36. RFID in Healthcare – Current Trends and the Future

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1 Introduction

Radio Frequency Identification (RFID) enables automatic identification of objects using radio waves. The identified objects can be in and out of the line of sight and there is no need for physical contact with them. RFID technology is deployed in a wide range of industries such as supply chain management, inventory control, farming (to track animals), e-Passports, the tracking of humans (in prisons and hospitals) and in healthcare [1]. The three key elements of an RFID system are the tags, readers and the backend server. Tags are devices physically attached to objects and readers (wired or mobile) recognize the presence of objects in its range. The server maintains all the information about IDs for the tags and readers, their respective secrets and any information about the object attached to the tag. A tag is typically made up of an antenna for receiving and transmitting a radio-frequency (RF) signal and an integrated circuit for modulating and demodulating the signal and storing and processing information. There are three types of RFID Tags: active tags, semi-active tags and passive tags [2]. Active tags have their own battery to power its internal circuitry and transmission components; semi-active tags also have their own power source which is used only for powering the internal circuitry but not for transmission; passive tags have no internal battery to power themselves and they use the electromagnetic signal from the reader as the power source. This makes passive tags highly cost-effective thereby enabling large-scale applications. However, they are highly resource constrained and have very limited capabilities in terms of functionalities. The total volume of tags used worldwide was estimated to be 10.6 billion in 2011 of which 80% were low-cost UHF passive tags such as the EPC Class-1 Generation-2 (C1G2) tags [3].

The ability for readers and tags to be mobile and wireless in an RFID system opens up a world of possible applications in healthcare. In this chapter, we provide extensive coverage of how RFID impacts the healthcare arena. In depth analysis is

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provided covering areas such as RFID based healthcare applications (including tags with sensor capabilities and implantable tags), a study on Electro Magnetic Interference (EMI) caused by RFID, security and privacy issues of RFID in healthcare, secure RFID protocols for healthcare, the ethical implications of deploying RFID in healthcare, barriers impacting their deployment, benefits reaped from successful implementation, and finally we provide future research directions. By taking a holistic approach, we aim to assist common healthcare users who wish to gain an understanding of the impact of RFIDs in healthcare and provide guidance to Information Technology professionals to design innovative applications and further research in this field. Table 1 gives a brief list of some commercially available RFID healthcare products and Table 2 shows some of the experimental studies conducted on RFID based healthcare deployments and the results obtained from these studies. The following statistics emphasize the need for deploying RFID in healthcare not only to improve services but to save precious human lives.

1.1 Healthcare Statistics

In 1999, the Institute of Medicine (IOM) estimated approximately 98,000 deaths would occur each year in the US due to preventable medical errors, costing $37.6 billion [4], and becoming the sixth biggest killer in the US [5]. Five years later, a study released by Health Grades [6] reported the same number of deaths due to a failure to improve patient safety. One in five Americans (nearly 22% of the population) say they or a family member have faced a medical error of some kind [7], while McGann [8] argues the percentage of Americans who believe they have personally experienced a medical error could be as high as 42%. Graban [9] states that about 7,000 people are estimated to die each year due to medication errors costing USD $4 billion, and that the US is not alone in experiencing these problems. The 2008 British Parliamentary report estimated over 11,000 cases of serious injury or death due to medical errors, while the Health Select committee estimates the number to be as high as 72,000. In Canada, the estimate is 9,000 to 24,000 deaths each year, while in Germany the estimate is 17,000. In Australia 11% of all deaths are attributed to medical error, while an in depth analysis may conclude it to be as high as 19%, which is 1 in every 5 deaths. A report on Sentinel and Serious Untoward Events from Hong Kong (cited in [10]) states that complaints about retained instruments after surgery constituted about 36.4% while the 3^{rd} highest medical error happens to be wrong site/patient surgery which constitutes 15.2%. A 2009 report [11] says western medical practice in countries such as Europe, USA, Canada, Australia and New Zealand has killed more than 5 million in the past decade; the economic impact of which is estimated to be over USD $1 trillion. McGee (2005) (cited in [12]) states that in the US, 5 to 8 wrong-site surgeries occur every month. Pappu *et al.* (cited in [12]) state the cost to hospitals in the US is $3.9 billion every year due to theft of equipment and supplies. Wurster *et al.* (2009) (cited in [13]) state that healthcare expenses in the US are expected to go up by nearly 20% by 2017.

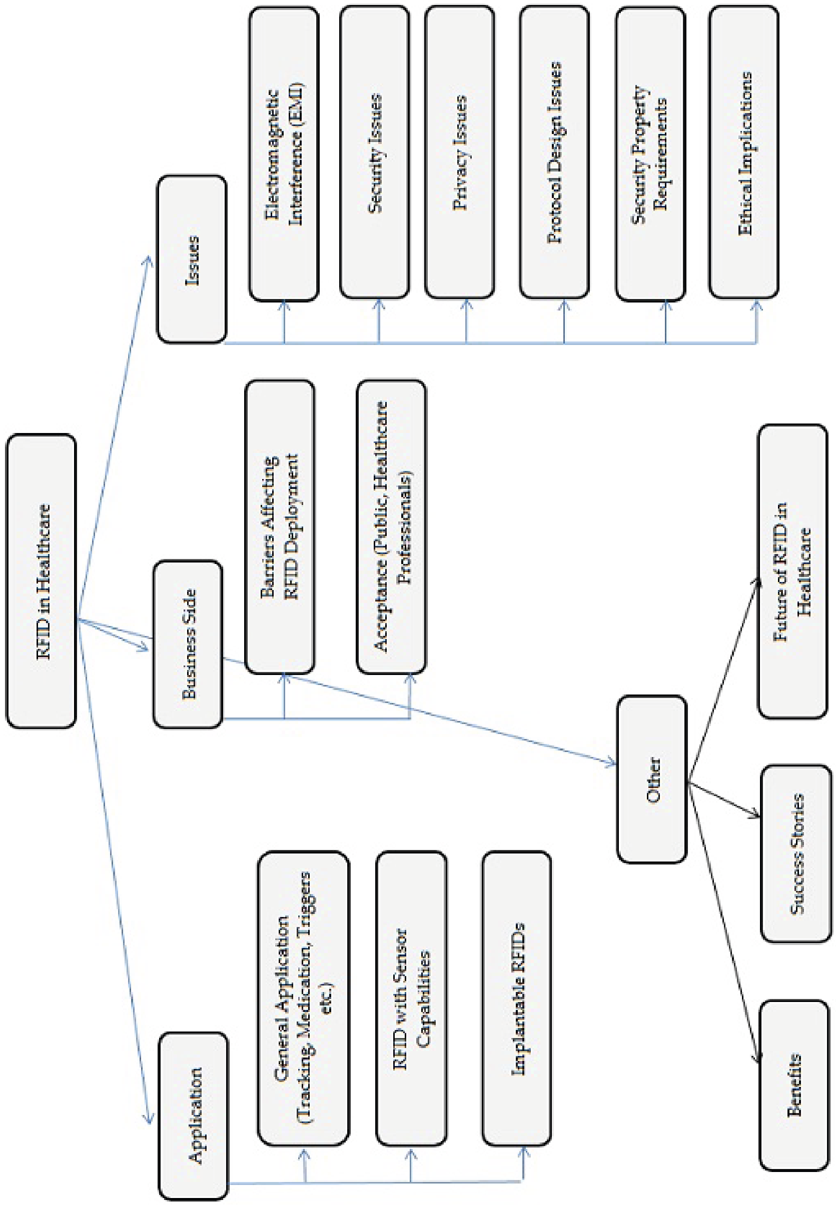

Fig. 1 Impact of RFID in Healthcare - An Overview

2 RFID'S Impact in Healthcare

From the above statistics, it is evident there are many convincing reasons to adopt Information and Communication Technology (ICT). The goal of this chapter is to explore how RFID contributes to improving healthcare services thereby helping to increase public confidence in the system. In healthcare, RFID is widely deployed in the context of patient identification [14] and realtime location tracking systems (RTLS) to track healthcare professionals and patients [14, 15, 16, 17, 18, 19] and assets [20]. It is also used for inventory control of equipment, medical supplies and medicine, and tracking the expiry dates of medicines [21]. RFID is expected to solve some of the major problems in healthcare such as reducing medical errors [22, 23, 24, 25] thereby improving patient-safety [13, 26, 27, 28, 29], improving work efficiency [10, 30, 31], producing cost savings [12], and reducing litigation from incorrect treatment, surgery or medication. Barua *et al.* (2006) (cited in [32]) state the financial benefits of RFID in retail and healthcare touch the $40 billion mark with an estimated Return on Investment (ROI) of 900%. We now explore in detail the impact of RFID in healthcare and Figure 1 reflects the same.

2.1 RFID Based Healthcare Applications

Mowry [12] highlights several RFID based healthcare applications. The deployment of active tags with thermometers to combine patient location tracking and real time patient symptom tracking was used by Taipei Medical University Hospital to contain a SARS outbreak. A RFID based Real Time Location System (RTLS), eShephard from Exavera Technologies, allows doctors to correctly identify patients thereby assuring correct treatment, reducing medical errors and increasing operational efficiency. RFID tagged implant objects introduced by implant manufacturer Biomet in 2006 have assisted in identifying items used from a kit so they could quickly and accurately invoice the hospital. RFID enabled smart cabinets track inventories of medical devices to ensure patient safety, improve billing efficiency and inventory management, and reduce the error-prone manual labor involved in the process. RFID based system SurgiChip assists doctors to prevent wrong-site and wrong-procedure surgery by correctly identifying the patient, the exact surgical site and other vital information. ClearCount that uses RFID tagged surgical sponges ensures sponges are not left inside patients after surgery. Macario *et al.* [33] proposed a similar system to detect commonly used surgical gauze sponges tagged with RFID. 8 patients undergoing abdominal and pelvic surgery participated in the evaluation. 8 untagged sponges and 28 tagged sponges were placed in patients. The result of the study showed the RFID reader detected all tagged sponges correctly (100% accuracy) in less than 3-seconds with no false-positives or false-negatives. A context-aware middleware for mobile healthcare services has been proposed by Song *et al.* [34] which focusses on preventive medicine. Information about a patient is gathered using middleware and the Bayesian probability formula is used to determine the high-frequency context to manage risk situations. The middleware also provides real-time analysis of information, calculating risk frequency via a real-time sensor and RFID.

Martinez *et al.* [15] proposed an application that uses RFID for tracking patients and Near Field Communication (NFC) for drug administration. It was argued RFID is not yet compatible with universal devices such as cell phones and this was the reason why NFC was used. This argument is not true, as RFID enabled mobile phones are already in use [35, 36]. A similar patient tracking system was proposed in [21, 22]. Lin *et al.* [37] proposed a remote healthcare system (RHS) using RFID with an emergency monitoring and reporting mechanism to protect the safety of senior patients who live on their own. Though the application has potential use, there is a major weakness in the design. The system requires the patient to be at home to scan his RFID tag to the reader connected to the home computer. The patient ID is sent to the server in the clinic which automatically completes the authentication and authorization. The system measures the physiological signals of the patient and sends it to the clinic. The downside is that, if a patient's tag were lost or stolen, an adversary can use the publicly available system and compromise the safety and privacy of the patient. This is because the system does not verify the person scanning the tag is actually the patient and it simply performs the authentication and authorization once it receives the request. Similar applications are discussed in [38, 39].

Chen and Collins [16] proposed a Real-Time Tracking System to optimize healthcare facility operations, throughput time, room utilization and patient flow. The system expects to increase visibility within the facility by allowing medical staff to find where their co-workers and patients are at any given time. The system also records the amount of time nurses and doctors spend performing their tasks. While these two features help the administrative side of healthcare, in our opinion, this system poses some privacy issues for both staff and patients. Kim *et al.* [40] proposed an indoor Ubiquitous Healthcare (U-Healthcare) system using RFID to locate and track the elderly. Sensors were used in U-Healthcare to record information about patients such as heart rate, blood pressure, pulse oximeter readings and electrocardiogram data. When an abnormal condition was detected, the system alerted healthcare providers/family members so immediate action could be taken. The system uses modules such as 1) a Tag Sensing Module to determine tag location, 2) a Location Sensing and Tracking Module that uses the tag's location to know the patient's location, 3) a Monitoring Module to monitor the patient's health status, 4) an Alarm Module to alert concerned people when certain events occur, and 5) a Health Status Information Analysis Module which analyzes the data gathered. The system uses encryption techniques such as a cryptographic hash function to secure the communication, and employs timestamps and a MAC algorithm to defend against spoofing attacks.

An evaluation was done at a medical center to see if RFID along with infrared signals would increase equipment tracking/utilization [20]. Results showed the system performed well in localizing equipment to a ward with over 80% accuracy compared to a specific room (between 60 - 80% accuracy). Accurate designation of beds to patients assisted in capturing charges accurately and improving equipment utilization/availability-status. Despite some concerns, the system was fairly well received from the focus group. Polycarpou *et al.* [14] presented design, implementation and testing of a RFID system in healthcare aimed at error-free patient identification, RTLS and drug-inventory management. The application was tested in a hospital environment. The results showed tag readability was in the order of 88% for vertically oriented tags, which is considered satisfactory. The down side of the system was that while it worked well in powder-based drugs, there were readability issues when the tag was in direct contact with liquid bottles as the reflection coefficient at the chip's terminal was severely affected thus reducing the input power to the chip. To improve readability, it was suggested near-field tags with near-field antennas could be used. The patient identification system worked well and proved quite useful to doctors.

Symnonds *et al.* [41] discuss the challenges and solutions involved in implementing RFID for assisted living especially in cases where people experience short term memory loss. Factors such as providing a means of locating objects, being unobtrusive, being usable by older people and its cost effectiveness were considered in designing the system. The system also accounted for broken tags (when an object is dropped for example), with the loss of a signal from the tag time stamped, the nearest landmark noted and an alert stating where the object was last located and the time it was located. Unluturk and Kurtel [27] proposed an RFID and Web Service based Assisted Living System for elderly people. The system aimed to reduce medical costs and the complexity of services, improve patient safety and quality of care, and provide timely decision making capabilities.

A High Efficiency Particulate Air (HEPA), an Air Ventilation System using RFID was developed by Lin *et al.* [42]. The system aims to control the quality of air in hospital operating rooms to prevent hospital-acquired infection. The system is composed of RFID tags for staff and patients, sensors and a reacting module that receives information about the number of staff, the status of the surgery and the volume of air in the room. Of the two control mechanisms that were deployed, one was time-based where the system will keep the volume of airflow to a minimum when the operating theater is not in use. The second control mechanism was controlled by RFID which monitors the number of people in the room and regulates the airflow accordingly. By installing two readers in the room, the system achieved a 99% read rate. While the initial setup cost may be high, results show that an energy savings of 50% and 40% were achieved thus providing more life for the air-filter. It is important to note the system not only aids in preventing hospital-acquired infection but other occupational diseases from spreading.

The European Agency (2000) (cited in [43]) states that over 5720 fatal work-related accidents occur in the European Union. This prompted the development of the Human Condition Monitoring System in Hazardous Locations using RFID [43]. The application uses a mobile system based on energy-efficient wireless sensor networks (WSNs) and active RFID to achieve ubiquitous positioning and monitoring of people working in hazardous locations. The system uses an algorithm called Time Division Double Beacon Scheduling (TDDBS) to increase operation time and data transmission rates of nodes in the system. The implementation results show the system was able to pinpoint the location and state of an individual, and also provide analysis of potential risks at any given time. The system uses radio communication between transmission points which form a network of routers sending and receiving information, and acting as signal repeaters. When a lack of signal is detected (in a mine for example) using an acoustic warning signal, the individual can take a few steps backwards to activate and deposit a new repeater. The ZigBee communications network is used among these repeater nodes and a RF signal is also used from the tagged bracelet to the nodes. The system can also detect emergency situations such as a fall or loss of consciousness to trigger an alarm.

McCall *et al.* [44] proposed a RFID based Medication Adherence Intelligence System (RMAIS) that enables patients to manage their medications in terms of taking the right dosage at the right time in an automated fashion. The system also provides medication reminders and sends alerts to care-givers about non-compliance. The National Council Report (2007) (cited in [44]) states there is compelling evidence to show patients are not taking their medicines as prescribed for one or more of the following reasons: a) patients are not convinced about the need for treatment, b) fear of adverse effects, and c) difficulty in managing the medication. The proposed system addresses the last concern - medication management. Medicine bottles fitted with RFID tags enables the system to read the medicine information, and the built-in scale tells if the patient has taken the right dosage, while the motorized rotation platform positions the correct medicine bottle in front of the patient and the built-in network interface card enables the system to alert medical professionals when necessary. A similar application was proposed by Sun *et al.* [45]. and a medicine manufacturing system using RFID and Service Oriented Architecture (SOA) was proposed by Deng *et al.*

Ting and Tsang [10] investigated the potential use of RFID in surgery management specifically targeting hospitals where the nurse to patient ratio is much lower. This Surgery Management System addresses issues such as: a) identifying/tracking patients, b) eliminating manual redundant checks to increase work-efficiency, c) automating materials and equipment management, d) retention of instruments inside a patient's body, and e) wrong site/person surgery. Critical elements to be considered when implementing RFID are discussed: i) technical dimensions covering encryption for security; EMI interference and reliability of communication in terms of reducing false reads and misreads by deploying anti-collision/error-correcting codes, ii) a management dimension that includes gaining top-level support and training, iii) capital costs, and iv) privacy issues. Yamashita *et al.* [46] studied data management of surgical instruments using RFID. A tag was designed and attached to surgical instruments used in the experimental study. The tag was cylindrical in shape with a diameter of 6mm, a thickness of 2mm, weighing 1 gram, a storage capacity of 128bytes and consisting of an original loop antenna. The internal chip was manufactured by Philips (ICODE SLI) and a frequency of 13.56MHz was used. The focus was on the effect of the tag being repeatedly sterilized, its durability to contamination tests during the washing process and finally its impact resistance against being dropped. The results of the study showed no tags were incapable of communicating or had any damage after high-pressure sterilization (50 times for 30 minutes on 30 tags), the high-heating challenge test (200 degree centigrade for 300 hours on 20 tags), the contamination test (77 surgical instruments for 31 cycles using a washer disinfector), high-pressure steam sterilization (68 surgical instruments for 15 cycles using an autoclave process) and were resistent to repeated impact. The failure rate was remarkably 0%.

Wang *et al.* [47] conducted a case study on RFID integration in a Taiwan hospital. This RFID infrastructure consisted of 163 field generators, 41 RFID readers, 27 Yagi antennas, 15 programming stations and one system API. The project was a huge success motivating the hospital to develop other medical applications based on this to track equipment, auditing of medicine, and drug control. Some of the key findings from the project were: a) RFID was considered a part of the entire IT infrastructure rather than an add-on, b) device management is highly environment and context dependent. In hospitals, an active RFID solution is more appropriate, and frequency spectrum management is vital along with a combination of tags with sensors that help to provide better care for patients.

Stahl *et al.* [48] conducted a study to determine if a RFID based indoor positioning system (IPS) could objectively and unobtrusively capture outpatient clinic behavior. The key performance parameters were flow-time, wait-time and patient to doctor face-time. The tags in the system generated events based on the current location and time. The data stream provided an indication of how long a tag was in a given location. Thus, the system allowed the tracking of not only the path the patients took but also how long they spent in each location. Face-time was calculated when the doctor's tag and patient's tag were together in the same place at the same time. The study was conducted in a primary clinic and an urgent care clinic. The results showed the flow time and wait time were similar in both places but face time was significantly longer in the primary clinic. It thus proved that a) the use of RFID based IPS had strong potential to provide insight into the behavior of tightly coupled clinical systems enabling them to identify bottlenecks; and b) it can help identify room utilization patterns to enhance scheduling processes. Similar work to track cardiac patient flow was proposed by Baarah *et al.* [49] and Unluturk [50] proposed a system called Supervised Event Executive (SEE) to improve nurse-patient communications. The system aims to provide a common, convenient and reliable way to transfer nurse call system events.

Shim *et al.* [30] proposed a specimen management system and architecture with RFID for a clinical laboratory to solve the known problems of specimen management using barcodes. In order to avoid interference with other electrical systems in the lab, the antenna's reading range was adjusted to 10cms. The following observations were made: a) the location of tags and the antenna should be parallel to decrease false recognition; b) the reading ability decreases if the tags overlap each other; and c) there has to be some distance between tags to increase reading ability. The advantages of the system include an expectation that overall clinical laboratory work processes will improve and work efficiency will increase. From sampling to analysis, the number of contacts between a person and the container reduced by at least 1 from 4 or more.

The numerous applications of RFID in healthcare make it evident that RFID has become an integral part of healthcare. We now explore RFID tags with sensor capabilities and their impact in healthcare.

2.2 RFID Tags with Sensor Capabilities

Tags can be used to collect sensor-derived data by extending the chip's interface capability to a sensor [51]. Combining the tag's sensor capabilities with sensor nodes has provided new dimensions for interaction and operation with each other [43].

Pletervsek *et al.* [52] proposed a hand disinfection control system using RFID named Automatic Disinfectant Tracker (ADT). Experimental results show 100% efficiency in detecting propanol and ethanol concentration using the static disinfectant control method. Ethanol sensors were used with the IDS-SL900A RFID data-logger which can be used to record both body temperature as well as readings from an external sensor. The 8Kb EEPROM memory was used to store the level of alcohol concentration with a timestamp of hand rubbing. The reader detects the presence of an individual then records the time period of hand scrubbing, the temperature and concentration of the applied ethanol. When the reader detects the ethanol from a tag-sensor that exceeds a certain level, it updates the nearby person's tag with the disinfection information. If the desired level of disinfection is not achieved, the system alerts the personnel. Thus, ADT allows the quality of hand rubbing to be monitored via a clean and contact-less method.

Hung *et al.* [53] proposed a Blood Pressure Measurement (BPM) with ease of use, low cost and wireless connectivity. The authors note that recording blood pressure changes over a period of time will help doctors control cardiovascular conditions. A condenser microphone is used to listen to a weak heartbeat and amplify it. The Micro Controller Unit (MCU) listens to the heartbeat until the sound disappears and calculates the time difference between start and end. This allows the system to calculate the Systolic Blood Pressure (SBP), Diastolic Blood Pressure (DBP) and heart rate. Functions such as measuring the BPM signal, detecting the position, intercepting the tag identifier information and analyzing/transferring the BPM signals form the core components of the system. The RFID module is added for convenience and security reasons in the sensor because it is used to identify the patient, thus eliminating the need for manual entry of the ID and other personal information.

Vecchia *et al.* [54] proposed intelligent infrastructure for smart hospitals to optimize medical staff to patient interaction and to provide ubiquitous and transparent access to medical data. The system uses RFID and photosensor technologies to accomplish these tasks. The purpose of the photosensor is to trigger RFID antennas to on/off to reduce RF exposure and power consumption. The architecture is three-layered: application layer, service layer and data layer. RFID and photosensor systems are part of the data layer. The system is event driven and service oriented, aimed to shorten the existing gap between healthcare professionals and patients. Opasjumruskit *et al.* [55] proposed an RFID based temperature sensor.

Though the design is aimed at implantable chips for application in animal healthcare, it does raise some interesting points. The RFID chip has five parts: a) analog front, b) digital controller, c) charge pump d) EEPROM, and e) temperature sensor. The metal-oxide semiconductor temperature sensor is suggested for passive RFID since it consumes less power allowing for ease of integration. The microchip in the tag can operate and communicate in ice or water-filled packages, or food containers without any problems. When a reader sends a command to the tag using a 100% Amplitude Shift Keying (ASK), the demodulator in the tag converts this RF signal to digital data. If the sensor unit received a "read temperature" command, it converts the temperature to 16bit output data. During this phase, care is taken not to modulate the RF field to avoid power supply fluctuation that would deteriorate the accuracy of the measurement. The authors note that embedding RFID with other sensory circuitries such as a humidity sensor, pressure gauge or a chemical detector, will dawn a new age in measurement techniques.

Other notable sensor-attached RFID based applications include Barman *et al.*'s [56] sensor enabled RFID for monitoring arm activity after a stroke. Catarinucci *et al.* [57] proposed a label-type sensor tag that uses as input a generic sensor and transmits the measured data. The sensor tag is based on four optimized antennas and it takes into account the size constraints and mutual coupling effects. Experimental results have shown the antenna design and their optimized mutual position reduced coupling/parasitic effects by 44%. Romain *et al.* [58] proposed an implantable RFID based pressure sensor that could be used in network configuration. The goal is to develop a communicating endo-prosthesis which includes integrated sensors made of a pressure transducer. RFID used in recording and transmitting recordings of pressure in the aneurysmal sac during post-surgical consultations provides a means to monitor the condition of Abdominal Aortic Aneurysm (AAA).

The above RFID sensor tag based applications support the statement that chemical sensing can aid in advanced medical monitoring [59]. We now explore the on-body/implantable RFID tags and their impact in healthcare.

2.3 On-Body/Implanting RFID in Humans

Aubert [60] conducted an indepth analysis of RFID implants on humans for locating/tracking and remotely controlling human biological functions. Miniature implantable RFID devices assist in biomedical/therapeutic applications such as blood-sugar sensors. Implantable chips also assist in monitoring brain functions via implanted probes that communicate via a transponder embedded within a skull. The author notes that RFID implants are not mature enough to communicate with GPS satellites to facilitate real-time tracking of a person however the remote control of human biological functions are more realistic. Some of the technical requirements for RFID human implants include: a) implants have to be as small as possible; b) they have to be passive because using a battery to power the device is impractical; c) selecting the human biological functions that will be remote controlled; d) using bio-compatible material for fabricating the device to avoid tissue reactions; e) secure and reliable wireless transmission of data; f) complying with human tissue exposure IEEE standards for safety reasons related to implanted antennas, and g) feasibility to remotely control at a bio-molecular scale level. Two wireless techniques for powering passive RFID-implant devices are: 1) inductive coupling is where the power required to operate the device is supplied by an interrogator via inductive (near field) coupling, and 2) electromagnetic coupling which is based on an electromagnetic field that uses electromagnetic waves propagating from the antenna in the far field region to power the passive tag.

Grosinger and Fischer [61] evaluated backscatter RFID systems on the human body at two different frequencies (900 MHz and 2.45 GHz). The necessity to investigate the on-body RFID propagation channel, including the effects of antennas to understand the robust power transfer and communication in such systems is emphasized. It is noted mutual influence between the antenna and the human body should be low. The system uses a monopole antenna/patch antenna and five on-body tags at various locations in a human-body to measure the physiological parameters of a person with the reader placed on the stomach. The study concluded that patch antennas were suitable for on-body applications and the outage probabilities at 900 MHz were lower than the probabilities at 2.45 GHz due to increased energy absorption in human tissues at higher frequencies.

Occhiuzzi *et al.* [62] proposed a design for implanting RFID tags for passive sensing of the human body. The purpose is to sense the evolution of human physiological and pathological processes involving a local change for effective permittivity inside the body. Medical devices such as prosthesis, sutures, and orthopedic fixings can be fitted with battery-less RFID radio-sensors to acquire data at varying times. This helps to record the geometrical/chemical features of the tissues to observe the healing process, and identify possible complications. It is noted that biological processes differ in terms of timeline and amplitude, and hence the measurable response of RFID radio-sensors needs to be properly correlated to the process under observation. This design particularly focuses on the monitoring of biological ducts that host a stent implant. To achieve the best result from the sensors, careful attention was given to the shape of the antenna in the RFID tag, the power threshold and input impedance of the Integrated Circuit (IC) and lastly, the state of the biological process where the antenna was forced to have the best impedance to match the IC. Analysis and experimentation suggest the possibilities of sensing some inner biological processes using implanted RFID tags. It is noted this design technique could be extended to other implanted devices mentioned earlier where long-term monitoring may provide added value.

Thevissen *et al.* [63] proposed the use of implanted RFID tags into a human tooth to handle mass deaths that arise from diaster situations such as tsunamis and hurricanes. Tags used by veterinarians were modified for this purpose. During the modification process, 10% of the tags failed due to the unavoidable manipulation of the fragile connections. To minimize the loss, naked tags were protected with polymerized composite bonding. It was shown that dental x-rays could be taken without disturbing the normal activity of the tags. A similar application to identify disaster victims was proposed in [64], the difference being the placement of the chip inside cranial structures. The maxillary sinus seemed most suited for the purpose and the majority of chips were placed in that area for identifying the 2004 tsunami victims. Madrid *et al.* [65] have also studied the reliability of RFID in the identification of dentures in long-term care facilities. The tag was programmed and inserted in the dentures, with only one tag unreadable and the rest still operational at the end of three months. At six months, 100% of 50 initially placed tags were readable proving the reliability of the technology for tracking and identifying dentures.

Other applications that use implantable RFID technology include the following. Burke *et al.* (cited in [60]) discuss the possibility of using RFID in the remote activation/deactivation of biochemical activity in a single living cell. The miniature nanotechnology FM-radio by Jensen *et al.* (cited in [60]) could be inserted into a living human cell to give a subcellular remote and real-time controlled interface. Berger (2008) (cited in [12]) proposes an RFID enabled orthopedic implant to assess the function of the implanted device and the surrounding tissue. VeriMed application from VeriChip (cited in [12]) uses a small glass capsule about the size of a grain of rice (FDA approved device) that is implantable in humans. This capsule assists in patient identification when they arrive at a hospital unconscious or unresponsive. Zhou *et al.* (cited in [12]) propose a human implantable RFID enabled sensor tag that could help diabetic patients monitor their blood sugar levels and save them from having to prick themselves several times a day to check their blood-sugar levels.

2.4 Insight into EMI Caused by RFID

Varying results can be seen from the extensive research carried out to measure the Electro Magnetic Interference (EMI) caused by RFID. Here, we analyze some of the important studies conducted in this area.

Houliston *et al.* [66] conducted a study to replicate EMI due to RFID with a drug infusion device. Infusion pumps known to have failed due to EMI were placed in RF fields with varying strengths created using the following: varying numbers of RFID readers; high-gain antennas; varying distance between readers to infusion pump; and the presence of an RFID tag on the infusion pump. The results concluded the infusion pump was not affected by low-power RFID readers even when they were in direct contact. However, the pump attached to a tag was disrupted when a high-power reader was used at a distance of 10cms. Similar interruptions were noticed when high-power and low-power readers were used at a distance of 10cms. It was noted that once the pump failed due to EMI, it subsequently failed at other times even when no RFID readers were active. This points out the unreliability of a device once it has failed due to EMI, thus emphasizing the importance of thoroughly resetting medical devices after failure. It was concluded that EMI incidents increase due to: higher RF field strengths determined by high output power from the RFID system; a shorter distance between the reader and the medical device, and the presence of a tag.

Fiocchi *et al.* [67] conducted an EMI study of a RFID-based mother-newborn identification system with some interesting results. The study included testing the compliance of the EMF exposure guidelines in terms of the magnetic field threshold and the maximum distance of the reader to wake the tag. The results indicate the need to identify the technical specifications of the optimal reader-tag for this type of application by performing an accurate exposure assessment investigation particularly for newborns. The study used two realistic Virtual Family Models based on high-resolution Magnetic Resonance (MR) images of healthy volunteers. The system used passive inductive coupling RFID at a frequency of 13.56MHz. Experiments showed higher levels of EMF for both the mother and newborn in the regions of the body that were closer to the reader, with a trend for higher values in the newborn compared to the mother for all reader positions. In addition, the highest exposure value for the newborn was not only restricted to the proximal limb but also extended to the trunk, genital organs and head/neck regions. Hence, it is recommended the tag be positioned on the ankle instead of the wrist so the reader is at a greater distance from the sensitive organs.

Kapa *et al.* [68] evaluated the likelihood of EMI when using RFID. 32 medical devices were tested with a maximum magnetic output field ranging from 8 to 800 mgauss. Results show light-to-hazardous incidents occurred in 8 devices, hazardous EMI in 2 devices, significant EMI in fluoroscopy and echo-cardiograms, and 1 out of 5 cardiac monitors plus light EMI in a defibrillator and cardiac monitor. It is important to note that no EMI was recorded in any device at distances greater than 4 ft. The authors recommend rigorous on-site testing before implementing such devices. Kuo *et al.* (cited in [69]) observed that a shift in resonance frequency causes a degraded reading range for RFID. A thin EMI sheet made of a magnetic composite absorber placed between the tag and the metal recovered nearly 60% of the reading range. An EMI study by Ting and Tsang [10] recommends that RFID systems be positioned at least 30cm away from a medical device to avoid problems of interference.

Togt *et al.* [70] conducted a study to assess the EMI interference from RFID. The study was conducted in a controlled environment without patients using active 125KHz and passive 868 MHz tags. 41 medical devices under 17 different categories from 22 different manufacturers were tested. The results showed that out of 123 EMI tests, 34 EMI incidents were induced by RFID, of which 22 were classified as hazardous, 2 as significant and 10 as light. The 868 MHz passive tags induced 26 incidents in 41 EMI tests and its counterpart induced only 8 incidents. The passive tags induced EMI in 26 medical devices, 8 of which were also affected by active tags. The authors concluded RFID potentially induced hazardous incidents in medical devices and the implementation of RFID in healthcare should require on-site EMI testing and that international standards be followed. As Payne [71] quotes *"..these findings sparked a flurry of media attention and panic regarding the safety of RFID.."* Bacheldor [72] quotes John Collins (Director of Engineering and Compliance with the American Society for Healthcare Engineering) who says *"There needs to be a growing awareness among hospitals that problems can occur and it is difficult to say if something such as an RFID system will interfere with critical* *care equipments unless a study is conducted"*. Collins did deem the study well conducted. Following this, several reports came out to address consumers' concerns. Payen's [71] report states the following: a) the research has not been in line with most current hospital RFID deployments where passive RFID is the mainstream technology; b) most UHF deployments call for a 1-watt or less reader but the study used 3-watt readers which are far more powerful; c) this, combined with the gain of antenna used, indicate that the study was highly unlikely to be compliant with FCC regulations; and d) the most commonly used frequency (13.56 MHz) in hospital settings was not mentioned in the study and hence does not truly reflect the reality of most current RFID deployments. The author does note the value of the study as it would serve as a warning for future RFID deployments based on UHF tags and emphasizes the need for standards in relation to RFID in hospitals. Roberti's [1] report states the following: a) no known cases of patients being harmed have been reported due to RFID, and b) every speaker who participated in the *RFID in Healthcare* event [1] stated they have not seen RFID equipment affect medical devices of any kind. Researchers from Indiana University and Purdue University, Indianapolis, USA found no incidents of EMI from passive UHF RFID systems [73]. The first test used 868 MHz tags and an interrogator to study the effect on 41 medical devices. The second test used 902-928 MHz tags and readers on 25 medical devices. Iadanza *et al.* [74] conducted a similar study by testing 16 medical devices from 5 different categories in a children's intensive care unit using active RFID systems with low power and a relatively high operating frequency. The results do not report any malfunction in any devices.

Cheng and Chai [69] proposed an experimental design using simulation to measure the efficiency and reliability of implementing RFID in a MRI department which is a major source for EMI. Cheng's experimental results show the MRI machine did not cause any interference on RFID readability. The tags were also functioning normally without any data loss after the MRI scanning, and the tags did not lose any identifying function in the MRI environment. In addition, patients did not have to remove their tags during the scan and doctors did not have blurred images during diagnosis. The study concluded there was no evidence to prove interference between the two technologies.

Other noteworthy studies/results in this area include the following. Macario *et al.* [33] note RFID did not exhibit any EMI while using their RFID wand device to detect surgical sponges. Rieche [75] proposed a novel modulation and transmission technique named the Gaussian Derivative Frequency Modulation (GDFM) to mitigate EMI interference. Censie *et al.* [76, 77] analyzed EMI of RFID regarding medical devices and recommended standards of electromagnetic immunity for devices, and standards for the electromagnetic compatibility (EMC) of RFID systems. Ogirala [78] mathematically analyzed the EMI of RFID specific to Cardiac Rhythmic Monitoring Devices (CRMD) and proposed mitigation strategies. The study concluded that the power level of RF alone does not contribute to the EMI but the rate of change of the power output does play a significant role in the interference. The use of Pitt interference as a mitigation technique has been experimentally shown to solve the interference issue.

As clearly seen above, results vary and it highlights the need for continuing research in this area to ensure RFID technology is safely deployed in healthcare.

Table 1 Commercial RFID Healthcare Products and their Applications

Product Name	**Product Category**	**Application**	**Pros & Cons**
eShepherd	Real Time Location Tracking (RTLS)	Patient, staff and equipment tracking	Initial investment of USD$400,000 could potentially save USD 4 million annually
Biomet	Supply Chain	Knee implant surgical kits	Enables effective tracking, invoicing and replenishing
Mobile Aspects, TAGSYS RFID and Terso Solutions	Inventory	Smart Cabinets to inventory medical devices	Costs about USD$25,000. Improves patient safety, billing efficiency and inventory management
SurgiChip	Patient/Site/Surgery verification	Helps to identify patient and surgical site	Prevents wrong site and wrong procedure surgery
ClearCount	Detection	Detects surgical sponges and other surgical devices placed in a patient	Prevents leaving surgical devices inside patients; cost-savings; prevents litigations
VeriChip	Implantable Device	Patient identification	Ethical and privacy issues; associated health hazards; helps identify patients and retrieve patient medical history in emergency situations
Medication Adherence Intelligence System (RMAIS)	Medication Management	Enables patients to take medications in an automated fashion	Provides medication reminders and alerts care-givers
Specimen Management System	Specimen management	To manage specimens in clinical laboratories	Improved work flow and specimen management
Blood Pressure Management	Monitoring	Records blood pressure changes over a period of time	Helps doctors to control cardiovascular conditions; low-cost

2.5 Secure RFID Based Protocol Designs for Healthcare

Several protocol designs have been proposed over the years, specific to RFID based healthcare applications. Here, we analyze some of them, highlight their strengths and weaknesses and identify areas of improvement.

Rrub *et al.* [79] proposed a secure RFID model based on smartcard RFID design. The model adopts the technology in a contactless payment module used in credit cards to design a secure, practical and cost-effective solution for the healthcare sector. The proposed solution is based on Mifare cards DesFire EV1 and is

Table 2 Deployment of RFID Healthcare Products and their Effects

Product Description	Where Deployed	Environment	Issues	Results
Patient Identification	Chang-Gung Memorial Hospital, Taiwan	13.56MHz tags embedded in wrist-bands; HP iPAQ PDS equipped with RFID interrogators	None Identified	Hospital saved 4.3 minutes per patient in identification and verification and achieved 100% identification accuracy.
Patient Tracking	Eastern Asia	-	None Identified	Helped contain SARS outbreak
Real Time Location Tracking (RTLS)	Virginia Hos-pitals, USA	303MHz tags, 100s of readers	None Identified	Net Savings of USD 3 million in the first three years
Implantable sensor tag to monitor blood sugar levels	Inside hu-man body	N/A	Body's reaction to foreign objects; pri-vacy issues;	Enables diabetics patients to accu-rately measure blood-sugar levels painlessly
High Efficiency Particulate Air (HEPA) Air Ventilation System	Taiwan Hospital	434MHz active readers (model: ARUnew01); Tags (model: ACUnew01-Passlt); 1500 bed hospital; 20 staffs wearing tags	Reader cost $600; tag cost $20USD, software $50K	Two readers en-sured 99% read rate; 50% energy savings; 40% more filter life; pre-vents occupational diseases
Indoor Positioning System (IPS) to evaluate patient flow-time, wait-time and face-time	Primary & Urgent Care Clinics	-	None Identified	Showed flow-time and wait-time to be the same in both clinics but face-time was significantly longer in primary clinic, thus en-abling bottle-neck identification.
Automatic Disinfectant Tracker (ADT)	Slovenia	Clinical Hospital; Ethanol sensors used with IDS-SL900A RFID data logger	None Identified	The system suc-cessfully alerted when disinfec-tion has not been achieved to the desired level
EMI Study 1 - Mother-Newborn Identity Reconfir-mation	Virtual Family Model / Hospital in Italy	13.56MHz reader/tag; ISO 15693 Tags	None Identified	Results showed for both mother and newborn the regions closer to the reader were exposed to higher levels of EMF. It highlights the need for optimal reader-tag technical specifications
EMI Study 2 - Passive UHF RFID Systems	Purdue Uni-versity, USA	868MHz and 902 – 928MHz tags	None Identified	No EMI incidents were reported

ISO/EPC-14443A compliant. The tags used in this model have more storage capacity and processing power than passive tags. The model leverages these abilities to perform complex security operations to protect the security and privacy of the tag holder. The advantages are strong security options and fast communication ability. However, the downside is the 10cm maximum reading distance that requires the tag to be close enough to the reader so it can be read. In terms of security, it uses Message Digest to generate a digital signature, along with random numbers and hashing algorithms as part of the communication protocol. Yu and Hou [80] introduced the common criteria security evaluation methodology known as ISO/IEC 15408 for security evaluation of RFID tags and proposed a framework as a minimal requirement for RFID tags to improve security assurance. The framework consists of a) identifying information value and threats; b) defining the evaluation assurance level; c) deriving the security objective; d) deriving security functional requirements and e) performing rational mapping.

Min and Yih [81] proposed a fuzzy-logic based RFID monitoring system for an outpatient clinic. The motivation was to collect raw data from a RFID system containing noise and missing reads that prevented the identification of the exact tag location. Fuzzy-logic algorithms were used to interpret the raw RFID data to extract accurate information. Tag location was determined by evaluating the possibility of presence/absence. Their experimental study in an eye exam room with two readers showed significant false-positives and false-negatives, thus making unreliable RFID reads as one of the main obstacles in its implementation. It was noted the average read rate in real-world RFID applications is only 60-70% which is consistent with this study. Smoothing methods (static and dynamic) have been used to overcome these issues but they don't entirely solve the problem. The static smoothing method uses a fixed window size that cannot be effective for all applications. The dynamic smoothing method is based on the assumption that the read rate of RFID decreases proportionally to the distance from the antenna, however in a small enclosed area, the effect of distance from an antenna on the read rate is not significant. Information on the amount of time a RFID tag is detected or not detected motivates the use of fuzzy-logic based possibility-theory in the protocol instead of probability-theory. Two algorithms were proposed in the protocol. The first algorithm determines the presence of a RFID tag by simply comparing the possibility of presence over the possibility of absence. If the possibility of presence is greater than the possibility of absence, then the algorithm considers the tag to be present. The second algorithm not only considers the current possibility when the tag is detected or not detected but it also considers the previous decision. If the current decision is consistent with the previous one then it definitely confirms the presence/absence of a tag. If the current decision is not consistent then the maximum possibility is taken for the final decision. Numerical experiments show both the proposed algorithms perform better than the static smoothing method by minimizing false positives/negatives. Tu *et al.* [82] also conducted a similar study in healthcare, along with the dynamics of locating and identifying the presence of a tag and have proposed algorithms to accomplish the same. It was noted that both false-negatives and false-positives can be a problem in RFID embedded systems particularly when tags are blocked by impenetrable objects. The algorithms aims to reduce this problem through a variation of triangulation where the presence/absence of a related tag is considered. The results of the study indicate the location accuracy of tags can be improved through the proper collection of data and the use of algorithms for inference of data.

Many yoking-proof/grouping-proof RFID protocols have been proposed over the years, however in this chapter we limit them to the healthcare context. The purpose of the yoking-proof protocol is to build a validation chain to sequentially verify each tag [83]. Juels (2004a) cited in [83] presented a classic example of the application of this protocol in a hospital setting. US FDA regulations require pharmacists to attach leaflets that describe the side-effects and dosage instructions of medications. When a tag is attached to the medicine container and to the leaflet, the yoking-proof can verify if the pharmacist has complied with the requirement by validating the presence of the tags together. Huang and Ku [83] proposed a light-weight grouping-proof protocol for EPC C1G2 tags using CRC and PRNG operations. The authors also presented a practical application of the protocol in a hospital environment to enhance patient medication safety. The nurse giving medication to a patient would scan all drugs from the medicine trolley and the pallet tag from the patient's bracelet to verify if the drugs were consistent with the prescription of the patient. The association rule would be derived from the medical record of the patient and hence the protocol would ensure that nothing more or nothing less was given to the patient. The authors state that more focus should be given to the integrity and accuracy of the data rather than security strength or issues regarding malicious attacks. In our opinion, this is incorrect as security is just as critical in healthcare as the application of RFID is in any other field. Otherwise, attackers could easily compromise the system causing severe risks to patient safety (for example, giving incorrect medication or performing the wrong surgery on the wrong patient). Chein *et al.* [84] proposed online and offline verifier yoking-proof protocols similar to [83], however the difference is that tags are authenticated in an independent way. Wickboldt and Piramuthu [85] on the other hand identified vulnerabilities in both protocols: [83] is vulnerable to DoS attack and patient privacy/security is compromised because the EPC of the tag is sent in plaintext; [84] is also prone to tracking/tracing attack due to the same issue. Yu *et al.* [86] proposed a binding-proof protocol using AND, XOR and ADD logic gates for low-cost passive tags to reduce medication errors. This protocol is based on the Lightweight Mutual Authentical Protocol (LMAP) from Peris *et al.* (2006). Wu *et al.* [87] highlight that LMAP has been broken by Barasz *et al.* (2007) and argue that [86] is vulnerable to the same type of attacks. An improved version of the protocol is presented in [87]. More recent developments in grouping proofs by Sundaresan *et al.* [88] and Sundaresan *et al.* [89] cover all the unique design requirements of grouping proofs and have been shown to be resistent to the known attacks on RFID systems. The protocols are light-weight in terms of applying only XOR, PRNG and MOD operations on the tag which make them compliant with EPC C1G2 standard and enable large-scale implementations.

Other significant contributions in this area include Chen *et al.*'s [90] proposal for an RFID based tamper resistent prescription access control protocol with an authentication and authorization mechanism. The protocol claims to protect against attacks such as MITM, and spoofed-reader/tag, and provides mutual authentication and location privacy. The protocol aims to reduce forged/altered prescriptions and deter drug use. The downside is its use of complex symmetric encryption scheme and a hash function. Their implementation in low-cost passive tags is not practical as these tags are highly resource constrained in terms of storage and computation capabilities. Zhou *et al.* [91] proposed a multi-level RFID tag ownership transfer protocol for healthcare environments based on symmetric-key cryptography. Three different scenarios were considered: a) where tagged-items in the healthcare supply chain had different levels of ownerships; b) seamless ownership incorporation by a third party logistics provider; and c) where tags simultaneously possess a temporary and a permanent key for communicating with a temporary and a permanent owner respectively. Yeh and Wang [92] proposed an e-Health system based on RFID that addresses patient privacy and increases the efficiency of the out-patient clinic procedure. The protocol uses lightweight functions such as XOR and PRNG, making it possible for large scale implementation using low cost passive tags. However, an in-depth security analysis is missing from this study to prove the robustness of the design which is an important factor for implementation.

2.6 Security and Privacy Issues of RFID in Healthcare

Gasson [93] conducted an interesting experiment with an implantable RFID tag infected with a virus. Through the experiment, successful infection of computer systems via the spread of the infection from the tag was demonstrated. It was claimed the author may have been the first human to be infected with a computer virus. A glass capsule sized tag HITAG S 2048 infected with a malicious code was implanted in the hand of Gasson, and his mobile phone was RFID reader enabled. The malicious code was written in such a way so instead of simply reading the data, it also executed some SQL injection code which successfully damaged the user's profile information with further payloads. Through this experiment, the author highlights that implantable devices have evolved to the point where they should be treated as small computers and close attention should be paid to security issues.

Thiesse *et al.* (cited in [32]) pointed out some security/privacy issues that may arise from the use of RFID. These issues are injection attack, eavesdropping and DoS attacks that could compromise the security of the system, and the ability to permanently save and link information about individuals through temporal and spatial extension of data collection activities representing the privacy aspect. Parks *et al.* [32] applied the Fair Information Practice (FIP) principles such as *Notice, Choice, Access, Security and Enforcement* to address the privacy issues in RFID. It was noted that the *Health Insurance Portability and Accountability Act* (HIPAA) privacy and security requirements, such as Security Breach Notification Requirements and Patient Rights, can be addressed by applying FIP principles in RFID development and deployment. The technical approach takes two dimensions: 1) the *physical solution* comprises options like faraday-cage and the active jamming method;

2) *logical solution* comprises a destruct-tag using a kill command, a control tag response using blocker tag and agents, use of encryption schemes such as hash-lock, re-encryption, silent tree walk and zero knowledge. Kim [94] addresses the security and privacy issues suggesting that confidentiality can be achieved by authentication and encryption, and data privacy and availability can be achieved through authorization, encryption and data backups. The author also adopted the four security layers proposed by Ko *et al.* (2010): mobile layer, network, application and database. The mobile layer is where components such as RFID and NFC are incorporated.

Hawrylak *et al.* [95] address several security risks associated with using RFID in healthcare, such as threats to patient privacy and safety based on interception of messages, interruption of communication, modification of data, and fabrication of messages and devices. Attacks are categorized as interception, interruption, modification and fabrication. Interception can be carried out by wireless sniffing (eavesdropping) and man-in-the-middle (MITM) attacks. The former is where an attacker simply listens to the communications between tags and the reader attempts to retrieve the information. MITM attacks are even more difficult to detect because they overcome a number of security issues. In a relay attack, the attacker uses a fake reader and tag to extend the range of a legitimate reader and tag. Several distance bounding protocols have been proposed to solve relay attacks but they do not offer complete protection as they can be defeated using a modified transmitter. Interruption attacks are accomplished by jamming the network and blocking reader-tag communication. Some methods include interference of RF noise with any RFID signals using rogue devices, killing tags and energy draining attacks. Currently, only physical security offers the best defense, however monitoring for abnormal conditions does add some value but does not entirely solve the problem. Modification attacks focus on maliciously modifying the information in the RFID system by performing injection attacks. Countermeasures such as mutual authentication, encryption, and challenge-response methods are suggested. Fabrication attacks use a separate device to inject false information into the system. Cloning is one type of attack where an attacker reads the data from the legitimate tag and writes the data to a counterfeit tag. As a countermeasure, strong authentication schemes, and two-factor authentication schemes are suggested. The authors note that while countermeasures do exist, some are too costly to be implemented in low-cost systems.

The required security and privacy properties common to most RFID systems as noted in [96] [97], can be applied in the context of healthcare and can be summarized as follows:

- *Tag Anonymity*: The protocol should protect against information leakage that can lead to the disclosure of a tag's real identifier. This is important as an attacker may be able to clone a valid tag.
- *Tag Location Privacy*: The protocol should ensure the message contents is sufficiently randomized so they cannot be used to track the location(s) of the tags and thereby glean social information about the wearer of the tag.
- *Forward Secrecy*: The protocol should ensure that on compromise of the internal secrets of a tag, its previous communications cannot be traced by an attacker.

This requires previous messages be independent of current resident data on the tag.
- *Forward Untraceability*: The protocol should ensure the old owner is unable to trace or communicate with the tag post-ownership transfer. This means the old owner is unable to learn or compromise any new secret(s) that have been established between the tag and the new owner.
- *Replay Attacks*: The protocol should be able to resist compromise by an attacker through the replay of messages that have been collected by an attacker during previous protocol sequences. This requires protocol messages in each round of the protocol are unique.
- *Denial of Service (DoS)*: The protocol should be able to recover from incomplete protocol sequences that can occur due to an attacker selectively blocking messages. Importantly, such blocking of messages by an attacker should not lead to desynchronisation between the tag and the servers.
- *Server Impersonation*: The protocol should ensure the new server cannot be impersonated by an attacker. This requires the tag to challenge a server requesting ownership transfer to prove its legitimacy.

2.7 Ethical Implications of RFID in Healthcare

Lewan (2007), cited in Katz and Rice [98], notes that two states in the US, Wisconsin and North Dakota, have passed legislation proscribing mandatory microchip implantation in humans, and other states like Oklahoma are considering implanting chips in certain violent criminals upon their release from prison. The latter is definitely worthy of consideration. Under normal circumstances, every human and even animals deserve complete freedom. But when freedom is abused to the extent of harming themselves and others, then it calls for restrictions. People who have a history of harming others, inevitably lose that freedom because of the choices they make. The Government and the Justice System have a duty to protect the common person and if technology can be exploited to do this, then why not use it?

Though the effects of RFID in healthcare have been explored from various perspectives, the ethical implications have not been significantly addressed. Monahan and Fisher [99] conducted a study in 23 US hospitals that use an RFID based patient-identification system. The study used semi-structured interviews to find the social and ethical implications of such systems and some important findings were discovered. These included a) unfair prioritization of patients; b) diminished trust of patients; and c) endangerment of patients. More detailed and commendable work in this area has been done by Foster and Jaeger [100]. Key issues such as ethics, concerns about privacy and potentially forced implantations of RFID are discussed emphasizing the need for a national discussion to identify the limits regarding implantable RFID tags in humans before it is too late to prevent the misuse of this useful but ethically problematic technology. The following implantable RFID systems are quoted in [100]: a) VeriMed from the VeriChip corporation for use by patients who present themselves to healthcare facilities unresponsive; b) implantable tags in dentures/human molars by Thevissen (2006); c) edible RFID tags from Eastman Kodak Company to monitor internal bodily events following the ingestion of medication (Spoonhower 2007); d) ClearCount Solution to detect implanted surgical sponges; e) VeriGuard from VeriChip to control individuals accessing secure areas; f) the proposal from VeriChip to implant chips into immigrants and guest workers. Colombian President Alfaro Uribe apparently welcomed the idea and was quoted as telling a US senator he would get Colombian citizens to agree to being implanted with RFID chips if they were granted permission to work in the US. VeriChip is also trying to convince the US military to replace metal "dog tags" worn by soldiers with implantable RFID tags, and g) Professor Kevin Warwick from the University of Reading, UK implanted an RFID chip as part of his work *Cyborg I project*. He was able to walk the halls of his university, operating doors and lights without lifting a finger. He had a microelectrode array implanted in the median nerve fibers of his left arm to allow him to send signals back and forth between his nervous system and a computer. Using these examples as a baseline, Foster and Jaeger [100] reported the following implications:

1. **Possible Medical Risks:** In its ruling, the US Food and Drug Administration (FDA) classified VeriChip as a class II device and listed the potential hazards as: *adverse tissue reaction, migration of implanted transponder, compromised information security, failure of implanted transponder, failure of inserter, failure of electronic scanner, electromagnetic interference, electrical hazards, magnetic resonance imaging incompatibility, and needle stick (US FDA 2004)*. Controversy also arose about possible carcinogenic effects of implanted chips. Blanchard *et al.* (1999), Elcock *et al.* (2001) and Tillmann *et al.* (1997) (cited in [100]), state that it has been known for implanted RFID tags, similar to the ones used in the VeriMed system, to be associated with tumors in rodents, mostly sarcomas. Vascellari *et al.* (2006) (cited in [100]), mentioned tumors in dogs implanted with microchips.
2. **Ethical Issues:** A lot of literature can be found about privacy and security issues of RFID and activists' websites also discuss possible harm from implanted RFIDs, which included the tracking of individuals to mind control. The latter being in the realm of science fiction at least for the foreseeable future.
3. **Disclosure of Risks:** It is only ethical to disclose adverse effects of a treatment and individuals have a right to know about the effects. It was noted that VeriChip failed to disclose the rodent studies until the issue was raised by activists. In addition, the carcinogenic effect of an implant in rodents suggests the possibility of a similar effect in humans. A cancer researcher states - "*I think the evidence from the animal studies is indeed alarming and one should refrain from chipping people unless the mechanisms and long-term effects are known*". Foster [100] suggests cancer be added to the list of adverse side effects provided by the FDA.
4. **Truth in Advertising:** The above-mentioned occurrences call for an independent assessment of risks and benefits using implanted RFID tags so they can be advertised truthfully.

5. **Coercion:** Cottle (2006) (cited in [100]) stated the *New Republic Online* defended a proposal to implant RFID tags in sex offenders because such people are already subject to extensive restrictions and tracking via chips might be preferable. However, fundamentalist Christian groups in the US vehemently objected to such ideas as "marks of the beast". Judaism and Islam also prohibit tattoos and their religious heads may forbid implanted tags for similar reasons. The proposal from VeriChip to implant immigrant/guest workers indirectly forces some people to accept the chip because of poverty at home and the greater likelihood of a job in the US. This would be deeply offensive on the grounds of human rights and would be in violation of Article 3 of the Universal Declaration of Human Rights (1948) which guarantees right to "life, liberty and security of person". It would also be a violation of the privacy provision of the International Covenant on Civil and Political Rights (1966) to which the US is a party.

Foster and Jaeger [100] conclude that technologies such as fingerprint and retinal scans allow reliable identification of individuals without the need to compromise bodily integrity. They also quote Anderson and Labay's remark - "*a decision about where to draw the line of acceptable use must be made soon, before the technology becomes rampant and it becomes too late to prevent misuse*".

2.8 Barriers Impacting Adoption of RFID in Healthcare

The key barriers to adopting RFID include high up front costs and the global healthcare industry's main objection to adopting ICT solutions in general because paper is more reliable even though it is harder to manage [101]. In addition, barriers such as technological limitations, interference concerns, lack of global standards, privacy concerns, and social and legal issues also slow down the adoption of RFID in healthcare [51].

Fisher and Monahan [102] evaluated several RTLS systems currently in use in US hospitals. The results of their study showed most RTLS systems have substandard functionality, including material and organizational constraints that pose major obstacles to effective deployment of systems, not to mention the best use of RTLS is asset-tracking. Some reasons for the failure of RTLS systems are identified as: short battery life of tags; failure to achieve room-level accuracy when it comes to tracking which reveals the technological incapabilities of RTLS; the difference in the physical structure of every hospital may pose major deployment challenges; and the organizational culture of hospitals - territoriality and poor division of labor may result in limiting the scope of deployment. It was also noted that using RTLS to track people yielded worse results due to resistance from staff.

Katz and Rice [98] note that many object to the technology on religious grounds and that many web sites refer to the biblical chapter of Mark as justification for their opposition. Verse 16-17 states the Antichrist will "*causeth all*" to "*receive a mark in their right hand or in their foreheads and that no man might buy or sell, save he that* *had the mark*". This is quoted as a prophetic warning to resist RFID as the mark of the devil. However, experts in the industry are confident that despite these barriers, RFID in healthcare will be where wireless technology ends up.

2.9 Benefits, Success Stories and Future of RFID in Healthcare

Here, we discuss some of the benefits and successful implementations of RFID in healthcare and also briefly address the industry forecast concerning future prospects.

Improved patient safety, reduced medical errors, time and cost savings, and improved medical processes are some of the major benefits identified by Yao *et al.* [51]. ClearCount, (cited in [12]), states that nurses spend 15 to 30 minutes counting surgical sponges and other instruments after every surgery, costing more than $1 billion every year. When the count does not match, X-rays are taken to look for items inside patients costing $375 million, and any resulting litigation costs an additional $125 million. The ClearCount application that helps identify RFID tagged surgical sponges, improves patient safety, work efficiency and saves the image of healthcare professionals and hospitals by reducing the number of litigations. Chang-Gung Memorial Hospital in Taipei, Taiwan, achieved time savings of 4.3 minutes per patient to perform a patient identification/verification procedure with an accuracy level of 100% for patient identification [12]. Virginia Hospital realized a net savings of USD$3 million over the first 3 years after implementing RTLS from Agility Healthcare Solutions [12]. The system was used to track over 10,000 pieces of equipment. The RFID Lab Specimen Tracking System claims to achieve an error-rate of less than 1%, which is far below average lab error rates [26].

Saarijarvi [101] predicts a promising future for RFID in Healthcare. It is noted that "*RFID tops the chart in medicine with vastly increased safety, efficiency and ROI*". For example, staff can quickly identify an optimal bag of blood from a blood bank freezer close to its expiry by using RFID that can read as many as 400 bags per second. Needless to say, with barcodes this is an impossible task to carry out in freezers that maintain subarctic temperatures. After implementing an RFID/infrared tracking system in 2010, Mission Hospital in California posted an ROI of 186% within a year. The system also boosted device utilization rates, eliminated equipment rentals/thefts, and equipment shrinkage dropped from $150,000/yr to zero. When trauma cases came to the hospital, equipment was ready and waiting because of the ability to locate it within seconds. After their huge success with RFID in other areas, Mission Hospital is planning on expanding the system to prevent cross-contamination (hand washing for example, the number one preventer of cross-infection in hospitals). Healthcare professionals will receive alerts on their mobile devices should they forget/neglect to wash their hands after moving in and out of patient rooms. The forecast is that in 15 years, all healthcare processes will be electronically managed because RFID enables hospitals to do things they have never done before.

3 Future Direction

Here we present some research directions for RFID in healthcare so it can be safely and securely deployed.

- Most of the literature addresses the application of RFID in healthcare in one form or another. But not many address the security and privacy issues RFID may cause in healthcare, even though there are few security protocols specifically designed for this sector. It is vital this gap be filled. Recent developments by Sundaresan *et al.* [88] and Sundaresan *et al.* [89] address this gap in the context of grouping proofs and this can be extended to other areas.
- As seen in Section 2.4, several contradicting reports about electromagnetic interference due to the use of RFID. There is a definite need for further research to qualitatively and quantitatively measure this factor. Ensuring RFID is a safe and reliable technology to be used in healthcare is vital to increase consumers' confidence in the technology as well as in the healthcare system.
- Implantable RFIDs and the impact it could have on humans is still among the major unknowns. Though there are some reports that make speculations, further in-depth research needs to be undertaken to clearly identify the pros and cons of such systems before large-scale implementations are encouraged.
- The medical industry does not have any universal standard RFID products or practices [12]. Hosaka [103] recommends following the use of anti-medical tags in healthcare, reducing Q (the quality factor) in the resonance circuit of tags to improve the communication distance, and adhereing to 125KHz and 2.4GHz bands as the communication frequency. The need for universal standards for RFID enabled healthcare products is apparent.
- While the benefits of RFID in terms of work efficiency, and cost savings are discussed, statistics on how RFID has helped to reduce medical errors (or even the number of deaths) were not found. It would be interesting to find out if the implementation of RFID has improved the situation. A detailed survey of the hospitals before and after RFID would provide a good answer. As seen, the statistics shown in Section 1.1 depict the dark side of the medical industry. A thorough research on the after-effects of deploying technologies such as RFID would not only help improve the consumers' confidence in the medical system but definitely help improve the image of RFID and promote the technology further.

4 Summary

In this chapter, we provided extensive coverage of RFID in the healthcare context, in order to gain a clear understanding of current trends and to explore future prospects. Analysis included areas such as RFID based healthcare applications (including sensor based and implantable tags); Electro Magnetic Interference (EMI) and RFID; healthcare specific security protocols; security and privacy issues posed by RFID in healthcare; ethical implications; factors acting as barriers in the adoption of RFID in healthcare; benefits reaped from the system; and finally, the future of RFID in healthcare. This holistic approach aims to help the common healthcare users who wish to gain an understanding of RFID's impact in healthcare, and serve as a guide for Information Technology professionals to design innovative applications and motivate further research in the area.

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Questions

Q1. Discuss the Role Played by RFID with Sensor Capabilities

Q2. Comment on EMI Effects due to the Use of RFID in Health Care

Q3. Discuss Any Five Health Care Applications That Uses RFID

Q4. Comment on On-Body /Implanting RFID in Humans

Q5. Comment on Security and Privacy Requirements of RFID in Healthcare

Q6. Discuss about Ethical Implications of RFID in Healthcare