A Radio Frequency Identification (RFID) Enabled Fixed Prosthesis and Its Applications in Clinical Dentistry

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(**Received** 22 February 2013; **Accepted** 1 Aril 2013; **Published on line** 1 June 2013)

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DOI: 10.5875/ausmt.v3i2.192

Abstract: RFID-enabled dental prostheses can facilitate the use of relatively noninvasive procedures, and such a fixed prosthesis may provide significant additional benefits. This article describes the insertion of High frequency (13.56 MHz) RFID devices in dental fixed prostheses. A high frequency (13.56 MHz) system using sheet-type RFID-tags is inserted in the bilateral lower first molar buccal area to allow for direct identification through the cheeks without saliva contaminations. Simulations and experiments indicate that both the area occupied by the antenna and the number of coil turns influence the density of the electromagnetic field. Experimental results show that, as the tag's area increases, the tag's detecting distance is increased to more than 1 cm throughout the agarose, consisting of about 98% water to mimic the physiology of a human cheek. We also successfully download data from the tag including the prostheses design date, installing dentist identifier, and the materials used. Such a mechanism can protect patient privacy, while providing benefits for medical therapy as well as facilitating forensic identification. Further studies to minimize the antenna dimensions and improve its directional propagation are still needed for future applications.

Keywords: Radio frequency identification (RFID); fixed prosthesis; clinical dentistry; medical therapy

Introduction

The development of radio frequency identification (RFID) systems has given rise to various applications especially in the health care sector [1]. The specific conditions of these applications require different types of RFID tags operating at different frequencies. For example, ultra-high frequency RFID (UHF; > 900 MHz) suffers high attenuation in water, making them difficult to use in biomedical applications. An RFID transponder covering the 13.56 MHz band was adapted to minimize the tag's volume for placement into endodontic human tooth chambers [2]. Teeth are the hardest and strongest part of the human body, and intra-oral identification devices can offer an instant and inexpensive means of personal or public recognition, and often play an important role in forensic science. Research into intra-pulp RFID loadings have been reported [2, 3], but loading RFID tags into healthy teeth may cause discomfort and unnecessary injury.

Information loaded over dental prostheses brings some significant benefits [4, 5]. They allow for easy identification and recognition [6], and provide information to facilitate further clinical management for secondary dental procedures. Furthermore, RFID devices embedded in teeth can serve as mobile tracking devices for seniors and young children [7].

Given the popularity of dental prosthetic implants among adults, RFID tags can be inserted into fixed dental prostheses prior to implantation. Such RFID tags could be pre-loaded with particular information including the material used for the implant, along with the design and manufacture date. Such information is useful for both long-term functional maintenance and personal identification. Such information could also assist in identifying victims of neurodegenerative disease, e.g., Alzheimer patients. The performance of such devices can be ensured through tag-sealing techniques.

Materials and Methods

RFID tags

Tags are categorized by the radio frequency used, or by their read-out process (i.e., active or passive). Tags typically deployed in animals or humans are usually rod-shaped, with passive and read-only characteristics [8, 9]. However, sheet-form tags may be suitable for insertion into dental prostheses [10]. Thus, for the purposes of the present experiment, sheet-form tags with high frequency (13.56 MHz) and erasable memory compatible with the ISO 14443A standard were selected. The antenna coil was re-designed to minimize its area such that it could fit within a dental prosthesis. Simulations and experiments were then conducted to evaluate detection performance between the magnetic field and the area of the antenna.

Yu-Jung Li received his bachelor degree in Dentistry from Chung Shan Medical University, Taiwan, in 2002. Then he completed the training program of Oral and Maxillofacial Surgery in Veterans General Hospital, Taiwan, in 2006. He also received his master degrees in Dentistry from National Yang-Ming University (2006), Biophysics from National Central University (2009), and Chemistry from Tamkang University (2010) in Taiwan. He is currently with St. Mary Medicine, Nursing and Management College as a Lecturer, where he is responsible for Biology and Pathology. He is working toward Ph.D. degree at Institute of Mechanical and Electrical Engineering, National Taipei University of Technology, Taiwan. His research interests include oral and maxillofacial surgery, clinical dentistry, and cancer biology.

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Dental prosthetic design

For convenience in reading tag information and in the prosthetic design process, a sheet-form RFID tag was placed on the buccal area of bilateral molars, as shown in Figure 1. The design thus allows direct detection outside the cheek with minimal modification to the prosthesis. In addition, the relatively large size of molars allows for minimal impact to the prostheses' esthetics and strength. To simulate a human cheek, we used an agarose gel consisting of about 98% water. Different thickness of such agarose barriers were designed to evaluate the maximum detection distance, with measurement results summarized in Table 1.

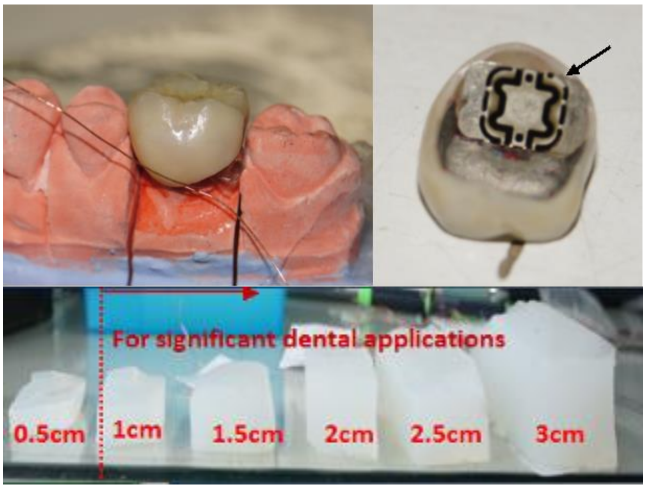

Figure 1. Tag insertion site in the dental prostheses. The buccal site of the bilateral upper and lower first molars provides a larger installation area with reduced esthetic concerns. The agarose gel mimics the buccal cheek to evaluate tag detection distance.

Results and Discussions

Electromagnetic simulation

Electromagnetic simulation and analysis were carried out by using COMSOL Multiphysics® software, and modeled by an NXP HF (13.56 MHz) RFID-tag complying with the ISO 14443A standard. The input current is set at 40 mA to evaluate the relationship among the magnetic flux field, the area of the antenna, and the number of coil turns. The right semisphere media is set as water while the left is set as air to mimic the intra-oral conditions of the posterior right molar area. This is considered analogous to a human cheek and can be regulated according to biological composition. Figure 2 presents a 3-D illustration including the sheet-form antenna (the black frame), the input current (40 mA), and the magnetic field distribution (indicated as red lines). From these simulated results, we can further evaluate the mutual relationship and interactions among the design of antenna area, the number of antenna coil turns, and the corresponding magnitude of magnetic flux. Ultimately, the simulation results show no significant difference in the induced electromagnetic field patterns between the air and water media, corresponding to the experimental results completed using agarose gel. These will be introduced in a later section.

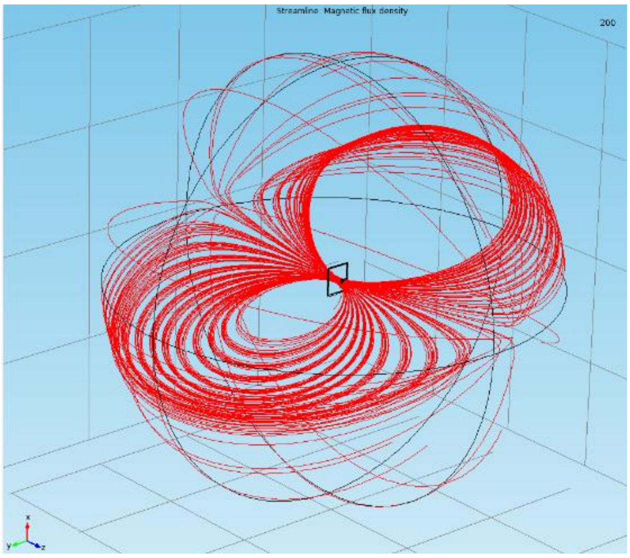

Figure 2. 3-D magnetic field simulation completed using COMSOL Multiphysics®. A 13.56 MHz sheet-form RFID-tag is modeled to examine the magnetic field distribution. Note that the media of the anterior semisphere is water and that of the posterior is air.

To optimize coil design, we measured the magnetic flux with respect to the area of the tag antenna and the number of antenna coil turns. In Figure 3, given a static distance (15 mm) from the tag to the RFID reader, the magnetic flux is clearly enhanced when the area of the antenna increases. For actual dental applications, the height of the prostheses is limited. We thus leave the length of the antenna fixed, while varying its width. In addition, Figure 4 shows the relationship between the number of the coil turns and the magnetic field. Holding the antenna area static, increasing the number of coil turns (i.e., 5, 10, and 15 turns) thus strengthening the magnetic field.

Experimental results

We determined the communication distance of the RFID transponder to the reader antenna. Tag minimization ensures that the strength and esthetic of the dental prostheses remain unchanged. The impact of antenna size was evaluated while the thickness of the 2% agarose gel was held at a constant 15 mm to simulate a the soft tissue of a human cheek. The thickness of the agarose barrier was increased with the area of the square antenna coil, as shown in Figure 5(a). Furthermore, based on practical requirements, the width of the coil was controlled while the coil length was modified to fit the dental crown. As a result, the thickness of the agarose barrier was also increased to correspond to the length of the rectangular coil, as shown in Figure 5(b). A comparison of the results of these different antenna designs shows that signal detection through the agarose tissue is proportional to the antenna area and the number of the coil turns, which is consistent with theoretical predictions and is useful for the variation of antenna design with respect to the thickness of human cheeks.

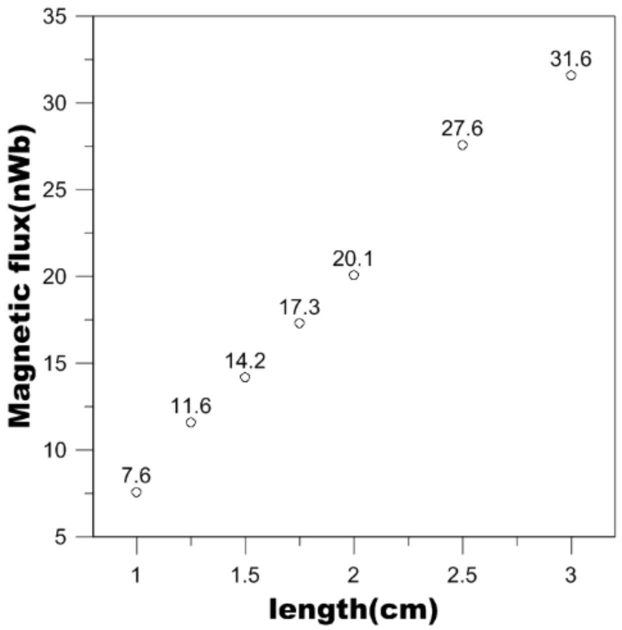

Figure 3. The relationship between the antenna area and the magnetic field. The width is controlled to mimic the dental prosthetic design.

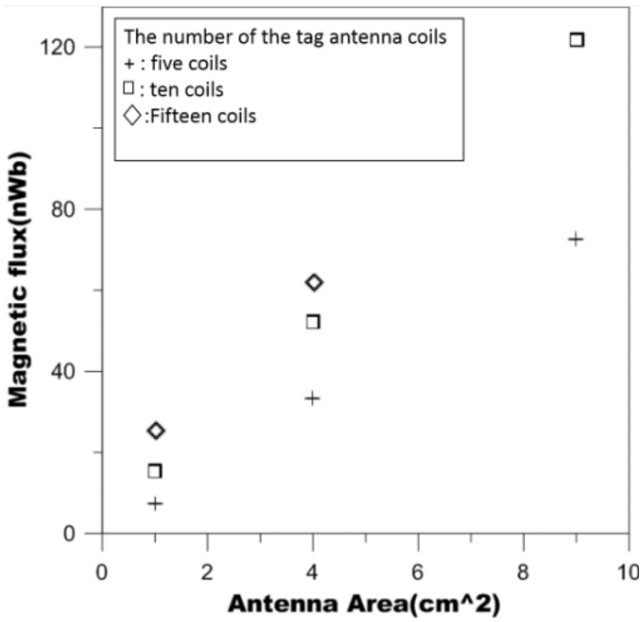

Figure 4. The magnetic flux vs. the number of antenna coil turns, with antenna area held static.

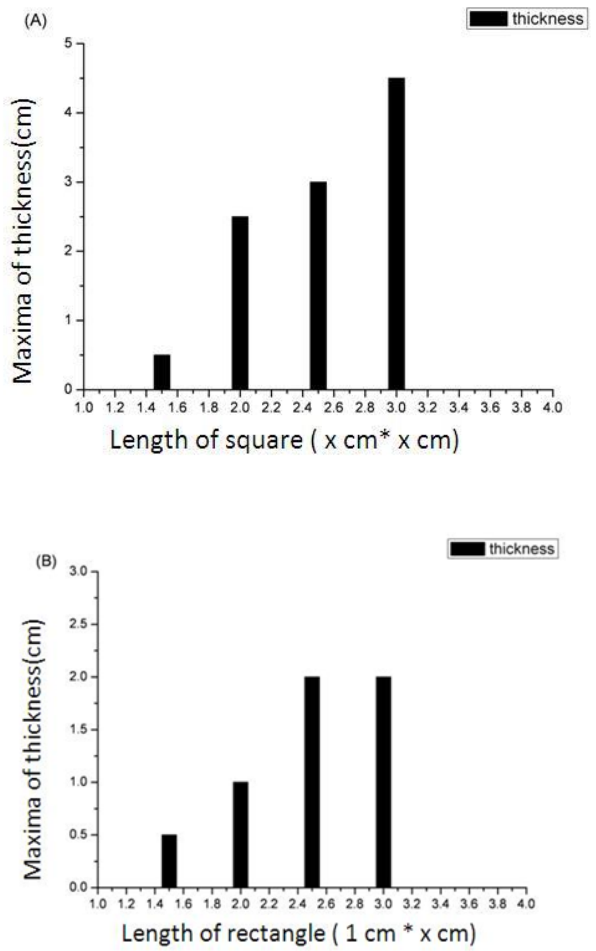

Figure 5. RF detection capability with the corresponding antenna coil area: (a) square coil design; (b) rectangular coil design.

Table 1 summarizes the response times of all rectangular tag designs, indicating no significant difference between the required response times despite increased detection distance from the agarose surface. The average value for all response times is around 1 sec, which is acceptable for practical applications.

Table 1. Average response time of RFID-based prostheses with respect to various antenna areas and agarose barriers.

D \ A	1cm×1.5 cm	1 cm×2 cm	1 cm×2.5 cm	1 cm×3 cm
0.2 cm	1.02 (sec)	1.04 (sec)	0.96 (sec)	1.06 (sec)
0.5 cm	1.04 (sec)	1.05 (sec)	0.10 (sec)	1.10 (sec)
1.0 cm	Nil	1.07 (sec)	0.11 (sec)	1.12 (sec)
1.5 cm	Nil	Nil	1.05 (sec)	1.06 (sec)
2.0 cm	Nil	Nil	1.02 (sec)	1.03 (sec)

D: Agarose tissue thickness. **A**: Tag coil area.

Nil: Tag cannot be detected.

Figure 6 illustrates the process by which information is read and downloaded from the RFID-tag to a computer via an interface program. The number before AA is the author's dentist certificate number, the digits before BB are the prosthesis design date, and those before CC represent the materials from which the dental prosthesis is made. Depending on future application requirements, further medical or forensic information can be loaded to the tag depending on storage capacity.

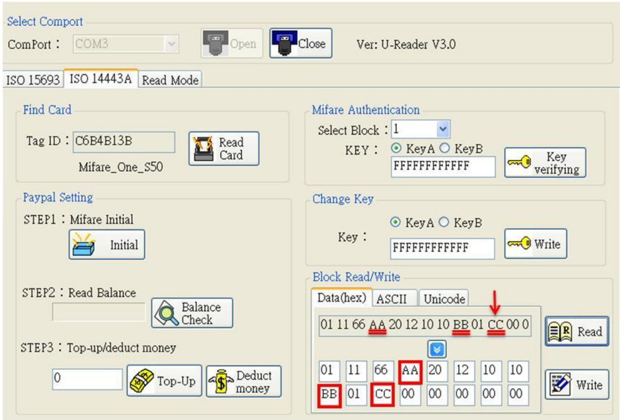

Figure 6. Data loaded to the RFID tag, including the dentist's certificate number, the design date, and the materials from which the dental prosthesis is made.

Discussion

The simulation and experimental results indicate a sheet-form RFID-tag with a 1.0 cm × 1.5 cm antenna satisfies the 15 mm detection range requirements, providing detection response within 1 sec through the agarose tissue barrier. The size of the tag allows for insertion into fixed dental prostheses for both single dental crowns and bridges containing more than two teeth. Figure 5 shows that the thickness of the human cheek may require a larger antenna. However, the average thickness of the human cheek is less than 1 cm, thus an antenna coil of 1.0 cm × 1.5 cm should be sufficient for clinical applications. However, more work is needed to further minimize antenna size to maximize the structural strength of the prostheses and provide for more advanced applications. Standardization of the inserted RFID tag and reliable sealing procedures are also needed to improve the functional reliability of the proposed method.

Moreover, Figure 5(b) indicates that the 1 cm × 3 cm rectangular coil does not provide improved signal detection, seemingly contradicting the simulated results. However, that is not correct if one compares the results of square coils in Figure 5(a). On the contrary, the experimental results in Figure 5 are considered rationally compatible and conform to our comprehensive electromagnetic simulation and analyses (not provided here).

Our experimental results indicate that the 13.56 MHz sheet-form RFID implanted dental prostheses can be efficiently identified directly through the cheek. The development of further miniaturized applications requires more investigation into the minimization of tag sizes.

Conclusions

A high frequency (13.56 MHz) RFID system inserted in a dental fixed prosthesis to allow direct detection through the cheek is reported. Relevant simulations and experiments demonstrate effective signal detection through an agarose gel barrier mimicking human tissue. RFID-enabled dental prostheses may allow significant benefits for both dental health and public security management. The proposed method offers a new way to download data including manufacturing date, material types dentist identification to meet clinical requirements. The approach could raise privacy concerns that may require cross-discipline discussions.

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