



Modelling and assessment of the electric field strength caused by mobile phone to the human head

Modelovanje i procena jačine električnog polja mobilnog telefona u predelu glave

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Abstract

Background/Aim. Electromagnetic field exposure is the one of the most important physical agents that actively affects live organisms and environment. Active use of mobile phones influences the increase of electromagnetic field radiation. The aim of the study was to measure and assess the electric field strength caused by mobile phones to the human head. **Methods.** In this paper the software “COMSOL Multiphysics” was used to establish the electric field strength created by mobile phones around the head. **Results.** The second generation (2G) Global System for Mobile (GSM) phones that operate in the frequency band of 900 MHz and reach the power of 2 W have a stronger electric field than (2G) GSM mobile phones that operate in the higher frequency band of 1,800 MHz and reach the power up to 1 W during conversation. The third generation of (3G) UMTS smart phones that effectively use high (2,100 MHz) radio frequency band emit the smallest electric field strength values during conversation. The highest electric field strength created by mobile phones is around the ear, i.e. the mobile phone location. The strength of mobile phone electric field on the phantom head decreases exponentially while moving sideways from the center of the effect zone (the ear), and constitutes 1–12% of the artificial head's surface. **Conclusion.** The highest electric field strength values of mobile phones are associated with their higher power, bigger specific energy absorption rate (SAR) and lower frequency of mobile phone. The stronger electric field emitted by the more powerful mobile phones takes a higher percentage of the head surface. The highest electric field strength created by mobile phones is distributed over the user's ear.

Key words:
cellular phone; electromagnetic fields; health; head.

Apstrakt

Uvod/Cilj. Izloženost elektromagnetnom polju spada u najvažnije fizičke agense koji aktivno utiču na žive organizme i na prirodu. Stalna upotreba mobilnih telefona povećava radijaciju elektromagnetnog polja. Cilj ove studije bio je da se izmeri i odredi jačina električnog polja koje stvara mobilni telefon u predelu ljudske glave. **Metode.** U ovoj studiji koristili smo softver COMSOL *Multiphysics* za utvrđivanje jačine električnog polja koje stvaraju mobilni telefoni oko glave. **Rezultati.** Druga generacija telefona 2G GSM (*2nd Generation Global System for Mobile*) frekvencije od 900 MHz i snage od 2 W ima snažnije električno polje od mobilnih telefona 2G GSM koji rade u višem opsegu frekvencije, tj. 1 800 MHz i snage do 1 W tokom razgovora. Treća generacija pametnih telefona 3G UMTS koji efektivno koriste visoki opseg radiofrekvencije, tj. 2 100 MHz, emituju najslabije električno polje tokom razgovora. Najjače električno polje mobilni telefoni zrače u predelu uha, tj. na mestu mobilnog telefona. Jačina električnog polja mobilnog telefona na model glave opada eksponencijalno kada se pomera na stranu od epicentra efektivne zone (uho) i iznosi 1–12% površine modela glave. **Zaključak.** Najviše vrednosti jačine električnog polja mobilnih telefona povezane su sa većom snagom, većom specifičnom brzinom apsorpcije energije (*specific energy absorption rate* – SAR) i nižom frekvencijom. Jače električno polje koje emituju mobilni telefoni veće snage zauzima veći procenat površine ljudske glave. Najjače električno polje mobilnog telefona stvara se u predelu uha korisnika.

Ključne reči:
mobilni telefon; elektromagnetna polja; zdravlje; glava.

Introduction

The world we live in is constantly modernizing and the electromagnetic radiation emitted by electronic devices, electric power transmissions, television and radio stations, computers, radars, mobile phone antennas and, especially by mobile phones constantly affects people and can cause various health problems. Electromagnetic waves surround us, however, we do not smell, see, nor feel them¹. A rapid increase in the level of electromagnetic radiation (many times exceeding original background) that can damage ecological balance of the environment has been observed; therefore it should be researched and evaluated by theoretical and experimental methods².

In the 21st century, with the spread of mobile phone networks and the introduction of GSM-900, GSM-1,800, UMTS-2,100 systems, the number of sources of electromagnetic radiation increased^{3,4}. A lot of people use mobile connection without being concerned about its operating principles: something that is not seen can cause harm⁵. Active use of mobile phones and their level of temporal dynamics allow for perceiving the component of electromagnetic background as one of the most important physical agents that actively affect live organisms and environment⁶.

Due to the growing number and scope of sources of electromagnetic radiation from mobile phones, their effect is significant not only for specialists but for all the inhabitants of surrounding areas^{7,8}. In some countries, mobile-free zones are demanded. In such zones it is forbidden to install mobile communication base stations, it is also required to reduce the highest levels of allowed electromagnetic radiation or other restrictions may be imposed⁹.

A mobile phone is one of the most actively used sources of electromagnetic radiation. It is a small compact transmitter and receiver in a single casing¹⁰. The owner always carries mobile phone nearby; therefore, it has effects on the owner^{11,12}. When the mobile phone is used, it is put to the ear, and when not – it usually stays in the pocket, near the body. In this way the electromagnetic radiation, emitted by (ringing) mobile phone directly interacts with the human body^{13,14}. While talking on the phone, the electromagnetic field is directly pointed towards the brain. During conversation, each mobile phone emits different strengths of electric field¹⁵.

The World Health Organisation's International Agency for Research on Cancer on May 31, 2011 announced that when the mobile phone is used for a long time, 30 or more minutes per day, radiofrequency electromagnetic fields could increase risks of brain tumour. The World Health Organisation stresses that when used properly and all safety measures followed, the negative effects of a mobile phone on health caused by electromagnetic radiation can be minimised or avoided^{16,17}. The contemporary opinion on the negative effects of mobile phone antennas and electromagnetic radiation from mobile phones does not allow for making assumptions about future consequences¹⁸.

Measurement and evaluation of electromagnetic radiation level, reduction of the highest allowed level of electromagnetic radiation and establishment of other regulations are the issues of worldwide importance. At the moment, the

most important concern is the contradictory information about mobile phones and mobile communication base stations, and their declared effects on human health^{19,20}.

Due to the lack of scientific research on electromagnetic field radiation from mobile phones and public concern, the electromagnetic field radiation strength parameters of various mobile phones and emission to the human body are discussed in this study. The aim of the study was to create and to assess the strength spread by the electric fields of mobile phones around the head.

Methods

We used the software "COMSOL Multiphysics" for modelling of the mobile phone electric field around the head during the call mode.

"COMSOL Multiphysics" is a powerful, interactive environment which we can apply for modelling of the mobile phone electric field. By using this software, we can simulate the propagation of electromagnetic fields induced in the human head while it is in active mode. For the propagation of electromagnetic fields, the program "COMSOL Multiphysics" uses the proven finite element method (FEM). Using a various number of solutions, the software performs finite element analysis, error control, and activates the adaptive grid (if selected). "COMSOL Multiphysics" is suitable for evaluating human exposure to radiofrequency of electric field strength.

"COMSOL Multiphysics" for simulation of the electric field strength uses the artificial head model (phantom) composed of different thicknesses layers: skin, fat, muscle, skull and brain. In addition to the head, it shows a mobile phone. The mobile phone simulates a half-wave length dipole, which is equal in frequencies 900 MHz – 166 mm, 1,800 MHz – 83 mm, and 2,100 MHz – 71 mm. The dipole antenna is divided into segments of length $\lambda/30$, and the brain, skin and other tissue segmentation selected $\lambda/15$ side, according to the creators of the program guidelines. The distance between the mobile phone and the head is equal to 1 cm (Figure 1). The program simulates electric field intensity distribution in the mobile phone active mode. In view of the use of mobile phones and antennas, the dipole model is used with a 2 W, 1 W, 0.8 W, 0.25 W and 0,125 W radiant power and dipole wave impedance of 50 Ω .

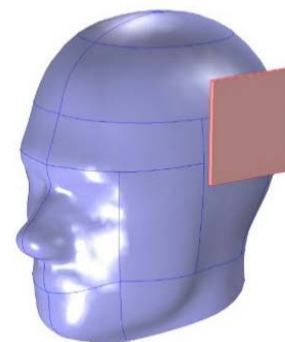


Fig. 1 – Electric field strength simulations using the artificial (phantom) head and a mobile phone.

Taking into account the use of mobile phones and their characteristics, the simulation program allows to change the basic settings and monitor the electric field distribution on the surface of the head. In order to simulate the electric field distribution in the artificial head, we also used the following data: the mobile phone of the specific energy absorption rate (SAR), the maximum transmission power, frequencies, and electromagnetic signal levels in the environment. After setting up the necessary parameters, the software "COMSOL Multiphysics" allows to model the spread of mobile phone electric fields in the head at the distance of 1 cm.

The research was conducted by using GSM second generation (2G) mobile phones that operated within frequency range from 900 MHz to 1,800 MHz and by UMTS third generation (3G) smart mobile phones that operated in 2,100 MHz frequency range. The main criteria in the choice of mobile phones were the differences in power, SAR, and frequency.

Results

SAR is a measure to estimate the absorbed energy by the human body when exposed to electromagnetic field. Reliable estimation of SAR values has become a very important concern. It is impossible to measure SAR *in vivo*, but reliable SAR values can be easily obtained from electric field data.

The experimental electric field distribution in the real human head is not a simple task. Thus, we used the artificial head with the following layers: skin, fat layer, skull and brain, and we accessed possible electric field strength values distribution around the head in active call mode.

Figure 2 shows smart mobile phone (power – 2 W, SAR 1.4 W/kg, frequency – 900 MHz) electric field intensity distribution in the active mode.

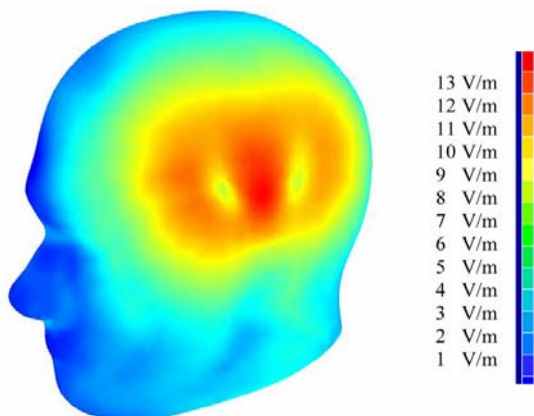


Fig. 2 – Mobile phone [power 2 W, specific energy absorption rate (SAR) 1.4 W/kg, frequency 900 MHz] and the distribution of electric field values during phone talk.

Figure 3 displays the distribution of mobile phone electric field strength during conversation (SAR 0.6 W/kg, maximum power – 0.8 W, used frequency – 900 MHz).

Figure 3 shows that the electric field strength created by the mobile phone (colour red) reaches 6–7 V/m around the ear (i.e. the place to which the mobile phone is put) in a 3 cm

radius. In a 4–5 cm radius (colour yellow) the electric field strength is lower (4–5 V/m). At the distance of 5–10 cm radius (colour green) the electric field strength is 2–3 V/m. In the upper part of the head (light blue colour) the electric field strength is about 2 V/m. In the upper and lower parts of the head, at both sides of the head or on top of it the electric field strength decreases to 1 V/m. The electric field strength of the mobile phone takes about 8% of the whole artificial head.

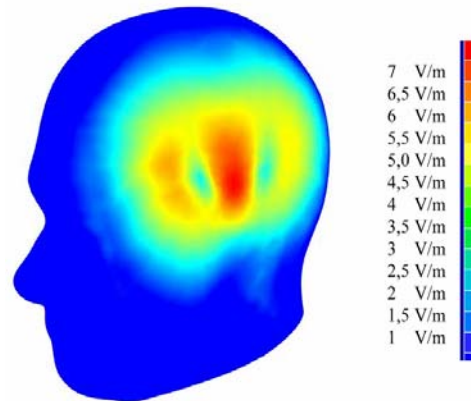


Fig. 3 – Mobile phone [power 0.8 W, energy absorption rate (SAR) 0.6 W/kg, frequency 900 MHz] and the distribution of electric field values during phone talk.

The study shows that the electric field strength of 0.8 W power mobile phones is weaker and smaller by size compared with a mobile phone 2 W power. As we see, the electric field strength of the mobile phone takes about half of the human head compared with the mobile phone of 0.8 W power. Here, the electric field strength takes only one-third of all the head.

Figure 4 displays the distribution of mobile phone electric field strength during conversation on the mobile phone of 0.99 W/kg SAR, 1 W maximum power, 1,800 MHz used frequency.

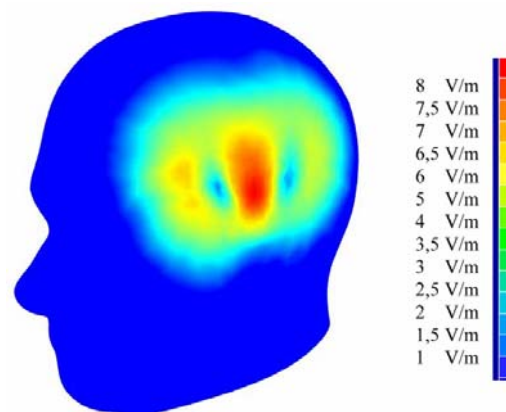


Fig. 4 – Mobile phone [power 1 W, energy absorption rate (SAR) 0.99 W/kg, frequency 1,800 MHz] and the distribution of electric field values during phone talk.

The study reveals (Figure 4) that the electric field strength created by the mobile phone (colour red) reaches 6–8 V/m around the ear (i.e. the place to which the mobile phone is put) in a 3 cm radius. In a 4–5 cm radius (colour yellow) the electric

field strength is lower (5 V/m). Furthermore, at the distance of 5–10 cm radius (colour green) the electric field strength is 2–4 V/m. In the upper part of the head (light blue colour) electric field strength is about 2–4 V/m. In the upper and lower parts of the head, at both sides of the head or on top of it the electric field strength is decreasing to 1 V/m. The electric field strength of the mobile phone takes about 7% of the whole artificial head.

Figure 5 displays the distribution of mobile phone electric field strength during conversation over the mobile phone of 0.6 W/kg SAR, 0.25 W maximum power, 1,800 MHz used frequency. The results show (Figure 5) that the electric field strength created by the mobile phone (colour red) reaches 4–5 V/m around the ear (i.e. the place to which the mobile phone is put) in the radius 1.5 cm. In radius 1.5–2 cm (colour yellow) the electric field strength is lower (3.8 V/m). At the distance of 2–3 cm radius (colour yellow green) the electric field strength is 2–4 V/m. In the upper part of the head (blue colour) electric field strength is about 1 V/m. In the upper and lower parts of the head, at both sides of the head or on top of it the electric field strength decreases to 1 V/m. The electric field strength of the mobile phone takes about 4% of the whole artificial head.

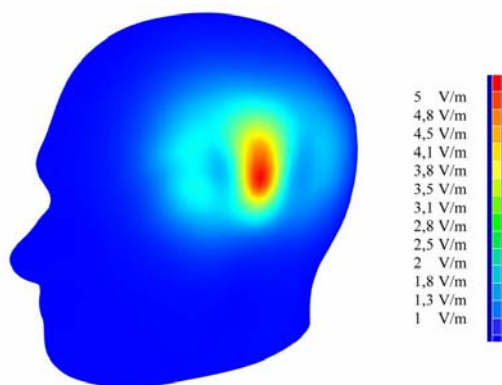


Fig. 5 – Mobile phone [power 0.25 W, energy absorption rate (SAR) 0.6 W/kg, frequency 1,800 MHz] and the distribution of electric field values during phone talk.

The experiments reveal that electric field strength of 0.25 W power mobile phones is 1.6 times weaker compared with 1 W (SAR 0.99 W/kg) power, 2.5 times weaker compared with 2 W (SAR 1.4 W/kg) power, and 1.4 times weaker compared with 0.8 W (SAR 0.99 W/kg) power mobile phones.

The third generation of smart mobile phones Universal Mobile Telecommunication Systems (UMTS) (3G) emits 2,100 MHz frequency range waves. The emitted wavelength of smart phones is quite short (about 7 cm). Figure 6 displays the distribution of smart mobile phone electric field strength during conversation over a mobile phone, 1.22 W/kg SAR, 2 W maximum power, 2,100 MHz used frequency. The study reveals (Figure 6) that the electric field strength created by the mobile phone (colour red) reaches 9–11 V/m around the ear (i.e. the place to which the mobile phone is put) in a 2 cm radius. In a 3–4 cm radius (colour yellow) the electric field strength is lower (3.8 V/m). At the distance of 2–3 cm radius (colour yellow green), the electric field strength is 4–7 V/m. At the distance of 4–6 cm radius (light blue colour) the elec-

tric field strength is 1–4 V/m. In the upper part of the head (blue colour) the electric field strength is about 1 V/m. In the upper and lower parts of the head at the distance of 6 cm, at both sides of the head or on top of it the electric field strength decreases to 1 V/m. The electric field strength of the mobile phone takes about 5% of the whole artificial head.

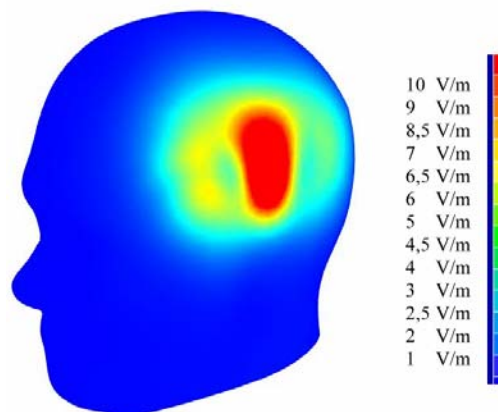


Fig. 6 – Smart mobile phone [power 2 W, energy absorption rate (SAR) 1.22 W/kg, frequency 2,100 MHz] and the distribution of electric field values during phone talk.

Figure 7 displays the distribution the electric field strength of the mobile phone during conversation over the mobile phone 0.57 W/kg SAR, 0.125 W, maximum power 2,100 MHz used frequency. The study reveals (Figure 7) that the electric field strength created by the mobile phone (colour red) reaches 1 V/m around the ear (i.e. the place to which the mobile phone is put) in a 1 cm radius. Because the mobile phone emits a very low electric field strength, its radiation area is very small, only 3 cm. In this area the prevailing electric field strength is 0.1–0.9 V/m. When the distance from the mobile phone is more than 3 cm, the electric field strength is not detected on the upper and lower parts of the head, at both sides of the head or on top of it. The electric field strength of the mobile phone takes about 1% of the whole artificial head.

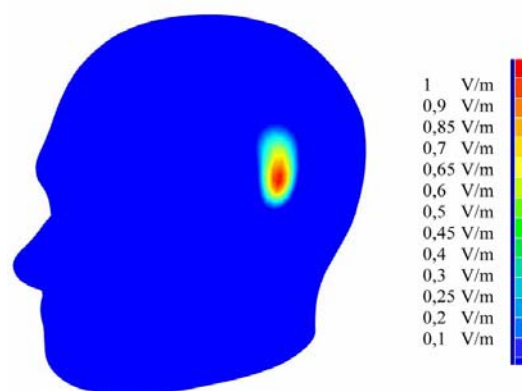


Fig. 7 – Smart mobile phone [power 0.125 W, energy absorption rate (SAR) 0.57 W/kg, frequency 2,100 MHz] and the distribution of electric field values during phone talk.

The experiments revealed that the electric field strength of 0.125 W power mobile phones was 10 times weaker compared with 2 W (SAR 1.22 W/kg) power mobile phone, 7 times weaker compared with 0.8 W (SAR 0.6 W/kg) power mobile phone, and 13 times weaker compared with 2 W (SAR 1.4 W/kg) power mobile phone.

The study shows that stronger power, higher SAR and lower frequency of the mobile phone is associated with the stronger electric field of the device. As we can see, the highest values of electric field strength are determined by the powerful mobile phones. The electric field strength of the powerful mobile phones is stronger and bigger. A stronger electric field emitted by more powerful mobile phones takes a higher percentage of the head surface. The third generation (3G) UMTS smart phones that operate in the frequency band of 2,100 MHz, emit smallest electric field strength values during the conversation. This is determined by the effective usage (smart phones use communication types of extended spectrum) of radio frequency (2,100 MHz). In addition, the electric field emitted by smart phones constitutes the smallest percentage (only 1%) of the head's surface.

Discussion

The interaction between the human body and electromagnetic radiation can induce electric currents and electric fields inside human bodies, what can produce side effects to health. Adverse effects investigated by various clinical trials include the possible link to increased risk of leukaemia, sleep disturbances and brain tumours^{1, 2, 4, 21}. Numerous studies stated that the intensive use of mobile phones can cause headache, fatigue, insomnia, muscle pains, hearing and eyesight defects, failures of memory, neck and facial skin redness, and increase stress^{12, 13, 21}. The mentioned symptoms can short-termed arise either during or sometimes after phone conversation¹⁸. It means that adults, young people, and children spending a number of hours for talking with mobile phone are directly exposed to the harmful effects of electromagnetic fields. Considering all these points, the current studies are necessary to investigate the effects of electromagnetic fields on the humans¹⁴. Some uncertainties concerning possible carcinogenic effects should also be considered. According to epidemiological studies on mobile phones and cancer (children and teenagers leukaemia, adult leukaemia, lymphatic leukaemia, breast and brain tumour), it was concluded that the possibility of the enhanced cancer risk could not be excluded². The use of mobile phones is associated with the increased risk for brain tumour after 10 years^{1, 4, 12}. The International Agency for Research on Cancer stated overall evaluation that radiofrequency electromagnetic fields are possibly carcinogenic to humans^{7, 21}. Exposure to electromagnetic radiation can cause nerve and muscle stimulation and changes in nerve cell excitability in the central nervous system⁸.

Exposure to electromagnetic radiation normally results in negligible energy absorption and no measurable temperature rise in the human body. The effects of external exposure to electromagnetic radiation on the human body depend mainly on the time and strength of electromagnetic fields^{8, 21}.

In order to assess potential health risks, reliable exposure assessment and modelling are necessary. Radio frequency electromagnetic radiation from mobile phones can be reliably modelled using special programs like "COM-SOL Multiphysics". In epidemiological studies on the adverse health effects of mobile phones, it is especially important to determine exposure size and strength considering that electromagnetic radiation has a potential hazard to the human head. Our results show that most of the electric fields are absorbed at the side of the head nearest to the mobile telephone.

The user of a mobile phone is exposed to radiofrequency radiation much higher than those found in the environment (mobile telecommunication, television or radio antennas). Mobile phones are in a very close contact with the human head. That is why the distribution of absorbed energy by the head of the user must be determined. From sophisticated computer modelling and measurements using models of heads, it appears that the energy absorbed from a mobile phone is not evaluated quite enough.

According to the results of the research, it is possible to renew the legal regulatory framework of electromagnetic expertise, that regulates the allowed intensity level of the electromagnetic fields, and to improve evaluation methods and methodologies for electromagnetic radiation. Considering the results of the analysis of electric field radiation of mobile phones, it is possible to provide recommendations for mobile phone safety. This could protect mobile phone users from biologic effects, health problems, and from the possible carcinogenic effects. According to other studies, using a safer device at the safe distance, and following safety measures, the harm caused by mobile phone could be minimised^{16, 17, 21}.

The most common document with recommendations concerning electromagnetic radiation is The Council Recommendation on electromagnetic field exposure limits (1999/519/EC), where standards of 41 V/m and 58 V/m are set as the limits (at 900 MHz and 1,800 MHz). However, many countries follow up the guidelines what are below this limit, because of public complaint and attitude. Lithuania does not have limitation for electric field strength at 900 MHz and 1,800 MHz (the only limitation for electromagnetic field power density is 10 $\mu\text{W}/\text{cm}^2$).

The strong side of the study was the assessment of the electric field strength exposure, to the phone user, by various models of mobile phones with different technical parameters. The results of the study could be used for public health risk and hazard prevention, measurement of electromagnetic radiation emitted by mobile phones, and regulatory documents, legislation, and limitation preparations.

Conclusion

The highest electric field strength values are emitted by more powerful mobile phones, with the bigger specific absorption rate and with lower frequency mobile phones. The second generation 2G Global System for Mobile phones that operate in the frequency band of 900 MHz and reach power of 2 W have the stronger electric field than the second gen-

eration 2G Global System for Mobile mobile phones that operate in the higher frequency band of 1,800 MHz and reach power up to 1 W (during conversation). The third generation 3G Universal Mobile Telecommunication System smart phones that effectively use high (2,100 MHz) radiofrequency band, emit the smallest electric field strength values during conversation.

The highest electric field strength created by mobile phones is absorbed by the user's ear (i.e. in the mobile phone location). The strength of mobile phone electric field to the

phantom head decreases exponentially while moving sideways from the center of the effect zone (the ear), and constitutes 1–12% of the artificial head's surface. A stronger electric field emitted by the more powerful mobile phones takes higher percentage of the head surface.

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