With the increasing prevalence of PACS over the past decade, face-to-face image review among health care providers has become a rarity. This change has resulted in increasing dependence on fast and accurate communication in radiology. Turnaround time expectations are now conveyed in minutes rather than hours or even days. Ideal modern radiology communication is a closed-loop cycle with multiple interoperable applications contributing to the final product.

The cycle starts with physician order entry, now often performed through the electronic medical record, with clinical decision support to ensure that the most effective imaging study is ordered. Radiology reports are now almost all in electronic format. The majority are produced using speech recognition systems. Optimization of this software use can alleviate some, if not all, of the inherent user inefficiencies in this type of reporting. Integrated third-party software applications that provide data mining capability are extremely helpful in both academic and clinical settings. The closed-loop ends with automated communication of imaging results. Software products for this purpose should facilitate use of levels of alert, automated escalation to providers, and recording of audit trails of reports received. The multiple components of reporting should be completely interoperable with each other, as well as with the PACS, the RIS, and the electronic medical record. This integration will maximize radiologist efficiency and minimize the possibility of communication error.

Key Words: Reporting, speech recognition, computerized physician order entry (CPOE), decision support, results communication, data mining

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OVERVIEW

Accurate and timely communication of patient care-related information among medical professionals represents a major challenge in prevailing health care delivery systems, which typically involve multiple providers and auxiliary sources of information, such as laboratory and imaging data. Knowing that information sent has been successfully received and understood by the intended recipient is important for each participant in patient care. This type of communication is called “closed-loop” because the information is first sent out to its intended recipient to start the cycle and then a message comes back to the originator, confirming that the information was received and completing the loop.

Confirmation of receipt and understanding is easy when communication is synchronous (ie, both participants involved in the communication physically participate in the activity at the same time via telephone, online meeting, etc.), but when communication is asynchronous (eg, e-mail) and separates participants in space and time, confirmation of successful communication may be more difficult. Additionally, permanent documentation of successful and timely communication is often critical for medicolegal and quality assurance activities, despite the challenges of asynchronous communication.

Radiologists are particularly susceptible to the consequences of failures in closing the communication loop. With speech recognition software, reports can be created...
and finalized in near real time. Such reports are immediately available in the RIS and, if an electronic health record is present, may become available in a patient’s electronic medical record (EMR) soon thereafter. However, no built-in confirmation mechanism ensures that the ordering and consulting physicians have read (and completely understood) the report. In many instances, reports are still distributed to referring physician offices via fax or other analog means. In rare instances, an imaging examination may have been requested by a third party, such as an insurance company, in connection with employment or immigration procedures. In those instances, an ordering physician may not have been recorded, and the radiologist may have entered what is normally a direct doctor-patient relationship, with all of the associated responsibilities. This relationship may require direct communication of results of the examination to the patient [1]. In addition, a specific radiologist’s recommendations in a given report may be overlooked; as a result, failure of communication is one of the most common sources of litigation against radiologists [2].

When emergent or urgent findings are discovered, radiologists may decide to use synchronous communication tools to convey the critical information (eg, a telephone call to the ordering physician). However, even this system may succumb to closed-loop failures when the ordering physician is unavailable and a proxy, such as a nurse or physician assistant, must be used. Furthermore, synchronous communication methods are resource intensive for both the radiologist and the ordering physician, and they require physician time; therefore, such methods cannot be applied universally to radiology interpretations. Direct radiologist-to-patient communication is one method of addressing this issue, but it does not solve the underlying problem that the ordering physician may not have received the needed information. Additionally, patients may not be able to fully understand the information given to them by their radiologist.

Ensuring that routine results and long-term follow-up recommendations are received and understood is a universal challenge in medical imaging. To ensure complete and timely relay of relevant information, the entire communication loop must be considered, from the decision to order a radiologic test to image creation, report creation, report dissemination, and confirmation of receipt. Seamless interoperability of software systems is a necessary foundation for success, as is a data model that allows for quality control and benchmarking of successful closed-loop communication.

ORDER ENTRY
Order entry or request for a radiology consultation by the clinician is, ideally, the start of a closed-loop communication instance that ends with the clinician receiving the finalized radiology report.

RIS or EMR
The number and complexity of imaging procedures are increasing. Many clinicians, especially nonspecialists, may find that selecting the most appropriate examination is a challenge. In many cases, the study eventually performed is not the correct or most appropriate one. Telephone communication between clinician and radiologist may be required to determine what procedure best answers the clinical question.

Computerized Physician Order-Entry Software with Decision Support
A description of the computerized physician order-entry (CPOE) process is as follows:

- Clinician chooses patient’s signs and symptoms as well as reason for study from menu;
- Clinician chooses imaging study from menu;
- CPOE software analyzes the entered data as well as patient demographics and presence of prior examinations;
- ACR Appropriateness Criteria® rank is assigned to the examination order entered;
- Clinician is notified at the time of order entry if the study is deemed appropriate, questionable, or inappropriate. Often an empiric sliding scale is used to express level of appropriateness;
- The system may suggest an alternative imaging study if the initial study requested is considered inappropriate;
- Clinician can override the suggestion if so desired, but this action may be logged and can be subjected to peer and/or administrative review.

Current ACR Appropriateness Criteria combine consensus-based or evidence-based approaches to arrive at decision rules. Advantages of CPOE with decision support include the following:

- Clinician receives assessment of choice at the time of order entry, which provides guidance and an educational opportunity;
- The software process is accepted by some insurance companies in place of authorization by radiology benefit-management companies;
- The database of historic physician orders is available for process management by authorized administrators. Outliers and undesirable ordering patterns can be identified, and physicians may be counseled on better choices;
- Substantial decreases in the growth rate for imaging utilization have been described after deployment of such systems, documenting a potential sustained effect on ordering behavior [3].

The CPOE software ideally should be embedded within the EMR for seamless physician ordering; however, standalone technology is available from several companies engaged in this domain. Ordering rules should be
extensible and updated periodically. Centers may decide to codify interdisciplinary consensus on an institutional standard of care in a particular clinical context. Some systems are highly customizable, allowing for rapid incorporation of such local preferred practice patterns. A standing committee consisting of radiologists and referring physicians may be assigned to this task of defining ordering rules.

REPORT CREATION

Speech Recognition

Speech recognition software has been available in various forms for decades, although few radiologists initially adopted the technology. New technologies finally allowed continuous and rapid dictation, enabling speech recognition program use in a typical busy radiology practice. Pressure from clinicians to improve turnaround time, and from administrators to save transcription costs, has been a major factor in the transition to use of speech recognition technologies.

Original voice-to-text speech engines relied on the dictionary model. Each spoken word was considered on its own, with little or no contextual analysis. In the late 1990s, hardware and software advances enabled a fundamental change in speech recognition capabilities. The newer (and current) speech recognition engines consider not words but individual and unique sounds called phonemes. The sounds that come before and after each phoneme are analyzed in an iterative statistical model to create the most likely text from a spoken phrase. Rather than having to pause after each word, users can now dictate in continuous and rapid speech. A language model was created specifically for radiology reports. This model allowed the software to “expect” the phrasing typical for radiology reports, which is often different from regular English prose. In addition, most current speech engines are able to track and learn the pronunciation and syntax patterns of individual users, allowing recognition to improve with time.

Speech Recognition Versus Conventional Dictation

The advantages of using speech recognition technology have been debated at length [4,5]. Improved turnaround time has been realized by most users. Rapid return on investment with transcription cost savings is also a common result. The specifics differ by site and can be calculated depending on the number of studies that are self-edited versus the number sent to transcription for back-end correction.

Some sites report decreased productivity [6,7]. Some argue that radiologist salaries are too high to have them spend time editing text. Others contend that it is the radiologist’s primary responsibility to provide an accurate report [8]. As a result of the often complex workflow involved in report creation using speech recognition software, the potential for distraction during image interpretation is ever present.

The benefits of a shorter turnaround time are most apparent to the recipients of the reports and are often invisible to the radiologist; therefore, alterations to radiologist workflow to achieve shorter turnaround times are frequently met with resistance. Likewise, transcription cost savings most often accrue across the board to the hospital or health system. Radiologists benefit indirectly from this savings, but the effect is often so diluted as to be negligible [7]. With more time needed for report creation using speech recognition, radiologists bear the brunt of decreased productivity, but these inefficiencies are often invisible to both administrators and referring physicians. Thus, the opportunity cost of using speech recognition technology usually falls squarely on the shoulders of the radiologists.

For these reasons, many radiologists resist the transition to using speech recognition technology to generate reports. Even after installation of the technology, some radiologists find it faster to send cases to a backup transcriptionist for editing rather than make corrections themselves and sign the report at the time of dictation. This workflow removes the advantages of both shorter turnaround times and the cost savings created by use of speech recognition technology but improves radiologist productivity. Each site should evaluate the motivating factors for implementing speech recognition software use and create workflows to achieve the desired effects.

Components of Speech Recognition Technology

Speech engine. The speech engine software converts the spoken word into text. Basic knowledge of the technical aspects of the speech engine can be valuable in optimizing recognition accuracy. Application specialists for a particular product may be able to help radiologists learn the specifics of the system and optimize recognition.

Dictation style. The speech engine searches for a string of individual sounds, or phonemes, to build words and phrases. Phoneme-model recognition requires continuous rather than halted speech. Enough phonemes must be dictated without pausing to give the software enough context to create the proper text. For example, consider the words “and” and “diastematomyelia.” The first word gives little context as to the difference between it and other near-homophones, such as “an” or “than.” Consequently, this and other similar short words are common sources of error. They need to be dictated as part of a longer phrase. By contrast, very few phoneme strings could be confused with “diastematomyelia.” This word can be dictated alone without the need for surrounding contextual phrases. This concept applies not only to dictation but also, perhaps more importantly, to spoken corrections; radiologists can become frustrated at the futility of trying to correct single, short, ambiguous
words. An example is the phrase “one of these.” Rather than train the software to recognize each individual word, adding the entire phrase to the system dictionary is a better solution.

**Corrections.** Dictation errors may be corrected in several ways. One is to highlight the error and speak the correct word or phrase. Other ways vary with the speech recognition system vendor and engine employed. For example, voice commands to assist in editing are commonly available, as well as opportunities to train the software to recognize certain phrases or words within the dictionary. Some vendors allow users access to the vocabulary editor. Using this tool, words and phrases can be added to the individual user profile. The system can be trained to accept idiosyncratic pronunciation. This feature is particularly useful for non-native-English speakers. Unwanted problem words can also be deleted from the dictionary.

**User profiles.** The speech engine software in most speech recognition systems tracks and updates individual user profiles after each reading session. The system should improve as the number of entries in the statistical database of typical phoneme strings increases for each user. This learning feature of the speech engine works best when reports from a particular user are consistent in structure and syntax across time. Using speech recognition systems is similar to training a dog in that consistency is key. This learning feature can often be deactivated if users find that the system does not improve.

**Microphone.** Knowledge and control of microphone functionality is vital for recognition accuracy. The volume setting within the speech recognition software should be adjusted frequently and in certain situations: when a microphone is changed, when a new user logs on, and when recognition accuracy is poor or decreases.

Correct microphone position is critical. Almost all microphones have noise-canceling technology in which the microphone “listens” to a small cylinder of sound directly in front of it. For this reason, the best position for the microphone is <1 inch from the side of the mouth, pointed toward the mouth. Many users have a tendency to lose this configuration owing to head movements during image viewing and dictation. In these cases, a headset microphone has proven helpful. Headsets can be used without losing microphone button functionality. Not holding the microphone has other potential positive effects including eliminating noise from microphone handling and freeing hands for another task such as using the keyboard. Using an array microphone allows the hands to be free, but the disadvantage of faulty microphone position remains and is often worse than that created by a conventional handheld microphone.

If dictation is begun too quickly after pushing the record button, the first syllable of the dictation might be dropped. This problem is a common cause of diminished recognition accuracy. Many users report diminishing accuracy during the course of the day. Sometimes changing the microphone and rebooting the system can help. In some cases, the decreased accuracy may be due to slight changes in voice, or slurring of speech, due to fatigue.

**Navigation.** Most radiologists view images and dictate nearly simultaneously. Therefore, navigation tools must control both the PACS and speech recognition functions at the same time. The traditional keyboard and mouse combination is not ideal for this task. Alternate interface devices should be considered, including multifunction mice, one-handed keypads, foot pedals, or combination keypad-scrolling devices. The exact combination of navigation devices will depend on specific PACS and speech recognition software as well as user preference.

Department-wide solutions are ideal, especially if workstations are shared by several users. The overall goal should be to keep the radiologist’s eyes on the images and not on navigational icons or keyboard keys.

**Interoperability**

**PACS integration.** The reporting system should be interoperable with a PACS and a RIS. Ideally, RIS creates an accession number at order entry and sends this to both the PACS and the speech recognition engine to be stored in the databases. When a case in a PACS is opened for interpretation, the PACS queries the speech recognition database for a matching accession number. The appropriate dictation shell is presented to the radiologist, ready for dictation or other data entry without any requirement other than pressing the record button on the microphone. This feature is not found with all PACS/speech recognition system integrations but is certainly desirable. When the study is signed off at the speech recognition stage, a message is sent to the PACS to close the case. The next case on the PACS worklist can be opened automatically depending on user preference and specific PACS software. The cycle can be continued as needed.

**RIS Interface.** RIS/speech recognition system interoperability is a 2-way interface. A RIS creates an accession number for each study and sends these data to the speech recognition system. When the dictated report is finalized, text is sent automatically to the RIS and populates the proper patient and study record based on the accession number. The report is distributed based on RIS rules to the EMR and other software. In addition, the RIS or speech recognition program can fax or print reports as desired. Addenda should be treated in the same manner as a finalized report.

Text reports can be stored by speech recognition technologies for varying periods based on system preference. This function is desirable if the speech recognition software is needed for historical comparisons. In addition, keeping recent reports in speech recognition software is very helpful for facilitation of addenda.
Decision Support for the Radiologist

Just as clinicians derive benefit from decision support, so can radiologists. This support can take the form of automated Internet searches, information searches in a favorite online text, or access to free or subscription-based websites. Decision-support tools are not specifically a part of speech recognition technologies, but having radiologist decision support tightly coordinated with the reporting system is helpful. Voice-enabled decision support without the need for a third-party login can save time and decrease distractions during image interpretation.

Training and Applications

Training and application specifics should be included in any vendor contract. Protected radiologist time for initial training should be built into the radiologist schedule. The learning curve will vary depending on the user. Part-time users will have longer learning curves. Non-native-English speakers may require more training. Larger departments should plan for decreased productivity initially and consider phased rollout by division. In addition, consideration should be given to scheduling initial training sessions followed by the return of the training team after several months. The need for ongoing applications systems training for radiologists new to the group after initial deployment, and for residents and locum tenens, should not be overlooked. Large sites should consider employing a full-time on-site vendor application specialist or an in-house full-time administrator/trainer. Radiologist “superusers” should be developed when possible. A superuser is one who has a deep understanding of system features and can use this knowledge to help others improve their accuracy and efficiency.

Problem-Solving

Dissatisfaction with speech recognition technology is often due to user-related issues, which can be corrected with good training and application support:

- A dictation style that uses complete phrases rather than individual words (see Speech Engine section) will result in greater accuracy;
- Microphone position and timing issues (see Corrections section) are among the most common causes of poor recognition. These problems can be corrected with user education and practice. Many users will benefit from the use of a headset microphone;
- If a user reports a sudden decrease in recognition, the microphone connection should be checked. If the problem persists, the microphone setup steps and volume adjustments should be performed within the speech recognition software. If the problem persists, the microphone should be changed;
- Extraneous noise can cause decreased recognition, particularly with sudden sounds such as a door slamming. Carpeting and acoustic ceiling and wall panels may be helpful. Some individuals have reported improved recognition with low-volume white noise generators [9];
- Despite multiple correction attempts, often speech recognition software repeatedly cannot understand certain words, which vary by user and vendor. In some cases, a slight workaround can be helpful (eg, “gouty arthritis” instead of “gout”;
- “First digit” instead of “thumb,” etc.);
- Frequent use of the vocabulary editor to correct errors will result in long-term improvement in accuracy;
- Non-native-English speakers may have recognition difficulties. Using the vocabulary editor (see Corrections section) to alter the pronunciation expectations of the software will be especially helpful. These users will likely have longer learning curves;
- Resident/attending dictations and double reads can present workflow issues. Vendor workflow should be evaluated before purchase if possible;
- Dictation using multiple accession numbers (eg, chest CT, abdomen CT, pelvis CT) can be problematic in some cases. These instances require coordination between speech recognition and RIS software. User should check whether this option is available to them and which specific workflow they need to follow for multiple accession number dictations;
- Users must be motivated for successful implementation (see Radiologist Resistance section). Implementation of individual incentives for using speech recognition systems and for self-editing should be strongly considered.

Newer Technologies

Improved speech engine accuracy. Speech engines are continuously being updated and incorporated into newer versions of speech recognition programs. Although accuracy will continue to improve, even achievement of 100% error-free recognition would not be sufficient for efficient reporting. Navigation tools, macro features, and other workflow enhancements will still be necessary.

Findings-only dictation. At least one vendor offers a feature known as “findings-only dictation.” With this advancement, the user can dictate findings in random order without navigating a macro. The software uses predefined editable key words and key-word fragments to place each individual sentence in the proper place within a standardized or structured report.

Natural language processing. Natural language processing (NLP) can be considered speech recognition’s smarter cousin. Although speech recognition programs recognize spoken sounds, NLP technologies can infer specific meaning from text. This technology can create backend structure to a report, to facilitate data mining and search features (see Data Mining section). NLP technology can also be used for automated coding and correction of reporting errors. Some vendors refer to this feature as “clinical language understanding.” Advanced
NLP that incorporates such understanding is geared to health care concepts and context and may be able to detect “left-right” errors and other inconsistencies and alert the dictating radiologist in real time.

Auto-population of PACS and modality data. Work is underway to enable population of the report with measurement data from imaging modalities, a 3-D workstation, or a PACS. Achieving this goal will prove particularly helpful for studies with multiple measurements, such as fetal ultrasound. Further development of the DICOM speech recognition program standards will assist vendors who wish to share this type of structured data.

Annotated image markup. Developers are making good progress in creating methods to generate a complete report using a combination of PACS measurements and computer-assisted diagnosis. This technology is currently in the research stage but shows promise as a timesaver for report creation.

Mobile dictation. With improved speech engine accuracy, mobile dictation is becoming increasingly available and will become even more important as mobile image-viewing technology progresses. This feature will allow radiologists to create, edit, and sign reports when they are away from workstations and even outside the hospital or imaging center. It will also facilitate clinicians’ remote access to imaging data and reports.

Macros and Templates

Definition. Macros can be defined as any text or data stored and inserted by user command. The terms macro and template are often used interchangeably. Sometimes, template refers to a macro with blank spaces to be filled in by the user. A macro can consist of an entire report, a commonly used sentence or phrase, or even a problem word that is poorly recognized. It is helpful to create a macro for any report or phrase that is dictated frequently. If a group of radiologists use a macro in the same way, it may be used to standardize reporting of certain imaging examinations of choice.

Macro naming. Macros are most often inserted by speaking the macro name. Macro naming becomes important when choosing between the hundreds of macros available. Naming should be systematic and consistent across all modalities, logical and descriptive, and as short as possible, to minimize spoken syllables, particularly for commonly used macros. For example, use chest two instead of chest two view normal; use CT AP IV instead of CAT scan abdomen and pelvis with contrast normal. Macro lists can grow to include hundreds and even thousands of entries. As the number increases, a well-organized, systematic, and consistent naming convention becomes more critical. Newer systems can auto-populate the correct macro based on procedure and diagnostic codes as well as patient demographics.

Macro number. In some older software, the number of macros is limited to several hundred. In these cases, macros need to be multiuse (eg, rather than using a separate macro for right and left side, the laterality can be left as a blank within the template, to be filled in by the user). An example of a multiuse macro is as follows: *There is no acute fracture in [ ] ribs.* The blank space is filled in by the user as right, left, or bilateral.

Optimizing macro use. Use of macros can decrease both dictation and proofreading time. They also decrease the need for report editing and result in standardization of reporting frameworks. Macros should be constructed to minimize the need for modifications. Navigation and changes within the macro text should be easily voice driven. In many systems, RIS data can automatically populate various macro fields, further minimizing the need for data input by the radiologist. This feature requires a robust RIS/speech recognition system interface.

Consider the following macro example, which can be used to understand the following list.

*[CT ABDOMEN AND PELVIS with IV CONTRAST]*

Comparison: [None]

IV contrast: yes; Oral contrast: no

Liver is normal in size and CT density. Spleen is normal in size and CT density. Pancreas is normal in size and CT density.

Kidneys are normal in size and CT density. Adrenal glands are unremarkable. Aorta is normal in caliber.

No adenopathy is identified.

Bowel loops are unremarkable.

Visualized pelvic organs are unremarkable. Bladder is normal. Skeletal structures are unremarkable.

**IMPRESSION:** No significant CT abnormality

Issues to consider when implementing macros:

- Create macros to automatically insert RIS data (in this case the procedure description). In the example above, the procedure description can be inserted automatically from RIS data. This feature is dependent on RIS, interface, and speech recognition system functionality;
- Use *None* as the comparison default so that a prior date must be dictated only when necessary;
- Match the order of anatomy with the general search patterns of most radiologists;
- Begin each sentence with the organ name when possible, as doing so makes it easy to navigate and modify dictation by voice only. For example, to modify the spleen sentence in the earlier example, the following can be dictated: `<select spleen thru period> <spleen is slightly enlarged period>;`
- Modify macros without visual input. The eyes should be reserved for image viewing, minimizing "look-away..."
time” when the radiologist’s eyes are diverted from the clinical images;
• Note the phrase “Visualized pelvic organs.” If the uterus is absent or an ovary is not identified, this will not need to be modified;
• Note the phrase “No significant CT abnormality.” If an incidental finding occurs, such as a renal cyst, this will not need to be modified.

In some cases, building a report using individual smaller macros is easier than modifying an existing complete report. If you read hundreds of portable chest radiographs, consider this: Commonly used sentences can be created as individual macros, and verbal commands become text as follows:

<macro large> <macro sternal> <macro con mild> <new paragraph> <macro ET>

The heart is enlarged. There has been prior cardiac surgery with sternal wires sutures. Pulmonary vasculature is mildly congested.

ET tube tip overlies trachea at the level of aortic knob.

Multiple sentences for any common finding can be created as macros and used to build a report or modify an existing one. Examples are as follows:

• <Macro IJ right> Right IJ catheter is present with tip overlying SVC;
• <Macro CVP left> Left CVP catheter is present with tip overlying SVC;
• <Macro NG> Enteric tube is present with tip below the diaphragm;
• <Macro cast> Fine bony detail is obscured by a cast;
• <Macro wet reading> Findings were reviewed at the time of dictation with the ordering provider who expressed understanding;
• <Macro tics> There are scattered colon diverticula with no evidence of diverticulitis;
• <Macro no tail> Pancreatic head and body are normal sonographically. Pancreatic tail is obscured by bowel gas.

The greater the number of macros used, the less the time required to dictate and edit. This time savings allows for improved productivity and may increase image eye-dwell time, with the potential for increased accuracy.

Sound Cues
Most systems have sound cues that are triggered when a command is recognized. These cues can be configured in the user preferences. They are extremely helpful in providing user feedback without the need for visual inspection of the text, and when using a complex macro that requires insertion of multiple words and phrases.

STRUCTURED REPORTING

Formats
The term structured reporting is often used to refer to various reporting formats, such as those that follow.

Standardized. The standardized format is most commonly a prose format in which each organ system or descriptive process is in the same physical location across all reports. Use of this style often includes some type of structure, including organ name headings and consistent formatting. This type of report can be created using conventional dictation or speech recognition programs. Most radiologists use some type of such standardization in their reports. Example of standardized format:

PROCEDURE: Chest 2 view
COMPARISON: None
FINDINGS: Heart is normal in size. Lungs are free of active disease. No pleural fluid is seen. Bony structures are intact

IMPRESSION: No active disease

Itemized. The itemized format consists of a list of organs or body parts, each followed by a short description of findings. Studies have shown that this style is preferred by clinicians [10]. However, another study has shown that no significant amount of time is saved in creating or reading reports in this format [11]. The itemized report is referred to in some published studies as a structured report. One example of an itemized format includes the following:

PROCEDURE: Chest 2 view
COMPARISON: None
HEART: Negative
LUNGS: Negative
PLEURA: Negative
BONY STRUCTURES: Negative

IMPRESSION: No active disease

Some software can facilitate the use of this itemized format with automated field voice navigation. With this feature, the user can move to any field with a quick voice command. This dictation method takes a bit longer to set up but can prove very useful in minimizing distraction and decreasing dictation time.

Structured. For the purposes of this discussion, a true structured report is one in which each data element is coded for later automated data retrieval. This capacity requires specialized software for report creation. Traditional structured reporting software has, in the past, required user input such as selections from a pull-down menu or other on-screen choices. Later iterations allow speech-driven choices. More modern versions create some structure with backend NLP.

Advantages and Disadvantages
In general, the advantages of structured reporting versus conventional dictation or speech recognition are enjoyed mainly by consumers of the report (clinicians, researchers, and administrators). The disadvantages fall more squarely on the shoulders of the report creators (radiologists). Advantages include the following:

• Vocabulary can be easily standardized using RadLex or other ontologies;
• Coding can be built into the process, facilitating billing at the time of dictation and avoiding down-coding secondary to insufficient clinical documentation;
• Comparison with payer initiatives, such as pay-for-performance, is easier;
• Data mining is facilitated, enabling research and other tracking capabilities such as compliance analytics;
• Real-time parallel decision support can be more easily achieved;
• Recommendations for follow-up or additional studies can be easily tracked.

Disadvantages include the fact that the actual process of structured report creation can be more time consuming and distracting compared with conventional dictation or speech recognition. This difference is a result of the fact that most current structured report systems require visual input for report creation. In fact, many current software versions require visual input using multiple mouse clicks, increasing the time spent looking away from the radiographic display.

Radiologist Use and Resistance
True structured reporting (see Structured Reporting section) is not widely used for imaging studies in most radiology practices, with the exception of mammography. By contrast, cardiologists and other clinical specialists are more accepting of this type of reporting. One of the reasons may be that, in general, clinicians typically do not create a report while simultaneously performing a procedure or viewing images, a practice that minimizes the potential negative effects of distraction and look-away time. In addition, most clinicians are consumers of their own reporting product and therefore benefit from many of the advantages of the structured report.

Future of Structured Reporting
The disadvantages of structured reporting can be minimized by speech-enabling report creation, which creates a hybrid of speech recognition and structured reporting, allowing fewer radiologist distractions during image viewing. NLP is used by some vendors and allows a deeper understanding of context, rather than simple conversion of spoken sounds to text. This understanding enables automated backend creation of a structured report with radiologist input very similar to the process with speech recognition programs.

DATA MINING
Data mining (knowledge discovery in databases) is a process designed to discover patterns in large data sets by extracting information and transforming it into knowledge. Alternatively, text data mining applies the concept of data mining to unstructured textual data. This process typically involves structuring input text and deriving patterns within the structured data. The field of NLP blends computer science, artificial intelligence, and linguistics and is concerned with the interactions between computers and human (natural) languages. Specifically, NLP is the process of a computer extracting meaningful information from natural language input and/or producing natural language output.

Hospital information systems (HIS) and RIS are rich sources of clinical and operational information. Health care data are often stored as free text. Radiology reports are largely unstructured text. However, most EMR systems and RIS maintain data in proprietary or complex databases, making data mining difficult and expensive. Radiology report text can be indexed to allow end-users to perform string searches. By applying advanced NLP techniques, radiology report text can be mined for purposes of research, clinical decision support, education, operational analyses, and quality improvement. More specifically, radiology reports can be mined for the following data:

• Clinically important findings;
• Positivity rates;
• Degree of uncertainty;
• Recommendations for follow-up/subsequent action;
• Coding checks;
• Physician Quality Reporting System measures (eg, fluoroscopy exposure/time recorded, inappropriate use of BI-RADS 3, direct or indirect reference to measurement of distal internal carotid diameter as the denominator for stenosis measurement);
• Laterality errors;
• Gender errors;
• Critical results and notification documentation.

Challenges and issues to consider when creating an application to perform text data mining of report text include the following:

• Data access and storage;
• Free text versus structured reports;
• Indexing and search speed;
• Application development;
• Intelligence and NLP expertise along with domain expertise in radiology;
• User management;
• Security and audits.

Software that uses NLP to automatically perform knowledge discovery in databases is commercially available and can be interfaced with one or several information sources in a given health care enterprise. As a result, more meaningful analytics can be performed. Examples include contextual display of (prior) relevant clinical information at the point of service (while dictating a current radiology report) or facilitating compliance analysis of radiology reporting.

INTEROPERABILITY
Shared Data
By necessity, medical enterprises almost always rely on numerous software packages created and sold by various
vendors. The needs of each health care system are unique, and the optimum data storage for a retrieval system differs for each hospital system and may even require various software applications within a single department. Because no one product can optimally address all needs/aspects of a unique health care enterprise, transfer of data is critical. Unfortunately, data are often stored in proprietary formats that cannot be transferred between systems. Rather, the data in each system must be normalized into standard formats so that it can be transferred and received by other data systems. Several standards are in place in medical imaging to achieve this goal.

**DICOM**
The DICOM standard defines the format of messages sent and received by PACS. Information systems that comply with the standard are “DICOM conformant,” and the vendor will provide a DICOM Conformance Statement to attest to conformance and provide details of implementation. Not all PACS store image data internally in DICOM format, but all should be able to export data (eg, on a CD) in a DICOM-compliant format.

**Health Level 7**
Health Level 7 (HL7) defines the format of messages exchanged by software systems within the health care enterprise. Familiar examples of HL7 messages include admission, transfer, and discharge (ADT) messages. HL7 is employed far beyond the boundaries of radiology but is necessary to transfer data (such as clinical history) into a RIS and to schedule examinations from an EMR.

**Specific Relationships Between Information Systems in Radiology**

**RIS/PACS.** The most familiar data-sharing relationship in radiology is the RIS/PACS exchange. The RIS stores scheduling and workflow information for the department, whereas the PACS primarily stores images. However, these systems need to be tightly coordinated, so a highly detailed interface is an absolute necessity. In fact, the relationship is so important that some RIS/PACS are offered as a single entity from one vendor.

**Speech Recognition Technology/PACS.** The speech recognition software system needs to be tightly integrated with both the RIS and the PACS. Older speech recognition systems were standalone entities that ran separately on the PACS computer or on a separate computer nearby. Historically, although RIS integration was seen as essential from the beginnings of speech recognition technology, PACS integration lagged. This situation led to potentially catastrophic errors such as dictations appearing for the wrong patient or being lost entirely. Lack of speech recognition integration also undermined efficient workflow. Tight integration between PACS and speech recognition software is now standard, and speech recognition software vendors are generally expected to support this integration. Integration and connectivity can be facilitated with an application programming interface (API). The API specifies how various software components should interact with each other. An open API is a desirable feature found on many speech recognition systems.

**Modality worklists.** Integration between imaging modalities (ie, individual scanners) and the RIS permits the forwarding of patient information to the modality in preparation for patient scanning. This integration reduces data entry errors at the scanner and can substantially improve technologist workflow.

**Federated PACS vaults.** Radiology groups often use different PACS in different locations, either within a single enterprise or across enterprises in a single practice group. Even if all the PACS vaults are from a single vendor, creating a single repository for all data is often undesirable because transfer times may be unacceptable. However, radiologists may need a single worklist that incorporates all studies into a single user interface regardless of physical location of storage. If all the PACS are from a single vendor, a “federated” relationship may be available such that the PACS vaults are aware of each other. In addition to providing a single worklist, these systems should allow automatic identification of comparison examination across PACS vaults. If the PACS are from different vendors, some features of federated PACS vaults may not be available, but third-party software can create single worklists. These products can function either as a temporary repository for images or as a portal to the main PACS vaults.

**EMR/PACS.** Complete access to patients’ EMR is desirable for radiologists when they are reviewing images. Although missing or insufficient patient histories were previously commonplace in radiology, a modern environment requires efficient digital access to relevant clinical data. Access to the EMR from the same computer as the PACS is an acceptable means of information retrieval, but more complete integration between EMR and PACS, with retrieval of contextual data, will improve workflow for the radiologist.

**Integrating the Healthcare Enterprise**
Integrating the Healthcare Enterprise (IHE) is an organization founded by the RSNA that creates technical frameworks to guide robust integration of information systems in medicine. Although these frameworks are not strictly “standards,” they serve a similar role to ensure successful communication between or among information systems. The frameworks are organized into “integration profiles” that each deal with a specific problem in software integration. The RSNA continues to support “Connect-a-thon” events in which vendors can test their ability to integrate with other information systems.
Vendor Interactions
Radiologists can support robust integration when negotiating with vendors. In particular, hardware or software used for patient care in the radiology department should have a DICOM Conformance Statement and an IHE Integration Statement. These documents should be carefully reviewed prior to any purchase. Furthermore, new purchase contracts should include explicit language to ensure interoperability with existing systems and clear assignment of responsibility for troubleshooting interoperability failures.

Summation
A critical feature of health care information systems is the ability to share data in an automated and efficient manner. Usually, a single vendor does not have complete control of system integration and cannot meet all of the needs of a radiology department or health care delivery system. Thus, communication standards and integration frameworks are essential for smooth operations [12]. Even with tight adherence to these standards, interoperability failures are frequent. Radiologists and radiology administrators are urged to make interoperability a key component of contract negotiations with equipment vendors. Ideally, information exchange should be demonstrated with real-world data before final payment is made to the vendor.

RESULTS COMMUNICATION: CLOSING THE LOOP
Communication of results, whether routine or emergent, closes the loop that began with order entry.

Report Content and Format

Prose. The prose format consists of regular sentences describing the findings. This style is still the most common. Use of this style does not preclude some type of structure, including organ headings and consistent formatting.

Itemized. The itemized format consists of a list of organs or body parts, each followed by a short description of findings. An itemized report is sometimes referred to as a structured report, as described in more detail in the section on structured reporting.

Structured. Structured reporting falls into 1 of 3 categories: a prose format in which each organ system or descriptive process is in the same physical location across all reports; an itemized report with a header for each organ system; a report in which each data element is coded for later automated data retrieval. See the Structured Reporting section for more information.

Multimedia. This type of report can take many forms. For example, an annotated image can be linked with a short textual description. This format is uncommon in current practice and requires interoperability between the reporting system and the PACS, as well as an EMR capable of accepting such a format. This type of annotated image markup shows promise in streamlining future report creation and consumption.

Impression or summary. All reports should have a short summary of findings organized in a systematic manner, usually by order of importance.

Delivery of Routine Results

Timing. Routine finalized reports should be delivered as quickly as possible. Exact timing will depend on the type of reporting circumstances. For example, a mammogram result will not be as critical as a routine emergency department study.

Format. Various delivery formats can be used. Depending on software capabilities, the reporting system itself can be used for report delivery (eg, fax to provider, text to voice). The reporting system can store text reports for variable periods. This feature is desirable as a backup to the RIS and to facilitate addenda creation. The RIS is currently the most common storage of record for all radiology reports. This may change with the ascendance of the EMR, which may come to serve as the portal for clinicians to access both images and reports, if available. Alternatives are needed if the EMR is not accessible by some clinicians (fax, e-mail, postal service, direct remote RIS or PACS access for report and image viewing). In these cases, the lack of a formal audit trail is a distinct disadvantage.

Audit trail. All activities in the EMR are tracked and recorded. All reports should appear in the clinician’s inbox and not simply populate the patient chart. In this manner, active delivery of all reports is ensured. Flagging positive reports is helpful to clinicians. A return receipt option for radiologists can be used, if necessary, to close the communication loop. Sensitive information, such as health information of health care system employees, may be protected through additional monitored layers of access control.

Delivery of Critical Results

Communication policy development. Both the ACR [1] and The Joint Commission [13] (formerly the Joint Commission on Accreditation of Healthcare Organizations) strongly advise radiologists to expedite notification of critical findings to referring providers in a timely manner. However, neither standard timeframes for notification nor delivery methods have been suggested by these entities. Therefore, establishing a solid underlying policy for all related activities is crucial as the first step of this process. In addition, “critical results” must be clearly defined. The use of disease-based definitions has been proposed, but this approach is often not comprehensive, and broader definitions, to include clinical interpretation, have been preferred by many.
Criticality levels and escalation. All critical findings should not be treated equally. Developing predefined levels (typically 3-5) of criticality is an important second step to assign appropriate communication methods and notification timeframes. In addition, the policy can establish predefined procedures in the event that the intended recipient cannot be reached. The escalation parameters should be predetermined and end only when an appropriate provider acknowledges receipt of the critical findings or the entire report.

Format. Results with higher levels of criticality are best conveyed by synchronous communication (telephone or physician-to-physician communication). Nonurgent communications can potentially happen asynchronously, but best practice in these situations is to ensure receipt of the findings by using a verifiable method of communication. This approach allows both parties to determine whether the important finding was received and appropriately understood.

Audit trail. An important element of software that deals with communication of critical test results is the ability to track access to patient health information, communication attempts, and acknowledgement of receipt. The application ideally should capture the critical finding itself, the individuals involved in the communication, the method of notification, acknowledgment of receipt of the findings, and time and date of each activity. These variables are important in determining adherence to local policy and are necessary to understand the sequence of actions if a case requires further investigation.

Radiologist tasks. The radiologist workflow to communicate a critical test result begins with recognizing the importance of the finding and the urgency level in relation to the underlying policy. Once this is established, the communication of critical results (CCR) application typically walks the radiologist through the process to ensure that all pertinent variables are captured. Tight integration between the CCR application and other radiology systems (PACS, speech recognition, or RIS) allows greater efficiency of the entire process. Manual data entry should be reduced to a minimum, to decrease human error. Patient context sensitivity is very important and is aided by this integration.

Maintenance of database. One important aspect of the CCR software is the accuracy of its provider database, which is important from a variety of perspectives. Ensuring the message reaches the intended person is a key element to HIPAA compliance and timely CCR. If electronic escalation is built into the system, the database will also need to include the role of each individual and their relationships to each other in a particular environment. Depending on the sophistication of the enterprise master physician index and the availability of an enterprise patient list, identification of the individual caring for a patient at a specific point in time may be possible. This dynamic database can be integrated into the CCR application to increase the efficiency of the communication process by recognizing a shift change or assignment of different responsibilities in the care of a patient. Irrespective of the type of implementation and level of integration, all provider contact information must be current and accurate. Such databases require ongoing resources to maintain and may be time consuming to set up.

Nonautomated alternatives. Institutions without automated software can and should create a manual process to address CCR. As previously mentioned, developing a policy is crucial for both manual and automated efforts.

Measurement of performance. Performance metrics should be part of policy creation and are required by the Joint Commission. Without implementation of a CCR application, measurement of performance is typically manual, except when a department can mine the radiology report using NLP technology. These tools make possible the capture of standard communication statements within the report and extraction of appropriate information to determine policy adherence. However, NLP applications are not typically 100% accurate, and some level of data compromise is typically seen. Using a dedicated application for CCR is advantageous when the data are typically appropriately captured and structured in such a way that standard report generation is generally straightforward. Business intelligence can be used in this process and may facilitate the creation of ad hoc queries for data analysis.

CONCLUSIONS
Accurate and timely communication of patient care-related information among medical professionals represents a major challenge in prevailing health care delivery systems. Order entry, such as use of CPOE with decision support, begins the closed-loop communication that ends with the clinician receiving the finalized radiology report. Pressure from clinicians to improve turnaround time, and from administrators to save transcription costs, has been a major factor in the transition to use of speech recognition technology, which is continuously improving. Good training and application support can alleviate much of the dissatisfaction experienced by end users of speech recognition programs. Once created, radiology report text can be indexed to allow data mining for purposes of research, clinical decision support, education, operational analyses, and quality improvement. As single vendors do not usually meet all of the needs of a radiology department or health care delivery system, radiologists and radiology administrators are urged to make interoperability a key component of contract negotiations with vendors. Finally, confirmation of accurate and timely results communication closes the communication loop that began with order entry.
TAKE-HOME POINTS

- Radiology communication is a closed-loop cycle that begins with computerized order entry and ends with automated results communication.
- Integration of all involved systems is essential for efficient and safe communication.
- The inherent inefficiencies of speech recognition technology can be minimized with proper use and software configuration.
- Data mining software is useful in both clinical and academic settings.

REFERENCES