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Review Article

A review of radio frequency identification technology for the anatomic pathology or biorepository laboratory: Much promise, some progress, and more work needed

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Abstract

Patient safety initiatives throughout the anatomic laboratory and in biorepository laboratories have mandated increasing emphasis on the need for accurately identifying and tracking biospecimen assets throughout their production lifecycle and for archiving/retrieval purposes. However, increasing production volume along with complex workflow characteristics, reliance on manual production processes, and required asset movement to disparate destinations throughout asset lifecycles continue to challenge laboratory efforts. Radio Frequency Identification (RFID) technology, use of radio waves to communicate data between electronic tags attached to objects and a reader, shows significant potential to facilitate and overcome these hurdles. Advantages over traditional barcode labeling include readability without direct line-of-sight alignment to the reader, ability to read multiple tags simultaneously, higher data storage capacity, faster data transmission rate, and capacity to perform multiple read-writes of data to the tag. Most importantly, use of radio waves decreases the need to manually scan each asset, and at each step, identification or tracking event is needed. Temperature monitoring by on-board sensors and three-dimensional position tracking are additional potential benefits of using RFID technology. To date, barriers to implementation of RFID systems in the anatomic laboratory include increased associated costs of tags and readers, system software, data security concerns, lack of specific data standards for stored information, and potential for technological obsolescence during decades of specimen storage. Novel RFID production techniques and increased production capacity are projected to lower costs of some tags to a few cents each. Potentially, information security concerns can be addressed by techniques such as shielding, data encryption, and tag pseudonyms. Commitment by stakeholder groups to develop RFID tag data standards for anatomic pathology and biorepository laboratories could avoid or mitigate the "islands of data" dilemma presented by barcode usage where there are innumerable standards and a consequent paucity of hardware or software "plug and play" interoperability. Work remains to be done to establish the durability and

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appropriate shielding of individual tag types for use in harsh laboratory environmental conditions, and for long-term archival storage. Finally, given the requirements for long-term storage of biospecimen assets, consideration should be given to ways of mitigating data isolation due to eventual technological obsolescence of a particular RFID technology or software.

Key words: Challenges, implementation, radio frequency identification tags, standards

INTRODUCTION

Radio Frequency Identification (RFID) is an automated wireless technology that uses radio waves to remotely communicate data between an electronic tag and a reader, generally for the purpose of identification and tracking. Originally developed in World War II for use in military aircraft radar identification systems, RFID has gained civilian acceptance in today's world of "smart labels." Considered a technological leap from barcodes,[1] RFID has been applied successfully by a wide spectrum of industries, including healthcare, for a variety of applications. For example, large-scale retail chains such as Wal-Mart have utilized RFID to achieve real-time, automated item product tracking and inventory control. Other applications include livestock and endangered animal tracking via subcutaneously implanted Identification (ID) tags, parking and toll payment systems, library inventory control, as well as anti-counterfeiting systems.[2] Given the promising results of RFID adoption in other industries, there is an increasing interest in developing innovative RFID solutions to improve healthcare efficiency and enhance the quality of patient care. With the current US healthcare system spending on RFID systems estimated at approximately $90 million, and 10-year projections estimating growth to almost $2 billion,[3] the RFID technology and its applications warrant further research and analysis for its applicability to the anatomic pathology laboratory. Initial healthcare applications have included patient identification and tracking, electronic health records storage, surgical instrument and hospital equipment tracking, medication tracking, as well as product authentication.[4] While the potential benefits of adopting RFID technology for use in pathology appears significant, the relatively limited adoption that has occurred to date, can be attributed to several challenges including costs associated with tags and readers, data security concerns, lack of laboratory-specific data standards for the information stored on the tag, physical durability of the tags, and the potential for technological obsolescence. In this review, we will discuss the basics of the technology, its uses in other industries, potential applications in pathology, current barriers to adoption, and highlight potential solutions to these barriers and also possible research initiatives that can help facilitate widespread implementation of this technology.

Types of RFID tags

While RFID technology has a variety of applications, encompassing an array of features and different price points. At the basic level, most applications of the technology serve a similar purpose: To identify a specific item as it moves through a particular point in a workflow process, and account for the event as a transaction in a back-end database. The components of an RFID system include an electronic tag, a tag reader, and associated software system. RFID tags store unique ID information, while RFID readers detect and communicate with tags through a generated radio frequency field to extract the stored information.[5] RFID tags can be broadly classified as either of active or passive type [Table 1]. The active type incorporates an internal battery to provide an extended transmission range.[6] Conversely, the passive type lacks an internal power source and instead converts radio frequency energy, emitted by an RFID reader's transmit function, into electrical energy that powers the integrated circuit of the tag.[1] With this electrical energy, the integrated circuit then transmits tag data back to the RFID reader's receiver function, which interprets the tag's signal into meaningful data strings.[1] With no power source to wear down, passive RFID tags, when properly protected from environmental conditions, are known to

Table 1: Comparison of active and passive RFID tags

Active	Passive
Requires internal battery	Powered by radio frequency energy from reader
Function limited by battery lifespan	No battery limitation
Higher cost	Lower cost
Requires increased size for battery	Small and practical for specimen labeling
Average read range of about 18 m or 60 ft	Read range of up to 4.6 m or 15 ft
Less sensitive to radio frequency interference	More sensitive to radio frequency interference
Higher data transmission speed	Lower data transmission speed

survive for years and, in theory, can do so indefinitely if they remain physically intact.[1] Eliminating the internal battery also allows passive tags to be smaller, lighter, and more inexpensive than active tags. On the other hand, active RFID tags can be read with relatively imprecise aiming of the reader, are less sensitive to ambient radio frequency interference from electronic devices or other wireless devices such as routers or mobile phones, and have higher data transmission rates than passive tags.[7] Each type of tag may have potential usage within the anatomic laboratory. Owing to their durability, small size, and relatively lower costs, passive tags may be a good option for high volume, general tracking laboratory applications. Active RFID tags may be best utilized for biospecimens with specialized needs. An example might include frozen tissue specimens used for clinical trials that require the ability to monitor temperature fluctuations of the individually stored biospecimens for quality assurance purposes.

RFID tags may be additionally classified by the radio frequency with which the reader and the tag communicate. Currently, there are four categories of RFID frequencies [Tables 2 and 3]. Microwave frequency, Ultra-High Frequency (UHF), High Frequency (HF), and Low Frequency (LF).[8] On the upper end of the radio spectrum, microwave frequency tags are used extensively for active RFID systems, whereas UHF tags are commonly used in passive RFID system, such as those for retail supply chains or applications requiring read distances of several metres. HF tags have much shorter read distances than UHF tags and can be found in applications such as laundry and library book tracking. LF tags have the shortest read range and have been used in applications such as security access and livestock, pet, or endangered animal tracking. The choice of tag type in a laboratory setting would depend on the local environment, intended use, and the size of the tracked object. For example, if security is of prime importance, a very short read distance may be desirable to mitigate electronic eavesdropping. On the other hand, to minimize manual processing and permit a more seamless workflow, a greater read distance may be desirable.

Potential for Using RFID Technology in the Laboratory

Patient Safety and Increasing Workflow Efficiency

With the growing concern for preventing medical errors, there is an interest in leveraging RFID technology for improving patient care and safety.[4] Pressures to reduce expensive labor costs encourage evaluation of RFID tags for improving workflow efficiency. While RFID

Table 2: RFID frequencies- Properties and general applications

RFID type	Frequency range	Read distance	Transmission rate	General application
Low frequency (LF)	Less than 0.300 MHz[1]	0.45 m or 1.5 ft[1]	~5-98 kbps[8]	- Security access - Automobile immobilization - Personal and ranch animal ID[1]
High frequency (HF)	3-30 MHz[1]	0.91 m or 3 ft[1]	~106 kbps[9]	- Library book ID - Clothing ID[1]
Ultra-high frequency (UHF)	860-950 MHz[1]	1.8-4.6 m or 6 to 15 ft[1]	~115.2 kbps[10]	- Toll roads - Rail car IDs[1]
Microwave frequency	2450-5800 MHz[1]	2.5-30 cm or 1-12 inch[1]	~435.2 kbps[8]	- Toll collection - Anti-counterfeiting[1]

Table 3: RFID frequencies- Advantages and disadvantages

RFID type	Advantages	Disadvantages
Low frequency (LF)	Communicates best with items containing water or metal	Large tag size due to bulky antenna coils Higher tag costs Limited capability to read multiply tags simultaneously (anticollision)
High frequency (HF)	Tags can be flat labels, some with 1 cm diameter Lower tag costs than LF Established global manufacturing standards	Difficult to read multiple HF tags simultaneously in densely packed items such as slides
Ultra-high frequency	Increasing diversity in tag sizes and shapes, including small tag sizes for tagging slides and tissue blocks Established global manufacturing standard ISO 18000-6C Good capability to read multiple UHF tags simultaneously Lower tag costs	Typically does not function well when surrounded by high water or metal content Actual frequency varies by country
Microwave frequency	Small tag sizes	Limited number of suppliers Higher costs More common for active tags

technology has found numerous applications in the hospital setting, from patient identification[2] to tracking pharmaceuticals,[9] its use in pathology laboratories is still in infancy. The tradition of using hand-written logs documenting specimens at different steps of the workflow, such as recording when tissue cassettes are loaded on the tissue processor or recording when blocks are positioned at the microtome is decidedly laborious and error-prone. The recently implemented barcode-driven approach has expedited workflow while enhancing tracking,[10] but still requires the manual step of scanning the asset. Barcode scanning requires compliance and an additional motion to move the asset barcode into the barcode reader's line of sight or, alternatively, motion to move barcode reader over the asset barcode. Furthermore, this process is vulnerable to issues such as paraffin obscuring the barcode on a tissue cassette, which usually requires work stoppage for removing the paraffin in order to proceed.

RFID does not require a direct line of sight for reading, which means that tags may be read through fluids, fabric, plastic, cardboard, or other materials that are transparent to the operating frequency.[11] With an RFID tag of sufficient range and proximity to the reader, the tracking process is transparent to the histotechnologist, resulting in an enhanced ability to identify the asset as well as capture event data of the biospecimen, without requiring a change in their task-specific workflow. Examples of RFID application in the pathology laboratory include: (1) the use of glass-encapsulated passive RFID tags placed in specimen cassettes in a high-volume anatomic pathology laboratory to drive workflow and create an audit trail,[12] (2) the integration of RFID tags into tissue cassettes and slides along with building readers into workstations to bolster safety and reduce the probability of mistakes in histopathology processes,[13] and (3) the use of RFID tags to track specimen jars from endoscopy suites to the pathology accessioning area, reducing labeling error rates from 9.29% (without RFID) to 0.55% (with RFID).[14]

In the blood bank setting, using matching passive RFID tags (one attached to patient wristband and one attached to units of the correct blood type intended for transfusion) has significantly diminished potentially fatal mistakes in blood transfusion.[15] Such an approach opens the door to unique identification of a patient with an RFID transponder at the time of admission, facilitating the linking of all procedures and specimens over the course of the patient's hospital admission.[16] Therefore, all procedures (ie, bone marrow biopsies, surgeries, and autopsies, as well as biospecimens, including blood, urine, and surgical specimens) could leverage a patient-specific RFID wristband to correctly link the patient to his procedure or biospecimen. With appropriate software, the biospecimen containers could subsequently be labeled with RFID tags and coregistered to the patient and their wristband RFID tag. An appropriately designed information system along with strategically placed RFID readers could then facilitate tracking of the biospecimen throughout its workflow. This approach, using RFID-mediated linkage of the patient and biospecimen, would help eliminate the possibility of labeling a specimen container with the incorrect patient's ID label, a classic error that often results from leaving a prior patient's labels in the operating room.

Increased Data Storage, Read-Writable Memory, And high Reader Throughput

RFID technology offers several advantages over traditional barcode systems [Table 4]. First, RFID tags can contain more information, support faster data transmission, allow specific detection of target individual assets surrounded by most others, and can simultaneously read multiple tags.[17] Standard 1D barcodes (eg, UPC codes on retail items) are limited to approximately 12-20 characters, have a slow data transmission rate, and can only be read one by one.[18] While new 2D matrix barcode symbologies can store as much as 3,000 alphanumeric characters or 3,800 numbers, and are comparable to RFID tags in storage capacity, these generally have diminished redundancy capability similar to a traditional 1D barcode. Currently, RFID memory capacities of approximately 32,000 alphanumeric characters are available and technological progress is expected to increase memory capacity.[19,20] Furthermore, the RFID reader's ability to read 100-250 RFID tags per second has been leveraged to assess RFID-tagged contents within shipping containers, which would translate to applications where bulk shipments are delivered to the laboratory.

Table 4: Comparing RFID and barcode

RFID	Barcode
Does not require visual line of sight	Requires line of sight alignment
Increased transmission speed and data payload	Reduced transmission speed and data payload
Encapsulatable-increased protection from environmental conditions	Greater exposure to external damage
May be read simultaneously with multiple tags	Must be read individually
Allows transparent, automated tracking eliminating human error	Manual scanning susceptible to compliance and disrupts workflow
Supports read-write capabilities	Limited to read-only
Temperature tracking capacity	Restricted to identification data only
May potentially provide 3D position tracking	No position tracking capabilities

In contrast to barcodes, a read-only technology, RFID tags may support read-only, read-write, or "write once, read many" functions, a feature that expands their potential applications. Identification information stored in a read-write tag can be updated and revised immediately as it passes a reader,[21] a function that could provide information storage redundancy on the RFID-labeled biospecimen itself, in addition to the information system. Tags can, in principle, be written over 100,000 times. A potential use might be to automatically track how often a cryovial has been removed from a freezer, and therefore the number of freeze-thaw events. Time stamps may also be stored in a read-write RFID memory, potentially allowing tags attached to slides, tissue cassettes, or other assets to track and log the time and location a specific test or process was completed for the tracked item.

An additional advantage of RFID technology includes the ability to record data provided by onboard or linked sensors. An RFID temperature sensor could identify biospecimens and also ensure that they remain within a safe temperature range,[22] a valuable proposition for biorepositories and anatomic pathology laboratories. Temperature tracking has been applied successfully by Belgian health care provider GasthuisZusters Antwerpen (GZA) to monitor the temperatures of refrigerators and freezers containing high-value assets such as pharmaceuticals, tissues, and blood and plasma.[23] RFID tags with onboard sensors can potentially record temperature, pressure, or humidity data of tracked biospecimen, alert staff when environmental conditions deteriorate beyond preset parameters (ie, freezer malfunction), and provide a log of these conditions for later reference.

Three-dimensional Localization in Archives

When filing slides or blocks manually, it is not difficult to accidentally make a numerical transposition and misfile on that basis, or to include a slide from another case in the midst of another case's slides. Therefore, an ideal application for RFID technology would be to have detection capabilities sufficient to detect a misfiled slide in the archive. In the same vein, a library in Malaysia has built prototype smart shelves that can localize misfiled RFID-labeled books.[24] Real-time locating systems that allow Three-Dimensional (3D) position tracking of RFID tags via triangulation methods exist. Such systems have been developed for active tags, which broadcast their position through a radio beacon. The radio beacon is located by triangulation whereby the beacon signal is detected at slightly different times by different receiving antennas spaced at known distances. Using the known distance between antennas and the constant speed of the radio signal, the position of the signal source (RFID tag) may be calculated to a reasonable degree based on the difference in receiving times of the antennas. The same triangulation technique may be applied to passive tags, but the results have been less accurate, mostly due to the proximity of reader antennas, which increases the difficulty to discriminate return signal timings. The Science Application International Corp, contracted by the US General Services Administration, recently developed and integrated RFID real-time locating system scheme capable of determining the location of a tag with an accuracy of approximately 6-12 inches.[25] Further developments in positioning accuracy may expand the potential for RFID localization application in the pathology setting. A novel potential application lies in integrating robotics with RFID tracking for specimen retrieval. In one experiment, a mobile two-wheeled Pioneer 2 robot equipped with a laser range-finder and a 915-MHz RFID reader with two RFID antennas was able to locate and retrieve 100 tags in a 28-by-28 metre environment and generate a two-dimensional occupancy grid map.[26] One of the nightmares of the laboratory supervisor is the misfiled slide in the file room. Perhaps, one day, RFID will be leveraged to detect a misfiled item, and a robot will be able to retrieve and deliver this misfiled asset to the supervisor, dramatically decreasing search times. While an attractive thought, affordability and current reality remain a long way off for this scenario.

Barriers and Solutions to RFID

Lowering Cost

The most significant obstacle to widespread adoption of RFID tracking systems is cost [Table 5]. While RFID tags may currently be available from as low as 15 cents per tag (when purchased in volumes of 1 million tags or more,[27] this cost remains much higher than that of barcodes, which is 0.5-2 cents per label. The price of a passive RFID tag will depend on its frequency, memory, antenna design, and packaging or protective covering of the transponder.[28] New technological advances in printing RFID tags using carbon nanotube-based production techniques enhance the potential for using a roll-to-roll high-volume printing process to lower RFID costs to a 1 cent per tag price-point.[29] Unlike silicon-based tags currently used for RFID systems, thin-film carbon nanotube-based RFID labels printed onto paper or plastic could provide an inexpensive alternative, reducing costs for the base materials and supporting just-in-time manufacturing processes, similar to how barcode printing has been implemented in the laboratory.[29] We believe that development of this technology would permit on-demand production of a "triple-labeled" asset, containing human readable information, barcode-embedded data, and data stored in an RFID tag. Current challenges to bringing this technology to production laboratories include the need to reduce label sizes used, and the need to increase RFID label read distances.[30]

Implementation of RFID systems include additional costs such as those for RFID readers ($50-$3,000 each[28,31]), middleware to filter RFID data and software applications

Table 5: Challenges and solutions to RFID technology adoption

Challenges	Solutions
Cost for tags and implementation of RFID systems	Benefits of RFID technology, cost-reducing technology, and increased demand in conjunction with high-volume production
Potential for compromised patient information confidentiality due to open communication channels	Password protection, tag pseudonyms, or database protection may resolve privacy issues
Data standards for common RFID practice between institutions	API or CAP data standards may resolve uniformity and quality issues
Tag durability requirements for harsh conditions found in the pathology setting	Additional testing may be required to augment existing data
RFID system or tag obsolescence	Redundant and back-end barcode systems or upgrade of RFID systems may be required periodically

(from $25,000 for a small operation to hundreds of thousands for an enterprise-wide system,[32] technical support, management infrastructure, change in protocols, and upgrade expenses. However, expenditures will vary depending on operational volume, type of tag desired (additional features often correspond to higher prices), and specific needs of individual pathology practices. On the other hand, additional infrastructural costs for barcode systems including investment for scanners (as much as $400-$600 each[33]), software systems ($300-$1500 per station[33]), labor costs for manual labeling and scanning, technical support, and management infrastructure must be taken into account as well.[17] The difference between RFID and barcode hardware costs has blurred considerably with greater adoption in the commercial world. While the cost of implementation and operation of an RFID system may appear daunting, expenses can be offset by efficiency benefits inherent to using an RFID system, by ongoing cost-reducing advances in RFID technology, and by consortium-based volume purchasing discounts [Table 5]. As 10-year growth projections estimate a 20-fold increase in the US healthcare spending on RFID technology,[3] increased demand for RFID may drive developments in technology to lower associated costs through high-volume production.

Confidentiality and Encryption

Privacy and confidentiality of patient information stored in RFID tags remains a high priority and challenge to broad adoption of this technology in the pathology laboratory. Because radio wave frequencies utilize invisible communication channels, securing information that is communicated presents considerable technical difficulties.[34] For example, in libraries that have adopted RFID technology, an unauthorized reader may be able to detect RFID tags embedded in books and track books checked out by library users.[35] In hospitals, unsecured RFID tags encoding patient information have the potential to be read by any RFID reader, creating a potential for unauthorized access to confidential patient information.[34] Unfortunately, the very properties that make RFID technology attractive for implementation in the laboratory (ie, ease of use, non-line of sight, ability to scan through barriers/objects) also make it vulnerable to nefarious access. This challenge must be overcome for widespread adoption.

Fortunately, RFID privacy concerns may be addressed through the usage of password protection, RFID tag pseudonyms, or via database protection. Even a basic passive RFID tag has sufficient resources to verify Personal Identification Numbers (PINs) or passwords associated with data.[35] Pathology practices could program tags to respond to a specific password emitted only by an authorized RFID reader on the network. Again, the drawback to implementing this solution is the increased cost: RFID tags equipped with password protection generally cost more due to this additional feature.[35] RFID tag pseudonyms use a different approach to enhance information security by creating a set of false tag serial numbers, which tag cycle through when read.[36] While unauthorized scanners receive meaningless pseudonym serial numbers because each read event prompts the RFID tag to reply with an altered pseudonym each time it is queried, authorized readers can specifically interpret the set of tag pseudonyms.[36] While RFID pseudonym security may still be penetrated by highly malicious and intentional unauthorized readers, it requires only a small upfront tag costs, and reader programming costs, and is especially attractive in settings in which passive eavesdropping is a primary concern.[35] Lastly, database protection shifts the storage of confidential patient information to a secure database rather than putting this information directly on the tag. In this scenario, each RFID tag contains only a unique ID number that can be used to access the corresponding patient information stored in the database. Data are retrieved only by matching the ID number on the tag with the same number that was assigned to the corresponding patient information.[16] Without access to the database system on the network, the stored ID number is essentially useless. This mechanism leverages network security protocols, such as Wi-Fi protected access (WPA), a system that secures wireless networks through authentication and encryption.[37] Because most pathology information are already stored in laboratory information systems, this approach may be best suited for implementation in the pathology laboratory setting.

The security and confidentiality of this information doesn't just affect RFID implementation, as barcodes are also highly susceptible to unauthorized scanning. In addition, human-readable information, such as patient name, case number, and surgery ID number are often printed alongside barcodes, easily read by any passerby. Security measure will likely vary by setting and applications. Modest measures including shielding and using a short transmission range may be sufficient to guard against "RFID eavesdropping." However, for shipping of slides and tissue blocks through the mail, shielding or other security measures will likely be desirable.

Technology Standards and Interoperability

As with barcodes, copious efforts have been invested in developing standards for usage of RFID technology. The purpose of standards include: (1) to facilitate interoperability between different organizations; (2) to provide useful guidelines for components (ie, readers, tags, and software); (3) to broaden the potential usage and increase competition, ultimately lowering prices; and (4) to help build community acceptance and confidence in the technology.[38] Commercial entities use the Universal Product Code to standardize a single barcode type interoperable between disparate manufacturers and retailers.[39] The military uses numerous standards including MIL-STD-188-100, which ensures interoperability and performance of long-haul and tactical satellite communication systems.[40] In regards to RFID, standards have been developed around air interface communication protocols, data content, data communication, applications, and conformance to the standard [Table 6]. As the four different passive RFID frequencies lack interoperability [Table 2], establishing a standard RFID would be beneficial as well. Several leading standards organizations have developed RFID-related standards [Table 7].[41] In fact, in several industries, the number of RFID standards may be perceived to hinder adoption of RFID tags beyond the basic usage for unique identification due to the complexity of understanding and implementing these standards in the real world.[42]

One of the major limitations in the histology laboratory today is the use of proprietary barcode formats and contents for each vendor for assets and devices in the tissue to slide manufacturing process. A single barcode applied to an asset, printed from the laboratory information system, cannot guarantee that each device or process the asset participates in will be able to utilize this single barcode.

Other areas of the laboratory have recognized this fact and are ahead in the standardization of critical items. The International Council for Commonality in Blood Banking Automation, Inc (ICCBBA) manages the ISBT-128 global standard for identification, labeling, and processing of human blood, cell, tissue, and organ products across separate international healthcare systems. A component of this standard specifies a barcoding system for the transfer of information on the "product" label, including the type of barcode format (Code 128 and Data Matrix) to be used, as well as label formatting.[43] A recent proposal for guidelines on the use of RFID for transfusion medicine has been published.[44]

The Health Industry Business Communications Council (HIBCC) system adapted from International Organization for Standardization (ISO) standards for healthcare needs may provide the needed RFID hardware and systems interoperability in pathology.[45] The HIBCC system standardizes an internationally adopted air communication protocol (ISO 18000), a unique RFID tag manufacturer ID system to obviate ID duplication, uniform data protocol and tag memory organization, and multiple data identifiers including lot number, serial number, and expiration date.[45] The HIBCC identification system specifies the identity of an item by its unique serial number headed by the company ID, issuing agency ID, and appropriate data identifiers to guarantee the uniqueness of tagged assets.[45] A standardized frequency of 13.56 MHz for asset tagging is proposed as well.[45] HIBCC uses a common labeler identification code organization for barcodes, 2D barcodes, and RFID tags, ensuring the uniqueness of

Table 6: RFID standards

Standard	Description
Air interface communications protocol standards	Defines how the reader and the tag communicate, including physical characteristics of radio transmissions, structure of commands and responses, and "anti-collision" algorithms/methods for detecting and communicating with each tag in a dense multiple tag arrangement
Data content standards	Describes how information is to be formatted and stored on an RFID tag
Device communication standards	Describes how data are communicated from the reader to the computer
Application standards	Illustrates how products are used (ie, where does the tag go on an asset)
Conformance standards	Defines instructions for how devices are to be evaluated for compliance to a standard
RFID frequency	Sets a single, accepted radio frequency channel to avoid communication conflict between different frequencies

Table 7: RFID standards organizations

Acronym	Name	Industry	Type
EPC global	EPC global, Inc	Electronic Product Code consortium developing unique identification for supply chain items	International
IEC	International electrotechnical commission	Prepares and publishes standards for all electrical, electronic and related technologies	International
ISO	International organization for standardization	Standards across many industries	International
CEN	European committee for standardization	Business facilitator in Europe that develops standards that reduce trade barriers and develops standards in all areas except Electrotechnology and Telecommunications	Regional
NAFTA	North American free trade agreement	Business facilitator in North America to remove trade barriers between the US, Mexico, and Canada	Regional
ANSI	American national standards institute	Business facilitator in United States developing consensus standards and conformity assessment systems for many industries	National
E.U. Council	Council of European union	Main decision making body of the European Union	National
AAR	Association of American railroads	Standards for safety and technology for the Railroad industry	Industry
AIAG	Automative industry action group	Standards for all aspects of the automotive industry	Industry
ATA	American trucking association	Standards for the trucking industry	Industry
ETSI	European telecommunications standards institute	Standards for information and communication technologies including fixed, mobile, radio, broadcast, internet, aeronautical, and other areas	Industry
ERO	European radio communications office	Develops policies and regulations in the electronic communications and related applications for Europe	Industry

RFID tagged assets among barcoded assets.

Avoidance of ID collision (unintentional ID duplication between different manufacturers or between different user institutions) is built into most RFID systems, which are either proprietary or compliant to the ISO 15963 standard (for unique identification of radio frequency tags).[46] This standard mandates that RFID tags carry a unique manufacturer ID number and header that are assigned to the tag by the manufacturer. No two manufacturers share the same manufacturer ID number and header, thus obviating the risk for ID collision or duplication between companies. Should an RFID manufacturer cease tag production and system support, a possible event given the competitive volatility of the business environment, a replacement RFID manufacturer may be contracted without significant risk for ID collision as long as the replacement producer has adhered to ISO standards. In addition, tag users may add their own identification code(s) to the tags during commissioning. For example, UCLA could add "UCLA" to the tag data of all tags it consumes, a feature that would also mitigate ID collision should an RFID source cease tag production.

As the needs of pathology have some unique aspects, we believe that the Association for Pathology Informatics (API), perhaps in conjunction with other critical stakeholders, including the College of American Pathologists (CAP), the American Society of Clinical Pathology (ASCP), the Society of Laboratory Automation and Screening (SLAS), and other medical industry stakeholders, will need to proactively assess existing standards, adopt or modify as appropriate, promote a uniform system for generating identification codes, and establish a minimum bar of accuracy and quality for pathology RFID systems. Given that none of these major pathology organizations and stakeholders are The American National Standards Institute (ANSI)-accredited standards producing organizations, it will most likely be necessary to partner with a standards organization such as Health care Industry Business Communications Council (HIBCC), Clinical Laboratory Standards Institute (CLSI), Digital Imaging and Communication in Medicine (DICOM), or Health Level 7 (HL7). Alternatively, partnering with an organization that promotes adoption and use of standards such as Integrating the Health care Enterprise (IHE) may be useful, particularly considering the need to integrate several different standards. Otherwise, we can anticipate a situation similar to that existing in the pathology laboratory today with barcodes, and the need to continually relabel assets in order to facilitate automation devices.

Technological and Physical Durability of an RFID System

A pathology-specific requirement for RFID systems is the ability to function and endure the harsh laboratory conditions that high-value assets including biospecimens, tissue blocks, and slides are subjected to in the manufacturing and archiving process, such as exposure to chemicals during slide staining and tissue processing, or extreme temperatures during autoclave/sterilization or cryogenic storage.[46] While the Hitachi Mu-chip passive RFID tag has shown tolerance to most conditions encountered in pathology laboratories, additional testing of different types of tags and in larger testing samples may be required to ensure tag functionality prior to use in a pathology or biorepository setting.[47] An encapsulated RFID tag has the advantage over a printed barcode in that it is protected from exposure to solutions and solvents. To some degree, all tag frequencies are affected by nearby materials. The materials' dielectric property is the term used to describe how the material will alter, or detune RFID tag communication. In basic terms, water absorbs the RF energy and metals reflect or block it entirely.[48] During implementation of an RFID system, tag placement on an item relative to the item's contents needs to be evaluated and, in some cases, adapted and adjusted to compensate for the detuning or absorption effect, as practical. In most cases, frequency detuning is not a major concern in the pathology setting, though testing of specific laboratory conditions is recommended before installation of an RFID system to minimize the risk of frequency detuning.

The durability of an active RFID tag's battery remains a real limitation for its usage. Manufacturers often cite a lifespan of 5-10 years, depending on the transmission requirements placed on the active tag. Passive RFID tags reportedly survive up to 20 years, and may survive even longer. It is our observation that a majority of specimen retrievals from archives in our Department of Pathology, and in our brain tumor biorepository, are of materials collected in the last 10 years. This suggests that typical passive RFID tag lifespan would suffice for most pathology applications. However, one question that remains unanswered due to the limited penetration of RFID in the pathology laboratory is that labor savings during initial processing and retrieval efficiency gained over the typical lifespan of 10 years provides a return on investment that warrants the upfront increase in cost, particularly if tag failure rates increase over time.

RFID Quality Assurance and Backup

During production, a typical RFID tag and its individual components pass through multiple quality checkpoints designed to ensure the functionality of the produced tag. (1) RFID IC chips, like other semiconductor products, are quality tested at various points during manufacture; (2) inlays, or unlaminated RFID tags consisting of a chip attached to their antenna, are typically quality screened after assembly; (3) finished tags, or laminated inlays, are also quality tested for functionality at the end tag manufacturing; and (4) if the tag is a printed label fed through an RFID printer/encoder prior to placement on an item, the printer/encoder completes a final quality check and marks defective tags for non-use.

Owing to these extensive quality assurance measures, it is estimated that less than 1% of vetted RFID tags put into service are initially defective.[49] Our experience with deployment of approximately 4,900 RFID tags at a convention, in which only three tags failed, are consistent with that assessment. Another experience with a batch of 250 passive RFID tags did not yield any defective tags at initial reading. However, rare failures do occur, and these remain of concern as a fully operational pathology information system may deploy hundreds of thousands to possibly millions of RFID tags. Even an apparently "minor" defect rate of 0.1% in 1,000,000 tags means that 1,000 samples may not be readable. RFID network failures can occur when RFID readers and/or the operation system malfunction. To address both defective RFID tags and possible network failures, backup plans are necessary. Barcodes and human-readable labels are likely necessary safeguards in case of a network failure. A network malfunction alarm system is standard practice in most companies. Should a reader, server, or any other component of the RFID network breakdown, an alarm function within the system automatically alerts staff to respond immediately to the issue. It may then be possible to switch over to a barcode system or a paper trail approach to tracking items. A power failure would preclude using a backup barcode system. With paper-based tracking, imaging with digital cameras can be a potentially useful adjunct to document batches of slides or paraffin blocks.

Finally, consideration should be given to alleviate inevitable technological obsolescence of a specific RFID system and its platform software. Redundant barcode systems or back-end database solutions may mitigate transition between an obsolete RFID system and an upgrade to a new system. Strict adherence to ISO standards mandating manufacturer header codes can preclude risk for ID duplication between different RFID manufacturers, should a specific manufacturer cease production.

CONCLUSIONS

With significant advantages over the use of barcodes, including non-line of sight tag readability, higher data storage and transmission speeds, ability to perform multiple read-write events, ability to read hundreds of tags per second, and potential temperature sensing and 3D localization features, RFID technology presents a promising disruptive technology for automated tracking of high-value assets in the pathology laboratory. Fueled by global interests spanning multiple large-scale industries, further improvements in RFID technology should catalyze development of improved low-cost high-volume production techniques and new innovative features that speed adoption of RFID systems by the healthcare industry. Challenges to this adoption include the associated costs of implementation and operation of an RFID system, concerns for information privacy, and durability of the RFID tags subjected to manufacturing and laboratory storage conditions. Clearly, consensus by pathology stakeholders around major aspects of RFID technology including air-interface communication protocols, data content, device communication, application usage, and conformance standards is critical to avoid or mitigate the confusion experienced in the barcode setting where there are innumerable standards and a consequent paucity of hardware and software "plug and play" interoperability. Data standards promulgated by existing standards organizations and espoused by API or CAP in partnership with other healthcare industry stakeholders may be required to ensure uniformity of pathology RFID systems and a minimum requirement for accuracy and quality.

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