sciendo
Polish Journal of Medical Physics and Engineering
The Journal of Polish Society of Medical Physics
ISSN 1898-0309, doi: 10.2478/pjmpe-2024-0035

December 2024
Vol 30, Issue 4

Short Communication

Local diagnostic reference levels for cardiac computed tomography

Wiktoria PIŁAT[1,ABD,*], Joanna KIDOŃ-SZOŁTYSEK[1,2,CDE], Bartłomiej STASIÓW[3,EF]

[1]*Department of Medical Physics, Upper Silesian Medical Center, Katowice, Poland*
[2]*Invasive Cardiology and Electrocardiology Department, 3rd Department of Cardiology, Medical University of Silesia, Katowice, Poland*
[3]*Diagnostic Imaging Department, Upper Silesian Medical Center, Katowice, Poland*
[*]*Corresponding author: Wiktoria Piłat; wiktoria.pilat@gmail.com*

(received 30 September; revised 12 November 2024; accepted 18 November 2024)

Abstract

Introduction: Clinical applications of cardiac computed tomography in our center include the diagnosis of coronary arteries, assessment of their narrowing, evaluation of cardiac function, and assessment of the heart's structure. The aim of this study was the determination of local DRLs for cardiac CT sequence (designed to evaluate coronary arteries, function, and structure of the heart in one sequence) and calcium score sequence.

Material and Methods: The research group consisted of 2234 patients undergoing cardiac computed tomography, including calcium score, cardiac CT angiography, evaluation of cardiac function and cardiac structure. The studies were conducted using a dual-source Somatom Force computed tomography scanner (2019, Siemens). An assessment of the dose received by the patient was performed based on the analysis of the volumetric tomographic dose index (CTDIvol) and the dose-length product (DLP), taking into account body mass index (BMI).

Results: The DRL value for all patients undergoing cardiac computed tomography (one sequence including evaluation of calcium score, cardiac angiography, cardiac function, and cardiac structure) and calcium score sequence (in brackets) were 901.5 (92.3) mGy·cm. When broken down by BMI category, the values were 869.9 (87.7) mGy·cm, 880.9 (89.6) mGy·cm, 889.3 (91.4) mGy·cm, 941.0 (95.8) mGy·cm, for underweight, normal BMI, overweight and obese patients, respectively.

Conclusion: Diagnostic reference levels should be carefully determined, taking into account BMI, detailed information about the CT protocol, and type of CT scanner. Careful determination and regular updates of diagnostic reference levels are essential for optimizing the radiological protection of the patient.

Keywords: Cardiac Computed Tomography (CCT); dual-source computed tomography; Diagnostic Reference Levels (DRLs).

Introduction

The technological development of medical equipment contributed to the separation and modernization of multi-slice computed tomography (MSCT). Shortening the examination time, enabling imaging of the entire chest area during a single inspiration, as well as increasing the scan volume during X-ray tube rotation, allowed the implementation of MSCT into routine cardiological diagnostics.[1]

A computed tomography scanner used for myocardial diagnostics should have appropriate temporal and spatial resolution and a short acquisition time to prevent artifacts related to the imaging of a moving organ. Cardiac Computed Tomography (CCT) also requires synchronization of scanning with an electrocardiographic (ECG) recording, allowing the acquisition of the heart in the phase with the least mobility, i.e. mid- or end-systolic.[2] One of the image registration methods is prospective scanning (also known as triggering), which involves imaging only in a previously planned phase of the cardiac cycle. The second method is retrospective scanning, in which the cardiac cycle is divided into several phases that are used to reconstruct the image. Retrospective triggering involves a higher radiation dose than prospective triggering, but it allows image recording in any selected phase of the cardiac cycle.[3]

The heart rate is of great value for image quality – if the rhythm is too fast and irregular, it is impossible to perform the exam, so it’s required to administer beta-blocker intravenously. It keeps the heart rate below 65 beats/minute. A necessary condition for conducting a clinically useful examination is the patient's cooperation by holding his breath during the acquisition for about 10-15 seconds.[4]

Authors’ contribution: A – Research concept and design, B – Collection and/or assembly of data, C – Data analysis and interpretation, D – Writing the article, E – Critical revision of the article, F – Final approval of the article.

Multi-slice cardiac computed tomography involves volumetric scanning used in spiral tomography, in which an increase in the number of layers obtained during one rotation of the X-ray tube increases the speed of volume acquisition. An increase in the rotation speed of the X-ray tube contributes to improved time resolution and, consequently, to a reduction in the time of heart movement in diastole. Cardiac computed tomography in the spiral mode requires the use of a table motion intensity factor (pitch) ranging from 0.2 to 0.4 depending on the patient's heart rate. A necessary condition for precise reconstruction of myocardial images in the same phase of the cardiac cycle is the overlap of data from subsequent examination layers, which is only possible by controlling the pitch value, which is directly proportional to the distance between the layers. The low pitch value also increases data redundancy throughout the entire cardiac cycle, which in turn allows the use of the phase with the least residual motion.[5]

Clinical applications of computed tomography in the diagnosis of heart diseases include the diagnosis of coronary vessels with the analysis of the total calcium score (Coronary Artery Calcium Scoring, CACS), the assessment of their stenoses, and the control of coronary vessels after coronary artery bypass grafting and coronary angioplasty. MSCT is also used in the morphological assessment of heart valves, differentiation of the morphology of atherosclerotic plaques, and analysis of the pulmonary vein openings in patients before ablation due to atrial fibrillation.[1,6] A CT scan of the heart also allows for obtaining hemodynamic parameters defining heart function, such as end-systolic and end-diastolic volume, stroke volume, and ejection fraction, for both the left and right ventricles. It also allows for calculating the mass of the heart muscle. In addition, CT vessel imaging is used in planning procedures, such as endovascular implantation of stent grafts in the thoracic and abdominal aorta, as well as in qualifying patients for transcatheter aortic valve implantation (TAVI). Imaging of the cardiovascular system using CT is particularly important in congenital heart defects. This examination allows for tracing the course of arterial and venous vessels along their entire length and for demonstrating abnormal connections at the level of the heart septa. This is important in adults after the correction of congenital heart defects.[7]

The presented study aimed to establish diagnostic reference levels for cardiac computed tomography exams, including assessment of heart vessels, heart function and heart structure with one CT sequence and calcium score sequence.

Material and Methods

The research group consisted of 2234 patients undergoing computed tomography of the myocardium at the Upper Silesian Medical Center Prof. Leszek Giec of the Medical University of Silesia in Katowice in the period from January to August 2024. The availability of anthropometric data in most patients allowed the division of patients according to body mass index (BMI). The characteristics of the study groups are presented in **Table 1**. CCT examinations were performed using a dual-source computed tomography device Somatom Force (Siemens, 2019), equipped with two X-ray tubes and two detectors. The tube collimator has two shaped X-ray beam filters and one tin filter, which improves spectral separation by absorbing low-energy photons from the high-energy spectrum, which consequently contributes to improved imaging quality and reduced dose.[8] Good temporal resolution (TR, short data acquisition window) is crucial for a cardiac CT scanner. It is worth emphasizing that dual-source systems are characterized by an internal TR defined as one-quarter of the gantry rotation time.[9] Short scan times minimize motion artifacts, reducing the need for reexamination and potential patient dose.[8,9]

The study established diagnostic reference levels for cardiac computed tomography, encompassing several kinds of CCT protocols (differing mainly in the types of post-processing reconstruction), as well as one protocol solely for coronary artery calcium scoring. The majority of analyzed CCT protocols include several sequences: scout, calcium score, contrast inflow monitoring, and a retrospectively gated sequence to assess cardiac vessels, function and structure of the heart (CCTseq). The CACS protocol included scout and CACS sequence (CACSseq). DRL was determined for the CACSseq and CCTseq. Detailed scanning parameters are described in **Table 2**.

Table 1. Characteristics of the study group.

Parameters / study group	full study group
No. of patients	2234
No. of women	1223
No. of men	1001
Age (mean ± SD) [Y]	63.3 ± 11.7
BMI (mean ± SD) [kg/m^2]	28.7 ± 5.5

Table 2. Detailed scanning parameters.

Scanning parameters	CACSseq	CCTseq
Scanning mode	Axial	Helical
Dose optimisation	mAs weight-dependent	Dose adjustment along the z axis, optional - CareDose / Care kV
kVp	Sn150	90
pitch	1.0	0.15-0.32
Slice thickness [mm]	0.6	0.6
Exposure per rotation [ms]	0.12	0.25

CACSseq – coronary artery calcium scoring sequence, CCTseq – cardiac CT sequence, both CACS and CCTseq without scout and contrast inflow monitoring sequence, CareDose / Care kV – an options of Automated Exposure Control (AEC - a standard tool for reducing radiation doses and maintaining image quality in CT scans.[10])

Table 3. Local diagnostic reference levels divided according to BMI.

		CCTseq			CACSseq			Most common sequence		
		No	DLP [mGy×cm]	$CTDI_{vol}$ [mGy]	No	DLP [mGy×cm]	$CTDI_{vol}$ [mGy]	No	DLP [mGy×cm]	$CTDI_{vol}$ [mGy]
Whole group		2234	901.5	51.4	209	92.3	6.5	1186	896.0	51.3
BMI [kg/m²]	**<18.5**	17	869.9	47.8	3	86.7	4.9	15	896.9	47.8
	18.5-24.9	487	880.9	49.0	59	89.6	5.9	261	844.3	47.5
	25-29.9	905	889.3	50.5	72	91.4	6.3	467	875.8	50.5
	≥30	765	941.0	54.6	72	95.8	6.9	400	944.8	55.4

CACSseq – coronary artery calcium scoring sequence, CCTseq – cardiac CT sequence, both CACS and CTseq without scout and contrast inflow monitoring sequence

The DRL in analyzed examinations was assessed based on an analysis of the volumetric tomographic dose index ($CTDI_{vol}$) and the dose-length product (DLP). Five patient groups were identified: one disregarding BMI and four based on BMI categories, underweight (< 18.5 kg/m^2), normal (18.5 – 24.9 kg/m^2), overweight (25.0 – 29.9 kg/m^2) and obese (≥ 30 kg/m^2**)**. According to ICRP Publication No. 135, the DRL value is any theoretical value of a dosimetric quantity set at the 75th percentile of the distribution of this quantity observed in several healthcare facilities.[11] Local diagnostic reference levels have been established by the methodology described in "Local diagnostic reference levels and effective doses: single institution levels for interventional cardiology procedures for adult patients".[12]

Results

Local diagnostic reference levels derived in the study are presented in **Table 3.**

The analyzed dosimetric values are characterized by right-sided asymmetry, i.e. the lack of normal distribution, which is also evidenced by the results of the Shapiro-Wilk and Kolmogorov-Smirnov tests with the Lilliefors correction below the value of statistical significance at the level of 0.05.

Discussion

The consequence of the obligation to update the values of reference levels and their constant updating imposed by ICRP are numerous publications rationalizing the adopted standards and enabling comparison of the obtained DRL values with the results from medical facilities around the world. EUROATOM 97/43 guidelines also indicate the need to determine DRL for each radiological procedure. In CT both CTDI and DLP are used to establish Diagnostic Reference Levels (DRL), which were first introduced in the 73rd ICRP report at the end of the 20th century. The development of imaging technology necessitated updating the concept of DRL. According to the 135th ICRP Report, DRL is a research-level form used to assist in optimizing patient radiological protection against ionizing radiation in diagnostic procedures and interventions. According to the ICRP recommendations, it is necessary to include clinical and technical aspects of individual examinations, as well as to consider anthropometric data enabling the classification of patients according to their weight and height, which allows for the determination of DRL with greater accuracy.[11] These requirements were included in the definition of DRL included in the Atomic Law Act of 2023, according to which the diagnostic reference level in X-ray diagnostics and interventional radiology procedures is the dose level, and in the case of radiopharmaceuticals, their activity level, compared to typical diagnostic tests and procedures performed on standard phantoms or patients with a standard body build (170 centimeters in height and 70 kilograms in weight).[13] It is worth emphasizing that, unlike in other countries, in Poland, the DRL for computed tomography is determined based on specific values of the weighted tomographic dose index ($CTDI_w$)[13] instead of the volumetric dose index ($CTDI_{vol}$)[14]. When assessing exposure, one should therefore consider the pitch value in the conversions ($CTDI_{vol} = CTDI_w/pitch$)[15], and therefore consider the individual pitch value, which could be selected based on the subject's heart rate.

In this study, the determined DRL value for cardiac computed tomography was divided into two procedures: cardiac computed tomography and calcium scoring. The DRL value for all patients undergoing cardiac computed tomography sequence was 901.5 mGy·cm, and for patients whose BMI was between 18.5 to 24.9 kg/m^2 (BMI of the standard patient - 24.2 kg/m^2) 880.9 mGy·cm. DRL for calcium score sequence was 92.3 mGy·cm and 89.6 mGy·cm for all patients and normal BMI patients, respectively. The described statistical distribution of dosimetric parameters shapes corresponds to clinical practice in which, by the ALARA (As Low As Reasonably Achievable) principle, the lowest doses are most common. DRL published in the Regulation of the Minister of Health on December 6th, 2022, for computed tomography angiography of the heart and chest, was 700 mGy·cm. This value does not include information on the type of triggering and concerns studies evaluating only the heart vessels. Moreover, in our group of patients, we obtained DRLs only slightly higher than those proposed in the Regulation of the Minister of Health on December 6th, 2022 for a CCT examination that, in addition to assessing the heart vessels, also evaluates function and structure of the myocardium.

Furthermore, the average BMI in our study was 28.7 kg/m^2, while BMI for standard patient is 24.2 (70 kg, 1.7 m), which enables scrutiny. Unlike calcium scoring and cardiac computed tomography examinations, which assess the function and structure of the heart, DLP value for patients with a BMI under 18.5 kg/m² was higher than that for patients with a BMI between 18.5 and 24.9 kg/m². However, the differences in $CTDI_{vol}$ parameter between these two groups were not significant. It's important to note that DLP accounts for the length of the scan and $CTDI_{vol}$, while $CTDI_{vol}$ is directly related to the acquisition parameters. Additionally, the number of patients with a BMI under 18.5 kg/m² is significantly smaller than the other groups. The scanning range was similar across all patients; however, in individuals with a high BMI, the scanning range tends to be slightly shorter due to the horizontal positioning of the heart. Consequently, larger percentage differences in local diagnostic reference levels for different BMI groups are observed in the $CTDI_{vol}$ parameter. The discrepancies between the DLP and $CTDI_{vol}$ values in underweight and normal-weight patients can be attributed to the scanning length and the limited number of patients with a BMI of less than 18.5 kg/m².

Mafalanka F.'s team obtained a DRL of 870 mGy·cm for retrospective gating and 370 mGy·cm for prospective gating without considering the patient's weight for cardiac computed tomography without CACS measurement performed in eight hospitals in France.[16] The lack of data on study protocols (cardiac angiography vs. function) hinders thorough comparative analysis; however, the DRLs determined for retrospective gating are comparable.

The diagnostic reference level of cardiac computed tomography was also determined by the Amontree S. team. The exams were performed on a 320-slice Toshiba Aquilion ONE tomograph using the axial method and a 64-slice Philips IQon tomograph using the spiral method. The scope of examination for both devices covered the area from the tracheal bifurcation to the apex of the heart, and the layer thickness was 0.5 and 0.9 mm, respectively. Tomography was performed for the following voltage values: 100 kV, and 120 kV. The average BMI value characterizing the research group remained at the level of 26.77 kg/m^2 (similarly to our study), which, according to standards, is classified as overweight. DRL for the examination described as coronary computed tomography angiography was obtained for the Toshiba device at 579.3 mGy·cm, and for the Philips device – at 879.7 mGy·cm.[17] The lower DRL value (for Toshiba device) obtained in the study compared to our center result from the different method (axial vs. helical) and lack of information about cardiac function and cardiac structure evaluation. The DRLs determined for Philips device are comparable.

The study by Rawandesh M. and colleagues, was conducted using a wide range of scanners with various numbers of sections from GE (Optima 99 multislice), Siemens (Somatom Force, Multislices 128, Somatom Sensation 64, Somatom Sensation 64 dual Source), and Philips (Brilliance ICT scan 256, Philips multislice 64 p/s) in Jordan for a patient with a standard weight of 70 kg, an average BMI of 30 kg/m^2 (obesity grade I), the results obtained value of 1035 mGy·cm (without CACS), which is higher than the value obtained in our center.[18]

Araki S.'s team set the diagnostic reference level in studies conducted using single- and dual-source CT from Canon, Siemens, Philips, and GE with at least 64 detector rows, using voltages ranging from 80 to 135 kV. The DRL they obtained for cardiac computed tomography with CACS in the group of patients weighing 50-70 kg was 786.1 mGy·cm. The difference between DRLs may result from dissimilarity in the aim of the studies. Our examination included evaluation of calcium score, cardiac angiography, cardiac function, and cardiac structure whereas Araki S.'s team research contained only coronary computed tomography angiography.[19]

According to data from the Central Statistical Office from 2019,[20] as many as 65% of men and 49% of women were diagnosed with excessive body weight, defined as overweight and obesity, which was estimated based on BMI.[20] Compared to 2014, this represents a 3% increase in people with abnormal body weight both in the group of women and in the men's group.[20] Moreover, a report by the National Institute of Public Health - National Institute of Hygiene published in 2020 showed that during the COVID-19 pandemic, as many as 28% of Poles over 20 years of age experienced weight gain.[20] The BMI for a standard patient is 24.22 kg/m^2 (70 kg, 1.7 m), which indicates a normal weight, which in turn means that national reference levels should only be used in patients in whom excessive body weight was not observed. Considering the increasing percentage of obese people in Polish society and the importance of anthropometric data in assessing patient exposure, the definition of a standard patient should be updated or DRLs should be specified for size intervals (e.g. every 10 cm and 10 kg) or divided by BMI.

Cardiac computed tomography is an advanced diagnostic method, influenced by many factors, such as the patient’s clinical condition (in CCT in helical mode, the pitch factor is automatically selected based on the patient's heart rate) or weight. Carefully determined and updated diagnostic reference levels enable the optimization of patient radiological protection by establishing reference values for doses received because of exposure to ionizing radiation during a medical procedure, which, except in special clinical situations, must not be exceeded. This reduces the harmful effects of radiation on the body and the patient's exposure to side effects resulting from X-ray radiation.

Conclusions

Cardiac computed tomography is an advanced diagnostic method, which is influenced by many factors, such as the patient’s clinical condition or weight. Therefore, it is necessary to consider both these factors when establishing the DRL for this procedure. Determining the DRL should also consider the technical specifications of the CT unit and be defined for a detailed examination protocol, which is crucial. Careful determination and regular updates of diagnostic reference levels are essential for optimizing the radiological protection of the patient.

Editor's comment

The abstract of the work was submitted to the 18th Congress of the Polish Society of Medical Physics (held in Poznań, Poland, 19-21 September 2024). The authors of the work were invited by the Scientific Committee of the Congress and the Editor-in-Chief of the Polish Journal of Medical Physics and Engineering to present their work in the form of a Short Communication in the Journal.

References

1. Michalak M, Zawadzki M, Walecki J. Wielorzędowa tomografia komputerowa w kardiologii [Multi-Slice Computed Tomography in cardiology]. Choroby Serca i Naczyń. 2005;2:107-112.
2. Kuniej T, Derkacz A. Computer tomography in cardiology- a short review. Acta Bio-Optica et Informatica Medica. 2009;15(3):273-276.
3. Hedgire SS, Baliyan V, Ghoshhajra BB, Kalra MK. Recent advances in cardiac computed tomography dose reduction strategies: a review of scientific evidence and technical developments. J Med Imag. 2017;4(03):1. doi:10.1117/1.jmi.4.3.031211
4. Kulawik-Gałąska D, Gałąska R, Pieńkowska J, Fijałkowska J, Szurowska E. Zastosowanie tomografii komputerowej w kardiologii [The use of computed tomography in cardiology]. Forum Medycyny Rodzinnej. 2013;7(3):141-148.
5. Toia P, La Grutta L, Sollami G, et al. Technical development in cardiac CT: current standards and future improvements—a narrative review. Cardiovasc Diagn Ther. 2020;10(6):2018-2035. doi:10.21037/cdt-20-527
6. D'Arcy J, Myerson S. Investigation in valvular heart disease. Clinical Medicine 2010; Apr;10(2):172-176. doi: 10.7861/clinmedicine.10-2-172.
7. Fijałkowska J, Gałąska D, Pieńkowska J, Fijałkowski M, Szurowska E. The use of computed tomography in cardiology. Forum Medycyny Rodzinnej 2013; 7(3); 141-148.
8. Somatom Force service manual
9. Lewis MA, Pascoal A, Keevil SF, Lewis CA. Selecting a CT scanner for cardiac imaging: the heart of the matter. BJR. 2016;89(1065):20160376. doi:10.1259/bjr.20160376
10. Rego, S, Yu, L, Bruesewitz, M, Vrieze, T, Kofler, J, McCollough, C, CARE Dose4D CT Automatic Exposure Control System: Physics Principles and Practical Hints. Radiological Society of North America 2007 Scientific Assembly and Annual Meeting, November 25 - November 30, 2007, Chicago IL. http://archive.rsna.org/2007/5011233.html Accessed May 28, 2024
11. ICRP, 2017. Diagnostic reference levels in medical imaging. ICRP Publication 135. Ann. ICRP 46(1): 13-17, 27-37.
12. Kidoń J, Polaczek-Grelik K, Wojciuch L. Local diagnostic reference levels and effective doses: single institution levels for interventional cardiology procedures for adult patients. Pol J Med Phys Eng. 2022;28(2):77-83. https://doi.org/10.2478/pjmpe-2022-0009
13. Announcement of the Speaker of the Sejm of the Republic of Poland of May 11, 2023, on the announcement of the uniform text of the Atomic Law Act. Dz. U. 2023 poz. 1173.
14. Paulo G, Damilakis J, Tsapaki V, et al. Diagnostic Reference Levels based on clinical indications in computed tomography: a literature review. Insights Imaging. 2020;11(1). doi:10.1186/s13244-020-00899-y
15. Technical Reports Series No. 457, Dosimetry in Diagnostic Radiology: An International Code of Practice. Vienna: International Atomic Energy Agency; 2007
16. Mafalanka F, Etard C, Rehel JL, et al. Establishment of diagnostic reference levels in cardiac CT in France: a need for patient dose optimisation. Radiation Protection Dosimetry. 2014;164(1-2):116-119. doi:10.1093/rpd/ncu317
17. Admontree S. Assessment of radiation dose in cardiac CT angiography using retrospective ECG gating technique at Ramathibodi Hospital (P. 237). Chulalongkorn Medical Journal. 2020;64(3):237-245. doi:10.58837/chula.cmj.64.3.3
18. Rawashdeh M, Saade C, Zaitoun M, et al. Establishment of diagnostic reference levels in cardiac computed tomography. J Applied Clin Med Phys. 2019;20(10):181-186. doi:10.1002/acm2.12711
19. Araki S, Kitagawa K, Kokawa T, et al. Radiation exposure in cardiac computed tomography imaging in Mie prefecture in 2021. Jpn J Radiol. 2023;41(6):596-604. doi:10.1007/s11604-022-01380-0
20. The health status of the Polish population in 2019 (based on the results of European Health Interview Survey 2019). Central Statistical Office, Warsaw 2021. [access: 26.05.2024]. Available at: https://stat.gov.pl/obszary-tematyczne/zdrowie/zdrowie/stan-zdrowia-ludnosci-polski-w-2019-r-,6,7.html#