Technical Report

RadPath: A Web-based System for Integrating and Correlating Radiology and Pathology Findings During Cancer Diagnosis

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Rationale and Objectives: The current paradigm of cancer diagnosis involves uncoordinated communication of findings from radiology and pathology to downstream physicians. Discordance between these findings can require additional time from downstream users to resolve, or given incorrect resolution, may adversely impact treatment decisions. To mitigate this problem, we developed a web-based system, called RadPath, for correlating and integrating radiology and pathology reporting.

Materials and Methods: RadPath includes interfaces to our institution's clinical information systems, which are used to retrieve reports, images, and test results that are structured into an interactive compendium for a diagnostic patient case. The system includes an editing interface for physicians, allowing for the inclusion of additional clinical data, as well as the ability to retrospectively correlate and contextualize imaging findings following pathology diagnosis.

Results: During pilot deployment and testing over the course of 1 year, physicians at our institution have completed 60 RadPath cases, requiring an average of 128 seconds from a radiologist and an average of 93 seconds from a pathologist per case. Several technical and workflow challenges were encountered during development, including interfacing with diverse clinical information systems, automatically structuring report contents, and determining the appropriate physicians to create RadPath summaries. Reaction to RadPath has been positive, with users valuing the system's ability to consolidate diagnostic information.

Conclusions: With the increasing complexity of medicine and the movement toward team-based disease management, there is a need for improved clinical communication and information exchange. RadPath provides a platform for generating coherent and correlated diagnostic summaries in cancer diagnosis with minimal additional effort from physicians.

Key Words: Integrated reporting; Cancer diagnosis; Clinical workflow.

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INTRODUCTION

Cancer is one of the leading causes of death in the United States (1). Pathology and radiology form the basis of cancer diagnosis, yet the specialties remain isolated, reporting findings independently and often having only minimal communication. The combination of these factors may result in radiologic-pathologic discordance, defined as a discrepancy between imaging and histologic findings (2). Radiologic-pathologic correlation is utilized in various imaging specialties as a tool to assess the utility of new imaging modalities, to gauge interpretive performance, and to identify radiographic features corresponding to histologic findings (3–8). However, correlation in these instances takes place for research or quality assurance purposes, and is generally not a normal part of radiologist or pathologist workflow.

Radiologic-pathologic discordance can be problematic for the ordering clinician, who is left with the task of reconciling the diagnostic conflict (9). The process of resolution may encompass a spectrum of actions depending on the specific findings, but examples include (1) contacting both the radiologist and the pathologist for clarification of findings; (2) concluding that the computed tomography (CT)-guided biopsy retrieved tissue was not representative of the lesion of concern;

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or (3) accepting the histologic findings as the final diagnosis and mistakenly interpreting an inadequately sampled lesion as benign. Such actions may lead to a false-negative conclusion in which cases of high radiographic suspicion of malignancy are misdiagnosed as benign, leading to delay in diagnosis with subsequent higher treatment costs and worse clinical outcomes (10,11). A recent study found a nearly 20% discordancy rate in mammography biopsies, with over 1.2% resulting in delayed diagnosis of a carcinoma (12). Extrapolated nationally, this type of discordancy was projected to result in 9969 missed diagnoses of malignant disease. Other studies have found similar results in breast imaging with false-negative rates of image-directed core biopsies estimated to be between 1% and 9% (13–17).

In 2010, costs from the diagnosis and treatment of cancer were estimated to be $124.6 billion, and are expected to rise 39% to $173 billion by 2020 (18). Opportunities to lower costs in oncology may be realized through a variety of measures, including the establishment of multidisciplinary care teams and improvements to care coordination (19,20). Such team-based care requires enabling technologies that more effectively exchange information between providers (21), and succinctly highlight salient data points and educational information as the number of diagnostic tests grows with the realization of precision medicine (22). A system that more effectively integrates diagnostic findings could also reduce ambiguous conclusions impacting clinical care. In 2008, a pilot study of 106 breast cancer screening patients at the University of Kansas Medical Center found that a weekly audio-video conference between radiologists and a pathologist affected treatment plan decisions in over one-third of discordant cases (23). The radiologists and the pathologists came to an agreement on a treatment recommendation for each case and subsequently generated a "concordancy report" that was then sent to the ordering physician.

The goal of our project was to create a web-based platform for cancer diagnosis that is incorporated with the electronic medical record (EMR) and enables new methods of communication and coordination for oncology care teams. Current EMR systems are encounter driven, and offer little support for integrating the contents of separate clinical reports over time. The proposed system was designed to overcome two problems with current workflows: (1) a lack of communication between radiology and pathology resulting in discordant diagnostic conclusions, and (2) the amount of effort required for a downstream clinician (e.g., surgeons and oncologists) to locate and review information when determining a diagnosis and when developing a treatment plan. To address these problems, the system retrieves clinical reports and diagnostic tests, and joins them in a compendium highlighting the most important contents from each data source. An associated workflow ensures that diagnostic conclusions are correlated and further action steps (if necessary) are suggested. In this paper, we present a methodology for creating integrated reports, followed by a corresponding implementation in lung cancer diagnosis, a process where achieving radiology-pathology concordance is challenging (24). Usage statistics and user satisfaction scores obtained over a 12-month period are presented for the described system.

MATERIALS AND METHODS

System Architecture

Before development, a team of clinicians and informaticians collaborated to develop a methodology for selecting, prioritizing, synthesizing, and presenting information in an integrated diagnostic report. As described in detail in Figure 1, the team divided the task into multiple steps. The process begins with determining the information systems containing the relevant clinical documents, followed by the specification of the actual reports (e.g., pathology reports). Next, diagnostic elements within the reports (e.g., pathology final diagnosis) are targeted for integration based on their diagnostic salience. Given the diagnostic area, existing clinical data, and clinical workflows, report creators may consider what new information can be synthesized and can be added to the report to further the diagnostic process and provide actionable guidance for the referring clinician. Finally, a discussion regarding how the information elements should be accessed and organized for presentation will help to guide the eventual design and implementation of the interactive report. Across the various steps, designers should be aware of how data from a source may be modified over time (e.g., an amendment) and how such modifications may affect the integrated report. Additionally, there are legal requirements that must be adhered to at federal, state, and institutional levels, especially if new diagnostic information is synthesized.

Following the previously mentioned process, the *RadPath* system was designed as a web-based application using the Java-based Grails framework, with support for modern web browsers (IE8+, Firefox, and Chrome). This design enables RadPath summaries to overcome the constrained representations required by our EMR, which does not allow for the rich presentation of, and interaction with, textual elements and key images from radiology and pathology studies. Furthermore, RadPath summaries have the additional flexibility of being created and being viewed on any device with a web browser. The application has data feeds from several of our hospital's information systems: (1) a Digital Imaging and Communications in Medicine (DICOM) feed for retrieving images and reports from our General Electric (Fairfield, CT) Centricity radiology picture archiving and communication system (PACS) and radiology information system; (2) a structured query language stored procedure for retrieving reports, test results, and images from our Sunquest (Tucson, AZ) laboratory information system; and (3) a connection to our hospital's single sign-on server for user authentication and authorization. Additionally, the system utilizes a custom Health Level 7 (HL7) interface that communicates RadPath results to our Epic (Verona, WI) EMR in the form of hyperlinks, which may be clicked to display the specified RadPath summary in a web

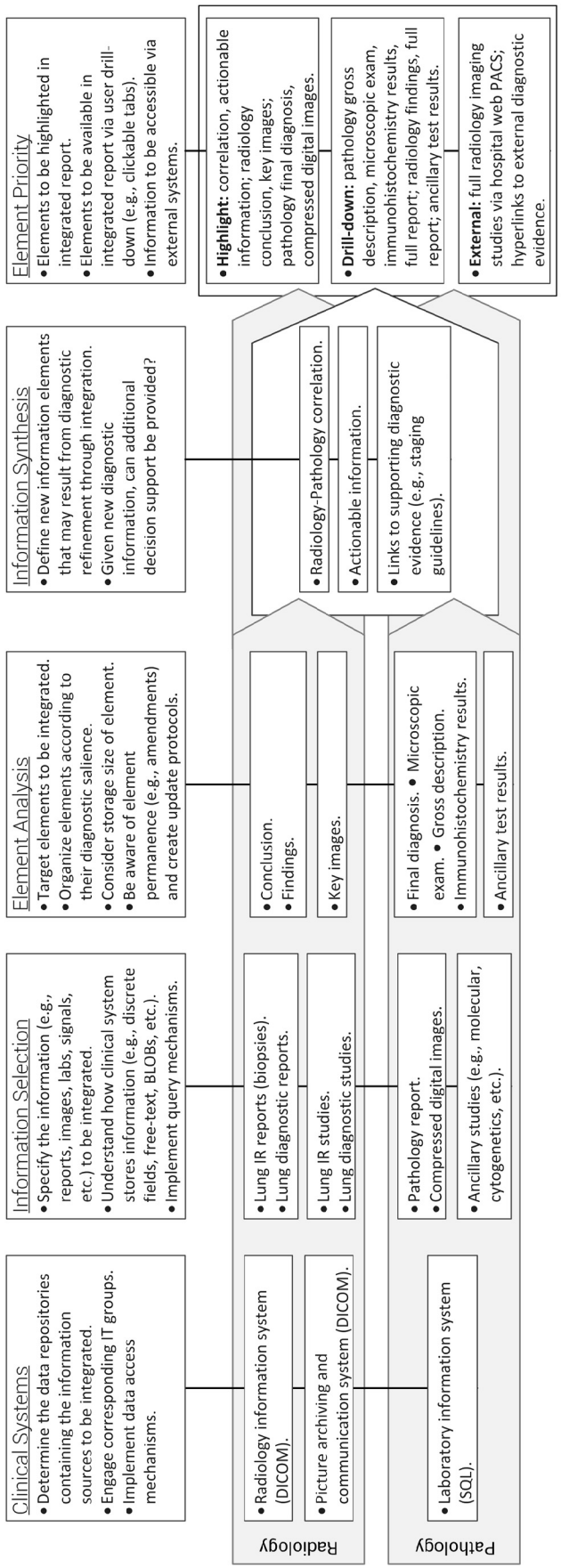

Figure 1. Process for creating integrated diagnostic reports. Shaded bars highlight results of following process to create an integrated report for percutaneous lung cancer diagnosis.

browser. When a RadPath report is finalized, these links are placed within the source diagnostic radiology and pathology reports, and an additional trigger notifies the referring physician.

Report Overview

The RadPath compendium consists of information from diagnostic radiology and pathology reports, as well as supporting images and tests (e.g., molecular diagnostics). This information is drawn from pre-existing reports in our EMR and is not edited within the RadPath application. Rather, the information is structured into interactive panels to bring the most important diagnostic information to the fore. This approach eliminates the need for the ordering clinician to navigate through several separate reports, searching for key pieces of information. Each panel employs tabs to organize information, with one tab always containing the complete source report. Figure 2 introduces the key pieces of the RadPath summary:

- Navigation menu. For each user, the RadPath system retains a profile that includes contact information. This information is populated through the single sign-on system but may also be customized by a user. RadPath offers the ability to share cases (Fig 2a) by generating hyperlinks that may be emailed from within the system. After clicking a link and signing in, RadPath displays the integrated summary. This feature allows for communication to be richly contextualized and case centric, eliminating the need to transmit patient identifiers and ensuring that all parties are reviewing the same information.
- Pathology panel. The pathology panel (Fig 2b) structures the diagnostic specimen report, highlighting the Final Diagnosis section. Key histopathologic images are displayed and ancillary test results are available. The results of immunohistochemistry studies and molecular tests are retrievable from the panel, which also lists pending studies whose results are automatically inserted when a study is completed.
- Correlation panel. The correlation panel (Fig 2c) synthesizes the results from the radiology and pathology studies into a single, coherent synopsis that explains any discordance and prescribes possible actions that may be taken. For example, if a radiology report describes a lesion as highly malignant but the pathology is benign, the correlation panel may be used to suggest a sampling error and recommend repeat biopsy. More complicated correlations, like dealing with discordance in cancer origin or multiple lesions, may also be resolved.
- Radiology panel. The radiology panel (Fig 2d) displays information from the diagnostic radiology report corresponding to the lesion(s) currently under study (e.g., a chest CT with and without contrast). The conclusion section of the report is highlighted, with additional sections placed in other tabs (e.g., Findings). Additional supporting reports (e.g., a radiology biopsy report) may also be attached. Key slices from the diagnostic imaging

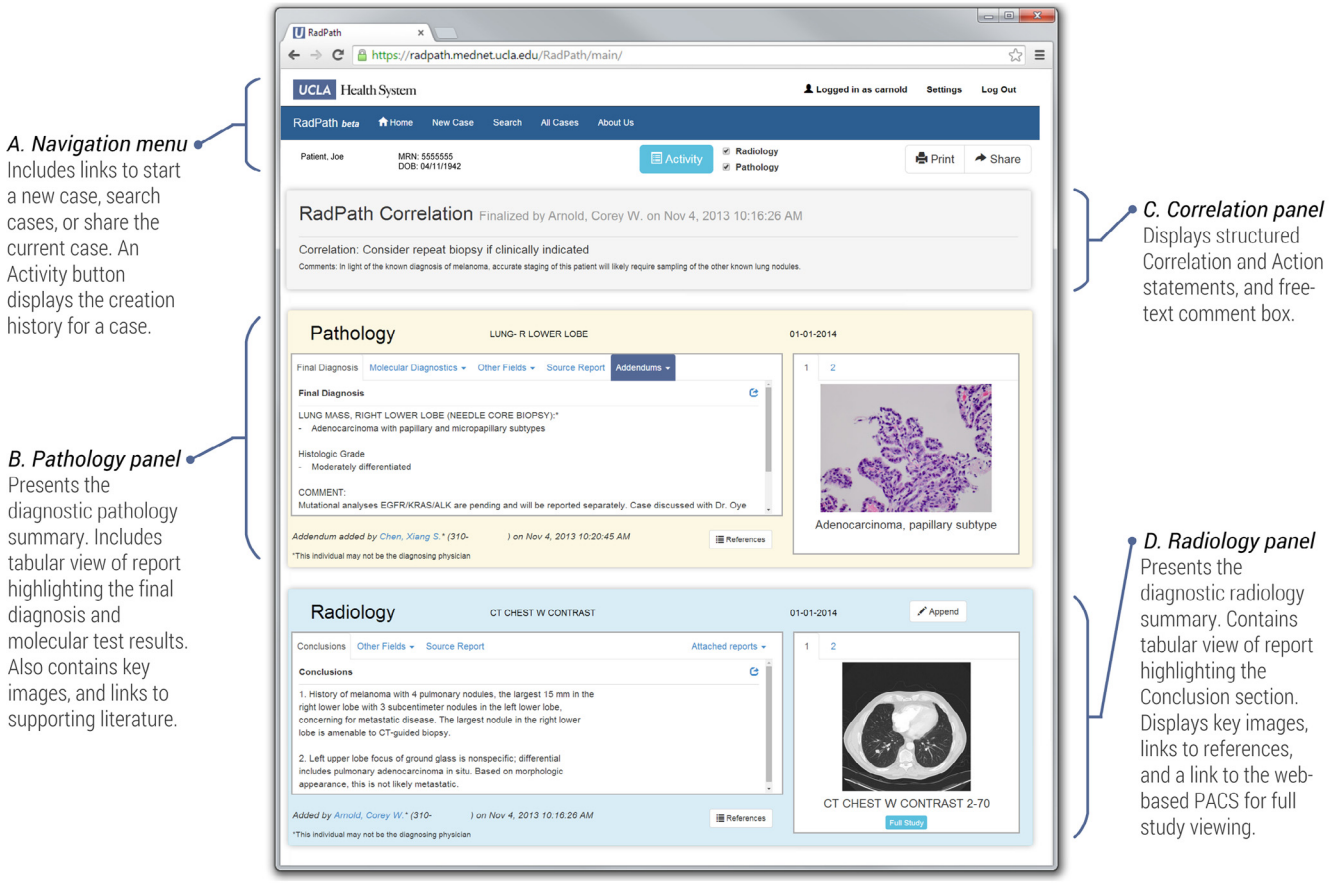

Figure 2. RadPath summary overview showing (**a**) navigation and sharing options, (**b**) pathology panel, (**c**) correlation panel, and (**d**) radiology panel.

study are displayed in the panel, as well as key slices from the biopsy study, showing from where a sample was taken. Finally, full imaging studies may be reviewed by clicking a link that launches our hospital's web-based PACS that defaults to a view of the clicked study.

- Literature links. Each panel may contain hyperlinks to literature supporting diagnostic conclusions. For example, radiology panels may contain links to the latest cancer staging guidelines to contextualize a study's findings and conclusion. Literature is selected by attending radiologists or pathologists, and may be included only in the current case, or can be included in all cases by default.

Workflow

The RadPath system was designed to support a general workflow, but the technical infrastructure is adaptable to deviations. RadPath summaries may be requested by a referring clinician, or may be initiated by either a radiologist or a pathologist. Figure 2 shows the normal diagnostic workflow, including diagnostic imaging, followed by image guided biopsy, and then pathology interpretation. The RadPath workflow (Fig 3) occurs after the normal clinical workflow, and may be divided into three phases: (1) pathologist review, (2) radiologist review, and (3) radiologist correlation.

1. Pathologist review. In general, tissue sampling and pathology diagnosis follow diagnostic radiology review, and therefore a pathologist will be the first user to interact with the RadPath system. RadPath connects to LIS and retrieves the diagnostic report and compressed representative digital images (as captured by the pathologist during interpretation) for the pathology study. RadPath structures this information into a tabular view, highlighting the final diagnosis, molecular results, and representative images (Fig 3a). The pathologist reviews RadPath's structuring of the pathology panel and adds any other existing diagnostic information if desired (e.g., the pathologist may choose to attach the concurrent cytology report if it contains information pertinent to the case). Then, the pathologist finalizes the pathology component of the report, which triggers a message to the radiology RadPath service.
2. Radiologist review. Upon receiving the notification of a RadPath request via an email work list, the radiologist who performed the biopsy logs into the system and is presented with the complete pathology panel and a suggested diagnostic radiology study (Fig 3b) retrieved from

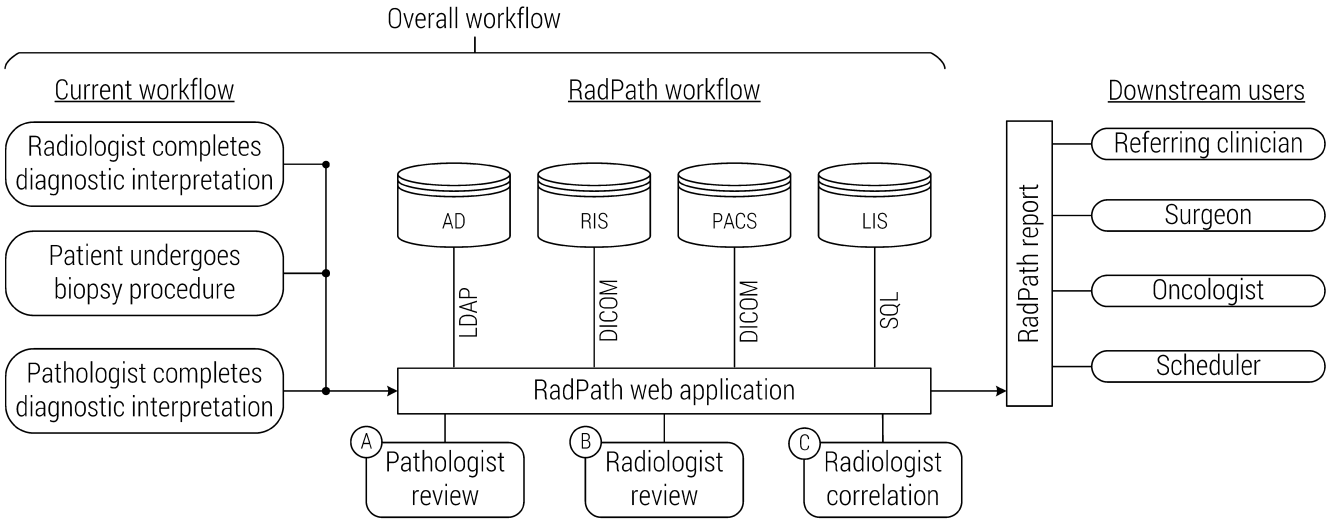

Figure 3. Overall new workflow showing the combination of the normal workflow and the new RadPath workflow. (**a**) Pathologist first reviews and finalizes the RadPath-auto generated pathology summary, which triggers a message to the RadPath service. (**b**) Radiologist reviews and finalizes radiology panel, adding additional images or diagnostic reports if desired. (**c**) Radiologist correlates radiology and pathology diagnoses. Abbreviations: AD, active directory; DICOM, Digital Imaging and Communications in Medicine; LDAP, lightweight directory access protocol; LIS, laboratory information system; PACS, picture archiving and communication system; RIS, radiology information system; SQL, structured query language.

our radiology information system using DICOM Query/Retrieve based on patient medical record numbers (MRN) and report accession numbers. Suggested studies are chosen according to their chronological proximity to the pathology exam and their study type (e.g., CT studies are prioritized over x-rays); however, a user may change the diagnostic study if desired (e.g., the radiologist may choose the biopsy procedure note if it contains more pertinent information for the given lesion). RadPath performs an initial structuring of the diagnostic study (Fig 4), extracting the Conclusion and Findings sections (Fig 4c) for tabular presentation and retrieving key image slices (Fig 4d). Regular expressions, specified and editable by radiologists, are used to identify key images in report text from the diagnostic and biopsy studies. For example, a mention of "best viewed on (4–22)" will trigger the system to retrieve series 4, slice 22 of the current study. Retrieval uses DICOM Query/Retrieve protocols based on MRN and study/series/instance unique identifiers. Automatic retrieval of key slices is a convenience for radiologists who choose to adhere to regular expressions supported by the system. If superfluous or incorrect, retrieved slices may be discarded by a user, and new slices may be added through an integrated PACS viewer. Key slices are converted from DICOM to JPEG format and stored locally on the RadPath web server. Additional key slices may be added through the *Add Images* button, which allows for real-time PACS queries and image viewing.

3. Radiologist correlation. After confirming/editing the contents of the radiology panel, the radiologist must correlate the radiology and pathology diagnoses (Fig 3c). This task is performed through structured *Correlation* and *Action* drop-down lists and a free-text comment box. The structured lists ensure that referring clinicians receive coherent and consistent feedback, whereas the comments box allows the radiologist to further contextualize the correlation and actions. Table 1 shows the correlation and action items, as well as a sample correlation panel from an actual case. After correlating the reports, the radiologist finalizes the RadPath summary and shares it with other clinicians.

Once finalized, an HL7 message is sent to the EMR, which addends the source radiology and pathology reports with hyperlinks pointing to the RadPath case hosted on the web server. In addition to hyperlinks, a notification is sent to the referring physician that a RadPath summary is available for his or her patient. All actions in the RadPath system are logged for auditing purposes and may be tied to EMR auditing as the systems used a shared authentication/authorization system. However, our EMR supports only static hyperlinks (i.e., EMR user credentials cannot be embedded), and thus when RadPath is accessed via the EMR, only the single case corresponding to the MRN and the study in which the hyperlink has been added is accessible. In this scenario, RadPath's audit logs would show a generic user, but this user could be identified when temporally aligned with the EMR's audit logs, which track hyperlink clicks.

After finalization, RadPath summaries may be addended or amended. This process can be initiated manually, but can also occur automatically in certain scenarios. Specifically, when molecular and genetic tests ordered at the time of pathology interpretation are completed, their results are automatically addended to the case (Fig 4) under the molecular diagnostics tab. This is possible as our current pathology workflows

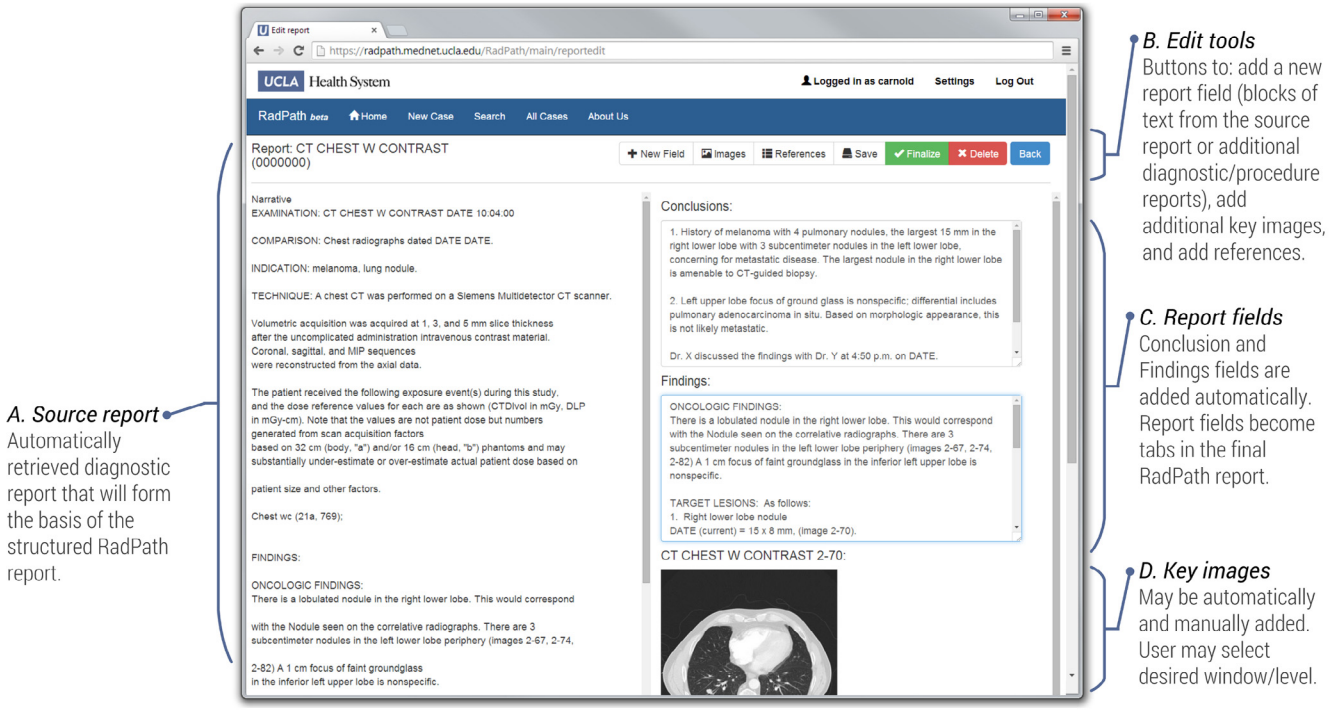

Figure 4. RadPath summary creation interface for radiology highlighting (**a**) source report, (**b**) editing tools, (**c**) structured report fields, and (**d**) key images.

maintain a database link between a tissue sample and its subsequent diagnostics, and because no structuring of these reports is necessary given their succinct format.

Clinician Survey

To measure the potential clinical utility of the system, we conducted a survey with RadPath report users. Questions were designed to provide feedback on specific RadPath report features and the potential of the report to improve diagnostic workflows for downstream users. Responses to questions were provided using a five-point Likert scale. In addition to the structured responses, survey participants were also asked to provide optional additional unstructured feedback to more general questions via a textbox. Survey participants were RadPath report users who were selected using convenience sampling.

RESULTS

The RadPath system required approximately 1 year to develop and is currently being used within our institution's health network for lung cancer diagnosis via percutaneous biopsy. Primary users are three radiologists, three pathologists, two surgeons, two pulmonologists, and two oncologists. However, the RadPath reports are accessible to all members of a patient's healthcare team via hyperlinks in the EMR. Detailed usage statistics of the system are summarized in Table 2, which covers 60 cases over a 12-month period. The average time taken to create a radiology panel is 196.18 seconds versus 62.5 seconds to create a pathology panel (Fig. 5, histogram). Creating a radiology panel requires an average of 2.5 clicks versus 1.7 clicks for a pathology panel (Fig. 6, histogram). This difference in time and clicks is due to the radiologist being responsible both for synthesizing the correlation panel and for sifting through a larger set of imaging data for potential inclusion in a summary. Although the system automatically pulls key slices from radiology studies based on regular expressions, radiologists are not required to follow a supported format. Thus, more effort may be required from the radiologist to review retrieved images, manually retrieve images that were not mentioned or that the regular expressions did not recognize, or add key images from other studies (e.g., a prior diagnostic exam). We have found that enthusiasm for standardizing RadPath key slice mentions has increased with the introduction of the system, and believe the average time and clicks will decrease as a result.

Two surgeons, two oncologists, and four pulmonologists were sent an invitation via email to complete the survey online. Our response rate was 62.5%, with one oncologist, two surgeons, and two pulmonologists completing the survey. All respondents are attending physicians at our institution. Table 3 details the Likert scale responses of survey participants, with Table 4 showing unstructured responses. Mean responses for each Likert-scaled question expressed positive sentiment for the RadPath system.

TABLE 1. *Correlation* and *Action* Options, and an Example Correlated Case

Drop-down	Text Options
Correlation	Radiology and pathology correlate. Defer to pathology diagnosis. Combined findings suggest sampling error. Findings are an incomplete representation of disease state.
Action	No further action needed from radiology and pathology. Consider repeat biopsy if clinically indicated. Other: see comments.
Field	**Example**
Radiology diagnosis	History of melanoma with four pulmonary nodules, the largest 15 mm in the right lower lobe with three subcentimeter nodules in the left lower lobe, concerning for metastatic disease. The largest nodule in the right lower lobe is amenable to CT-guided biopsy.
Pathology diagnosis	LUNG MASS, RIGHT LOWER LOBE (NEEDLE CORE BIOPSY): – Adenocarcinoma with papillary and micropapillary subtypes.
Correlation	Defer to pathology diagnosis.
Action	Consider repeat biopsy if clinically indicated.
Comment	In light of the known diagnosis of melanoma, accurate staging of this patient may require sampling of the other known lung nodules.

CT, computed tomography.

TABLE 2. Data Describing RadPath System Usage by Radiologists and Pathologists During Summary Creation

User	Average Time (seconds)	Median Time (seconds)	Average Clicks
Radiologist	196	120	9.4
Pathologist	63	35	2.7

Data cover a 12-month period and 60 cases.

DISCUSSION

During development, several unforeseen nuances were identified that required modifications to both our workflows and the technical platform. First, several workflows were discussed and attempted before arriving at the described general solution. One alternative was to have radiologists add the radiology panel first at the conclusion of a biopsy study. However, this would have either (1) put the burden of correlation on the pathologist or (2) required the radiologist to re-review the case after the pathologist had entered results. Both possibilities are suboptimal. There is a larger degree of ambiguity in radiologic diagnosis (in lung cancer) relative to pathology. This ambiguity is not a reflection of quality, but a result of the diagnostic information contained within the image under interpretation. Thus, in case (1), the pathologist would be responsible for reviewing a radiology study and "updating" its diagnosis, a task for which she or he is not trained; and in case (2), the radiologist would need to review the same case twice (before and after pathology), an inefficient scenario requiring additional time and redundant cognitive effort.

With the defined workflow, it was unclear as to which radiologist should complete a RadPath summary. It may be most natural for the original diagnosing physician to be selected. However, this individual may not be on service at the time a RadPath case is requested, and thus unavailable. The interventional radiologist who completed the biopsy has most recently seen the patient and reviewed his or her imaging, but not in a formal diagnostic capacity, and furthermore may also not be on service. For these reasons, our initial protocol was to implement a RadPath service, with the radiologist on service completing all RadPath reports. However, after several trials, the radiology team decided that a "soft" assignment of RadPath reports to the interventional radiologist who finalized the biopsy report would be most effective. Such an assignment ensures a particular individual who has already reviewed the patient's images is responsible for the case. As a tertiary care center, we receive many patients with outside studies who do not receive new diagnostic imaging, and thus the interventional radiologist will be the only physician to have reviewed the case, further justifying the interventional radiologist participation in the creation of the RadPath report. Additionally, the interventional radiologist is the most familiar with the results of the biopsy procedure, and is therefore best suited to comment on the correlative impact resulting from possible complications during tissue procurement. The assignment is "soft" in that if the interventional radiologist is unable to perform the correlation, a different radiologist may take over the case.

The selection of the correlating diagnostic radiology study is determined by the individual on RadPath service who may not be the person who generated the report. In some cases, the RadPath radiologist felt as though she or he was "correcting" the original radiologist, and was hesitant to do so. Creating the structured *Correlation* and *Action* (Table 2) drop-downs helped to mitigate this as they offer set dialogue for "correcting" (updating) the original conclusions. Similarly, there were general legal concerns regarding RadPath summaries. The system is primarily a communication tool and does not alter the content of the original radiology and pathology reports. However, because these reports are propagated in a new integrated summary and include a correlation component, accountability must be assigned to the RadPath radiologist and pathologist. This required that we add signature blocks with dates to both panels, as well as to the correlation panel.

The results of our survey analysis indicate that RadPath is a helpful new tool for cancer diagnosis. Although only one respondent indicated that there was a problem with his or her current diagnostic workflow, responders all agreed that RadPath would be an improvement to their workflow, and that it would also reduce their need to search the EMR for information: two critical objectives of the project. RadPath's features were

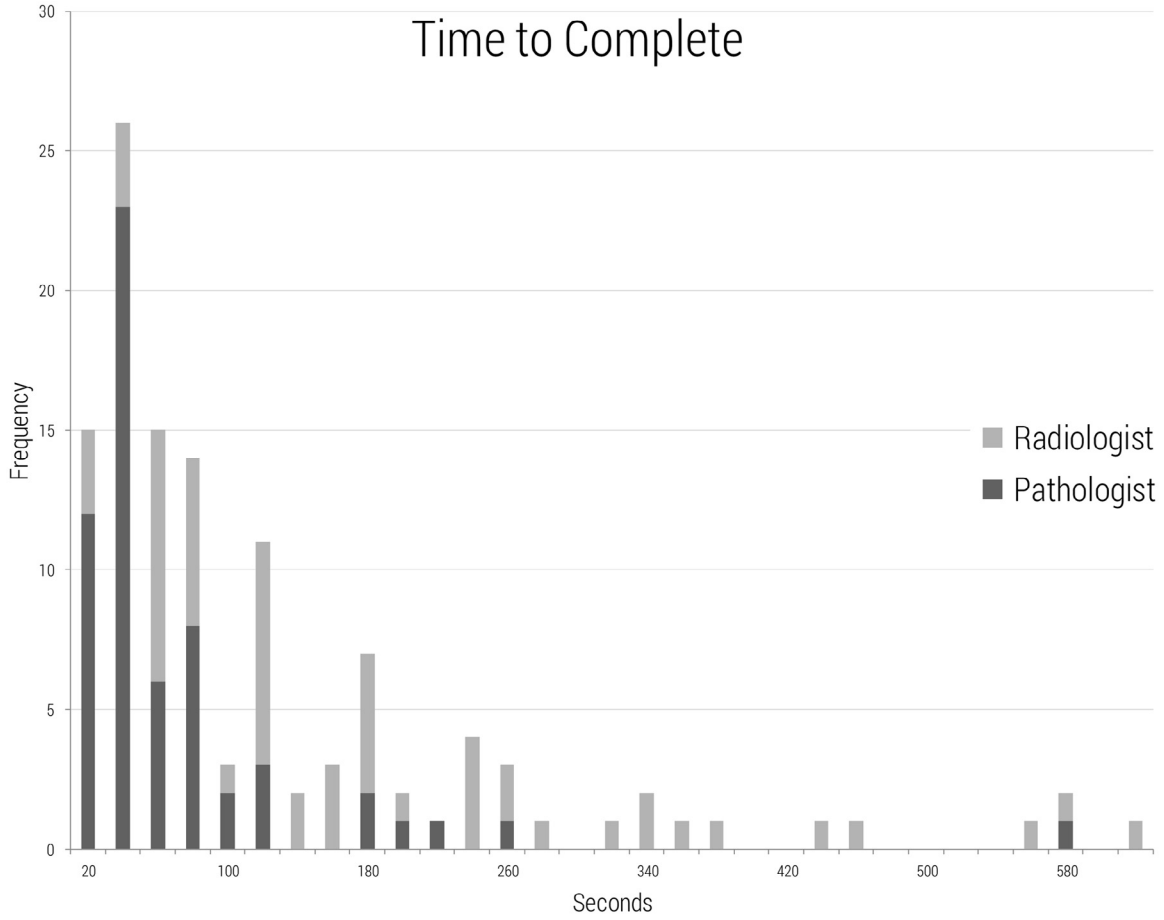

Figure 5. Histogram of time to complete RadPath reports in seconds (bin size 20) by pathologists and radiologists ($n = 60$ reports).

also well regarded, with four out of five respondents agreeing that the Correlation and Action components in RadPath would change their practice. The survey's free responses provide further details into why there is support for the system, and also raise possible new issues, most notably the potential for a RadPath correlation to go unnoticed. Through the described hyperlinks and our training efforts, we have publicized the existence of the RadPath report. However, as the compendiums are novel information sources, there is the potential for them to be overlooked, something we will evaluate in future studies. Also notable in the responses was the request for an image of the needle in the lesion being biopsied, something we now include in every report.

Several report creators now use RadPath for tumor board preparation. Given its interfaces to clinical repositories and its editing capabilities, for these users the system has expedited tumor board preparation relative to the standard practice of creating PowerPoint presentations. Similar to an email system, the folder view on the user's homepage allows for cases to be organized by labels, allowing the user to create a label for tumor board cases may be used for storing tumor board cases. In contrast to users adapting RadPath for other uses, they may also adapt their current reporting practices knowing that a subsequent RadPath report will be generated. As previously noted, radiologists have been more open to structuring mentions of key slices so that they are retrievable by RadPath, thereby saving time when creating a new integrated report. This type of adaptation may enable efficient automated processes and potentially even research endeavors that require analyzing reports in aggregate. However, despite our attempts to balance unstructured text in a structured framework, it is possible that some physicians may find the RadPath report structure limits their ability to effectively communicate diagnostic findings.

An important consideration for this work is the question of how easily a different healthcare provider could install RadPath. The answer to this question is not straightforward, and depends primarily on current technical infrastructure and commitment of information technology (IT) resources. Although RadPath is vendor agnostic and standards based (e.g., DICOM, HL7), it requires IT effort to establish, configure, and maintain data feeds from clinical reporting systems. Additionally, although we believe that RadPath follows a generally acceptable workflow, different providers may desire changes that could require software modifications. Such technical and workflow challenges to adoption are a consideration for any organization adding new software or processes to their clinical environment.

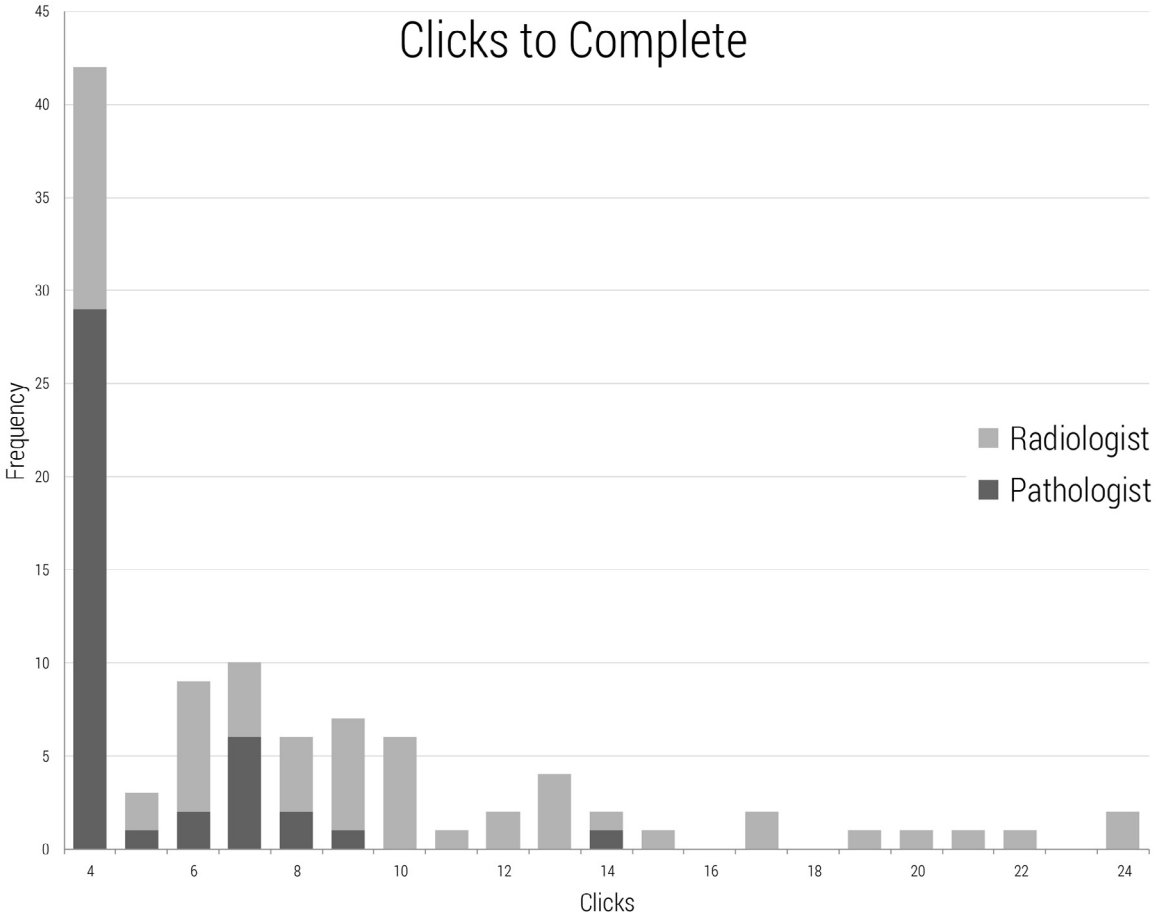

Figure 6. Histogram of the number of clicks to complete RadPath reports by pathologists and radiologists ($n = 60$ reports).

TABLE 3. Responses to Survey on the Perceived Utility of the RadPath Report ($n = 5$)

Question	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
There are problems with my current workflow for interpreting diagnostic results from Radiology and Pathology.	—	—	4	1	—
RadPath will be an improvement to my current patient preparation workflow.	—	—	—	2	3
RadPath will reduce my need to search for information in the electronic medical record.	—	—	—	4	1
RadPath will be a valuable educational tool for my patients.	—	—	—	4	1
RadPath will help me stage a disease.	—	—	2	3	—
I will feel comfortable using RadPath as my primary source for diagnostic results for radiology-guided needle biopsy results.	—	—	1	3	1
I will use the Share function to send a case to a colleague for discussion.	—	—	1	3	1
The References button will be useful.	—	—	—	2	3
The features are self-explanatory and easy to use.	—	—	—	2	3
The key images from Pathology will be useful.	—	—	1	2	2
The key images from Radiology will be useful.	—	—	—	2	3
The link to the complete Radiology study will be useful.	—	—	—	2	3
The Correlation statement will be useful.	—	—	—	3	2
The Action statement will be useful.	—	—	—	4	1
The Correlation and Action features will change my practice.	—	—	1	4	—

TABLE 4. Free-text Responses to General Questions Regarding the RadPath System ($n = 5$)

Question	Response
What are the problems, if any, with your current workflow for interpreting diagnostic results from Radiology and Pathology?	"The direct links on RadPath are helpful as typically one would have to pull up three separate files: the pathology report, the images of the CT biopsy, and the original CT images. This format provided with the correlate is very helpful."
	"The biggest issue is getting the results of molecular analysis."
Could the RadPath display be confusing or cause diagnostic misinterpretation?	"I am concerned that if the statement at the top isn't repeated in the appropriate panel, there is a risk that people will miss it."
Are there other features you would like RadPath to have?	". . .it would be helpful if we knew which nodule was biopsied (i.e., CT showing needle into target)."
	"Anticipated date of any outstanding studies."

CT, computed tomography.

CONCLUSIONS AND FUTURE WORK

The RadPath system allows users to efficiently locate, extract, integrate, correlate, and share diagnostic information stored in different vendor systems from different specialties in an interactive, EMR-linked report. Downstream users have reported that the platform will change their practice by improving their workflow and reducing their need to search the clinical record. A limitation of our survey analysis is that it included a small number of users. RadPath is currently being deployed to a larger user base, including physicians outside of our health system, a task that requires more complex security mechanisms. Future work will evaluate the utility of RadPath for this larger user base, as well as its impact on clinical care (e.g., time to diagnosis). Additionally, to further test and refine the software, we are seeking partners at external health systems where the system may be deployed. In support of the current roll out, pilot clinicians are acting as "champions" to assist in the education of their peers. Finally, during the course of this project's development, we identified several areas for improvement:

- Automatic correlation. To assist the radiologist and pathologist, we have begun the development of an automated correlation algorithm. The algorithm uses conditional random field models to identify a predefined set of diagnostic conclusions in source reports. Currently, this set consists of four labels: *benign, malignant, primary,* and *secondary*. Conditional random fields are a statistical natural language processing technique for information extraction that utilize context in the form of word sequences (25). In cases where the algorithm has high confidence of discordance based on its labeling (e.g., a radiology conclusion is labeled as *benign* and a pathology conclusion is labeled as *malignant*), the system can provide additional feedback to the user.
- Temporal disease evolution. Diagnosis is only the first step in the treatment of a cancer patient. Subsequent versions of the summary will incorporate treatment and response information through the integration of oncology and surgery panels. These extensions will provide users a comprehensive and integrated interface describing a patient's entire disease course.
- Research diagnostics. The developed solution provides a platform and workflow for the expedited delivery of validated research diagnostics. For example, quantitative image features and their histology correlations may provide useful information in guiding treatment. The RadPath system facilitates the explanation of such complex content through its ability to generate rich graphical representations, and a correlative workflow that allows for the injection of new information.

As medicine becomes increasingly specialized, there is a need to merge disparate and complex clinical information into coherent and efficient representations for medical decision makers. This project contributes a process for designing integrated reports and an illustrative platform and workflow for creating and sharing such representations in the area of lung cancer diagnosis.

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