

Multidetector CT Dose: Clinical Practice Improvement Strategies From a Successful Optimization Program

Anthony B. Wallace, MS^a, Stacy K. Goergen, MBBS^b, Daniel Schick, MS^c,
Tina Soblusky, MS^d, Damien Jolley, PhD^e

Purpose: The aims of this study were to collect data relating to radiation dose delivered by multidetector CT scanning at 10 hospitals and private practices in Queensland, Australia, and to test methods for dose optimization training, including audit feedback and didactic, face-to-face, small-group teaching of optimization techniques.

Methods: Ten hospital-based public and private sector radiology practices, with one CT scanner per site, volunteered for the project. Data were collected for a variety of common adult and pediatric CT scanning protocols, including tube current–time product, pitch, collimation, tube voltage, the use of dose modulation, and scan length. A one-day feedback and optimization training workshop was conducted for participating practices and was attended by the radiologist and medical imaging technologist responsible for the project at each site. Data were deidentified for the workshop presentation. During the feedback workshop, a detailed analysis and discussion of factors contributing to dose for higher dosing practices for each protocol occurred. The postoptimization training data collection phase allowed changes to median and spread of doses to be measured.

Results: During the baseline survey period, data for 1,208 scans were collected, and data from 1,153 scans were collected for the postoptimization dose survey for the 4 adult protocols (noncontrast brain CT, CT pulmonary angiography, CT lumbar spine, and CT urography). A mean decrease in effective dose was achieved with all scan protocols. Average reductions of 46% for brain CT, 28% for CT pulmonary angiography, 29% for CT lumbar spine, and 24% CT urography were calculated. It proved impossible to collect valid pediatric data from most sites, because of the small numbers of children presenting for multidetector CT, and phantom data were acquired during the preoptimization and postoptimization phase. Substantial phantom dose reductions were demonstrated at all sites.

Conclusion: Audit feedback and small-group teaching about optimization enabled clinically meaningful dose reduction for a variety of common adult scans. However, access to medical radiation physicists, assistance with time-consuming data collection, and technical support from a medical imaging technologist were costly and critical to the success of the program.

Key Words: Multidetector CT, optimization, dose audit

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^aMedical Physics Section, Australian Radiation Protection and Nuclear Safety Agency, Yallambie, Australia.

^bRadiology Department, Monash Medical Centre, Clayton, Australia.

^cBiomedical Technology Services, Queensland Health Department, Brisbane, Australia.

^dSkills Development Centre, Queensland Health Department, Brisbane, Australia.

^eSchool of Public Health & Community Medicine, The Alfred Hospital, Prahran, Australia.

Corresponding author and reprints: Anthony B. Wallace, Medical Physics Section, ARPANSA, 619 Lower Plenty Road, Yallambie 3085, Victoria, Australia; e-mail: anthony.wallace@arpansa.gov.au.

INTRODUCTION

The rapid expansion of multidetector CT (MDCT) scanning is well recognized, and with it has come an increase in population cumulative effective dose (ED) [1-6]. Although the use of MDCT generally occurs in a clinical situation in which the net benefit to the individual patient outweighs the small and theoretical increased risk for a radiation-induced malignancy, the growth in MDCT utilization generally does increase the probability of stochastic detrimental effects to the population (eg, expression of cancerous disease) [1,7,8]. Radiobiologic studies [9-13] also indicate the increased risk for stochas-

tic effects in the pediatric and young adult populations, compared with older adults, for the same radiation exposure [1,3,14-17]. Because the expression of stochastic detriment takes many decades to become apparent, we may only be at the threshold of an increasing MDCT-induced cancer rate [16,18-24].

Stochastic risk is best assessed epidemiologically because the application of population stochastic risk coefficients to individuals is inappropriate. Consequently, the application of radiation protection philosophy is, of necessity, conservative because of a lack of individual quantitative dose-response data [25-28], and the "as low as reasonably achievable" principle should be adopted [29].

Optimization is the process of maintaining diagnostic quality while minimizing the ionizing radiation dose required to capture an image [30-32]. Previously published studies [33-38] have focused on the technical parameters that may be modified in establishing an efficient radiation dose for image capture. These studies did not focus on practice-level training of professionals such as radiologists and medical imaging technologists in optimization methods.

The aim of this study was to validate an optimization training model beginning with a multisite survey of MDCT dosimetry to establish baseline practice for a series of common MDCT acquisition protocols. The ultimate purpose of the project was to establish a training resource that was feasible and deliverable in other practice settings nationally within Australia.

METHODS

In September 2008, the Queensland Department of Health invited all of the radiology practices it contracted to provide MDCT scanning services in Queensland to participate in data collection and a feedback workshop relating to the optimization of radiation dose delivered through MDCT scanning. Invitees were advised that this was a quality improvement project and that their data would be confidential and would not be identified to government or other practices. They were also informed that the project was cosponsored by the Queensland Department of Health and the Quality Use of Diagnostic Imaging program of the Royal Australian and New Zealand College of Radiologists, through a grant from the Australian Commonwealth Department of Health and Ageing. The project also gained support from the Australian Radiation Protection and Nuclear Safety Agency and the Australasian College of Physical Scientists and Engineers in Medicine.

When the project commenced, Queensland had a population of approximately 4.3 million. A total of 25 radiology practices (both public and private sector) were approached through an explanatory letter and asked to

become involved in the project. Invited practices were advised that they would be provided with some assistance to collect scan data, which would be entered into a Web-based audit tool for the purpose of dose calculation. They were also advised that the baseline data collection would take approximately 6 to 8 weeks, the feedback workshop was one day in duration, and the postintervention phase a similar time as the initial survey period. They were advised that technical support from an MDCT technologist (T.S.) and an MDCT radiation physicist (D.S.) employed by Queensland Health would be available in the postworkshop optimization phase.

Practices were not paid to participate, nor were they reimbursed for the costs incurred through technologists and radiologists being involved in the data collection, workshop, and optimization. There was no financial or other incentive to participate and no penalties for refusal to participate. Travel and accommodation to feedback workshop were paid.

Initially, 12 medical imaging departments, with one MDCT scanner each, volunteered to participate, but one withdrew before data collection because of staffing availability constraints, and the second withdrew when the required scan data were not collected by the due date. The 10 participating practices were composed of 5 public and 5 private facilities. All participating practices had little or no previous experience in CT optimization programs. Those practices that were approached to participate and declined cited staffing constraints as the major impediment to participation.

Scanner types for the 10 facilities that completed all phases of the project are shown in Table 1. The survey periods were as follows:

- baseline survey: October 13 to December 19, 2008;
- feedback and academic detailing workshop: February 14 and 15, 2009; and

Table 1. Multidetector CT platforms surveyed

Manufacturer	Model
GE*	2× LightSpeed VCT series (medium)
Philips†	3× Brilliance 40/64; 1× MX8000 IDT/Brilliance 16
Siemens‡	1× Sensation 64, 1× Definition AS+
Toshiba§	2× Aquilion-8 to Aquilion-64

*GE Medical Systems (Milwaukee, Wisconsin).

†Philips Medical Systems, Koninklijke Philips Electronics N.V. (Best, The Netherlands).

‡Siemens Medical Systems (Erlangen, Germany).

§Toshiba Medical Systems Corporation (Tochigi-ken, Japan).

- follow-up survey: April 13 to May 15, 2009.

Four adult examination protocols were investigated:

- noncontrast brain CT,
- CT pulmonary angiography (CTPA),
- CT lumbar spine, and
- CT urography (or CT kidneys, ureters, and bladder).

The choice of these examinations was pragmatic in that they were commonly performed at the majority of sites, and thus it was likely that representative numbers of examinations would be achieved during the required survey periods. In addition, the choice was influenced by the desire to avoid differences in dose that were due purely to the use of multiphase studies, such as scanning of suspected liver or kidney lesions. The intent was to focus on examinations that were performed commonly in a reasonably standard way so that the scanning parameters, such as tube voltage, tube current–time product (mAs), and the use of dose modulation, rather than the variable of multiphase scanning use, would be the main determinants of dose variation.

There were no minimum requirements for patient numbers. All patients were aged >18 years. The National Health and Medical Research Council has guidelines for institutional review board approval requirements [39]. This investigation satisfied all National Health and Medical Research Council criteria for a quality improvement project and therefore required no institutional review board approval.

For each examination, the following information was recorded:

- the patient's age, sex, and initials
- scan date and time
- scan length
- girth measurement (to compare patient size from one site to another)
- CT scanner manufacturer and model
- tube voltage (kVp)
- table increment (mm)
- beam collimation (mm)
- mAs
- volume CT dose index ($CTDI_{vol}$) (mGy)
- dose-length product (DLP) ($mGy \cdot cm$)
- dose modulation technique used

Each site entered its own data in an online audit survey form that enabled automatic insertion into an MDCT dose evaluation tool, CT-Expo [8,40]. At the end of the baseline data collection period, two consecutive 1-day small-group face-to-face workshops were conducted over a weekend in Queensland to minimize travel for participating practice staff members. The costs of travel and accommodation were reimbursed by the project grant. Attendees consisted of (1) the radiation physicist and

medical imaging technologist appointees to the project; (2) one radiologist (designated by the practice as being responsible for the on-site medical supervision of the optimization process); (3) one technologist (usually the MDCT chief technologist) from each practice; (4) two additional, nationally recognized medical physicists; (5) secretariat and management staff members from the Quality Use of Diagnostic Imaging program and Queensland Health; and (6) the Quality Use of Diagnostic Imaging project director, who was a radiologist not from a participating practice who practiced radiology in another state of Australia.

The participants from the 10 sites were divided into two groups of 5, and two separate workshops were held on consecutive days. The data fed back to each site were deidentified for the other 9 sites at both workshops, and academic detailing was identical on both days.

Academic detailing was provided by 3 radiation physicists (A.B.W., D.S., and Dr John Heggie), the project medical imaging technologist coordinator (T.S.), and the project radiologist (S.K.G.).

The academic detailing workshop lasted approximately 7 hours each day and provided the following:

- Theoretical information on dose reduction and MDCT dosimetry.
- Multidetector CT technology and optimization strategies.
- Specific platform optimization requirements.
- Tabling of the deidentified total dose data set and confidential feedback to individual participants on their delivered doses for each of the examinations, comparative graphs of first and second survey results per protocol for their practices in units of median DLP, and comparative graphs of first and second survey results per protocol for all practices in terms of minimum, maximum, median, and 75th-percentile DLP. This was presented as Microsoft PowerPoint (Microsoft Corporation, Redmond, Washington) slides and in hard copy for participants to take away after the workshop.
- Implication of survey findings for scanning protocols. A detailed deidentified site-by-site discussion of the 4 scan types (CT lumbar spine, CTPA, CT head, and CT urography) with a comparison of dose across the sites took place. Lowest and highest dosing practices were emphasized, and the scan parameters likely to be responsible for this were identified on PowerPoint presentations to the group.
- A discussion forum to communicate concerns about dose optimization and provide feedback to one another on tips for good practice optimization.

A step-by-step "how to do it" dose optimization sheet was prepared after the workshop and was distributed to

Table 2. Number of scans per practice for surveys 1 and 2

Study	A	B	C	D	E	F	G	H	I	J
Brain	13/45	45/52	15/10	129/92	36/27	20/65	71/58	26/83	79/89	41/85
CTPA	4/2	27/27	0/1	21/30	37/12	16/4	32/17	30/30	49/34	9/1
Lumbar spine	51/28	27/8	6/16	15/9	17/6	53/55	12/26	6/15	11/8	52/54
Urography	16/4	27/18	2/2	45/12	49/17	29/3	25/51	30/22	25/16	10/19

Note: CTPA = CT pulmonary angiography.

each participant practice for future review. Emphasis was given to the need for an outcome of a clinically diagnostic image obtained with an acceptably low radiation dose. To obtain an optimized balance between image quality and dose, it was suggested that region-of-interest analysis be used as an image quality metric while individual, moderate adjustments of tube voltage, mAs, pitch, beam collimation, and scan length could reduce overall scan dose. It was emphasized that any adjustment of scan protocol should be undertaken in close consultation with a radiologist, and each factor modification should be assessed with region-of-interest review to determine image quality impacts. For more details, see [Appendix A](#).

Practices were then given 2 months to apply the workshop dose optimization theory and then resurveyed to test the impact of training on scanning dosimetry for the same protocols.

Statistical Analysis

Standard statistical regression methods were used to estimate the magnitude and direction of any change in ED, within site and protocol, before and after the intervention workshop. By using a logarithmic transformation of measured ED, we were able to estimate the relative change in ED that might be attributable to the intervention workshop. The distribution of ED measures themselves were highly skewed (within protocol groups), while the distribution of $\log(\text{ED})$ satisfied conditions for a normal distribution. For each protocol (CT brain, CTPA, CT lumbar spine, and CT urography) and each site separately, we performed a two-group regression analysis to estimate the difference in mean $\log(\text{ED})$ before and after the intervention workshop. The antilog of this estimated difference in means of $\log(\text{ED})$ provides an estimate of the relative change in ED measures within each site and for each protocol. Ninety-five percent confidence intervals were estimated by a similar back-transformation of the confidence intervals of differences in mean $\log(\text{ED})$.

When the entire confidence interval for a site-protocol combination was less than -25% , we concluded that the intervention had clearly been successful. When the point estimate of relative change was less than -25% , but the associated confidence interval included -25% , we

judged that the site was likely to have been successful. If both the point estimate and the 95% confidence interval were above the target of -25% , we concluded that the intervention was not successful for that site and for that protocol. These pragmatic, a priori definitions of success were based on considerations of the financial and other costs involved in optimization weighed against well-established assumptions about the theoretical reductions to population stochastic risk that might be achieved through proportionate dose reduction.

We used Stata version 10 (StataCorp LP, College Station, Texas) for all statistical calculations.

RESULTS

Over the survey period, a total of 1,208 scans were submitted for survey 1 and 1,153 scans for survey 2 across the 4 common protocols (CT brain, CTPA, CT lumbar spine, and CT urography) surveyed. There was considerable variation in the number of scans taken per protocol per practice during both survey periods (see [Table 2](#)).

A mean decrease in ED was achieved with all scan protocols. Average reductions of 46% for CT brain, 28% for CTPA, 29% for CT lumbar spine, and 24% for CT urography were calculated ([Table 3](#)). Median values of ED minimum, maximum, median, and 75th percentile showed equivalent or lower dose values comparing survey 1 data with postoptimization training survey 2 data ([Figure 1](#)).

Analysis of the range and spread of DLP per protocol across the 10 practices indicated a substantial number of higher dose outliers that were “resistant” to optimization. This may have been due to different operators with vary-

Table 3. Percentage effective dose reduction after optimization training

Study	Percentage Decrease	95% Confidence Interval
Brain	45.9%	43.1%-48.6%
CTPA	27.8%	17.1%-37.1%
Lumbar spine	28.7%	17.4%-38.4%
Urography	23.7%	13.5%-32.7%

Note: CTPA = CT pulmonary angiography.

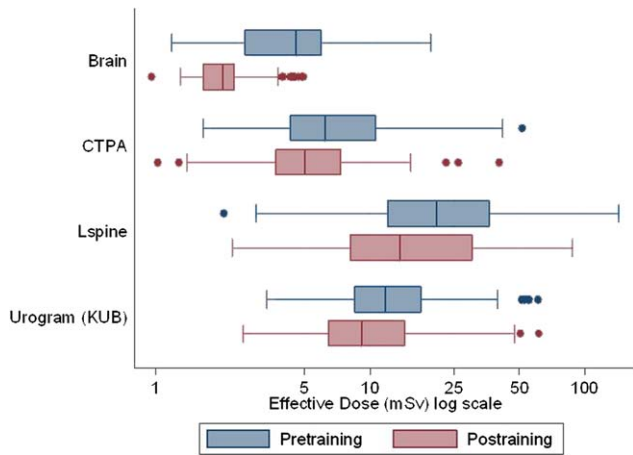


Fig 1. Effective dose spread, before and after optimization training. CTPA = CT pulmonary angiography; KUB = kidneys, ureters, and bladder; Lspine = lumbar spine.

ing levels of experience, individual patient requirements relating to girth, or poor protocol choices. It is noted that for all protocols, there is a noticeable shift of the DLP curve peak toward lower dose values (Figure 2).

Statistical analysis showed an overall measurable reduction in DLP for all protocols, but not all at the specified 25% level. Two practices had a slight increase in CTPA DLP, while one practice had a large increase in CTPA DLP, but this increase was based on a very small number of scan acquisitions (<5) and therefore may not reflect what would have been observed had a larger amount of data been available. Two practices had an

increase in CT lumbar spine DLP, but this also was based on small scan numbers (<10). Most practices had reductions in DLP for all protocols of up to or >25%. Using a 25% reduction in ED with a 95% confidence interval as a measure, for noncontrast CT brain, CTPA, CT lumbar spine, and CT urography, 4, 3, 3, and 2, respectively, of the 10 sites achieved notable reductions in ED. For the same scans, 4, 3, 5, and 7, respectively, of the 10 sites achieved reductions in ED but not at the 95% confidence level [41] (see Figure 3).

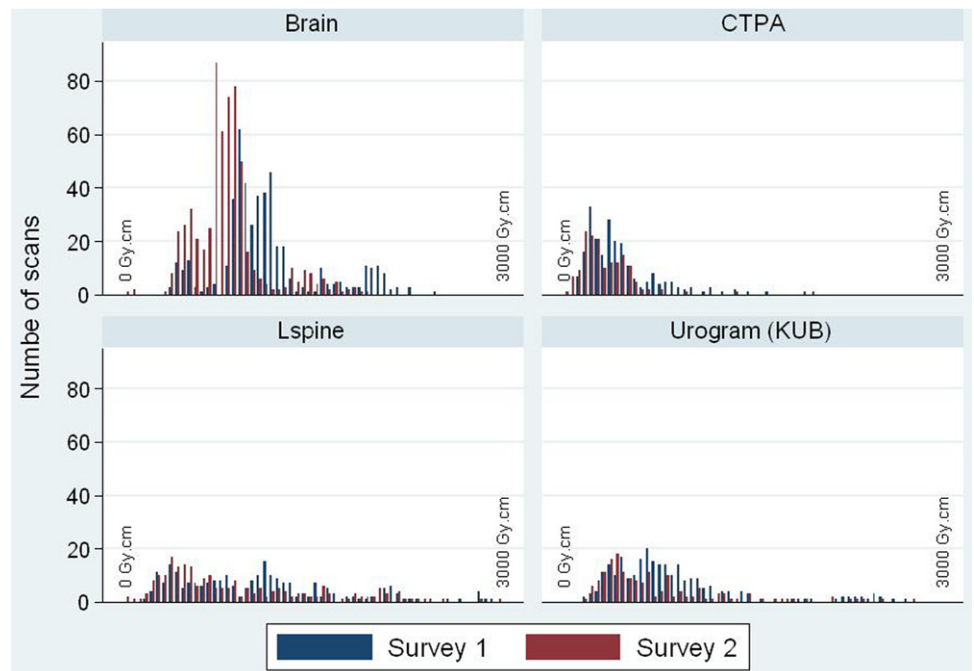
DISCUSSION

Our study showed that audit feedback and academic detailing in a small-group setting could achieve clinically important dose reductions in volunteer practices. As the number of MDCT scans continues to grow in Australia at approximately 9% per year and the estimated per capita dose to the Australian population from MDCT is 1.2 mSv per year, any dose-saving strategy should provide substantial benefit from a public health perspective [42].

Our study also demonstrated that the use of MDCT platform calculated and displayed DLP can be used as a primary metric for dose optimization by the operator. If clinical staff members are more comfortable with ED as a metric, simple conversion factors from DLP to ED are available in the literature [8,43].

Patient dosimetry was positively influenced by the study, and although not all practices and protocols achieved our specified 25% reduction in ED, there was a marked decrease in patient dose over the majority of practices and protocols. It is assumed that optimization is

Fig 2. Dose-length product distributions for surveys 1 and 2. CTPA = CT pulmonary angiography; KUB = kidneys, ureters, and bladder; Lspine = lumbar spine.



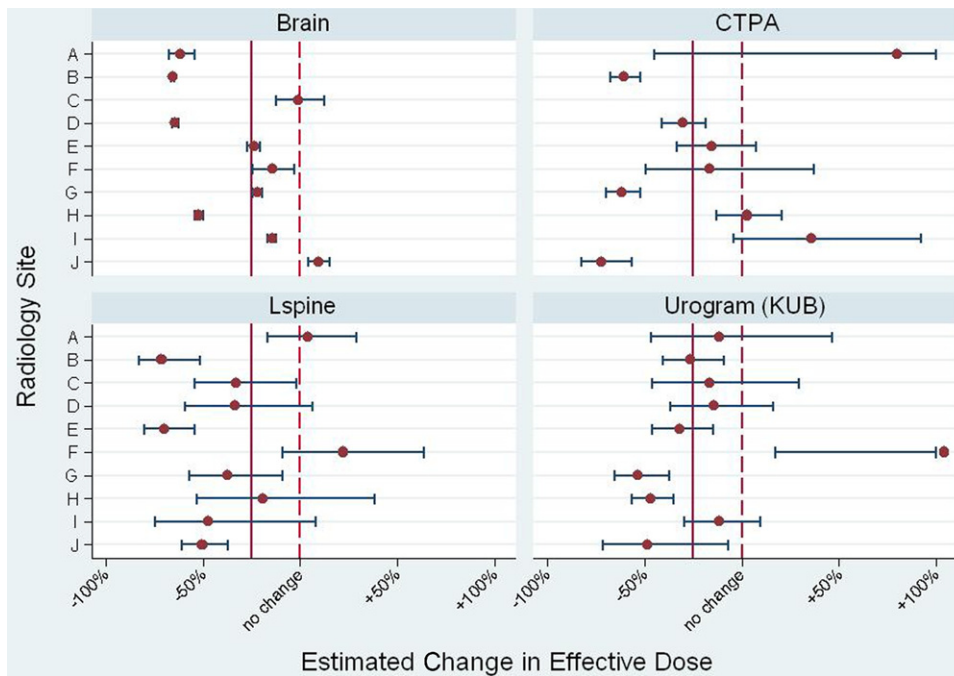


Fig 3. Estimated change in geometric mean effective dose, with 95% confidence intervals, by site and protocol. Broken vertical red lines locate the point of no change; solid vertical red lines indicate the prespecified target minimum change of -25% [41]. CTPA = CT pulmonary angiography; KUB = kidneys, ureters, and bladder; Lspine = lumbar spine.

an ongoing process of iterative improvement, so that the small number of resistant protocols may be improved over further application of the optimization protocols.

However, the process did not occur without some practical difficulties that needed to be overcome. First, a significant problem occurred with the estimate of generic dose from a modulated mAs scan. CT-Expo was not written to take into account dose modulation, which is now the common method of scanner acquisition. The study required documentation of the average mAs for examinations performed with dose modulation; however, this value was not readily available, and it became necessary for a calculated value to be determined, which was dependent on manufacturer-specific platform data (Appendix B).

Second, the audit tool was modified after the entry of preliminary data to eliminate unnecessary work. The first version of the data input screen was closely based on the CT-Expo input worksheet (Figure 4). Most scanners present their protocol data in formats that do not match the CT-Expo input format and required some interpretation of information. This proved to be a strategic risk to data integrity, requiring a review and reworking of the data input screen in an attempt to make it of a more generic nature.

Third, the second version of the audit tool input screen was modified to facilitate data entry by using data available from a MDCT control console (Figure 5). Patient girth, at a protocol-dependent specified anatomic plane, was added to give indicative information on patient size variation, which could be correlated with dose modulation and manual scan dose variations for similar

patient size. The pitch input field was amended to a default value of 1 to account for axial and helical scanning. If a helical protocol was chosen, a background calculation was performed to determine pitch by dividing the table increment per rotation by the isocentric beam width, and the default pitch value of 1 was overwritten. The scanner $CTDI_{vol}$ and DLP were recorded, as all scanner platforms presented these dose metrics and could be compared with CT-Expo lookup table values. The operator was requested to input whether z-axis or rotational dose modulation was used to provide some baseline information on what types of dose modulation were applied.

Review of the variations in scanning protocols over the 2 survey periods revealed that the majority of sites did not change their tube voltage or pitch for acquisition. The median girth of patients and the median length of scan did not vary by >2 cm between survey periods. However, there was a 24% to 28% reduction in the median mAs applied over all sites per protocol. This may have been due to more intelligent use of the dose modulation software accompanied by greater noise tolerance by the radiologists.

Greater positive outcomes may be more likely to be seen in the scenario described in this study, compared to a situation in which the intervention had been imposed as a regulatory or legal requirement because the practices were self-selected and therefore may have had different attitudes with regard to the work involved in optimization, in comparison with other radiology practices. There was also no compulsion to participate, and no remuneration for survey participation was involved, although the

Fig 4. Version 1 of audit tool.

costs of attending the optimization workshop were covered. Peer group pressure at the workshop may have acted as an added enabler to a change in clinical practice. It is questionable whether large-group instruction or on-line delivery of the information would have had the same effect because these were not tested. Thus, the results achieved by this small group of 10 practices in one Australian state may not adequately represent the national radiology practice population, making it difficult to extrapolate these results as representative of potential dose savings in Australian MDCT practice. On the other hand, it is arguable that the volunteer practices that participated in this project were, on average, better performing than those practices that declined to be involved, and greater dose sav-

ings may have been achieved at practices with worse baseline performance than those surveyed here.

We think it was important that practice confidentiality was maintained throughout the project. During the survey periods and workshop, it was important to remove any perception of blame or poor performance while having access to the overall collated data for individual practice performance comparison.

After the workshop, practices were given an optimization reference document for future application (Appendix A). Practices were informed that this was an iterative process that would need to be continued with each upgrade of system hardware or software, staff turnover, and introduction of new protocols.

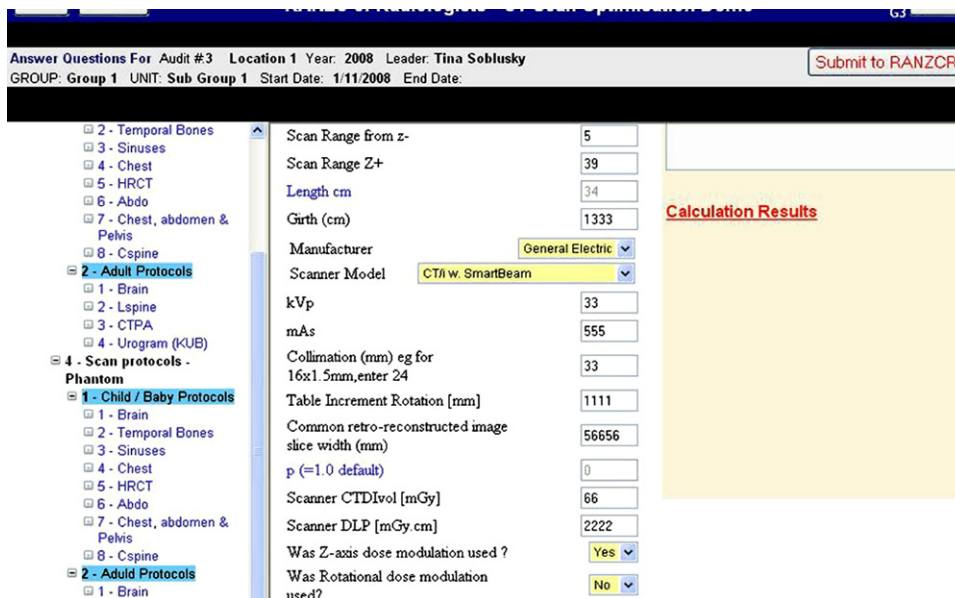


Fig 5. Version 2 of audit tool.

During the workshop, a detailed data presentation per site was given so that practice representatives could see what specific protocol parameters were making substantial contributions to the delivered dose. Deidentified site protocol information was presented so that each site could compare its protocol parameter choice with their colleagues and note and discuss the reasons that may underpin site-to-site variations in practice.

Transcription data errors either at the practice site or in data analysis were a significant problem and required careful checking and review. It is expected that clinical workload may be a significant reason for this problem. The recording of dose metric numbers and parameters that are required for this analysis are not common to the daily working practice of most radiographers and radiologists, which increased error reporting. There were some fundamental misunderstandings of protocol parameters for example, electrical mAs, which is the current used in the tube, compared with effective mAs, which is the current used in the tube divided by the pitch.

The checking of MDCT system DLP per protocol is complicated when dose modulation is used, because the total DLP will be displayed on the system protocol page, but with dose modulation there is a variation of mAs with section attenuation, making the $CTDI_{vol}$ or $CTDI_{weighted}$ value slice position dependent. In comparison, the total DLP is the summation of all $CTDI_{vol}$ times acquired slice thickness over the length of the scan, including any contribution from overranging. Therefore, to check total scan DLP, it is necessary to calculate and sum each individual slice DLP. This dose modulation function is active on most common scans. Programs such as CT-Expo do not have the capacity to calculate a dose-modulated DLP, because the software assumes an unmodulated mAs, making CT-Expo DLP comparisons with dose-modulated system DLP problematic. For dose-modulated scans, the scanner-displayed DLP should be taken as accurate and can be used as an indicative dose measure for comparative purposes with previous scans or against other practices taking similar scans. It would be a significant development if scanner manufacturers could agree on an ED calculation program and embed that in the console display in addition to DLP and $CTDI_{vol}$.

Standardization of scan parameter metrics and display factors was also a complicating factor in performing the survey. While recognizing the need to differentiate design and style for commercialization of product, it was found that accurate comparisons of protocol nomenclature and data across manufacturers' platforms required either a close reading of system documentation or, in many cases, close interrogation of company representatives to define specific parameter definitions.

A concern of participating radiologists in our study was related to dose reduction, resulting in images that

were diagnostically suboptimal, and the risk for a perceptual error due to inadequate image quality. A suggested solution is for any optimization process to be undertaken in close cooperation between radiologists and radiography staff members. Any reduction in dose must be tested against the provision of adequate diagnostic image quality for the radiologist. However, participating radiologists found the concept of measurement of noise within a region of interest placed on a standardized position on the image (eg, within the mid-L3 vertebral body for lumbar spine CT) a useful one. A gradual increase in the noise within this region of interest while monitoring image quality allowed radiologists some control over the iterative process of collaborative optimization with the technologists.

Although recent advances in CT technology, such as ASIR (GE Medical Systems, Milwaukee, Wisconsin), offer dose savings without the need to undertake an optimization process as described above, recent work [44] indicates that optimization is still required to deliver maximum dose savings. This is due to image artifacts that can be introduced by such dose reduction techniques when they are used to their maximal extent. Therefore, it seems that for the foreseeable future, it will remain the responsibility of radiologists, in cooperation with technologists, to optimize dose reduction against acceptable image and diagnostic quality. It has been our experience that the support provided by vendors and application personnel is highly variable, and thus hands-on training of professionals at the practice level is an urgent need.

APPENDIX A

CT Dose Optimization Quality Improvement Activity

MDCT Optimization Advice

Principles

- 1) The successful outcome of optimization is a diagnostic clinical image obtained with an acceptably low radiation dose.
- 2) In terms of dose and image quality, this process IS NOT a drive to the bottom.
- 3) An acceptable outcome may be an increase in dose but this should be the exception rather than the rule.
- 4) Console DLP may be used as a comparative dose metric between systems for adult scans.

Region of Interest Assessment

- 1) Establish a Region of Interest (ROI) Baseline from an initial unoptimised protocol
 - a. Choose an ROI in a suitable, repeatable and anatomically well-defined region with a reproducible

shape and area. The ROI should be approximately 100 pixels.

- i. Record initial mean and standard deviation of the ROI
- ii. ROI standard deviation gives a good indication of image noise

Suggested Optimization Process

- 1) The choice of parameters to change in the optimization process may vary depending on your unoptimized scanning technique. This suggested process is not prescriptive but indicative.
 - 2) Parameters should be varied and impact assessed after each individual change of scanning parameter.
 - 3) Note that the console displayed $CTDI_{vol}$ and DLP may be used as indicators of the success or otherwise of technique factor changes. Where dose modulation is used changes in these parameters would need to be assessed by reference to patients of similar size. It is therefore prudent to make technique factor changes (see below) when an average sized patient presents for the examination type being optimized. This will also ensure that image noise is not biased high or low because of the very large or small patient being scanned.
 - 4) kVp
 - a. If your comparative kVp is higher than other practices, do you need the extra penetration of that beam quality?
 - b. If unsure, reduce the kVp to the next lowest station.
 - c. Assess change by repeating ROI procedure above and verify clinical image and dose acceptability with radiologist.
 - 5) $mAs_{effective}$
 - a. The most likely culprit for higher than necessary patient doses.
 - b. It is important for the radiographer to fully understand how their platform manufacturer displays and records the system mAs. Is it in terms of simple tube current mAs or effective mAs? The latter takes pitch into account.
 - c. Remember that simple comparison of $mAs_{effective}$ across MDCT platforms is inappropriate as the dose per mAs (mGy/mAs) can vary considerably.
 - d. The system may also display a 'protocol' page in which protocol summary information per phase is recorded. Once again, a sound understanding of the manufacturer's definition of these parameters is required.
 - e. To significantly decrease dose, a suggested reduction of 25% in effective mAs is required. This should increase the image noise by marginally more than 10% and, as such, a barely perceptible increase in image noise should occur.
 - f. Achieving this 25% mAs reduction with dose modulated protocols requires some careful consideration of the operating characteristics of your scanner's CT AEC. For example, in the case of Siemens' systems, a reduction of reference effective mAs will cause a predictable reduction in mAs for each patient scanned. GE and Toshiba owners may need to experiment with a water phantom to gauge the extent of mAs change when the noise index or target standard deviation is modified. Typically, it is suggested that the noise index be increased by approximately 10% e.g. from 12 to 13.5.
 - i. Philips owners using Automatic ACS techniques should await further advice from Danny Schick before changing protocol mAs settings.
 - g. Assess change by repeating ROI procedure above and verify clinical image and dose acceptability with radiologist.
- 6) Pitch & Beam Collimation
 - a. As a gross generalisation, for these two parameters, larger numbers are better than smaller but this is highly dependent upon the requirements of the imaging protocol; please consider the specifics of your scanner as presented by John Heggie at the workshop.
 - b. As above, only change one at a time.
 - c. Assess change by repeating ROI procedure above and verify clinical image and dose acceptability with radiologist.
 - 7) Scan length
 - a. This parameter has no impact on $CTDI_w$ or $CTDI_{vol}$ but longer scan lengths proportionally increase the DLP and may significantly increase effective dose.
 - b. Smaller numbers are better as long as an adequate volume is covered.
 - c. Assess change by comparative pre and postoptimized DLP, ROI procedure not required for this, and verify clinical image and dose acceptability with Radiologist.

*Anthony Wallace, John Heggie, Danny Schick.
ACPSEM Accredited - Radiology Physicists.*

APPENDIX B

Tube Current-Time Product Calculation for Dose-Modulated Scans

The study required documentation of the average mAs for examinations performed with dose modulation, but this value was not readily available. The following methods were used to determine average mAs.

- **Siemens:** Provided average mAs, therefore no further calculations were necessary.
- **Philips:** Displays an average $CTDI_{vol}$, slice mAs, and slice $CTDI_{vol}$ values, which allowed a simple calculation to determine the average mAs (equation 1). (1)

$$\begin{aligned} \text{Average mAs} \\ = \frac{\text{Average } CTDI_{vol} \times \text{Slice mAs}}{\text{Slice } CTDI_{vol}} \end{aligned} \quad (1)$$

- **Toshiba:** does not display slice $CTDI_{vol}$, so another equation (equation 2) was required to generate the average mAs value using the total mAs, beam collimation, pitch, and corrected (for overscan) length. (2)

$$\begin{aligned} \text{Average mAs} \\ = \frac{\text{Total mAs}}{\text{Scan length}/(\text{Beam collimation} \times \text{pitch})} \end{aligned} \quad (2)$$

- **GE:** the minimum and maximum values were selected and the average was estimated (equation 3). (3)

$$\begin{aligned} \text{Average mAs} \\ = \frac{\text{Maximum mAs} - \text{Minimum mAs}}{2} \end{aligned} \quad (3)$$

Inaccuracies in the estimation of average mAs led to the proposal of using a calculated average mAs to minimize errors. The procedure to determine a calculated average mAs was as follows:

1. Record each slice mAs for each protocol scanned (phantom) to determine the true average mAs.
2. Perform a quick check of the $CTDI_{vol}$, DLP, and scan length relationship to ensure that the information correlated.
3. $CTDI_{vol}/100 \text{ mAs}_{eff}$ from the scanner data was calculated.
4. This value ($CTDI_{vol}/100 \text{ mAs}_{eff}$) was then compared with the values that would be expected if the scan parameters were entered into CT-Expo for an adult scan and a pediatric scan (the mAs value entered into CT-Expo would be 100 mAs).

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