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Quebec-DRL-Project: Design and Validation for Effective Implementation

In memoriam of Gregory Ruthman

This Study was made Possible Through Greg's Unwavering Professionalism and Kindness. Though he is no Longer with us, His Memory will Forever be Honored and Preserved within this Article

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Abstract

Rationale: *The use of ionizing radiation provides undeniable benefits in medical imaging. However, the health risk linked to exposure to ionizing radiation increases with the level and frequency of exposure. With the number of computed tomography (CT) scans performed in Quebec growing by 204% in the last decade, it is essential to ensure that CT protocols are optimized.*

The International Commission on Radiological Protection (ICRP) introduced the concept of diagnostic reference level (DRL) in 1996 with the aim of optimizing the protection of patients during their exposure to medical imaging. The International Atomic Energy Agency (IAEA) specified, in 2016, that it was required to ensure that DRLs were established for health institutions using ionizing radiation.

Objective: *The final objective of this work is to establish DRLs for Quebec; this is the Quebec-DRL-Project (Q-DRL-P). The current study presents and validates the design of Q-DRL-P prior to its implementation for CT applications.*

Methods: *The Dossier santé Québec (DSQ) imaging directories collect medical imaging data from all radiology departments in Quebec. This communication platform allows to put into perspective transversal and longitudinal views of patient monitoring in radiology.*

The model proposed to establish and assume the continuous improvement of Q-DRL-P is a cyclical process maintained by three entities, which are all the radiology services, the DSQ and a processing unit.

We review data availability and nomenclature to ensure the success of Q-DRL-P. Since the patient exposure level may vary depending on the characteristics of the imaging device, we introduced a technology-based CT scanner categorization model into our design to ensure consistency of DRL values.

Preliminary Data: *For validation and illustration, we analyzed CT exposure data from non-contrast thorax examinations across 11 CT rooms, involving 13,235 adult women and 12,709 adult men. The local diagnostic reference levels (DRLs), expressed as dose-length product (DLP), were calculated at 270 mGy.cm for women and 351 mGy.cm for men. Additionally, we summarized a case report demonstrating the practical utility and relevance of the Q-DRL-P in optimizing radiation dose management, highlighting a 40% reduction in radiation exposure while maintaining diagnostic quality.*

Conclusion: *The Q-DRL-P is designed on robust theoretical and experimental foundations to establish and continuously refine DRL values. Whether it were implemented effectively, it would enable the optimization of ionizing imaging procedures, significantly reduce radiation exposure for patients and the Quebec population, with potential applications on a global scale. The Q-DRL-P aligns seamlessly with the international movement toward dose optimization in medical imaging, contributing to the emerging concept of green medical imaging that we are pioneering.*

Keywords: Medical Imaging, Ionizing Radiation, Computed Tomography (CT), Optimization of CT protocols, Diagnostic Reference Level (DRL), Quebec-DRL-Project (Q-DRL-P).

Introduction

The World Health Organization (WHO) estimates that medical use of radiation accounts for 98% of the population's contribution to doses from all human sources, and represents 20% of the total population exposure. More than 4,200 million diagnostic radiology examinations are performed, 40 million nuclear medicine procedures are carried out, and 8.5 million radiotherapy treatments are given annually worldwide [1].

Much attention is paid to radiation protection in medical imaging, particularly through international initiatives such as the Recommendations of the International Commission on Radiological Protection (ICRP) and the studies of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) [2, 3].

In such a context, the International Commission on Radiological Protection (ICRP) has introduced the concept of diagnostic reference level (DRL) in 1996 with the aim of optimizing the protection of patients during their exposure to medical imaging [4]. The International Atomic Energy Agency (IAEA) specified, in 2016, that it was required to ensure that DRLs were established for health institutions using ionizing radiation [5].

The integration of radiation protection has indeed evolved significantly over time in medical imaging. We can refer to the Dose Index Registry (DIR) introduced by the American College of Radiology (ACR) [6-8]. The registry data are used to establish national dose indices benchmarks. Similar initiatives have been issued by the European Union [9, 10].

To establish DRLs for Quebec can be seen as a contribution to the international movement to reduce doses administered to patients around the world; this is the Quebec-DRL-Project (Q-DRL-P). The current study presents and validates the design of Q-DRL-P prior to its implementation for CT applications.

Materials

Diagnostic reference level (DRL)

A significant part of radiation protection efforts in medical imaging is focused on optimizing the dose received by the patient. DRL was then introduced by the ICRP in 1996 in its Publication 73 on radiation protection and Safety in Medicine [4]. It is used for ionizing medical imaging modalities to indicate whether, under routine conditions, the radiation received by the patient, for a specific procedure, is abnormally high or low [11]. It is believed that DRL should be considered mandatory, at least for modalities and procedures in which patients are likely to be subjected to relatively high radiation exposure, such as in imaging-based interventional procedures and CT examinations [12].

Since it is difficult to determine what value of a DRL quantity is just low enough and what image quality is sufficient to provide the required diagnostic information, the ICRP proposed using the pooling of data from surveys or registers to provide results from which it would be possible to decide that the majority of radiologists agree on the fact that a particular value of the DRL quantity produces an adequate image for diagnosis [11].

The DRL provides the amount of radiation emitted by the equipment and correlates with the dose received by the patient. In CT exams, for example, the dose-length product (DLP) is used to quantify the DRL. The ICRP has established three levels of DRL values, set at the 75th percentile of the distribution of median values observed for each Rx room [11]:

- **Local DRL:** DRL value for a given Rx procedure in healthcare facilities in part of a country for a defined clinical imaging task, in a reasonable number of Rx rooms (e.g. 10 to 20).
- **National DRL:** Similar to the local DRL, this value is set for a country, based on data from a representative sample of healthcare facilities.
- **Regional DRL:** This is a DRL value set for a region, based either on a representative sample of healthcare facilities or on national DRL values; “region” is defined as a group of countries.

Dossier Santé Québec (DSQ)

DSQ is a secure platform that enables the sharing of health information deemed essential to primary care services and the continuum of care in Quebec. This health information is coming from various domains, including medical imaging. Fig-1 presents a simplified diagram illustrating how the DSQ medical imaging domain works. Its architecture is essentially composed of three serial parts, namely health facilities, DSQ modules and consumers. This imaging domain relies on a parallel communication strategy which respectively transfers DICOM objects (for im-

ages and image metadata) and HL7 messages (for various data related to patient care) from facilities to DSQ modules. These data are first stored in the XDS.b repositories and then recorded in the XDS.b Registry. For compatibility with local document consumers that may not be fully XDS.b compliant, an XDS.b Proxy is used to transmit information to these actors, such as a PACS. Multiple consumers have access to the data hosted in the repositories; this will be the case of the Q-DRL-P.

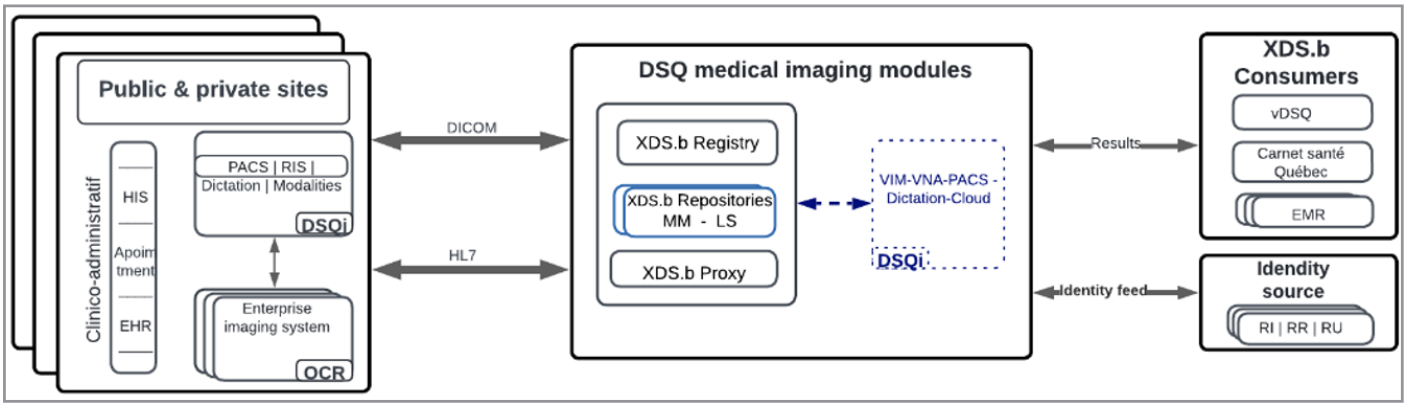


Figure 1: Simplified illustration of the medical imaging domain workflow. The information architecture is essentially composed of three serial parts, namely health facilities (left), DSQ modules (middle) and consumers (right).

Methods

As shown in Fig-2, the design proposed aims to establish and continually improve the DRL values of the the Q–DRL–P. It is essentially a cyclical process maintained by three entities:

- Health facilities, which provide the DSQ with data from imaging examinations;
- DSQ, the database where the Q–DRL–P extracts exposure data; namely radiation dose structured reports (RDSR);
- Processing center, where take place:

1. Extraction of exposure parameters from RDSRs and classification;
2. Data statistics and analysis;
3. Establishing and periodically updating DRL values;
4. Transmission of periodic reports to Healthcare facilities.

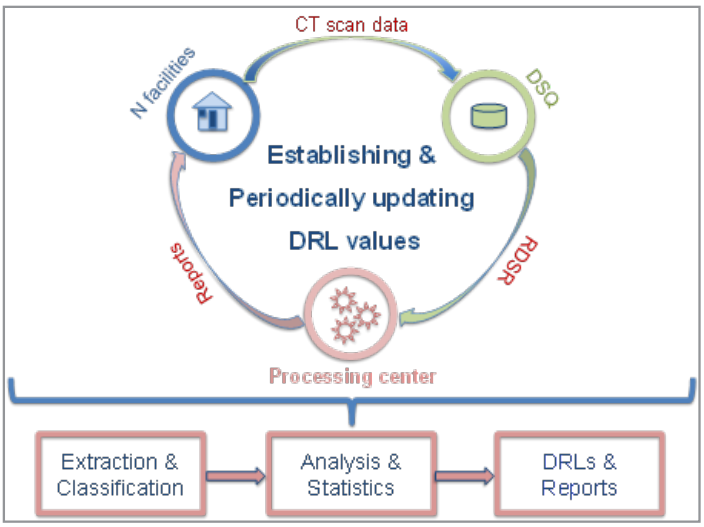


Figure 2: Q–DRL–P design: The communication platform is erected on a cyclic process that is maintained by three entities: The Health facilities, the DSQ and a processing unit.

Data Availability

The Health facilities must ensure that data are transferred appropriately to the DSQ. These data mainly consist of RDSRs, which are DICOM objects presented in the format of a text file; it notably includes most of the data related to CT examinations. On the other hand, the legacy dose report (LDR) is also a DICOM file, but presented as a screenshot. As illustrated in Fig-3, the main difference between RDSR and LDR is that the information included in the former is directly and easily accessible. The RDSR, now available in all new generation CT scanners, will be used for Q-DRL-P.

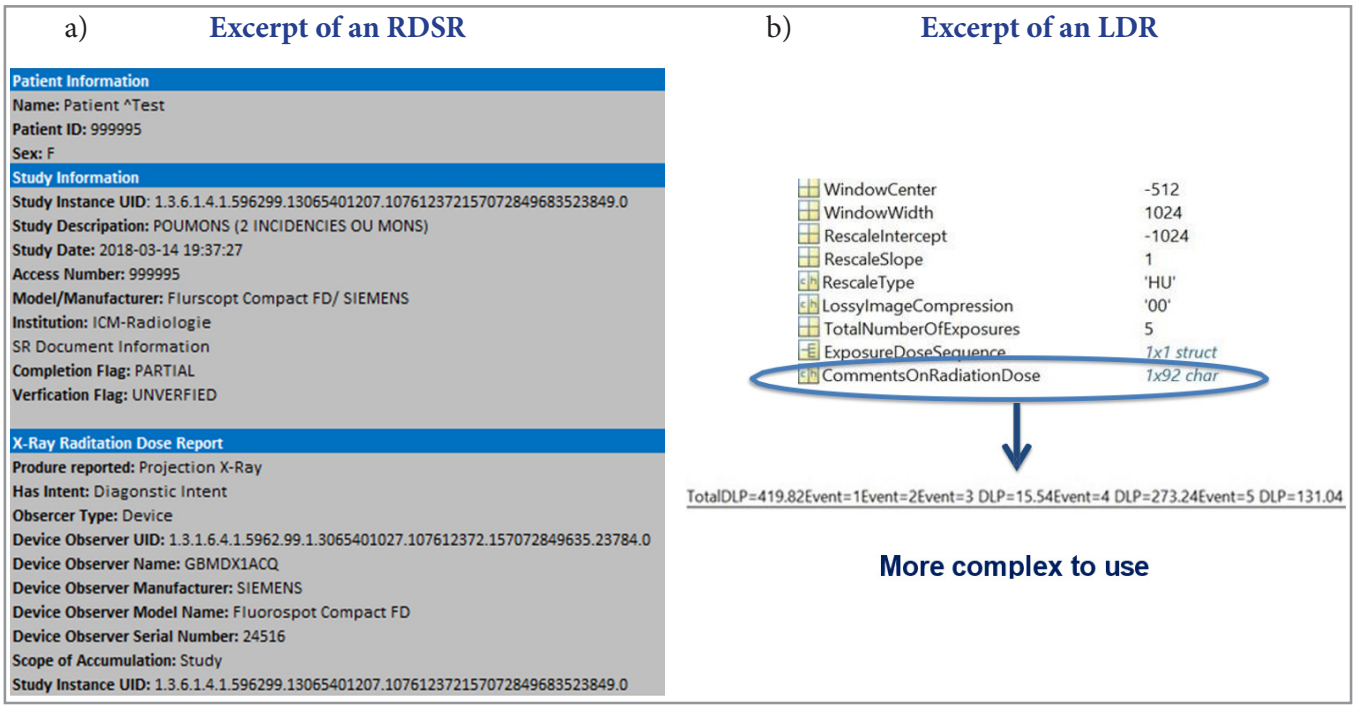


Figure 3: a) Excerpt of an RDSR; b) Excerpt of an LDR. The Q-DRL-P prioritizes the use of RDSR because the information included in this DICOM object is directly and easily accessible for processing

Data Nomenclature

The Health facilities must ensure that the data included in the RDSR are adequately standardized, according to the nomenclature requested by the MSSSQ (Ministère de la Santé et des Services Sociaux du Québec). As shown in Table-1, the structure consists of a combination of unique codes to provide a unique identification specific to each procedure. This optimizes the classification process required for Q-DRL-P.

Table 1: Example of nomenclature requested by the MSSSQ for the identification of imaging procedures

Digital code	Modality	Anatomical region	Procedure name
8263	CT	TH	CT Thorax

Data Requirements

The parameters required to operate the Q-DRL-P are usually represented in the RSDR. As shown in Table-2, there are four main groups of data.

- The descriptive parameters of the examination are used as inputs in the extraction procedure.
- The descriptive parameters of the examination are used as inputs in the extraction procedure.
- The scanner setting parameters provide information relative to the scanner itself and data acquisition procedure.
- Exposure parameters allow patient exposure to be quantified and then DRL values to be estimated.
- The somatic parameters of patients are important to apropriately determine specific DRLs.

Table 2: The four main data groups necessary for the operation of the Q-DRL-P

Types of parameters	List (non-exclusive)
Description of the exam	Institution Name; Study ID; Study Date; Modality (ex. CT); Study Description (ex. « Thorax C-); Target Region (ex. Head); Acquisition Protocol (ex. Thorax); SOP Class UID; SOP Instance UID; Study Instance UID;
Scanner setting	Manufacturer; Model; Device Observer UID; Station Name; CT Acquisition Type (ex. Spiral Acquisition); Nominal Total Collimation Width (mm); Pitch Factor; Number of X-Ray Sources; KVP (kV); Rx Tube Current (mA); Maximum Rx Tube Current (mA);
Exposure	Exposure time (seconds); Scanning length (mm); Mean CTDIvol (mGy); Dose length product (DLP in mGy.cm);
Somatic parameters	Patient gender; Patient age; Patient weight; Patient height.

Table 3: Technological categorization of CT scanners for Q-DRL-P. This proposal closely aligns with that put forward by the ECRI

Q-DRL-P compared to ECRI for CT scanner categorization					
ECRI			Q-DRL-P		
Naming of systems	Nb slices	Category	Category	Nb slices	Nb CT scans
Advanced Imaging	≥ 300	Class-1	Class-1	> 128	3
Specialzed Diagonstic	128–300	Class-2			
General High-Volume Diagonstic	64–128	Class-3	Class-2	128 ≥ x > 64	122
General Outpatient Imaging	≤ 64	Class-4	Class-3	≤ 64	37
Portable	≤ 64	Class-5			

In summary, as shown in Table-3, the MSSSQ radiology services have 162 CT scanners to their credit, including 122 in category Q-DRL-P class-2, 37 in class-3 and 3 in class-1.

-DRL-P operating Mode

Fig-4 represents a very simplified diagram of the flow of operations to follow in order to populate the database (DB) that would support Q-DRL-P.

From left to right of Fig-4, the process starts within the DSQ medical imaging domain where RDSRs are extracted and anonymized before being supported by the Q-DRL-P. From there, on the right side of the diagram, Q-DRL-P performs:

- Validation of the RDSRs;
- Confirmation and validation of the CT scans;
- Extracting parameters of interest;
- Transfer these data to the Q-DRL-P database;
- Processing and analysis.

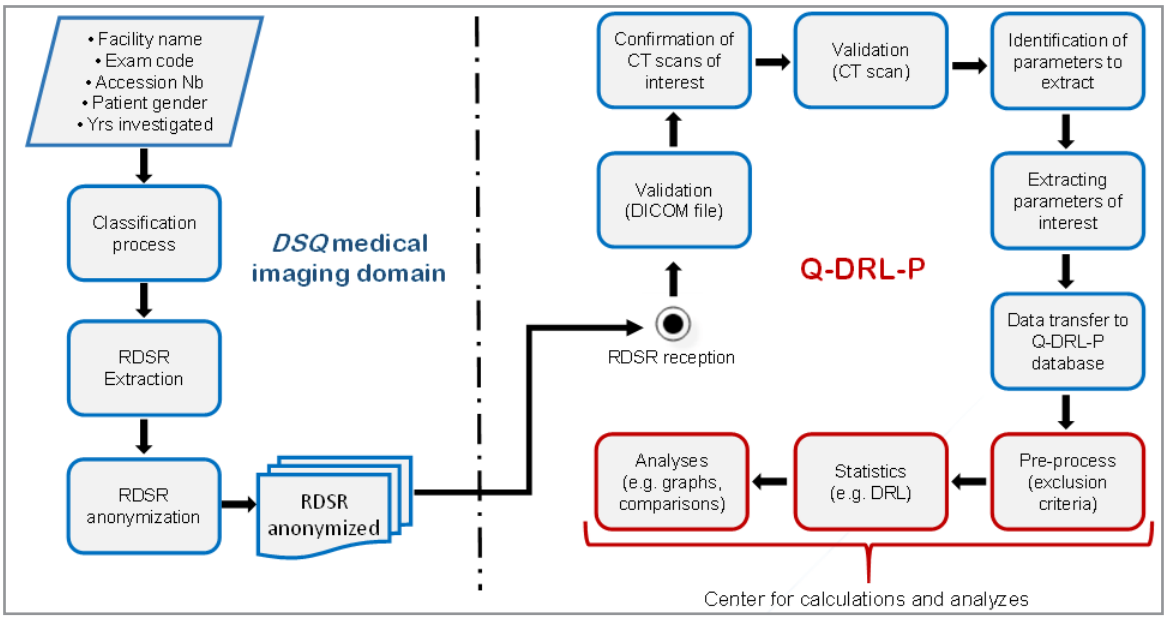


Figure 4: Simplified diagram of the flow of operations to follow in order to populate the database (DB) that would support Q-DRL-P.

Preliminary Data

Longitudinal tracking of radiation exposure trends across CT rooms

These preliminary data aim to put into perspective some outcomes expected from the Q- DRL-P. For example, Table-4 makes it possible to follow the evolution of exposure over time (years) according to gender (men, women) for a given Rx-room for "Facility-Y". The Thorax C- (without contrast agent) examinations were carried out over six years (from 2017 to 2022 inclusive). The median of the DLP distribution for men (DLP=118 mGy.cm) indicates that they were approximately 24% more exposed than women (95 mGy.cm). This analysis makes it possible to quantify an exposure reduction of 16% for women (R2=0.7313) and 11% for men (R2=0.8271) over the years.

Table 4: Evolution of exposure over time (years) according to gender (men (M), women (W)) for the CT Thorax C- protocol in Room-1 of Facility-Y

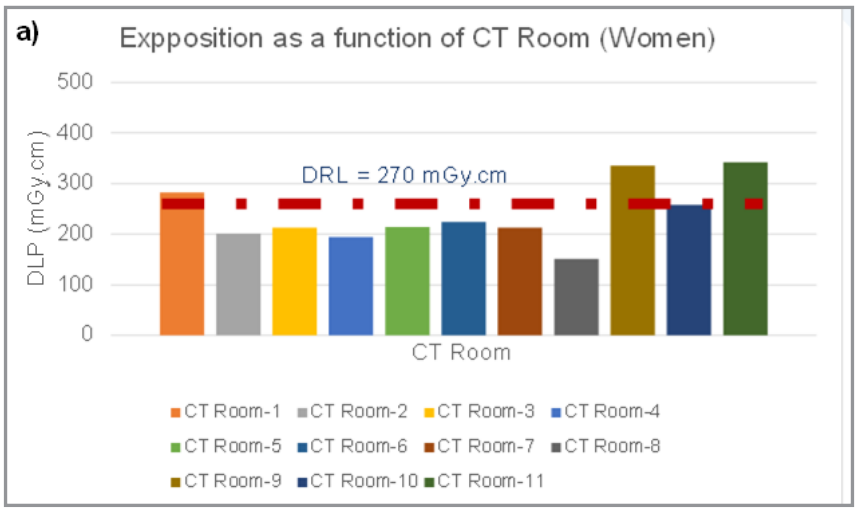
SUMMARY TABLE OF EXPOSURE PARAMETERS CT SCAN THORAX C- ROOM-1 CT SCANNER: SIEMENS - SOMATOM Force										
				Exposure parameters (mean ± std)						Median
Year	Gender	Nb scans	Age (yrs)	Exposure time (s)	Scan length (mm)	KVP (kV)	Tube current (mA)	CTDIvol (mGy)	DLP (mGy.cm)	DLP (mGy.cm)
2017	W	175	70 ± 11	2,75 ± 0,45	394 ± 34	100 ± 9	188 ± 66	3,08 ± 1,71	104 ± 52	94
	M	303	69 ± 12	2,99 ± 0,39	420 ± 33 1	102 ± 7	191 ± 54	3,32 ± 1,13	122 ± 42	114
2018	W	245	70 ± 11	1,41 ± 0,12	390 ± 33	113 ± 5	292 ± 118	3,49 ± 1,60	118 ± 52	106
	M	427	67 ± 12	1,49 ± 0,14	411 ± 40	114 ± 5	318 ± 115	3,84 ± 1,48	138 ± 53	126
2019	W	315	71 ± 12	1,45 ± 0,09	401 ± 25	111 ± 4	263 ± 85	2,97 ± 1,06	104 ± 37	96
	M	494	69 ± 11	1,52 ± 0,20	422 ± 55	113 ± 5	288 ± 76	3,41 ± 1,08	127 ± 42	118
2020	W	264	70 ± 14	1,46 ± 0,08	402 ± 23	111 ± 4	247 ± 52	2,79 ± 0,80	98 ± 27	94
	M	387	68 ± 13	1,56 ± 0,09	431 ± 26	112 ± 5	306 ± 103	3,54 ± 1,11	135 ± 42	123
2021	W	303	70 ± 13	1,44 ± 0,09	397 ± 24	112 ± 5	259 ± 73	2,99 ± 1,03	103 ± 34	96
	M	459	69 ± 12	1,54 ± 0,13	425 ± 37	112 ± 5	286 ± 75	3,32 ± 0,99	124 ± 36	117
2022	W	251	70 ± 13	1,43 ± 0,11	396 ± 30	111 ± 6	226 ± 103	2,62 ± 1,38	90 ± 45	79
	M	333	70 ± 13	1,54 ± 0,11	426 ± 30	114 ± 5	248 ± 90	3,06 ± 1,35	114 ± 47	101
				n = 1553	Median DLP for W over 6 years, 2017 - 2022 :					95
				n = 2403	Median DLP for M over 6 years, 2017 - 2022 :					118

Proposition of a "Local DRL"

At this point, it is worth recalling that the ICRP recommendations define a "local DRL" as the DRL value for a given Rx procedure in healthcare facilities in a reasonable number of Rx rooms, e.g. 10 to 20 [11]. In this regard, we propose here local DRLs for the following context:

- 11 CT Rooms;
- Non-contrast thoracic imaging protocols (C-);
- Adult women (n = 13,235) and adult men (n = 12,709), respectively;
- Data collected from 2015 to 2024;
- Class 2 CT scanners, according to our technological categorization;
- Single-energy CT scanners;
- CT imaging acquisition method;
- DLP as a DRL characterization parameter;
- DRL value calculated as the 75th percentile of the distribution of median DLP values.

Fig-5a (men) and Fig-5b (women) show the distributions of DLP values from which the DRLs were calculated. The local DRL value for women was calculated to be 270 mGy.cm and 351 for men, respectively.



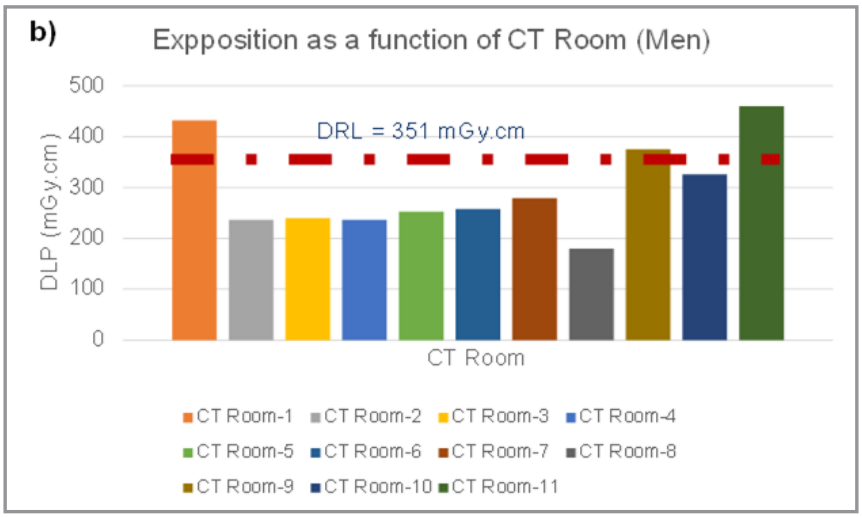


Figure 5: The local DRL values for women thorax C- protocol (a) and men (b) were estimated to be 270 mGy.cm and 351, mGy.cm respectively.

An example of the Potential Benefits Expected from Q-DRL-P – A Case Report: More details on these data can be found elsewhere [14]. We compared patient exposure to ionizing radiation from two technologically highly characterized CT scanners (CTSc-1 and CTSc-2), located at the same facility (Facility-X). We observed that there was no statistically significant difference in terms of age and somatic data for women and men, respectively (p=NS), between patients examined with CTSc-1 and CTSc-2. In contrast, as illustrated in Table-5, the comparison of exposures for the thorax protocol showed that CTSc-2 overexposed men by 134%, compared to CTSc-1 (DLP of 273 mGy.cm versus 117) in 2022; women were also overexposed by 104% (188 mGy.cm versus 92).

This led Facility-X to compare the "Thorax protocol" of the CTSc-1 scanner with that of the CTSc-2. This investigation showed that the difference in exposure essentially came from setting of the CTSc-2 "Reference Quality Imaging" (RQI) [15]. Following this observation, the RQI of CTSc-2 was adjusted appropriately.

Table-5 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). No significant quantitative modulation of exposure time and scan length was observed (for males and females, respectively) for CTSc-2 between pre- and post-adjustment periods. In contrast, the regression curves in Fig-6a (R2=0.7856) and in Fig-6a (R2=0.6515) indicates exposure reductions of 45% for men and 33% for women, respectively, after CTSc-2 RQI adjustment. It's important to note that no image quality issues have been reported more than two years after this correction.

Table 5: Contrast of CTSc-1 and CTSC-2 exposures before CTSc-2 RQI adjustment (2020a to 2022a inclusive) and after adjustment (2022b to 2024a inclusive). "2020a" and "2020b" represent the first and second half of "2020" respectively, and so on

Parameters	Genders	Year	2020a	2020b	2021a	2021b	2022a	2022b	2023a	2023b	2024a
DLP (mGy.cm)	Males	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
	Females	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)	Males	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
	Females	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)	Males	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
	Females	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)	Males	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
	Females	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

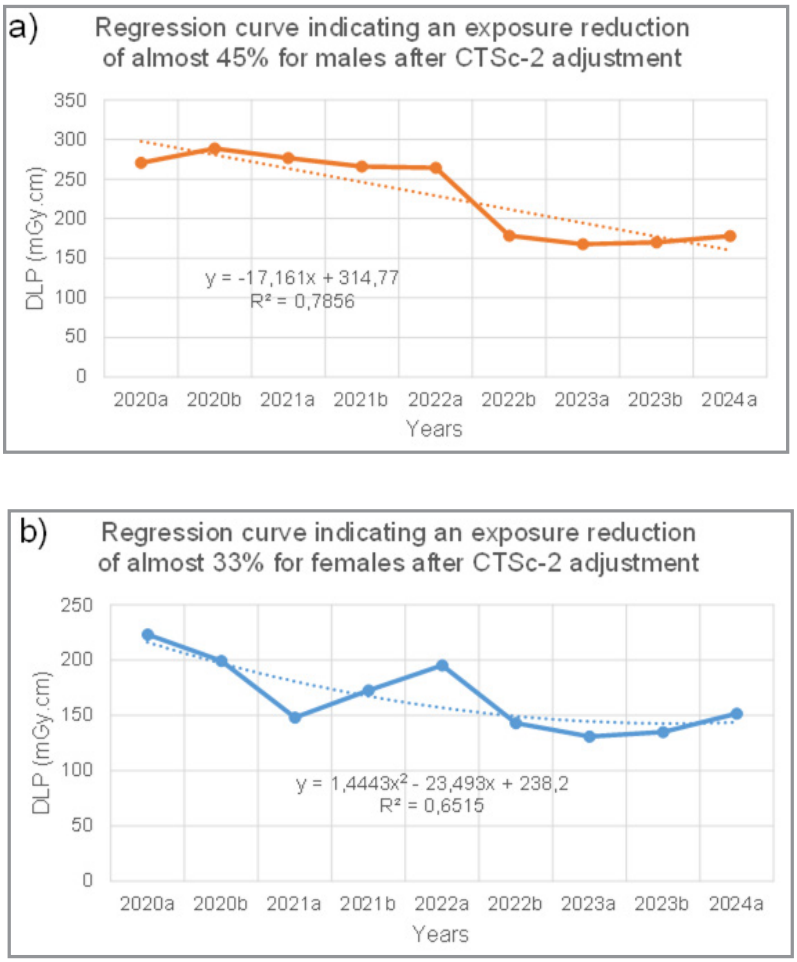


Figure 6: a-b) Regression curves illustrating exposure reductions for males and females, respectively, with respect to CTSc-2 RQI adjustment, relative to the CTSc-2 RQI adjustment.

Discussion

"The Q-DRL-P is based on the same concept as the dose index register [6-7] introduced by the American College of Radiology [8]. Additionally, being modular and scalable, the design could be implemented in the imaging architectures of most countries where RDSRs from multiple radiology departments are collected with standardized nomenclature in the same database.

We introduced an explicit scanner categorization model into the Q-DRL-P design to ensure more consistent diagnostic reference levels (DRLs). Indeed, integrating clinical and technological aspects enhances the methodology for procedure optimization.

These preliminary data show that local DRL values for women (270 mGy.cm) and men (351 mGy.cm) for the thorax C- protocol are on average favorably set in the range of those promoted internationally, as well as those presented in recent studies for Turkey, Uganda, South Africa [21], Nigeria and Egypt [16- 23].

We calculated explicit diagnostic reference levels (DRLs) separately for women and men due to the unavailability of somatic data (weight and height) for many patients. Future updates to the DSQ imaging platform will enable the seamless integration of clinical and somatic patient data, allowing DRLs to be calculated based on individual somatic characteristics rather than gender.

The success of the Q-DRL-P faces three primary challenges: data availability, nomenclature, and standardization. To overcome these, the initiative must foster collaboration among all relevant personnel and drive a cultural shift toward prioritizing radiation protection in medical imaging.

Here, we present preliminary data from over 25,000 CT scans collected over a 10-year period. While such a large dataset was not necessary to derive two NRD values, it demonstrates the Q-DRL-P's compatibility with the era of big data. This approach also highlights the potential for large-scale, retrospective, population-based clinical investigations, aligning with the vision of future medicine, i.e. shifting from diagnostic and curative to predictive and preventive paradigms [24]."

Conclusion

The Q-DRL-P is built on robust theoretical and experimental foundations, enabling the establishment and continuous refinement of diagnostic reference levels (DRLs). The current validation underscores its potential and relevance in optimizing medical imaging practices. Whether it were implemented effec-

tively, it would enable the optimization of ionizing imaging procedures, significantly reduce radiation exposure for patients and the Quebec population, with potential applications on a global scale. The Q-DRL-P aligns seamlessly with the international movement toward dose optimization in medical imaging, contributing to the emerging concept of green medical imaging that we are pioneering.

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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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