The concept of data reconciliation has been well described in the industrial and pharmaceutical literature and is designed to ensure the integrity, reliability, and accuracy of sequential data in a multistep process. This concept can similarly be applied to the delivery of medical imaging services, which begins with order entry and ends with reporting and communication. The ultimate goal of medical imaging data reconciliation is to ensure continuity of care, extending across multiple service providers and imaging and information system technologies. The longitudinal analysis of standardized data across the imaging continuum presents an opportunity to improve communication between service providers, education and training, workflow, and clinical outcomes. In addition, the derived data can in turn be used to create data-driven best-practice guidelines and computerized decision support tools.

Key Words: Data mining, medical imaging, clinical outcomes analysis

INTRODUCTION

One meaning of the word reconciliation is the process of getting two things to correspond with each other, as in the reconciliation of a checkbook and bank statement. When used in the context of industry, data validation and reconciliation is a technology that uses process information and mathematical methods to automatically correct measurements that arise during the course of industrial processes [1]. This is necessary because the raw measurements obtained during these processes are often inaccurate and affected by random or systematic errors, which can result from sensor drift, calibration errors, and instrument malfunctions [2,3]. As a result, data validation and reconciliation allow the extraction of accurate and reliable information from raw measurement data, producing a single consistent set of data, representing the most likely process operation [4].

The most common medical application of data reconciliation is in pharmaceutical reconciliation, which was created to reduce medication errors [5,6], and is now mandated by the Joint Commission [7]. Pharmaceutical reconciliation is designed to ensure the collection and communication of accurate patient medical information, with a goal of ensuring continuity of pharmaceutical care for patients at the beginning, through the course of, and at the end of clinical service [8]. The objective of this data reconciliation process is to ensure continuity of care delivery across multiple individual caregivers and institutional providers. The ability to perform pharmaceutical reconciliation has been greatly enhanced by the creation of supporting technologies, such as pharmacy information systems, computerized physician order entry, and clinical decision support systems [9].

The concept of medical data reconciliation can be applied to essentially all medical disciplines, including radiology, with the goal of ensuring continuity of care across the health care continuum. At the most superficial level, the radiology continuum would be defined by the individual steps that take place during the course of an imaging examination (ie, imaging cycle), beginning with examination ordering and ending with reporting and communication. Each of these individual steps in the imaging cycle would have its own associated data, contributing to the data reconciliation process (Table 1).

On a more in-depth analysis, data reconciliation within medical imaging should extend beyond the imaging cycle and include clinical data that are critical to ensuring imaging data optimization. Clinical data are critical to the steps of ordering, protocol optimization, image processing, interpretation, and reporting. Medical imaging in the absence of relevant clinical data is the equivalent of practicing radiology in a vacuum, with the potential for adverse clinical outcomes [10,11]. If data reconciliation is applied to radiology, therefore, it is critical to ensure that both clinical and imaging data are incorporated into the overall process, with the ultimate goal being improved patient outcomes.
IMAGING AND CLINICAL DATA RECONCILIATION

The relevant data sources for medical imaging reconciliation are listed in Table 2, consisting of longitudinal clinical and imaging data. For reconciliation of contemporaneous (ie, current) data, the clinical data requirements include the clinical indication for the ordered imaging examination (eg, chief complaint), the presumptive diagnosis (or diagnoses), and relevant clinical support data (eg, laboratory and physical examination findings). Three data components contribute to imaging data analysis: technical (ie, numeric), image (ie, pixel), and report (ie, textual).

An example would consist of clinical and imaging (report) reconciliation, for which the following analyses can be performed:

1. Was the appropriate imaging examination ordered for the clinical data presented?
2. Were the recorded clinical data sufficient in quality and quantity to optimize interpretation?
3. Did the radiology report data directly answer the primary clinical question?
4. Were clear and unambiguous report data presented to guide clinical management (eg, clinical significance, differential diagnosis)?

In addition to “current” clinical and imaging data, historical data are a critical component of data reconciliation. Important historical clinical data include prior clinical diagnoses, treatments, procedures and surgeries, laboratory and pathologic data, and clinical tests. Historical imaging data consist of prior imaging examinations of relevance to the current examination, with an emphasis on the historical report data. An example of longitudinal data reconciliation would consist of historical imaging report and current imaging report data reconciliation. In this analysis, the following analyses could be derived:

1. Were the historical report data (ie, findings) accounted for in their entirety on the current report?
2. Were accompanying report data provided to facilitate effective clinical management (eg, comparative measurements, follow-up recommendations)?
3. Were the historical report data accurate and complete in identification and interpretation of pathology?

Longitudinal data analysis would be incomplete without the incorporation of “future” clinical and imaging data, which provide the ability to retrospectively analyze the quality of previously recorded clinical and imaging data. Future clinical data would include diagnosis, clinical and laboratory tests, response to treatment, and pathology. Future imaging data would consist of “downstream” imaging report data of relevance to a given imaging examination (ie, follow-up study), with an emphasis on temporal change and radiologic diagnosis.

An example of future data reconciliation would consist of imaging and clinical data reconciliation, in which downstream clinical data are reconciled with current imaging report data. In this example, the discharge summary (ie, clinical data) could be correlated with the imaging report data to analyze the following:

1. Was the imaging report diagnosis consistent with the definitive clinical diagnosis?
2. Were the imaging report follow-up recommendations accurate and reliable in facilitating appropriate clinical diagnosis and treatment?
3. Were the imaging report data acted on in a timely and appropriate clinical fashion to positively affect patient outcomes?

INNOVATION OPPORTUNITY

An imaging or clinical data set is literally and figuratively a snapshot of a patient’s medical record at a single point in time. Because a patient’s medical history is a dynamic process, these combined snapshots coalesce to tell a story, which is corroborated by longitudinal clinical and imaging data. As a result, any attempt to reconcile medical data within an individual patient’s medical record requires both retrospective and prospective analysis of these data, which will ultimately prove or disprove the veracity of a single “point-in-time” decision.

In the current practice environment, longitudinal analysis of clinical and imaging data is hampered by the lack of supporting technology, nonintegrated clinical and imaging data, and workflow constraints. As a result, health care professionals are forced to rely on whatever data are readily available to them at the time of task
performance. For a radiologist tasked with the interpretation and reporting of an imaging data set, “readily available” data consist of the clinical data provided at the time of order entry, archived historical imaging pixel and report data, and current imaging technical data in the Digital Imaging and Communications in Medicine header. In the absence of automated data extraction technologies, most radiologists elect to maximize productivity by limiting data review to the clinical order entry data and most recent comparable historical imaging image and report data. This has the potential to overlook additional clinical and imaging data that could be of potential value to interpretation of the imaging data set.

During the cumulative course of patient care, sequential imaging and clinical tests are performed, contributing to diagnosis and clinical management. In most cases, downstream clinical and imaging data are not brought to the attention of the radiologist who interpreted a prior imaging data set, resulting in lost educational opportunity. The lack of clinical and imaging data follow-up has been exacerbated by the decreased frequency of radiologist-clinical consultations since the transition to filmless imaging [12] and the emergence of teleradiology, whereby access to historical imaging data is often limited [13]. With the exception of mammography (because of Mammography Quality Standards Act requirements), the majority of imaging report diagnoses are not analyzed longitudinally [14], resulting in limited radiologist feedback. The creation of a technology that improves data quality and quantity across the clinical and imaging spectra, while providing objective context and user-specific data analyses, could provide educational benefits along with the potential to improve clinical outcomes. The successful implementation of such a technology would require data standardization, integration, and automated extraction.

One can think of these clinical and imaging data reconciliation analyses as formal “checks and balances” in the clinical care continuum, ensuring that clinical and imaging data are working in tandem, outliers are promptly and efficiently recognized, responsible parties are being held accountable, and the relationship between clinical and imaging data and patient outcomes is being analyzed and acted on. In addition to these important clinical benefits, the proposed technology offers additional research and technology development opportunities.

**DECISION SUPPORT**

The longitudinal reconciliation of imaging and clinical data presents an opportunity to analyze the completeness and accuracy of the data being recorded and the subsequent impact on patient outcomes. Clinicians could gain important knowledge through context-specific feedback as to what clinical data are relevant to specific diagnoses and imaging examinations, as well as the most efficient utilization of imaging services. Radiologists would be provided with feedback and guidance as to the clinical value of imaging report data, along with finding-specific and examination-specific interpretation accuracy statistics. These analytics can be further enhanced by the integration of existing computerized decision support tools, such as appropriateness criteria for imaging examination ordering [15], context-specific and user-specific reporting requirements [16], and computer-aided detection and differential diagnosis [17].

The combined clinical and imaging databases can also provide the opportunity to create new computerized decision support tools, which can assist both radiologists and clinicians in data extraction, diagnosis, workflow, and clinical management. Although data extraction is, and remains, a particularly challenging problem in medical informatics, the clinical and imaging data reconciliation process helps in identifying what specific data are relevant for a given clinical context, anatomic region, imaging modality, and medical history. When radiologists provide feedback to ordering physicians as to the completeness and accuracy of the clinical data presented at order entry, they are also providing feedback as to what specific clinical data are lacking, to effectively render an accurate imaging diagnosis. In many instances, prior imaging report data may contain valuable clinical data not presented in current clinical order entry. When these “historical” clinical data are identified by a radiologist as relevant, they can be electronically tagged and added to the data repository, providing automated feedback to the referring clinician.

As downstream clinical and imaging data are being reconciled, the specific clinical data that confirm or reject the imaging report data are recorded in the database and incorporated into the “relevant clinical data” repository. As more data are accumulated over the course of a given patient’s lifetime, as well as other patients with similar clinical and imaging data, an expanded database is created, which identifies the specific clinical and imaging data of relevance for a given patient and context. These data can in turn be used to create computerized data extraction tools, which can automatically sort through the electronic medical record and create customizable data association linkages between clinical and imaging data.

In addition to the automated extraction of predefined association data, a radiologist could manually input specific database queries, which could in turn prompt the computer agent to search the clinical and imaging databases for corresponding data. Once these data have been recognized as having relevance to a given context, end user, or patient, they would become automatically incorporated into the automated data extraction software. Individual end users (ie, radiologists or clinicians) could create customized data extraction profiles on the basis of the individualized feedback provided or instead elect to use standardized default extraction templates. The system would be designed to be iterative in nature, as more data are collected and validated through continued use.
CONCLUSIONS
Data reconciliation in medicine offers an opportunity to introduce objective accountability measures across the continuum of multistep service delivery, which typically involves multiple providers, both individual and institutional, and supporting technologies. Medical imaging is particularly well suited for its application because a well-defined stepwise process occurs in the delivery of medical imaging services, beginning with order entry data and concluding with the communication of report data. The corresponding data derived from each individual step in this process can undergo sequential analysis and be used to create best-practice guidelines, along with automated feedback and education to improve performance of individual end users, institutional providers, and technology producers. The challenges to creating such a technology are significant and include the standardization and integration of multisource data, which are currently largely disparate and proprietary in nature. A collective effort by the medical imaging community and technology providers can overcome these challenges if united, with the goal of promoting continuity of care and improved clinical outcomes.

TAKE-HOME POINTS
1. Adequate clinical history and questions to be answered are essential components of a reconciled radiology report.
2. Radiology data reconciliation should include all individual steps and participating stakeholders in the imaging continuum.
3. The reconciliation of radiology report data should include analyses of “historical” and “contemporaneous” report data, which can become an integral component of radiology peer review.
4. More robust quality assurance is essential in improving radiology service delivery and should include a number of data reconciliation analyses, including clinical history, radiology report, and clinical outcomes data.
5. Radiology report and clinical outcomes data reconciliation can be facilitated through the automated data extraction of clinical data sources, including pathology reports, clinical tests, and hospital discharge summaries.

REFERENCES

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