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Views & Comments

Compelling Challenges in Antenna Technologies for Future Medical Applications

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1. Introduction

Numerous types of antennas have been developed, tested, and utilized for medical applications such as diagnosis, treatment, data transmission, and wireless power transfer (WPT). Recently, compact and robust antennas are needed to realize implantable and wearable wireless devices for medical applications such as delivering drugs from implanted capsules, stimulating nerve systems, and monitoring physiological data [1]. Because antennas for medical applications are used close to or in a human body, their effects on the human body should be included in their development and evaluation [2]. However, it is rather difficult due to ethical and practical reasons to employ a real human body when experimentally evaluating the characteristics of antennas or wireless devices for medical applications. Thus, numerical simulations are generally conducted as an alternative, using elaborate digital human models [3]. Many different types of software are now commercially available for this purpose, along with digital human-body models.

With the advent of the fifth generation mobile communication technology (5G) and smart technologies, as well as the increasing demand to improve the quality of life (QOL) of patients, there are many challenges to antenna technologies for future medical applications. This paper highlights the following three challenges:

(1) The evaluation of antennas for medical applications;

(2) The development of electromagnetic theranostics for cancer treatment;

(3) The development of human-centric antennas.

Antenna researchers—particularly young professionals or graduate students—are encouraged to grapple with these important and interesting topics with the aim of making great contributions to a global healthy society.

2. The evaluation of antennas for medical applications

Unlike the evaluation of antennas used for communications, there are generally five steps involved in the performance evaluation of antennas used in medical applications, including numerical simulation, phantom measurement, "meat" experiment (i.e., experiment on nonliving tissues), animal experiment, and clinical trials.

As the first step in medical antenna performance evaluation, numerical simulation is generally conducted using elaborate and precise digital animal- or human-body models [3], which are now commercially available. Under certain circumstances, multiphysics simulation is a powerful tool for the development and evaluation of antennas. Recently, the US Food and Drug Administration (FDA) announced the new Medical Device Development Tool (MDDT) program [4]. According to this program, the FDA will qualify tools that can be used by the sponsors of medical devices in the development and evaluation of devices. Sophisticated numerical simulation with a qualified MDDT may eliminate or mitigate much of the risk and uncertainty in product development, including animal experiments. Therefore, it may accelerate and promote the research and development (R&D) of medical devices.

Experiments using physical human-body phantoms, as the second step in antenna evaluation, are indispensable for the validation of numerical simulation results or to minimize animal experiments, particularly in the R&D of implantable antennas. Various kinds of physical phantoms have been widely developed to meet different requirements. Physical phantoms are typically categorized into four groups: liquid, gel, semi-solid, and solid phantoms [3]. In particular, semi-solid phantoms are considered to be suitable for experiments involving implantable antennas or devices. This is because it is quite easy to implant antennas or devices into the right place in a semi-solid phantom and then hold them in place without additional fixtures.

There is still a great deal of room to further improve physical human phantoms or to develop novel ones, such as transparent phantoms or phantoms without water. Collaboration with researchers in other fields, such as chemistry or materials, will be helpful for these purposes.

3. The development of electromagnetic theranostics for cancer treatment

The term "theranostics" is a combination of "therapeutics" and "diagnostics." In a clinical situation, theranostics may involve the combined use of drugs, radiation, electromagnetic waves, or other techniques to simultaneously or sequentially diagnose and treat medical conditions. For example, Ref. [5] reports a microwave theranostic device that acts as both a sensor to detect malignant tissue and an applicator for thermal ablation. Typical approaches for cancer treatment are surgery, radiotherapy, chemotherapy, gene

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therapy, immunotherapy, and thermal therapy, which includes hyperthermia and ablation. It is practical to combine two or more different approaches for a better clinical outcome. For example, hyperthermia gently employs the thermal effect of electromagnetic waves to make use of the difference in thermal sensitivity between healthy and tumor tissue [6]. The target tumor is generally warmed up to the therapeutic temperature—which is roughly between 42 and 45 °C—while avoiding overheating the surrounding healthy tissues.

Fig. 1 shows a schematic diagram of an annular phased array antenna for heating deep-seated tumors. The array consists of 12 (6 × 2 rings) microwave antenna elements, which are placed around the human body. By properly adjusting the excitation phases of the antennas, microwave energy can be focused on the target tumor to be treated. For this particular purpose, lower frequencies (50–200 MHz) are generally used. Before the treatment, the location and size of the tumor are usually identified with conventional imaging techniques such as X-ray computed tomography (CT).

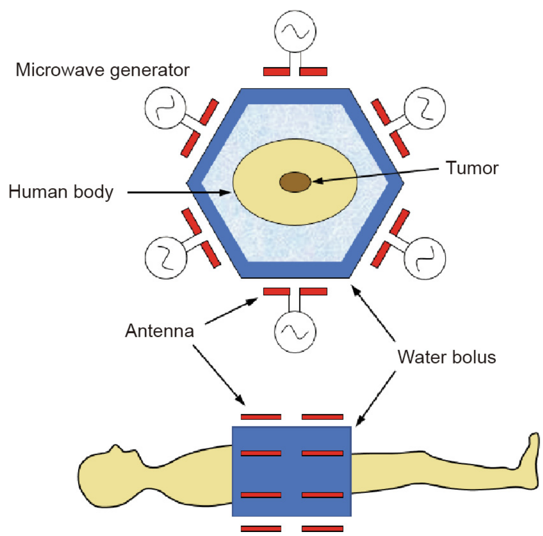

Fig. 1. Diagram of an annular phased array for heating deep-seated tumors.

Microwave imaging is a safe and promising technique for non-invasive diagnostics. There is a significant contrast in the dielectric properties of healthy and malignant tissues at microwave frequencies [7]. In microwave imaging, a transmitting antenna radiates low-power microwaves into human tissue, while a set of receiving antennas receives scattered and/or transmitted signals to gather image information, based on the contrast between healthy and malignant tissues. If the phased array shown in Fig. 1 could also act as a microwave imaging system, then there would be no need to employ another imaging device for diagnosis. Such a device would hold considerable promise as a form of theranostics for cancer treatment in the future. Unlike the theranostic microwave device reported in Ref. [5], which is essentially invasive, such a device could non-invasively diagnose and treat deep-seated tumors. Although it will be challenging to achieve this goal, doing so would be tremendously beneficial, not only to hospitals and medical doctors, but also to patients.

4. The development of human-centric antennas

Wearable and implantable antennas are widely used for communications or to monitor vital data. The antennas employed for treatment or surgical operations in hospitals have a range of different functions, but all are commonly used in the vicinity of a human body. Fig. 2 illustrates the various applications of antennas placed close to or in the human body. The concept of human-centric antennas—that is, antennas specifically designed for use in or near the human body [8]—can be applied as a unified approach to deal with such antennas for different purposes. Generally speaking, the problem of an antenna that is placed close to or in the human body may be considered as a so-called "boundary value problem," in which the human body is treated as a complex lossy medium. In principle, by solving Sommerfeld integral equations, the electromagnetic fields generated around the antenna could be obtained [9]. This theoretical approach could distinguish among three different waves—namely, space waves, surface waves, and bulk waves—generated by the antenna. However, considering the difficulty of this approach and its lack of popularity, individual cases involving antennas in or near the human body are usually

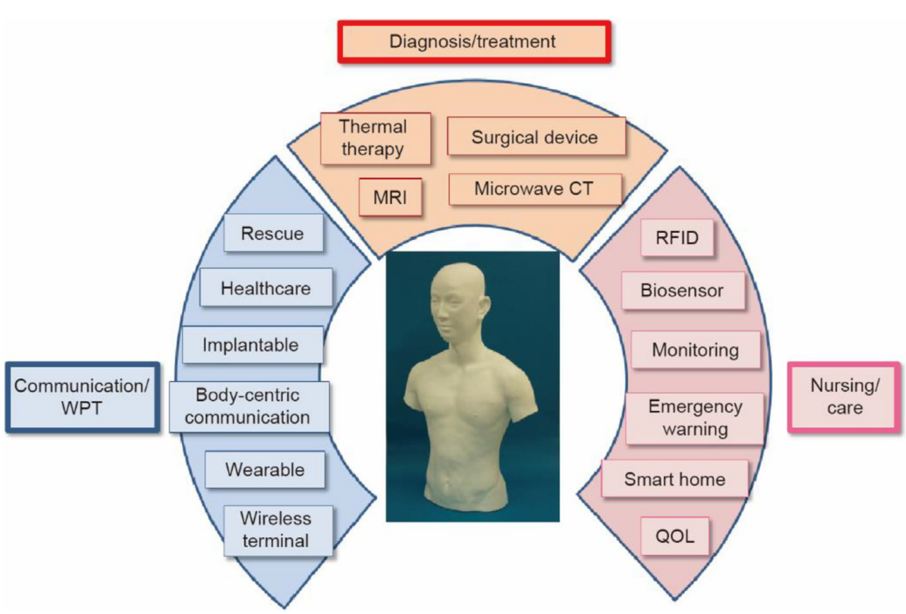

Fig. 2. Various applications of antennas placed close to or in the human body. MRI: magnetic resonance imaging; RFID: radio frequency identification.

addressed appropriately in a specific manner by means of numerical or computer simulation.

Nevertheless, the concept of human-centric antennas could be used to further mitigate potential risks, such as mutual interference between different antennas. In addition, promoting the use of a common antenna for different purposes could reduce the number of antennas needed, which would benefit not only the patient's body, but also the environment. This topic still requires further elaboration, and remains as a key challenge.

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