Optimization of radiation dose in CT scans

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Computed tomography (CT), which began as a novel tool over 40 years ago that enabled detailed examination of the human body in cross section, has become an essential component to modern day healthcare. It has without doubt revolutionized the way medicine is practiced today, allowing earlier diagnoses of pathology. This has in turn resulted in reduction of morbidity and mortality due to more timely treatment of diseases. Furthermore, the improved identification of pathology itself has reduced morbidity by reducing the number of invasive surgical procedures that were previously required to diagnose disease before treatment could even be started.

As the CT scan has become more ubiquitous over the years, there has been a concomitant increase in the amount of radiation patients are receiving. Between 1996 and 2010 us of CT scans in the United States has tripled from 52 scans per 1000 patients to 149 scans per 1000 patients (1). This translates to 8% annual growth of CT scans between 1996 and 2010, or stated another way, doubling radiation dose per capita from 1.2mSv to 2.3mSv. One of the concerns with the increasing radiation dose is the risk of cancer. Although the precise risk of developing cancer due to radiation is incompletely understood, it has been suggested that increasing lifetime radiation exposure increases overall risk of developing cancer. One study suggests that children who have had 2-3 CT scans in childhood triple their risk for brain cancer, and children who have had 5-10 CT scans triple their risk for leukemia (2).

As such, there has become increasing scrutiny to the overall utilization of CT and to ensure the appropriate use of these scans. There are many initiatives to aid in the appropriate use of CT scans. For example, the use of clinical decision support is mandated to be used by 2020 in the United States in certain practice settings. However, while ensuring the appropriate utilization of CT scans is important, it is also imperative to carefully review the parameter of the scans themselves to ensure the use of techniques which utilizes only the necessary amount of radiation necessary to produce quality examinations. The attention to this issue by both the public and medical communities in recent years has spurred the development of techniques and tools to more efficiently use radiation to produce optimal scans.

OUR APPROACH

To this end, our radiology department made the commitment to reduce overall radiation dose to our patients while preserving or increasing the quality of our CT scans. Between August 1, 2014 and December 31, 2015, we underwent an initiative to optimize our CT scans. We have previously described the component of this initiative in improving the consistency of administered radiation dose to our patients (3). In this article, we describe the component of our initiative that allowed us optimize radiation dose. Our plan to affect a network wide reduction of radiation dose while preserving or improving the quality of CT scans employed a multifactorial approach.

First, a Radiation Dose Optimization Committee (RDOC) was formed which would meet monthly. The role of this committee is to evaluate and implement strategies designed to maximize reduction of radiation dose while maintaining or improving diagnostic quality of the examinations. The committee included a wide cross-section of stakeholders including the radiology section chiefs (chest, abdomen/pelvis, musculoskeletal, and neuroradiology), CT supervisors from each facility, along with the radiation safety officer and medical physicist to ensure input from all viewpoints. This committee became the key oversight entity responsible for disseminating protocols and policies to each site. Previously, there was no formal entity that had authority for every site in the network. Adherence to these policies was monitored and enforced by this committee, which evaluated the dashboards monthly and directly followed up with the CT supervisors at each site. Strategies for radiation dose reduction concurrently with strategies for improving the quality of the studies were discussed, debated, and tested under the oversight of this committee.

There is a growing body of literature describing methodologies which have allowed for the reduction of CT radiation dose administered (4). The American College of Radiology (ACR) has long been a champion of radiation dose reduction well before it became a mainstream topic (5) and have advocated many of these techniques. Since then, there has been a proliferation of approaches that have been well described in the literature [4-]9). We performed a comprehensive literature search of these techniques, and subsequently evaluated and tested those that were most relevant for our network at one test site before deploying to the whole network.

Those exams with the highest dose and greatest utilization

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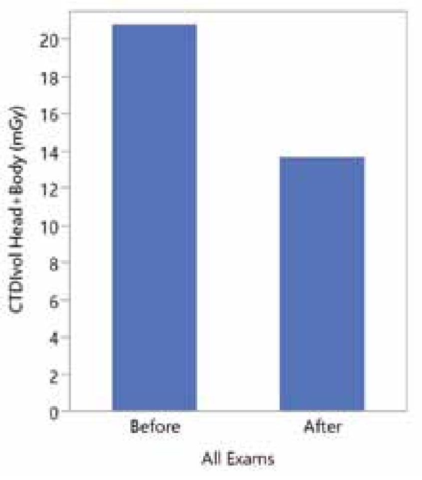

Figure 1. Mean radiation dose of all exams across the network before and after the intervention period.

were the initial focus, and included head, chest, abdomen/pelvis, and cervical spine studies. Thorough review of current literature, and input from the clinical (radiologists), technical (technologists), and radiation (radiation safety officer and medical physicist) perspectives gradually improved protocols from both a radiation reduction perspective as well as a diagnostic quality perspective.

MAJOR PROTOCOL CHANGES

• ***Development of low dose protocols for stone search [10, 11].***
The primary focus of these studies is the visualization of renal calculi. Since calculi can be seen with lower doses and the other organs in the abdomen are less important to delineate, a lower dose specifically to answer this question can be employed.

• ***Development of low dose cancer screening lung CT.***
The use of low dose chest CT for screening for lung cancers has been well described in the literature as an effective screening tool with a minimal radiation cost [12].

• ***Reduction of mAs for pulmonary nodule follow up.***
Similarly, follow up of pulmonary nodules can be adequately followed up with lower doses [13].

• ***Reduction of kVp from 120 to 100 for CT brain.***
While reducing radiation, this can also improve gray/white matter differentiation [14].

• ***Reduction of kVp for CTA brain, chest, and abdomen/pelvis studies from 120 to 100.***
Decreasing tube kilovoltage for CT angiograms has the benefit of increasing vascular signal intensity as the energy of the x-ray beam approaches the k-edge of iodine [15].

• ***Z-axis reductions for chest/abdomen/pelvis protocols.***
A review of all protocols to ensure we were including only necessary regions resulted in decreased radiation for various protocols.

• ***Implementation of "large patient" protocol for chest/abdomen/pelvis.***
The decision was made to accept a lower signal-to-noise images for larger patients with BMI>30. The result is overall less dose administered for a given patient compared to using the regular protocols.

IMPLEMENTATION OF MODEL-BASED ITERATIVE RECONSTRUCTION

The final major component in addressing radiation dose reduction was the implementation of new technology. We installed several new scanners that employed the use of newer reconstruction techniques. One important piece was the introduction of a model-based iterative reconstruction in our newer CT scanners (*Iterative Model Reconstruction-Philips (Philips, Amsterdam, Netherlands)*). This reconstruction technique results in higher signal-to-noise images for a given amount of radiation dose compared to conventional reconstruction techniques. This in turn allowed us to reduce dose regardless of protocol while still maintaining diagnostic quality. With the improved signal-to-noise afforded by this reconstruction technique, dose was gradually lowered in stepwise fashion, with images acquired at each lowered dose critically evaluated. This process was repeated until image quality was judged to be compromised. In the end, evaluation of the scans by the radiologists judged these new lower dose images to be at least of equal diagnostic quality, and in some cases, of better quality. For example, evaluation of nodules using the model-based iterative reconstruction was actually improved even with the lower doses due to the overall improved contrast resolution.

DOSE MONITORING

To obtain real-time feedback on the effect of our interventions, a comprehensive radiation tracking software is required which allows for the management of the tremendous amount of data gathered. Having a sophisticated dose tracking software is a necessity to properly monitor radiation doses. The software used in our network is Radimetrics (*Bayer Healthcare LLC., Whippany, New Jersey*). This software allows us to sort our radiation data into various dashboards and cross reference different protocols, scanners, and hospitals. Previously the only data that we could obtain was the specific radiation dose from a specific scan. No aggregate radiation data in any of the above categories could be obtained prior to the use of this software. The power of the software is that it allows for the sorting and analyzing of data, which in turn allows us to identify changes and make adjustments from the individual

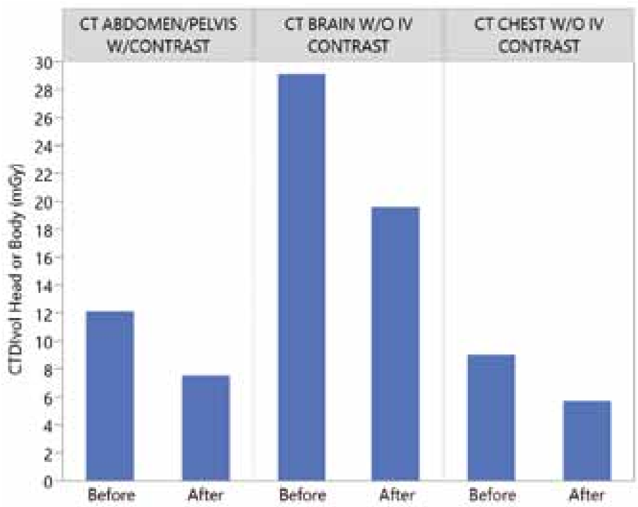

Figure 2. Mean radiation dose of select common exams before and after the intervention period.

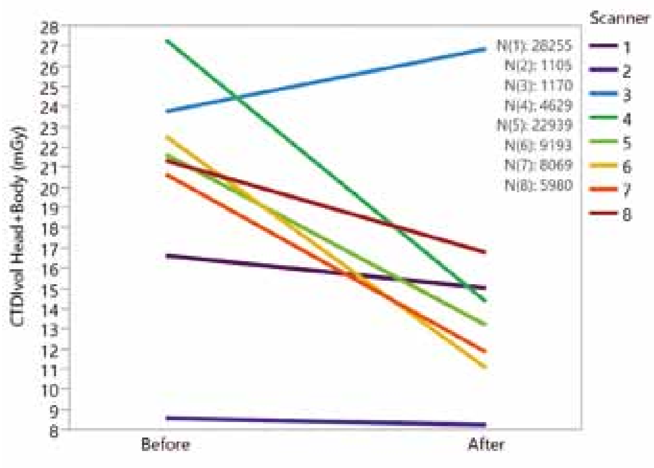

Figure 3. Mean radiation dose for all exams before and after the intervention period grouped by individual scanner. N= number of exams performed by the corresponding scanner.

scanner all the way up to the level of entire network.

Eight CT scanners located in settings including an urban level 1 trauma center, suburban hospitals, and an outpatient imaging center contributed to the data. These scanners include: GE (*GE Healthcare, Chicago, Illinois)* Lightspeed 8 slice, GE Lightspeed VCT 64 slice, Philips iCT 256 slice (x3), *Philips* Brilliance 64 slice, and Philips Ingenuity 128 slice CT/PET.

The Mann-Whitney U test was employed to assess the significance of the changes we observed.

OUTCOME

We utilized the time period of January 1, 2013- July 31, 2014 as our baseline or preintervention data ("before") prior to our period of intervention, August 1, 2014- December 31, 2015. We then designated January 1, 2016- December 31, 2016 as our post intervention time period ("after") to assess the effects of our intervention. Across the network, the average radiation dose of all CT exams combined (N=81340 exams) significantly decreased from 20.8 CTDIvol pre-intervention to 13.8 CTDIvol post-intervention with $p<0.0001$ [Figure 1]. Examining three common exam protocols (contrast enhanced CT abdomen/pelvis, unenhanced CT brain, and unenhanced CT chest) also demonstrates significant decreases in mean radiation dose for each individual exam type following the intervention ($p<0.0001$) [Figure 2].

Examining individual CT scanners, we found that our interventions consistently resulted in lower radiation dose. Seven out of eight scanners demonstrated lower mean dose post-intervention [Figure 3]. One scanner demonstrated an increase in radiation dose as it was transitioned from a general-purpose scanner to a scanner used predominately for head examinations, which have a higher CTDIvol than body exams.

These results demonstrate that minimizing radiation while preserving or increasing diagnostic quality can be obtained.

In our view, the most important component is the formation of a committee that meets on a regular basis to discuss, implement, and evaluate methodologies on a continuing basis. Even without the implementation of new technology, we would have experienced significant gains in radiation dose reduction simply by awareness via critical review of radiation data that the software allowed, and more importantly, the manipulation of protocols through the committee. We attribute the continued improvements to installation of the technology at more sites as well as the ongoing efforts of the RDOC. We view our work in radiation dose reduction as well as improving scan quality not as a one-time project, but a continuous process that can be constantly improved.

CONCLUSION

The optimization of CT radiation dose should be an ongoing part of every radiology department's quality improvement agenda. A multifactorial approach that includes evidence-based examination protocols and employing new reconstruction techniques can be effective in lowering radiation dose. In turn, the Radiation Dose Optimization Committee brings the different stakeholders together to optimize these efforts which can reduce radiation dose without sacrificing image quality.

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