Numerical simulation of SAR in eye tissues under near-field EM exposure

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***Abstract*—This paper focuses on the numerical evaluation of the impact of high-frequency electromagnetic fields (EMF) on human eye tissues, specifically examining the distribution of the Specific Absorption Rate (SAR). Due to its high water content and limited thermoregulation capabilities, the visual system represents a highly sensitive structure vulnerable to electromagnetic energy absorption. The research was conducted using three-dimensional electromagnetic simulations within the CST Studio Suite software environment. The analysis utilized two distinct model types: a simplified multi-layer eye model and anatomically realistic voxel phantoms of an adult male and a child from the Voxel Family database. Exposure scenarios were simulated using microstrip patch antennas operating at frequencies of 1800 MHz, 2,4 GHz, and 5 GHz, analysing the effects of varying the source position and distance relative to the eye. Simulation results revealed the highest localized energy absorption in deeper tissues at 2,4 GHz, whereas the 5 GHz frequency exhibited dominant absorption in the superficial layers of the eye, reaching a peak SAR of 1,18 W/kg. Comparative analysis demonstrated higher localized energy absorption rates within the child phantom, attributed to anatomical variances and smaller head dimensions. The obtained quantitative data provide an essential foundation for assessing the electromagnetic safety of modern wireless communication devices operating near the human body.**

Keywords—electromagnetic fields (EMF), modelling, simulation, SAR (specific absorption rate), human eye, CST Studio Suite

I. INTRODUCTION

The rapid advancement and widespread proliferation of modern wireless communication technologies—such as mobile devices, Wi-Fi networks, and wearable electronics—have led to continuous exposure of the human body to high-frequency radiofrequency electromagnetic fields (EMF). Among various human organs, the eye is considered particularly vulnerable to electromagnetic radiation. This heightened sensitivity stems primarily from its high water content, specific dielectric permittivity, and the complete lack of vascularization in critical structures such as the lens and cornea. Consequently, the visual system exhibits severely limited thermoregulation capabilities, as blood flow cannot efficiently dissipate heat generated by absorbed electromagnetic energy. Prolonged or intense exposure to radiofrequency energy may therefore lead to localized thermal stress, potential structural alterations in ocular proteins, and increased long-term risk of tissue damage. Understanding the exact interaction between high-frequency EMF and ocular tissues makes the precise quantification of energy deposition a critical safety concern. The fundamental metric used to evaluate this thermal absorption is the Specific Absorption Rate (SAR), expressed in watts per kilogram (W/kg). Because direct in vivo measurements of internal SAR within human ocular structures are technically challenging and ethically unacceptable, high-resolution computational modeling serves as an essential alternative methodology for exposure assessment. This paper deals with the construction of anatomical numerical models of the human eye and high-frequency electromagnetic field sources to simulate, quantify, and analyze the impact of RF exposure. The primary objective is to evaluate the spatial distribution of absorbed radiation within individual ocular layers and systematically compare the obtained simulation results with international safety limits established by ICNIRP guidelines and relevant exposure legislation. To achieve this, a series of comprehensive three-dimensional electromagnetic simulations was executed in CST Studio Suite using custom-designed simulation profiles. These configurations combine microstrip patch antennas operating across multiple frequency bands (1800 MHz, 2.4 GHz, and 5 GHz) with multi-layered eye structures and anatomically detailed adult and child head voxel phantoms. The dielectric properties (permittivity and electrical conductivity) of all ocular tissues were precisely configured according to frequency-dependent biological databases. The investigation focuses on calculating localized and 10g-averaged maximum SAR values, analyzing wave penetration depths across different frequencies, and systematically evaluating how absorption levels vary as a function of radiated power, antenna positioning, and physical distance from the human eye [1], [2].

EMF absolute exposure is gauged using the electric field strength **E** and radiation flow density |**S**|. The value of the electric field vector is represented by the electric field strength **E**. Impact wave energy is represented by the radiated power density |**S**|. The specific absorption rate SAR (W/kg) is regarded as the pertinent indication of exposure to non-ionising electromagnetic radiation with frequencies between 100 kHz and 10 GHz. The SAR value, which can be described as the absorbed power in the volume of the tissue, measures how much energy W of radiofrequency radiation with the intensity of electric field **E** is absorbed by the biological tissue of volume V with conductivity σ and density ρ.

The local SAR value at a position r is defined as:

$$SAR\,(r) = \frac{\sigma\,(r)|E(r)|^2}{\rho\,(r)} \qquad (1)$$

The strength of the EMF field, the characteristics of the exposed tissue and the location of the body part exposed to