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A Systems Approach to Evaluating Ionizing Radiation: Six Focus Areas to Improve Quality, Efficiency, and Patient Safety

Jonathan B. Perlin, Laura Mower, Chris Bushe

Abstract: Ionizing radiation is an essential component of the care process. However, providers and patients may not be fully aware of the risks involved, the level of ionizing radiation delivered with various procedures, or the potential for harm through incidental overexposure or cumulative dose. Recent high-profile incidents demonstrating the devastating short-term consequences of radiation overexposure have drawn attention to these risks, but applicable solutions are lacking. Although various recommendations and guidelines have been proposed, organizational variability challenges providers to identify their own practical solutions. To identify potential failure modes and develop solutions to preserve patient safety within a large, national healthcare system, we assembled a multidisciplinary team to conduct a comprehensive analysis of practices surrounding the delivery of ionizing radiation. Workgroups were developed to analyze existing culture, processes, and technology to identify deficiencies and propose solutions. Six focus areas were identified: competency and certification; equipment; monitoring and auditing; education; clinical pathways; and communication and marketing. This manuscript summarizes this comprehensive, multidisciplinary, and systemic analysis of risk and provides examples to illustrate how these focus areas can be used to improve the use of ionizing radiation. The proposed solutions, once fully implemented, may advance patient safety and care.

Background

Ionizing radiation is an integral part of modern medicine. Patients have seen enormous benefit from its use, including the identification of previously undetectable pathology, more effective diagnoses and treatment, and improved monitoring. The introduction and proliferation of newer and more advanced technologies over the past several decades have stimulated demand from patients and physicians, resulting in a steady increase in the number of procedures per year (Amis et al., 2007; The Morgan Company, 2010). Consequently, patients' cumulative exposure to ionizing radiation has increased (Board on Radiation Effects Research & National Research Council, 2006; Brenner & Hall, 2007; Mettler, Huda, Yoshizumi, & Mahesh, 2008), which could affect long-term cancer risk (Board on Radiation Effects Research & National Research Council, 2006; International Commission on Radiological Protection [ICRP], 2005).

Overshadowing this long-term risk are high-profile incidents involving inappropriate or excessive radiation doses that resulted in acute patient injury (Bogdanich, 2010; Landro, 2010; Steenhuysen, 2010; Szabo, 2009). As tragic reminders of the short-term consequences of radiation overexposure, these incidents captured the attention of the mainstream media, contributing to growing concern and demand for action by the public and regulatory agencies. Standard guidance for dose levels at the time of these events was "as low as reasonably achievable" (ALARA) (Alliance for Radiation Safety in Pediatric Imaging, 2013; Amis et al., 2007). Subsequent recommendations to improve radiation safety and reduce exposure were issued by national organizations, including the U.S. Food and Drug Administration (FDA), the Medical Imaging and Technology Alliance (MITA), and the American College of Radiology (ACR, 2009; Center for Devices and Radiological Health, 2010; MITA, 2011; FDA, 2009). Other groups expanded upon these recommendations, including ICRP (2007, 2012) and The Joint

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Commission (2011). In addition, the Centers for Medicare and Medicaid Service (CMS) has implemented outpatient imaging efficiency measures to drive reductions in combination studies or inefficient examination protocols (CMS, 2011).

Although recommendations and guidelines are useful in theory, providers are challenged with translating these into operating principles for daily clinical practice. This includes the design of systems-level layers of controls, processes, and preventative "fail-safe" mechanisms to defend against patient harm caused by human factors, including judgment and operator error, or technological failures. Yet as described by James Reason's "Swiss cheese" model of system accidents, these individual defensive layers are imperfect. Because of the complexity of the work environment, potential holes and gaps in these barriers and defenses can align and allow errors to perpetuate throughout the system (Reason, 2000; Reason, Carthey, & de Leval, 2001). Thus, efforts to identify gaps and create redundancy are crucial to ensuring patient safety.

Accordingly, we proposed a comprehensive analysis of existing radiation safety processes in a large healthcare system. This evaluation revealed that ionizing radiation has become a standard and expected, if not defensive and reflexive, component of medical care. Diversity in services and processes, variation in equipment types and available controls, inconsistencies in education, and limited patient radiation exposure tracking were some of the observed weaknesses that suggested a need for multifaceted, systems-level solutions. Six focus areas were identified to guide the development of projects that could improve the safety of ionizing radiation use while aligning with changing regulatory requirements. This paper describes the observed deficiencies and proposed solutions for these six focus areas. Results of initial implementation efforts are also presented in order to assist other healthcare providers in analysis of their own systems, with the ultimate goal of preventing patient harm.

Methods

Setting

This systems analysis was conducted within a large healthcare organization that includes 166 hospitals, 124 surgical and imaging centers, and more than 650 physician practices. Together these facilities handle over 18 million patient encounters per year and provide approximately 5% of major hospital services and medical procedures involving ionizing radiation in the United States.

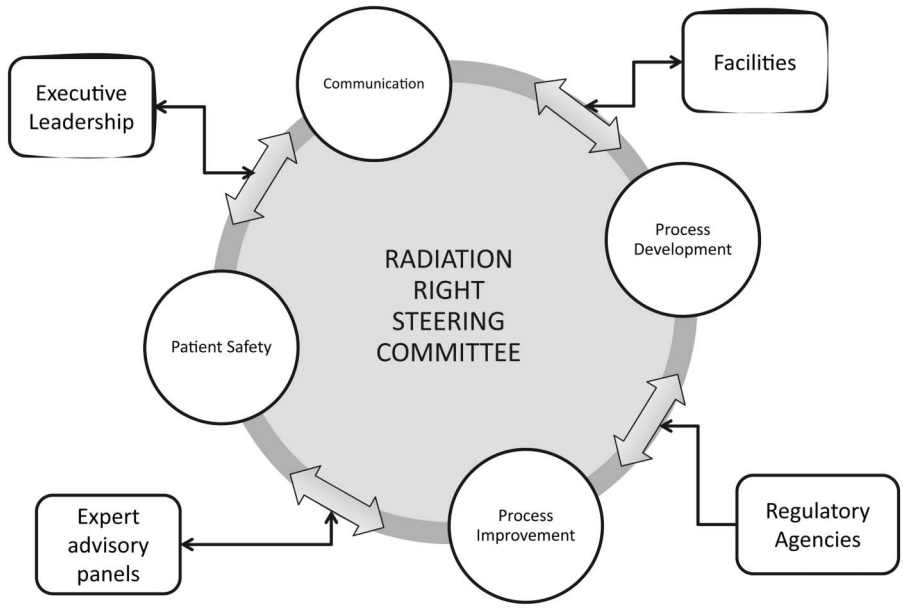
In this organization, enterprise level functions such as financial operations, organizational and clinical goals, and supply chain management are coordinated at the corporate level. Clinical operations and market strategy are managed by 15 regional divisions, which provide daily operating leadership for facilities. Division leadership is responsible for facility performance as supported by corporate tools and resources. Facility leadership is responsible for all aspects of facility performance, including achievement of division and corporate goals.

Evaluation of Current Practices

The evaluation was coordinated at the enterprise level with input from facilities and the field. Central to this was the creation of the Radiation Right Steering Committee. The goal of this committee was to facilitate communication, encourage collaboration between various groups, and ensure that proposed solutions are reflective of practical needs at the local level while meeting national and organizational guidelines.

Key members of this committee included quality and patient safety experts as well as clinical contacts from various levels of the organization, including experts in imaging and cardiovascular services. These individuals led the assessment of processes and the development of practical solutions that reflected the needs of the various facilities. The Radiation Right Steering Committee also included representatives from risk management, education, leadership,

Figure 1. Role and Responsibilities of the Radiation Right Steering Committee.



and information technology to assess all proposed solutions. The Steering Committee coordinated with corporate executive leadership, facility leadership, and internal expert advisory panels, and incorporated guidelines and requirements from regulatory agencies. Through this process, the Steering Committee acted as the discussion group that assigned tasks, ensured continuity, coordinated workgroups, and provided overall direction for the entire initiative (Figure 1).

The Steering Committee directed the formation of workgroups consisting of experts in various areas. Each workgroup had a specific role in the analysis of current processes and the development of solutions (Table 1). These groups drew upon the expertise of corporate clinical leaders, division quality leadership, and facility-based subject matter experts. In addition, these groups consulted with risk management, audit, human resources, supply chain, project management, and information technology as well as external vendors and additional facility-based experts as needed.

Workgroups assessed the current state of radiation services through directed self-reporting and audit by providers, comprehensive review of existing event reports, surveys and site visits, and evaluation of current vendor-provided solutions. This was enhanced by patient safety data from facilities when available, and complemented by a survey of peer-reviewed, evidence-based literature. Best practices from the literature and from facilities were evaluated for their applicability across the entire enterprise.

Development and Implementation of Solutions

The development and implementation of solutions based on workgroup reports are an ongoing organizational goal. All projects are prioritized by the Radiation Right Steering Committee based on potential patient risk as assessed by expert opinion and workgroup recommendations.

Workgroups use information gathered during their assessments to develop initial opinions that are submitted to the Radiation Right Steering Committee. The Radiation Right Steering Committee initiates program development and deployment based on the

Table 1. Workgroup Roles and Participant Categories

Workgroup	Role	Participant Categories*
Radiation Right Core Team	Participate in all workgroups to provide oversight and ensure continuity of projects.	Operations leaders Subject matter experts
Technology	Develop new tools to monitor and track radiation dose. Work with vendors to assure the appropriate adoption of new technologists.	Information technology experts Risk management experts Vendor representation
Reporting/monitoring/auditing	Develop and monitor effectiveness and direction of tools. Assure that that data collected leads to performance improvement and increased patient safety.	Supply chain contact Quality experts Patient safety experts Risk management experts Clinical analytics expert Clinical compliance expert Audit expert
Clinical (CVL/IR/EP)	Provide direction and leadership for the CVL/IR/EP lab regarding education, competency, and privileging policy development.	Clinical personnel Interventional radiologist Registered nurses Cardiovascular technician Radiology technologist Radiation safety officer Interventional cardiologist
Privileging/credentialing	Assure appropriate enterprise-wide processes are used for credentialing and privileging of all physicians using or ordering ionizing radiation procedures.	CVL team members Quality standards experts
Communications	Develop, pilot, and distribute communication tools. Work with physician marketing services to assure a consistent message to the provider market.	Communications specialist Graphic artist Radiology oncology subject matter expert Physician marketing services

(*Continued*)

Table 1. (*Continued*)

Workgroup	Role	Participant Categories*
Education	Develop content of Radiation Safety University.	Education specialists Patient safety expert CVL team members
Policy	Develop and release policies on CT radiation dose reduction, governance of radiation safety officers and equipment monitoring, and fluoroscopy dose reduction and monitoring.	Quality expert CVL team members Legal experts Risk management experts Patient safety experts Quality standards experts Human resources experts
Clinical pathways	Assure that all medical imaging pathways take radiation safety into consideration in future order sets.	Electronic health record experts Education experts Meaningful use team Physician advisors
Expert review	Oversee the increasing body of evidence-based literature and regulatory information then provide input, analysis, guidance, and direction.	Physicists Interventional radiologists Radiologists Hospitalists Surgeon Cardiologist
Dosing	Establish a tool that will collect radiation dose and make these values available for use in radiation reduction safety measures.	Information technology experts Risk management experts Vendor representation Radiology representatives

Note. CVL, cardiac catheterization laboratory; IR, interventional radiology; EP, electrophysiology.
*Individual participants may contribute to more than one workgroup.

existing literature, media reports, federal regulations, and workgroup recommendations. The Steering Committee coordinates the development of tools and communication guides with input from leadership, facility-based teams, expert advisory panels, and regulatory agencies (Figure 1). Acknowledgement and approval are obtained from the appropriate workgroups, leadership, and expert panels prior to the development of implementation timelines. Programs are approved by executive leadership and assigned an executive sponsor. Implementation teams are developed based on the work required, with both facility representation and ad hoc subject matter experts. The Steering Committee facilitates communication and continuity of information between the teams as work progresses. The Steering Committee also engages frontline practitioners to aid in the development of solutions in order to maximize practicality and acceptance into the workflow. Individual facilities are engaged to pilot solutions prior to system-wide implementation.

The recommendations and policies developed by the corporate-level workgroups include opportunities for management at the division and facility level. In general, implementation follows the established organizational structure (corporate, division, field). Policies and guidelines are established at the corporate level. Tools and resources are also developed at the corporate level with input from experts in the field. These materials are provided to division leadership for implementation. Division leaders are held accountable for initiating implementation within their facilities and monitoring progress. Responsibility for implementation of individual items is at the facility level. With assistance from division leadership, facility leaders can interpret recommendations, adapt tools, or adjust timelines based on local needs, state regulations, or other factors. Facilities within a division share best practices related to regional characteristics, and all facilities provide feedback to division and corporate leaders. Guidelines were established to observe implementation progress through division monitoring, facility monitoring and tracking, and compliance monitoring.

Results

This comprehensive analysis resulted in (1) the development of standard policies for the use of ionizing radiation, and (2) the identification of six key focus areas for improvement (Table 2). The deficiencies identified, proposed solutions, and the results of initial implementation efforts (Table 3) are discussed for each focus area.

Policies

Three company-wide policies were implemented in all facilities that utilize ionizing radiation: Radiation Governance, computed tomography (CT), and fluoroscopy. The Radiation Governance policy expanded and standardized the roles of the Radiation Safety Committee (RSC) and Radiation Safety Officer (RSO) at each facility. Responsibilities of the RSC include monitoring occupational dose policies, approving authorized users and radioactive material usage, approving changes to radiation safety programs, reviewing equipment service records and audit findings, and reviewing all dose quality records to assure ongoing compliance with policies and ALARA principles. The primary responsibility of the RSO is to ensure that all radiation safety activities across the entire facility are performed with approved procedures and meet regulatory requirements. This includes areas outside of radiology (e.g., cardiology services, surgical services, and oncology).

The Radiation Governance policy also included guidelines for equipment service and repair. In brief, equipment is to be tagged "Out-of-Service, Do Not Use" during downtime. This tag offers a process to bridge the gap between the completion of service and the receipt of electronic service documentation, which could be up to 72 hr after completion of service. The field service technician uses this tag to confirm the reported equipment issue, the repair performed, and the recalibration of the equipment to the manufactures original specifications. No equipment can be returned to service until this information is acknowledged by a responsible staff member (e.g., certified technologist,

Table 2. Focus Areas Identified and Proposed Solutions for Observed Deficiencies

Focus Area	Observation	Proposed Solution	Implementation Status (Project Owner)
Competency and certification	No standard training regarding operation or interpretation of dose display	Provide skills and knowledge training on equipment operation	Created standard CT tech competency tool (C)
			Assessing and determining local needs (D/F)
	Privileging guidelines vary by service area	Develop privileging and credentialing guidelines to meet current and future requirements	Working with experts to establish guidelines (C)
	Lack of structured training after initial equipment install	Stage follow-up training sessions; ensure training of vendor field service technicians	Cooperating with national organizations and vendors to develop training programs and requirements (C)
Equipment	Dose reporting unavailable on some equipment	Encourage upgrade to equipment with dose reporting capabilities and manage type of procedures scheduled on equipment	Created Equipment Risk Assessment Tool, provided results of risk assessment to divisions (C)
			Using results to inform equipment decisions (D/F)
	Maintenance and calibration services vary by vendor; no standard check routine	Define standard expectations for maintenance and calibration services	Created standard policy for equipment maintenance and return to service (C)
Monitoring and auditing	Deviations in individual, process, and system performance are often undetected at time of scan	Establish monitoring and auditing guidelines to review performance	Created standard policies (C)
			Evaluating potential automation tools (C)
			Using existing tools for ongoing monitoring (D/F)
	Measurement criteria varies by facility, service area, scan type	Establish standard metrics for monitoring	Created standard policies for CT, fluoroscopy (C)
			Determined top five CT procedures by volume (C/D)
			Implemented manual monitoring of fluoroscopy time (D/F)
	Prevention of and response to events depends on knowledge of risk	Encourage event reporting	Clarified event definitions and emphasized importance of event reporting (C/D)

(*Continued*)

Table 2. (*Continued*)

Focus Area	Observation	Proposed Solution	Implementation Status (Project Owner)
Education	General lack of understanding about recommendations, effectiveness, cancer risk	Educate staff, physicians, technicians through "Radiation Safety University"	Designed courses with assistance of experts and vendors (C)
Clinical pathways	Physicians need options for reducing dosage/ alternative to radiation	Integrate radiation safety principles into CPOE, order sets	Ongoing as part of electronic health record implementation (C)
Communication and marketing	Ineffective distribution of safety message to staff, patients	Establish compelling campaign to inform stakeholders	Created and distributed materials (C)
	Need proper identification of patient characteristics for care planning	Encourage patient participation in identification and care plan	Implementation in progress (D/F)

Note. Project owner: C, corporate; D, division; F, facility.

department supervisor, director, or designated representative).

The CT policy set baselines for CT Technologist certification and competency, provided guidelines for the adoption and review of standardized protocols, and established parameters for monitoring, auditing, and reporting radiation dose for CT patients. The fluoroscopy policy established safety strategies to reduce radiation exposure, including privileging and competency expectations, radiation dose thresholds for fluoroscopy, and the development of systems for the monitoring, auditing, and reporting of patient dose.

Focus Areas

Focus area 1: Competency and certification.

Problem and proposed solutions: Our comprehensive analysis revealed a lack of standardized competency and certification programs as well as a fragmented system of vendor training and basic radiation safety courses (Table 2). Proposed solutions included defined standards for privileging of personnel, competency guidelines that accommodate regulatory requirements, and training standards for field service technicians and physicists. These assure a standard base of knowledge and training within the department.

Implementation and results: The first competency tool designed was for annual assessment of CT technologists. The competencies checklist directs the evaluation of key knowledge points and skills that must be demonstrated before job assignment without direct supervision. This includes reference levels, required documentation, allowable deviation from established procedural protocols, use of shielding, and appropriate equipment settings for specific patient populations and scan types. Competency is evaluated by a combination of observation, proficiency testing, demonstration, or verbalization. Results are recorded for the employee's personnel file and serve as a framework for training, if necessary.

Privileging criteria are currently being established for interventional radiology, electrophysiology, and cardiac catheterization laboratory personnel. As part of biannual privileging, physicians who perform procedures or otherwise utilize radiation (such as interventional cardiologists who use fluoroscopy) will need to complete a course on radiation safety. Course work is being developed by internal and external subject

Table 3. Barriers to Implementation and Successful Solutions

Project	Barrier(s)	Solution(s)
Standardize certification and competency requirements for technologists	Certain certifications require advanced schooling	Support additional schooling Encourage local flexibility in establishing date of compliance
Implement standard process for returning equipment to service	Resistance from certain vendors	Query vendors on reasons, develop processes that met both policy and the vendor needs
Assess risk associated with current equipment	No upgrade path available for some equipment	Designate nonupgradable equipment for low-risk situations (low-dose procedures performed by trained personnel)
Implement guidelines for monitoring radiation doses	Manual process relies on self-reporting	Pilot automated reporting and monitoring processes Work with vendors to design and develop solutions
Improve education of providers	Need high-quality courses that are applicable to providers' work Vendor training often requires off-site travel or attendance outside of work hours	Help experts develop courses, provide CE where appropriate Consolidate training courses into centralized online education system
Ensure that data are being utilized to improve processes	Data collection is manual and episodic	Encourage use of data as tool for reacting to outliers and evaluating patient experience Develop plans to incorporate data into CPOE
Create and distribute tools and other communications materials	Materials not reaching intended audience and not being utilized as expected	Engage physician sales team to lead education of physicians and increase staff awareness

matter experts with additional input from vendors for specific equipment-related skills. These courses will present relevant information and best practices while also meeting all minimum state licensing and certification requirements. Participation in this course, as part of the privileging process, would only be required for those who do not have documented completion of radiation safety education during their residency training.

A challenge facing the implementation of these competency and certification efforts has been variation in educational backgrounds (Table 3). For instance, while the goal is for all technologists that routinely provide radiology services in CT to achieve advanced certification, certain certifications required advanced academic preparation. Individuals without this academic preparation should be accommodated through support for additional

Figure 2. Sample of an Equipment Risk Assessment Tool report.

Modality	Technology Level	Description	Risk Factors			Hi Dose Frequency	Utilization	Life/ End of Svc Life (EOSL)
			Enable Low Dose	Monitor Dose	Record Dose			
PET	PET	DISCOVERY ST HP 4SLICE MOBILE	High	Low	Med	Med	Low	Med
PET	PET	DISCOVERY LS4	High	High	High	Low	Low	High
PET	PET	DISCOVERY ST 8 DIAGNOSTIC CT	High	Low	Med	Low	Low	Med
CT	8 Slice	LIGHTSPEED ULTRA	High	Low	High	High	Low	Med
CT	16 Slice	BRIGHTSPEED 16 SLICES	Med	Low	Med Low	High	Low	Med Low
CT	16 Slice	LIGHTSPEED 16 SLICE	High	Low	Med	Med	High	Med
CT	64 Slice	VCT 64 SLICE XT	Med	Low	Med Low	Med	Med	Med Low
IR	Digital	INNOVA 3100	Low	Low	Low	High	Low	Low
IR	Digital	INNOVA 2000	Med Low	Low	Med Low	Med	High	Med Low
IR	Analog	LC BIPLANE NEURO +	High	Med	Med	Low	High	Med
IR	Digital	Philips FD20/20 Bi-Plane	Low	Low	Low	Low	Low	Low

training and alternative mechanisms to ensure competency.

Focus area 2: Equipment. *Problem and proposed solutions:* Installed equipment varies greatly in capabilities and controls. Newer equipment features improved speed and image quality but may increase the risk for harm, either through inadvertent misuse (due to the inherent complexity of the equipment) or accelerated injury (due to the intense amount of radiation that can be delivered). Although software controls can aid in dose control and monitoring, the cost of upgrades can be significant and certain equipment may not accommodate new software. Staff must also be adequately trained to use equipment features, software controls, and upgrades.

There is a need for a more complete understanding of available equipment. This would allow for the development of a standard set of expectations for technology, linked to effective processes and training requirements, which could bolster against risk and allow all providers to meet safety regardless of equipment type (Table 2).

Implementation and results: This analysis utilized the Equipment Risk Assessment Tool—an existing vendor tool that was modified to evaluate the full inventory of current equipment and characterize risk factors. Preliminary data were collected from purchasing records. Facilities received a prepopulated document listing all equipment, and designated personnel validated and updated the inventory list, and answered questions about utilization, including frequency of use and type of procedures. The results were summarized into a report that displayed (1) dose technology (ability to automatically adjust, monitor, and record dose); (2) frequency of high-dose procedures; (3) utilization; (4) useful life of the equipment; and (5) available upgrade options. A portion of this report is presented in Figure 2.

Results were provided to senior leadership promoting discussion and assisting in decision making regarding utilization, dose reduction practices, and capital expenditures. In total, the Equipment Risk Assessment Tool provided an understanding of both equipment abilities and human factors that affect equipment operation. For instance, an older piece of equipment may have a similar level of risk to a newer piece of equipment if used for routine procedures and by a highly skilled operator. This knowledge contributes to the strategic utilization of equipment and related operational and behavioral changes to reduce risk and protect patient safety.

Focus area 3: Monitoring and auditing. *Problem and proposed solutions:* Although equipment safety controls and procedural guidelines are immensely important, an incomplete understanding of systems capabilities can impede appropriate use of safeguards. In an effort to complete a task, operators may inadvertently circumvent technology and employ creative but

unintended use of equipment. Therefore, it is necessary to have mechanisms for monitoring radiation dose at delivery and reporting any irregularities, whether or not patient harm occurred.

Various organizations have proposed evidence-based guidelines or consensus recommendations, such as the appropriateness criteria from the ACR (2011) and diagnostic reference levels from the ICRP (2001). The creation of standard policies and guidelines for auditing and monitoring, as well as increased internal reporting, were proposed (Table 2).

Implementation and results: Currently, monitoring is a manual process due to technology constraints. The dose delivered to the patient is monitored for appropriateness based on ordered exam, with quality assurance processes to verify that the best image is produced using the lowest dose of radiation. Guidelines for acceptable performance have been established, and the process is supported and verified by internal survey and audit teams. The long-term goal is to integrate automated systems for dose reporting and cumulative dose reports into standard care processes, which could allow physicians and providers to monitor outcomes, better plan for future care, and have informed discussions of risk with patients. Several products are currently being pilot tested and the results will be shared with the vendors to improve the design and development of automated solutions.

Modifications were made to the existing event reporting system to encourage the reporting of events related to radiation safety and provide additional information about risk. Corporate clinical leaders updated guidelines to clarify what types of events are considered reportable. This included defining reportable variances in dose limits for fluoroscopy; additional guidelines will follow as dose limits are determined for different modalities. Division and facility leadership were encouraged to reinforce reporting behavior and to provide training for personnel in the event reporting process.

Focus area 4: Education. *Problem and proposed solutions:* Although radiologic technologists viewed the presentations offered by vendors and knowledge leaders as a useful review of techniques and equipment use, this analysis revealed the need for coherent educational processes with adequate oversight and a defined curriculum. In addition, there was a need for additional instruction on specific aspects of radiation safety, including dosing and advanced equipment usage.

Accordingly, clinical experts and vendors coordinated to design educational courses for radiation safety. These courses present topics such as new practices, event reporting, protocols, and physicians' roles in fostering a culture of safety at the unit level.

Implementation and results: Educational programs were developed by external subject matter experts, internal technical experts, and relevant technology vendors. The programs were tailored to specific specialties and designed for economy and consistency across practice areas. Materials were produced in a variety of formats—from online webcasts to recorded instructor-led presentations—to meet audience needs.

In retrospect, previous vendor-provided training courses had several limitations, including inconvenience (e.g., travel to vendor site, weekend training), little ability to track participation, and no universal curriculum. The consolidation of training courses to a centralized online education system both standardized content with the most current evidence and reduced employee burden by allowing them to participate whenever their work schedule allowed.

Currently four courses have been deployed with a total of 2,100 completions. These courses provide CE credit as applicable in order to help technologists meet requirements for continuing education. Future plans include educational courses with CE or CME credit, courses specific to equipment operation, and education sessions targeted to particular groups, such as referring physicians. The first course with CME credit was launched at the end of 2012. This course was designed for physicians who perform fluoroscopy, with the ultimate goal of

integrating it into privileging criteria at the facility level.

Focus area 5: Clinical pathways. *Problem and proposed solutions:* The tracking of radiation dose and patient exposure in electronic health records would help physicians and prescribers develop appropriate care plans that consider the necessity of particular tests. The utility of such systems has been shown by various providers, such as the pioneering efforts by Massachusetts General Hospital to send alerts based on collated dose (Massachusetts General Hospital, 2012).

Creating radiation-specific order sets that are available, appropriate, and offer alternatives to high-dose procedures is an institutional and provider responsibility. These order sets should be evidence-based and informed by the dose range for the intended test as well as patients' prior exposure. System developers should be prepared to incorporate and respond to current and future regulatory requirements, such as the imaging efficiency measures being developed by CMS (Magellan Health Services, 2010).

Implementation and results: The previously described policies for CT and fluoroscopy included recommended protocols as a preliminary step toward evidence-based order sets. Physician advisors encouraged adoption of these protocols within facilities, using event reporting and available data to drive awareness of risk and the potential effect on patient safety. In this way, the existing manual data system was leveraged to monitor and evaluate the entire patient experience, from determining if care was appropriate to reacting to outliers. The implementation of these recommended protocols also brought forth several issues that could affect the success of Computerized Provider Order Entry (CPOE) and evidence-based order sets, including variability in equipment and the clinical preferences of radiologists.

Order sets will be designed by physicians and multidisciplinary experts to maximize acceptance and address current needs. When automatic data collection is fully developed, the CPOE system will provide physicians with current patient characteristics and history, including exam frequency and dose, at the time of exam ordering. The development of order appropriateness guidelines, including criteria for ordering pathology-specific procedures, is an ongoing project.

Focus area 6: Communications and marketing. *Problem and proposed solutions:* The importance of these proposed solutions must be communicated to key stakeholders including leadership, clinicians, technicians, patients, and the general public. Accordingly, communication and marketing strategies to promote radiation safety were developed. Dubbed "Radiation Right," these campaigns presented a consistent safety message to all stakeholders.

Implementation and results: The communication campaign for imaging featured the tagline "Right Exam. Right Site. Right Dose." Materials were specifically designed for staff, patients, and the public with messaging about safety efforts including dose reduction, dose tracking, and equipment maintenance. For patients, this included materials to increase awareness about their responsibility for ensuring radiation safety, such as telling care providers about their previous radiation exposure history. Additional materials for technologists, physicians, and staff displayed updates in regulatory requirements or provided reminders of imaging alternatives. A similar campaign was also developed for therapeutic radiation.

With corporate guidance, one division created and piloted a "Radiation Right" webpage to be presented as a community educational resource on the publicly available websites for each facility within that division. The webpage was designed to be easily adapted to any facility and featured educational messaging about the use of ionizing radiation and radiation safety efforts. A social marketing vendor was engaged to post articles on social media sites with links to facility websites for more information. This concerted campaign effort by all facilities within the division may have increased its effectiveness; post-campaign feedback from physicians and

staff indicated that patients had fewer questions and concerns regarding radiation through imaging. In addition, using social media to drive patients to facility websites capitalized on publicity due to concurrent reports of radiation overexposure in the lay media. The template for this webpage has been offered to all facilities, and is fully implemented within eight divisions.

Discussion

The broad availability and high utility of ionizing radiation services have desensitized providers, prescribers, operators, and even patients to the associated risks and potential for harm. This presentation of areas for improvement, proposed solutions, and initial implementation efforts provide a framework for minimizing risk through the development of appropriate processes, utilization of available technology controls, and the creation a culture of safety.

The broad and comprehensive scope of our assessment confirmed the complexity involved in providing high-quality, safe, effective, and efficient delivery of ionizing radiation. We expect that all our proposed solutions will ultimately build upon each other. For instance, upgraded equipment and software will require knowledgeable operators as well as dose standards and tracking of patient exposure. The consolidation of educational courses into a centralized online system will help eliminate many of the barriers to training, creating a better educated workforce that is more able to safely operate equipment and evaluate the appropriateness of ionizing radiation. Increased availability of patient radiation histories could lead to more informed decision making and ordering, potentially reducing the tendency to overprescribe scans, especially in the context of "defensive medicine."

Yet these changes will not be possible without the support of stakeholders from throughout the ionizing radiation delivery process. The Radiation Right Steering Committee was essential to coordinating this process and eliminating barriers to communications between various groups. The inclusion of experts from all levels of the organization enabled the proposed solutions to reflect the practical needs of the field and include the most up-to-date regulatory and evidence-based practice requirements. The solicitation of feedback and guidance by the Steering Committee improved communication and collaboration that was crucial to the success of the proposed solutions. Input from physicians and other clinical experts supported the development of privileging requirements and encouraged adoption within facilities. Similarly, leadership support was vital. This was cultivated by providing open access to data, soliciting and responding to feedback, and allowing for flexibility in implementation to meet local needs. Finally, many of the proposed solutions, from equipment repair policies to ongoing personnel training, depend on maintaining an effective working relationship with vendors. Facilities are conducting pilot tests and providing feedback to help vendors develop products that are evidence-based, appropriate to the workflow in various environments, and include the required process checks, such as dual sign-offs on dose calibration.

With continued process improvement, further reductions can be made in radiation dose while still providing high-quality diagnostic exams to the radiologist. Sharing this information with a national database can effectively drive new industry standards. Future efforts will refine the collection, monitoring, and utilization of data. Automatic data collection will expand availability of information about the patient experience and allow for integration with CPOE. Radiation dose tracking systems will need to be designed and implemented, with attention to the goals and guidelines for health information technology that result from national standards-determination processes (U.S. Department of Health and Human Services, 2009). Additional considerations include state regulatory requirements for radiation controls through equipment maintenance and monitoring policies as well as the establishment of databases for the tracking of delivered doses, such as those required by the California legislature (California State Legislature, 2010). The solutions presented here will continue to

evolve with additional state legislation and changing regulatory requirements.

Limitations

The facilities involved may have benefited from resources inherent to a system as large and interconnected as ours, such as access to training materials or assistance with vendor negotiations. Although some challenges are universal, such as variability in equipment and the need to evaluate rapidly emerging vendor products, our implementation of proposed solutions benefited from the ability to move equipment and technology purchasing toward a centralized system. It should be noted, however, that the integration of these system-wide benefits was dependent on local support and acceptance of the proposed solutions. As facilities within this system are highly diverse, primarily community-based hospitals in a variety of locations, it is likely that the findings presented here would be applicable to a wide range of unaffiliated facilities.

Implications for Practice

In order to maximize risk reduction, the solutions developed as a result of this analysis focused on forcing functions, automation of processes, and standardization when possible (Reason, 1997). Higher level solutions such as dose monitoring, software controls, and standard protocols were preferred. As our evaluation demonstrated, maximizing the safety of ionizing radiation delivery will require such interventions due to the inherent complexity of the processes involved. These efforts could also improve patient satisfaction, as improved access to protocols and patient data could reduce provider workload, allowing more time for patient–provider interaction and care planning.

However, these high-level solutions were not always feasible due to factors such as technology limitations and the cost of equipment upgrades. Accordingly, solutions related to the human factors involved in care delivery, such as checklists, policies, and education, were necessary to foster a culture of safety. Efforts to change attitudes and behaviors, such as education and communication campaigns, complement these strategies. As the identified areas for improvement cross a variety of functions, the importance of cooperation from leadership, providers, and vendors cannot be overemphasized. All personnel must be empowered—and expected—to voice their concerns and contribute to creating an open and constructive culture of safety.

In total, improvements in the quality, safety, effectiveness, and efficiency of ionizing radiation use for patient care are possible and achievable. A comprehensive review of radiation policies, procedures, and utilization can identify potential areas for improvement where more robust and systematic layers of processes could reduce the risk of harm. By maintaining diagnostically useful examination while minimizing harm, providers can fulfill their responsibility to provide the best possible care for patients when using ionizing radiation.

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Authors' Biographies

Jonathan B. Perlin, MD, PhD, MSHA, FACP, FACMI, is the President of the Clinical & Physician Services Group, and Chief Medical Officer of HCA.

Laura Mower, MS, is the Vice President of Outpatient and Ancillary Services of the Clinical Services Group of HCA.

Chris Bushe, MSHA, MT(ASCP), is the Director of Laboratory Services of the Clinical Services Group of HCA.

The authors declare no conflict of interest.

For more information on this article, contact Jonathan B. Perlin at Jonathan.Perlin@HCAHealthcare.com.