JOURNAL OF ELECTROMAGNETIC ENGINEERING AND SCIENCE, VOL. 15, NO. 3, 167~172, JUL. 2015

http://dx.doi.org/10.5515/JKIEES.2015.15.3.167
ISSN 2234-8395 (Online) · ISSN 2234-8409 (Print)

Children's Mobile Phone Use and Dosimetry

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Abstract

Research results on possible effects caused by radiofrequency fields in children are limited because most of the studies published so far have focused on adults, rather than children. Mobile phone use is now widespread, even among younger children. If a biological risk due to mobile phone exposure is found, it might be greater in children because their bodies might be more sensitive to radiofrequency energy. The issue of a possible difference in sensitivity between adults and children begins with whether any difference exists physically in terms of electromagnetic absorption. This paper presents a review of recent publications on dosimetric comparisons between children and adults with respect to radiation from mobile phones. The issue of the health effects of mobile phone use is beyond the scope of the present review. Most of the dosimetry research on possible differences in power absorption between children and adults has been based on numerical modeling and analysis. The understanding of the results so far is presented and needed studies are described.

Key Words: Adults, Children, Mobile Phone, Radio Frequency (RF), Specific Absorption Rate (SAR).

I. INTRODUCTION

Public concerns about the possible health effects of mobile phones continue because mobile phone use continues to spead. The International Telecommunication Union has estiated that mobile-cellular subscriptions worldwide reached almost 7 billion by the end of 2014 [1]. South Korea, in particular, has the highest mobile phone penetration rate in the world.

International scientific bodies have stated that no adverse health effects have been established by mobile phone use. The balance of evidence to date suggests that exposure to low level radiofrequency (RF) fields, such as those emitted by mobile phones and their base stations, does not cause detrimental health effects such as increased risk of cancer of the head [2−4].

However, the Ministry of Science, ICT and Future Planning, Korea introduced the system grading mobile phone models based on their specific absorption rate (SAR) values [5]. This is construed as a governmental 'precautionary approach' to raised public concern since the World Health Organization/International Agency for Research on Cancer classified RF electromagnetic fields as group "2B" (possibly carcinogenic to humans) in 2011 [6].

The issue of whether children are more sensitive to electromagnetic fields emitted from mobile phones has been a hot topic among many researchers. However, only very limited research has specifically addressed the issue of a possible difference in sensitivity between adults and children.

One of key questions regarding this issue has been "Do children absorb more radiation power in their heads than adults do from mobile phones?" This is a simple question but very difficult to answer definitively because most dosimetric research compares the absorption of RF power in different individuals. In addition, the structures of the mobile phones examined differ among the various studies.

Manuscript received May 4, 2015 ; Revised June 26, 2015 ; Accepted June 26, 2015. (ID No. 20150504-023J)

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Nevertheless, some recent publications have examined possible age-related differences in exposure from RF radiation of mobile phones. These are reviewed in this paper to provide a better understanding of the current status of the relevant research.

II. HEAD SIZE AND EXPOSURE COMPARISONS

Mobile phone technology was introduced in the early 1980s, but it was not widely used until the mid-1990s. Some researchers had become interested in possible age-related differences in exposure from RF radiation of mobile phones by the mid-1990s [7, 8]. Dimbylow and Mann [7] reported that the SAR values, which averaged over 10 g for infants, were comparable or in most cases lower than the values in the adult phantom, while Gandhi et al. [8] suggested a deeper penetration of electromagnetic energy and a higher 1-g SAR in a smaller head. This controversy continues regarding whether children absorb more RF energy in their heads than adults.

By the mid-1990s, mobile phone use started in earnest and at the same time medical imaging technology was achieving remarkable developments, with the support of high quality computer resources. The first studies used child head models that were linearly scaled down from a realistic adult model. The new advances enabled researchers to develop more realistic human models for numerical simulation of electromagnetic dose in different human tissues and organs [9−11].

Schönborn et al. [12] analyzed the electromagnetic energy absorption using anatomical head models based on magnetic resonance imaging (MRI) scans of a 7- and a 3-year-old children. No significant differences were found between adults and children in terms of the absorption of electromagnetic radiation in the near field of sources. The same conclusion was obtained when children were approximated as scaled adults.

The use of mobile phones, and especially smart phones, is rapidly increasing, even among preschool children. Electromagnetic absorption testing of mobile phones is typically carried out on a mold in the shape of a large adult head, called the Specific Anthropomorphic Mannequin (SAM). This mold is filled with a liquid that simulates the electrical properties of human tissue. The rationale for choosing that specific head model (i.e., SAM) in standards [13, 14] is based on the following criterion: The peak spatial-average SAR shall be a conservative estimate of the actual value expected to occur in the heads of a significant majority of persons, from adults to young children, during the intended use of wireless handsets.

Children's skulls and scalps are thinner than those of adults. This leads many people to think that the radiation from a mobile phone would penetrate more deeply into the brains of children than of adults. Some publications on the growth and development of the human head were reviewed from a dosimetry perspective in [15]; the head circumferences of a 1-year-old infant and a 7-year-old child are approximately 84% and 93%–95% that of adults, respectively. This growth mainly takes place in the skull and brain. When considering that children generally do not use mobile phones until they reach school age, the similarity between adults and schoolchildren in terms of internal morphology leads us to expect no significant differences in absorption.

Several studies have measured electromagnetic absorption in realistic child and adult head models that were developed based on medical images and compared this to absorption in the SAM phantom exposed to radiation from a mobile phone antenna [12, 16−20]. Some studies comparing the peak local SAR in the MRI-based head models from adults and children have found either no significant difference or a statistically higher peak SAR in the larger (adult) head [12, 16, 17]. The results of [16, 17] showed that the SAM gives a conservative estimate of the exposure in the anatomical head models that were considered for two standards, IEEE C95. 1−1999 and the International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines, if head-only tissue (i.e., exclusion of the pinna during the SAR evaluation) is considered.

Wiart et al. [18] reported that the peak 1-g SAR in the brain tissues of models of children aged between 8 and 15 years is comparable to that of adult models, while it is about two times higher for models of children aged between 5 and 8 years, due to the smaller thicknesses of the pinna, skin, and skull.

The radiation quality from a mobile phone determines the input antenna power of the phone in a real environment. In most systems, a mobile phone and its corresponding base station check the signal strength between each other and the power level is automatically increased or decreased.

Lee et al. [19] used modified SAM phantoms with head sizes varying according to age and observed a concerted increase in the peak 1- and 10-g SAR with age for a constant radiated power from a mobile phone. The increase in head volume with age means that a higher input power of a mobile phone is needed for a constant radiation. Nevertheless, the results suggested that the whole-head averaged SAR in children would be higher than in adults for a constant radiation power.

The spatial peak SAR in the head generally shows a strong dependence on the pinna shape and internal morphology of muscle and fat tissue. A difference in internal morphology, such as tissue distribution inside the considered anatomical models, seems to be one of the most important factors influencing spatial peak SAR values [20].

To date, the reported variability in the peak SAR between adults and children seems to be attributed to individual differences in anatomy rather than age.

III. AGE AND DIELECTRIC PROPERTIES OF TISSUES

Simulation using numerical techniques relies heavily on the dielectric properties of the tissues. In 2001, Peyman et al. [21] reported the changes in the dielectric properties of various tissues in the rat, from birth up to an age of 70 days, in the frequency range of 130 MHz to 10 GHz. The results showed a general decrease in the dielectric properties with age and provided some insight into possible differences in the exposure assessment for children and adults. However, how and whether these data can be extrapolated to humans is unclear because the development of the head and brain of rats and humans follows a different time pattern.

The effect on SAR of different dielectric properties between adults and children was examined in a few studies [22−24]. The variation in the dielectric properties with age is mainly due to the changes in the water content of tissues. Wang et al. derived the dielectric properties in 7- and 3-year-old child head models as a function of age according to the total body water, but no significant difference was found in peak 1- or 10-g averaged SAR for mobile phone use [22], because the total body water varies to a great extent in humans under 3 years of age. Peyman et al. [23] measured the dielectric properties of three age groups of pigs (less than 30 days old, about 100 days old, and fully matured) and applied them to 3- and 7-year-old child head models. They concluded that the effects on an average SAR of 10 g were marginal for walkie-talkie exposure.

Christ et al. [24] compared the SAR produced by three different phone models in anatomical head models of two adults and four children at different ages, together with age-dependent dielectric properties of tissue, based on porcine data reported by Peyman et al. [23]. The used phone models were a generic mobile phone equipped with a monopole antenna, a generic mobile phone with an integrated dual band antenna at the top of the body, and a CAD model of the Motorola Timeport T250 with a helical antenna. Christ et al. [24] reported that age dependences of dielectric tissue properties did not lead to systematic changes in the spatial peak SAR.

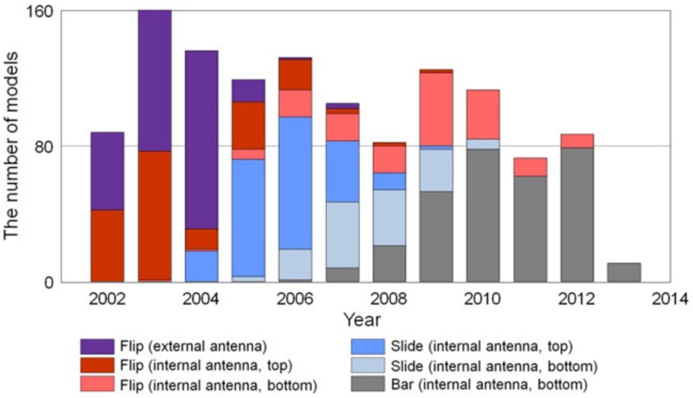

Fig. 1. Changes in mobile phones in the South Korean Market.

IV. CHANGES IN MOBILE PHONE TECHNOLOGY

Another difficulty in generalizing age-related differences in electromagnetic absorption, especially the spatial peak SAR between adults and children, arises from the variability in the structure and location of the antenna and the structure of the phone. The public has seen rapid changes in mobile phone technology since the 1st generation (1G) mobile communication system was commercially introduced in the early 1980s; this used analogue technology operating in the 800 MHz range. The 2G systems were launched in most countries in the 1990s and they vary somewhat from each other in the frequency range and access mode. The biggest change between the 2G and 3G systems has been observed in the phone use pattern: the 1G and 2G systems were voice-oriented, whereas the 3G system allows phone users to access data communication applications such as email, internet etc. with higher data rates. Generally, initiating with the 3G phones, the antenna started to be inserted into the phone body.

Fig. 1 shows the changes in outer shapes and antenna types and locations of the most commonly released phone models in South Korea by year. Flip, slider, and bar types make up the largest proportion in the early, mid, and late 2000s, respectively, and the antenna has been primarily located at the bottom of the phone body since the late 2000s. In particular, since the release of smart phones, the most recent Korean models have been bar-type, with the antenna at the bottom of the phone body.

These trends in phone structure might be characteristics limited to the Korean market, but this change needs to be considered in exposure evaluation. However, the research that has investigated possible age-related differences in SAR and that has tested the conservativeness of the SAM phantom has been performed using mobile phone models with the antenna on top of the body, in the form of an external whip,

Table 1. A summary of studies on SAR in head models exposed to radiation from a mobile phone

Reference	Head model and electromagnetic source	Results
Dimbylow and Mann [7] (1994)	A real adult model and a model scaled by 0.7; a λ/4 monopole antenna on a metal box; 900 and 1,800 MHz	Calculations on an adult head for the handset provide conservative estimates of the SAR, averaged over 10 g, deposited in the model of a head representing a 1-year-old infant.
Gandhi et al. [8] (1996)	A real adult model and scaled 10 and 5 years child models; monopole antennas of lengths λ/4 and 3λ/8 on a metal box; 835 and 1,900 MHz	Because of the deeper penetration of EM energy in smaller models, considerably higher internal tissue SAR's are obtained both at 835 and 1,900 MHz.
Schönborn et al. [12] (1998)	MRI based adult and child (3 and 7 years) models, 0.45λ dipole; 835 and 1,900 MHz	The results revealed no significant differences in the absorption of electromagnetic radiation between adults and children.
Kainz et al. [16] (2005)	SAM phantom and 14 anatomical head models including two child (3 and 7 years) and scaled models; a generic phone model consisting of a flat metallic plate, a plastic box, and a monopole antenna; 835 and 1,900 MHz	The SAM gives a conservative estimate of the exposure in anatomically correct head models for head only tissue. Characteristic differences between adults and children are not shown.
Beard et al. [17] (2006)	SAM phantom, and adult and scaled models; a generic phone model; 835 and 1,900 MHz	The larger (adult) head gave a statistically higher peak SAR than did the smaller (child) head for all conditions. The SAM produces higher SAR than the anatomically correct models.
Lee et al. [19] (2007)	SAM phantom and its modified and scaled models; a generic phone model consisting of a flat metallic plate, a plastic box, and a monopole antenna and a monopole antenna on a metal box; 835 MHz	For a fixed input power, the head models by age changed peak 1- and 10-g SARs by approximately 15%. The electromagnetic absorption depths in the head models in the same test position were about the same, but the head-averaged SAR was higher in the younger model because of the smaller head volume.
Wiart et al. [18] (2008)	Seven adult and six child (5, 6, 8, 9, 12 and 15 years) models based on MRI data; a dipole and a generic phone; 900, 1,800, 2,100, and 2,400 MHz	The maximum SAR in 1 g of peripheral brain tissues of child models aged between 8 and 15 is comparable to that of adult models while it is about two times higher for child models aged between 5 and 8 years than in adult models.
Lee and Yun [20] (2011)	SAM phantom and child (5, 7, and 9 years) head models; a generic phone model at 835 and 1,900 MHz and a phone model with a planar inverted F antenna at 1,900 MHz	The SAM phantom does not always provide a conservative estimate of child head exposure at 1,900 MHz; in 45% of the 40 total cases, the peak 10-g SAR was higher in the child models than in the SAM phantom.
Wang et al. [22] (2006)	A real adult model and scaled 3 and 7 years child models; monopole antenna on a metal box; 900 MHz	An empirical formula derived with the total body water was applied to the dielectric properties of children. The age effect on the spatial peak SAR of dielectric properties is within 10%.
Peyman et al. [23] (2009)	Two child (3 and 7 years) models; a walkie–talkie operating at 446 MHz	The dielectric properties of tissues from 10, 50, and 250 kg pigs were assumed to correspond to those of 1- to 4-year-old, 11- to 13-year-old, and adult human bodies, respectively. The data were used to calculate the SAR values in children aged 3 and 7 years, exposed to RF induced by walkie–talkie devices. No significant differences were observed between the SAR values for the children of either age or for adults.
Christ et al. [24] (2010)	Two adult and four child models (3, 6, 7, and 11 years); three phone models (a generic phone with a monopole, a generic phone with an integrated dual band antenna, Motorola Timeport T250); 900 and 1,800 MHz	Age dependencies of dielectric tissue properties do not lead to systematic changes in the peak spatial SAR. The geometric properties of the head do not have a systematic impact on the peak spatial SAR; i.e. no correlation could be established between the size of the head and the peak spatial SAR.

SAR = specific absorption rate, EM = electromagnetic, MRI = magnetic resonance imaging, SAM = Specific Anthropomorphic Mannequin.

an external helix, or an internal planar inverted F antenna (PIFA) [7, 8, 16, 17, 20, 22, 24].

Long Term Evolution (LTE) is the latest step toward 4G radio technologies designed to increase the capacity and speed of mobile telephone networks: downlink and uplink peak rates reach 100 Mbps and 50 Mbps, respectively, and the advantages expand the functions of a mobile phone. High-speed technology gives mobile phone users instant access to text messaging, email, and other Internet-based information, including entertainment and multimedia content. Another RF radiation which the public almost daily exposed to is coming from the Wireless Local Area Network (WLAN) system, an ad-hoc system operating in the 2.4 GHz or 5 GHz range and set up within limited areas, such as homes, hotels, cafes, or office buildings. It allows the general public to use various devices such as tablet computers, wireless transceiver-equipped notebook computers, and mobile phones (smartphones) with wireless internet access.

V. CONCLUSION

Accurate and reliable dosimetry and exposure assessment are key requirements of scientific studies on the health effects of electromagnetic fields. The antenna types and locations on commercial mobile phones have undergone a number of changes from those used in early research on health effects. Therefore, these changes need to be considered in future studies.

Until now, most of the computational simulations have been performed under specific conditions; for example, the standard phone positions against a head model and the maximum output power of a phone model. However, phone usage patterns due to high-speed technology could be quite different among children, adolescents, and adults. Exposure in real environments also needs to be assessed according to different usage patterns between different age groups.

This work was supported by the IT R&D program of MSIP/IITP (No. B0138-15-1002, Study on the EMF exposure control in smart society).

REFERENCES

[1] International Telecommunication Union, "World Teecommunication/ICT Indicators database 2015 (19th Edition /June 2015)," 2014; http://www.itu.int/en/ITU-D/Statistics/Pages/publications/wtid.aspx

[2] World Health Organization, *Establishing a Dialogue on Risks from Electromagnetic Fields*, Geneva, Switzerland: World Health Organization, 2002.

[3] Scientific Committee on Emerging and Newly Identified Health Risks. *Health Effects of Exposure to EMF*, Brussels, Belgium: European Commission; 2009.

[4] International Commission on Non-Ionizing Radiation Protection, "ICNIRP statement on the guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz)," *Health Physics*, vol. 97, no. 3, pp. 257−258, 2009.

[5] Korea Ministry of Science, ICT and Future Planning, *Guidelines for EMF Grade, Target Equipment and Labelling (Notification No. 2013-29)*. Gwacheon, Korea; 2013.

[6] International Agency for Research on Cancer, "IARC classifies radiofrequency electromagnetic fields as possibly carcinogenic to humans," 2001; http://www.iarc.fr/en /media-centre/pr/2011/pdfs/pr208_E.pdf

[7] P. J. Dimbylow and S. M. Mann, "SAR calculations in an anatomically realistic model of the head for mobile communication transceivers at 900 MHz and 1.8 GHz," *Physics in Medicine and Biology*, vol. 39, no. 10, pp. 1537−1553, 1994.

[8] O. P. Gandhi, G. Lazzi, and C. M. Furse, "Electromagnetic absorption in the human head and neck for mobile telephones at 835 and 1,900 MHz," *IEEE Transactions on Microwave Theory and Techniques*, vol. 44, no. 10, pp. 1884−1897, 1996.

[9] M. J. Ackerman, "The visible human project," *Proceedings of the IEEE*, vol. 86, no. 3, pp. 504−511, 1998.

[10] A. K. Lee, J. K. Byun, J. S. Park, H. D. Choi, and J. Yun, "Development of 7-year-old Korean child model for computational dosimetry," *ETRI Journal*, vol. 31, no. 2, pp. 237−239, 2009.

[11] A. Christ, W. Kainz, E. G. Hahn, K. Honegger, M. Zefferer, E. Neufeld, et al., "The virtual family: development of surface-based anatomical models of two adults and two children for dosimetric simulations," *Physics in Medicine and Biology*, vol. 55, no. 2, pp. N23−N38, 2010.

[12] F. Schönborn, M. Burkhardt, and N. Kuster, "Differences in energy absorption between heads of adults and children in the near field of sources," *Health Physics*, vol. 74, no. 2, pp. 160−168, 1998.

[13] IEEE Recommended Practice for Determining the Peak Spatial-Average Specific Absorption Rate (SAR) in the Human Head from Wireless Communications Devices: Measurement Techniques, *IEEE Standard 1528−2013*, 2013.

[14] Human exposure to radio frequency fields from hand-held and body-mounted wireless communication devi-

ces – Human models, instrumentation, and procedures - Part 1: Procedure to determine the specific absorption rate (SAR) for hand-held devices used in close proximity to the ear (frequency range of 300 MHz to 3 GHz), *IEC 62209 –1:2005*, 2005.

[15] E. van Rogen, E. W. Roubos, L. M. van Aernsbergen, G. Brussaard, J. Havenaar, F. B. Koops, et al., "Mobile phones and children: Is precaution warranted?," *Bioelectromagnetics*, vol. 25, no. 2, pp. 142–144, 2005.

[16] W. Kainz, A. Christ, T. Kellom, S. Seidman, N. Nikoloski, B. Beard, and N. Kuster, "Dosimetric comparison of the specific anthropomorphic mannequin to 14 anatomical head models using a novel definition for the mobile phone positioning," *Physics in Medicine and Biology*, vol. 50, no. 14, pp. 3423–3445, 2005.

[17] B. B. Beard, W. Kainz, T. Onishi, T. Iyama, S. Watanabe, O. Fujiwara, et al., "Comparisons of computed mobile phone induced SAR in the SAM phantom to that in anatomically correct models of the human head," *IEEE Transactions on Electromagnetic Compatibility*, vol. 48, no. 2, pp. 397–407, 2006.

[18] J. Wiart, A. Hadjem, M. F. Wong, and I. Bloch, "Analysis of RF exposure in the head tissues of children and adults," *Physics in Medicine and Biology*, vol. 53, no. 13, pp. 3681–3695, 2008.

[19] A. K. Lee, H. D. Choi, and J. I. Choi, "Study on SARs in head models with different shapes by age using SAM model for mobile phone exposure at 835 MHz," *IEEE Transactions on Electromagnetic Compatibility*, vol. 49, no. 2, pp. 302–312, 2007.

[20] A. K. Lee and J. Yun, "A comparison of specific absorption rates in SAM phantom and child head models at 835 and 1,900 MHz," *IEEE Transactions on Electromagnetic Compatibility*, vol. 53, no. 3, pp. 619–627, 2011.

[21] A. Peyman, A. A. Rezazadeh, and C. Gabriel, "Changes in the dielectric properties of rat tissue as a function of age at microwave frequencies," *Physics in Medicine and Biology*, vol. 46, no. 6, pp. 1617–1629, 2001.

[22] J. Wang, O. Fujiwara, and S. Watanabe, "Approximation of aging effect on dielectric tissue properties for SAR assessment of mobile telephones," *IEEE Transactions on Electromagnetic Compatibility*, vol. 48, no. 2, pp. 408–413, 2006.

[23] A. Peyman, C. Gabriel, E. H. Grant, G. Vermeeren, and L. Martens, "Variation of the dielectric properties of tissues with age: the effect on the values of SAR in children when exposed to walkie-talkie devices," *Physics in Medicine and Biology*, vol. 54, no. 2, pp. 227–241, 2009.

[24] A. Christ, M. C. Gosselin, M. Christopoulou, S. Kuhn, and N. Kuster, "Age-dependent tissue-specific exposure of cell phone users," *Physics in Medicine and Biology*, vol. 55, no. 7, pp. 1767–1783, 2010.

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