Radiology Stewardship and Quality Improvement: The Process and Costs of Implementing a CT Radiation Dose Optimization Committee in a Medium-Sized Community Hospital System

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Purpose: The aims of this study were to measure the effectiveness of a multidisciplinary CT dose optimization committee and estimate its costs and to describe a radiation stewardship quality improvement initiative in one CT department at a medium-sized community hospital system that used a participatory design committee methodology.

Methods: A CT dose optimization committee was conceived, funded, and formed, consisting of the following stakeholders: radiologists, technologists, consultant medical physicists, and an administrator. Volume CT dose index (CTDIvol) and repeat rate were monitored for 1 month, for one scan type, during which iterative protocol adjustments were made through committee interaction. Effects on repeat rate and CTDIvol were quantified and benchmarked against national diagnostic reference levels after retrospective medical record review of 100 consecutive patients before and after the intervention. Labor hours were reported and wage resources estimated.

Results: Over 3 months, the committee met in person twice and exchanged 128 e-mails in establishing a process for protocol improvement and measurement of success. Repeat rate was reduced from 13% (13 of 100) to 0% (0 of 100). Scans meeting the ACR reference level for CTDIvol (75 mGy) improved by 34% (38 of 100 before, 51 of 100 after; Fisher's exact 2-tailed $P = .09$), and those meeting ACR pass/fail criterion (80 mGy) improved by 29% (58 of 100 before, 75 of 100 after; Fisher's exact 2-tailed $P = .01$). Committee evolution and work, and protocol development and implementation, required 57 person-hours, at an estimated labor cost of $12,488.

Conclusions: An efficient process was established as a proof of concept for the use of a multidisciplinary committee to reduce patient radiation dose, repeat rate, and variability in image quality. The committee and process ultimately improved the quality of patient care, fostered a culture of safety and ongoing quality improvement, and calculated costs for such an endeavor.

Key Words: Dose audit, Joint Commission, patient safety, protocol review, quality improvement

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INTRODUCTION

Professionals working in radiology have observed heightened awareness of radiation use in medicine [1-6]. This awareness, fueled largely by media reporting on the subject, has led interested imaging facilities to consider more rigorous internal scrutiny and analysis of imaging procedures. Radiologists, seeing themselves as stewards of radiation, just as infectious disease specialists are stewards of in-hospital antibiotic use [7], are leading efforts to reduce unnecessary radiation exposure. With this in mind, facilities have become interested in the pursuit of safety through quality improvement generally and more specifically through the implementation of a CT protocol review process [3], intent on implementation of the principle of "as low as reasonably achievable" as defined by statute [8], optimizing image quality at the lowest reasonable dose given the available resources.

Discussions of a facility CT protocol review process may break down quickly as stakeholders begin to understand the daunting scope of such a process. When admin-

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istrators and radiology managers consider the resources and support that would be required internally, the prospect of adding physics support to the cost of the project may dampen enthusiasm further.

If discussions proceed far enough, participants will eventually ask, "Where do we begin?" One aim of our work is to answer that question by describing a CT protocol review process that was successfully implemented in a community health system in the northeastern United States. Another aim of our work is to provide the CT community, including legislative, accreditation, and professional bodies, with economic context for the increased scrutiny directed toward CT.

The William W. Backus Hospital (WWBH) is located in Norwich, Connecticut, with 3 sites providing CT: 2 standalone imaging centers and an acute care hospital with an emergency department. WWBH itself is a 213-bed hospital with approximately 65,000 emergency department visits per year. WWBH employs 16 CT technologists, with a group of 9 contracted, hospital-based, private practice general radiologists. Each imaging center contained one CT system (2004, LightSpeed QX/i 4 [GE Healthcare, Waukesha, Wisconsin], and 2009, Definition AS 40 [Siemens Healthcare, Erlangen, Germany]), and the hospital had two systems (2003, LightSpeed Pro 16 [GE Healthcare], and 2007, Brilliance 64 [Philips Medical Systems, Andover, Massachusetts]). None of the systems had iterative reconstruction capabilities; all had automatic exposure control features available.

The (non-CT) medical physicist (Stuart Korchin, PE, DABR, PMP), supporting WWBH before the project, recommended that the interested radiologist in charge of CT (J.R.Q.W.S.) attend the American Association of Physicists in Medicine's 2010 CT Dose Summit, cosponsored by the Medical Imaging & Technology Alliance and the ACR. After the Summit, WWBH radiologists were motivated to activate a CT protocol review process and create a CT dose optimization committee. As is common at smaller hospitals and private imaging facilities [9], "physics support" for CT had historically taken the form of a consultant physicist providing ACR Accreditation-style physics surveys during annual site visits. Questions about image quality and radiation dose were generally answered by the service and applications personnel provided by manufacturers. Protocols were originally developed by vendor on-site applications at installation, with technologist and radiologist input. Physicists performed annual surveys and specific consultations regarding dosimetry.

Considering the institutional demographics described above, notably the presence of CT scanners of different capabilities from 3 major manufacturers and the physics support provided by consultants, this health system is anecdotally representative of a large portion of health systems in the United States. These aspects make WWBH's experience an exemplar one for other imaging facilities and institutions seeking ideas on how to go about implementing a CT protocol review process.

METHODS

We gained institutional buy-in, formed a team of stakeholders, and, using participatory methods, established a process to implement protocol evaluation in a CT department through the formation of a CT dose committee [10,11]. Using this committee to assess baseline status, set priorities, and agree to metrics for change, we used a team approach to improve the quality of care by monitoring and reducing patient radiation dose, and then estimated the costs of such a project.

Quantification of Results of the Specific Intervention

Repeat rate and volume CT dose index (CTDIvol) were quantified in 100 consecutive adult patients undergoing routine head CT 1 month before and after the intervention. Repeat rate was defined as the number of scans repeated by the technologist, divided by the number of total scans, multiplied by 100%. The images from every head CT and callback CT scan were reviewed by one radiologist within 24 hours.

Although not a direct measure of patient dose [12], radiation exposure levels attained with the clinical protocols were compared with established benchmarks for a valid quality metric, CTDIvol [13], as surrogate values for diagnostic reference levels. The Surrogate diagnostic reference level values were the ACR reference level of 75 mGy and the ACR pass/fail criterion of 80 mGy. PACS filters were created for desired date ranges, patient ages, and scan types. Radiation dose structured report static image captures from the PACS were printed out, and the CTDIvol from each examination was manually entered into an Excel spreadsheet (Microsoft Corporation, Redmond, Washington) for analysis [14].

Personnel hours on the project were measured and reported from an institutional perspective. Participating radiologists, technologists, and physicists tracked time dedicated to the project, in full committee and ad hoc meetings, and submitted time sheets. Administrator hours were based on participation during committee meetings only. Mean labor rates from accepted national databases and professional society publications were then applied to the project work hours by occupation [15-17]. E-mails between team members contained special labels to denote their relevance to the project and were counted at the determined measure point for the intervention.

Formation of and Process of a CT Dose Committee

The first step in the development of the CT Dose Optimization Committee was to identify, inform, and gain formal support from hospital leadership. In the case of WWBH, this included the institution's chief medical and executive officers, and radiology administrator. The information transmitted to the leadership included summaries of media publications [6], regulatory [18,19], accreditation [3,20], and professional (Image Gently,® Image Wisely®) body initiatives, small pilot data about the variability of dose estimates within the institution, literature context concerning variation [21,22], educational opportunities, potential benefits, and theorized costs. Theoretical hospital benefits included higher quality and more efficient patient care [23], and improved morale through teamwork. Predicted costs included the time of various personnel, including, but not limited to, radiologists, technologists, administrators, and consulting medical physics support. The private practice radiology group partners agreed that the allocation of time to the project was appropriate, as it was consistent with their model of providing additional value by having committed in-house community radiologists. At the time the project was proposed, it required a significant leap of faith on the part of hospital administration and radiology group partners because no cost estimates for a similar endeavor at a community hospital were available in the public domain.

For the next step, recruitment, the radiologist identified 3 technologists (the supervisor and 2 others who expressed interest in dose management) and a medical physics consulting firm. Because the facility had never before worked with a large medical physics group, and this type of service was considered beyond the scope of normal medical physics consulting, the radiology administrator and radiologist together negotiated the project scope of work with the firm.

After the formation of the committee, each party was required to prepare before the committee's first in-person meeting. The radiology administrator established a budget. Physicists performed baseline physics surveys. In the spirit of the impending project and on the basis of preliminary discussions with WWBH radiologists and technologists, the physicists directed additional quantitative analysis and qualitative scrutiny at certain frequently used protocols. Technologists cataloged salient existing protocols for physicist review and worked with vendors to configure each CT system to automatically send a radiation dose structure report to the PACS with each patient study. Technologists also revisited the Image Gently website. Radiologists queried an outside expert, and one radiologist performed a literature review and critical analysis of clinical image quality, compiling CT examinations demonstrating undesirable image features, particularly those that resulted in peer review because of difficult diagnosis, discrepant opinions, or misinterpretation.

After preparation, the committee met in person at WWBH. Full support and empowerment were given by the radiology administrator and radiologists. From the outset of the project, we cultivated an amicable environment, fostering an environment for interprofessional education [24], in which all voices were heard and respected, with transparent processes (Table 1). Here, the committee evaluated workflow, the frequencies of examination types, internal and external data about high variability of techniques and radiation exposure [21,22], and recent scientific articles [25,26]; decided on CTDIvol as a valid quality metric, using the ACR reference level and pass/fail criterion as benchmarks; and decided on head CT as the first protocol to evaluate.

Table 1. Key points facilitating group dynamics

- Roundtable approach, with empowered stakeholders
- Appropriate preparation with preeducation of all parties in the committee before meeting
- Availability of radiologists and medical physicists in the CT control area during clinical scans
- Willingness of radiologists and medical physicists to patiently discuss and communicate their perspectives on the images and scan parameters of interest
- Adaptability of the department and its personnel to foster interaction between radiologists and medical physicists during busy patient care hours
- Ability of CT technologists to maintain patient care as their top priority in the midst of image analysis and discussion by radiologists and medical physicists
- Timely availability of appropriate patients

Note: Although the relatively simple nature of a "routine adult brain" protocol contributed to the brevity of the initial pilot phase, we believe that the key factors listed in this table also contributed.

A single, older, reliable scanner, located at WWBH, was chosen as the target for novel protocol piloting. The central location permitted regular in-person interaction, which was desirable during the outset of the project while committee members were becoming familiar with one another. The physicists developed a substantively unique protocol from existing protocols and phantom tested it for image quality. After review with the radiologist and technologist, this new protocol was piloted on a patient with exceedingly low risk for manifesting stochastic radiation effects during the patient's lifetime, and the study was evaluated for clinical utility. Patient proximity in the department was maintained for availability if rescan was required. With the physical presence in the control room and reading station of both the physicist and the radiologist, the examination was evaluated and deemed clinically interpretable. Key benefits and some unacceptable negative characteristics were identified. The physicists worked to adjust acquisition parameters to mitigate the identified negative image characteristics. The new protocol was used on the next patient sent for a head CT study, after which the resulting protocol was deemed a significant improvement from the old protocol by the radiologist. During this pilot phase process, the physicists and committee and floor technologists continuously dialogued regarding the reasons various modifications were made, focusing on the importance of CTDIvol and dose-length product as quality metrics for CT technologists on a per patient basis.

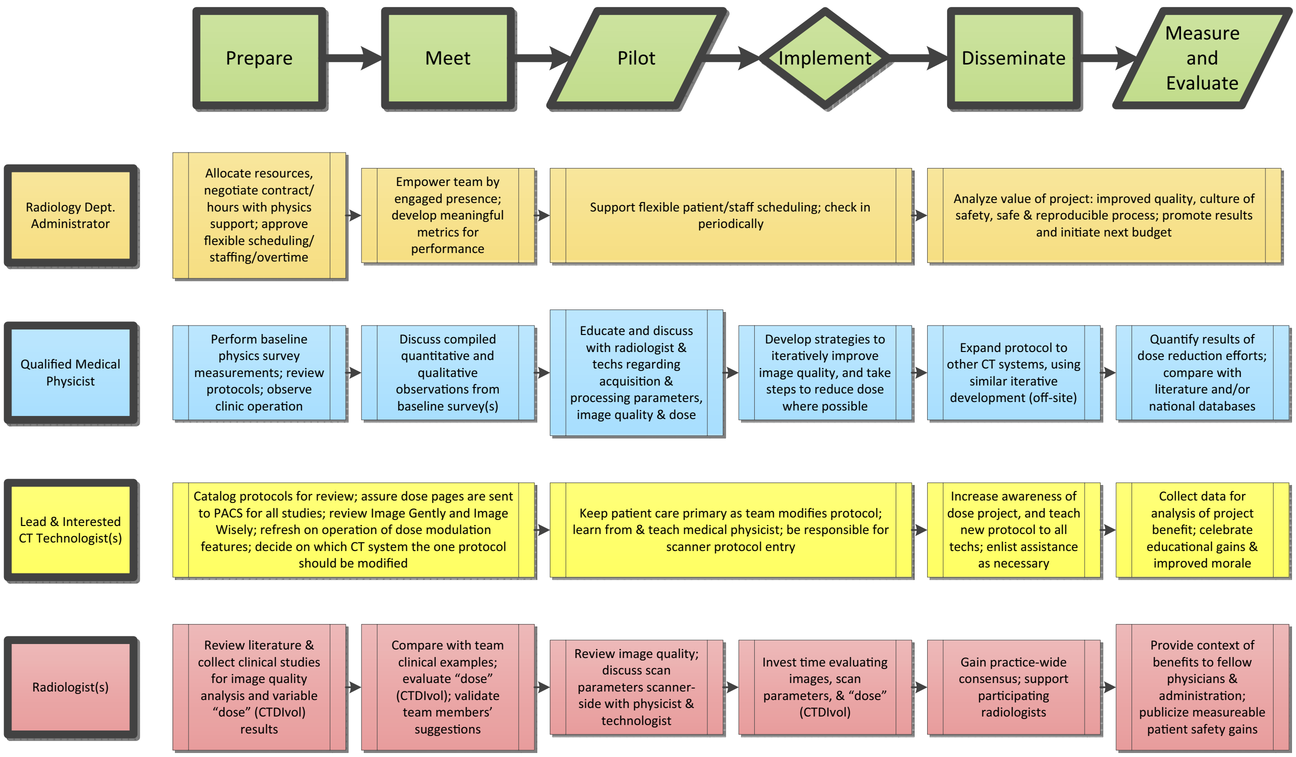

Fig. 1. Flowchart depicting how the CT Dose Optimization Committee worked together and in parallel during the project.

The scanner-novel protocol was uniquely named, saved, verified, locked, and externally recorded into the protocol database with an experimental moniker. Subsequent patients who underwent head CT were deliberately funneled to the scanner with the new protocol. Clinical image quality, repeats, and CTDIvol were closely monitored over approximately 1 month. For repeated images, the documentation was reviewed by the radiologist for etiology, using feedback loops via e-mail communication to the committee. With the physicist now interacting remotely from off-site, the protocol was implemented broadly over the subsequent month, with the team developing and implementing similar protocols on the other CT systems. Senior technologist committee members installed the new protocol(s), piloted with the lead radiologist, implemented minor scan protocol and reformat modifications made iteratively per the request of previously uninvolved radiologists (thereby gaining further buy-in and extending the influence of the quality and safety paradigm), and then disseminated across all personnel. Floor technologists were blinded to the study and the metrics being used. Fig. 1 depicts how the CT Dose Optimization Committee worked together and in parallel during the project.

RESULTS

Quality Improvement

In 100 consecutive patients 1 month before and after the intervention, the repeat rate was reduced from 13% (13 of 100) to 0% (0 of 100). Scans meeting the ACR reference level for CTDIvol (75 mGy) improved by 34% (38 of 100 before, 51 of 100 after; Fisher's exact 2-tailed $P = .09$), and those meeting the ACR pass/fail criterion (80 mGy) improved by 29% (58 of 100 before, 75 of 100 after; Fisher's exact 2-tailed $P = .01$).

Cost

Committee work, culminating in protocol development and implementation, required 57 person hours, including 10 radiologist, 18 physicist, 20 technologist, 5 administrator, and 4 clerical hours. Using these data and available wage data, the financial resources required for a similarly structured institution to conduct a comparable project were calculated as $12,488.

Measurement of the direct benefits of the intervention required an additional 8 radiologist and 8 technologist hours, totaling an additional estimated $1,640. Assuming 4 CT units, 30 CT protocols per CT unit, and similar personnel time requirements, the result was a total cost of $165,836 for one cycle of protocol evaluation for all protocols on all 4 CT units.

Process Improvement

Over 3 months, the full CT Dose Optimization Committee formed, organized, met in person twice, set priorities, intervened, and measured results. We identified one modifiable examination and examined all 8 existing head CT protocols in the context of the institutional repeat rate and performance relative to the ACR's CTDIvol benchmarks. One protocol for each of 4 CT systems was created and implemented. Radiologist consensus regarding image quality being equal or superior to the preintervention scan quality was obtained by iterative protocol modification, in small group meetings (eg, conference calls) with minutes communicated, and group e-mails (n = 128). All 9 radiologists agreed that subjective image quality was improved over baseline.

DISCUSSION

Our work demonstrates the ability to establish a codified process for quality improvement in CT in a medium-sized community hospital, supporting the institution's intent of becoming a highly reliable organization [23].

We were able to use interprofessional education [27], reduce the repeat rate, meet national performance benchmarks set forth by a major accreditation body (the ACR), and quantify resources necessary for a similar project. Through this committee, we began extending the culture of patient safety, taking the principle of "as low as reasonably achievable" from its usual locus—the opinion of an individual technologist, radiologist, or physicist—and advancing it via a team of local stakeholder "experts." This endeavor raised awareness of processes, system efficiencies and deficiencies, educational and safety opportunities, and provided a financial benchmark by which this institution was able to measure the relative value of homegrown and commercial strategies for radiology patient safety.

Repeat rate analysis has historically been a widely used quality metric in radiology [28,29] and increasingly so in CT [30,32,33]. Three factors contributing to reduced repeat rate were improved protocols, improvement of technologist education, and technologist-patient collaboration. Persistent artifacts, some directly attributable to acquisition parameters, were corrected. Patient motion, attributable to inadequate patient cooperation, was mitigated with an expedient protocol and technologist education about the role of patient volition. Technologists were also aware of the evolving workplace paradigm (ie, the heightened expectation of continuous quality, in addition to throughput). With the improved protocol, the radiologists at WWBH may have experienced enhanced diagnostic confidence because of higher quality thin images and multiplanar reformats, as many of the repeats in the preintervention group were recalled by radiologists because of the suspected but not certain presence of blood, an uncertainty previously described [31,34,35].

The per scan CTDIvol reduction was due to the optimization and balancing of acquisition and reconstruction parameters. The routine brain protocols were modified from axial acquisition to facility-novel helical protocols using lower tube current and low pitch (approximately 0.5-0.6), with automatic exposure control and gantry tilt when available [36-38]. Exposure and dose may also have been reduced because of additional technologist training, leading to a heightened awareness of optimal patient positioning, with appropriate isocentering [39] and chin tuck [40].

Many of the person-hours quantified were spent collaboratively, with team members observing processes and clinical performance of real-time patient scanning, with an eye toward improving quality and safety [41]. The observation time allowed the radiologists and physicists to gain significant insight into each other's expertise, with each gaining a deeper understanding of the relevant physics and clinical significance of image characteristics.

During the pilot phase, physicists' educational outreach to technologists, using the scanner itself as an instructional tool demonstrating how parameters individually and collectively influenced CTDIvol, patient dose, and image quality, we believe was a unique and effective strategy. This face-to-face discussion on site with physicists was novel in our environment, and we believe aided the technologists' understanding of the priority the institution placed on their education as patient radiation safety advocates and on highly reliable practices.

This initiative and study began before The Joint Commission's Sentinel Event Alert [3] recommendation that facilities "institute a process for the review of all dosing protocols either annually or every two years to ensure that protocols adhere to the latest evidence." Anecdotally, we assert that most scanners have upward of 100 protocols at the time of installation. Even within a single manufacturer of CT scanners, nuanced machine specifications and capabilities, such as 16, 40, or 64 detector rows, different software versions, tube current modulation features, and the presence of and levels of postprocessing (eg, iterative reconstruction), may result in varying capabilities for dose modulation or time to complete a scan. These various CT system configurations may have different patient radiation exposure and dose profiles and will consequently necessitate unique protocols for each CT unit.

On the basis of actual personnel hours on the project, we calculated the resources an institution with employed radiologists, consultant physicists, and employed technical, administrative, and secretarial staff members would have to allocate to conduct a similar project for a 4-scanner department to be $12,488. Given these results, the resources required to review and modify 30 protocols per year on each of 4 CT systems would be $165,836 the first year.

We agree that medical physics expertise was both "costly and critical to the success of the program" [42]. It is strongly recommended that facilities performing similar CT protocol review projects budget for medical physics support, including onsite time and additional time spent on preparation, baseline physics surveys, and offline data analysis (See Table 2).

The expected costs in subsequent years are difficult to

Table 2. Technical process summary: scope of work

1. Perform baseline performance survey of CT systems.
    a. Evaluate existing protocols quantitatively and qualitatively.
    b. Identify potential improvements and quantify effects of parameter adjustments.
2. Identify with radiologists any persistent negative image characteristics observed in clinical CT examinations.
3. Identify acquisition and processing parameters that can affect previously identified negative image characteristics.
4. Generate a novel protocol or adjust the existing protocol, as appropriate.
5. Pilot the new protocol and evaluate the resulting study, including multiplanar reformations (if applicable), with radiologists.
6. Adjust the protocol further to eliminate or lessen any negative results of the pilot protocol.
7. Implement the general protocol strategy across all facility CT systems, making an effort to exploit advantageous capabilities and to compensate for limitations of the various manufacturers' and vintage CT systems.
8. Iteratively evaluate and adjust protocol as necessary.

Additional tips

1. Limit the initial scope of the project to one CT unit to iteratively find a good general approach or strategy for the protocol.
2. Be aware of potential trade-offs of adjustments (eg, acquisition image thickness*); quantify these if possible, ideally in advance.

*Kanal KM, Stewart BK, Kolokythas O, Shuman WP. Impact of operator-selected image noise index and reconstruction slice thickness on patient radiation dose in 64-MDCT. AJR Am J Roentgenol 2007;189:219-25.

predict, as this report describes a first attempt with an intrinsic learning curve, but the protocol selected was unrepresentative in its simplicity. As the process becomes more established and efficient, it will be possible to achieve more cost effective results with additional protocols, but the learning effects may be offset by the additional complexity of other examinations. Cost data are specified as a point value rather than a salary range.

The data are limited, representing only the anecdotal experience of a single institution. Identified stakeholders not represented on the committee included patients, but as a community hospital, all hospital-based committee members, or members of their families, had been imaged at WWBH.

Manual labor to accurately marshal the active protocols was not inconsequential in our relatively small organization. The process of continuously improving quality and patient safety remains a work in progress, even in the current age of innovative commercial solutions to the dose optimization challenge [43]. With new image-processing algorithms, data extraction and dashboard software, and the availability of national dose registries, data collection is becoming less cumbersome. With the efficiencies intrinsic to many new technologies, cost estimates based on manual assessment and iterative protocol adjustment may remain valid, as the investment in improved infrastructure will likely require improved processes to continuously improve performance and maintain a culture of safety.

TAKE-HOME POINTS

- A team composed of stakeholders, including administrators, physicists, technologists, and physicians, is feasible and effective to monitor and control image quality and CT protocol-related radiation exposure.
- Variability analysis using comparisons with benchmark data on CTDIvol and dose-length product can and should be used to assess quality in a CT department; such analysis provides reliable and reproducible data for cross-hospital standardization.
- Through the development of transparent processes for quality and safety improvement in radiology, project costs can be assessed for quality improvement strategies, and the necessary resources can be predicted and allocated.

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