List of Attachments

1. Keegan J, Miglioretti DL, Gould R, Donnelly LF, Wilson ND, Smith-Bindman R. Radiation Dose Metrics in CT: Assessing Dose Using the National Quality Forum CT Patient Safety Measure. *Journal of the American College of Radiology: JACR.* Mar 2014;11(3):309-315. This article published in JACR summarizes CT radiation dose for a large facility using the NQF format.

2. Miglioretti DL, Zhang Y, Johnson E, et al. Personalized Technologist Dose Audit Feedback for Reducing Patient Radiation Exposure From CT. *Journal of the American College of Radiology: JACR*. Mar 2014;11(3):300-308. This article published in JACR describes randomized trial of an intervention to standardize radiation dose for CT, using the NQF format.

3. UCSF Compute Tomography Dose Report, used in several clinical trials to provide feedback to clinical facilities on the radiation dose they use for their studies using the NQF format. The trials are focused on how to standardize dose, and the way dose is assessed is using the NQF endorsed format.

4. University of California, San Francisco National Quality Forum Measure: UCSF CT Exam Doses Compared to all Like Facilities

Radiation Dose Metrics in CT: Assessing Dose Using the National Quality Forum CT Patient Safety Measure

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Purpose: The National Quality Forum (NQF) is a nonprofit consensus organization that recently endorsed a measure focused on CT radiation doses. To comply, facilities must summarize the doses from consecutive scans within age and anatomic area strata and report the data in the medical record. Our purpose was to assess the time needed to assemble the data and to demonstrate how review of such data permits a facility to understand doses.

Methods and Materials: To assemble the data we used for analysis, we used the dose monitoring software eXposure to automatically export dose metrics from consecutive scans in 2010 and 2012. For a subset of 50 exams, we also collected dose metrics manually, copying data directly from the PACS into an excel spreadsheet.

Results: Manual data collection for 50 scans required 2 hours and 15 minutes. eXposure compiled the data in under an hour. All dose metrics demonstrated a 30% to 50% reduction between 2010 and 2012. There was also a significant decline and a reduction in the variability of the doses over time.

Conclusion: The NQF measure facilitates an institution's capacity to assess the doses they are using for CT as part of routine practice. The necessary data can be collected within a reasonable amount of time either with automatic software or manually. The collection and review of these data will allow facilities to compare their radiation dose distributions with national distributions and allow assessment of temporal trends in the doses they are using.

Key Words: CT, dose metrics, radiation, quality improvement

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BACKGROUND

CT delivers higher doses of radiation than conventional radiography, and the dramatic rise in CT use over the last 15 years [1,2] has resulted in a 6-fold increase in population exposure to radiation from medical imaging [2,3]. Although CT is useful across a broad range of indications and leads to improved patient outcomes, the radiation doses delivered by CT are in the range that carry a small but significant risk of cancer [4-7], and patients and their physicians are increasingly interested in understanding and minimizing this risk [8,9]. An increasing number of reports have documented a high level of variation in the doses used for common exam types across patients, providers and institutions [2,10,11]. This means that when a patient is evaluated with CT for a particular clinical indication, even accounting for patient size differences, the dose received may vary by more than 50 fold depending on where the scan is performed and who performs the scan [11]. Thus, many patients are put at a higher risk than necessary and there is an opportunity for significant improvement [2,11]. Further, because there are no widely endorsed or explicit standards for determining CT radiation dose, few institutions quantify routinely used doses. A guiding principle in radiology is that doses of radiation should be as low as reasonably achievable (ALARA), but with an absence of defined

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standards for the assessment and reporting of the doses used in actual practice, it is impossible to assure this standard is upheld.

Well-publicized radiation overdoses [12,13], coupled with studies reporting variation in dose metrics both within and across institutions [10], have caught the attention of professional societies such as ACR and the American College of Cardiology (ACC), as well as federal and state regulators [14-16]. This has prompted calls to monitor and standardize doses and to develop guidelines for appropriate utilization [17,18]. For example, the Joint Commission issued a Sentinel Event Alert on radiation and suggested that appropriate dose ranges for high-volume and high-dose diagnostic imaging studies be established and that physicians and technologists be provided with reference doses [19].

The National Quality Forum (NQF) is a nonprofit organization dedicated to improving the quality of American health care by focusing on building national consensus goals for performance improvement, creating standards for measuring and publicly reporting on performance, and promoting these goals through education and outreach programs. *Radiation Dose of Computed Tomography (CT)* is a NQF—endorsed quality metric that facilities can collect and review to help guide opportunities for quality improvement and dose optimization [20]. The use of this measure would further facilitate the pooling of doses across facilities for the creation of CT dose benchmarks and possibly dose reference levels (DRLs). DRLs are standardized dose levels for radiation procedures. DRLs do not define maximum or "do not exceed" levels, nor are they are ideal dose levels, but rather provide a level that should not be routinely exceeded without justification. If doses are to exceed a given DRL, then the appropriateness of the dose should be reviewed. Routine transgression of a set DRL can reveal systematic problems with dose optimization.

The Maintenance of Certification process of the ABR is a program designed to ensure the competence of radiologists by certifying that they are continuing to provide quality care and improving their practices through the incorporation of new information. Completion of the program requires fulfillment of 4 separate parts. Part 4 is the completion of a Practice Quality Improvement (PQI) project [21-24], and completion of a PQI project sometimes comes with the added benefit of higher reimbursement from CMS. The approach of a PQI project is the *Plan, Do, Study, Act* approach [23]. To complete a PQI project, the diplomate(s) must select a project, specify the goal, and focus on a relevant metric [23]. Baseline data are collected or evaluated and an improvement plan is created and implemented. Data around the metric are re-evaluated as compared to the established goal [23].PQI projects can be done as individuals or by a group [23]. The projects can be selected from pre-approved templated projects approved by the ABR, or participants can create their own projects [23]. There are currently 39 ABR-approved projects and templates, including the University of California at San Francisco (UCSF) project that focuses on assessing dose per the NQF approved measure [25].

In this paper, we describe our experience with collecting institutional radiation dose metrics information using the NQF measure as a guide. Further, we discuss the process through which a facility can upload their data to a dose registry server at UCSF, which is under development as part of the report to receive an audit that can be used to create a report and to compare with benchmarks. This will provide a framework for ABR diplomates to complete an ABR-approved PQI project.

METHODS

We collected radiation dose metrics from consecutive CT scans performed on adults at UCSF, a single, large, academic medical center in San Francisco. UCSF provides primary, secondary, and tertiary care and performs approximately 25,000 CT scans a year on 8 scanners (GE Lightspeed 16, Lightspeed VCT, and Discovery CT750) located at several inpatient and outpatient facilities in San Francisco. To assess change over time, we included CT scan data from 2 time periods, March and April of 2010 and 2012, to assess change over time. For 50 examinations, we used 2 different approaches for assembling the CT dose metrics to quantify the time and effort involved in data collection. For the remaining cases, we used a single method to collect the dose metrics. The UCSF Institutional Review Board approved the study.

NQF Measure Specifications

The NQF measure has 2 parts; part A is an outcome measure that calls for collection of radiation dose metrics, and part B is a process measure that assesses the proportion of CT examinations where dose is reported in the medical record. This manuscript focuses on part A. The measure specifies assembling and summarizing the distribution in CT dose metrics (such as the 25th, 50th, and 75th percentile distribution) using CT dose index ($CTDI_{vol}$), dose-length product (DLP), and effective dose for consecutive CT scans. The dose metrics are stratified by anatomic area (head, chest, abdomen and/or pelvis) by scanner model, and calculated within age strata ("adults" includes all individuals age 15 years and older, and children are separated into 4 age groups: <1 year, 1-5 years, >5-10 years, and >10-15 years). For adults, a minimum of 100 consecutive scans is required per strata, and for children, a minimum of 50 CT scans (or 1 year of data) per age strata. Data are not required to be compiled for all age groups, and this manuscript is limited to adults. Per NQF measure specifications, CT scans performed as part of an interventional radiology procedure, for radiation oncology planning, or that cover multiple regions as part of a single scanning event (eg, chest-abdomen-pelvis) were excluded. The measure does not require grouping CT exams by indication, protocol, or number of series. Although it is not specified in the endorsed NQF measure, we also assembled data on the size-specific dose estimate (SSDE) [26], a metric introduced after the submission of the NQF measure that adjusts for patient size in the calculation of $CTDI_{vol}$ [27].

Dose Metrics

The $CTDI_{vol}$ (a standardized measure of dose to a specified phantom), DLP (the product of the $CTDI_{vol}$ and the scan length), scan length, patient age, CT scanner manufacturer and model were recorded for each CT examination. Effective dose was calculated using software that sums absorbed organ doses using ICRP 103 weighting factors [28]. SSDE was calculated for abdominal/pelvis examinations, using a mid-scan measurement of body circumference. For multiphase exams, where the exposure events covered the same scan region (ie, routine abdomen-pelvis with and without contrast), DLP was defined as the sum of the individual phase DLPs, and scan length was defined as the sum of the individual series scan length. The $CTDI_{vol}$ was defined for multiple phase exams as the summed DLP divided by the summed scan length. Multiphase exams covering different anatomic areas were excluded.

Recording Dose and Patient Information

We used eXposure™, a commercially available dose monitoring software product, to assemble the radiation dose metrics. We exported dose metrics for all exams within the specified time periods for adult patients. We used the protocol name to identify the anatomic area imaged. We exported the dose metrics and other variables (such as anatomic area) using the program export feature. eXposure calculates effective dose using estimated organ doses and the ICRP 103 weighting factors [28]. eXposure calculates SSDE using a midscan measurement of circumference, as specified in the American Association of Physicists in Medicine (AAPM) report from Task Group 204 [26].

For a subset of 50 CT examinations, the radiation dose metrics were collected manually in order to compare the feasibility of assembling the data using different approaches. For this method, we used PACS to review CT scans performed on prespecified days and selected 50 consecutive scans within our included anatomic areas categorized by the study name. For each examination, we recorded patient age, date of scan, anatomic area, $CTDI_{vol}$, and DLP for each series into a Microsoft Excel spreadsheet, and for examinations with multiple series, the dose metrics were combined using the method described above.

Clinical Interventions

Between the 2 data collection periods (2010 and 2012), UCSF instituted several policies and procedures aimed at optimizing radiation doses used for CT. Interventions included the creation of a radiation safety committee tasked with reviewing and monitoring CT radiation dose metrics administered across all departmental sites, the formulation and implementation of dose reduction strategies, the adoption of Adaptive Statistical Iterative Reconstruction dose-reduction software on several CT scanners, reduction in the use of multiphase high-dose protocols, and the replacement of a Lightspeed Ultra scanner with a Discovery CT750 HD. These interventions likely contributed to changes in CT dose metrics between the 2 time periods.

RESULTS

Overall, 5,846 CT examinations of the head, chest, and abdomen/pelvis in adult patients are included in this report (Table 1). The majority of examinations were performed on Lightspeed VCT scanners.

Table 2 shows the 25th, 50th, and 75th percentiles of the dose metric distributions by anatomic area and time period. Between 2010 and 2012, there was around a 30% to 50% reduction in the dose metrics across each of the 3 anatomic areas. Of note, patterns in dose over time were similar across all dose metrics. For example, the median (50th percentile) head $CTDI_{vol}$ decreased from 57 mGy to 33 mGy, a 41% reduction. Similarly, the abdominal/pelvic $CTDI_{vol}$ decreased from 11.7 mGy to 6.5 mGy, a 44% reduction. In general, there was a

Table 1. Included number of CT exams by patient age, sex, anatomic area, scanner model, and year

Characteristic	2010	2012	Total
Sex			
Female	1598	1367	2,965
Male	1492	1389	2,881
Age			
18-19	35	15	50
20-29	215	217	432
30-39	283	250	533
40-49	408	327	735
50-59	655	554	1,209
60-69	625	631	1,256
70-79	509	459	968
80+	360	303	663
Anatomic Area			
Head	895	817	1,712
Chest	734	750	1,484
Abdomen/Pelvis	1,461	1,189	2,650
Scanner			
Lightspeed 16	742	699	1,441
Lightspeed VCT	2,133	1,851	3,984
Lightspeed Plus	215	-	215
Discovery CT750 HD	-	206	206
Total	3,090	2,756	5,846

Between the 2 collection periods, the CT750 HD replaced the Lightspeed Plus.

Table 2. Summary of dose metrics including the 25th, 50th and 75th percentiles, by anatomic area and study year

	CTDI$_{vol}$ (mGy)			DLP (mGy cm)			E (mSv)		
	2010	2012	% change	2010	2012	% change	2010	2012	% change
Head									
25%	49	28	−44%	1,127	491	−56%	2.1	1.0	−52%
50%	57	33	−41%	1,205	645	−46%	2.4	1.3	−46%
75%	68	49	−29%	1,394	945	−32%	2.8	1.9	−32%
Chest									
25%	5.1	3.5	−31%	174	119	−32%	3.5	2.4	−31%
50%	8.1	5.5	−32%	282	189	−33%	5.2	3.6	−31%
75%	15.5	9.5	−39%	491	333	−32%	9.7	6.1	−37%
Abdomen/Pelvis									
25%	7.6	4.5	−41%	496	247	−50%	8.5	4.1	−52%
50%	11.7	6.5	−44%	808	490	−39%	14.1	8.1	−43%
75%	17.5	12.2	−30%	1,304	890	−32%	21.6	14.9	−31%

Values may appear to be off because of rounding. CTDI$_{vol}$ = volume of CT dose index; DLP = dose-length product.

slightly greater percentage reduction in dose metrics at the 25th and 50th percentiles, compared with the 75th percentile. Additionally, there were slightly smaller changes for chest examinations compared with those of the head and abdomen/pelvis.

The changes in dose metrics over time were similar whether measured using CTDI$_{vol}$ or SSDE (Table 3), though the values of SSDE were slightly higher than CTDI$_{vol}$.

The full distribution of the dose metrics over time is shown in Figure 1. These graphs demonstrate a consistent reduction in the mean and median dose metrics as well as a reduction in the variation in dose in 2012.

For the sample of 50 exams, the data extraction with eXposure took under an hour. The manual data extraction of 50 CT examinations took 2 hours and 15 minutes (2 minutes and 42 seconds per examination).

DISCUSSION

The CT radiation dose measure endorsed by the NQF provides an easy way for facilities to begin to assess dose levels used for CT imaging in practice. Using the NQF dose format, we were able to easily assess CT dose metrics at UCSF over 2 time periods and identify patterns. Our data show that all dose metrics considered gave similar results.

The NQF measure will also facilitate the creation of standards and guidelines, including benchmarks, for appropriate CT doses. This could help reduce the currently high variation in doses used for CT by creating explicit target dose levels and diagnostic reference levels. Although DRLs for CT have been used for quality improvement programs in many industrialized nations for over a decade and have lead to increased standardization in CT [29], widely endorsed DRLs have yet to be established in the United States. The ACR Dose Index Registry began a pilot program in 2010 to collect CT dose metrics data in the US [30], but public reporting and endorsement of DRLs are not part of the current objectives. To create DRLs, it is necessary to collect information across a large number of facilities on actual performance, and, by convention, DRLs are set at the 75% distribution in dose. Only a small number of publications describe specific DRLs that might be used in the United States, and these have been based on relatively small number of patients and facilities [31,32]. However, pooling data using the NQF measure would allow for the creation of both national and regional DRLs.

SSDE was introduced after the submission of the NQF measure, and was therefore not included as part of the NQF measure. Concern that it would be better to include this metric has been raised [33]; however, we found little difference in change over time using these 2 different metrics. On an individual patient level, SSDE may be a better method of assessing the appropriateness of dose because it takes patient size into account; however, when evaluating dose on the facility level, we found it does not matter which metric is used.

The purpose of assembling data at the facility level is to understand the dose metrics used for imaging in a population of patients. It should not replace careful review of protocols, or the optimization of dose focused on individual patients and their individual requirements for diagnosis. However, review of data

Table 3. Summary of CTDI$_{vol}$ and SSDE for abdomen and pelvis by study year

	CTDI$_{vol}$ (mGy)			SSDE (mGy)		
Percentile	2010	2012	% change	2010	2012	% change
25%	7.6	4.5	−41%	10.5	6.4	−39%
50%	11.7	6.5	−44%	14.9	7.9	−47%
75%	17.5	12.2	−30%	19.8	13.7	−31%

CTDI$_{vol}$ = volume of CT dose index; SSDE = size-specific dose estimate.

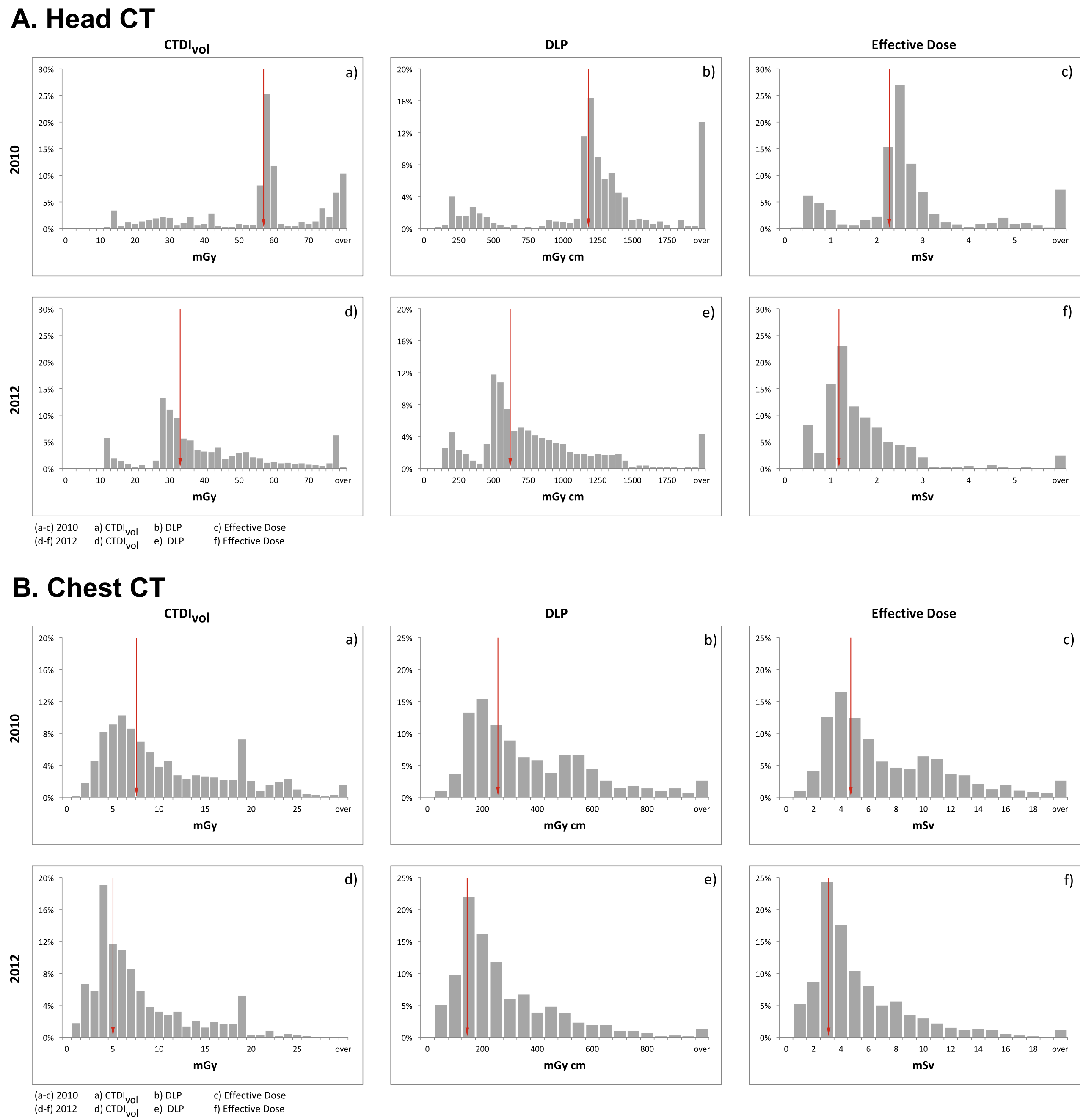

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Fig 1. **(A)** Radiation dose metrics for head CT scans, 2010 (top) and 2012 (bottom). Red line indicates median. **(B)** Radiation dose metrics for chest CT scans, 2010 (top) and 2012 (bottom). Red line indicates median. **(C)** Radiation dose metrics for abdomen and pelvis CT scans, 2010 (top) and 2012 (bottom). Red line indicates median. $CTDI_{vol}$ = volume of CT dose index.

assembled using these summary statistics provides an opportunity to identify areas where institutional doses may be higher than needed thereby prompting careful protocol review.

We explored different methods of assembling dose to test whether NQF measure data could be collected by facilities with varying resources. Although the manual extraction method may be more prone to error, it is a feasible method for data collection for a practice that wants to assess their performance without purchasing commercial dose monitoring software. Calculating the distribution of dose as specified by the NQF measure (100 examinations for each of the 3 anatomic areas) would require approximately 13.5 hours of data extraction on PACS per CT scanner type (4 hours and 30 min per 100 scans times 3 anatomic areas equals 13.5 hours). For a facility with 2 types of CT scanners, this would require approximately 27 hours of data extraction. The lead study author, a high school student, abstracted the data for this study, so a practice could hire

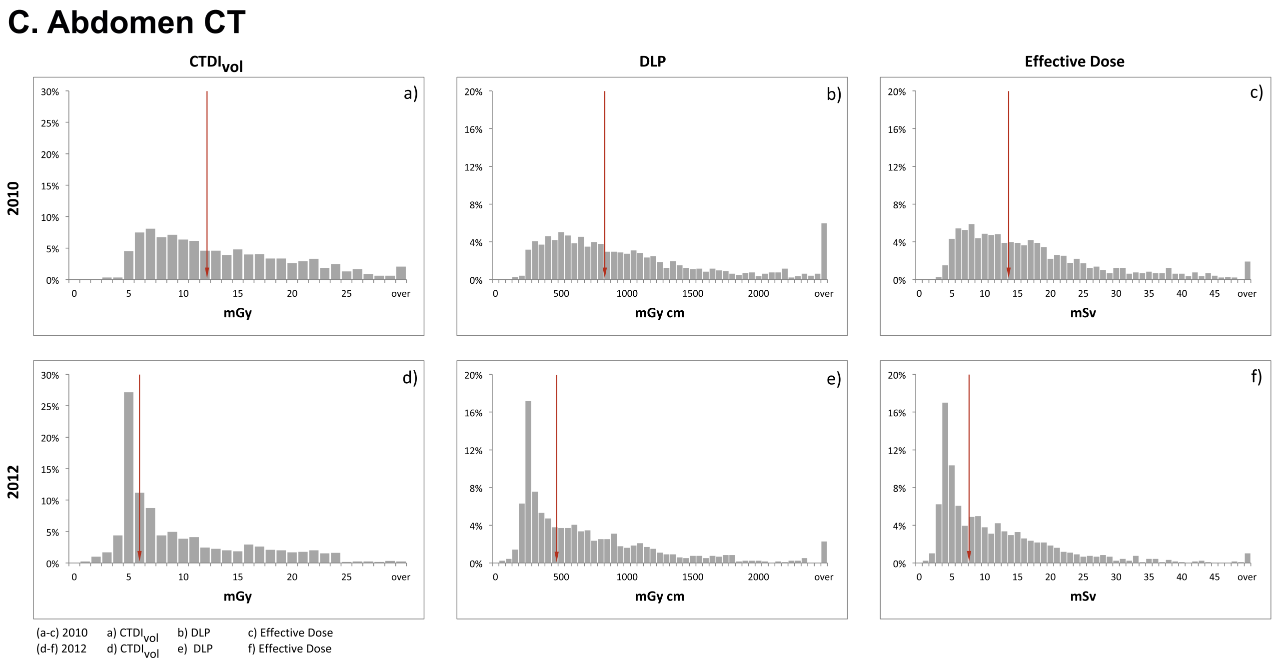

Fig 1. (*continued*).

a student to collect the data necessary to comply with the NQF measure in a single week. eXposure required time to learn how to use the product, but the actual data extraction time was brief—under an hour. There are also freeware products available for download, such as Radiance (http://radiancedose.com). Radiance would take time for installation and adjustment, similar to eXposure, but once set up should take only about 1 second per exam to extract dose metrics.

In California, legislation requires the reporting of radiation dose metrics in the patient record, specifically $CTDI_{vol}$ and DLP, and the reporting of certain high exposure events that are the result of repeat examinations or scanning of the incorrect body part. Reporting of this dose information requires that facilities either manually record the dose in the patient record or use automated software solutions to track and report dose. Other states, the federal government, and/or accrediting bodies may eventually follow suit and require similar dose monitoring and reporting. This means that many facilities may already be tracking doses, or may have to do so in the near future, which makes submitting data to fulfill this measure even more practical.

As part of the Virtual Symposium on Radiation Safety in CT, we are creating an opportunity for individuals and institutions to upload their own data and receive an NQF-style audit report that summarizes dose similar to what we report in this manuscript. A detailed report of facility doses will be provided to participating institutions and is intended for use by the facility to evaluate their performance. Individuals can use the process of reviewing their data to complete a PQI project on optimizing doses used in practice. We will then aggregate the data to create benchmarks by anatomic region and make these data widely available.

The NQF measure requires sorting exams by anatomic area, but not by the specific protocol or clinical indication. Although this would be useful (ie, to compare dose metrics within more nuanced reasons for scanning), this is currently not feasible. The Radlex is a relatively new development in radiology to help organize the indication for imaging, but requires a specialized tool to map the protocols to specific clinical indications. The NQF CT Dose Measure does not require that protocols be mapped to the Radlex and therefore all protocols used for a particular anatomic region are included.

The study has several limitations. We included data from only a single institution, and it is possible that a more varied population would result in differences across doses metrics. This paper is meant to be a description of the methods for collecting basic CT dose measures at a facility and to demonstrate how the data can be displayed to evaluate the need for dose optimization. Specific reasons for changes in the dose metrics seen over time are outside the scope of this analysis; however, as outlined in the methods, strategies we employed included careful review of patient doses. Because the measure only subdivides dose metrics into 3 broad anatomic areas, it cannot be used to find the ideal dose for a given patient. However, this broad classification makes the measure easy to fulfill. Though it does not directly identify specific causes or solutions, by helping facilities to understanding their CT radiation dose metrics in a larger context, the NQF measure can highlight potential areas for improvement and is an important first step in getting institutions to lower doses where the need is greatest.

The ultimate goal of the NQF measure is to build national consensus for quality improvement in dose optimization, to create standards for measuring and publicly reporting on performance, and to promote patient safety and health care quality through education and outreach programs.

TAKE-HOME POINTS

- With the methods outlined in the NQF's measure on radiation dose, facilities can assess the dose metrics they use for CT as part of routine practice.
- Fulfilling the NQF measure should take 13.5 hours of work if data is collected manually, and even less time if collected with commercial software or freeware.
- The NQF's broad methods of organizing scans make it easy to fulfill and can be an important first step in getting institutions to lower doses where the need is greatest.

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SA-CME

Personalized Technologist Dose Audit Feedback for Reducing Patient Radiation Exposure From CT

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Purpose: The aim of this study was to determine whether providing radiologic technologists with audit feedback on doses from CT examinations they conduct and education on dose-reduction strategies reduces patients' radiation exposure.

Methods: This prospective, controlled pilot study was conducted within an integrated health care system from November 2010 to October 2011. Ten technologists at 2 facilities received personalized dose audit reports and education on dose-reduction strategies; 9 technologists at a control facility received no intervention. Radiation exposure was measured by the dose-length product (DLP) from CT scans preformed before (n = 1,630) and after (n = 1,499) the intervention and compared using quantile regression. Technologists were surveyed before and after the intervention.

Results: For abdominal CT, DLPs decreased by 3% to 12% at intervention facilities but not at the control facility. For brain CT, DLPs significantly decreased by 7% to 12% at one intervention facility; did not change at the second intervention facility, which had the lowest preintervention DLPs; and increased at the control facility. Technologists were more likely to report always thinking about radiation exposure and associated cancer risk and optimizing settings to reduce exposure after the intervention.

Conclusions: Personalized audit feedback and education can change technologists' attitudes about, and awareness of, radiation and can lower patient radiation exposure from CT imaging.

Key Words: CT, radiation exposure, audit feedback, radiologic technologists

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INTRODUCTION

The use of CT has increased dramatically over the past few decades [1-4]. CT greatly improves diagnostic capabilities but exposes patients to higher levels of radiation than conventional radiography. Radiation exposure and subsequent cancer risk vary greatly by individual, even for CT scans conducted for the same indication [1,4,5]. Cancer risk rises with increased radiation exposure [6], so to minimize potential harms from CT, we need ways of standardizing and reducing radiation exposure from CT imaging where practical.

Radiologists choose the CT protocols for assessing patients; however, radiologic technologists implement the protocols and influence radiation exposure to patients by determining CT scanner settings. One approach to improving the performance of health professionals is personalized audit feedback, which has not been studied among radiologic technologists.

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Providing CT technologists with radiation dose indices from scans they performed might motivate them to implement methods that can appropriately lower radiation exposure. Another approach recommended by the Image Gently® campaign is to increase awareness and understanding of CT radiation dose issues among radiologic technologists through additional training [7].

We conducted a pilot study to evaluate the feasibility, acceptability, and effectiveness of providing technologists with personalized dose audit reports and an educational seminar on reducing patients' radiation exposure from CT. We assessed the impact of this intervention by comparing dose indices for patients scanned before and after the intervention. We included a control facility to examine changes in radiation that may have occurred due to factors unrelated to the intervention, such as recent media attention to radiation from CT.

METHODS

This pre-post, nonequivalent controlled pilot study was conducted within Group Health Cooperative, an integrated health care system in Washington State, from November 2010 to October 2011, with the intervention taking place on April 2, 2011. The intervention group included 10 technologists at 2 facilities; the control group included 9 technologists at a third facility. Facilities were chosen so that the study arms had similar numbers of technologists and so that participating technologists worked at only a single facility. Scanners at the intervention facilities were a GE LightSpeed VCT 64-slice scanner (GE Healthcare, Milwaukee, Wisconsin) and a Toshiba Asteion 4-slice scanner (Toshiba, Tokyo, Japan). The scanner at the control facility was a Toshiba Aquillion 16-slice machine. Our HIPAA-compliant study was approved by the Group Health Cooperative Institutional Review Board.

Intervention

Dose Audit Report. Technologists at intervention facilities were given personalized audit reports showing dose metrics from a sample of CT scans they performed in the preceding 5 months on patients aged ≥15 years, relative to their peers (a sample audit report is provided in the online Appendix). The two dose metrics provided were dose-length product (DLP) and effective dose. DLP is the product of the scan length, in centimeters, and the volumetric CT dose index, an estimate of the radiation delivered to a specified phantom for a single scan slice, in millgrays. DLP, expressed as milligray-centimeters, thus reflects the total radiation output for a scan [8]. Effective dose, in millisieverts, accounts for radiation from the scanner and the sensitivity of irradiated organs and tissues to developing cancer from the exposure. We included effective dose in the reports because it is useful for comparing CT scans of different anatomic regions on a common scale; for individuals without training in medical physics, effective dose may be easier to understand than DLP.

The audit reports provided feedback for the 4 most common anatomic regions, using a format endorsed by the National Quality Forum [9]. For each anatomic region, the report included the median values and histograms of dose metrics for examinations conducted by the technologist, examinations performed by all technologists at their facility, and examinations performed at all 3 facilities. We included UK 2003 national diagnostic reference dose values representing the 75th percentile of doses in the United Kingdom [10] because no US values exist. We listed the technologists' cases with dose metrics that were high relative to their facilities, so that they could examine those cases on their own.

Educational Seminar. Technologists in the intervention group participated in an interactive 6-hour seminar by a medical physicist, Richard Morin, PhD, and a radiologist, Rebecca Smith-Bindman, MD. They reviewed the basic physics of radiation from CT machines, factors causing higher radiation exposure, and dose-lowering strategies.

Intervention Evaluation. Two weeks after the intervention, participating technologists completed an online evaluation of the audit report and seminar (SurveyMonkey.com).

CT Examinations and Radiation Dose Measurement

For each CT technologist, before and after the intervention, we randomly selected up to 30 examinations on patients ≥15 years of age for each anatomic region. We sampled 1,630 CT studies performed within 4 months before the intervention and 1,499 within 6 months after the intervention.

Our main outcome measure of radiation exposure was DLP, directly abstracted from CT examination dose reports from one intervention facility and the control facility. DLP was not on the dose report for the other intervention facility; therefore, we abstracted scan parameters (scan length, slice thickness, kilovolt, milliampere or milliampere second, rotation time, and pitch) and estimated DLP from these metrics [11-13]. Because facility-specific DLPs were compared before and after the intervention using the same method at each facility, the technique used to measure DLP should not affect the estimates of change in DLP, but it could influence absolute levels of DLP for each facility.

Patient age, gender, and height and weight measurements closest to the time of the CT examination were obtained from the medical record. Body mass index (BMI) was calculated as weight in kilograms divided by the square of height in meters squared.

Table 1. Demographic characteristics of participating CT technologists

Variable	Intervention Facilities	Control Facility*
Gender		
Male	3 (30%)	4 (44%)
Female	7 (70%)	5 (56%)
Years of experience as CT technologist†	19 (2–31)	9 (3–29)
Highest level of education completed		
Technical degree or certification	3 (33%)	0 (0%)
2-y college degree	6 (67%)	4 (67%)
4-y college degree	0 (0%)	1 (17%)
Missing	1	4
Participated in CT dose reduction training courses as part of job training and skill development		
Yes	6 (75%)	1 (17%)
No	2 (25%)	5 (83%)
Missing	2	3
Average number of work hours per week		
20	1 (13%)	0 (0%)
36	0 (0%)	2 (40%)
40	8 (89%)	3 (60%)
Missing	1	4

Note: Data are expressed as number (percentage) or mean (range).
*Two radiologists from the control facility retired before the survey was conducted, and 2 others did not respond.
†Years of experience was missing for 1 intervention radiologist and 4 control radiologists.

Technologist Survey

We surveyed CT technologists about their attitudes toward and awareness of radiation exposure from CT imaging. Intervention technologists were surveyed on the day before the intervention and again 8 months later. Control technologists were surveyed 9 months after the intervention.

Statistical Analysis

To evaluate intervention effects on radiation exposure, we used two-stage quantile regression to compare DLPs before and after the intervention across the distribution, with particular interest in changes that might occur at the highest DLPs [14-16]. Models were fit using quantreg in R version 2.15.0 (R Foundation for Statistical Computing, Vienna, Austria). The first-stage models were parameterized to allow inference on quantile-specific estimates of preintervention DLP values for each technologist, intervention effects for each intervention facility, and a temporal effect for the control facility. Models for abdominal and chest CT studies adjusted for patient age (15−50 vs ≥50 years) and BMI. The model for chest CT additionally adjusted for an indicator of whether the study was CT angiography. To estimate adjusted quantile-specific preintervention and postintervention doses by facility, we used a second-stage linear regression of technologist-specific estimates on facility effects. Inverses of the variances of estimated DLP values for each technologist from the first-stage model were incorporated as weights in the second-stage model, and a random effect accounted for residual variation among technologists.

To determine if results were sensitive to modeling assumptions, we refit models by adjusting for age in years as a continuous variable, including a quadratic term for BMI, treating BMI as a categorical variable, including height and weight instead of BMI, adjusting for gender, and removing angiographic studies. We also refit models without examinations from a technologist who did not participate in the seminar but received an audit report. Results were similar for all sensitivity analyses.

Table 2. Characteristics of CT examinations and patients

Variable	Intervention Facility 1		Intervention Facility 2		Control Facility	
	Pre	Post	Pre	Post	Pre	Post
Total	589	554	380	390	661	555
CT type						
Abdominal and pelvic	173 (29%)	142 (26%)	123 (32%)	103 (26%)	234 (35%)	162 (29%)
Brain	143 (24%)	145 (26%)	99 (26%)	102 (26%)	189 (29%)	149 (27%)
Chest	145 (25%)	140 (25%)	91 (24%)	101 (26%)	145 (22%)	146 (26%)
Maxillofacial/sinus	128 (22%)	127 (23%)	67 (18%)	84 (22%)	93 (14%)	98 (18%)
Age (y)						
15−29	60 (10%)	60 (11%)	29 (8%)	34 (9%)	53 (8%)	43 (8%)
30−49	110 (19%)	115 (21%)	90 (24%)	97 (25%)	136 (21%)	111 (20%)
50−74	299 (51%)	262 (47%)	199 (52%)	202 (52%)	297 (45%)	278 (50%)
≥75	120 (20%)	117 (21%)	62 (16%)	57 (15%)	175 (26%)	123 (22%)
Sex						
Female	344 (58%)	343 (62%)	233 (61%)	241 (62%)	401 (61%)	327 (59%)
Male	234 (40%)	211 (38%)	147 (39%)	149 (38%)	260 (39%)	228 (41%)
Body mass index						
Underweight	13 (2%)	8 (2%)	5 (1%)	6 (2%)	13 (2%)	12 (2%)
Normal weight	194 (34%)	186 (36%)	88 (24%)	81 (21%)	202 (31%)	157 (29%)
Overweight	197 (35%)	168 (32%)	110 (29%)	139 (36%)	221 (34%)	188 (35%)
Obese	163 (29%)	156 (30%)	170 (46%)	157 (41%)	213 (33%)	179 (33%)
Missing	22	36	7	7	12	19

RESULTS

Demographic characteristics of radiologic technologists are shown in Table 1. Most had 2-year college degrees and worked 40 hours a week. Patient age and sex distributions were similar across facilities (Table 2). Patients at intervention facility 2 were more likely to be obese.

Radiation Exposure From CT Decreased After the Intervention

Abdomen CT. DLPs varied widely, ranging from 116 to 2,613 mGy · cm. Before the intervention, facility 1 had the lowest median DLP (712 mGy · cm) but the highest variability (interquartile range [IQR], 468–996 mGy · cm). After the intervention, the distribution shifted toward lower doses (median DLP, 591 mGy · cm; IQR, 402–934 mGy · cm). Preintervention DLPs were similar at intervention facility 2 (median, 847 mGy · cm; IQR, 665–1,048 mGy · cm) and the control facility (median, 800 mGy · cm; IQR, 675–1,010 mGy · cm). After the intervention, the median DLP stayed the same at facility 2 and increased at the control facility (843 mGy · cm). DLPs became less variable at facility 2, with high DLPs shifted downward after the intervention relative to the control group (IQR, 726–988 mGy · cm intervention vs 679–1,063 mGy · cm control).

From the quantile regression, DLPs for abdominal CT decreased at both intervention facilities, with the control facility unchanged (Fig. 1, Table 3). For intervention facility 1, DLPs decreased significantly or with borderline significance up to the 75th percentile of the DLP distribution. For example, the 70th percentile decreased by 82 mGy · cm (95% confidence interval [CI], 3 to 161 mGy · cm; P = .042). Intervention

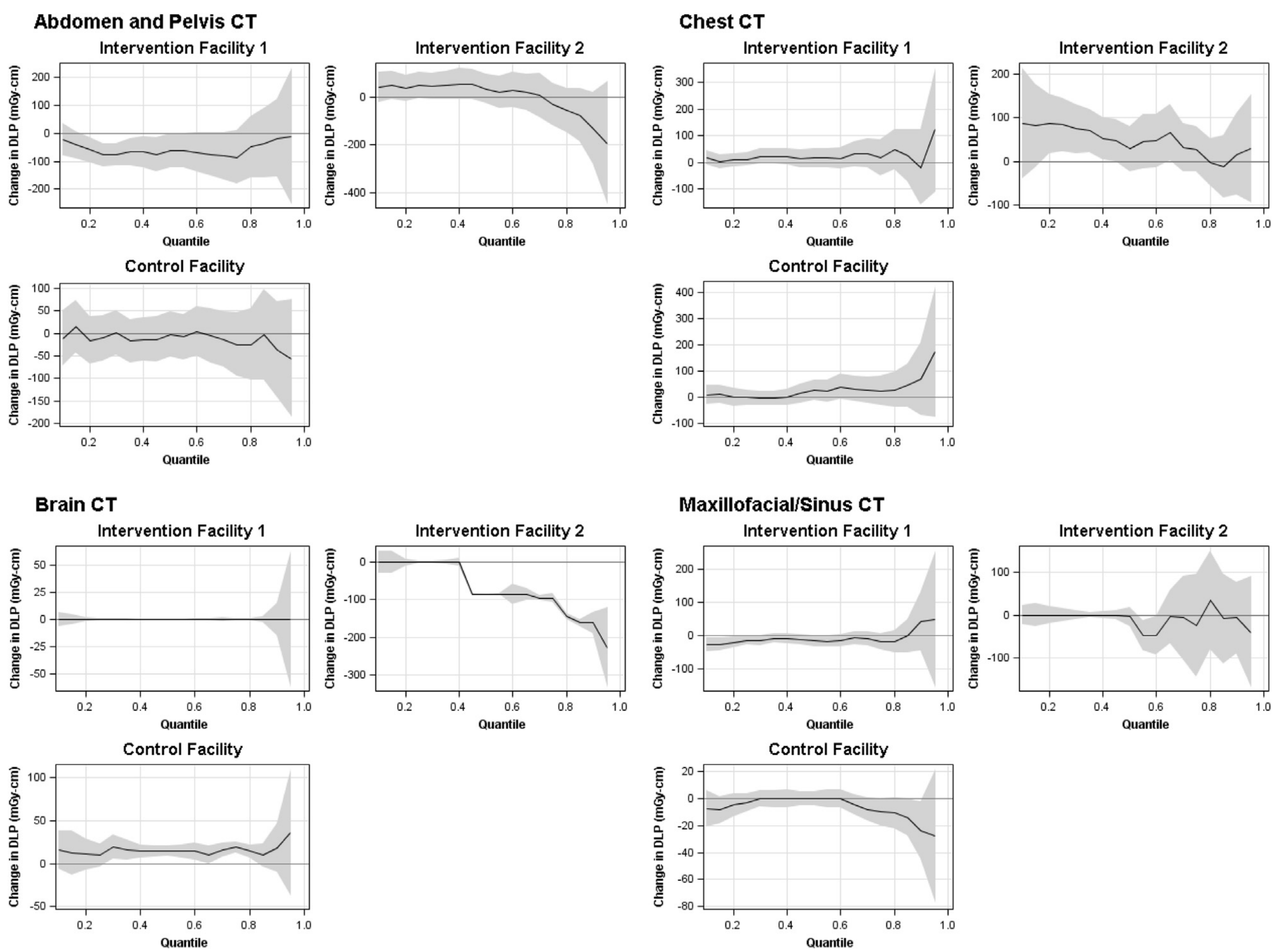

Fig 1. Quantile process plots showing estimated facility-specific intervention effects by anatomic region. Lines indicate estimated changes in dose-length product (DLP) after the intervention compared with before the intervention over the full distribution of DLPs for randomly selected CT scans preformed by technologists at indicated facilities. Values below zero indicate reduced DLP after the intervention. Gray bands show 95% confidence intervals, with more narrow intervals indicating more precise estimates. Bands that exclude zero are significantly different from zero at the .05 level. Estimates for abdominal and pelvic CT and chest CT are adjusted for age and body mass index. Chest CT is additionally adjusted for angiography.

Table 3. Preintervention DLP (mGy · cm) and change from postintervention to preintervention (95% confidence interval)

CT Type	50th Percentile Change		70th Percentile Change		75th Percentile Change		80th Percentile Change		85th Percentile Change		90th Percentile Change	
	Pre	Post vs Pre	Pre	Post vs Pre	Pre	Post vs Pre	Pre	Post vs Pre	Pre	Post vs Pre	Pre	Post vs Pre
Abdomen and pelvis												
Facility 1	677	−61 (−130 to 8)*	793	−82 (−161 to −3)†	817	−86 (−175 to 3)*	838	−50 (−157 to 58)	914	−36 (−170 to 99)	1,009	−17 (−176 to 141)
Facility 2	744	35 (−44 to 114)	890	7 (−99 to 113)	952	−30 (−140 to 81)	992	−56 (−168 to 56)	1,037	−74 (−210 to 61)	1,089	−130 (−308 to 49)
Control	781	−3 (−57 to 52)	871	−14 (−80 to 53)	892	−25 (−101 to 52)	919	−21 (−110 to 68)	956	−3 (−107 to 100)	1,021	−36 (−157 to 86)
Brain												
Facility 1	707	0 (0 to 0)	707	0 (0 to 0)	707	0 (0 to 0)	707	0 (−7 to 7)	707	0 (−26 to 26)	712	0 (−56 to 56)
Facility 2	1,131	−85 (−160 to −10)†	1,220	−95 (−154 to −37)†	1,236	−95 (−159 to −31)†	1,275	−143 (−201 to −86)†	1,294	−162 (−210 to −114)†	1,304	−162 (−221 to −103)†
Control	832	14 (−2 to 31)*	908	18 (5 to 30)†	911	19 (7 to 32)†	920	15 (0 to 29)†	934	10 (−10 to 30)	956	18 (−12 to 48)
Chest												
Facility 1	298	16 (−24 to 56)	392	34 (−24 to 92)	434	16 (−51 to 83)	477	48 (−30 to 127)	542	26 (−73 to 125)	691	−18 (−164 to 128)
Facility 2	487	29 (−32 to 90)	598	32 (−37 to 102)	618	28 (−40 to 96)	679	−2 (−74 to 69)	709	−11 (−93 to 71)	779	17 (−84 to 117)
Control	262	27 (−16 to 71)	381	28 (−29 to 84)	408	25 (−37 to 87)	449	28 (−51 to 107)	482	45 (−64 to 155)	500	71 (−88 to 231)
Maxillofacial/sinus												
Facility 1	567	−14 (−33 to 5)	587	−3 (−27 to 21)	602	−14 (−42 to 13)	606	−16 (−53 to 21)	607	−3 (−61 to 55)	630	37 (−83 to 156)
Facility 2	477	0 (−42 to 42)	532	−2 (−113 to 109)	584	−25 (−163 to 114)	619	28 (−112 to 167)	712	−8 (−128 to 112)	728	−13 (−110 ,85)
Control	278	0 (−4 to 4)	277	−6 (−16 to 3)	280	−9 (−20 to 1)*	285	−11 (−22 to 1)*	295	−15 (−30 to 0)*	313	−24 (−46 to −2)†

Note: Abdominal examinations are adjusted for age and BMI. Chest examinations are adjusted for age, BMI, and angiography. BMI = body mass index; DLP = dose-length product.
*$0.05 \le P < 0.10$
†$P < 0.05$

facility 2 showed a nonsignificant reduction of the highest DLPs. For example, the 90th percentile decreased by 130 mGy · cm (95% CI, −49 to 308 mGy · cm; $P = .15$).

Brain CT. DLPs varied widely, especially between facilities, ranging from 261 to 1,840 mGy · cm. Intervention facility 1 had the lowest DLPs before the intervention with very little variability and no change after the intervention (median, 707 mGy · cm; IQR, 707−707 mGy · cm at both time periods). Before the intervention, facility 2 had the highest and most variable DLPs (median, 1,134 mGy · cm; IQR, 1,106−1,268 mGy · cm), with a dramatic reduction in postintervention variability to the lower end of the preintervention distribution (median, 1,106 mGy · cm; IQR, 1,106−1,006 mGy · cm). At the control facility, the median DLP increased from 880 mGy · cm (IQR, 818−914 mGy · cm) to 900 mGy · cm (IQR, 856−933 mGy · cm).

From the quantile regression, DLPs for brain scans were significantly reduced at intervention facility 2 (Fig. 1, Table 3). For example, the 70th percentile decreased by 95 mGy · cm (95% CI, 37−154 mGy · cm; $P = .004$). DLPs were unchanged at intervention facility 1 and significantly increased at the control facility (eg, the 70th percentile increased by 18 mGy · cm; 95% CI, 5−30 mGy · cm; $P = .006$).

Chest Examinations. DLPs varied widely from 13 to 3038 mGy · cm. There were no significant reductions at any facility (Fig. 1, Table 3).

Maxillofacial/Sinus Examinations. DLPs varied from 75 to 1,941 mGy · cm. From the quantile regression (Fig. 1, Table 3), intervention facility 2 showed a borderline significant reduction in the 60th percentile of 50 mGy · cm (95% CI, −8 to 109 mGy · cm), with no significant changes at the other facilities.

Technologists' Attitudes About and Awareness of Radiation-Related Issues

Technologists' attitudes about and awareness of radiation-related issues changed after the intervention (Table 4). The percentage of technologists who reported that they "always think about radiation dose when imaging a patient" increased from 56% to 100% in the intervention arm, compared with 83% of control technologists. The percentage of technologists who reported that they "always think about radiation dose and its relationship to cancer risk for the patient" increased from 33% to 75% after the intervention, compared with 0% of control technologists. The percentage of technologists in the intervention arm who reported that they "always altered the settings of an exam with the intent to minimize radiation exposure to the patient" increased from 22% to 56% after the intervention. The percentage of technologists who "strongly agreed that CT imaging increases a patient's risk for cancer" increased from 0% to 75% after the intervention.

Table 4. Technologists' attitudes about and awareness of radiation exposure from CT before intervention and 8 to 9 months after the intervention (for postintervention and control)

Question	Intervention Facilities		Control Facility n (%)
	Preintervention n (%)	Postintervention n (%)	
Total	9	8	6
How often do you think about radiation dose when imaging a patient?			
Never/rarely	0 (0%)	0 (0%)	0 (0%)
Sometimes	1 (11%)	0 (0%)	0 (0%)
Often	3 (33%)	0 (0%)	1 (17%)
Always	5 (56%)	8 (100%)	5 (83%)
How often do you think about radiation from CT imaging and its relationship to cancer risk for the patient?			
Never/rarely	1 (11%)	0 (0%)	0 (0%)
Sometimes	4 (44%)	0 (0%)	2 (33%)
Often	1 (11%)	2 (25%)	4 (67%)
Always	3 (33%)	6 (75%)	0 (0%)
How often do you alter the settings of an exam with the intent to minimize radiation exposure to the patient?			
Never/rarely	0 (0%)	0 (0%)	0 (0%)
Sometimes	0 (0%)	0 (0%)	1 (17%)
Often	7 (78%)	4 (50%)	1 (17%)
Always	2 (22%)	4 (50%)	4 (67%)
CT imaging increases a patient's risk for cancer.			
Strongly disagree/disagree	0 (0%)	0 (0%)	0 (0%)
Neutral	2 (22%)	1 (13%)	0 (0%)
Agree	7 (78%)	1 (13%)	6 (100%)
Strongly agree	0 (0%)	6 (75%)	0 (0%)
The amount of radiation from a CT exam is significantly more than from a conventional x-ray.			
Strongly disagree/disagree	0 (0%)	0 (0%)	0 (0%)
Neutral	0 (0%)	0 (0%)	0 (0%)
Agree	1 (11%)	1 (13%)	0 (0%)
Strongly agree	8 (89%)	7 (88%)	6 (100%)
CT imaging poses a risk to patients if done frequently.			
Strongly disagree/disagree	0 (0%)	0 (0%)	0 (0%)
Neutral	0 (0%)	1 (13%)	0 (0%)
Agree	3 (33%)	2 (25%)	4 (67%)
Strongly agree	6 (67%)	5 (63%)	2 (33%)
Radiation reduction efforts are important and worth the time and effort to implement.			
Strongly disagree/disagree	0 (0%)	0 (0%)	0 (0%)
Neutral	0 (0%)	0 (0%)	1 (17%)
Agree	1 (11%)	0 (0%)	1 (17%)
Strongly agree	8 (89%)	8 (100%)	4 (67%)
I am in the position to impact the amount of radiation exposure to patients.			
Strongly disagree/disagree	0 (0%)	0 (0%)	1 (17%)
Neutral	0 (0%)	1 (12%)	1 (17%)
Agree	0 (0%)	0 (0%)	0 (0%)
Strongly agree	9 (100%)	7 (88%)	4 (67%)
The benefit CT examinations provide outweigh the risks associated with them.			
Strongly disagree/disagree	1 (11%)	0 (0%)*	0 (0%)
Neutral	3 (33%)	1 (14%)	2 (33%)
Agree	4 (44%)	5 (71%)	1 (17%)
Strongly agree	1 (11%)	1 (14%)	3 (50%)

(continued)

Table 4. Continued

Question	Intervention Facilities Preintervention n (%)	Intervention Facilities Postintervention n (%)	Control Facility n (%)
Altering the CT exam parameters on the machine at the time of the exam to deviate from standard protocol is an important step that determines radiation dose from a CT exam.			
Strongly disagree/disagree	0 (0%)	0 (0%)	0 (0%)*
Neutral	0 (0%)	0 (0%)	1 (20%)
Agree	0 (0%)	0 (0%)	2 (40%)
Strongly agree	9 (100%)	8 (100%)	2 (40%)
Altering the CT exam parameters on the machine at the time of the exam to deviate from standard protocols, based on patient characteristics, is a way to lower the radiation dose from a CT exam.			
Strongly disagree/disagree	0 (0%)	0 (0%)	0 (0%)
Neutral	0 (0%)	0 (0%)	1 (17%)
Agree	1 (11%)	2 (25%)	0 (0%)
Strongly agree	8 (89%)	6 (75%)	5 (83%)
When compared to other types of imaging procedures how important do you think CT exams are for being able to diagnosis and treat disease?			
Unimportant/little importance	0 (0%)*	0 (0%)*	0 (0%)
Moderately important	1 (13%)	0 (0%)	0 (0%)
Important	2 (25%)	5 (71%)	2 (33%)
Very important	5 (63%)	2 (29%)	4 (67%)

* = No response received.

DISCUSSION

Our pilot study is the first controlled trial to evaluate an intervention among radiologic technologists aimed at lowering radiation exposure from common CT examinations. We found that providing CT technologists with personalized dose audit feedback and education on dose-reduction strategies increased their knowledge about radiation exposure from CT imaging and lowered radiation exposure to patients for the two most commonly performed examinations, abdominal and brain CT. It is not surprising that we found no reduction in doses for maxillofacial examinations, given these are low-dose examinations, with less room for improvement from dose optimization.

A prior study found that a collaborative radiation dose-reduction program reduced patient radiation exposure from a single, specific examination: cardiac CT angiography [17]. These examinations have much higher dose than most CT studies, and the intervention was multifaceted. Although our dose reductions were modest in comparison, approximately 10%, our results are striking because of the simplicity of the intervention, the fact that this impact occurred across a large range of study types (ie, abdominal CT includes dozens or more different examination types), and the fact that the greatest reductions occurred for technologists at facilities that delivered the highest doses at baseline. In addition, we studied commonly performed CT examinations conducted for a wide variety of indications.

A Cochrane Collaboration review of 26 types of audit feedback across 21 studies found a weighted median adjusted percentage change relative to control of 1.3% [18]. For 8 comparisons from 5 studies of patient outcomes, the weighted median percentage change was 17%. We found significant reductions in dose metrics of 7% to 12% for 2 of 4 CT types after a single audit feedback presentation. On the basis of the Cochrane review, we might expect larger improvements from multiple audit report presentations that include targets with an action plan. For future studies, we hope to develop targets based on institutional-level data, which may be more meaningful than UK reference values, along with individualized action plans.

The education we provided encouraged technologists to adjust the scanner settings they use for each patient. Obtaining larger dose reductions may require a medical physicist to develop lower dose protocols [19,20] and engagement with the radiologists who choose the protocols. Interestingly, several technologists noted that they wanted to involve radiologists in future dose-optimization efforts because radiologists develop the protocols. An intervention involving both radiologists and technologists may have an even greater influence on patient radiation exposure.

DLPs vary widely within and among facilities [1-3], meaning that some patients receive unnecessarily high levels of radiation directly linked to increased cancer risk [1,6]. However, excessively low DLPs can result in image noise that leads to repeat examinations, increasing overall radiation exposure. Therefore, a successful intervention to reduce radiation exposure from CT imaging will reduce the high end of the DLP distribution but not necessarily change the mean if variability is also reduced by increasing doses at the low end. The quantile regression approach we used is ideal for measuring intervention success in this setting, as it compares the full dose distribution [21]. Quantile regression does not assume normally distributed data, allowing exploration of intervention effects on the original scale and aiding interpretation. However, precise estimates of effects at the high end of the distribution require a large number of observations. The wide CIs we report, especially for upper quantiles, reflect the relative instability of these estimates. However, our results are strikingly consistent, if not always significant: DLPs decreased at intervention facilities for the most common and highest-dose examinations, while DLPs were unchanged or increased in the control group.

All new CT scanners report radiation dose indices for patient exposure, allowing assessment of performance. Our feedback reports are consistent with a National Quality Forum CT dose measure that endorses collection of dose metrics by anatomic area and age [9]. This is a simple approach for understanding current performance and for assessing the impact of efforts to lower radiation exposure. We found that adjusting for BMI, height, and/or weight had little effect on DLP variability or our results, so this additional data collection might be unnecessary. DLP collection via chart abstraction was time-consuming, but software is now available for automated collection of CT dose indices, making wide-scale, regular provision of this information feasible.

The main limitation of our pilot study was the small number of facilities and technologists. In addition, we provided audit information only once, without US targets. Some technologists performed small numbers of examinations, and two retired during the intervention. Strengths include collecting DLPs for a large number of CT examinations for the 4 most commonly imaged anatomic areas and using quantile regression to examine full DLP distributions. We adjusted for patient age and BMI, which could influence DLP. Importantly, we included a control for changes in DLP due to reasons other than our intervention.

TAKE-HOME POINTS

- Providing radiologic technologists with personalized dose audit reports and education can change their attitudes about and awareness of radiation exposure from CT and lower radiation exposure to patients.
- Future studies should evaluate multiple audit report presentations that include meaningful targets with individualized action plans.
- Obtaining larger radiation dose reductions may require a medical physicist to develop lower dose protocols and engagement with the radiologists who choose the protocols.

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COMPUTED TOMOGRAPHY *Dose Report*©

Preliminary Dose Summary - report format and analysis under development.
Data reflects an estimated distribution of CT radiation dose.
Metrics based on facility submitted data using an adaptation of the NQF Endorsed CT Dose Measure.
Measurements do not reflect individual patient dose.

Requested by: XXXX Medical Center
CT Scan Dates: October 1, 2012 to February 28, 2013
Report Generated: October 21, 2013

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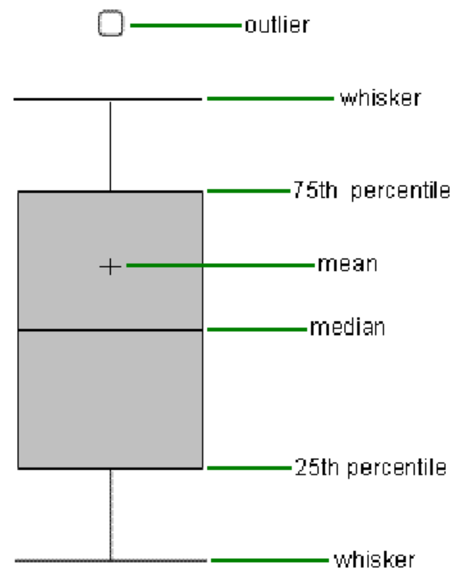
How to Use this Report

The first two pages of this report provide a summarized overview of your facility's doses using the four metrics: Effective Dose (mSv), SSDE (mGy), CTDIvol (mGy), & DLP (mGy-cm). Values highlighted in orange reflect medians from 'Your Site' that are statistically significantly higher than 'All Other Sites'. Medians highlighted in blue are stastically significanly lower in 'Your Site' compared with 'All Other Sites'. For each metric by anatomic region, the percent of 'Your Site' observations over the 75th percentile is also displayed. For an average facility, 25% of the observations would be over the 75% percentile. Sites with high dose distributions would have a higher percentage of observations over this threshold while sites with lower dose distribution would have less than 25% of their scan doses above the 75th percentile.

Box plots included on the report display distributions of dose within anatomic region stratified by machine type. The figure to the right provides a schematic of how to interpret box plots. Note that the bottom of the box represents the 25th percentile value while the top of the box is the 75th percentile. The solid line in the middle is the 50th percentile and the '+' denotes the mean. The interquartile range IQR) is defined as the difference between the 75th percentile and the 25th percentile, essentially the length of the box. Note that the whiskers are clipped for values beyond 1.5 times the IQR.



Dose Summary
October 21, 2013

The first page provides an overview of your CT doses and the following pages provide a more detailed comparison of your institution to those of other facilities.

Adult Imaging - Including All Models

	Effective Dose (mSv)		
	All Other Sites	Your Site	
ANATOMICAL REGION	Median [IQR]*	Median [IQR]*	Pcnt over 75th %ile+
ABDO/PELVIS	12.4 [7.4,19.9]	**17.9 [13.3,23.3]**	*39%*
CHEST	6.4 [3.8,10.3]	**13.3 [10.9,17.8]**	*81%*
HEAD	1.8 [1.3,2.3]	**1.1 [1.0,1.3]**	*5%*

SSDE (mGy)		
All Other Sites	Your Site	
Median [IQR]*	Median [IQR]*	Pcnt over 75th %ile+
13.1 [9.1,17.8]	**17.9 [15.5,20.3]**	*50%*
11.7 [7.4,17.8]	**20.7 [16.9,24.0]**	*71%*

	CTDIvol (mGy)		
	All Other Sites	Your Site	
ANATOMICAL REGION	Median [IQR]*	Median [IQR]*	Pcnt over 75th %ile+
ABDO/PELVIS	10.5 [6.9,15.7]	**14.4 [11.7,17.1]**	*37%*
CHEST	9.7 [5.8,15.3]	**16.3 [12.5,19.7]**	*57%*
HEAD	55.2 [37.3,62.1]	**33.9 [30.8,37.0]**	*1%*

DLP (mGy-cm)		
All Other Sites	Your Site	
Median [IQR]*	Median [IQR]*	Pcnt over 75th %ile+
719 [436,1172]	**1019 [755,1356]**	*36%*
355 [209,549]	**695 [574,903]**	*80%*
894 [623,1193]	**573 [487,670]**	*4%*

* *Cells highlighted in* orange reflect medians from 'Your Site' that are statistically significantly **higher** than 'All Other Sites'.

Cells highlighted in blue reflect medians from 'Your Site' that are statistically significantly **lower** than 'All Other Sites'.

\+ *An average performing facility would have 25% over the reference level.*

Dose Summary - by Anatomic Region and Model

		Effective Dose (mSv)			CTDIvol(mGy)			SSDE(mGy)			DLP (mGy-cm)		
		All Other Sites	Your Site		All Other Sites	Your Site		All Other Sites	Your Site		All Other Sites	Your Site	
ANATOMICAL REGION	Device	Median [IQR]*	Median [IQR]*	% over 75th %ile+	Median [IQR]*	Median [IQR]*	% over 75th %ile+	Median [IQR]*	Median [IQR]*	% over 75th %ile+	Median [IQR]*	Median [IQR]*	% over 75th %ile+
ABDO/PELVIS	Machine #1	15.5 [10.1,21.4]	**19.9 [14.9,25.0]**	*41%*	13.0 [10.2,16.2]	**14.3 [11.9,16.8]**	*31%*	17.1 [14.3,19.7]	**18.4 [16.1,20.4]**	*32%*	945 [632,1346]	**1112 [828,1397]**	*28%*
	Machine #2	12.2 [9.6,15.7]	**20.1 [14.7,25.7]**	*71%*	14.0 [12.6,15.6]	**13.4 [11.4,15.6]**	*25%*	17.9 [15.7,20.0]	**17.0 [15.1,18.6]**	*9%*	688 [559,893]	**1187 [856,1500]**	*73%*
	Machine #3	15.1 [10.4,21.3]	**17.0 [12.9,21.7]**	*27%*	12.9 [10.2,16.4]	**14.5 [11.8,17.2]**	*32%*	15.5 [13.4,18.1]	**17.9 [15.6,20.5]**	*49%*	864 [605,1152]	**968 [726,1263]**	*32%*
CHEST	Machine #2	7.6 [7.1,8.3]	**11.5 [9.9,14.0]**	*93%*	11.7 [11.7,11.7]	**14.7 [10.3,18.0]**	*71%*	14.1 [12.7,15.4]	**19.1 [13.7,22.5]**	*70%*	401 [366,435]	**604 [516,748]**	*91%*
	Machine #3	10.5 [8.7,13.8]	**13.4 [11.0,17.7]**	*46%*	15.3 [12.4,16.5]	**16.6 [12.9,19.6]**	*51%*	18.0 [15.6,20.1]	**20.9 [17.3,23.8]**	*57%*	532 [461,716]	**704 [589,889]**	*48%*
HEAD	Machine #1	2.4 [1.0,2.6]	**0.9 [0.6,1.1]**	*3%*	74.4 [28.9,78.1]	**27.0 [22.2,30.0]**	*1%*	32.1 [31.3,49.5]	**26.3 [21.8,29.0]**	*1%*	1203 [497,1312]	**414 [312,527]**	*3%*
	Machine #2	2.0 [0.8,2.1]	**1.5 [1.0,1.9]**	*20%*	55.9 [22.7,55.9]	**44.6 [32.6,49.7]**	*6%*	53.0 [24.3,55.3]	**43.5 [31.9,46.6]**	*3%*	1013 [381,1091]	**720 [512,947]**	*17%*
	Machine #3	2.3 [2.0,2.5]	**1.1 [1.0,1.3]**	*4%*	62.7 [62.7,62.7]	**34.1 [31.5,36.7]**	*0%*	59.6 [56.6,62.0]	**32.7 [30.5,34.7]**	*0%*	1201 [1076,1301]	**575 [499,656]**	*3%*

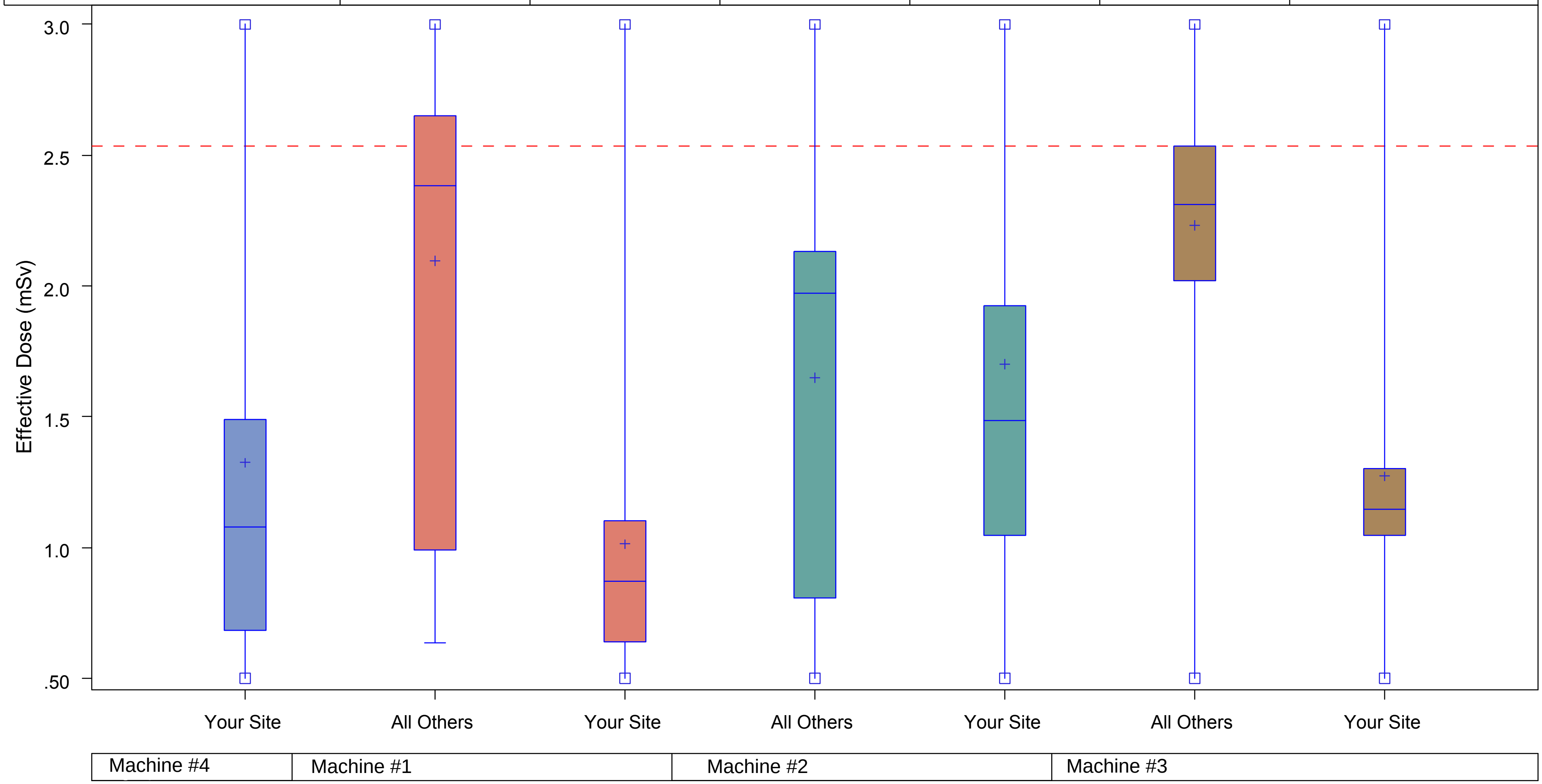
* *Cells highlighted in* orange reflect medians from 'Your Site' that are statistically significantly **higher** than 'All Other Sites'.

Cells highlighted in blue reflect medians from 'Your Site' that are statistically significantly **lower** than 'All Other Sites'.

\+ *An average performing facility would have 25% over the reference level.*

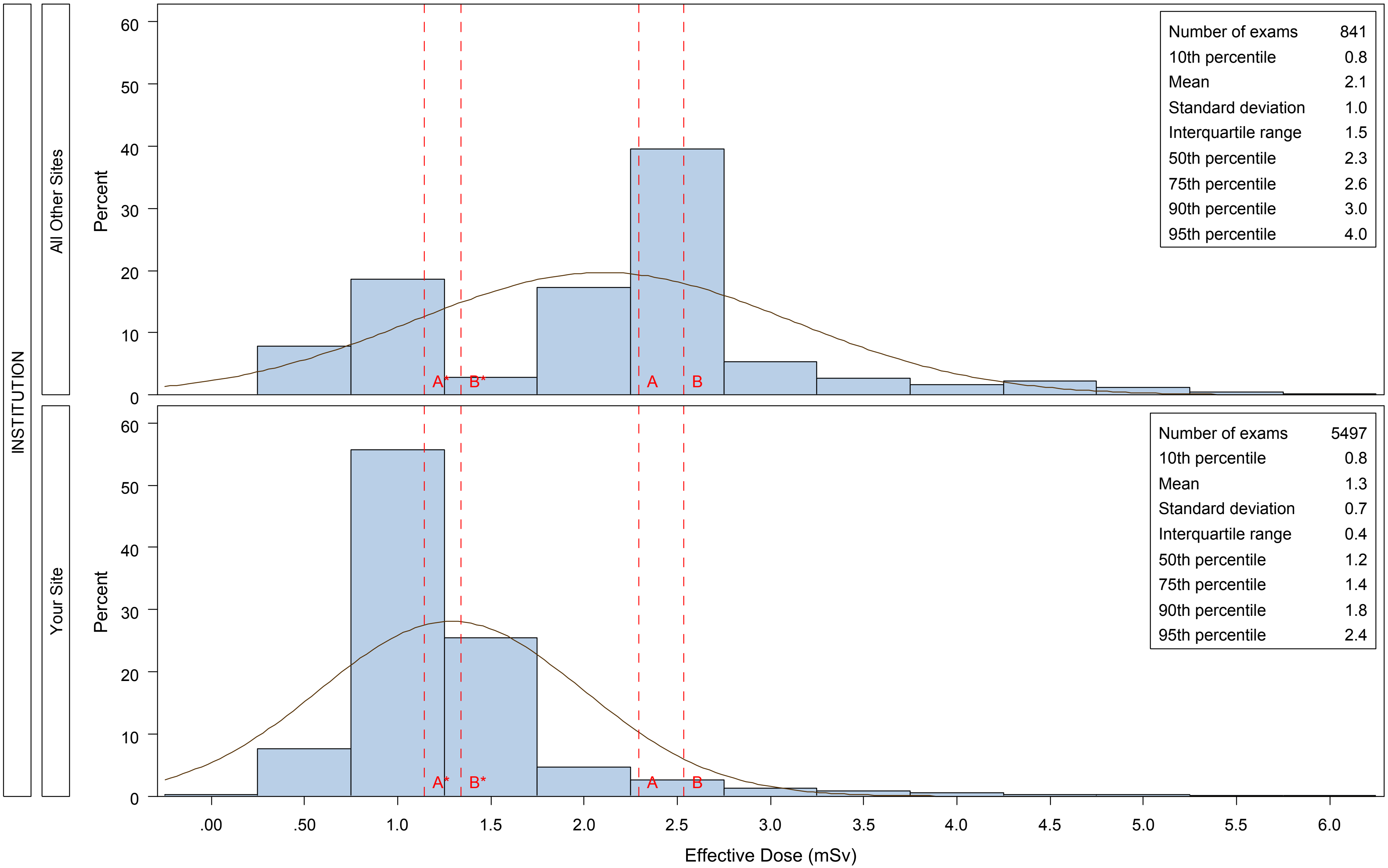
Dose Summary - Head Scans
Mean Effective Dose (mSv) by Device and Institution

HEAD EXAMS BY EQUIPMENT							
25th percentile	0.7	1.0	0.6	0.8	1.0	2.0	1.0
50th percentile	1.1	2.4	0.9	2.0	1.5	2.3	1.1
75th percentile	1.5	2.6	1.1	2.1	1.9	2.5	1.3
Minimum	0.1	0.6	0.1	0.4	0.2	0.5	0.1
Maximum	21.0	5.6	6.0	4.5	8.6	7.4	10.3



Dashed line indicates 75th percentile value for all head exams, irrespective of device.
Outlier values beyond 2 standard deviations have been clipped.

Dose Summary - Head Scans
Mean Effective Dose (mSv) by Institution



A=50th percentile of all other sites B=75th percentile of all other sites
A*=50th percentile of your site B*=75th percentile of your site

University of California, San Francisco National Quality Forum Measure

UCSF CT Exam Doses Compared to all Like Facilities

October 12, 2012

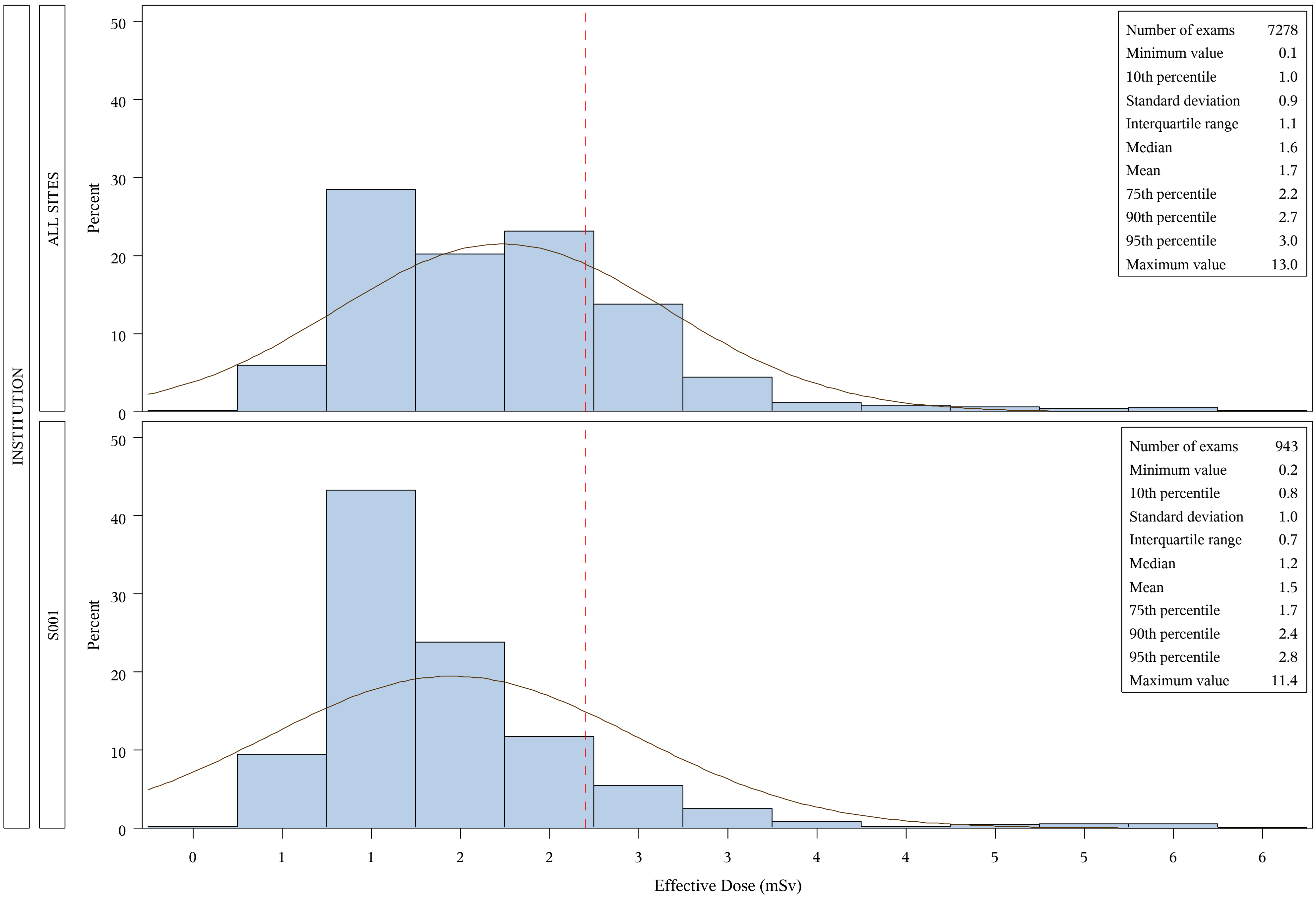
The FREQ Procedure

Frequency Percent Row Pct Col Pct

Table of SITE by anatomic_area				
	anatomic_area(anatomic_area)			
SITE(INSTITUTION)	abdpel	chest	head	Total
ALL SITES	7296 33.65 38.96 85.20	4154 19.16 22.18 84.81	7278 33.57 38.86 88.53	18728 86.38
S001	1267 5.84 42.89 14.80	744 3.43 25.19 15.19	943 4.35 31.92 11.47	2954 13.62
Total	8563 39.49	4898 22.59	8221 37.92	21682 100.00

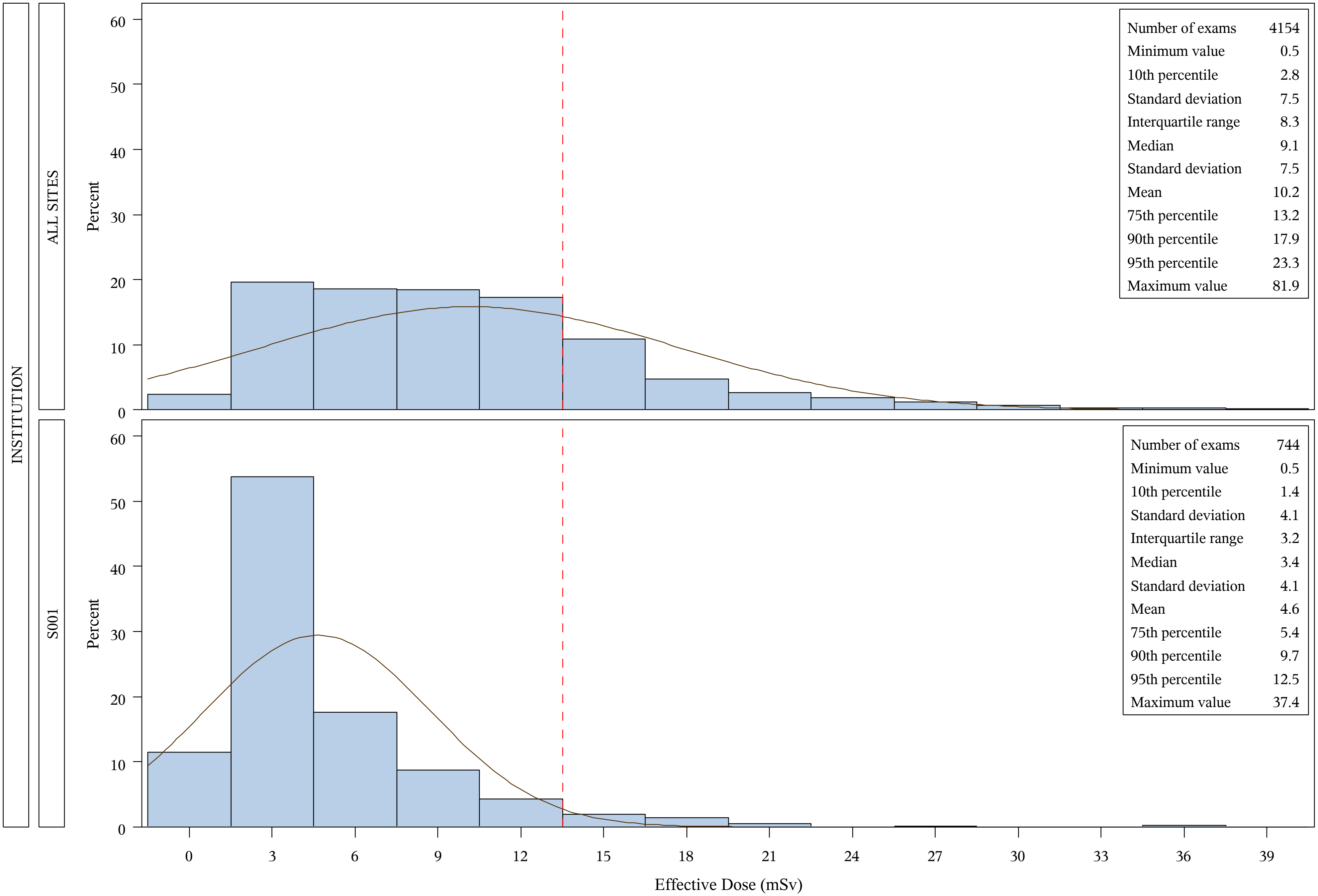
This report analyzes 2 months of CT dose information for the UCSF Medical Center and compares this facility level datawith the data on all sites. The file name: UCSF_NQF_Q3_2012R, was submitted on October 7, 2012

Effective Dose (ICRP103) (MSV) Head Exams



RED DASHED LINE INDICATES 75TH PERCENTILE FOR ALL LIKE FACILITIES

Effective Dose (ICRP103) (mSv) Chest Exams



RED DASHED LINE INDICATES 75TH PERCENTILE FOR ALL LIKE FACILITIES