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Periodic Review of Computed Tomography Protocols: Utility and Relevance Revisited through an Optimization Example

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Abstract

Rationale: *Population exposure to ionizing radiation from medical imaging has been an important concern for decades. With the number of computed tomography (CT) scans performed in Quebec growing by 204 % in the very last decade, it is essential to ensure that CT protocols are optimized.*

Main Objective: *The final goal of this study, beyond the scope of this article, is to establish provincial diagnostic reference levels (DRLs) for Quebec with the purposes of: 1) optimizing imaging protocols so as to minimize patient exposure to ionizing radiation while maintaining sufficient image quality for diagnosis and thus 2) reduce the population's exposure to ionizing radiation. This investigation is called Q-DRL-P, meaning "Quebec-DRL-Project".*

Specific Objective: *These preliminary data, reported here, aim to highlight the utility and relevance of periodic review of CT protocols; this is a basic feature included in Q-DRL-P.*

Materials and Methods: *This study began in early 2022. We evaluated patient exposure to ionizing radiation from two highly technologically categorized CT scanners (CTSc-1 and CTSc-2), located in the same facility (Facility-X), for CT examinations of the chest. In total, from 2017 to 2024, 2,480 women and 3,808 men (total of 6,288 patients) were examined with CTSc-1 (5,074 examinations) and CTSc-2 (1,214 examinations), for a total of 6,288 CT exams.*

We analyzed separately and respectively the CTSc-1 exposure data of women (70 ± 13 years) and men (69 ± 12 years), as well as the CTSc-2 exposure data of women (70 ± 12 years) and men (69 ± 12 years), from the year 2020 until the beginning of 2022. This first analysis showed that CTSc-2 overexposed men patients by an average of 134%, compared to CTSc-1 (DLP of 273 mGy.cm vs 117 mGy.cm). Equivalently, women patients were also found to be overexposed to the extent of 104% (DLP of 188 mGy.cm vs 92 mGy.cm). This led Facility-X to contrast the "Chest protocol" of the CTSc-1 scanner with that of the CTSc-2.

Results: *Overexposure to CTSc-2 was found to be due to over-optimization of "Reference Quality Imaging," which is the strategy used to achieve automatic exposure control (AEC) in modern CT scanners. This has been* *adjusted accordingly and appropriately. We then compared the pre-adjustment data with 24-month post-adjustment data. For women and men, respectively, no statistically significant difference was observed for somatic data (age, weight and height) between the pre- and post-adjustment periods. In contrast, CTSc- 2 shows an exposure reduction of 46% for men and 33% for women. Furthermore, no significant qualitative and quantitative differences were observed in terms of image quality for CTSc-2 before and after adjustment in the CT Chest protocol.*

Discussion and Conclusion: *Current technologies have significantly improved the performance of CT scanners. On the other hand, as in Quebec, the number of CT examinations is experiencing impressive growth throughout the world. Our results showed and confirmed that patient exposure to radiation can be reduced while maintaining good image quality that is suitable for the intended diagnostic purposes; this is consistent with the ALADA principle which states "As low as the diagnostically acceptable". These results also support the current global movement to optimize patient exposure to radiation in medical imaging.*

Keywords: Radiation Protection, Radiation Exposure, Ionizing Radiation, Medical Imaging, Computed Tomography (CT), CT Protocol Optimization, Chest CT Protocol, Preventive Methods in Medical Imaging, Quebec-DRL-Project (Q-DRL-P).

Introduction

From 2013 to 2022, computed tomography (CT) scan examinations increased by an amount of 204% in Quebec [1]. In the last three decades, similar statistics can be observed worldwide, e.g. in Canada and USA [2, 3]. Because CT is known to be a significant source of patient radiation exposure in medical applications, some studies investigated the lifetime risk of radiation-induced cancer from CT scan examinations [4-7]. In this regard, optimizing patient exposure by reviewing CT protocols becomes an essential component of quality assurance in ionizing radiation-based medical imaging for Quebec.

The final goal of this study is to establish provincial diagnostic reference levels (DRLs) for Quebec as a mechanism for optimizing imaging protocols in order to minimize patient exposure to ionizing radiation and at the same time reduce that of the population. This investigation is called Q-DRL-P, meaning "Quebec-DRL-Project". Nevertheless, these preliminary data, reported in this article, aim to highlight the usefulness and relevance of the periodic review of CT protocols through a precise and informative optimization example; this is an essential feature included in Q-DRL-P.

Methodology

The Population Investigated

We report radiation exposure data for chest CT examinations. Chest CT scans can be used to detect problems such as infection, lung cancer, pulmonary embolism, and other lung problems. They may also be used to see if cancer has spread to the chest from another part of the body. Additionally, chest CT is one of the three most common CT examinations, e.g. in Quebec and USA [8, 9]. Table-1 summarizes all of the data that were analyzed, from 2017 to 2024. Quantitatively speaking, 2,480 women and 3,808 men (total of 6,288 patients) were examined with the CTSc-1 (5,074 examinations) and the CTSc-2 (1,214 examinations) for a total of 6,288 CT examinations without contrast agent (Chest C-)

Table 1:Summary of all of the CT Chest C- data analyzed for the period standing from 2017 to 2024: 2,480 women and 3,808 men, for a total of 6,288 patients; 5,074 examinations with the CTSc-1 and 1,214 examinations with the CTSc-2, for a total of 6,288 CT examinations.

Population of patients investigated with a protocole "Chest C-" from 2017 to 2024																	
	Year→	2017		2018		2019		2020		2021		2022		2023		2024	
	Gender	CTSc-1	CTSc-2	CTSc-1	CTSc-2	CTSc-1	CTSc-2	CTSc-1	CTSc-2	CTSc-1	CTSc-2	CTSc-1	CTSc-2	CTSc-1	CTSc-2	CTSc-1	CTSc-2
Nb Patients	F	175		245		315	41	264	67	303	77	258	135	257	94	194	55
	M	303		427		494	68	387	137	459	130	349	173	411	147	233	90
Age	F	70±11		70±11		71±12	69±13	68±13	68±13	69±12	70±13	70±13	72±11	69±12	70±11	71±12	71±13
	M	69±12		67±12		69±11	68±10	68±13	68±13	69±12	67±13	70±13	69±12	69±12	71±11	71±12	70±11

Materials

We assessed patient exposure to ionizing radiation from two technologically highly classified CT scanners based on ECRI Institute categorization [10], located in the same facility (Facility-X), for CT examinations of the chest. For the purposes of this article, they are labeled CTSc-1 and CTSc-2.

The energy imparted during a CT scan examination is measured and reported by every modern CT scanner through the dose length product (DLP). DLP reflects the total radiation produced during a scan over the whole scan range; its unit is mGy.cm. In this investigation, we mainly compared the DLP between CTSc-1 and CTSc-2. Besides DLP, other exposure parameters, namely exposure time, scan length and tube current, are also analyzed. All chest CT examinations were performed with spiral acquisition with a single energy source.

Patient exposure parameters are typically reported in a Digital Imaging and Communications in Medicine (DICOM) file called a Structured Radiation Dose Report (RDSR). The RDSRs are transmitted to the picture archiving and communication system (PACS) of the radiology department of Facility-X where they were extracted and analyzed for the purposes of this study.

Methods

This study began in early 2022. We analyzed retrospectively and respectively the CTSc- 1 exposure data of women (70 ± 13 years) and men (69 ± 12 years), as well as the CTSc-2 exposure data of women (70 ± 12 years) and men (69 ± 12 years), from the year 2020 until the beginning of 2022. This first analysis showed that CTSc-2 overexposed men patients by an average of 134%, compared to CTSc-1 (DLP of 273 mGy.cm vs 117 mGy.cm). Equivalently, women patients were also found to be overexposed to the extent of 104% (DLP of 188 mGy.cm vs 92 mGy.cm). This led Facility-X to contrast the "Chest protocol" of the CTSc-1 scanner with that of the CTSc-2.

To complete this table of patient data, somatic information (age, weight and height) was extracted from the radiological information system (RIS) to appropriately complete the database created to carry out this study. Statistics (t-test ($p < 0,05$), mean ± std, regression analysis, etc.) were processed with Excel software.

Results

Somatic Data

As shown in Table-2, we observed that there was no statistically significant difference in terms of somatic data for women and men, respectively (p = NS in both cases), between patients examined with CTSc-1 and CTSc-2 throughout the study period.

Table 2: Somatic data for women (F) and men (M), respectively, from 2020 to 2024. No statistically significant difference was observed for age, weight and height, between patients examined with CTSc-1 and CTSc-2 throughout the study period; p = NS.

Somatic data for the population investigated									
		Nbscans		Age (yrs)		Weight (kg)		Height (cm)	
Year	Gender	CTSc-1	CTSc-2	CTSc-1	CTSc-2	CTSc-1	CTSc-2	CTSc-1	CTSc-2
2020	F	264	67	70±14	68±13	72±16	75±15	159±6	158±6
	M	387	137	68±13	68±13	86±17	84±17	172±7	172±6
2021	F	303	77	70±13	70±13	74±17	71±9	160±5	159±5
	M	459	130	69±12	67±13	84±21	86±17	172±6	173±6
2022	F	251	127	70±13	71±11	73±14	72±11	159±12	159±5
	M	333	167	70±13	69±12	85±19	84±23	172±6	172±5
2023	F	257	94	70±14	70±11	73±21	70±13	159±8	159±6
	M	411	147	69±12	71±11	87±19	82±17	173±8	172±8
2024	F	194	55	70±13	71±13	73±20	75±17	159±8	161±7
	M	233	90	71±12	70±11	84±17	84±19	174±8	174±8
				p=N.S.		p=N.S.		p=N.S.	

Comparison of CTSc-1 and CTSc-2 exposures before and after CTSc-2 Adjustment

One of the most important technologies used to reduce dose in CT scanning is automatic exposure control (AEC), which aims to automatically modulate tube current to compensate for variations in patient attenuation, both between different patients and within a given patient [11]. Strategies for achieving AEC, technically referred to as "Reference Quality Imaging," (RQI) are based on the principles of optimizing noise or/and image quality [11].

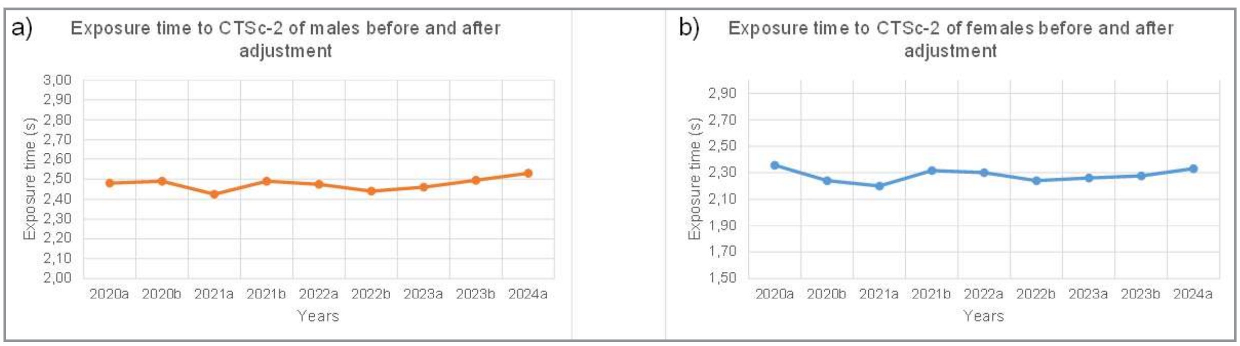
Comparison of the "Chest protocol" of the CTSc-1 scanner with that of the CTSc-2 by the radiology department of Facility-X showed that the difference in exposures essentially came from an over-optimization of the CTSc-2 RQI. Following this observation, the RQI of CTSc-2 was adjusted appropriately. We now explicitly present CTSc-1 and CTSc-2 exposure data for chest protocol without contrast agent, before and after CTSc-2 RQI adjustment.

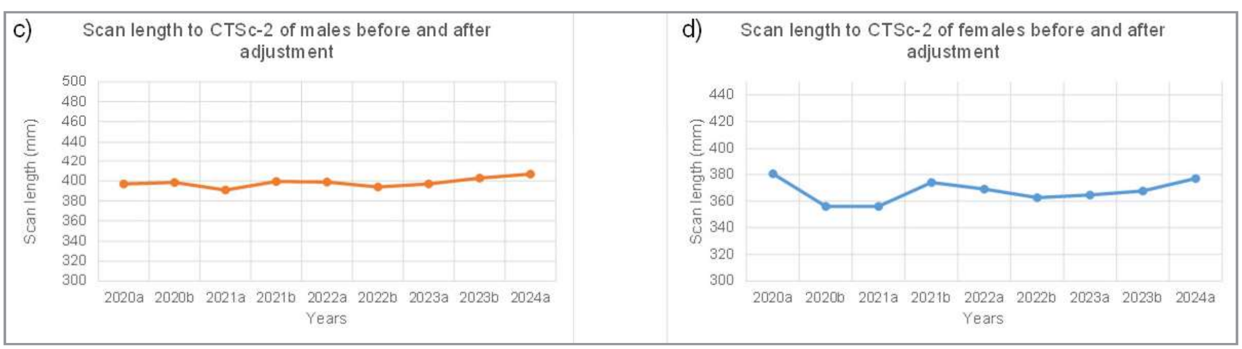
For clarity and simplification, these data are presented at six-month intervals; that is, "2020a" and "2020b" represent the first and second half of "2020" respectively, and so on. Table-3 quantifies the exposure data of CTSc-1 and CTSc-2 before adjustment of CTSc- 2 RQI (2020a to 2022a inclusive) and after adjustment (2022b to 2024a inclusive). As visually illustrated in the curves of Fig-1, and similar to the somatic data, no significant quantitative modulation of exposure time (Fig-1a and Fig-1b, men and women, respectively) was observed on average for CTSc-2 between pre- and post-adjustment periods. A similar observation can be made for the scan length (Fig-1c and Fig-1d).

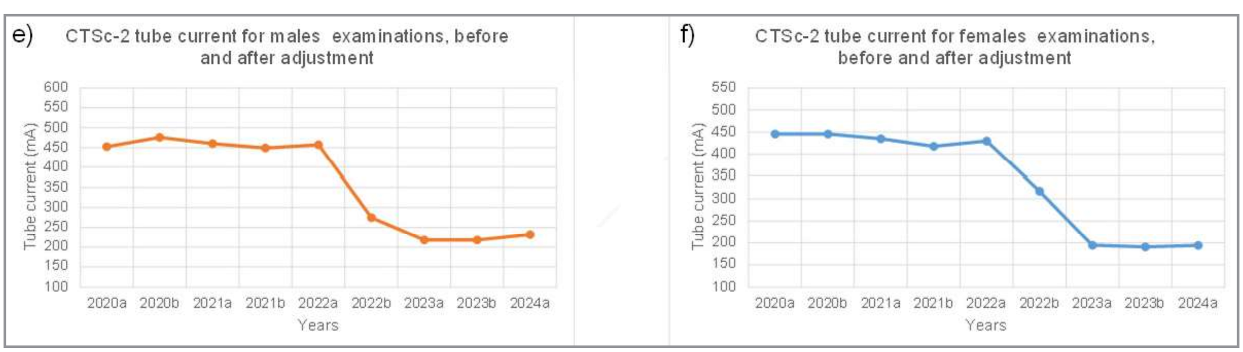
In contrast, following parametric adjustment of CTSc-2, the current decreased by approximately 50%; that is approximately 450 mA to 225 mA for men (Fig-1e) and 425 mA to 200 mA for women (Fig-1f). This resulted in a significant reduction in patient exposure. This is very explicit in Fig-1g, which contrasts CTSc-1 and CTSc-2 for men, showing a near-asymptotic convergence of the exposure of CTSc-2 to CTSc-1 during the post-adjustment period. The linear regression curve in Fig-1i ($R^2 = 0.7856$) impressively indicates an exposure reduction of approximately 46% for men after CTSc-2 RQI adjustment. The reduction in exposure is less impressive for women, but remains very significant at 33% (Fig-1h and Fig-1j).

Table 3: Contrast of CTSc-1 and CTSC-2 exposures before CTSc-2 RQI adjustment (2020a to 2022a inclusive) and after adjustment (2022b to 2024a inclusive).

Comparison of CTSc-1 and CTSc-2 exposure data before CTSc-2 adjustment (2020a to 2022a inclusive) and after adjustment (2022b to 2024a inclusive)											
Parameters	Genders	Year	2020a	2020b	2021a	2021b	2022a	2022b	2023a	2023b	2024a
DLP (mGy.cm)	Men	CTSc-1	133±40	136±44	128±37	120±35	114±41	115±53	113±41	124±52	108±38
		CTSc-2	288±98	297±107	295±105	284±96	271±76	174±43	181±54	189±72	209±92
	Women	CTSc-1	99±26	98±27	106±34	101±34	90±46	91±44	93±48	105±59	102±55
		CTSc-2	225±95	217±103	184±88	191±77	215±96	161±66	150±74	151±70	164±63
Exposure-time(s)	Men	CTSc-1	1,57±0,10	1,55±0,09	1,53±0,15	1,54±0,11	1,55±0,11	1,53±0,11	1,55±0,11	1,55±0,10	1,57±0,09
		CTSc-2	2,51±0,22	2,49±0,35	2,47±0,23	2,51±0,17	2,48±0,18	2,42±0,17	2,46±0,18	2,49±0,18	2,48±0,26
	Women	CTSc-1	1,46±0,09	1,46±0,08	1,44±0,08	1,44±0,09	1,44±0,09	1,42±0,12	1,44±0,10	1,43±0,10	1,46±0,09
		CTSc-2	2,37±0,23	2,28±0,20	2,16±0,32	2,33±0,16	2,29±0,16	2,26±0,16	2,27±0,18	2,28±0,13	2,33±0,15
Scan length (mm)	Men	CTSc-1	433±27	429±24	424±41	427±31	429±29	423±30	429±30	430±28	435±25
		CTSc-2	397±28	394±51	393±24	400±23	399±28	391±28	398±29	401±28	399±42
	Women	CTSc-1	403±24	402±22	397±23	398±25	398±26	394±33	397±27	394±27	404±25
		CTSc-2	379±31	362±26	348±52	374±23	369±25	365±25	366±30	367±21	376±24
Tube current (mA)	Men	CTSc-1	296±86	314±114	296±78	276±71	243±81	254±100	240±66	265±114	232±65
		CTSc-2	464±94	462±87	484±98	459±71	457±79	299±85	232±74	251±93	273±124
	Women	CTSc-1	250±53	245±51	265±67	252±78	225±108	228±98	232±113	251±126	238±122
		CTSc-2	456±114	455±109	440±97	424±80	443±94	323±115	225±110	231±120	236±94







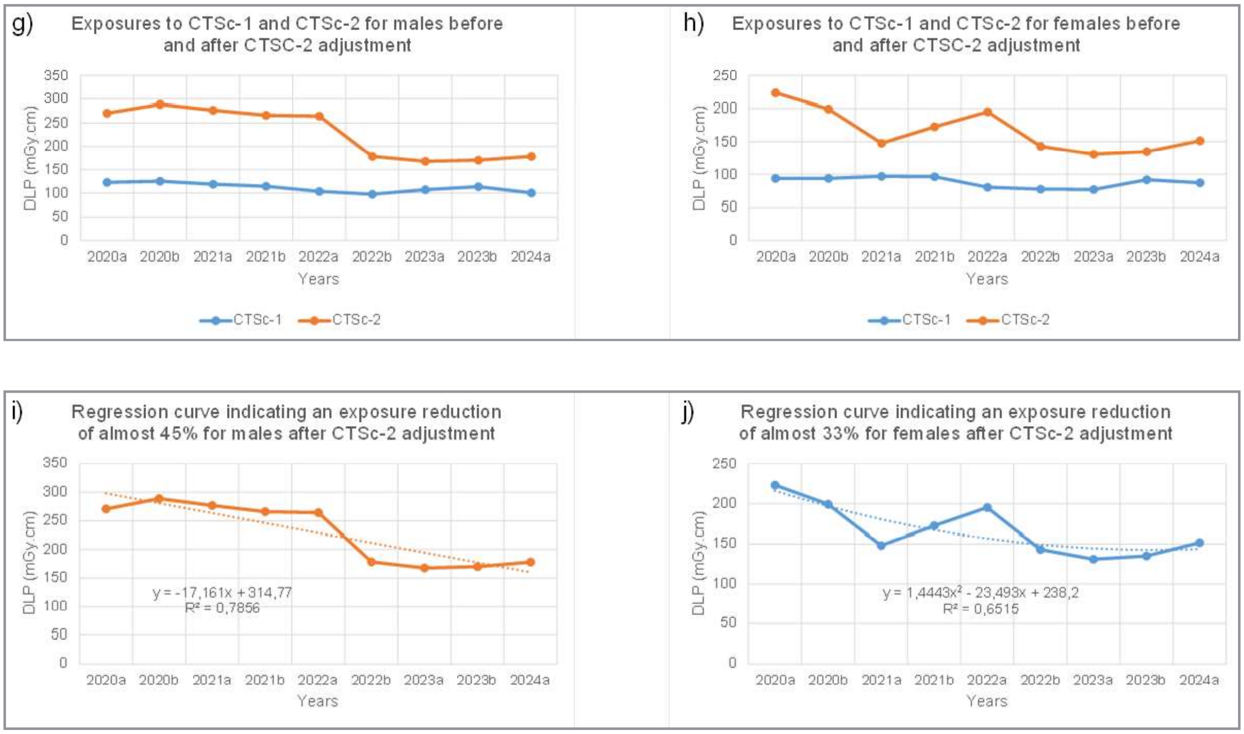


Figure 1: a-b) Exposure times to CTSc-2 of men and women, respectively, before RQI adjustment (2020a to 2022a inclusive) and after adjustment (2022b to 2024a inclusive); c-d) Scan length to CTSc-2 of men and women, respectively, before RQI adjustment (2020a to 2022a inclusive) and after adjustment (2022b to 2024a inclusive); e-f) CTSc-2 tube current, for men and women examinations, respectively, before RQI adjustment (2020a to 2022a inclusive) and after adjustment (2022b to 2024a inclusive); g-h) Contrasting CTSc-1 and CTSc-2 exposures for men and women, respectively, before and after CTSc-2 RQI adjustment; i-j) Regression curves illustrating exposure reductions for men and women, respectively, with respect to CTSc-2 RQI adjustment, relative to the CTSc-2 RQI adjustment.

Discussion and Conclusion

Although our main objective remains the implementation of the CT Q-DRL-P in Quebec, these preliminary data remind us of the importance of periodically reviewing the CT protocol. From a diagnostic perspective, one of the most important results of this study is that more than two years after this impressive reduction in patient exposure thanks to an instrumental parametric adjustment of the protocol, no questioning of the image quality was reported. From a technical perspective, very basic analyzes of signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) indicate no statistically significant difference between CTSC-2 images before and after RQI adjustment, for one sample of 20 images. This is entirely in agreement with the "International Commission on Radiological Protection" (ICRP)" which maintains that adequate image quality for diagnosis must accompany any dose reduction process [12].

These results reinforce campaigns such as "Image wisely" run jointly by the American College of Radiology (ACR) and the Radiological Society of North America (RSNA) [13]. They also support the U.S. Food and Drug Administration's (FDA) call for improving education and monitoring radiation doses [14]. Across the Atlantic, similar recommendations have been issued by the European Union regarding exposure to medical radiation [15].

Although current technologies have significantly improved the performance of CT scanners, CT protocol optimization remains a crucial step in CT quality assurance. This study has shown and confirmed, through the analysis of more than 6 000 CT chest exams, that periodic review of CT protocols has the potential to significantly reduce patient radiation exposure while complying with ALADA (As low as the diagnostically acceptable) principle [16].

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Conflicts of Interest

The authors declare no conflict of interest

Disclosure clause

The authors declare no non-disclosure clause

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