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LOW-COST HEAD PHANTOM FOR THE EVALUATION AND OPTIMIZATION OF RF-LINKS IN OPHTHALMIC IMPLANTS

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Abstract: *An inexpensive head phantom for the evaluation and optimization of radiofrequency communication links in ophthalmic implants such as the Artificial Accommodation System is presented. The eye balls of the phantom are gelatine-based and have a solid consistency to hold the test implant in its place. A thin plastic head shell serves as a container for the homogeneous head tissue-equivalent. All deployed tissue-simulating materials are based on a sugar-salt-solution whose properties can be adjusted to approximate the permittivity and conductivity values of the human head/eye at the used frequency band. Additionally, the head phantom comprises a glass insert that can optionally be introduced to simulate the effect of nasal cavities and sinuses on the signal propagation and antenna characteristics.*

Keywords: *Artificial Accommodation System, ophthalmic implant, head phantom, tissue equivalent*

Introduction

The ability of the eye to adjust its focal length to the target distance is called accommodation. As a result of presbyopia (age-related stiffening of the eye lens) or after implantation of a conventional intraocular lens (IOL) as a remedy for cataract (clouding of the eye lens), accommodation is lost. In this context, a miniaturized active medical implant – the Artificial Accommodation System (AAS) – is being developed to restore accommodation [1]. It is intended to replace the natural lens inside the capsular bag of the eye and function autonomously inside the human body.

For measuring the target distance based on eye ball rotations, the AAS requires a synchronized exchange of sensor data between both eyes [2]. Additionally, communication with an external programming device for configuration and monitoring purposes is required. The Medical Implant Communication Service (MICS) at 402–405 MHz was chosen as the communication standard for both wireless links [3].

Compared to free space conditions both signal attenuation and antenna impedances are altered by the human body. In order to evaluate the performance of the RF-links during the development phases, a tissue-simulating head phantom is required. Existing phantoms for implant evaluation lack the anthropomorphic accuracy needed for ophthalmic implants (e.g. cylindrical shape [4]) while head phantoms for specific absorption rate (SAR) measurements are usually solid [5] and can hardly be adapted to accommodate a test implant. Therefore, a tissue-simulating head phantom with a special focus on the eye area was developed and will be presented in this paper.

Methods

For a realistic simulation of the implant inside the human eye, the head phantom must meet the following main requirements: (a) geometrical accuracy of the eye area, (b) precise positioning of the implant inside the eye, (c) realistic shape of the human head including air cavities (nose, sinuses), and, (d) realistic permittivity and conductivity values of the tissue substitute at the target frequency. To meet these demands, the phantom is composed of three parts: gelatine eye balls, a liquid-filled head shell and air cavities representing the nasal cavities and sinuses.

Eyes: The human eye has a diameter of about 24 mm in which the AAS will be implanted just 5 mm behind the outer boundary surface of the cornea into the capsular bag of the eye. To form the eye balls and place the implant in it, a five-part mould was manufactured of acrylic glass to be filled with a gel-like tissue substitute (Fig. 1, right). First, the anterior part of the eye is moulded with a placeholder of the size of the implant. Then, the implant is inserted and recasted by the posterior part. The solid consistency of the eye is obtained by a combination of gelatine and Natrosol™ hydroxyethylcellulose (HEC) at the ratio of 3:1 in addition to a common sugar-salt-solution recipe [6]. As the eye lens is mainly surrounded by the aqueous humour and the vitreous body, the targeted permittivity and conductivity are those of the vitreous humour measured by [7].

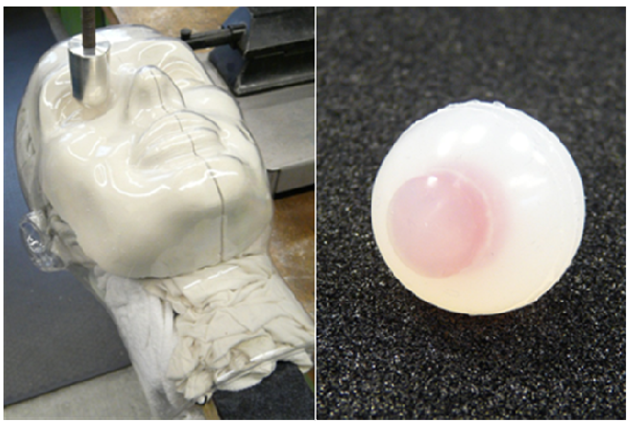

Figure 1: Thermoforming of eye orbits (left); Gelatine eye balls with lens implant dummy (right).

Head: The head shell is derived from a common plastic decoration head and the eye sockets were subsequently inserted via thermoforming (Fig. 1, left). Thereby, the head shell can be filled with a tissue-equivalent liquid that does not touch the eye balls. The targeted relative permittivity and conductivity of the head tissue are chosen to be 44.1 and 0.87 S/m respectively, according to IEEE-Std 1528-2003 [8].
Air cavities: To model the nasal cavities and sinuses which are located around both eyes, a glass form was manufactured by KIT's glassblowing department. The air-filled glass piece can be inserted into the head shell to simulate the entrapped air.

Results

The different parts of the phantom were assembled as depicted in Fig. 2 and the head shell was filled with tissue-equivalent liquid. The consistency of the eye material was solid enough to substain the eye form and keep the implant (red dummy implant in Fig. 2) in its place. The dielectric properties of the eye and head materials were measured with the *Sequid* time-domain reflectometer *STDR-65* and the open-ended coaxial line sensor *SDM-10G* [9]. The corresponding results are shown in Tab. 1.

Table 1: Measured and literature (brackets) permittivity and conductivity of the tissue-equivalent materials.

	Head	**Eye**
ε_r	47.2 (44.1)	46.5 (69)
σ (S/m)	0.67 (0.87)	0.76 (1.53)

The relative permittivity of the head is in good agreement with the target value. However, a considerable discrepancy between measured and targeted conductivity of the eye-substitute can be observed. Most likely, this is due to the added gelatine which is not part of the original recipe. To obtain a higher conductivity for future mixtures, the proportion of NaCl will be increased.

Figure 2: Assembled head phantom including eye balls and the air-filled glass insert (nasal cavities and sinuses).

Discussion

An inexpensive head phantom aiming at testing and optimizing the RF communication/antennas of active ophthalmic implants such as the Artificial Accommodation System was presented. The eye balls of the phantom were modelled with a gelatine-based sugar-salt-solution to obtain solid consistency and dielectric properties comparable to the human eye at around 400 MHz (MICS-band). The interior of the head shell is filled with a homogeneous liquid that averages the different types of head tissue at the considered frequency. Additionally, the effect of nasal cavities and sinuses on the antenna impedance and signal propagation can be simulated by a special glass insert.

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