-term use of mobile phones and health have been highlighted. Despite limited knowledge and research inconsistencies, established precautionary measures are provided to protect against adverse effects associated with radiofrequency radiations.

2.0 METHODOLOGY

The literature search was conducted on "Google scholar", "Hindawi", "PubMed" and "Google" of which relevant articles were downloaded. Keywords for the search criteria included "mobile phone, health effect, radiation, health issues and phone, brain tumors, radiofrequency and hearing, radiofrequency, cancer and phone, network operation and mobile phone safety. Experimental reports, review studies, comments, and research articles were downloaded. Criteria for selection were irrespective of the date of publication, age, and gender of research subjects but excluded studies on only animals. Search on "Google" was also conducted to look for relevant statistics and data associated with mobile phone use.

3.0 ADVERSE HEALTH EFFECTS OF RADIOFREQUENCY RADIATION FROM MOBILE PHONES

3.1 Mobile Phone and Cancer

Studies conducted in previous years have shown some degree of correlation between mobile phone use and the risk of developing and/or promotion of cancer [17]–[20].

3.2 Brain Tumor

The chances of developing brain tumors have been a concern to users and policymakers owing to the proximity between the mobile handset and the head when receiving or placing a call. Iqbal-Faruque et al. (2014) [14] researched the level of SAR absorbed by the head concerning the orientation of the phone. The computational analysis of absorbed radiation was done with the aid of a computer simulation technology (CST) microwave studio. The outcome indicated that much low SAR values were recorded when the phone was held in the position of the cheek rather than tilting it. Hardell et al. (2009) [21] conducted a pooled analysis to examine mobile phone use and the risk of developing brain tumors. Findings indicated that the risk of developing astrocytoma was highest when the phone was used ipsilaterally for more than 10 years' latency category with odd ratio (OR= 3.3), 95% confidence interval (CI=2.0 - 5.4) and a phone without a cord, OR=5.0, 95% CI =2.3 - 11. Among them, the higher risk was noted with people who used phones before the age of 20 years with OR=5.2, 95% CI= 2.2-12 and for a phone without a cord, OR= 4.4, 95% CI=1.9-10. Higher risk for acoustic neuroma was also reported for more than 10 years' ipsilateral mobile phone use. A meta-analysis by Bortkiewicz et al. (2017) [5] reviewed the link between brain tumors and mobile phone use on several published case-control studies. For all types of brain tumors, there was a higher risk with using mobile phones for more than 10 years with OR= 1.324, 95% CI= 1.028-1.704, and ipsilaterally with OR=1.249, 95% CI= 1.022-1.526. Hardell et al. (2013) [22] performed case-control research on patients diagnosed with brain tumors between the period of 2007 and 2009 to find a possible association with mobile and cordless handsets. The outcome predicted an increased risk of brain tumor with OR=1.7, 95% CI= 1.04-2.8 for wireless phones. No conclusion has arrived regarding 3G mobile phones since the technology has not been on the market for more than a decade. Morgan et al. (2015) [19] reviewed and concluded on a study by CERENAT that radiofrequency fields cause cancer and should be classified as Group 2A as categorized by the International Agency for Research on Cancer. A case-control study by Takebayashi et al. (2006) [23] was carried out in Japan and the risk of acoustic neuroma was not significantly influenced by mobile phone use irrespective of the aggregate period of use or aggregate call time. In comparing regular phone users with non-users, the risk of developing a brain tumor was not found with OR=1.24, 95% CI=0.86-1.77 for gliomas and OR=0.9, 95% CI=0.61-1.34 for meningiomas [24]. Notwithstanding, a significant association was identified with heaviest users for life-long aggregate use (≥ 37.3 days). A retrospective cohort research was carried out in Denmark on mobile phone users from 1982 to 1995. The risk of developing or promoting brain tumor, leukemia, or other cancer was irrespective of mobile

handset use, the time of use, the type of handset or user's age at the period of maiden subscription [6], [25]–[27]. Several other researchers [28]–[30] have reported no significant risk associated with microwave radiofrequency radiation from mobile phones while other reports provide inconsistent evidence [31], [32].

3.3 Skin cancer

Among the various organs of the body, the skin receives most of the radiofrequency radiation and therefore the development of skin cancer of the head and neck has been of interest to researchers and mobile phone users. Current scientific knowledge indicates that the common cause of skin cancers is known to be radiation in the ultraviolet region however, some researchers have investigated the possible connection between radiofrequency radiation and skin cancers. The high incidence rate, chronic nature of skin cancers, and negative weight on the quality of life, call for critical attention to this and related fields of studies [33], [34]. In a large cohort study in Denmark by Poulsen et al. (2013) [35], mobile phone subscribers within the period of 1987 to 1995 were understudy to investigate the development of basal cell carcinoma, melanoma, and squamous cell carcinoma. There was no link between using mobile phones and the risk of developing skin cancers. The study however did not factor in the relationship between heaviest users and skin cancer development. A similar finding was reported [36]. A review study by Keykhosravi et al. (2018) [33] found no significant link between skin diseases and radiofrequency radiation from mobile phones.

3.4 Neurological Effects

Cognitive functions such as concentration difficulties, memory loss, loneliness, depression, fatigue, and sleep disorders have oftentimes been reported among mobile phone users. Whiles these symptoms may be caused by an aggregate of other factors with or without radiofrequency radiation inclusive, several researchers have investigated the degree of influence by low-level radiofrequency radiation on these ill effects. Research conducted by Khan (2008) [37] on mobile phones using the health of medical students reported the following findings. 24.48% of users linked fatigue to their mobile phone, 34.27% linked it with impaired concentration, 40.56% linked it with memory disturbances, 38.8% linked it with sleeplessness. This study indicates to some degree the level of knowledge some users have on the negative effect of mobile phone use and their quality of life. This report however had a small sample size (286), gender-biased (73.77% males and 26.23% females) and its findings cannot be substantiated with scientific evidence. A study by Parmar et al. (2019) [38] to analyze the activity of the brain on electroencephalography (EEG) concluded that changes in EEG can be initiated by radiofrequency fields from mobile phones which have the potential to initiate ill effects in the long term. A cohort study of young adults aged between 20 to 24 years by Thomée et al. (2011) [39] reported that symptoms of depression, sleep disturbances and stress were a result of using mobile phones frequently. At a follow-up period of 1 year, the risk factor of sleep disturbances could be developed by men who use mobile phones frequently while depression may be developed by both sexes. This report is however subjective and not validated cognitive disorder by radiofrequency radiations from a mobile handset. Psychological behaviors of low sleep quality, depression, and impaired personality traits contribute to health problems and are associated with the intensity of mobile phone usage. Using mobile phones at night contributes to a reduction in sleep length and quality [40]. Research by Schoeni et al. (2015) [41] further supports this claim. A study conducted by Söderqvist et al. (2008) [42] among adolescents between the ages of 15 to 19 years revealed that using mobile phones regularly results in sleep disturbances, tiredness, stress, and concentration difficulties. A recent cohort study consisting of Finnish and Swedish participants by Tettamanti et al. (2020) [43] investigated the long-term effect of mobile phone use on the quality of sleep. The findings showed no relationship between mobile phone use at baseline and sleep disturbances, daytime somnolence, and sleep latency. However, insomnia had a moderate link with call-time > 258mins / week which the authors associated with other factors such as stress, behavioral factors, and blue light exposure at bedtime. Mohril et al (2020) [44] have indicated that well-controlled research has found no relationship between radiofrequency radiation and neurological effects but rather these symptoms may be caused by pre-existing situations like anxiety other than radiofrequency in particular.

3.5 Eye Effects

Due to the proximity between the cell phone and the eye during a call, eye problems such as eye cancer, irritation, damage to the cornea and retina are of primary concern. The thermoregulatory mechanism of the eye is low due to the reduced supply of blood to the eye. The lens of the eye in particular cannot dissipate heat due to no blood supply root and therefore may be sensitive to the thermal effects of microwave radiofrequency radiation. Cataracts can therefore be produced in the cornea [45]. Repacholi (2001) [46] indicated that the iris, the retina, and corneal endothelium were vulnerable to low-level radiofrequency fields. Joshi et al. (2008) [47] noted that cataract and eye irritation among workers with high-level exposure to radiofrequency radiations have been reported however, studies with animals prove otherwise. Stalin et al. (2016) [4] investigated mobile phone usage and associated health effects among 2054 adults and concluded that mobile phone use was associated with various health issues including eye symptoms. Khan et al. (2008) [48] indicated that eye cancer, damage to the retina, and cataracts can be direct

health issues caused by radiofrequency radiation.

3.6 Headache

The incidence of headache happens to be part of self-reported health symptoms among some users of mobile phone. Some reports have attributed persistent headache to radiofrequency radiations from mobile handsets. Among them are 14 different studies that have linked headache as a consequence of exposure to microwave electromagnetic frequency radiation from cell phones [49]. Parmar et al. (2019) [38] in a study reported that among the most frequent negative effect of cell phones, headache is the commonest. Research by Hillert et al. (2008) [50] also confirmed this finding. In a cross-sectional study by Sandstrom et al. (2001) [51], a significant link between call duration and headache was reported. A review and meta-analysis studies by Wang et al. (2017) [52] indicated that the risk of developing headaches by mobile phone users is 38% higher than non-users with OR=1.38, 95% CI=1.18-1.61, P<0.001. Longer call duration and more call cycles further increased the risk of a headache. A prospective cohort study by Auvinen et al. (2019) [53] reported that users with average call-time >276 min per week at baseline exhibited a weak link between the frequency of weekly headaches and mobile phone use.

3.7 Auditory Effect

Alteration in the auditory role of the ear by electromagnetic radiation from a cell phone has been reported by some cross-sectional population studies. Among the subjective symptoms reported by users, hearing difficulties is prominent mainly because the pinna is closest to the phone. Using a mobile phone for longer periods of years increases the hearing threshold [54]–[56]. However, sudden sensorineural hearing loss is not associated with mobile phone use [57]. Hearing loss by high frequency (greater than 8kHz) was investigated by Velayutham et al. (2014) [55] among mobile phone users. The outcome indicated that the ear dominantly used to receive calls has a higher risk of hearing loss compared to the other ear. The duration and frequency of use (>40.8 ± 24.2 min/day) also showed a significant link to hearing loss. A clinical study to investigate the auditory function of 1000 participants reported that no significant hearing loss is associated with users notwithstanding, using mobile phone for more than 4h/day for 4-6 years can result in moderate to severe hearing loss [58]. Auvinen et al. (2019) [53] found no link between the amount of call-time and hearing loss. Hegde et al. (2013) [59] reported in research that 0 – 25dB hearing loss was experienced by mobile phone users compared to non-users however, the degree of loss is considered normal for all practical purposes. For users who reported 2h/day of mobile phone usage, a further decline of 5 – 15dB was observed.

4.0 POTENTIAL LIMITATIONS THAT COULD AFFECT THE QUALITY OF FUTURE RESEARCH

In a document by the European Parliamentary Research Service [60], scientific uncertainty and bias by researchers have brought about divided opinions on health hazards associated with radiations from mobile phones. Further quality research is therefore needed to arrive at a scientific conclusion. Caution, however, is needed due to the following potential limitations that may affect scientific findings, interpretations, and applications.

4.1 Contribution from Other Sources of Radiofrequency Radiation

The WHO in 2010 issued a research agenda for radiofrequency fields and among the health research needs in dosimetry, new technologies that use radiofrequency changes the pattern of exposure in both the general public and workers continually and therefore warrant the developments of new instruments to measure the different waveforms and frequencies [61]. Contributions from other radiofrequency technologies such as wireless data networks, body image scanners, cell towers, electrical power transfer through wireless systems, tracking, and identification systems are therefore significant to account for in evaluating the health impact of radiofrequency radiation. A report by Pall (2018) [62] indicated that WiFi and other sources of electromagnetic radiation devices result in sperm damage, apoptosis, DNA damage, neuropsychiatric effects, and EEG alteration and therefore there is a need to factor other sources of microwave radiation in future evaluation. Studies on cell towers have also reported similar health hazards [44], [63], [64].

4.2 Change in Technology

With every generation of telecommunication technology, there are improvements and subsequent changes in the mode of operation and frequency bands. GSM operates in bands of 850MHz and 1900MHz. The evolution of 3G technologies introduced additional bands of frequency around 2100MHz. Current 4G technologies operate in frequency bands of 600MHz, 700MHz, 2.1GHz, 2.3GHz, and 2.5GHz. Future technologies will probably operate with new spectrum and higher frequency bands which implies that the rate of cumulative absorbed energy for years alters with changing technologies in phone type and generation of network. Yekeen et al. (2020) [65] showed that the 5G frequency band of operation has a higher power density and therefore has the potential to induce a high electric field inside the tissues of the body relative to 2G, 3G, and 4G networks. Short-term exposures could therefore be higher and pose detrimental health risks which could be attributed to long-term exposure. On the other hand, an increase in the frequency of mobile use has the potential to result in findings that reflect current behaviors than the past [32].

Study designs should therefore factor in both long term and short term analysis.

4.3 Research bias

Bias in research introduces systematic errors when evaluating outcomes and therefore affects the quality of research findings. Some reports on electromagnetic radiations from mobile phones and health have been fraught with bias [66] in study designs. In a large population-based case-control study in 5 North European countries [32], selection bias due to the low number of control participants and selective participants resulted in exposure overestimation among controls. Bias and random error were also cited in reporting which side of the head mobile phone was held in long term estimation by participants. In all, the risk of glioma was found for ipsilateral use for a duration exceeding 10 years but this result was attributed to chance or casual effect or bias in information. Thomée (2018) [40] reviewed some publications related to mobile phone use and mental health and reported that many adult-centered population studies were conducted among university students or self-selected participants. Selection bias, in this case, affects the generalization of the outcome to the general public. Little coherency between logged data and reported call or texting time was also cited. A similar limitation of recall bias in exposure was reported by Coureau et al. (2014) [24] which resulted in a possible exposure overestimation among heaviest users in the last decile. Takebayashi et al. (2006) [23] indicated the possibility of recall bias in ipsilateral and contralateral mobile phone use reporting about tumor location. Participants were therefore likely to report frequent use on the affected size of the head. Notwithstanding, analysis on the location of phone when in use exhibited no risk increment on the affected side. Recall bias in the average number of text messages and calls made within a day over a month resulted in a likelihood of misclassification and obscure results [39].

The way forward should therefore be an improvement in tools and techniques used in various exposure analyses, factoring exposure from other sources of microwave electromagnetic radiation, evaluating both short-term and long-term analysis, and elimination or reduction in bias.

5.0 PRECAUTIONARY MEASURES

Although research inconsistencies and limited knowledge on the effect of electromagnetic radiation from cell phones on human health are prevalent, we provide below established precautionary measures when using these devices.

1. Mobile handset should be on a loudspeaker and held a hand's length away from the body when making or receiving calls to reduce the radiation levels received onto the body and the head in particular [67]. Exposure levels reduce drastically due to the inverse-square distance relationship. Bluetooth handsets could be employed.
2. When the network signal is weak, calls should be avoided [68]. An increase in the transmission power of the handset will result in a higher absorbed dose.
3. Radiation emitted by digital phones is lower relative to analog handsets. Digital Phones should therefore be preferred.
4. As much as possible, text messages should be sent instead of calling.
5. Various government institutions responsible for radiation and consumer protection should finally set up radiofrequency testing centers where citizens can check the SAR values of their mobile handset either for free or at a reduced cost. SAR values registered on phone batteries or the manufacturer's website may be different from actual SAR values emitted.

CONCLUSION

The mobile phone has become an indispensable device in our daily activities and it is an indisputable fact that it has to a large extent improved the quality of communication. Due to the rising number of mobile phone usage, there is a growing interest in research on the effects of radiofrequency radiation from mobile phones on health. Several studies have highlighted the adverse health effects associated with short-term and long-term use of mobile phones such as brain tumors, skin cancer, headache, neurological, eye, and auditory effects. Therefore, precautionary measures have been established to reduce, if not eliminate the effects associated with radiofrequency radiation from mobile phone usage. An important thing worth noting is the potential limitations to future studies that need to be overcome as they may affect the quality of scientific findings, interpretations, and applications.

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