Radio-Frequency Identification Specimen Tracking to Improve Quality in Anatomic Pathology

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• ***Context.***—**Preanalytic errors, including specimen labeling errors and specimen loss, occur frequently during specimen collection, transit, and accessioning. Radio-frequency identification tags can decrease specimen identification and tracking errors through continuous and automated tracking of specimens.**

Objective.—**To implement a specimen tracking infrastructure to reduce preanalytic errors (specimen mislabeling or loss) between specimen collection and laboratory accessioning. Specific goals were to decrease preanalytic errors by at least 70% and to simultaneously decrease employee effort dedicated to resolving preanalytic errors or investigating lost specimens.**

Design.—**A radio-frequency identification specimen-tracking system was developed. Major features included integral radio-frequency identification labels (radio-frequency identification tags and traditional bar codes in a single printed label) printed by point-of-care printers in collection suites; dispersed radio-frequency identification readers at major transit points; and systems integration of the electronic health record, laboratory information system, and radio-frequency identification tracking system to allow for computerized physician order entry driven label generation, specimen transit time tracking, interval-based alarms, and automated accessioning.**

Results.—**In the 6-month postimplementation period, 6 mislabeling events occurred in collection areas using the radio-frequency identification system, compared with 24 events in the 6-month preimplementation period (75% decrease; $P = .001$). In addition, the system led to the timely recovery of 3 lost specimens. Labeling expenses were decreased substantially in the transition from high-frequency to ultrahigh frequency radio-frequency identification tags.**

Conclusions.—**Radio-frequency identification specimen tracking prevented several potential specimen-loss events, decreased specimen recovery time, and decreased specimen labeling errors. Increases in labeling/tracking expenses for the system were more than offset by time savings and loss avoidance through error mitigation.**

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A guiding principle of laboratory medicine is to reduce preanalytic, analytic, and postanalytic sources of error to continuously improve patient care. Laboratories that provide high-quality and reliable results address analytic and postanalytic sources of error directly, but preanalytic errors (eg, specimen mislabeling or loss), which are the largest source of risk in laboratory testing, frequently occur outside of the laboratory domain.[1–4] Pathologists often have limited oversight of practices in clinical areas collecting specimens, yet elimination of specimen-mislabeling errors remains a Joint Commission National Patient Safety Goals priority for laboratories,[5] and, ultimately, quality systems in pathology must address and mitigate all sources of preanalytic error to be effective.

The frequency of specimen loss in anatomic pathology is not known; it is thought to be rare, but estimates in the literature have ranged from 0.002% to 0.1%.[1,6] Mislabeling events are far more common and account for most preanalytic errors.[1] Root cause analyses of specimen mislabeling and loss events have revealed various sources of error, including mix-ups due to specimen and label batching, failure to label specimens, incorrect (wrong patient) specimen labels, manual data entry errors, and loss during transport from collection site to laboratory.[7] Technology has been instrumental in preanalytic error reduction; in particular, computerized provider order entry and specimen bar coding have fostered major decreases in error rates.[8,9] Properly implemented computerized provider order entry standardizes ordering processes, eliminates missing order components, and notifies the laboratory to expect a specimen.[10] Bar coding of specimens for tracking and identification has most likely been the greatest contributor to decreases in preanalytical error and has also enabled the use of automation in specimen accessioning and processing.[11] Yet, despite these successes, specimen identification

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Table 1. Types and Characteristics of Commercially Available Passive Radio-Frequency Identification Tags				
Tag Type	Frequency Range	Practical Range	Interference From Metal/Water[a]	Passive Tag Size[b]
Low frequency	125 KHz and 134 KHz	<15 cm	+	++++
High frequency	13.56 MHz	<1.5 m	++	+++
Ultrahigh frequency	433 MHz; 860–960 MHz	<5 m	+++	++
Microwave	2.45 GHz; 5.8 GHz	<1 m	++++	+

[a] Rated as follows: +, minimal; ++, moderate; +++, significant; ++++, extensive.
[b] Rated as follows: +, small; ++, small to medium; +++, medium to large; ++++, large.

and tracking errors still occur, and there remains a need for technologic and process solutions to further reduce such errors in pathology practice.

Radio-frequency identification (RFID) tags have been proposed as a potential solution for specimen identification and tracking in anatomic and clinical pathology.[12–14] Radio-frequency identification tags are small integrated circuits with an antenna.[15] Tags are available in active (battery-powered) or passive (deriving energy from the radio signal emitted by the reader) varieties and operate within a series of regulated frequency ranges, from low frequency to microwave (Table 1).[12,16,17] Passive RFID tags are powered entirely by the radio-frequency signal emitted by the tag reader, with size and range characteristics determined by the frequency of operation and type of coupling that powers the tag.[18] Radio-frequency identification is widely used in sectors such as manufacturing, agriculture, finance, retail, and government.[15] To date, RFID has seen some limited adoption in health care for applications that include patient identification and localization, staff identification and localization, pharmaceutical inventory, equipment tracking, and supply chain management.[19]

Current examples of RFID use in laboratory medicine and pathology include blood product tracking and specimen labeling and tracking; although experiences with RFID tracking in pathology are limited, the reports have been largely positive.[16,20,21] In a trial implementation involving a 14-bed bone marrow transplant unit and remote emergency department blood storage unit, the use of RFID technology led to an 83% reduction in process errors and 10% reduction in labor expenses (system payback calculated at 2–5 years) in their transfusion medicine practice.[21] Two studies have reported on RFID specimen tracking for anatomic pathology. One study observed significant decreases in both minor and clinically significant labeling errors after introduction of RFID to an outpatient gastrointestinal endoscopy practice.[20] Another pilot study of end-to-end RFID specimen labeling and tracking of 1067 prostate biopsy specimens through preanalytic, postanalytic, and analytic phases reported significant workflow efficiencies but limited overall success (78.3% of specimens) in specimen tracking, largely because of software errors and tag failure.[16]

In 2007, investigators at our institution launched a pilot study using a high frequency (HF; 13.56 MHz) Library Sciences RFID system (3M) for tracking endoscopy specimens from gastroenterology and colorectal surgery (GI/CRS).[20] During the initial 3-month period, HF RFID tracking led to a large decrease in the number of mislabeled or unlabeled specimens, from a baseline of 765 to 47 (93%). Importantly, of those 47 errors, only 2 had the potential for patient harm, and because of the HF RFID system, both were identified and corrected before patient harm could occur. In the subsequent years, HF RFID tags continued to perform well, leading to consistently lower specimen mislabeling rates when compared with other high-volume specimen collection areas in the institution. A recent annual review showed a 0.12% rate of hard-stop errors (errors or labeling issues that required a process delay for resolution) for RFID GI/CRS specimens, versus 0.87% for non-RFID specimens from other areas.

Despite the clear success of the HF RFID project in reducing errors, the system had limitations. The passive HF tags required manual activation and had to be separately affixed to the specimen container (in addition to the specimen label), which required an estimated 4.5 to 6 hours per week of staff time. Furthermore, the combined cost of the HF RFID tag and traditional bar code label was approximately $1.00, which was a substantial labeling expense for an area collecting more than 40 000 specimens per year. Although passive HF tags have a theoretical range of 1.0 to 1.5 m, in our experience the practical read range was only ≈0.3 m. This required both staff handling and physical contact between the specimen RFID tag and the RFID reader for tags to be read. In addition, the software supporting the HF RFID tracking infrastructure required user input for each specimen, which prevented batch processing. Although the HF RFID implementation led to marked improvements in quality outcomes, many of the theoretical advantages of the RFID technology over bar coding were not fully realized in the implementation. As a result, and despite the clear effectiveness of the technology, cost and workflow complexity limited the expansion of the HF RFID program to other specimen collection areas.

In response to near miss events (temporarily lost but recovered specimens) or actual loss events involving irretrievable and irreplaceable pathology specimens, an institutionally supported specimen tracking and identification initiative was formed at our academic medical center. The initiative resulted in a multidisciplinary task force to identify and implement a solution to improve the quality of specimen tracking. The group's work ultimately led to institution-wide implementation of RFID-based specimen tracking for high-volume biopsy collection areas. Here, we report on this experience and the initial results of the project in a 6-month postimplementation period.

METHODS

Environment

Our institution is a large integrated academic medical and tertiary care center with ≈2000 hospital beds and ≈90 operating rooms. Most inpatient and outpatient clinical services are provided within a 12–city-block radius that encompasses hospital buildings, outpatient clinical facilities, and clinical laboratory space. All sites use the same electronic health record (Epic, Epic Systems) and laboratory information system (SCC Soft, SCC Soft Computer). The division of anatomic pathology processes more than 110 000

Table 2. Baseline Quality and Cost Metrics and Quality Improvement and Cost Goals for the RFID Project

Goal	Baseline	Target[a]	Projected Results[b]
Average No./y of missing/not-found specimens	5	1.5	0
Average time to locate temporarily missing specimens, h/event	8	<0.5	<0.5
Average No./y of hard stops for labeling errors requiring follow-up	48	14.4	12
Relative GI/CRS RFID label expense, %	100	<20	<15

Abbreviations: GI/CRS, gastroenterology and colorectal surgery; RFID, radio-frequency identification.

[a] Targeted outcomes included 70% decrease in missing/not-found specimens, 70% decrease in hard stops for labeling errors, decrease in time to locate temporarily missing specimens to <30 min/event, and decrease in cost of GI/CRS RFID labeling expenses by at least 80%.

[b] Projections for annual rates or relative costs are based on the initial 3 months of postimplementation data.

surgical specimens and 60 000 cytopathology specimens per year from procedures performed on campus.

Project Details

Scope.—The project included representatives from 4 clinical departments: laboratory medicine and pathology, dermatology, radiology, and medicine (division of gastroenterology). The multiyear success of the prior HF RFID project in improving quality and reducing identification errors in specimens collected by the GI/CRS outpatient endoscopy unit (average of 200 specimens daily) provided a template for the implementation of RFID-based specimen tracking in the other departments, including the dermatology and interventional radiology practices (collectively generating approximately 300 specimens per day). The institution decided to pursue development of a specimen tracking infrastructure that could meet current needs and also have the potential for future growth and expansion to additional departments. With the extensive nature of the proposal, approval from institution governance and oversight committees was required. After a 6-month review period, a phased implementation was approved, and institution funding was provided for deployment of a new specimen tracking system for the department of radiology, for replacement of the existing GI/CRS HF RFID specimen tracking system, and for subsequent expansion of RFID tracking to the department of dermatology.

Team.—The project team was composed of a pathologist, a radiologist, a gastroenterologist, a dermatologist, a project manager, a business analyst, industrial/systems engineers, and allied health and operations personnel from each respective department.

Outcome Requirements.—The primary (patient safety) project requirement was to establish a specimen tracking infrastructure that enabled a sustainable improvement in core safety and quality metrics over the preimplementation baseline. Baseline metrics for participating departments were established from a retrospective analysis of (1) projected annual specimen-loss events (estimated using specimen volume with a calculated loss of 0.002%),[6] (2) average number of reported mislabeling events, and (3) average time to locate a temporarily lost specimen (Table 2). Improvement goals were established for each metric (70% decrease in specimen loss or mislabeling events, and a decrease in time to locate a recoverable specimen to <30 minutes) on the basis of the expected performance of the RFID system and influenced by our institution's prior RFID experience (Table 2). Secondary (cost and workflow) requirements included reducing labeling costs, maintaining at least the current state for existing RFID functionality but with improvements in batch processing, and capturing specimen-tracking data for development of quality metrics. Outcome measurements were planned for 3, 6, and 12 months after each departmental implementation.

Table 3. Comparison of Bar Coding and Passive Radio-Frequency Identification

Feature	Bar Coding	Radio-Frequency Identification
Line of sight required	Yes	No
Batch processing	No	Yes
Manual scanning required	Yes	No
Susceptible to radio-frequency interference	No	Yes
Cost	Low	High

With regard to cost, the goal was for the new RFID system to reduce ongoing labeling expenses by at least 80% compared with the existing HF RFID system. Functional requirements for a new RFID system were to (1) maintain current state functionality (wireless encoding and transmission of a unique specimen identifier), (2) add capability for batch processing of at least 40 simultaneous specimens, (3) allow generation of a single integral label/tag, and (4) store tracking data in a common database standard, to enable access for quality metric development and future quality-improvement initiatives.

Choice of RFID Technology.—The dominant technology for specimen tracking in medicine is bar coding. Bar coding uses optically recognized machine-readable labels to encode specimen-identifying information. The widespread adoption of bar coding in the laboratory has led to immense improvements in quality over paper-based and manual entry systems, and the technology is now commoditized.[11] Radio-frequency identification is an emerging competitor to bar coding in the specimen-identification space and has several advantages and disadvantages (Table 3) (reviewed in Lou et al[12] and Hanna and Pantanowitz[13]). For the purposes of specimen tracking, the key advantages of RFID technology over bar coding are the automated tracking and batch processing features, which substantially decrease the number of manual interactions necessary to track or accession specimens. Major disadvantages include cost (both of infrastructure and per tag) and the potential for radio-frequency interference, which must be investigated in the areas of application.

The previous RFID implementation at our institution used passive HF tags, the most common technology described in pathology applications to date. The favorable physical characteristics of the HF range (13.56 MHz) make it a logical choice for many health care applications, but we opted against HF tags for several reasons: (1) the magnetic coupling required to generate a signal from HF tags substantially limits their effective range (in our experience, read ranges averaged only 0.3 m); (2) HF tags are comparatively bulky, and it was difficult to identify a vendor that could supply point-of-care printers capable of generating a single integral HF RFID tag/label; and (3) HF RFID tags remain expensive and prices have not decreased as quickly as some competitive RFID technologies.

After the options were considered, a system using passive ultrahigh frequency (UHF) (902–928 MHz) RFID tags was selected (Quake Global, Inc). Passive UHF RFID tags have advantages in both range and cost over HF RFID tags but are potentially susceptible to greater interference from metal, water, and other sources of radio-frequency signals (ie, medical or industrial devices). The decision to use UHF tags was reached after in-house testing showed no notable radio-frequency interference or difficulties in tag reading with UHF tags affixed to any of the more than 10 styles of specimen containers (ranging from lavender-top tubes to larger specimen containers) in use at our institution. Environmental radio-frequency signal profiling of laboratory spaces identified 2 systems susceptible to potential interference: wireless

Figure 1. *Sample radio-frequency identification (RFID) tag. Integrated ultrahigh-frequency RFID tag, 2D bar code, and 1D bar code for specimen identification (front and reverse).*

temperature monitoring devices for refrigerators or freezers (signals on shared frequency blocked by the RFID reader; Isensix sensors, Isensix, Inc) and legacy pagers using the 929-MHz band (signals blocked by the RFID reader when <8 feet from the device; Unication USA, Inc). The concern was that either those devices might interfere with the RFID tag readers (ie, prevent signals from being read) or, more likely, signals emitted from the RFID tag readers would interfere with those devices (blocking the wireless transmission of temperature data or pages). The potential for bidirectional interference was ameliorated by selective positioning of the RFID receivers to control the direction and dispersion of the reader signal, calibration of RFID receiver signal strength to the minimum necessary for reliable reads, and (in select areas) the design of Faraday cages to further control the directionality of the reader signal.

Other considerations that influenced the choice of UHF tags were the availability of small point-of-service RFID tag/label printers and favorable characteristics of the available UHF tag readers. The printers used in the project (Zebra ZD500R, Zebra Technologies Corporation) generate a single label with (1) an integral activated RFID tag, (2) a 2D bar code encoding the RFID identifier, and (3) a 1D bar code encoding the patient medical record number (Figure 1). The tag readers (Quake Global) are powered by Ethernet (no separate line power required), which allows readers to be optimally placed around collection, transport, and receipt areas without substantial infrastructure costs.

During evaluation, the typical rate of successful reads with 40 concurrent specimens passing readers was better than 98.5% overall, with critical readers (such as those used for accessioning) 100% successful. In a few cases, it was necessary to place redundant readers in areas with fast-moving specimens or high specimen flux to improve the successful read rates to acceptable levels. The variables that most influenced reader accuracy were specimen tube size and shape (smaller circumference tubes had more read failures, most likely because of distortion of the RFID tag) and the speed with which specimens passed over readers.

Reliability and Data Security.—The reliability and security of data encoded in RFID tags are important considerations for RFID in specimen identification and tracking. In our application, the RFID tags are encoded only with a unique dummy tracking key and no protected health information. At the time of specimen tag creation, the tracking key is associated with patient-specific information in the tracking database, along with location and time information. When the specimen(s) reach the accessioning station, the RFID software uses the tracking key (read at the reader) to query specimen information required for accessioning from the specimen database and passes that information to the laboratory information system. Patient information is never transmitted wirelessly from the tag and is therefore not accessible via eavesdropping or unauthorized interrogation of the RFID label.

The tracking key and patient medical record number are redundantly encoded on the 2D and 1D bar codes, respectively, on the specimen label. The redundant encoding ensures that a specimen can be identified if the RFID tag fails or if the specimen is routed to a laboratory not yet interfaced with the RFID system. Because in this application the RFID tags are used to track specimens only to the point of laboratory accessioning, the reliability of the tags after long-term storage was not an important consideration. In a limited evaluation, UHF RFID tags were found to be viable (100% read success) after 7 days of immersion in liquid nitrogen. Other studies have demonstrated that HF RFID tags are stable through most forms of tissue processing, and it may be possible to use RFID tags to track specimens throughout tissue processing and downstream processes.[16,22]

Business Plan

Maintaining specimen identification and integrity are fundamental patient safety activities for the laboratory, with profound patient care and resource-use implications. Mislabeling errors can affect the preanalytic, analytic, and postanalytic quality of a laboratory and lead, in the worst cases, to either inappropriate or delayed treatment or lack of necessary care. Irretrievable loss of a specimen is a similarly critical event that, in the most severe circumstances, can deprive a patient of the opportunity for diagnosis, prognosis, or therapy. Either occurrence represents a fundamental breach of the laboratory's duty to the patient, and both are "never" events, for which any rate of occurrence is too high.

Mislabeling or loss events affect much more than the laboratory or clinical departments involved in specimen collection: such events are reportable to quality monitoring organizations, represent a risk to institutional reputation, and may result in considerable financial liability and loss of public trust. Even near misses (ie, mislabeling or loss events that are prevented or resolved) can be costly in terms of delayed time to diagnosis and employee effort redirected to the non–value-generating tasks of resolving mislabeling problems or locating lost specimens. After the risks and potential costs are accounted for, it is logical to frame specimen identification and tracking not as a laboratory, departmental, or interdepartmental problem but as an institutional opportunity for risk and harm avoidance. Thus, a clinical or laboratory department interested in pursuing an RFID specimen tracking initiative should consider seeking institutional support for the effort.

For this project, we determined that return on investment for the continuation and expansion of RFID specimen tracking would occur in less than 12 months, with the bulk of the economic benefits attributable to cost avoidance related to irretrievable specimen loss. The return on investment calculations compared the initial and ongoing expenses of deploying and maintaining the system and the cost of consumables versus improved process efficiencies and cost avoidance related to decreases in mislabeled or lost specimens. Lost specimen costs were projected from a combination of measured and estimated costs, including the cumulative average full-time equivalents used in a search for misplaced specimens, average cost of repeating a specimen collection procedure, potential costs of litigation, and estimated costs of lost institutional prestige or public trust due to a lost specimen. As a result of this analysis, our institution provided enterprise capital funding to this project.

Table 4. Project Timeline			
Phase	**Time, mo**	**Activities**	**Issues Encountered**
Planning	8	Building team Business case System architecture review Preliminary design Building vendor contract Committee approvals Cost estimations	NA
Execution			
Preimplementation	10	Build infrastructure Integrate systems Deploy to receiving areas	Label design Label sourcing Printer integration LIS and RFID system interface
Phased implementation	2.5	Deploy to GI/CRS Deploy to radiology	NA
Expansion phase	1.0	Deploy to dermatology	NA

Abbreviations: GI/CRS, gastroenterology and colorectal surgery; LIS, laboratory information system; NA, not applicable; RFID, radio-frequency identification.

Timeline

The project had an initial total planned duration of 11 months and an actual duration of 13.5 months (including a 1-month extension and 6-week variance) (Table 4). Project implementation was delayed 6 weeks to resolve issues related to label design, label supply, and development of a custom interface between the RFID tracking system and the ProVation procedure management system (ProVation Medical) in use in the GI/CRS endoscopy area. An additional 4-week extension was required to facilitate rollout of the RFID systems in dermatology procedural areas.

Hardware Infrastructure

The UHF RFID technology was deployed in GI/CRS procedure areas, interventional radiology procedure areas, dermatology patient rooms, central specimen processing, and the accessioning areas of anatomic pathology, cytology, and clinical microbiology. A total of 170 hybrid RFID/label printers were placed in the specimen collection areas. The collection area printers generate single integral tag/labels and also verify tag activation. In addition, 37 RFID readers were deployed at strategic areas throughout common specimen-transport pathways and in the accessioning areas of destination laboratories, which allowed for specimen tracking from the point of collection to accessioning. The RFID tracking process ends at accessioning, and specimens are tracked for downstream operations with bar codes.

Software Infrastructure

Specimen tracking was enabled by a dedicated custom software infrastructure that includes a specimen tracking dashboard, automated alert system, and interfaces to the electronic health record and laboratory information system. Specimen RFID tags are generated in response to an order placed in the electronic health record, which also creates an active specimen entry in the tracking database. Each encounter of a specimen tag with a reader generates an additional database entry containing time and location information, which thus provides a record of specimen flow. Specimen tracking rules are activated in the system on the basis of the RFID printer location (corresponding to a specific clinical area and expected transit time to the laboratory), which allows for the initiation of clean sweep and late specimen alerts. The *clean sweep* alert confirms that no prior patient labels are active in the collection environment before a new label is printed. The *late specimen* alarm alerts clinical and laboratory staff to a potentially lost specimen and is activated if the specimen has not arrived in the destination laboratory within a preestablished interval after label generation. Over time, transit time intervals were refined to maximize sensitivity for potentially lost specimens, while not generating excessive false alarms in response to normal variation in transit time. A dashboard provides details on the status of all active specimens and also shows relevant time/location information needed to investigate a potential lost specimen. Finally, an interface between the specimen tracking database and the institutional laboratory information system facilitates automated accessioning of specimens (in batch) as they transit specimen receiving areas within destination laboratories.

Statistical Analysis

Fisher exact tests were used to compare the rates of misidentification errors before and after implementation of the RFID system.

RESULTS

Outcome Measurements

In a 6-month period postimplementation (during 2018), 55 953 specimens from participating clinical areas were tracked by the RFID system. Exact data on the number of specimens that would have been tracked in the preimplementation period (2017) were not available, but overall specimen volume from clinical areas inclusive of participating areas (in which RFID-tracked specimens now make up the majority) was largely unchanged between 2017 and 2018. We therefore conservatively estimated a prior year specimen volume that would have been RFID tracked to be 56 513 specimens, 1% greater than the 2018 volume, and this estimate was used to calculate the preimplementation misidentification error rate for participating areas. Twenty-four specimen misidentification events were recorded in the preimplementation period (0.042%), compared with 6 events (0.011%) after RFID implementation ($P = .001$). Further analysis of the 6 errors reported in our laboratory error-management system showed that none of the misidentification events involved RFID-tracked specimens.

Postimplementation, no RFID-tagged specimens were irretrievably lost from participating clinical areas, although 3 near-miss events occurred, including (1) a specimen container left in the procedure room, (2) a specimen container placed in the pocket of a laboratory coat, and (3)

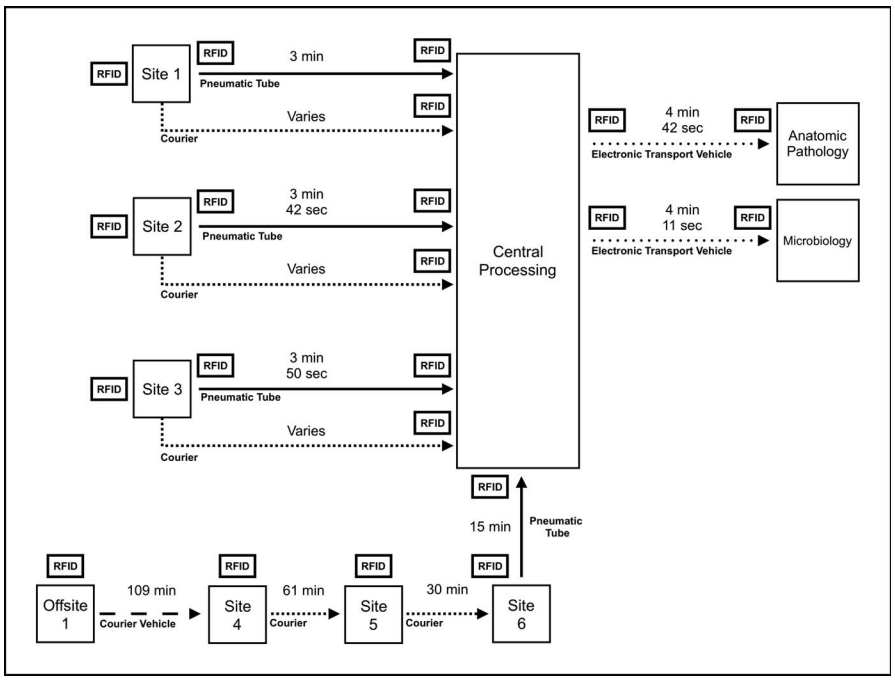

Figure 2. *Sample flow and transit times of specimens tracked with the radio-frequency identification (RFID) system. Locations of RFID readers are indicated.*

a specimen misrouted by the pneumatic tube system back to its point of origin. In all 3 cases, automated alerts were generated when the specimens failed to reach accessioning within the allowed transit period and triggered targeted searches. Searches were initiated at the last known location of the specimen as provided by the RFID system, and all specimens were located in less than 30 minutes (a primary project goal) from the time of alert.

A secondary goal of the project was to reduce GI/CRS specimen tagging/labeling expenses from approximately $1.00 per specimen to less than $0.20 per specimen (80% decrease). Replacement of the HF tags with UHF tags/labels and elimination of redundant second labels reduced the baseline labeling expense to less than $0.15 (>85% decrease). Additional unexpected savings (estimated >$200 000/y) were realized in reduced full-time equivalent–related expenditures because the single-step process of affixing the combined UHF tag/label at the point of collection was substantially less time-consuming than previous multistep labeling and tag activation/affixation processes.

Incidental Discoveries

To integrate UHF RFID into the collection and transport areas, detailed process mapping was performed early in the project. The collection and transport processes had never been previously mapped in this detail, and several interesting observations emerged. First, specimens were being transported to laboratory areas by various methods (eg, pneumatic tube, courier cart, hand carried) and paths. To reliably track the specimens, it was necessary to account for the variations in transport practices by placing readers in strategic locations to capture specimens by whichever transit mode was used. Second, single specimens often moved along complex pathways before and after accessioning: clinical laboratory to clinical laboratory, clinical laboratory to research laboratory, and/or directly to research laboratory. Although internal transfers between laboratories usually transited the accessioning area, additional readers sometimes had to be placed in other areas within destination laboratories to ensure that laboratory-to-laboratory transfer of specimens by any modality would still result in a tracking entry. Third, mapping the specimen collection and transit processes provided the necessary data for establishing expected specimen transit times from each collection area (Figure 2). Before the project, only sparse and anecdotal data were available on the expected transit time of a specimen from a procedure area to the laboratory.

Unexpected Benefits

Mapping the processes of specimen collection and transport during this project provided additional (non–RFID-related) opportunities to improve efficiencies and decrease error. Although specimen collection processes were beyond the scope of this project, operations managers in clinical procedure areas have used the process maps to streamline and standardize their workflows. The additional efficiencies generated by the process changes are expected to produce substantial annual savings in full-time equivalent–related costs in procedural areas.

DISCUSSION

Specimen identification and tracking are fundamental laboratory quality and safety activities. Mislabeling or specimen-loss events can confer substantial patient harm and represent serious risks both to affected departments and to the institution. Technologic and systems-based solutions can ameliorate the risks of mislabeling or loss events, but optimal solutions necessitate the input of all stakeholders and institution-wide support.

Radio-frequency identification technology offers several practical and theoretical benefits over bar coding, including automated reading at a distance, reduced susceptibility to defacement, and batch processing. Continued decreases in the cost of RFID technology have increased the practicality of implementing this technology in medicine, although up-front capital costs are still considerable for institution-level projects. In our return on investment analysis, the costs of

implementing an RFID system in our environment were expected to be more than offset by workflow enhancements and mitigated losses through improved patient safety. The initial effects of the RFID system have largely been in line with those expectations, and we have noted substantial improvements in workflow efficiency, unexpected cost savings through reduced accessioning and labeling effort, and improvements in specimen labeling quality. A total of 24 mislabeling errors occurred during the preimplementation period, compared with 6 in the postimplementation period (a 75% decrease, exceeding the project goal of 70%). Although these initial anecdotal results are promising, the performance and economic value of the system will require a more thorough and long-term evaluation.

This study has several limitations. The preimplementation specimen volumes were estimated, and substantial variance from those estimates could either improve or decrease the apparent effectiveness of the RFID system. The cost estimates provided in the study are limited in detail and may reflect institution purchasing agreements that could differ substantially between settings. Also, potential workflow and full-time equivalent–related saving estimates are most likely idiosyncratic and may vary between departments or organizations. The study also has several strengths. It details the application of an RFID-based specimen-tracking system at a large institution with multiple collection sites and a high volume of specimens. We reviewed the current state of RFID technology and compared experiences using HF RFID technology and UHF RFID technology in a production environment. We also discussed approaches for scientific and practical justification of RFID-based specimen tracking in a real-world setting.

To date, reports are limited but positive on the application of RFID technology in specimen tracking. Our experience adds to those data, demonstrating that a large-scale implementation of RFID technology for pathology specimen tracking is possible, with acceptable costs, rapid return on investment, and substantial initial improvements in preanalytic error rates.

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