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Six Characteristics of Effective Structured Reporting and the Inevitable Integration with Speech Recognition

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The reporting of radiological images is undergoing dramatic changes due to the introduction of two new technologies: structured reporting and speech recognition. Each technology has its own unique advantages. The highly organized content of structured reporting facilitates data mining and billing, whereas speech recognition offers a natural succession from the traditional dictation–transcription process. This article clarifies the distinction between the process and outcome of structured reporting, describes fundamental requirements for any effective structured reporting system, and describes the potential development of a novel, easy-to-use, customizable structured reporting system that incorporates speech recognition. This system should have all the advantages derived from structured reporting, accommodate a wide variety of user needs, and incorporate speech recognition as a natural component and extension of the overall reporting process.

KEY WORDS: Data mining, direct reporting, dynamic menu, English composition software, free text, guidepost, hierarchical organization, knowledge base, lexicon, macro, macro reporting, menu navigation, radiology reporting, RadLex, semantic net, speech recognition, structured report, structured reporting, talking template, taxonomy, template, speech recognition software, voice user interface (VUI)

BACKGROUND OF APPLICATION

The traditional method for generating radiology reports has been dictation, followed by transcription. This process, although familiar and easy to learn, does not take maximal advantage of digital advances in radiology nor does it exploit present-day and future software capabilities. Its turnaround times and error rates are suboptimal, and it produces reports that are not amenable to subsequent data analysis and require additional steps for bill coding.[1–6]

Recently introduced structured radiology reporting systems[7,8] represent a paradigm shift in the reporting process. By taking advantage of advances in computing capabilities and digital radiology, structured reporting systems have potential benefits such as instant turnaround times and instant feedback to report authors. Furthermore, they allow the generation of reports with standardized organization, consistent word usage, and uniform language style that are thus easy to interpret; allow the coding of key terms in meaningful ways that facilitate data retrieval and billing; and eliminate typographical transcription errors.

The medical community, supported by initiatives from government and industry, is looking for faster and more efficient communication between radiologists and medical clinicians along with the efficient storage and retrieval of electronic medical record systems. Digital technologies and standards for electronic storage and access to medical records and diagnostic images have improved with automation. The Digital Imaging and Communications in Medicine (DICOM) Standards Committee introduced DICOM SR[9] in 2000, a

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standard in radiology imaging for the tagging, exchange, and management of specific image-related information. It specifies standards for mapping radiological information in reports, thus giving consistency to the access in the same report information created in different systems. Such standards in reporting provide for interoperability between radiology information systems (RIS), picture archiving and communication systems (PACS), and hospital information systems (HIS), which are core components for electronic radiology records. Other standards are in the process of completion such as RadLex, which will specify a standardized lexicon for radiology.

This article describes the six characteristics of an effective structured reporting system and concludes with an explanation of how speech recognition can be incorporated into the structured reporting process. This new radiology reporting paradigm has the potential to deliver radiology reports with all the advantages of current structured reporting systems, with the benefit of making voice input easier to use, thereby creating a much lower learning curve.

STRUCTURED REPORTING DEFINED

"Structured reporting" is defined as the creation of standardized, organized information from templates navigated via menus into a natural-sounding language report. The purpose of structured reporting is to provide a method of direct reporting that can replace the dictation and transcription processes for documenting medical image interpretation. However, a distinction needs to be made between the "outcome" of a structured report and the "process" by which a structured report is composed.

The *outcome* is the ultimate report itself. Structured reports have consistent organization and terminology, uniform language style and syntax, are free from transcriptional errors, and are easily interpreted by referring physicians from a wide range of medical disciplines. For example, key terms in a structured report are organized in meaningful ways that would reflect each term's relatedness to other key terms, and this facilitates data retrieval. Such reports can be instantly communicated to other standard compliant systems and electronically distributed to referring physicians. Uniform organization allows referring physicians to quickly scan the report and find the information they need.

A structured *process* is the process by which radiologists enter their findings about an image directly into a software program that captures these radiological findings as structured data. Data entry can be facilitated by the selection of data elements from a comprehensive branching knowledge base and the translation of the combinations of selected data elements into natural, readable, semantically correct English sentences, arranged into well-organized paragraphs.

DESIRED ATTRIBUTES OF AN IDEAL REPORTING SYSTEM

An ideal system would create fully structured reports from uninhibited, free-form dictation[10] (see Fig 1). It would

(1) allow report authors to dictate freely, without constraints, and without having to move their eyes away from the medical image, and to use whatever organization is convenient—or even without organization at all;
(2) produce completely structured reports
   (a) that use consistent medically accepted terminology and nomenclature
   (b) that are consistently organized
   (c) that contain end-user hidden codes and data relationships that can be used for data mining and billing
   (d) that can be disseminated electronically as soon as they are dictated.

Such a perfect system would require a remarkable software. Naturally, it would have to include a speech recognition system to interpret spoken words. It would have to invoke very advanced English composition software that could understand vast variations of synonyms and then substitute optimal word choices to render reports with consistent terminology. (Accordingly, this software would require a vocabulary of at least several hundred thousands of words.) But the primary obstacle would be, perhaps, the requirement that the software be able to understand and translate every conceivable type of sentence structure, including every conceivable type of

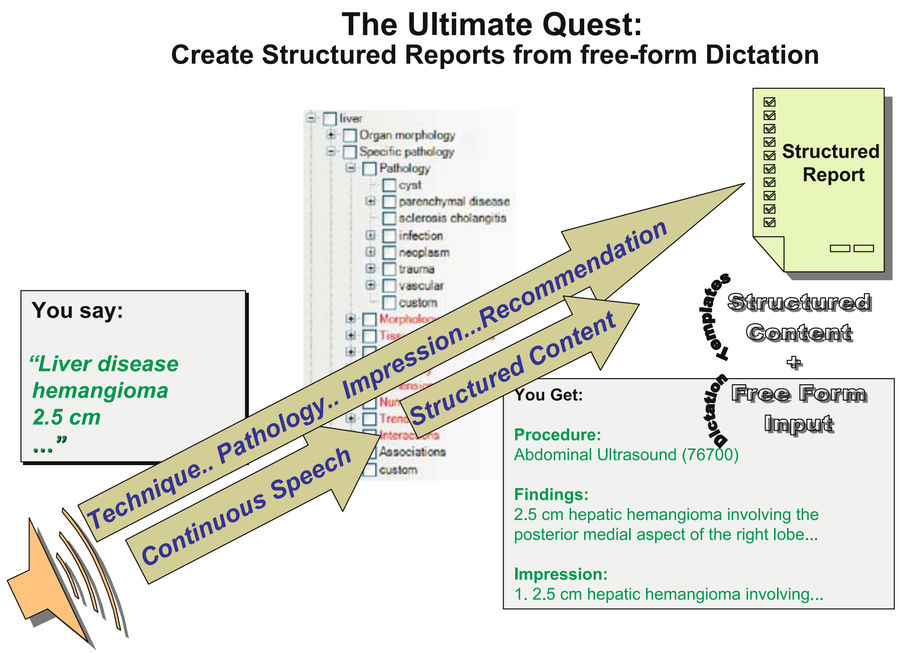

Fig 1. Architecture of the ideal reporting system.

incorrect sentence structure, and correctly interpret all possible ambiguities. (For example, if the user says "X Y X", the computer needs to be able to translate that into " X y Z" but not " X Q D".) In addition, a multidimensional semantic network would be required to contextualize the use of the lexicon in mapping during sentence construction. To date, such complex software exists only in a narrow research-oriented domain.

CHARACTERISTICS OF AN EFFECTIVE STRUCTURED REPORTING SYSTEM

To approach this ideal, a structured reporting system must maximize flexibility while minimizing constraints on the report-generating process, yet produce fully structured reports. To accomplish this, it is proposed that a structured reporting system should employ the following six characteristics in its design. Three concern the outcome or the content of the report, and three concern the reporting process itself.

Content-Related Characteristics

Report outcomes must incorporate the following three requisite characteristics.

Categorization of Elements

The primary organization layout of a report, or the *categorization* of its elements, can be thought of as options on a continuum ranging between a taxonomy based on the relatedness of elements (such as pathologies listed under "findings") at one end and a numeric coding system based on arbitrarily assigned numbers (such as ICD and CPT codes used to describe procedures and clinical information) at the other end. An effective structured reporting system must be able to accommodate all possible types of categorization from this continuum.

Organization of Macros

The process of generating a report is more efficient if a new report can be quickly assembled from components or macros that allow the reuse of previous reports in part or in whole. How the macros are organized and recalled affects the speed and robustness of the reporting process. At its most basic level, the organization and management of macros can range from a simple collection or single-level list at one end to an ordered hierarchy at the other. Macros for complete reports can be created from a combination of submacros or subcomponents. A system to manage a large volume of these subcomponents must be available to facilitate the creation and editing of macro-level content.

Relating of Report Elements

A structured report depends on the assembly of report elements into a natural English sentence-like composition. This can be thought of as the micro-level of content—or what is inside selected macros. An effective structured reporting system allows an English composition software to link assembled relationships in a semantic net. This semantic net encapsulates patterns, associations, and relationships between elements of a knowledge base. The selected elements can then be composed into grammatically and syntactically correct narratives (i.e., meaningful sequences of English words, phrases, sentences, and paragraphs) as intended by a report author.

Process-Related Characteristics

We argue that a fully robust system of structured reporting must address these three aspects of the actual process of authoring structured reports.

Navigation of Menus

An effective structured reporting system must allow the process of menu navigation to be either unbounded, or a fixed path, or some user-defined process between the two extremes. For example, with highly repetitive common reporting tasks (such as a large number of negative or normal reports) a streamlined, automated, or constrained menu process might be more appropriate, whereas in a more advanced system, a user may desire to have all functionality and flexibility options available. End-user productivity depends on the user interface for the navigation of menus and element selection having complete flexibility and ability to customize the menu for various and differing reporting methods and tasks.

Sequencing of Workflow

An effective structured reporting system will allow interpreting medical images in any progression (e.g., right to left, top to bottom, or inside to outside) in some situations or in a predetermined sequence in others. The corresponding input selection must not be constrained to a rigid sequence and must allow subsequent edits and changes until the report is final. Alternatively, sequencing workflow at this level can help attending radiologists enforce a style of interpretation by the resident radiologists. It is the reporting corollary to the "hanging protocol" in image viewing.

Reuse of Components

An effective structured reporting system will allow frequently used components of the knowledge base to be reused in different ways. Such systems would allow a report author to insert a static piece of text into a report or call up a dynamic macro. "Dynamic" refers to the ability of components to carry behavioral characteristics such as execution of programmatic procedures or rearrangement of content in the report. An efficient system will allow short cuts to all modes of using components repeatedly.

IMPLEMENTATION OF A STRUCTURED REPORTING SYSTEM—CASE STUDY

The structured radiology reporting system, a point-and-click graphical interface system based on the six characteristics of a structured reporting system described in the previous section, was first installed in a test hospital in 1995.[8]

To produce StructuRad reports, users enter their findings into the StructuRad software. This program consists of a knowledge base of all possible radiological findings, techniques, clinical histories, and indications (logically organized into a knowledge base by exam modality and anatomic site in the form of a branching tree) coupled with English composition software. Users select data elements from the tree, while navigating toward the ends of its branches, and English composition software simultaneously writes the sentences comprising the report. Every StructuRad report is organized into seven sections: Procedure, Clinical Information, Technique, Limitations, Comparison, Findings, and Impression.

The initial StructuRad system demonstrated that completely structured radiology reports can be created from knowledge tree templates containing a radiology lexicon. However, initial use showed that this original point-and-click tree navigation user interface has some drawbacks: there is a steep early learning curve, and users must take their eyes off the medical image while they interact with a graphical interface on a computer screen to select data elements for the report.

Two potential solutions identified to improve user interaction are: (1) use of high-level report macros to reduce the number of data selections, and (2) use of voice dictation using speech recognition.

As the technology for speech recognition software has improved, its feasibility as an option for radiological reports has been considered. Its advantages are that it allows radiologists to keep their eyes on the image and it is easy to learn.[11] However, it can be more time-consuming than traditional dictation, can involve a substantial learning curve, can require time-consuming post-dictation correction, and does not provide structured reports.

A REPORTING SYSTEM THAT COMBINES SPEECH RECOGNITION WITH A STRUCTURED OUTCOME

A novel, fully integrated, efficient, workable system that addresses the drawbacks of current speech recognition dictation systems (in terms of speed, accuracy, uniformity, and coded content) and of computer screen-based structured reporting systems (in terms of ease of use) is proposed. This interactive reporting system incorporates the fundamental elements of an effective structured reporting system described in "Characteristics of an Effective Structured Reporting System."

The system interacts audibly with the report author while he or she is dictating. The author speaks and then the computer voice asks the author to confirm his or her meaning with audio feedback, or it gives a list of options. Thus the author is guided, by a "talking template," into saying the phrases the computer can use to write the structured report. In this way, report authors do not need to move their eyes away from the medical image nor navigate through a knowledge-base menu on a computer screen.

Audio prompts provide a mechanism for novice computer users to produce a structured report and additionally help them organize their thoughts.

This integrated system lowers the learning curve and decreases its steepness so that report authors can start authoring structured reports immediately. Yet, it does not sacrifice any of the desirable features of the resultant fully structured report.

PROPERTIES OF A STRUCTURED REPORTING SYSTEM WITH INTEGRATED SPEECH RECOGNITION

The following are examples of how an integrated speech recognition/structured reporting system with a substantial amount of adaptability may allow users to maximize their efficiency and minimize their reporting effort.

Input Modalities

The system should allow user input via keyboard, mouse, microphone, or stylus.

Frequently Needed Phrases—Macro or Report Reuse

Many radiological facilities repeatedly see the same disorders and normal conditions. One way to save time is to be able to incorporate frequently seen findings into a report with one quick action such as a spoken word[12] or a mouse click. The system may provide users with prewritten macros they can use and reuse, or they can customize their own. Such macros can be recalled by voice or mouse, depending on the user's preference.

Placement of the macro-induced text adds another layer of complexity. If the macro-induced text can only be added to the current position of the cursor, then application of (multiple) macros can only take place while the report is being manually edited with cursor control. This process for the insertion of multiple macros inhibits automation. This limitation can be overcome by the use of English composition software and structured macro organization.

Shortcuts to Frequently Needed Locations

Many radiological facilities, for example, facilities in hospitals that specialize in female reproductive disorders, will have many occasions to return to the same part of a radiological knowledge base. For additional productivity, a shortcut feature would allow radiologists to take a shortcut from the trunk of the database immediately to one of the outer branches, for example, to a specific anatomical location such as the breast.

Unique Situations—Free Text Options

The system should allow users to easily input their own words or sentences, which can be inserted anywhere. Multiple input scenarios ranging from simple word insertion in front or after a word or phase to complete sentences and paragraphs are possible.

CONCLUSION

The process of making radiological reports is undergoing a revolution. The authors' experience with one such integrated system, *StructuRad with Dictation Protocol*, can be likened to using or playing a musical synthesizer because of its flexibility and customizability. A synthesizer player can play a keyboard with both hands and all 10 fingers and either play her own original composition or a piece composed by someone else. Or she can use one finger to play a melody with her choice of synthesizer-generated accompaniment in whatever style she chooses (e.g., mambo or rock). Her one-finger melody can be configured into *Beethoven's Fifth Symphony* or *A Fifth of Beethoven*, depending on her preference. Or she can press a button once and initiate one preset melody or a whole cascade of preset melodies. Or a synthesizer player can start out playing the music entirely on her own, then push a button and get up and dance while the synthesizer finishes the song.

This analogy illustrates the ways an advanced integrated structured reporting system could benefit users by providing them with a superfluity of possible ways of customizing the system to their own changing needs. *Such a reporting system* gives users all the benefits of being able to produce coded structured reports that allow the easy retrieval of bill coding and other kinds of data, and to use easy-to-interpret consistent terminology and uniform organization. In addition, the process used to produce such reports is easy to master by using a talking template.

APPENDIX: GLOSSARY OF TERMS

Data Mining	The retrieval of meaningful information and relationships from databases
DICOM SR	Digital Imaging and Communications in Medicine (DICOM) Structured Reporting (SR); the set of guidelines for the radiology and cardiology imaging industries that specify standards for structuring information about radiological and other images
Dynamic Menu	A menu that changes when the user presses a modifier key
Guidepost	A shortcut that takes a user to a menu of macros, knowledge tree selections, or user inputs such as dictation
Lexicon	The vocabulary of a special language or field
Macro	A sequence of computer steps that can be recorded so that they can be triggered by one or a small number of keystrokes, mouse clicks, or voice commands
Macro Behavior	A macro that is an action as opposed to a simple set of words
Menu Navigation	The process of moving a computer's attention from one part of a list of choices to another or from one list of choices to another
PACS	Picture archiving and communication systems
RIS	Radiology information systems
Structured Reporting	The capturing of standardized/organized information from templates navigated via menus
Template	Something that is copied. StructuRad's unique use: data elements from which a report is constructed
Talking Template	A voice-based, interactive template
Taxonomy	A classification
Voice recognition software	Software that can translate vocal input into text or commands
Voice User Interface (VUI)	Computer interface that enables users to interact with a computer using speech

REFERENCES

1. Reiner BI, Siegel EL, Shrastri K: The future of radiology reporting. In: Reiner BI, Siegel EL, Weiss DL Eds. Electronic

Reporting in the Digital Medical Enterprise: Society for Computer Applications in Radiology, Great Falls, 2003, pp 83–104

2. Seltzer S, Kelly P, Adams D, et. al.: Expediting the turnaround of radiology reports: Use of total quality management to facilitate radiologists' report signing. Am J Roentgenol 162:775–781, 1994

3. Holman B, Aliabadi P, Silverman S, et. al.: Medical impact of unedited preliminary radiology reports. Radiology 191:519–521, 1994

4. Sobel J, Pearson M, Gross K, et. al.: Information content and clarity of radiologists' reports for chest radiography. Acad Radiol 3:709–717, 1996

5. Digital Imaging and Communications in Medicine Standards Committee. (2000) DICOM Supplement 23: Structured Reporting Storage SOP Classes (proposed final text). National Electrical Manufacturers Association, Rosslyn, VA

6. Dai BY, Thompson L, Dionisio JDN, Kangarloo H, Taira R, Sinha U: The Next Step.http://www.imagingeconomics.com/library/200004-03.asp

7. Langlotz CP, Meininger L: Enhancing the expressiveness and usability of structured image reporting systems. Proc AMIA Symp 2000:467–471, 2000

8. Liu D, Berman GD, Gray RN: The use of structured radiology reporting at a community hospital: A 4-year case study of more than 200,000 reports. Appl Radiol 32:23–26, 2003

9. Digital Imaging and Communications in Medicine Standards Committee. DICOM Supplement 23: Structured Reporting Storage SOP Classes (proposed final text). National Electrical Manufacturers Association, Rosslyn, VA, 2000

10. Bajai S: Expanding the reach of speech recognition: extending speech technology benefits to transcription workflow can boost productivity—medical practice Health Management Technology. March, 2004.http://www.findarticles.com/p/articles/mi_m0DUD/is_3_25/ai_114167703/

11. Batchelor JS: Optimizing alternative reporting strategies, 16 July, 2004. http://www.auntminnie.com/index.asp?Sec=sup&Sub=ris&Pag=dis&ItemId=62275

12. Baumann J: Voice Recognition, 25 Sep. 2004. http://www.hitl.washington.edu/scivw/EVE/I.D.2.d.VoiceRecognition.html>