Cloud Publications
International Journal of Advanced Dental Science and Technology
2013, Volume 1, Issue 1, pp. 1-9, Article ID Med-32

Review Article **Open Access**

Radiofrequency Identification Technology and Its Potential Applications in Dentistry: A Review

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Publication Date: 09 January 2013

Article Link: http://medical.cloud-journals.com/index.php/IJADST/article/view/Med-32

Abstract In this era of globalization, despite leaps in modern technology, medical breakthroughs and the geographical changes that the last century has brought, crime still persists in all aspects of our lives. Dentistry has much to offer law enforcement in the detection and solution of crime or in civil proceedings. Worldwide, dentists qualified in forensic science are giving expert opinion in cases related to human identification, bitemark analysis, craniofacial trauma and malpractice. Identification of deceased individuals is always a difficult job. Forensic identification using odontology is based on the comparison of antemortem and post mortem dental records. Unsolved cases are mostly due to insufficient antemortem or post mortem data. In such circumstances forensic workers mostly have to rely on time and money consuming DNA identification procedures. In order to avoid these difficult and lengthy identification procedures one could think of incorporating radio frequency identification (RFID) tags into the strongest and most protected human body part: the tooth. In case of absence of teeth, it can be incorporated into dentures also. This article aims to review the role of dentists in person identification in scenes of crime and mass disaster and how new technologies like RFID tags can be of help to them.
Keywords *RFID Technology, Post-Mortem Identification, Dentures*

1. Introduction

As we enter a new millennium, society is faced with fresh challenges in every conceivable area. Despite leaps in modern technology, medical breakthroughs and the geographical changes that the last century has brought, crime still persists in all aspects of our lives. Violent and heinous activities that shatter the lives of victims, their friends and families occur every day. Often, little can be done to repair such damage. The apprehension and subsequent prosecution of the perpetrator(s) is essential to maintain law and order. Through the specialty of forensic odontology, dentistry plays a small but significant role in this process. By identifying the victims of crime and disaster through dental records, dentists can thus assist those involved in crime investigation [1]. Forensic Odontology was taught throughout the world in 1960’s but interest in forensic dentistry was relatively dormant. Renewed interest was sparked by the first formal instructional program in forensic dentistry given in the United States at the Armed Forces Institute of Pathology. Since then the number of cases reported has expanded to such an extent that the term “forensic odontology” is familiar, not only to the dental profession, but also to law enforcement agencies and other forensic groups.

Forensic odontology involves the management, examination, evaluation and presentation of dental evidence in criminal or civil proceedings, all in the interest of justice. The forensic odontologist assists legal authorities by examining dental evidence in different situations. The subject can be divided roughly into 3 major fields of activity: civil or noncriminal, criminal and research [2]. Always a part of the bigger team, such personnel are dedicated to the common principles of all those involved in forensic casework: the rights of the dead and those who survive them [1]. For example, the devastating consequences of the seaquake in South-East Asia in December 2004 led to the greatest international effort undertaken so far to identify victims of natural catastrophes. Since the 28th of December 2004, International Disaster Victim Identification (DVI) teams have been working in Phuket/ Thailand to identify the victims of the disaster. The teams mainly consist of police officers, forensic odontologists, medicolegal experts, fingerprint and DNA specialists [3].

The use of teeth as evidence is not recent. There are historical reports of identification by recognizing specific dental features as early as 49 B.C. However, Forensic Odontology, as a science, did not appear before 1897 when Dr. Oscar Amoedo wrote his doctoral thesis entitled “L’Art Dentaire en Medecine Legale” describing the utility of dentistry in forensic medicine with particular emphasis on identification. Traditionally, Forensic Odontology covered various topics that can be broadly classified into human identification and injury analysis [4].

Henceforth, this article aims to review the role of dentists in person identification in scenes of crime and mass disaster and how new technologies like radiofrequency identification tags can assist them in doing so. Also it will help dentists to keep a record of patient information in a digital format, thereby eliminating tedious paper work.

2. Identification

Dental identification assumes a primary role in the identification of remains when postmortem changes, traumatic tissue injury or lack of a fingerprint record invalidate the use of visual or fingerprint methods. The identification of dental remains is of primary importance when the deceased person is skeletonized, decomposed, burned or dismembered. The principal advantage of dental evidence is that, like other hard tissues, it is often preserved after death. Even the status of a person’s teeth changes throughout life and the combination of decayed, missing and filled teeth is measurable and comparable at any fixed point in time. The fundamental principles of dental identification are those of comparison and of exclusion. For example, dental identification is used when antemortem records for the putative deceased person are available and circumstantial evidence suggests the identity of the decedent [2].

People have long recognized that a person’s teeth are unique. Although great attention was not paid to dental identification until recent times, the process has been used for 2000 years [5]. It has been said that Nero's mistress, Sabina, in 66 A.D., satisfied herself that the head presented to her on a platter was Nero's wife as she was able to recognise a black anterior tooth [6]. Sansare K and Dayal PK in their review in 1995 have mentioned that according to Elphinstine, M. Raja Jayachandra Rathore of Canouj, died on the battlefield in 1191. His body was identified by false anterior tooth. This was probably the first case of identification using dentition from India [5]. Identification requires a list of the possible persons involved so that appropriate antemortem records can be located. The availability and accuracy of these records determine the success of identification. Unfortunately, dentists often maintain poor records, resulting in confusion that makes dental identification impossible [2].

A range of conclusions can be drawn following a comparison of ante-mortem and post-mortem records. The American Board of Forensic Odontology (ABFO), however, recommends these to be limited by four conclusions, viz [5].

1. Positive identification: the ante-mortem and post-mortem findings match in sufficient details, without any unexplainable discrepancy, to establish that they are from the same individual.
2. Possible identification: the ante-mortem and post-mortem data have consistent features but, because of the quality of either the post mortem remains or antemortem evidence, it is not possible to establish identity positively.
3. Insufficient evidence: the available information is insufficient to form the basis for a conclusion of any sort.
4. Exclusion: the ante-mortem and post-mortem data are clearly inconsistent [1, 5].

When the comparison between the antemortem and postmortem data does not reveal common features, or when the antemortem data is unavailable, or the condition of the remains of the deceased do not allow the identification, at that time a postmortem dental profiling gives the solution. Features like age, ancestry, sex, socio-economic status and sometimes occupation, diet, habits and diseases can be acknowledged [7].

Sex and Ancestry: Ancestry can be assessed by studying the facial skeleton and comparing the features with the main characteristics of the three racial groups: Mongoloid, Negroid, and Caucasoid. *Gender* can be accessed via the results of the study of the skeleton or the teeth [7]. RK Khangura et al conducted a study which indicates that maxillary canines show significant sexual dimorphism and can be used as an adjunct along with other accepted procedures for sex determination when fragmentary remains are encountered in mass disasters [8].

New approaches that involve the tools of molecular biology like DNA analysis can help ascertaining the gender of the deceased [7]. Crime scenes present potential sources of DNA from victims, suspects, and inanimate objects in the vicinity. The source yielding the highest DNA content is whole blood; however, it may not be available in all situations. The collection and storage of blood requires high-level aseptic protocol and trained personnel. Moreover, in certain criminal jurisprudence systems, blood collection from a suspect may be denied due to privacy laws [9]. Therefore, non-invasive techniques are more acceptable and popular. The oral cavity is a useful source of evidence. Dentists may be required to provide samples for DNA analysis in many cases. The sources include saliva, mucosal swabs, and teeth [9].

Inspite of the advances, problems still exist in identification of person relying on the above mentioned procedures. Various limitations are as follows:-

Patients that do not have physical teeth anymore, represent a problem for the identification process of human remains. Even if there are antemortem radiographs, there are morphological changes in the jaw bone due to the resorption of the alveolar ridges, which render the identification difficult [7].

Panoramic radiographs that exist antemortem as mentioned above can provide useful information only when the time space betweem the acquisition of the radiographs and the circumstances of the death of the victim is short. Lateral skull radiography is the solution in these cases, because of the reproductability of the method. Goodman and Himmelberger presented a case of an unsolved homicide, where postmortem casts of the victim were obtained for the acquisition of a cephalometric radiograph for the superimposition with a putative antemortem radiograph [7].

Palatal rugae impressions can also serve as a medium for identification in edentulous patients. Because this is a soft tissue identification method, therefore this approach cannot be followed in cases of skeletal remains [7].

In order to ensure an easier identification process for edentulous victims it is suggested to introduce a denture marking system either with the form of a surface marker(engraving the casts, scribing the denture) or with an inclusion method(metallic labels, microchips) [6]. Labelling of all the dentures is recommended by most international dental associations and forensic odontologists [10]. It also helps in identifying an unconscious person as well as identifying misplaced dentures in geriatric institutions [11].

Unsolved cases are mostly due to difficulties in obtaining and collecting ante mortem dental information, and in comparing with the remaining post mortem dental information. In those circumstances forensic workers mostly have to rely on time and money consuming DNA identification procedures. In order to avoid these difficult and lengthy identification procedures one could think of incorporating radio frequency identification (RFID) tags into the strongest and most protected human body part: the tooth [12]. In various studies, it has been incorporated in dentures also.

2.1. What is RFID?

The acronym RFID stands for radio-frequency identification, which is a wireless electronic communication technology. RFID technology was first introduced in 1940, during World War II, and used to identify aeroplanes belonging to the Royal Air Force. During the 1980's and 1990's, with the advances in information technology and the possibility of producing low cost tags the interest in RFID was renewed. It forms part of a technology known as "automatic identification and data capture" and is used to identify, locate and track people, animals and property [13].

Radio Frequency Identification (RFID) enables the identification of nearby objects or people by means of Radio-Frequency (RF) signals. The communication takes place between small and inexpensive devices called *tags* which are attached to the items to be tracked, and *readers* which collect and manage information about these items. This process is performed in the coverage area of the reader, or checking area. RFID is increasingly being used to identify and track objects in supply chains and manufacturing process [14]. The RFID system consists of five components: tag which is attached with an object and has a unique identification, antenna which has a tag detector and creates magnetic field, reader which is the receiver of tag information, communication infrastructure which enables reader/RFID to work through IT infrastructure, and application software (user database/application/interface) [15]. The use of radio frequency identification (RFID) techniques is pervasive throughout both the clinical setting and the commercial world. Applications vary widely from tracking sponges during surgery to locker rentals at amusement parks. Creative applications continue to emerge encouraged by falling RFID tag costs [16].

The recently declining cost along with improved sensitivity and durability of RFID systems has made these systems increasingly interesting for the distribution and retail industry. In fact, RFID has been identified as potential technology to replace the currently dominant bar-code system. RFID is very attractive for medical applications and if properly utilized can potentially lead to breakthroughs in the way medical examinations and monitoring of patients are conducted [17]. In the healthcare sector the use of the RFID-tags has been tested for suitability in various fields, such as transfusion medicine replacing the bar code with a tag. In Italy at the Ophthalmologic department of Niguarda Hospital

(Milan) patients wear a microchip bracelet which stores all the medical data relevant to the surgery they will be undergoing. The cost for an RFID tag is nowadays around US$ 20; making the procedure a viable option [13]. This is, however, valid in European and western countries only. In developing country like India, this is a little expensive option. But in future, the cost of "smart labels" will reduce further, thereby, making the procedure extremely cost-effective [13].

2.3. How Does RFID Work?

RFID tags are small electronic devices working in the radio frequency (RF) range. They use wireless radio communications to automatically identify objects or people without the need for line-of-sight or contact, and have the advantage that they can be read through a variety of visually and environmentally challenging conditions. Their properties such as low cost, small size, and wireless functioning make them widely used in inventory tracking, object location, environmental monitoring, *etc*. Based on their energy source, RFID tags are categorized into three types: passive, semi-passive, and active. Passive RFID tags use energy from the incoming signal to power themselves, while semi-passive and active RFID tags use an internal power source, usually a small battery. Thus, active RFID tags can perform advanced functions and also work over longer ranges [18]. (Figure 1)

A serial number that identifies a person, animal, or object is stored in a microchip with an attached antenna. The chip and antenna together are called an RFID-tag or transponder. The antenna enables the chip to transmit the serial number, or other information to a reader. The reader converts the radio waves reflected back from the RFID-tag into digital information that are then passed to a computer with applications to interpret it. There are 'passive' tags, so named because the power for reading the information on the chip is sent from the reader. 'Active' tags on the other hand, carry their own power supply enabling them to communicate between tag and reader, thus increasing the potential for detection of the signal. Another feature of RFID-tags is a read/write function. There are 'read only' and 'read/writable' chips, to which new data can be transmitted. Tags come in various forms and dimensions, and can be adapted to specific applications. Every transponder has an unchangeable unique identification number, allowing individual tags to be identified within a group [13].

It is also worth mentioning that, a European sanitary regulation, European directive 9342C implemented in 1993, requires that prosthesis provided by a laboratory to a dentist be accompanied by a record, either paper or digital, which includes the history of manufacture of the item [13]. In addition, it is important to note that the tags themselves do not produce enough electromagnetic energy to have an impact on the function of electronics. The electromagnetic fields are generated in varying strength from the antennas. The antennas needed for the two different types of tags do vary in their power intensity. Passive tag antennas generally produce higher power electromagnetic fields than active tag antennas [16].

Most RFID tags work in a passive mode without an own source of energy and transmit signals only on demand from a reader. RFID-systems work at different frequency bands (Table 1).

Table 1: *RFID frequencies, read distances and their typical applications*

Frequencies Used for RFID	Read Distances	Typical Applications
Low frequency (30-500 KHz)	0.1-0.3 m	Access control, storage administration, animal marking
High frequency (10-15 MHz)	0.1-1.0 m	Logistics & management
Ultra-high frequency (0.3-3 GHz)	1.0 – 30.0 m	Toll collect systems, box car detection

RFID tags are also being imbedded in dental prosthetics to help identify wearers. While seeming to be a supportive innovation when considering the mission of the organization, such tracking may be deemed an invasion of privacy from a patient/consumer point of view. To illustrate, imbedding a chip in an Alzheimer's patient would allow them to be identified and their medical record accessed immediately regardless of their level of mental acuity. Driven by privacy concerns, bioethicists argue that vulnerable populations may be coerced into having the chips imbedded and that the data may be misused for research or commercial purposes. Patients sensitive to privacy issues are particularly likely to consider the tracking/monitoring and medical records applications as invasive and consequently disruptive to them as consumers [19].

2.4. Possible Uses in Dentistry

In dentistry, RFID technology can be used to maintain records for the patient. Should a need arise; it can be easily retrieved by the help of the tag and transponder. In various studies conducted worldwide, tags have been incorporated in teeth, dentures (Figure 2), orthodontic retainers etc. and these give promising results [12, 13, 20, 21].

In a study conducted by E. Nuzzolese et al in Itlay, an attempt was made to develop a denture marking system which improves on previous systems in terms of its simplicity, cost and effectiveness, with particular emphasis on the amount of storable data. A small passive, 12 mm X 2.1 mm, torpedo shaped read-only low frequency tags {provided by an Italian RFID manufacturer (MRFID Network) was incorporated into three sample complete upper dentures. The dentures were then tested to verify the efficacy and range of data transmission. They concluded that the reader sends a coded signal that is returned by the transponder, and then converts it into readable data. The tag was visible even when embedded in pink acrylic resin. The read out was positive. The optimum read-out position in the *in vitro* test was achieved with the reader perpendicular to the long axis of the microchip, with a maximum scanning range of 1 cm. No special training or a dental technician is required and the device incorporation can be made in the dental office [13].

In another study conducted by Patrick W. Thevissen et al in Belgium, thirty extracted mandibular and maxillary first, second and third well developed molars were selected. All the teeth were stored separately in a 3% chloramine solution at room temperature. Class I cavities with standard dimensions 2 mm in excess of the modified 8 mm tag dimensions (length 8 mm, width 3 mm, depth 3 mm), were made by two investigators, using water cooled diamond coated burs on high speed. The prepared cavities were thoroughly rinsed and subsequently dried with moisture-free air after etching the cavity with 37% phosphoric acid. The modified and prepared ID-tag was softly pressed into the composite using pincers holding the tag at the coil part. The long axis of the device was placed longitudinally in mesio-distal direction with the coil at the distal side of the tooth. After curing, the ID-tag was already properly fixed and immobilized at the cavity bottom. Next another thin layer of flowable composite covered the whole tag, and was cured. Finally a posterior composite (Filtek Z25O, 3M Espe, St-Paul, US) was placed, cured, finished and polished with discs (Sof-Lex, 3M Espe, St-Paul, US) according to classic restoration prescriptions. The whole procedure took no more than 2 min extra time of a normal class I cavity and filling sequence [12].

The read-out of the tags was tested after every step during the modification process of the commercial tags, after every step of the implantation procedure, after periapical X-rays were taken and every 24 h, during at least 14 days, after implantation and storage in a 3% chloramine solution at room temperature. It was observed that the dental X-ray could be taken without disturbing the normal activity of the implanted tags. It allows detecting the existence of a tooth implanted device in general dental practice. Storing the implanted tags in the 3% chlooramine solution had no negative influence on the working capacities of the ID-tags, which gives an indication of the resistance of the implanted

ID-tags against the humidity conditions of the mouth. The read-out of the tag is best with the largest antenna coil, in a reader position perpendicular on the ID-tag length and the centre of the reader at the same height as the central axis of the ID-tag. In an oral and forensic situation the reader cannot be held, at tag level, in a mesial or distal position of the tooth, without tissue removing technics. The limitations of mouth opening, the surrounding soft tissues, the neighbouring teeth and the bony structures make this impossible. The easiest and quickest way to get the implanted tags information is by moving the reader over the cheek nearby the prepared tooth. Therefore the tag should be implanted with its length axis in a bucco-lingual direction [12].

Martin Brandl et al of Austria thought that, for an orthodontic treatment with removable retainers to succeed, it is very important to consistently adhere to the prescribed regular daily application hours. The removable retainers are mostly worn for less than the prescribed time or not at all. The desired result is partially delayed or not archived. Additionally, results have shown that tooth alignment can degenerate (relapse) when the retainer is not worn even for short and especially for longer periods (e.g., summer holidays). In the case of a longer intermission, a relapse can require an additional expensive new adjustment or a new preparation of the retainer. They intended to create a possible way to determine and supervise the duration of retainer use as accurately as possible and with high reliability with the help of low-cost wireless sensor device including a RFID interface equipped with a battery for standalone operation. To proof the concept, they used miniature temperature data logger molded into a dental retainer for observing the retainer usage and the system was tested on several patients. The temperature range of the sensor was from 18.7 ˚C to 46.3 ˚C with an accuracy of 8 bits (resolution 0.1 ˚C). The measurement interval was set to 20 min. The threshold for the decision “retainer used” or “retainer not used” was set to 35 ˚C. From the measured data, they found a clear difference between the ambient temperature and the temperature in the mouth which allowed a simple decision for the retainer usage [21].

All these studies suggest that future is very bright with RFID technology. It is a cheap, easy to use and convenient method for identification of individual and storage of patient records.

3. Conclusion

Inclusion of RFID offers many benefits; allowing not only the storage of patient’s medical records on a searchable database, but also information on the materials used and thus providing traceability. Ultimately the chip could play an invaluable forensic role in assisting with human identification which could not have been possible in cases where antemortem records are not available. Just like the two sides of the coin, every technology has a negative side to it. There are certain disadvantages associated with RFID tag. The major one being the high cost of the tag (almost $20). RFID technology currently lacks sufficient capacity to provide portable storage for an individual’s complete medical history. The tag should have provision to store entire record of the patient so that when it brought near the reader it should display the unique serial number along with complete patient file. The patient’s record should be to be stored on a password protected centralized database so that every dentist has an access to the patient information which will help in identification of the deceased anywhere in the world. However, with this centralization, the issue of violation of privacy of the individual arises. If this is to be avoided, tag should have the name of manufacturer mentioned on it and the company which makes the tags should have address of patient to whom that particular tag is being given. The family can be contacted and details of the dentist can be taken and he will provide with the records of the patient. However, this will be a time consuming procedure. Therefore, it is reasonable to conclude that further investigations are needed before RFID tags can be used in dentistry completely.

Figures

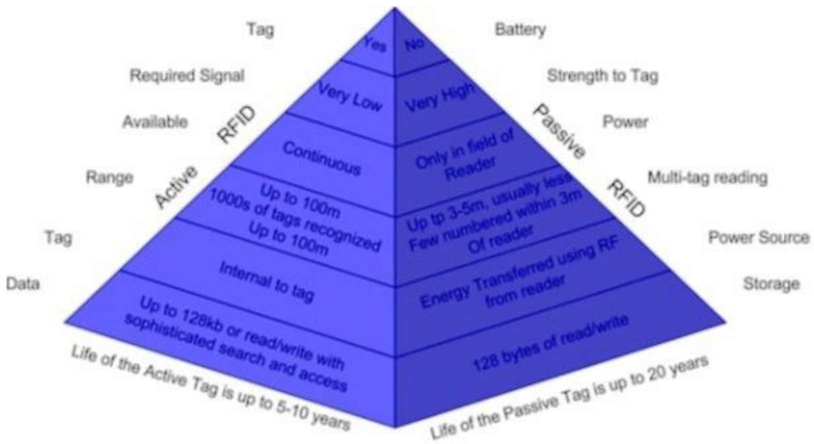

Figure 1: *RFID active and passive tags comparison tags*

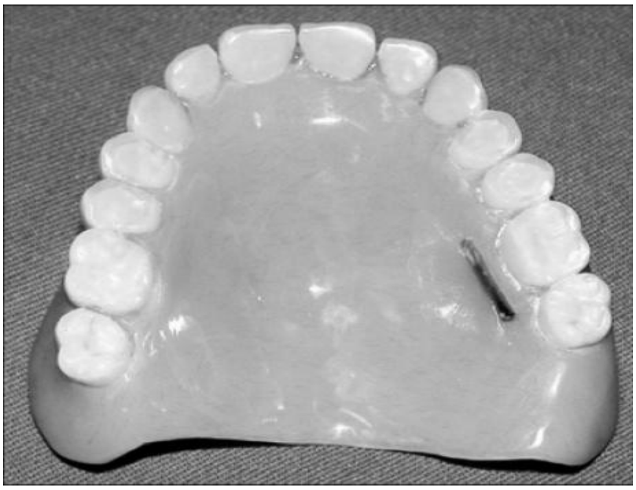

Figure 2: *showing passive, 12 mm X 2.1 mm, torpedo shaped, read-only low frequency tag incorporated into complete upper denture*

Acknowledgement

I would like to thank Dr. E. Nuzzolese, for letting me use picture from one of his articles.

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