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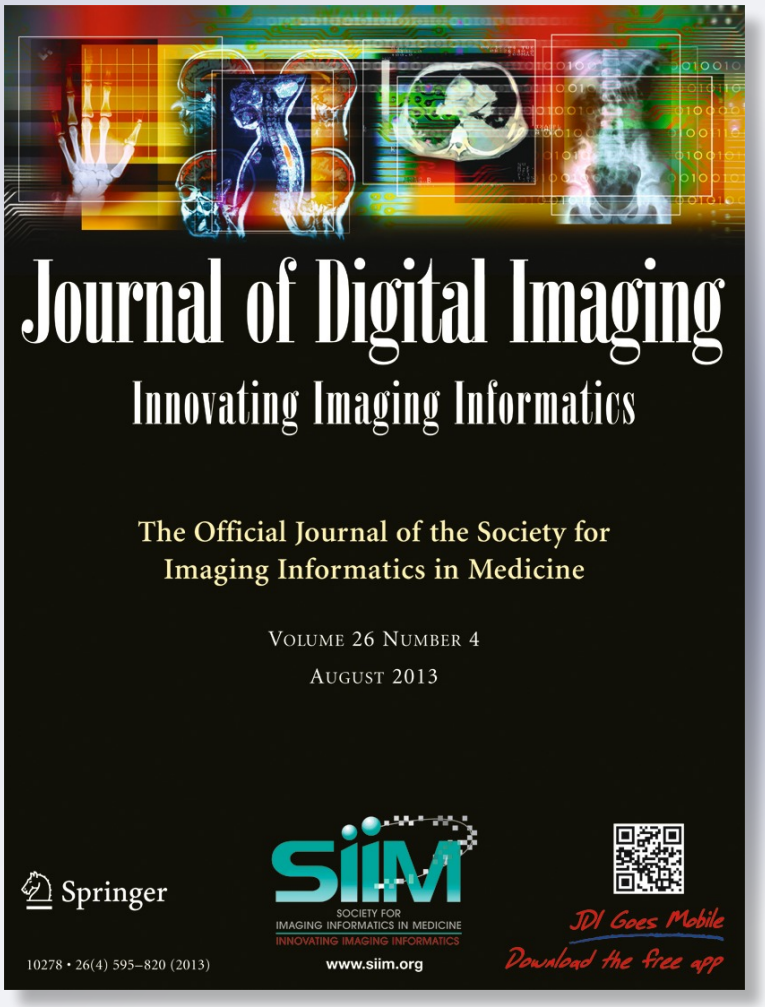
Journal of Digital Imaging
The Journal of the Society for Computer Applications in Radiology

ISSN 0897-1889
Volume 26
Number 4

J Digit Imaging (2013) 26:643-650
DOI 10.1007/s10278-012-9563-6



Springer

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Advanced Medical Imaging Protocol Workflow—A Flexible Electronic Solution to Optimize Process Efficiency, Care Quality and Patient Safety in the National VA Enterprise

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Published online: 4 January 2013

Abstract Radiologists routinely make decisions with only limited information when assigning protocol instructions for the performance of advanced medical imaging examinations. Opportunity exists to simultaneously improve the safety, quality and efficiency of this workflow through the application of an electronic solution leveraging health system resources to provide concise, tailored information and decision support in real-time. Such a system has been developed using an open source, open standards design for use within the Veterans Health Administration. The Radiology Protocol Tool Recorder (RAPTOR) project identified key process attributes as well as inherent weaknesses of paper processes and electronic emulators of paper processes to guide the development of its optimized electronic solution. The design provides a kernel that can be expanded to create an integrated radiology environment. RAPTOR has implications relevant to the greater health care community, and serves as a case model for modernization of legacy government health information systems.

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Keywords RIS · Protocol · Informatics · Efficiency · Quality · Patient safety · Open source · Drupal · Content management · Workflow · Web services

Background

Advanced Medical Imaging Protocol Assignment—Undervalued, Inefficient

Protocol assignment for approved advanced medical imaging (computed tomography, magnetic resonance, nuclear medicine) orders is an indispensable but undervalued function within the workflow of an imaging department. Performance variation of this function impacts patient safety, department efficiency and productivity, quality of care, and patient satisfaction.

Radiologists review clinician orders for advanced medical imaging exams and assign specific protocol instructions directing the performance of each exam. These medical decisions are typically poorly documented and are made based upon limited information. To point, exam requisitions, whether provided electronically or paper-based, frequently do not contain sufficient and/or accurate, information to optimize the quality and safety of radiologist protocol decisions [1].

Information to augment clinical detail not provided by an exam requisition—such as allergy, laboratory, medication lists, historical clinical information, and others—is frequently available, but rarely rapidly accessible. Often, multiple user events in multiple systems are necessary to find and retrieve the desired data. Communicating with ordering providers to, for example, clarify orders, is time-consuming. As the protocol assignment process is typically an "uncompensated" duty not subject to performance measurement, the radiologist is presented (unintended) adverse incentive to

select "efficiency" over effectiveness in performance of advanced medical imaging protocol assignment.

A recent VA healthcare inspection has found incomplete prospective identification of at risk patients requiring consent prior to the administration of intravenous contrast agents for cardiac and vascular interventional procedures [2]. This safety concern can be extrapolated to advanced diagnostic imaging as similar intravascular agents are used and similar department processes are employed to identify this subset of at risk patients. Furthermore, paper-based processes have inherent weakness that can lead to potentially significant process inefficiencies as well as additional quality and safety concerns. These include duplicate and unauthorized provider orders within the paper workflow, instances of unsigned protocol decisions (i.e., ambiguous medical decision accountability), and potential critical clerical errors (e.g., stapling the workflow face sheet for one patient on the order paperwork for another patient).

Opportunity exists to improve safety, quality, and efficiency of advanced medical imaging protocol assignment workflow by leveraging enterprise health information systems, shared services, secure messaging and web-based delivery to transition from what is a predominantly paper-based system at most institutions to a flexible, extensible, optimized computerized system. Such an electronic program could provide the desired information in a timely and organized fashion without the expenditure of human resources. Protocol actions could be guided and streamlined by the system based upon configurable facility rules. The importance of integrating decision support tools into the workflow of an imaging department has been demonstrated for related workflows [3, 4].

Veterans Administration Health Care Information Systems—Modernization Efforts

The VA provides health care benefits and services to veterans through the Veterans Health Administration (VHA). As part of its patient care mission, the VHA performs diagnostic imaging procedures at over 150 medical centers and nearly 1,400 community-based outpatient clinics [5]. Veterans Health Information Systems and Technology Architecture (VistA) is an award-winning integrated longitudinal electronic medical record (EMR) that is used throughout the VHA in all healthcare settings (inpatient, outpatient, and long-term care) [6]. It is a standardized, comprehensive, nationwide EMR credited for enabling the VHA to become a national leader in the delivery of quality health care [7, 8]. However, as it is built from tightly integrated proprietary components, integration of new technology and ideas is difficult and takes too long to deliver. VistA's technology foundation has become dated, and maintenance, installation and operations are needlessly complex. A 42-member industry expert panel was chartered at the request of the VA in 2009 for best advice on how to modernize the VA legacy health information system. It was recommended unanimously that the VA move to an open source, open standards model for the reengineering of VistA [9]. In response, VA leadership has embraced a development philosophy for VistA to be transformed into an openly architected, standards based, and modular platform so as to meet the maintenance, scalability and extension needs of the future [10, 11].

The Radiology Protocol Tool Recorder—RAPTOR

A recent VA Innovations Initiative [12] award has enabled the development of a prototype electronic solution for use within the VA health system which optimizes the advanced medical imaging protocol assignment process. The Radiology Protocol Tool Recorder (RAPTOR) allows efficient protocol assignment from within a web-based environment. It provides the radiologist with seamless just-in-time patient information and clinical data served from within its own database, the EMR, and the Radiology Information System (RIS) to facilitate prompt informed decisions. RAPTOR can be used throughout the advanced medical imaging workflow—protocol assignment, exam acquisition, and study interpretation phases.

RAPTOR utilizes mature open source, open standards application development to enable high functionality in a short time, and facilitate future development, with zero licensing costs, and low administration burden. RAPTOR is in concordance with recommendations made by the American Council for Technology—Industry Advisory Council VistA Modernization Report [9]. This paper describes RAPTOR development, and explores the broader implications of its application to the greater health care community.

Methods

Advanced medical imaging protocol workflow is predominantly a paper-based process at VHA facilities, but a few facilities utilize locally developed electronic solutions. Key process attributes of these paper and electronic systems were defined and opportunities to leverage information systems interoperability and process functionality improvements were identified to guide development of a comprehensive electronic solution (Table 1). Recognizing that the targeted information and systems interoperability would support both the protocol assignment and image interpretation processes, workflows from initiating clinician order through to image interpretation and results communication were mapped. The related business requirements were captured in order to identify all opportunities for an optimized electronic solution (Figs. 1, 2, 3, and 4). User permissions were defined and workflow states were conceived and modeled

Table 1 Attribute comparison between existing paper and identified local VA electronic advanced medical imaging protocol assignment systems with optimized solution design

Attribute	Existing paper processes	Existing Class III (local) electronic processes	Optimized Class I prototype solution
Environment	Paper	Terminal window or VistA CPRS Shared templates window	Web-based
Level of interoperability	Level 1 (paper) or Level 2 (scanned)	Level 3 (retrievable electronic input)	Level 4 (computational electronic data)
User access	Poor security controls	Access through desktop/application login	Access through authenticated secure web services
User roles	Radiologists, Technologists, Schedulers	Radiologists, Technologists, Schedulers	Radiologists, Technologists, Schedulers and System Administrators
Interface—textual input	Manual	CPRS orders	CPRS orders
Interface—images and reports	None	None	Yes, integrated information dashboard
Signature	Technologist and radiologist initials on paper form	None or digital	Digital
Record management	Can be scanned into EHR, but typically shred	Log file with suboptimal accessibility or Windows explorer folder	Saved and accessible for management
Workflow distribution	Paper stack	Work list	Work list
Urgency	Listed; not prioritized	Listed; can be prioritized	Listed; baskets; prioritized
Communications with requestor	Telephone contact listed, but not integrated	Telephone contact listed, but not integrated	Secure messaging through Outlook
Communications with technician	Freehand text comments field	Electronic free text comments field	Electronic free text comments field; Secure messaging through Outlook
Provider alerts	Not automated	Contrast allergy alert	Automated detection of patients at high risk for IV contrast administration (allergies, renal function, informed consent flag), and repeat/duplicated exams.
Availability	24/7	Variable; 24/7 possible	24/7
Bar codes	Not integrated, printed on form	Not integrated, printed on form	Integrated with bar code system
Integrated scheduling	No	No	Integrated
Contrast dose recording	No	No	Yes
Radiation dose recording	No	No	Yes

CPRS Computerized Patient Record System, *VistA* Veterans Health Information Systems and Technology Architecture

so that users can efficiently progress through the three phases of workflow: protocol, examination, and interpretation (Fig. 5).

RAPTOR was created using an open source, open standards, agile development strategy. Existing robust tools and service components were identified and utilized by the project whenever possible, while still producing a flexible, customized solution for advanced medical imaging protocol assignment. RAPTOR was developed by SAN [13] utilizing Drupal [14], an open source content management system, and using LAMP. LAMP is an acronym for a solution stack of free, open source software referring to the first letters of Linux (operating system), Apache HTTP Server, MySQL (database software) and PHP (programming language). These represent the principal components to build a viable general purpose web server. RAPTOR reuses VA Medical Domain Web Services (MDWS "Meadows") for data interconnectivity with the VistA EMR (Fig. 6). MDWS is a suite of Service Oriented Architecture middle-tier web services that is equipped with the capacity to virtualize any legacy VistA Remote Procedure Call as a web service. MDWS facilitates creation of client applications which incorporate the organization's business rules and provide access to data from multiple VistA instances and other data sources.

Pertinent, current patient and clinical information is displayed by RAPTOR as a tailored dashboard. Information required for protocol decisions on advanced medical imaging examinations—such as allergy history, laboratory estimates of renal functioning, recent clinical notes, recent radiology reports, clinician contact information, and other relevant reports and laboratory values—is automatically populated and easily accessed. This data is served in real-time each time a worklist ticket is viewed, and is thus not subject to delay from paper transit through the department or transcriptional error. A simplistic, yet crucial, advantage to this computerized system is that all data entered is legible. In addition, data moves instantly to the next staff member responsible, and the formerly paper stack of protocols is easily prioritized and distributed within a multiuser accessable worklist.

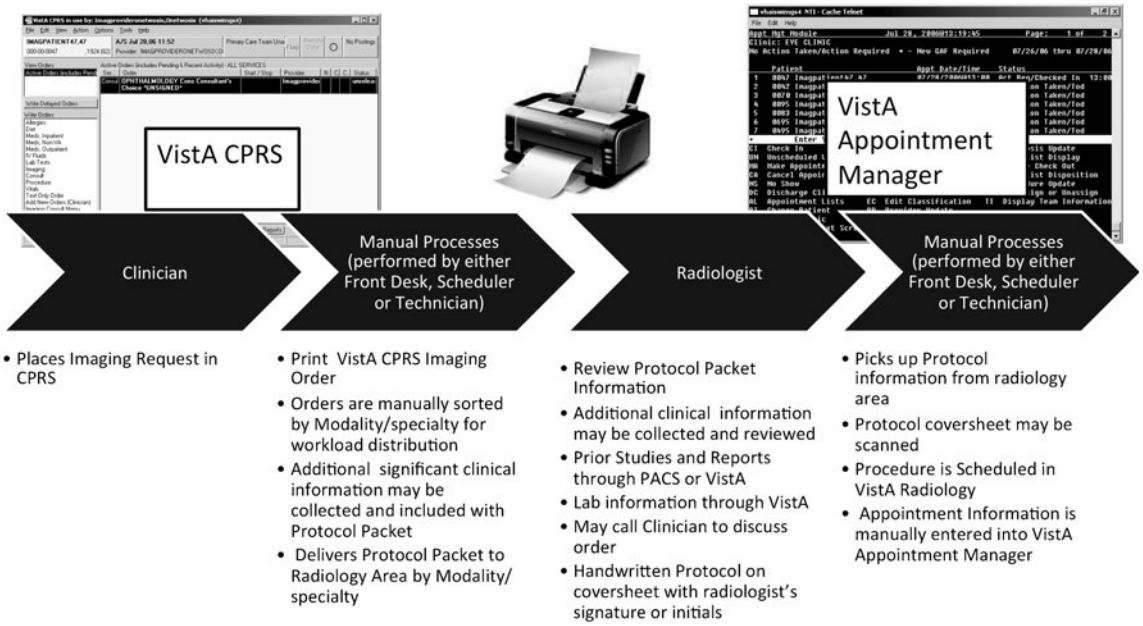

Fig. 1 Current (typical) paper-based protocol assignment workflow – exam order to appointment scheduling

The interface also includes a complete list and details of current department-approved protocols, which is useful as a reminder—especially in the setting of rotating resident coverage at VA facilities affiliated with teaching institutions. It also offers an opportunity to standardize exam-name ontology across a department or an enterprise.

Enterprise quality goals are facilitated by RAPTOR configurable identification, flagging and recording of patients at risk for harm from and/or in need of written informed consent for administration of intravenous contrast agents due to allergy history, medication use, or reduced renal function. RAPTOR suggests use of pre and post examination hydration for patients when appropriate and provides the necessary department standardized protocols.

Some studies within imaging departments may have ordering restricted to certain providers because of their specialized

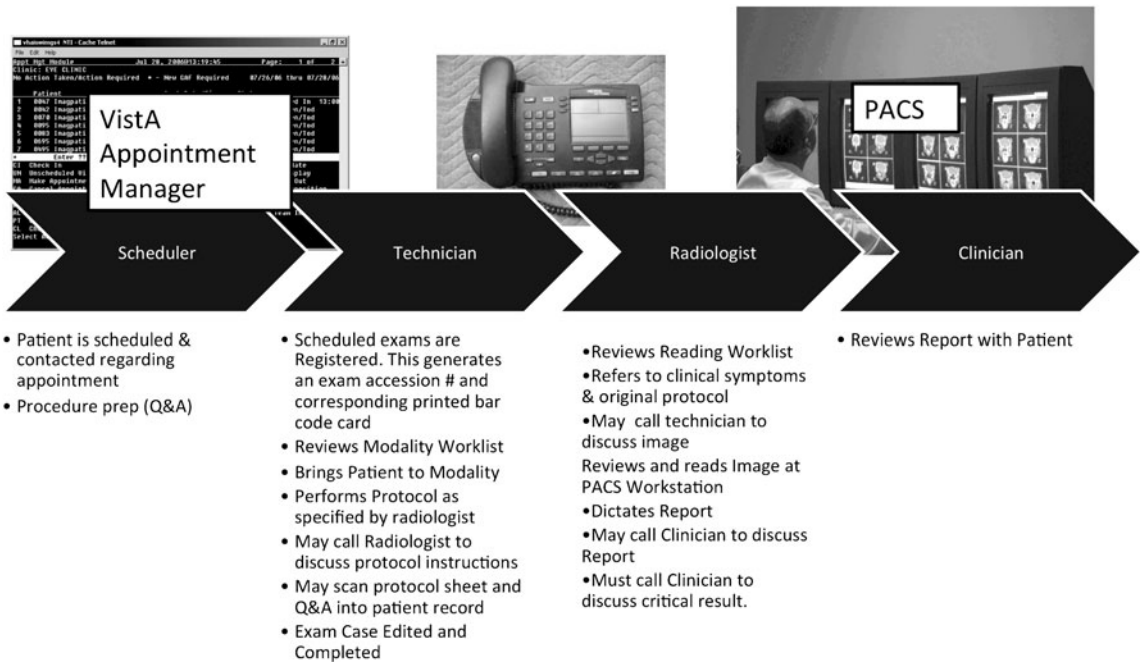

Fig. 2 Current (typical) paper-based protocol workflow—appointment scheduling to reporting

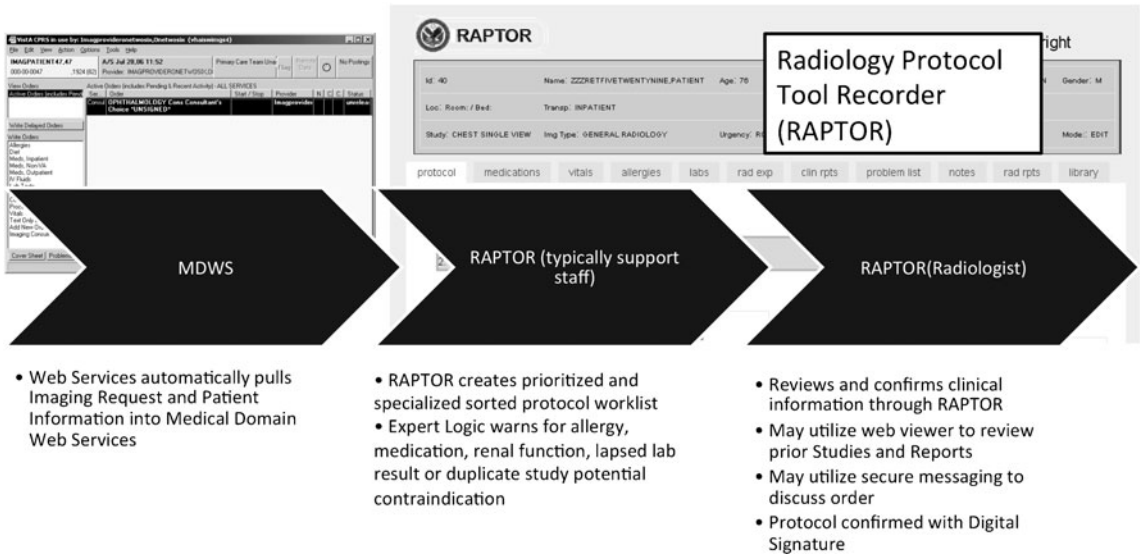

Fig. 3 Optimized electronic workflow—exam order to protocol assignment. Process functions and business requirements are supported, coordinated and recorded

nature. RAPTOR can enable automatic recognition of unauthorized orders and recommend refusal. Secure messaging can provide the ordering clinician with the correct procedure for further evaluation and referral through an approved provider (e.g., musculoskeletal MRI). Duplicate orders are also easily captured and grouped or pruned as needed, such that department effort is not wasted. With a paper system, signatures (or initials) are needed to identify individuals responsible for actions related to protocol processing. These signatures can be forgotten, leading to ambiguous responsibility for decisions and actions. Further, paper requisition documentation is routinely destroyed at some facilities either immediately after completion of examination acquisition and interpretation or after a few weeks' delay. Within RAPTOR, every action is archived. Should questions arise regarding a specific study or action, the appropriate staff member is readily apparent.

RAPTOR can capture a patient's radiation dose history and the decisions and communications between all key stakeholders in the radiology workflow. It also has the ability to monitor dose at the modality and facility level, and can be used to establish dose-reduction practices. RAPTOR architecture specifies further integration of shared services—e.g., secure messaging, a zero

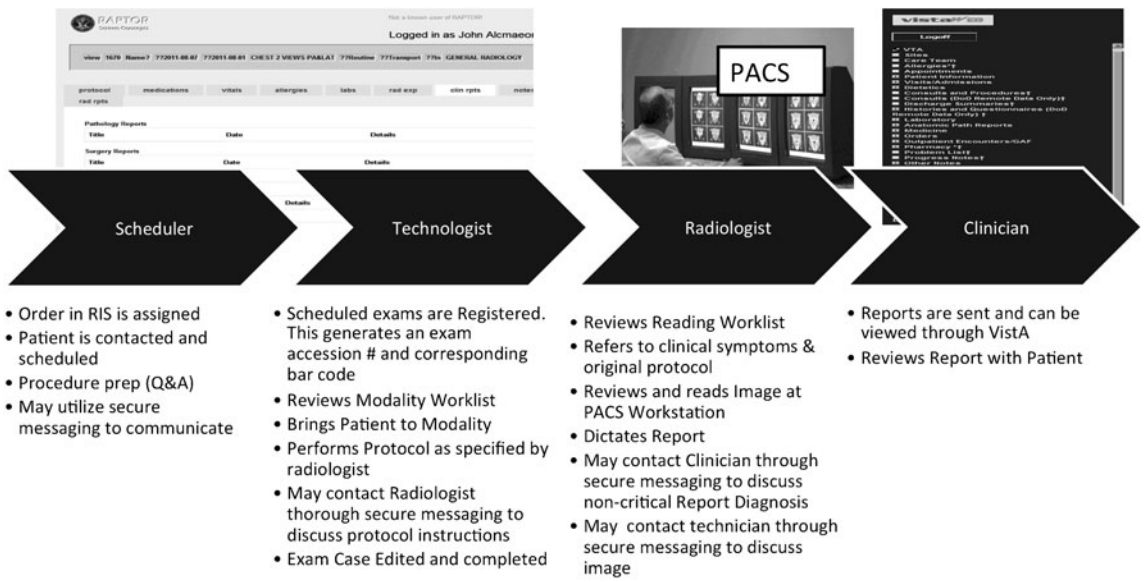

Fig. 4 Optimized electronic workflow—exam scheduling to reporting. Current prototype is used in parallel with VistA Radiology Information System and Appointment Manager. Future extension to integrate these components is envisioned. Pertinent, current clinical information served by RAPTOR benefits informed radiologist interpretations of completed exams

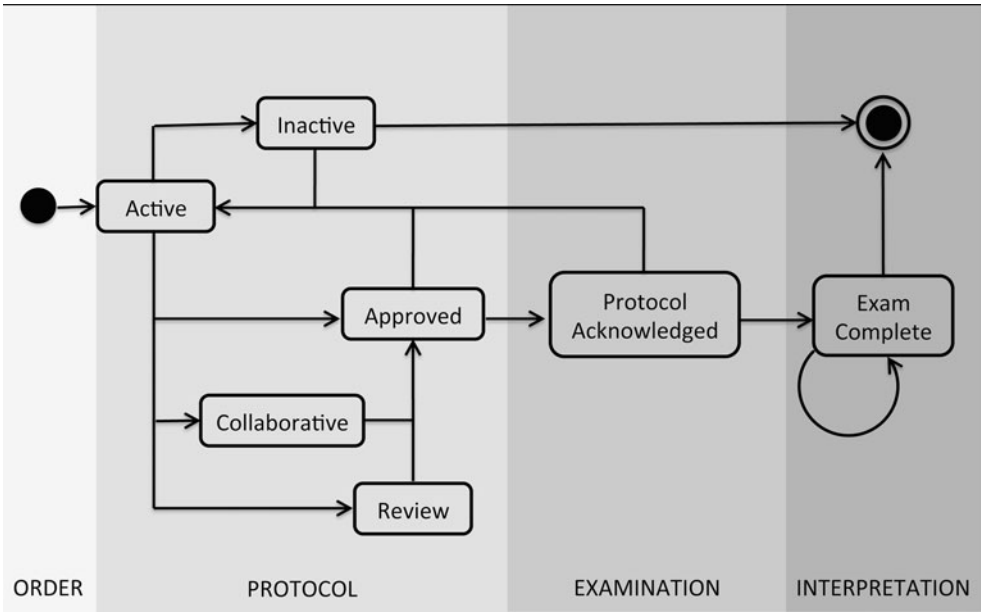

Fig. 5 RAPTOR Workflow Diagram defines states and possible state transitions of advanced medical imaging requisitions within the workflow. *Blocks* symbolize entity states, and *text inside a block* is a state title. Transitions possible from each state are represented as lines connecting to other states. Transitions can return to the same state and arrows signify the flow. From these states, RAPTOR users can efficiently progress through the three phases of workflow: protocol, examination, and interpretation

footprint web viewer, or integration with additional clinical systems such as picture archiving and communication systems (PACS)—promising future functionality, utility and adaptability.

Results

At the time of this writing, the RAPTOR solution is a completed functional prototype. Its operation and utilities have been demonstrated within a development environment, the VAi2 "sandbox," which mirrors the live VistA environment. Nearly one half of regional VA Integrated Service Networks have facilities enthusiastic to begin clinical use due to the promise of significant time savings and other department efficiencies concurrent with improved quality and safety. Necessary procedures and permissions for regional deployment of RAPTOR for clinical confirmation and adoption are in process, consistent with VAi2 stated goals to identify, prioritize, fund, test and deploy the most innovative solutions that enhance the performance of VA operations and improve the quality of services delivered to veterans [11].

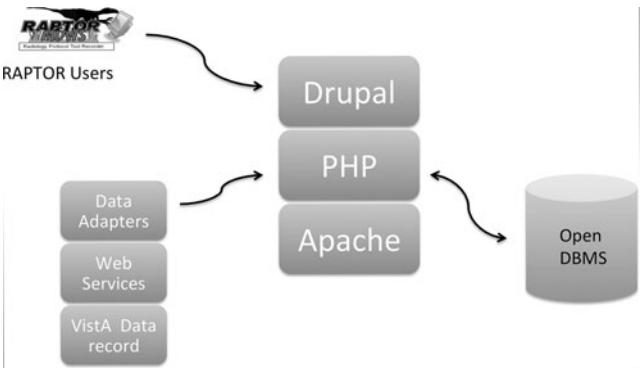

Fig. 6 RAPTOR open architecture

Discussion

The RAPTOR project represents an efficient and economical solution to the undervalued department process of advanced medical imaging protocol assignment. The open source design is potentially transferable to other systems within the healthcare community. Perhaps more importantly, however, RAPTOR serves as a demonstration strategy on how to modernize legacy government healthcare information technology systems.

Paper processes have inherent shortcomings. Lost and duplicated exam requests negatively impact efficiency. Current paper-based workflow for advanced medical imaging protocol assignment requires extensive human resources to collect and organize—tasks which are well suited to database applications. Information necessary for optimized protocol selection can be missing from paper processes and may be cumbersome to obtain if data is stored in disparate health information repositories. Multiple electronic repositories for medical information can provide a significant barrier to integrative processes. However, with database standards, information from different medical repositories (i.e., EMR, laboratory/pathology systems, PACS, RIS) is attainable. Electronic emulators of paper

processes are at risk for providing non-optimized functionality and falling short of efficiency and quality targets if sufficient systems interoperability is not achieved.

Recordable electronic transactions assure documentation of responsibility and allow for rapid reporting when practice-based questions arise. The use of Drupal roles groups the permissions of the radiologist, technologist, administrative, and, for teaching facilities, resident staff authorized to participate in the system. Sufficient security and collaboration tools will allow for enterprise deployment. Diverse health system requirements (e.g., consent for contrast agents, application of conscious sedation protocols and documentation of order changes) can be automated within an optimized electronic dashboard solution. Provision of available protocol lists, protocol details, and other resources, reminds physicians and staff of current standards of care practice, facilitating interdepartmental uniformity.

Open Source

Mature open source software provides a variety of advantages to developers and enterprises, including zero licensing fees, stability and security. Open standards facilitate software development by providing a framework on which to build more complex structures. Standards offer a common programming convention that allows multiple developers to write programs that interact in a predictable pattern. RAPTOR development used a variety of open standards and tools including Linux, Apache, MySQL, PHP, Drupal, BitNami, Dia, Open Flash Chart, and Filezilla [15].

Utilization of open standard, open source architecture and tools allows for development to focus on higher level issues rather than basic coding, facilitates maintainable intuitive code, reliable functionality, maintainable extensions and minimizes staff requirements. It provides a known framework which allows development to start at a more advanced and abstracted level. It also minimizes ownership costs and development time and provides a good foundation for accessibility, versatility, and scalability.

These innovations within RAPTOR provide a kernel that can be expanded to capture additional hospital and radiology information systems to create an integrated radiology environment. Many practices, including those at the VHA, have a separate system for each of the tasks performed by a radiology department, viewing images, scheduling studies, protocoling studies, viewing medical data, etc. RAPTOR makes an effort to meld information from other sources into a dashboard synchronized with the electronic protocoling tool. Ideally, all of these tools should integrate, allowing users not only to find the information they think they need but the computer system can proffer relevant data the user should incorporate into their decision process. Protocol assignment is a good example: in complex cases, the radiologist may need access to any or all of the following: renal function data, allergy history, clinical indication, recent medical history, medication list, patient problem list, prior radiologic/nuclear studies, pathology results, and relevant imaging and pretreatment protocols. A well-designed radiology "solution" would seek out this data for the user in real-time, or ahead of the actual user event, and would display it while emphasizing key details. A good system would also interact with the user, changing data displayed and options based on the anticipated needs of the user. To catalyze the growth of such tools, open standards for data interchange must be developed and adopted. Frameworks allowing plug-in modules for different functionalities and site customized functions will need to be programmed.

While this data is all already available in one form or another to most radiologists, it is not enough to simply be available. Data must be prepared in a logical and consistent manner to allow for an orderly assessment of the data. Many hospital systems are plagued by multiple independent computer systems which barely interconnect. For a busy practitioner, this could result in an incomplete review of the data before decision-making occurs. This is not necessarily due to the information being unavailable or to information overload, but rather that the data is not in the right place at the time a decision is made. If a practitioner must open a new application, login, enter a patient identifier, select a subject, select a test, and wait for each of the accompanying windows, usage may be inconsistent at best [4].

By providing a solution which achieves the desired systems interactivity and configurable decision support for the specific application of advanced medical imaging protocol

Table 2 Successes achieved with current RAPTOR platform

Attribute	Before RAPTOR	With RAPTOR
Environment	Paper, Informal manual process	Web-based, paperless, process is enforced by business rules
Level of Interoperability	Lowest-paper or scanned paper	Highest-computational electronic data
Information Access	Poor (if any) security control	Role based authentication for users
Collaboration, communication	Handwritten, Fax or phone	Automated collaboration and communication integrated into workflow
Work distribution	Stacks of paper manually distributed	Entire worklist process is automated with business priorities set by configurable rules
Records Management	Shred or scanned	Entire process is recorded for management review and reporting

assignment, RAPTOR is a case study for systems integration in any health care model. Layered programming architecture employing open source, open standards development and reuse of available middle-tier services allowed low-level legacy data sources to be abstracted and organized for current needs. This strategy enabled rapid development and high functionality at an affordable cost. It should be regarded as a candidate model to guide further VA legacy health information systems modernization.

Due to the flexibility of the RAPTOR concept, next steps can be envisioned in a number of dimensions. It provides an open source platform that can be extended to integrate additional aspects of the radiology workflow, such as laboratory and pharmacy systems in the protocoling phase, radiology ordering systems in the examination encounter phase, and viewing and dictation systems in the interpretation phase. With the current RAPTOR platform, users can achieve gains shown in Table 2. With its extensibility, users can achieve the optimized solution described in Table 1.

Conclusion

Evaluation of existing advanced imaging protocol assignment processes in use within the VHA enterprise has identified inefficiencies of paper-based systems and locally developed electronic solutions lacking optimized systems interoperability. In response to this opportunity, we describe an innovative web-based solution—RAPTOR—to improve productivity, quality, and patient safety. Observations and lessons learned are applicable to the broader health care marketplace, as well as provide a model solution upon which to modernize legacy government health care information systems.

Disclaimer None of this information is meant to endorse private sector activities, obligate the federal government to follow any particular course of action, nor to espouse an official position of the federal government, for the present or in the future.

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