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TECHNICAL NOTE

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The Use of Radio-Frequency Identification Tags for Labeling Dentures—Scanning Properties

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ABSTRACT: The inclusion of radio-frequency identification (RFID)-tags within dental prostheses has been suggested as means of effectively labeling such devices and permitting rapid and reliable identification of the wearer. Previous studies have suggested that patients will accept denture labeling and recognize the need for such systems. However, they demand systems that are aesthetic, durable, and secure. One concern over the use of RFID-tags is that they could be scanned by third parties without the patient's knowledge. This study categorizes the scanning patterns of RFID-tags both *in vitro* and *in vivo* to provide data for patients for the consent process and for forensic dentists to ensure that they are scanning prostheses optimally. The results demonstrate that the RFID chips can only be read when the interrogator is in close proximity to the denture and thus should alleviate any concerns over privacy issues. However, evidence obtained from both the literature and experiments suggests that authorities must agree upon a unified standard for chip and reader specifications and protocols in order to avoid cases in which RFID-tags may fail to be read by an incompatible reader.

KEYWORDS: forensic sciences, human identification, radio-frequency identification, dentures, forensic dentistry, privacy

Occurrences of mass disasters, both natural and man-made, reported worldwide over the last decade are numerous and well documented. The common type of events reported include: acts of terrorism, air crashes, earthquakes, hurricanes, and floods (1,2). Following such incidents, a definitive and early identification of the dead and injured becomes of utmost importance. The forensic team employed for human identification will involve some, or all, of the following professionals (1) which are costly in terms of both time and money:

- Medical examiner or forensic pathologist.
- Forensic odontologist.
- Forensic anthropologist.
- Forensic photographer.
- Evidence technician/gatherer.
- Fingerprint expert.
- DNA analyst.
- Radiologist and radiographic technician.
- Toxicologist.
- Dental hygienist/assistant.

From the above list, the forensic odontologist will almost certainly be one of those called upon to identify disaster victims or at any time when the features of the body are destroyed beyond all recognition (3). *In vitro* studies have demonstrated the oral cavities' ability to resist high temperatures, thus preserving many key features that facilitate identification (4–6).

Determination of the various individual anatomical and genetic characteristics of the human dentition has proved to be very efficient in aiding the task of identification. In cases of complete edentulousness, however, victims have lost all or most of the aforementioned features (4–6). To facilitate a simple and inexpensive means of dental identification, standard techniques of marking dentures have been advocated (over several decades) which involve typically the inclusion of some form of a printed label (7). More recently, however, authors have focused their attention on a more high-tech method of denture labeling achieved via the use of radio-frequency identification (RFID)-transponders (1). Transponders used in RFID are commonly called "tags, chips, or labels," and these terms are fairly interchangeable (8).

RFID Tag

The acronym RFID stands for radio-frequency identification, which is a wireless electronic communication technology designed specifically to identify tagged objects, animals, or people (9,10). There are several methods of identification, but the most common is to store a serial number that identifies a person, animal, or object, and perhaps other information, on a microchip that is attached to an antenna; the chip and the antenna together are called an RFID-tag or transponder.

The antenna enables the chip to transmit identification information to a reader. The reader converts the radio waves reflected back from the RFID-tag into digital information that can then be passed on to a computer containing relevant software that can make use of it. The basic architecture of the system consists of the following three components:

- An RFID-tag (AKA a transponder), composed of a semi conductor chip, an antenna, and sometimes a power source.

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- An interrogator (AKA a reader or read/write device), which is composed of an antenna, RF electronics module, and a control electronics module.
- A controller, which most often takes the form of a PC or workstation running a database and control software (often referred to as "middleware").

The tag and the reader communicate information between one another via radio waves. When a tagged object enters the read zone of a reader, the reader signals the tag to transmit its stored data. RFID-tags can hold many kinds of information about what they are attached to, e.g., serial numbers, time stamps, and configuration instructions, etc. Once the interrogator has received the tag's data the information may be relayed back to the controller via a standard network interface, e.g., an Ethernet LAN or even the Internet (9,10).

There are many types of RFID-tags and at the highest level of classification these can be divided into two distinct classes, "active" and "passive" (10). Active transponders are so designated if they contain some form of power source, e.g., a battery which allows them to communicate with the reader over hundreds of meters. Conversely, passive RFID transponders on the other hand lack any kind of internal power supply. Instead the device draws a minute amount of energy induced by the incoming radio frequency sent by the reader and uses it to power the microchip's circuits; hence the tag is only active whilst it is within the electromagnetic field emitted by the reader. The chip then modulates the waves that the tag sends back to the reader, which converts the new waves into digital data. Since they have no power of their own, passive RFID-tags have a typical operating range of only a few centimeters (9,11). Nevertheless, the lack of a dedicated power source is not necessarily a disadvantage since it enables the device to be miniaturized, maintenance free, and purports to have an indefinite operational life (12,13).

As a general rule, passive RFID-tags contain three or four components, i.e., an antenna, a memory chip (containing a unique electronic code), in some cases a capacitor, and some form of encapsulation to act as protection from the environment (10). Similar to chips in components used in a typical computer, passive RFID-tags may contain memory chips of varying computational power. Some tags contain "read-only" memory (ROM) and are programmed during the manufacturing stage, while other tags are capable of having data "written" to them and "read" from them via the reader (8).

Over the past few years a miniaturized form of the passive RFID-tag has appeared on the market designed specifically for implantation under the skin, e.g., such as those used in both human and animal identification. These miniaturized devices are made up of the aforementioned components and are coated normally with a 2–4 micron layer of a polymeric form of para-chloro-xylylene, trade name "Parylene-C," which is traditionally used to coat implantable devices as it purports to be biocompatible, chemically inert, and exhibits nonreactivity in the presence of body fluids and tissues (14).

The second component in the RFID system is the "reader." The reader (consisting of an antenna, transceiver, and a decoder), sends a signal to activate the tag so that it can read its data. The tag detects the reader's activation signal when it passes through the reader's interrogation field. The reader decodes the data in the tag's memory chip and eventually passes it onto a host computer for information processing. Conversely, this process may also be reversed in cases involving tags containing re-writable memory chips (8,10,15).

A Brief History of RFID

It is difficult to trace the history of RFID technology back to a particularly seminal moment. However, contrary to current belief RFID is not a new concept; in fact, the genesis of the technology stems from early identification systems in that the basic concepts of RFID emanate from the invention of radar in the mid 1930s (9).

The concept of automatic identification using a radio transponder originated during World War II as a way to distinguish friendly aircraft from the enemy; hence the name identification Friend or Foe (IFF). The "friendly" planes responded with the correct identification, whilst those that failed to respond were considered "foes" (8).

Advances in radar and RF communications systems continued throughout the 1950s and 1960s. Scientists and academics in the United States, Europe, and Japan did research and presented papers explaining how RF energy could be used to identify objects remotely (16). Later, work on access-control more closely related to modern RFID was utilized in the 1960s at the Los Alamos National laboratories. In this application, RFID-tags were incorporated into employee ID badges in order to limit access to restricted areas (10). In the 1960s to early 70s, RFID developed its first commercial application, the electronic surveillance (EAS) system, which uses a simple form of RFID with 1-bit tags to prevent shoplifting (i.e., everyone walks past EAS system panels when entering or leaving stores). Other commercial uses followed in the 80s and 90s, including livestock tagging, toll payment systems, etc. By the end of the 20th century the technology touched the lives of millions of people worldwide (8). Since then there has been an explosion in the use of RFID in the inventory and tracking of assets in the retail industry and more and more applications for RFID are being discovered every day.

In the 21st century however, the public's perception of RFID is not entirely positive. One of the reasons RFID has been written about so much in recent years is that some people believe that the introduction of RFID will erode their right to privacy (17). On a more positive note, RFID technology has, on the whole, been very well received by the retail industry. In medicine, RFID systems are also being used in some hospitals to reduce errors of patient identification, particularly during blood transfusions and drug administration in hospitals (15) and to provide real-time tracking of the location of doctors and nurses in the hospital. In addition, the system can be used to track the whereabouts of expensive and critical equipment, and even to control access to drugs, pediatrics, and other areas of the hospital that are considered "restricted access" areas (10).

In the field of forensics, RFID is beginning to be used in the task of identification and processing of victims of mass disasters. The tsunami catastrophe of December 2004 left more than 200,000 dead. Disaster Victim Identification (DVI) teams were presented with the unprecedented challenge of identifying thousands of mostly markedly putrefied and partially skeletonized bodies. Conventional body bag tagging in terms of writing on body bags and placing of tags inside body bags proved unsatisfactory. The placement of RFID-tags inside victims' bodies provided a practical solution to problems encountered in conventional body tagging methods (18).

In the aftermath of hurricane Katrina, RFID-tags supplied by a Florida based company called Verichip were used in a similar way to that reported. Described as "about the size of a grain of rice," their "read-only" microchip is designed to be implanted subcutaneously and contains no other information other than a unique 16-digit identifier. Furthermore, according to their website, their transponder tags are the only Federal Drug Administration (FDA) approved human implantable devices on the market; also, the company's database "……can be combined with nearly every database and related IT system currently utilized in offices, departments, and facilities of medical examiners, coroners, criminalists, crime scene investigators, forensic scientists, sheriffs, police, and related industries" (19).

RFID and Dentures

From a forensic odontological perspective, the feasibility of using RFID-tags was first investigated for forensic use in 2004 by Millet and Jeannin (15). They described the procedure as a simple means of denture identification and tracking based on the use of radio-frequency tagging systems. In contrast to that used by Verichip, their system employed "read-write" tags which were placed in removable partial or complete dentures so that the data could be collected using a hand-held reader. They contained limited data that could be altered, e.g., such as room or bed number, etc. The authors concluded that apart from cost, the only real disadvantage postulated would be the chip's vulnerability to fire. However, (20–22) cast doubt on this theory, stating that when nonmetallic, i.e., more combustible denture labels are situated in the posterior aspects of a complete denture they are more than likely to survive destruction even in the most severe cases of burning owing to the protective position of the tongue and cheeks. Further empirical evidence in support of their findings was offered by Luntz and Luntz (23) and reported by Thomas (24). The case cited pertains to an automobile accident in which the bodies were burned beyond recognition yet the victim's dentures were purported to have suffered minimal damage.

More recently, a denture identification company based in Australia has begun to compile a database for forensic detection purposes and also for denture marking in care homes. As part of their system, the company, "Dentident" offers an initial start-up kit comprising a microchip reader, 20 microchips, and an annual registration to a national database. The database purports to positively identify the practitioner and/or the denture manufacturer, hence details can only be accessed by authorized personnel (25).

The application of RFID-tags for forensic identification has since been further developed by Thevissen et al. (16,26). In this case the authors took tags similar to the aforementioned and stripped them of their glass protection in order to implant them into human molar teeth, suspended within a composite matrix. *In vitro* studies conducted relating to thermal insult yielded maximum temperature tolerances of above 300°C, i.e., far greater than that of the manufacturer's specifications. Furthermore, it appears reasonable to assume that survivability of these devices could be even greater at higher temperatures *in vivo* owing to protection provided by the surrounding tissues of the oral cavity (21).

Privacy Issues

Regarding the question of personal security, one fear held by both civil liberties groups and many members of the general public is the idea that anyone at a distance can read remotely a passive RFID-tag without the wearer's knowledge. It therefore seems reasonable to assume that there is a need to quantitatively assess the scanning range of a typical RFID-tag in order to determine whether this perception has any justification. Hence the purpose of this investigation is to conduct a series of *in vitro* and *in vivo* studies involving a type of RFID-tag that is currently being used for the purpose of denture identification.

Materials and Methods

The tag chosen for this experiment is similar to that used by the aforementioned company "Dentident." Dentident (Australia) purports to offer a unique global identification system for dentures utilizing a passive RFID-tag (embedded in each denture) manufactured by a company called Trovan Ltd (27). The RFID-tag can be read simply via a Trovan reader, and information relating to the denture, dental practitioner, and dental laboratory and patient contact details, can be stored and retrieved from their global database (25). The specifications of the RFID-tag used in this investigation are as follows:

- Trovan ID 100 passive read-only human implantable transponder.
- Length: 11.5 mm.
- Diameter: 2.12 mm.
- Weight: 0.09g.
- Scan angle: spherical.
- Frequency: 128 KHz.
- Transmission time: 0375 baud rate.
- IP 68: water resistant.

In Vitro *Study: RFID Read-Out Pattern*

The pattern of radiation emitted from radio-transmission applications involving small loop antennas, involves an amalgamation of electric and magnetic fields. Both the spread and intensity of these fields decrease in a complex way with the distance from the source and hence relates to the so-called "read-out performance" of the system (16,28). An investigation into the detection of read-out patterns was conducted by Thevissen et al. (16) using tags designed for animal identification. However, the following investigation is based on a modified version of their method using the aforementioned Trovan human implantable tags.

In this test, five randomly selected Trovan 128 KHz passive RFID-tags were used. Each tag was placed in fixed position in the center of a concentric circle that had been divided off into 10° increments. The tags were positioned so that their long axes were placed parallel to the 0°–180° line, with their chip sides orientated toward the left and the antenna side to the right (i.e., 180°). The reader (complete with new battery) was held flat at the edge of the circle in the 0° position and moved (with the on–off button depressed) slowly towards the ID-tag until the first signal contact was obtained; this position was then recorded with a black fine tipped marker. This procedure was repeated every 10° until a 360° scan was completed.

All five RFID-tags were scanned in this manner, which were found to be near identical to one another and hence represent a typical read-out pattern for the Trovan RFID-tag demonstrated in Fig. 1.

In Vivo *Study: Scanning Range*

RFID-tags were fixed onto hard maxillary and mandibular dentate baseplates adjacent to the upper and lower molars similar to that shown in Fig. 2. The maxillary and mandibular baseplates incorporating the tags were then worn by the test subject and the on–off button of the reader was depressed and held as the reader was moved slowly towards the side of the subject's face. At the moment of first signal contact the beeper within the reader was activated; this position was then photographed. This procedure was repeated 10 times for each of the chosen tag locations.

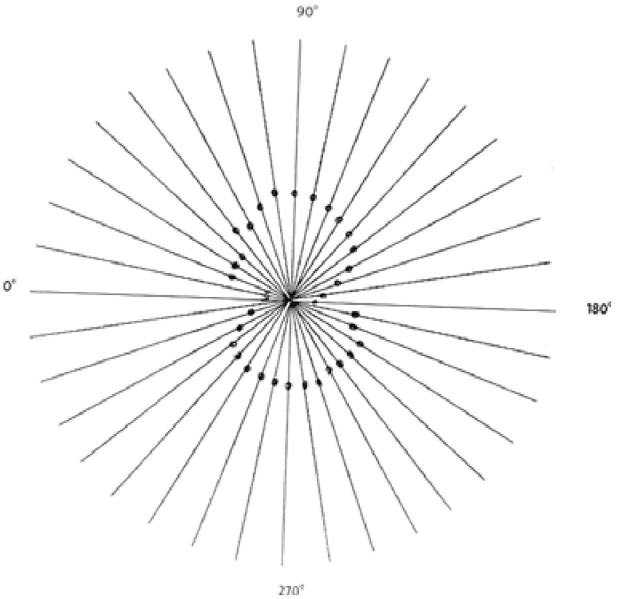

FIG. 1—*Two-dimensional pictorial representation of a typical read-out pattern of the Trovan 128 KHz passive RFID-tag.*

FIG. 2—*Placement of RFID-tags in the posterior segments of upper and lower complete dentures.*

Results

With regard to the read-out pattern, the optimum read-out positions obtained by the reader in the *in vitro* test were 90° and 270° (i.e., perpendicular to the long axis) giving a maximum read-out distance of 3 cm; conversely, the worst positions were 0° and 180° thus producing a minimum read-out distance of 1–2 mm. Results pertaining to the *in vivo* test indicate a reduced maximum scanning range of *c.* 1–1.5 cm. Furthermore, no difference in the maximum scanning rage could be determined between upper (encased in denture base resin) and lower baseplates.

Discussion

The read-out pattern obtained from the *in vitro* experiment yielded a read-out pattern that was somewhat surprising in that it differed greatly from work done by Thevissen and Poelman (26). Results of their experiments yielded read-out patterns that were opposite to those described above, i.e., the optimum read-out positions were located at either end of the tag rather than its mid-position. Thevissen and Poelman (26) also implanted their tags into human molars with their long axes orientated in a mesial—distal direction, a position not best suited (for their tag) to scanning outside of the mouth. Hence from the results of the Trovan tests it would appear reasonable to assume that the Trovan RFID-tag read-out pattern, with its maximum read-out range located perpendicular to its long axis, lends itself more to the purposes of implantation into human molars. With regard to security, and the potential for elicit scanning of a potential denture wearer, the results obtained from the *in vivo* test indicate it to be extremely unlikely that patient privacy would be at risk.

Conclusion

Upon inspection of the literature, there appears to be a growing amount of cogent evidence highlighting both the efficacy of RFID technology and its role in the identification and processing of mass disaster victims. Nevertheless, disasters are frequently international by nature, and will no doubt increase in number and scale, given the growth in the world's population and the ease of migration (29). Hence, evidence obtained from the aforementioned simple experiments indicates a need for authorities to agree upon a unified standard for chip and reader specifications and protocols in order to avoid cases in which RFID-tags may fail to be read by an incompatible reader. Furthermore, it is also reasonable to conclude that further empirical studies are required, relating to a range of postmortem assaults on RFID-tags in dental appliances, before a more definitive opinion can be formed on their use for forensic purposes.

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