Computed Tomography / Tomodensitométrie

Radiation Dose from Diagnostic Computed Tomography in Saskatchewan

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Abstract

Objective: To calculate the effective dose from diagnostic computed tomography (CT) scans in Saskatchewan, Canada, and compare with other reported dose levels.
Methods: Data from CT scans were collected from 12 scanners in 7 cities across Saskatchewan. The patient age, scan type, and selected technique parameters including the dose length product and the volume computed tomography dose index were collected for a 2-week period. This information then was used to calculate effective doses patients are exposed to during CT examinations. Data from 2,061 clinically indicated CT examinations were collected, and of them 1,690 were eligible for analysis. Every examination during a 2-week period was recorded without selection.
Results: The average provincial estimated patient dose was as follows: head, 2.7 mSv (638 scans; standard deviation [SD], ±1.6); chest, 11.3 mSv (376 scans; SD, ±8.9); abdomen-pelvis, 15.5 mSv (578 scans; SD, ±10.0); abdomen, 11.7 mSv (80 scans; SD, ±11.48), and pelvis, 8.6 mSv (18 scans; SD, ±6.04). Significant variation in dose between the CT scanners was observed ($P = .049$ for head, $P = .001$ for chest, and $P = .034$ for abdomen-pelvis).
Conclusions: Overall, the estimated dose from diagnostic CT examinations was similar to other previously published Canadian data from British Columbia. This dose varied slightly from some other published standards, including being higher than those found in a review conducted in the United Kingdom in 2003.

Abrégé

Objectif: Calculer la dose efficace de radiation qui se dégage lors des examens de tomodensitométrie en Saskatchewan, au Canada, et la comparer à d'autres doses déclarées.
Méthodes: Des données sur les tomodensitogrammes ont été recueillies à partir de 12 tomodensitomètrie dans 7 villes de la Saskatchewan. L'âge des patients, le type d'examen et les paramètres techniques choisis, y compris le produit dose-longueur et l'indice de dose tomo-densitométrique par volume, ont été compilés pendant deux semaines. Ces renseignements ont servi à calculer les doses efficaces auxquelles sont exposés les patients pendant les examens tomodensitométriques. Des données ont été recueillies sur 2 061 examens de tomodensito-métrie cliniquement indiqués. De ce nombre, 1 690 étaient admissibles à des fins d'analyse. Tous les examens pratiqués au cours d'une période de deux semaines ont été consignés sans aucune sélection.
Résultats: La dose estimative moyenne par patient pour la province était la suivante : tête, 2,7 mSv (638 examens; écart-type [ÉT], ±1,6); thorax, 11,3 mSv (376 examens; ÉT, ±8,9); abdomen-bassin, 15,5 mSv (578 examens; ÉT, ±10,0); abdomen, 11,7 mSv (80 examens; ÉT, ±11,48), et bassin, 8,6 mSv (18 examens; ÉT, ±6,04). On a observé un écart important dans la dose entre les

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différents appareils de tomodensitomètrie (P = 0,049 pour la tête, P = 0,001 pour le thorax, et P = 0,034 pour l'abdomen et le bassin).

Conclusions: Dans l'ensemble, la dose estimative de radiation émanant des examens de tomodensitométrie à visée diagnostique était semblable aux autres données canadiennes publiées antérieurement en Colombie-Britannique. Par contre, elle différait légèrement de certaines autres normes publiées; elle était notamment supérieure à celles relevées par une étude menée au Royaume-Uni en 2003.
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Key Words: Computed tomography; CT; Tomography, spiral computed; Tomography scanners; X-ray computed; Radiation dose; Radiation dosage; Radiation; Physics

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Computed tomography (CT) use and its associated radiation dose have increased over recent years. A 1997 report by Aldrich and Lentle [1] for the Advisory Committee on Radiological Protection of the Atomic Energy Control Board of Canada found that CT accounted for only 3% of radiological procedures performed on patients, although providing 20% of the radiation dose. In Canada, several provinces report that CT scans comprise 11% of diagnostic imaging tests [2,3], with Ontario citing nearly a 300% increase in CT scans during the 10 years leading up to 2005 [3]. A striking increase in CT dose also has been documented in British Columbia, Canada [4]. CT scans account for the largest portion of radiation dose to patients in tertiary care hospitals, providing 60% to 67% of the total patient dose [4,5].

Introduction

It is now estimated that radiation from medical procedures is the largest source of nonnatural radiation exposure to people living in developed countries [4,6].

The BEIR VII report on *Health Risks from Exposure to Low Levels of Ionizing Radiation* [7] recommended the linear no-threshold and the linear quadratic models as the most reasonable description of the relationship between low-dose exposure to ionizing radiation and the incidence of solid cancers and leukaemia, respectively. These models emphasize the impact of radiation doses in the range of diagnostic CT.

CT radiation dose can be compared with the radiation dose received by the survivors of the atomic bombs dropped on Japan in 1945 [8]. A long-term study of approximately 25,000 survivors indicated that there was a significant increase in the overall risk of cancer for those survivors who received radiation doses ranging from 5 to 150 mSv, with the mean radiation dose received by survivors in this subgroup of approximately 40 mSv [8], doses that are within the range of diagnostic CT.

Currently there are 13 CT scanners in Saskatchewan that are used for diagnostic examinations. Twenty-five percent of the scanners were purchased in the 2 years leading up to this study. Approximately 125,000 CT scans are performed annually across the province. Information from 12 scanners in 10 hospitals across 7 cities was entered into this study. Data were collected from a total of 2,061 patient examinations.

The objectives of this study were to calculate the effective dose from diagnostic CT scans in Saskatchewan and compare it with published standards. Before the publication from British Columbia, there was no recent publication of CT dose in Canada [6]. Our study is important because it provides further Canadian data to supplement the information from British Columbia. It has been shown that despite a recent emphasis on CT radiation dose, many radiologists remain uninformed regarding radiation dose levels and their risks [9]. It is hoped that through dissemination of these study findings we will be able to increase awareness further on this important issue.

Methods

Ethics approval was obtained from the University of Saskatchewan Research Ethics Board. All hospitals with CT scanners in the province were invited to participate. Ten of the 11 hospitals with CT scanners in Saskatchewan participated in this study for a total of 12 scanners. One hospital declined to participate, citing low staffing levels over the study period as the primary obstruction. Participating sites were as follows: Regina General Hospital (Regina), Pasqua Hospital (Regina), Victoria Hospital (Prince Albert), Battlefords Hospital (North Battleford), Swift Current Regional Hospital (Swift Current), Yorkton Regional Health Centre (Yorkton), Moose Jaw Union Hospital (Moose Jaw), Saint Paul's Hospital (Saskatoon), Saskatoon City Hospital (Saskatoon), and Royal University Hospital (Saskatoon). Participating Saskatchewan CT scanner types and detector rows are shown in Table 1.

A short questionnaire was given to each site asking 6 questions, including the model and type of the CT scanner, if the scanner was a multidetector-row scanner, and the number of detector rows, if an automatic tube current modulation (ATCM) dose-reduction system was used, if an axial collection of data was used when performing a head CT examination, which area on the body was scanned during an abdominal CT, and the area on the body scanned when performing a chest CT.

The CT technologists on duty at each site were asked to collect data from every patient who underwent a clinically indicated CT scan during a 2-week period in the summer of 2006. Booklets of data collection tables were distributed to the sites and were used to collect information. The data collected included patient age, the indication for the scan, the body part scanned, the tube current (mAs), the x-ray tube

Table 1
Specific CT scanner types and detector rows in use in Saskatchewan that were used in the study

Number of scanners	Scanner model	No. of detector rows
1	GE HiSpeed CTi (GE Healthcare, Milwaukee, WI)	1
1	Siemens Somatom +4	1
2	GE Light Speed Ultra	8
3	Philips Brilliance 10 (Philips, Best, The Netherlands)	10
1	GE Light Speed 16	16
2	Philips Brilliance 16	16
1	Philips Brilliance 40	40
1	GE VCT	64

voltage (kVp), number of phases, pitch, dose length product (DLP), and the volume CT dose index (CTDI$_{vol}$).

Data from each scan then were entered into Microsoft Office Excel 2003 spreadsheets (Microsoft Corp., Redmond, WA). Descriptive statistics was used to summarize the data. The t test or nonparametric Wilcoxon test was used to compare continuous variables. All statistical tests were 2-sided, with levels of 0.05 or less considered significant. The SAS software was used to perform statistical analysis (SAS Institute, Inc., Cary, NC).

Because the Siemens Somatom scanner (Siemens, Erlangen, Germany) does not display DLP values, the DLP was calculated manually using the CTDI$_{vol}$ and the scan length for data from this scanner. The product of the CTDI$_{vol}$ (measured in mGy) and the scan length (cm) yields the DLP (measured in mGy · cm). The DLP is displayed on all of the other scanner types involved in the study.

To calculate the effective doses from patient examinations, the DLP of each examination was multiplied by previously described conversion factors for a 70-kg male [6,10] as follows: head, 0.0023 mSv/mGy · cm; chest, 0.017 mSv/mGy · cm; abdomen, 0.015 mSv/mGy · cm; pelvis, 0.019 mSv/mGy · cm; and abdomen-pelvis, 0.017 mSv/mGy · cm.

Province-wide mean effective doses and standard deviations (SDs) of each examination type were calculated. Site-specific mean effective doses and SDs were calculated for CTs of the head, chest, and combined abdomen-pelvis examinations. Given the limited number of isolated abdomen and pelvis scans, site-specific assessment of these examination types was not performed.

Provincial mean effective doses and SDs also were calculated for both single-phase and multiphase head, chest, and abdominal-pelvic CT scans. The provincial mean effective doses for single-phase versus multiphase examinations at each body site were compared using an unequal variance t test. It should be noted that 42 head, 41 chest, and 53 abdominal-pelvic CT scans were not included in these calculations because the number of phases was not recorded during data collection at one centre (site 12).

The mean effective dose for head, chest, and abdominal-pelvic CT scans on single-detector-row (SDR) and

multidetector-row (MDR) CT scanners also was calculated and compared using an unequal variance t test.

Variation between our survey and previously published data was not directly comparable because not many studies reported SDs. However, we performed an ad hoc analysis based on our data. For example, if any data had a SD for chest of less than 7, then variation would not be different between that data and our survey.

After completion of data analysis, the radiation dose data were disseminated back to the participating sites, which were made aware of their own dose data while being blinded to the identities of the other hospitals.

Details linking both detector-row numbers and site name to radiation dose levels are unable to be included in this article. Because of Saskatchewan's small number of CT scanners, revealing the number of detector rows would essentially be revealing the identity of some sites, which cannot be done because of the promise of anonymity.

Results

From the 12 CT scanners involved in the survey, a total of 2,061 CT scans were collected. From this data 12 CT scans were excluded because of incomplete data; 95 CT scans were excluded because they provided only the total dose for CT scans of more than one body part; and 264 CT scans were excluded from the data analysis because they were from body parts other than the head, chest, abdomen, or pelvis. This resulted in data from a total of 1,690 CT scans being analysed. This included 638 head, 376 chest, 578 abdomen-pelvis, 80 abdomen, and 18 pelvis CT scans. The patient ages ranged from newborn to 100 years, and the average age of the patients was 59.0 years (SD, ±20.6 y).

Eighty-five percent of the scanners were MDR scanners. On these MDR scanners, an ATCM dose-reduction system was used for the majority of the examinations. The most common tube potential used for all studies was 120 kVp. In this study it was noted that kVp was not adjusted according to weight or height.

Concerning CT head examinations, 11 of 12 hospitals routinely performed head examinations by an axial mode of collection, with one site routinely using a helical mode. One site routinely used axial technique, but used the helical technique for combined postcontrast examinations. Another site routinely used axial acquisition except for trauma scans, which were acquired with the helical technique.

The average effective dose for each examination type across the province is summarized in Table 2, where it is compared with estimated CT doses from other studies [6,10–15]. The average provincial dose, number of examinations, and SD for head, chest, and abdominal-pelvic CT scans are presented as part of Table 3.

There was a variation of dose between the surveyed CT scanners. Variation between scanners for each examination can be seen in Figures 1 through 3. Significant variation in doses between the CT scanners for head examinations was observed (Figure 1, $P = .049$). Variations in doses for chest

Table 2
Summary of mean effective doses in Saskatchewan versus other reference studies and guidelines

	Saskatchewan 2006	British Columbia 2006[6]	Taiwan 2007[11]	Tanzania 2006[12]	United Kingdom 2004[13]	Germany 2003[14]	EU 1999[15]	European Guidelines 2000[10]
Head	2.7	2.8 (+4%)	1.6 (−41%)	2.1 (−22%)	1.5 (−44%)	2.8 (+4%)	2.0 (−26%)	2.4 (−11%)
Chest	11.3	9.0 (−20%)	8.4 (−26%)	13.0 (+15%)	5.8 (−49%)	5.7 (−50%)	8.8 (−22%)	11.1 (−2%)
Abdomen and pelvis	15.5	16.5 (−6%)			7.1 (−46%)	14.4 (−7%)		
Abdomen	11.7	10.2 (−13%)	7.4 (−36%)	15.0 (+28%)	5.3 (−55%)		9.0 (−23%)	11.7 (0%)
Pelvis	8.6	9.1 (+6%)	7.6 (−12%)	17.0 (+98%)		7.2 (−16%)	6.6 (−23%)	10.8 (+26%)

Average doses from this study are shown in the Saskatchewan 2006 column. Mean effective doses are presented (in mSv) with percentage difference from Saskatchewan in parentheses. Note that the Saskatchewan data are described as 2006 to represent the data collection period. All other dates provided are dates of final publication. Some values are left blank because doses were not provided for all body parts in the referenced studies.

(Figure 2, $P = .001$) and for abdomen-pelvis (Figure 3, $P = .034$) examinations were similarly significant.

The mean effective dose of CT scans of the head, chest, and abdomen-pelvis varied by factors of 3.5, 6.5, and 3.5, respectively, between sites.

The provincial-wide range of effective doses was 0.03 to 13.3 mSv for CT head examinations, 0.7 to 52.3 mSv for CT chest examinations, and 1.6 to 72.6 mSv for CT abdomen-pelvis scans. This compares with mean effective doses of 2.7 mSv, 11.3 mSv, and 15.5 mSv, respectively. Although these ranges seem wide relative to the mean, much of the high end of these ranges is accounted for by a few outlier scans (Figure 4).

The results of the comparison between provincial-wide single-phase and multiphase examinations are summarized in Table 3. Table 3 shows that single-phase examinations have a lower mean effective dose than multiphase examinations by 8% to 18%, depending on the body part scanned. However, this difference was statistically significant only for CT scans of the head.

Of the 12 CT scanners involved in this survey, 2 were SDR scanners and 10 were MDR scanners. MDR scanners provided a significantly greater dose than SDR scanners for both single-phase and multiphase examinations of all 3 scan types evaluated (Table 4). For chest and abdominal-pelvic CT scans, the mean effective dose from MDR scanners more than doubled the mean effective dose from SDR scanners for both single-phase and multiphase examinations (Table 4).

Discussion

There are many methods to express radiation dose from CT examinations. $CTDI_{vol}$ (measured in mGy) is the radiation dose in a single slice over a standard length [16]. DLP (measured in mGy.cm) is the product of $CTDI_{vol}$ and scan length [16]. Effective dose is the sum of the doses to each organ in the irradiated volume, weighted according to the radiosensitivity of each organ [4,17]. Effective dose is the only measurement that can be used to compare radiation dose between varying examinations [4,17]. We collected DLP because it is displayed on most CT scanners during planning of studies, and DLP is converted easily to effective dose. On the scanner in which DLP is not displayed we converted $CTDI_{vol}$ to DLP. The DLP had to be reported by technologists at the time of the study because DLP is, unfortunately, not recorded routinely on either archived images or in the patient chart at many institutions.

Because of the limited number of isolated abdomen ($n = 80$) and pelvic ($n = 18$) scans in this study, discussion and comparison with other studies focus on head ($n = 638$), chest ($n = 376$), and combined abdominal-pelvic ($n = 578$) CT scans.

Comparing the effective dose from the CT examinations with that from general radiography can be performed to help further illustrate the data. By using a value of 0.2 mSv for an average dose from a general procedure such as a 2-view chest radiograph [4], it can be estimated that average head, chest, and abdomen/pelvis CT examinations in Saskatchewan are equivalent to 14, 57, and 78 general examinations, respectively.

It also is helpful to consider that individual patients commonly receive CT scans of more than one body part during a visit to the Radiology Department. Although most studies on CT radiation dose focus on the average dose for an examination type, few studies have investigated the number of patients receiving multiple scans during a single visit [5]. Limited data published from New Mexico in 2000 indicated that 24% of patients receiving a CT head examination also had other body parts scanned the same day, whereas 35% of

Table 3
Comparison of provincial mean effective doses for single and multiphase examinations

	Overall mean dose for all scans, mSv	Single-phase mean dose, mSv	Multiple-phase mean dose, mSv	Single vs multiphase % difference (P value)
Head	2.7 (638) ± 1.6	2.5 (482) ± 1.4	3.0 (114) ± 2.0	16.0% (.004)
Chest	11.3 (376) ± 8.9	10.8 (281) ± 9.3	13.1 (54) ± 8.0	17.5% (.091)
Abdomen-pelvis	15.5 (576) ± 10.0	15.0 (390) ± 10.1	16.3 (135) ± 10.2	7.9 % (.185)

Comparison of provincial mean effective doses (in mSv) for all CT scans, single-phase CT scans, and multiphase CT scans. The data are presented as mean (sample size) ± SD. Please note that, as indicated in the text, some scans were omitted from single-phase versus multiphase assessment because these data were incomplete from one site.

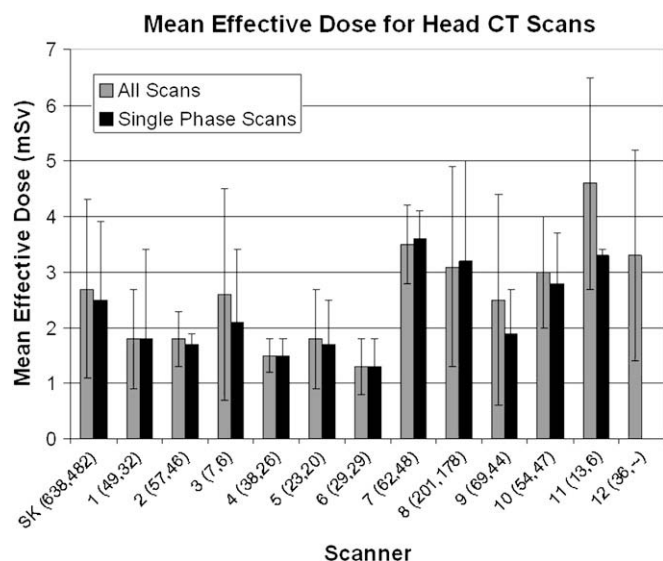## Mean Effective Dose for Head CT Scans

Figure 1. The radiation dose from head CT scans in Saskatchewan. The x-axis indicates the scanners, which are shown by number to retain anonymity. Scanners 1 and 2 are SDR scanners, with scanners 3 through 12 representing the MDR scanners, with no relationship between scanner number and CT scanner design. The numbers in parentheses indicate the number of total scans and the number of single-phase scans, respectively. Single-phase data are not presented for scanner 12 because information regarding the number of phases was not provided by that particular site. Note the difference in the y-axis scale between Figure 1 and Figures 2 and 3.
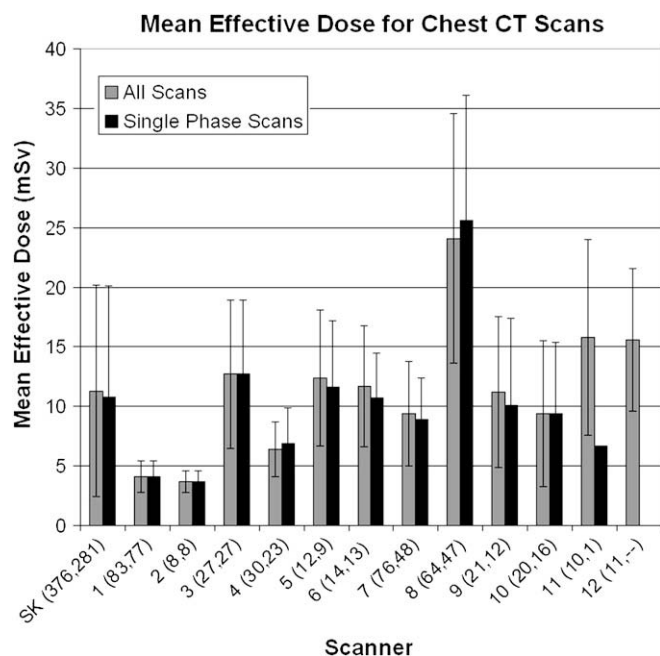
Mean Effective Dose for Chest CT Scans

Figure 2. The radiation dose from chest CT scans in Saskatchewan. The x-axis indicates the scanners, which are shown by number to retain anonymity. Scanners 1 and 2 are SDR scanners, with scanners 3 through 12 representing the MDR scanners, with no relationship between scanner number and CT scanner design. The numbers in parentheses indicate the number of total scans and the number of single-phase scans, respectively. Single-phase data are not presented for scanner 12 because information regarding the number of phases was not provided by that particular site.

patients receiving a chest CT also received a CT of their abdomen-pelvis at the same visit [5]. Our study was not designed specifically to identify patients receiving more than one examination type at a visit because we asked for separate values to be recorded for each examination location. However, it should be noted that data from 95 patients (5% of scans for which data were recorded) were excluded because it was entered inappropriately as a summation of dose for more than one body part. We can only assume that the number of patients receiving scans of more than one body part was significantly higher because we had asked for multiple scans on the same patient to be entered into the data tables as separate scans in our survey.

A common clinical example of a multiscan patient would be the trauma patient receiving a CT scan of the head, chest, abdomen, and pelvis. This theoretical Saskatchewan trauma patient would receive a 29.5-mSv radiation dose, based on a summation of provincial averages for a single-phase CT of each examination type. On the MDR scanners, site-specific doses to this theoretical trauma patient would range from 20.6 to 53.3 mSv. To put these values in perspective, atomic bomb survivors with a mean effective dose of 40 mSv (range, 5−150 mSv) showed a significant increased risk of malignancy [8]. A statistically similar association between radiation dose and cancer death also has been found in a study of 400,000 nuclear industry radiation workers receiving an average dose of approximately 20 mSv (range, 5−150 mSv) [8].

The most relevant study to compare our results with is the Aldrich et al [6] study from British Columbia. This is

because both are Canadian sites with data collected within a 2-year time (2004 in British Columbia and 2006 in Saskatchewan), with similar size (1,070 British Columbia scans vs 1,690 Saskatchewan scans) and similar scanner technology (89% of scanners were MDR in British Columbia vs 83% of scanners that were MDR in Saskatchewan). Compared with the British Columbia data [6], the average provincial dose was very similar for each examination type (Table 2). Specifically, the mean effective dose in Saskatchewan was lower for head and abdomen-pelvis examinations by 0.1 mSv (−4%) and 1.0 mSv (−6%), respectively. The mean Saskatchewan dose from chest CT examinations was higher by 2.3 mSv (+26%). Although the SD is not provided in the British Columbia data, the range of doses for head (1.7−4.9 mSv), chest (3.8−26.0 mSv), and abdomen/pelvis (7.3−31.5 mSv) scans was reported [6]. These ranges are narrower than in our Saskatchewan survey. Combined with the large percentage of SDs for Saskatchewan CT head, chest, and abdominal-pelvic scans of 64%, 71%, and 59%, respectively, it is unlikely that any of these differences would be statistically significant.

Comparison with other referenced studies is detailed in Table 2. As with the British Columbia data, the statistical difference in comparison with these other studies is unknown. The average Saskatchewan effective doses are similar to the European guidelines set by the European Commission in 2000 [10]. All mean effective doses in this study were nearly double those from a survey conducted in

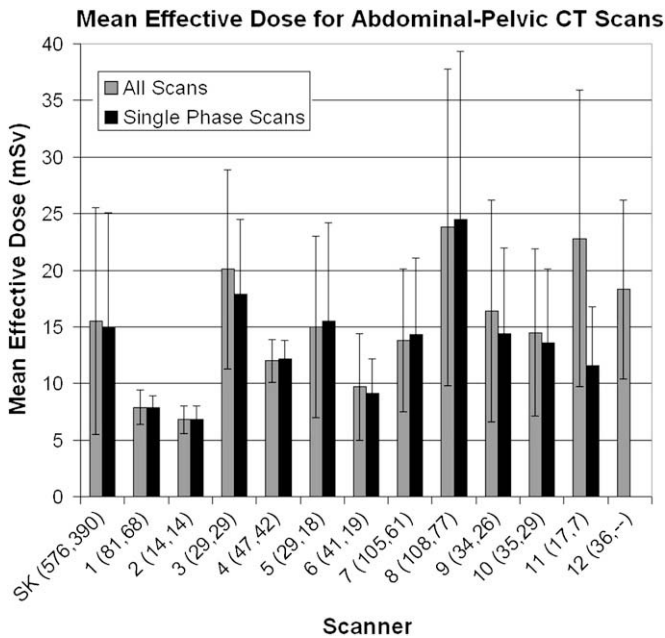## Mean Effective Dose for Abdominal-Pelvic CT Scans

Figure 3. The radiation dose from combined abdominal-pelvic CT scans in Saskatchewan. This chart does not include CT scans performed solely on the abdomen or pelvis. Scanners 1 and 2 are SDR scanners, with scanners 3 through 12 representing the MDR scanners, with no relationship between scanner number and CT scanner design. The x-axis indicates the scanners, which are shown by number to retain anonymity. The numbers in parentheses indicate the number of total scans and the number of single-phase scans, respectively. Single-phase data are not presented for scanner 12 because information regarding the number of phases was not provided by that particular site.

the United Kingdom in 2003 [13]. All doses were higher than those from a European Union study published in 1999 [15]. The Saskatchewan doses for chest, abdomen, and pelvis scans were higher than those from a German survey conducted in 2003 [14]. A possible partial explanation for the differing means is scanner technology. Thirty-seven percent of the scanners included in the United Kingdom study were multislice CT scanners [13], whereas the vast majority of all of the scanners in the German study were 2- or 4-detector-row machines with a single 8-detector-row scanner evaluated [14]. In Saskatchewan, 85% were multislice, with 9 of the 12 scanners having greater than 8 detector rows. Our comparison between SDR scanners and MDR scanners illustrate that MDR scanners do indeed produce a higher radiation dose. Comparing the dose from the Saskatchewan SDR scanners with the United Kingdom data reveals little difference in the mean doses for CT scans of the head (1.7–2.0 mSv in Saskatchewan vs 1.5 mSv in the United Kingdom), chest (4.0–4.7 mSv in Saskatchewan vs 5.8 mSv in the United Kingdom), and abdomen-pelvis (7.7–7.8 mSv in SV vs 7.1 mSv in the United Kingdom) [13].

Direct comparison of variation/range between our studies and other studies was not possible because few studies reported the data variations, and each study used different measurements, types, and machines. Based on the reported ranges and SDs in other studies, the variation of our study did not seem greater than any other studies.

All of the mean effective doses for each examination were found to be higher in Saskatchewan than in a recent study performed in Taiwan [11]. Direct comparison with the Taiwan study is difficult because of some methodologic differences. The Taiwan values were based on questionnaire information of standard practice, CTDI values from measurements, and calculations based on standardized data sets [11]. In addition, the Taiwan effective dose provided for chest, abdomen, and pelvic examinations were for a single-phase examination with higher effective dose values of 13.0 and 11.0 mSv reported for 2 different types of multiphase abdominal examinations [11]. This is opposed to our Saskatchewan study, which was a survey of actual practice, including a mixture of single and multiple-phase examinations. Compared with Tanzania in 2006 [12], the Saskatchewan mean effective doses for abdomen, chest, and pelvis CT scans were lower, with higher doses for CT head examinations.

As shown in Figures 1 through 3, the effective dose of each examination varied between scanners ($P < .049$). This was because of both varying routine protocols that each site used and different scanner types. There also was a wide variation of doses across the entire province, as illustrated by the dose histograms in Figure 4. This variation is because of both user-selected protocols and scanner design. Variation in patient dose for a specific body part within and between institutions is not necessarily a bad thing in a study of this type. A positive spin on variation is that it may indicate that scans are being tailored to patient body types and clinical indication. A good example of this is modifying parameters for pediatric patients. The use of ATCM systems also will provide variation in dose because tube current is tailored to patient geometry. However, a negative aspect of this variation, particularly variation between institutions, may reveal that dose optimization is not being used for some examinations because of either user-selected parameters or scanner design. The importance of user-selected scan parameters on CT dose was highlighted in a study on variation in dose from routine institutional scan parameters at 7 sites all using the same MDR scanner without ATCM [18]. The study revealed variation by 1.7-fold for routine chest scans and 1.4-fold for head and abdominal-pelvic scans between the 7 sites [18].

There is a linear relationship between tube current and radiation dose [19]. ATCM systems help optimize dose by using the lowest possible tube current to obtain images of a selected diagnostic quality. One major difference from the British Columbia study is that ATCM was used routinely on all of the multidetector scanners (83% of the scanners) in this study, as opposed to only 3 of the 18 departments in the British Columbia study [6]. Evaluation of the effectiveness of ATCM systems is difficult because performance varies significantly with radiologist and technologist technique choice. Allowing for this, a previous study showed dose-reduction ranges for ATCM systems as follows: chest, 14% to 20%; abdomen, 18% to 38%; and abdomen-pelvis, 26% to 32% [20]. Given the potential for dose reduction through use of ATCM systems, it is interesting how similar the
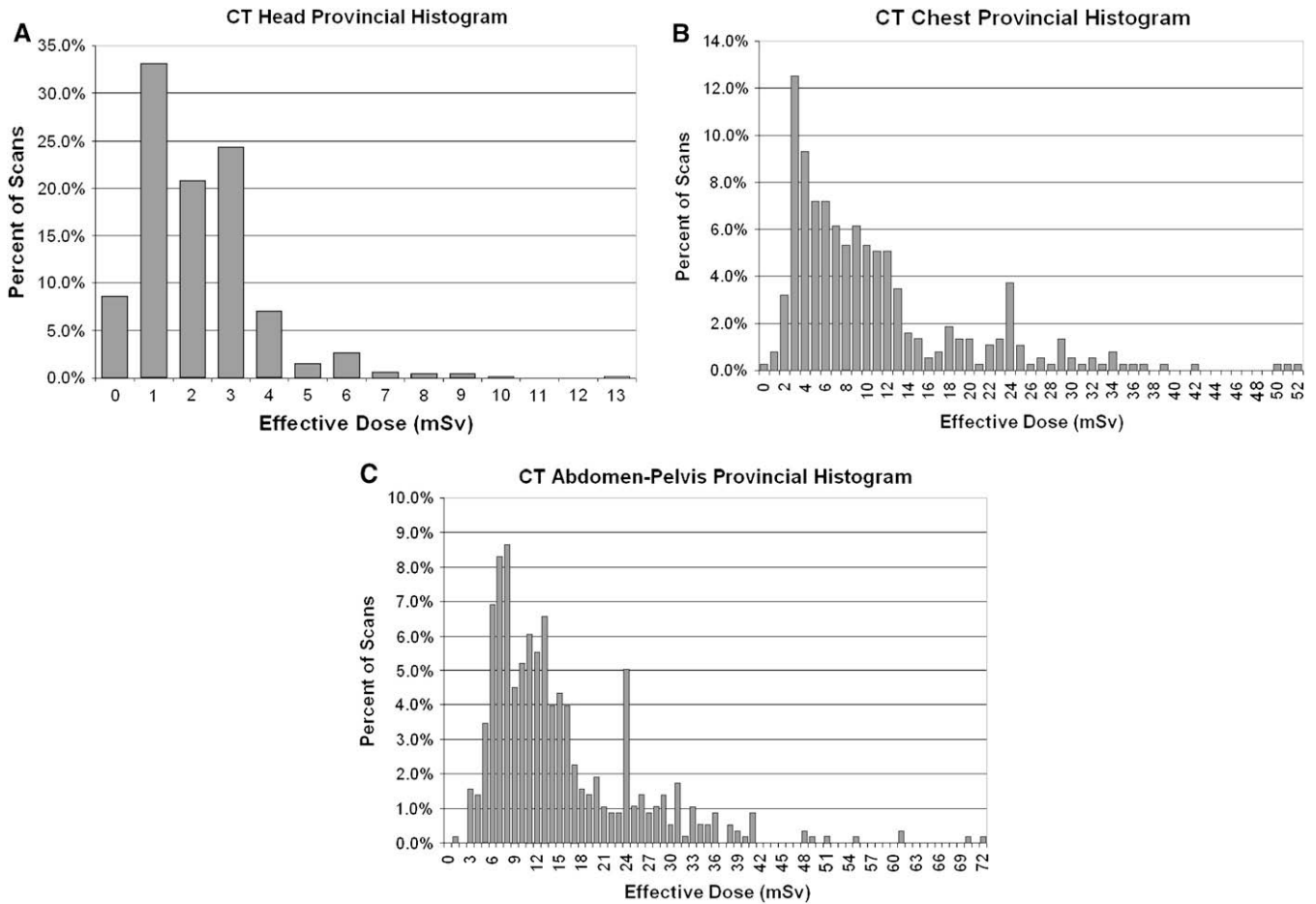
Figure 4. Provincial-wide effective dose histogram for CT scans of the (A) head, (B) chest, and (C) abdomen-pelvis. Note that although the range for head, chest, and abdomen pelvis scans is large, much of this apparent range is made up by outliers. Specifically, this can be seen by the 8 head scans greater than 7.5 mSv (3 SDs above the mean), 5 chest scans greater than 38 mSv (3 SDs greater than the mean), and 9 abdomen-pelvis scans greater than 45.5 mSv (3 SDs greater than the mean).

Saskatchewan and British Columbia doses for chest and abdomen-pelvis CT examinations are.

The exact relationship between CT detector-row number and CT dose is complicated because multiple factors are in play. One of the main advantages of higher detector row scanners is that they have made it possible to obtain near-isotropic data on most CT examinations when using only the smallest detector elements [21]. Although the value of routine isotropic acquisitions has been described as progress, it usually is accompanied by a penalty of higher radiation

dose [21]. However, a radiation penalty is experienced on all multidetector row systems if using an ATCM system with the image quality/noise index based on the thin, isotropic images instead of the routine axial images [21].

Presenting the SDR and MDR dose data separately was not performed, to reiterate the well-known finding that MDR systems are associated with higher CT dose levels. These data were presented to facilitate comparison with previous studies, some of which mainly involved SDR scanners. It also may be more appropriate to report the provincial

Table 4
Comparison of the mean effective dose between SDR and MDR scanners

	Single-phase mean dose			Multiphase Mean Doses		
	SDR dose, mSv	MDR dose, mSv	SDR vs MDR scanners, % difference (P value)	SDR dose, mSv	MDR dose, mSv	SDR vs MDR scanners, % difference (P value)
Head	1.7 (78) ± 0.7	2.7 (406) ± 1.5	37% (<.001)	2.0 (26) ± 0.8	3.3 (88) ± 2.1	39% (.004)
Chest	4.0 (86) ± 1.3	13.7 (200) ± 9.7	71% (<.001)	4.7 (6) ± 0.9	14.2 (48) ± 7.8	67% (.005)
Abdomen-pelvis	7.7 (81) ± 1.1	16.8 (319) ± 10.6	54 % (<.001)	7.8 (13) ± 3.2	17.2 (122) ± 10.3	55% (.001)

This table illustrates the difference in mean effective dose when comparing SDR with MDR scanners. The data are presented as mean dose (sample size) ± SD. Please note that, as indicated in the text, some scans were omitted from these assessments because single-phase versus multiphase data were incomplete from one site. Mean doses were significantly higher on MDR scanners for all scan types examined.

average dose in terms of MDR scanners because both SDR scanners in the province are scheduled for replacement, likely before the end of 2009.

Our study had several limitations. As in the British Columbia study [6], the conversion coefficients used to calculate the effective dose from DLP are based on a 70-kg male, even though ages ranged from newborn to 100 years. Although we did not collect data regarding sex, it safely can be assumed that approximately half of the patients likely were female.

Our published results also were somewhat limited because we were unable to link radiation dose with specifics of scanner type, including the number of detector rows. This was performed to maintain anonymity of the participating sites. The promise of anonymity was a key in recruiting sites to participate in the study.

Because of the geographically diverse nature of our survey, we limited the factors that we assessed to maintain simplicity and to help with study compliance. Unfortunately, this means that important factors such as detector configuration, slice collimation, pitch, and noise tolerance for ATCM use were not assessed.

A survey such as this can only establish the current state of practice, and not necessarily the best practice [6]. CT is a struggle between image quality and radiation dose. The exact nature of this struggle varies with clinical indication, patient body type, scanner type, referring clinician expectations, and radiologist preference. Although standardizing CT protocols to optimize the balance between image quality and radiation dose is beyond the scope of our study, we do encourage radiologists and technologists working in CT to consider radiation dose when planning examinations and establishing scan protocols.

Conclusions

The radiation dose from diagnostic CT in Saskatchewan is comparable with results from other published studies, including those from British Columbia. Variation in dose between and within specific sites suggests room for improvement with technique modification to balance image quality and radiation dose.

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