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FULL PAPER

Evidence of dose saving in routine CT practice using iterative reconstruction derived from a national diagnostic reference level survey

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Objective: To assess the influence and significance of the use of iterative reconstruction (IR) algorithms on patient dose in CT in Australia.

Methods: We examined survey data submitted to the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) National Diagnostic Reference Level Service (NDRLS) during 2013 and 2014. We compared median survey dose metrics with categorization by scan region and use of IR.

Results: The use of IR results in a reduction in volume CT dose index of between 17% and 44% and a reduction in dose-length product of between 14% and 34% depending

on the specific scan region. The reduction was highly significant ($p < 0.001$, Wilcoxon rank-sum test) for all six scan regions included in the NDRLS. Overall, 69% (806/1167) of surveys included in the analysis used IR.

Conclusion: The use of IR in CT is achieving dose savings of 20–30% in routine practice in Australia. IR appears to be widely used by participants in the ARPANSA NDRLS with approximately 70% of surveys submitted employing this technique.

Advances in knowledge: This study examines the impact of the use of IR on patient dose in CT on a national scale.

INTRODUCTION

Imaging techniques have become an indispensable part of modern medicine. It is important to acknowledge that, while largely beneficial, imaging may also involve some risk to the patient, particularly in the case of imaging modalities that employ ionizing radiation. For this reason, international bodies recommend the application of the principles of justification and optimization to the use of ionizing radiation in medicine.^{1,2} The principle of justification requires that the benefits arising from an imaging procedure, that is the appropriate diagnosis and management of the clinical condition of the patient, outweigh the risks involved. The principle of optimization seeks to maximize the benefit to risk ratio by delivering the image quality necessary for the diagnostic or management task at the cost of the least radiation dose to the patient.

Diagnostic reference levels (DRLs) are recommended as an optimization tool. DRLs are intended as advisory investigation levels for specific imaging tasks for standard-sized patients. Experience in the UK over the past two decades has demonstrated how the awareness of patient dose, coupled with advances in technology, can lead to lower imaging dose over time.³

In Australia, DRLs in CT have been promulgated through collaboration between the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA), the Department of Health, the Royal Australian and New Zealand College of Radiologists, the Australasian College of Physical Scientists and Engineers in Medicine and the Australian Institute of Radiography. As part of this project, ARPANSA has hosted a database and internet data portal for the National Diagnostic Reference Level Service (NDRLS).⁴

The NDRLS enables diagnostic radiology facilities to meet their obligations under the Code of Practice for Radiation in the Medical Applications of Ionizing Radiation (RPS 14, section 3.1.8)⁵ to periodically compare patient doses with established DRLs. Imaging facilities enter technique, patient and radiation dose data for routine imaging protocols and receive a report comparing that dose data to the current national DRLs. The NDRLS thus serves also as a repository of data reflecting current practice which can then be used in reviewing and revising the DRLs.

A recent innovation in CT is the introduction of various methods of iterative reconstruction (IR)^{6–9} to augment the previous standard filtered back projection (FBP) when producing the image data from the raw CT acquisition

Table 1. Median data for adult surveys in 2013–14 categorized by protocol, phases and iterative reconstruction (IR); and dose saving with IR by protocol, phases and dose metric with rank-sum test for significance of difference

Protocol	Phases	IR	Surveys	Median CTDI _{vol} (mGy)	Median DLP (mGy × cm)	Median weight (kg)	Median age (years)	Median scan length (cm)	Dose saving (CTDI) (%)	<i>p</i> -value (rank-sum test)	Dose saving (DLP) (%)	<i>p</i> -value (rank-sum test)
Head	1	No	95	53.9	920	75	61	17				
Head	1	Yes	165	44.6	792	75	66	18	17	<0.0001	14	<0.0001
Neck	1	No	47	23.6	513	75	55	19				
Neck	1	Yes	86	15.3	367	75	58	24	35	<0.0001	28	<0.0001
Chest	1	No	52	11.1	371	74	66	36				
Chest	1	Yes	135	7.4	282	74	66	39	34	<0.0001	24	<0.0001
Abdomen–pelvis	1	No	68	12.1	573	76	61	47				
Abdomen–pelvis	1	Yes	158	9.2	454	75	62	49	24	<0.0001	21	<0.0001
Lumbar spine	1	No	59	27.7	725	79	56	25				
Lumbar spine	1	Yes	134	20.7	523	78	59	24	25	<0.0001	28	<0.0001
Chest–abdomen–pelvis	1	No	9	13.4	780	72	67	69				
Chest–abdomen–pelvis	1	Yes	48	7.5	513	74	67	70	44	0.0011	34	0.0008
Chest–abdomen–pelvis	2	No	31	16.6	1047	76	65	73				
Chest–abdomen–pelvis	2	Yes	80	9.6	761	75	66	88	42	<0.0001	27	<0.0001

CTDI_{vol}, volume CT dose index; DLP, dose-length product.

data. There are a number of different data processing algorithms that come under the general heading of IR, and different equipment manufacturers have their own acronyms for their particular technique. IR reduces image noise at a given radiation dose and can therefore be used to reduce the dose required to achieve a given level of image noise.

Motivated by a desire to assess the effect of the use of IR on dose levels in CT in Australia, the NDRLS database was amended in April 2013 to enable clients to indicate whether or not IR was used for each protocol for which dose data was submitted. This article presents an analysis of the data collected following that change to the end of 2014.

METHODS AND MATERIALS

Survey data were obtained from the ARPANSA NDRLS. A survey consists of technique data, including categorical indicators for dose modulation, IR, body region, contrast, and helical or axial acquisition, and patient data: volume CT dose index ($CTDI_{vol}$), dose-length product (DLP), weight, age and sex, for up to 20 patients. Facility reference levels (FRLs) are computed for each survey with data for at least 10 patients. The FRL is the median value of the dose index. The median is used as it is a more robust indicator of the typical value, less sensitive to outlying data. FRLs are computed for both $CTDI_{vol}$ and DLP. Participation in the NDRLS is voluntary and there is no restriction on the number of surveys that can be submitted for a specific protocol and scanner by a given facility. For the purposes of the analyses presented here, each survey was treated as an independent sample, even if it was one of several submitted for the same scanner and protocol.

Survey data were extracted from the ARPANSA NDRLS database and analysed using MATLAB® v. 8.4 (R2014b; MathWorks® Inc., Natick, MA). Hypothesis testing and analysis of variance were performed using functions from the Statistics Toolbox within MATLAB. Confidence intervals for percentile points of distributions were computed using a non-parametric formula.¹⁰

RESULTS

A total of 1230 surveys with an indication of the use or not of IR were completed (minimum 10 patients) for adult protocols during 2013 and 2014. Most were for single-phase protocols. Only chest–abdomen–pelvis studies included a significant number of two-phase protocols. These two-phase chest–abdomen–pelvis protocols typically involve separate chest and abdomen components with some overlap, as opposed to a single scan covering the entire trunk. Multiple-phase studies for other protocols were excluded from the analysis, and chest–abdomen–pelvis studies with three or more phases were also excluded. These exclusions removed 34 surveys from the data set, leaving 1196 surveys. There were also a further 29 surveys that almost exclusively included young adult patients (age 15–20 years) and for which the median age was less than 20 years. These surveys were also excluded, leaving a final data set comprising 1167 surveys. This data set contained surveys submitted for a total of 189 scanners at 146 facilities. We estimate that this represents approximately 15–20% of all CT scanners in Australia.

Table 1 presents a summary of the data, showing the number of surveys by protocol, phases and IR, and the median value of each

metric. Included among the metrics is the scan length, which is the apparent scan length, calculated as the quotient of DLP by $CTDI_{vol}$. The value of each metric for each survey is calculated as the median of the patient data for that survey and it is the median of these survey metrics that is presented in Table 1. Table 1 also shows the dose saving indicated by the difference in median dose metrics for each protocol and the significance of the difference as determined by a Wilcoxon rank-sum test. The use of IR results in a reduction in $CTDI_{vol}$ of between 17% and 44% and a reduction in DLP of between 14% and 34%. The statistical significance of the difference is clear in each case. Overall, 69% (806/1167) of surveys included in the analysis used IR. The proportion was slightly higher for scans of the trunk (chest, abdomen–pelvis, lumbar spine, chest–abdomen–pelvis) at 72% (555/774) than for scans of the head and neck at 64% (251/393).

Figure 1 compares the third quartile of the distribution of DLP with and without IR to the established DRLs⁴ and includes 95% confidence intervals. For most protocols, the 95% confidence interval for the third quartile of the DLP distribution without the use of IR includes the established DRL. The exceptions are the Head protocol, where the entire confidence interval lies above the DRL, and the single-phase chest–abdomen–pelvis protocol, where the entire confidence interval lies below the DRL. By contrast, the confidence intervals for the third quartiles of the DLP distributions with the use of IR are all well below the DRLs.

DISCUSSION

Many studies have compared various IR algorithms with FBP as applied to phantoms or to small groups of patients at a single facility and found that radiation doses can be reduced whilst maintaining image quality. Reported dose reductions have ranged from 25% to 65%.^{11–17} Even greater dose reductions have been reported with the more computationally expensive model-based

Figure 1. Third quartile dose-length product (DLP) for adult surveys in 2013–14 by protocol, phases and iterative reconstruction (IR) with 95% confidence intervals in comparison with the established diagnostic reference levels (DRLs). Abdo, abdomen; CAP (1P), chest–abdomen–pelvis (single phase); CAP (2P), chest–abdomen–pelvis (two phase).

Figure 2. (a) Distribution of implied scan length (dose-length product divided by volume CT dose index) for single phase abdomen–pelvis protocol. Wilcoxon rank-sum test for difference $p < 0.001$. (b) Distribution of adjusted scan length (dose-length product divided by volume CT dose index minus total collimation) for single phase abdomen–pelvis protocol. Wilcoxon rank-sum test for difference $p = 0.08$. IR, with iterative reconstruction; No IR, without iterative reconstruction.

IR algorithms.^{11,18} In routine use however, dose reductions may be more modest. Kordolaimi *et al*¹⁹ show a dose reduction of 35% in $CTDI_{vol}$ for abdominal scans through gradual adjustment of scan parameters over the course of a year, although image metrics were improved and tests with phantoms suggested dose reduction of up to 75% was possible. Noël *et al*²⁰ tracked dose levels at one institution over a period of 3 years. A first-generation IR algorithm was implemented 15 months into the monitored period. They found a significant reduction in radiation dose, with the average effective dose across all scans falling from 10.1 mSv before the introduction of IR to 8.9 mSv afterwards, a reduction of 12%. Doses fell by 15% for thorax–abdomen–pelvis and 30–35% in aortic and pulmonary CT angiography, but there was no significant difference for cranial scans. Dose reductions have tended to be the greatest for patients with low body mass index and lower for more obese patients.^{16,21}

The ARPANSA NDRLS data, showing a reduction in $CTDI_{vol}$ of between 17% and 44% and a reduction in DLP of between 14% and 34%, are consistent with these previously reported trends, although it is important to stress that these are aggregate data across many imaging centres, in contrast to the studies cited, all of which relate to individual centres.

Patient weight is recorded in the NDRL database since it is correlated with patient size and in general larger patients require higher technique factors. It is common international practice to restrict the weight range of patients included in data used to generate DRLs.^{3,22} No restriction on patient weight has been applied for the data shown in Table 1. The median weight is approximately 75 kg, except for Lumbar Spine surveys where it rises to about 78 kg. Differences in median patient weight between categories are small. The principal reason for not

restricting patient weight was to minimize barriers to participation and encourage data submission. In adopting this approach, it was important to obtain an indication of patient weight to ensure that subsequent analyses were not unduly biased and to inform comparison with other data.

In some instances, the apparent scan length (the quotient of DLP by $CTDI_{vol}$) is longer for scans employing IR. This is further reflected in a smaller dose saving as measured by DLP than by $CTDI_{vol}$. A possible explanation for this observation is the hypothesis that, because IR tends to be available only on newer scanners and newer scanners tend to have wider beam collimation, scans using IR are prone to greater overscan. This possibility was tested by computing an adjusted scan length for each survey by subtracting the total collimation (number of slices $N \times$ slice thickness T), allowing for 180° of overscan at each margin. Figure 2 shows the effect of this adjustment for the case of the abdomen–pelvis protocol. The adjusted scan length reduces the observed differences but does not eliminate them entirely.

Table 2. Average of survey median volume CT dose index ($CTDI_{vol}$) in mGy for adult single-phase non-contrast head protocol categorized by use of dose modulation and iterative reconstruction. Number of surveys shown in parentheses

$CTDI_{vol}/mGy$ (number of surveys)	Dose modulation		Percentage change
	No	Yes	
Iterative reconstruction	No	60.3 (35)	55.7 (57)
	Yes	50.2 (39)	46.0 (117)
Percentage change		–17	–17

Table 3. Median data for adult neck single phase surveys in 2013–14 categorized by contrast and iterative reconstruction (IR); and dose saving with IR by contrast and dose metric with rank-sum test for significance of difference

Protocol	Phases	Contrast	IR	Surveys	Median CTDI _{vol} (mGy)	Median DLP (mGy × cm)	Median weight (kg)	Median age (years)	Median scan length (cm)	Dose saving (CTDI) (%)	p-value (rank-sum test)	Dose saving (DLP) (%)	p-value (rank-sum test)
Neck	1	No	No	33	28.6	547	74	54	18				
Neck	1	No	Yes	46	18.0	388	75	58	20	37	0.0002	29	0.0006
Neck	1	Yes	No	13	17.0	513	75	60	29				
Neck	1	Yes	Yes	40	12.6	359	75	58	28	26	0.0016	30	0.0005

CTDI_{vol}, volume CT dose index; DLP, dose-length product.

The use of contrast and dose modulation was also recorded for each survey but the data presented in Table 1 do not distinguish between these categories. In most cases, the surveys were predominantly of a particular category in relation to both contrast and dose modulation and thus a further breakdown by these variables made little difference to the overall result. In the case of Head surveys, however, after removing 12 surveys that used contrast, the remaining 248 non-contrast surveys were quite mixed in the use of dose modulation and IR. Table 2 shows the average of the survey medians (FRLs) for CTDI_{vol} categorized by the use of dose modulation and IR. The dose savings are approximately additive, with a saving of 8% owing to dose modulation and 17% owing to IR. Analysis of variance shows both effects to be statistically significant, with $p = 0.014$ for dose modulation and $p < 0.0001$ for IR.

Neck surveys show a significant difference in implied scan length (Table 1, Wilcoxon rank-sum test for difference $p = 0.001$). After removing the only survey performed without dose modulation, a reanalysis with categorization by both contrast and IR shows better consistency (Table 3). The dose saving with IR is still 30%.

The finding of a significant dose saving with the use of IR, and the marked improvement in dose relative to the DRLs demonstrated in Figure 1 raises questions for the review of the DRLs. There is an argument for promulgating separate DRLs with and without IR for each body region. An alternative would be to continue to provide only a single DRL for each body region but to set the revised value at the level demonstrated by those facilities using IR. Whilst this would set a more difficult benchmark for those facilities using older scanners without the option of using IR, in the Australian context, the reimbursement arrangements encourage the replacement of scanners aged >10 years and thus DRLs obtained with the use of IR will likely be more relevant to the future equipment base. These matters will be topics for discussion with representatives of the relevant professional groups when the current DRLs are reviewed.

CONCLUSIONS

Data submitted to the ARPANSA NDRL Service in 2013 and 2014 indicate that the use of IR is achieving dose savings of 20–30% in routine practice. Nearly 70% of surveys submitted to the ARPANSA NDRL Service in 2013 and 2014 included the use of IR, suggesting that the use of this important dose-saving measure has been widely adopted. We would strongly urge facilities with CT scanners capable of using IR to implement it as part of their dose optimization programme. Facilities that do not as yet have such capability should look to include it in requirements when purchasing new equipment. This analysis demonstrates the value of collecting information relating to scanning parameters and technique in addition to dose metrics when conducting DRL surveys.

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