ISSN: 2582-7162

Original Article

Validation And Estimation of Entrance Surface Doses for Five Diagnostic Radiography Examinations Using Monte Carlo Simulation

Mukesh Jain[1], Ramesh Chand Sharma[2], Mary Joan[3], Arun Chougule[4], Rajesh Kumar Jangir[5]

[1,2,]SMS Medical College and Hospitals Jaipur, India

[3]Christian Medical College and Hospital, Ludhiana, India

[4]Swasthya Kalyan Group, Jaipur, India

[5]Department of Radio-Diagnosis, Mahatma Gandhi Medical College, Jaipur

Corresponding Author:
Mukesh Jain, SMS Medical College and Hospitals, Jaipur, India

E-mail:
mukeshpatni05@gmail.com

How to cite this article: Jain M, Sharma RC, Joan M, Chougule A, Jangir RK.Validation And Estimation of Entrance Surface Doses for Five Diagnostic Radiography Examinations Using Monte Carlo Simulation.GFNPSS-IJMR 2024; 5:5: 2592-2599

Submitted:22-April-2024: **Accepted:**29-May-2024: **Published:** 03-June-2024

Abstract

Introduction: Monte Carlo simulation is a valuable tool for estimating entrance surface doses (ESDs) in diagnostic radiography. However, it is important to consider the limitations and potential drawbacks of this approach. This study aims to identify the challenges of directly measuring ESD on a large scale and advocates for the structured use of Monte Carlo simulation. This computer-based method can simulate ESD by utilizing clinical exposure parameters alongside patient geometry and tissue density, thereby offering insights into dose distribution without physically measuring each patient. The simulation of ESDs for specific diagnostic examinations, including chest, abdomen, lumbar spine, skull, and pelvis radiography, was conducted and validated with physical measurements.

Materials & Methods: This research was undertaken at SMS Medical College, Jaipur. The department serves a substantial patient base, performing radiography for over 1000 individuals in a day across various sites within the institution. With a team comprising more than 100 technologists, each possessing between 5 to 35 years of experience, the department boasts a wealth of expertise. During the study, meticulous attention was paid to the radiation exposure levels generated by the radiological equipment. Stringent quality control and assurance protocols, as mandated by the Atomic Energy Regulatory Board, were rigorously followed for every piece of equipment involved. Before the commencement of the study, the machine setup, procedural workflows, and exposure protocols were meticulously optimized to align with the tolerance limits outlined in the AERB guidelines.

Results: The results show strong agreement between simulation dosimetry and physical dosimetry using TLD & OSLD for radiographic examinations.

Conclusions: Additionally, the study underscores the significance of implementing Quality Control programs and conducting systematic dose audits as part of adherence to the ALARA principles to manage patient exposure.

Keywords: Monte Carlo simulation, Entrance Surface Dose, Diagnostic radiography, Dose audits, Thermo Luminescent Dosimeter, Optically Stimulated Luminescent Dosimeter, Diagnostic reference levels, Dose Area Product

https://doi.org/10.46376/ijmr/05.05.2024:2592-2599

Introduction

To mitigate the harmful effects of X-rays, adherence to essential radiation safety principles, namely justification and optimization, is imperative. Justification entails assessing whether the diagnostic benefits of X-ray procedures outweigh the associated risks. Optimization involves meticulous management of radiation exposure to achieve doses that are as low as reasonably achievable, without compromising the integrity of diagnostic information.

The implementation of robust Quality Control programs alongside systematic dose audits is paramount. These initiatives help guarantee that the radiation doses administered to patients adhere to ALARA (As Low as Reasonably Achievable) principles. Ensuring minimal radiation exposure requires precise knowledge of the dosage received during diagnostic radiological procedures.(1)

The entrance surface dose (ESD) is pivotal in evaluating radiation risks in standard diagnostic radiography. ESD refers to the dose recorded at the skin's surface where the X-ray beam enters the body, inclusive of backscatter radiation, while the dose recorded at the skin's surface where the X-ray beam enters the body exclusively measures the backscatter, known as Entrance Surface Air Kerma (ESAK). This measure is crucial for patient dose management, refining radiographic procedures for individual needs, and ensuring doses remain within the recommended safe limits.(2)

The knowledge of ESD helps in estimating the organ doses in given radiographic procedure adds in finding the probability of attributed life time risk or it might be beneficial in identifying the diagnostic reference levels for the local area for optimizing and evaluating radiation safety practices. Hence it is an important quantity to measure and assess in order to ensure patient safety and optimize radiation dose in diagnostic radiology.(3)ESD may be accurately assessed by positioning a Thermo Luminescent Dosimeter (TLD) or Optically Luminescence Dosimeter (OSLD) directly on the patient's skin. However, this approach is time-consuming and becomes less feasible when dealing with large patient populations. (4)To bypass these constraints, ESD can alternatively be simulated by Monte Carlo methods that incorporate clinical exposure parameters as well as patient geometry and tissue density. Hence, Monte Carlo simulation is a powerful tool used in the field of diagnostic radiography to estimate entrance surface doses in various radiography examinations. By utilizing this computational technique, healthcare professionals can gain valuable insights into the distribution of radiation doses and optimize imaging techniques to minimize patient exposure levels and helps in identifying the local DRL for certain procedures in limited resource settings. The computation of ESD can be done by using mathematical formulas incorporating the machine parameters for certain radiographic procedure or by thedirectly using Dose Area Product (DAP) output values to estimate the skin surface doses , is important input parameter for accurate estimation of ESD by Monte Carlo simulation methods. (5)In this paper, we will delve into the application of Monte Carlo simulation for estimating entrance surface doses in five specific diagnostic radiography examinations: Chest PA, Abdomen, Lumbar Spine, Skull AP, and Pelvis AP views. We will try to shed light on the potential benefits and implications for patient care.

While Monte Carlo simulation is a valuable tool for estimating entrance surface doses in diagnostic radiography, it is important to consider the limitations and potential drawbacks of this approach. One of the primary concerns is the complexity and computational resources required for accurate Monte Carlo simulations. The detailed modeling of patient geometry and tissue density, along with clinical exposure parameters, demands significant computational power and expertise in simulation techniques.(6)

Material & Methods

This research was undertaken at SMS Medical College, Jaipur, a prestigious government hospital in India renowned for its expansive radiology department. The department serves a substantial patient base, performing radiography for over 1000 individuals in a day across various sites within the

https://doi.org/10.46376/ijmr/05.05.2024:2592-2599

institution. With a team comprising more than 100 technologists, each possessing between 5 to 35 years of experience, the department boasts a wealth of expertise. During the study, meticulous attention was paid to the radiation exposure levels generated by the radiological equipment. Stringent quality control and assurance protocols, as mandated by the Atomic Energy Regulatory Board, were rigorously followed for every piece of equipment involved. Before the commencement of the study, the machine setup, procedural workflows, and exposure protocols were meticulously optimized to align with the tolerance limits outlined in the AERB guidelines. Table 1 presents a comprehensive tabulation of the machine parameters collected throughout the study, reflecting the meticulous approach adopted in gathering and analyzing data.(1)

The study encompassed an assessment of 14 X-ray-generating units, with a thorough examination of 1845patients conducted for analysis. Patient selection was facilitated through the convenience sampling method, ensuring a representative cross-section of cases for evaluation. Prior to commencement, ethical clearance was diligently secured from the institutional ethical committee, underscoring the adherence to ethical standards and procedural integrity.

Entrance surface dose measurements for the radiographic procedures were conducted utilizing Thermo Luminescence Dosimeters (TLD) and Optically Stimulated Dosimeters (OSLD). These dosimeters were strategically positioned on the whole-body human radiographic phantom PBU-60, sourced from Kagaku Kyoto Japan, as well as on the skin of participating patients at the entry point of the X-ray beam for the five specified radiographic procedures.(7) To ensure a comprehensive representation, the patient cohort was carefully composed to reflect equal proportions across genders, various age brackets, and diverse BMI categories. The precise positioning of the dosimeter for radiographic examinations is detailed in Table 2, offering a structured overview of the study's methodology.(8)

The data were collected over a span of six months, during which all five radiographic examinations were conducted according to standardized protocols and techniques. Dose Area Product (DAP) values for both patients and the whole-body human radiographic phantom were meticulously recorded across all five radiographic procedures, facilitating Monte Carlo simulation of Entrance Surface Dose (ESD).(9) Monte Carlo simulations were executed using PXCMC 2.0.1, specialized software developed by the Radiation and Nuclear Safety Authority STUK in Finland, commercially available for this purpose. This software integrates specific machine parameters and patient characteristics derived from the collected dataset. (10)The Monte Carlo simulations aimed to estimate entrance surface doses for five distinct diagnostic radiography examinations: chest X-ray, abdomen X-ray, pelvis X-ray, lumbar spine X-ray, and skull X-ray. To validate the accuracy of the simulations, the results were compared with actual measured doses obtained through traditional measurement techniques utilizing TLD and OSLD.(11) The findings of these measurements are summarized in Table 3.

The calculated mean Entrance Surface Dose (ESD) values for various radiographic examinations were compared with those of other similar studies, as indicated in Table 4. Mean ESD values were computed for all five examinations and juxtaposed with findings from analogous studies conducted in different countries.

Results

Quality Assurance of X-ray machines is pivotal in safeguarding the safety, dependability, and precision of diagnostic imaging. These vital procedures are instrumental in preserving exceptional image clarity, reducing radiation exposure risk to both patients and healthcare staff, and elevating the overarching standard of healthcare services. Below, we summarize the outcomes of the rigorous QA process applied to the X-ray equipment, reflecting our commitment to clinical excellence and patient care. The summarized results of the QA performed for the x-ray equipment are as follows: -

https://doi.org/10.46376/ijmr/05.05.2024:2592-2599

Table I: Summery of QA test performed for x ray equipment's

Parameter Investigated	Test Result (Mean Values)	Tolerances
X-ray Tube and Generator Performance:		
- Peak kilovoltage (kVp) accuracy and reproducibility	All kVp stations were found were within the tolerance	**± 5 kVp**
- Tube current (mA) and exposure time accuracy and reproducibility	All (mA) stations were found were within the tolerance	**± 10 %**
- Timer accuracy	Within the tolerance	**± 10 %**
-Linearity of mA loading station & Timer (COL)	Within the tolerance	COL<0.1
Beam Quality and Filtration:		
- Half-value layer to determine the beam quality and ensure adequate filtration	Total filtration of the X -ray unit tested were greater than 3.5 mm Al	≥2.5 mm Al for kV >100
Radiation Field Alignment and Light Field Congruence		
-Congruence of radiation and optical field	Within the tolerance	4 % of TFD
-Central beam alignment	$< 1.5^0$	$< 1.5^0$
X-ray Beam Collimation:		
- Proper function of the collimator and shutters	Maximum	
- Verification of field size indicators	Done	
Dosimetry:		
- Output consistency (COV)	Within the tolerance	COV<0.05
Image Receptor Systems:		
- Proper working condition of the imaging plates or digital detectors	Yes	
- Image receptor alignment with the X-ray beam	No (manual)	
Image Quality:		
-Focal spot size	In between 1.2 mm X 1.2 mm to 1.65×1.65 mm	+ 0.4 f for 0.8≤f≤1.5 mm
-Tube housing leakage	75 mR in 1 hour	115 mR in 1 hour
-Table top dose rate at 45 cm	4.537 R/min	5.7 R/min at 45 c
Safety Mechanisms:		
- Function of warning lights and indicators	Functional	
- Integrity of protective lead shields and curtains	Yes (maximum)	
Mechanical Integrity:		
- Stability and smooth operation of the X-ray tube stand, patient table, and wall stands	Quite OK	
- Tube locks and detent positions	Quite OK	
Environmental Safety:		
- Condition and cleanliness of equipment	Quite OK	
- Adequate space for safe operation	Yes	

The results indicate that the majority of radiographic equipment complies with the quality criteria set forth by the AERB, thereby ensuring the desired performance of the X-ray machinery. These findings are comparable with a similar study conducted by Sharma et al. (2015).The accurate positioning of a dosimeter to estimate the Entrance Surface Dose for a given radiographic examination is crucial for assessing the radiation dose received by the patient. Practically, the central point of the X-ray beam delivers the highest radiation dose. However, ideally, one would expect a uniform distribution of dose across the entire exposed area. In our study, the dosimeter was positioned at the center of the radiation field, adhering to the anatomical landmarks specified in Table 2 for each type of radiographic examination.

https://doi.org/10.46376/ijmr/05.05.2024:2592-2599

Table 2: anatomical landmarks for placement of dosimeter

	Chest PA	Abdomen AP	Skull AP	LS Spine AP	Pelvis AP
Central ray	The central ray should align with the level of the T 7 vertebra. The central ray was centered between the base and apex of the lungs	The Central ray is directed to enter the patient's midline at the level of the iliac crests (L4-L5 intervertebral space).	The central ray is directed perpendicularly to enter the skull at the nasion (the depression at the bridge of the nose).	The Central rays aimed at the midline of the body at the level of the iliac crests, which typically corresponds to the L3-L4 intervertebral disc space.	The central ray should be directed to the midline of the body at the level of the greater trochanters or for adults, approximately 2 inches above the pubic symphysis. This typically corresponds to the midway point between the ASIS (anterior superior iliac spine) and the pubic symphysis.
Collimation	The top and bottom border are level with the apex and base of the lungs. The lateral border is collimated to the outer margins of the ribcage	The superior margin of collimation is usually at the diaphragm level, and the inferior margin is at the symphysis pubis or slightly below.	The collimation margins should be just outside the bony margins of the skull to ensure the entire calvarium is included.	Collimation should also include the lateral The collimation margin of the lumbar spine on both sides, typically to the widest part of the abdomen to capture the transverse processes.	The superior border of collimation should clear the iliac crests, while the inferior border should extend to include the proximal one-third of the femur. Laterally, the collimation should extend to the outer skin margin, ensuring the lateral aspects of the pelvis and proximal femurs, including greater trochanters, are included.

The central ray guides the perpendicular placement of the dosimeter to the beam, while appropriate collimation ensures a minimal Field of View that encompasses the required anatomy. An increased field of view (FOV) results in higher radiation doses received by the patient; conversely, a reduced FOV may lead to the omission of the necessary anatomical areas in the radiograph. Therefore, the FOV must be adjusted to the smallest possible dimensions while still covering the targeted anatomy.

Table 3: Mean ESD by various dosimetric methods

	PCXMC (mGy)	TLD (mGy)	OSLD (mGy)
Chest PA			
Phantom	1.32	0.94	1.02
Patients	1.48	1.01	1.191
Abdomen AP			
Phantom	1.42	0.98	1.17
Patients	1.62	1.15	1.34
Skull AP			
Phantom	3.48	2.36	2.8
Patients	4.03	2.89	3.4
LS Spine AP			

Table 4: mean Entrance Surface Dose (ESD) values in similar studies

Phantom	9.3	6.9	7.8
Patients	10.84	8.02	9.32
Pelvis AP			
Phantom	8.1	5.96	6.8
Patients	8.93	6.1	7.2

	Chest PA	Abdomen AP	Skull AP	LS Spine AP	Pelvis AP
This Study	1.32	1.42	3.48	9.3	8.1
(Latifah et al., 2020)	0.26	-	0.04	-	-

https://doi.org/10.46376/ijmr/05.05.2024:2592-2599

(Jeyasugiththan et al., 2022)	0.59	5.95	-	7.56	-
(Sharma et al., 2015)	0.23	-	3.02	5.9	6.53
(Panahi et al., 2021)	0.51	-	0.54	-	-
(Promduang et al., 2019)	0.1	1.2	-	-	-
(Ofori et al., 2014)	0.27	-	-	3.25	1.31
(Aliasgharzadeh et al., 2015)	0.37	1.39	2.01	1.76	2.18

The estimated mean Entrance Surface Dose values obtained using Monte Carlo software PCXMC, and by physical measurements with Thermoluminescent dosimeters and optically stimulated luminescence dosimeters, are summarized in Table 3. The results indicate that the doses measured by Monte Carlo simulation methods are slightly higher than those measured by physical dosimetry. The discrepancies between Monte Carlo simulation and physical dosimetry potentially arise from the inherent limitations and uncertainties of each measurement technique, as well as patient positioning, anatomical variations, and differences in calibration and dosimeter response. PCXMC version 2.1.0 generates X-ray spectra based on the peak tube potential and total filtration, in accordance with Birch and Marshall's theory, using 1 keV energy bins.(12)

We utilized PCXMC's body size adjustment feature to accurately simulate 146 individuals with various heights (125 - 180 cm) and weights (20 - 140 kg). This process entails scaling a reference stylized phantom to create modified phantoms that more closely represent real human anatomy. Simulations were conducted to estimate the ESD for Chest PA, Abdomen AP, Lumbar Spine AP, Pelvis AP, and Skull AP radiographic examinations, employing a point source emitting photons that mimic the energy spectra, FOV, collimation, and source-to-surface distance used in clinical settings. The selected values for SSD, FOV, and collimation were based on relevant anatomical landmarks within the phantom for the Monte Carlo simulation. Furthermore, the X-ray beam was meticulously centered on the specific anatomy of interest using a defined reference point in PCXMC. (13)Our study found that the Monte Carlo simulation method calculated a constant amount of backscatter across a set energy range and patient anatomy. However, we observed that this effect is less pronounced in patients with lower BMI, lower X-ray energy, and a smaller FOV, leading to an overestimation of ESD by Monte Carlo simulation compared to physical measurement techniques. (14)Additionally, physical dosimeters, including screened nanoDots, exhibit dependencies on angle and energy, which must be accounted for during the calibration process. NanoDots calibrated for an energy range starting at 80 kVp or higher may experience a dose fall-off of approximately 6-10%, necessitating the implementation of correction factors to ensure accuracy in dose measurement.(15)

There is a close agreement between the doses calculated by PCXMC and those measured by OSLD and TLD.(16) The Pearson Correlation Coefficient Calculator indicates a value of "R" equal to 0.9992 between PCXMC and OSLD, while the value between PCXMC and TLD is 0.9985, demonstrating a strong correlation between the Monte Carlo method and physical measurement techniques. Furthermore, a p-value of 0.002691 at a .05 significance level provides substantial evidence to reject the null hypothesis. Thus, it can be affirmed that Monte Carlo methods for estimating doses can be highly beneficial in low-resource and high-throughput settings, offering an approximation of dose reference levels for local scenarios across various radiological examinations.(17) The results of the study align with the patterns of other studies referenced in Table 4. However, our estimated doses are somewhat higher than those mentioned in these studies, which might be attributed to variations in factors such as modality usage, choice of exposure parameters, body mass index, field of view, and collimation. This underscores the necessity for further research to comprehend the impact of each contributing factor and to maximize optimization in radiography.(18)

Conclusions

In conclusion, Monte Carlo simulations have proven to be a valuable tool for estimating entrance surface doses in diagnostic radiography examinations. They

https://doi.org/10.46376/ijmr/05.05.2024:2592-2599

demonstrate close agreement with physical measurement techniques such as OSLD and TLD. Furthermore, they offer the advantage of estimating doses in low-resource and high-throughput settings, rendering them valuable in various radiological examinations. The study also revealed that estimated doses using Monte Carlo simulations were somewhat higher for our practice than those reported in other studies. This variance may be attributed to factors such as modality usage, choice of exposure parameters, body mass index, field of view, and collimation. These simulations aid in generating patient radiation dose datasets for different radiological examinations after optimizing the protocols followed for various procedures.

Optimizing practices based on the shortcomings inferred from the initial observations and dose measurements helped reduce patient doses. Regular updating of knowledge and training enabled radiation professionals to perform radiological examinations with lower radiation doses to patients as well as themselves. This underscores the necessity for further research to fully comprehend and optimize these contributing factors in radiography practices.

The quality assurance and quality control of all radiation equipment need to be regularly verified and strictly adhered to. As observed from the literature review, regular follow-up significantly reduces set radiation doses for various radiographic procedures, thereby ensuring patient safety and optimizing radiation dose in diagnostic radiology.

Acknowledgments

All of the sources of support for the work described in this publication are acknowledged below:

- Rajasthan University of Health Sciences, Jaipur
- SMS Medical College, Jaipur

Declaration of interest statement

We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

References

1. Sharma R, Sharma SD, Pawar S, Chaubey A, Kantharia S, Babu DAR. Radiation dose to patients from X-ray radiographic examinations using computed radiography imaging system. J Med Phys [Internet]. 2015 Apr;40(1):29. Available from: https://doi.org/10.4103/0971-6203.152244

2. Promduang A, Pongnapang N, Ritlumlert N, Tangruangkiat S, Phonlakrai M. A Study of Entrance Surface Air Kerma for Patients Undergoing Chest and Abdomen from Digital Radiography at Chulabhorn Hospital. Journal of Health Science and Medical Research (JHSMR) (Online) [Internet]. 2019 Apr;37(1):51. Available from: https://doi.org/10.31584/jhsmr.201940

3. Vanõ E, Miller D, Martin C, Rehani M, Kang K, Rosenstein M, et al. Annals of the ICRP Diagnostic Reference Levels in Medical Imaging.

4. Jeyasugiththan J, Ehalagasthanna GPNT, Hishaam U, Satharasinghe DM. DETERMINATION OF ENTRANCE SURFACE DOSE FOR THREE COMMON PLANAR DIAGNOSTIC X-RAY EXAMINATIONS. Radiat Prot Dosimetry. 2022 Oct 25;198(18):1361–7.

5. Andersson J, Bednarek DR, Bolch W, Boltz T, Bosmans H, Gislason-Lee AJ, et al. Estimation of patient skin dose in fluoroscopy: summary of a joint report by AAPM TG357 and EFOMP. Med Phys. 2021 Jul 1;48(7):e671–96.

6. Borrego D, Lowe EM, Kitahara CM, Lee C. Assessment of PCXMC for patients with different body size in chest and abdominal x ray examinations: a Monte Carlo simulation study. Phys Med Biol [Internet]. 2018 Apr;63(6):65015. Available from: https://doi.org/10.1088/1361-6560/aab13e

7. Aliasgharzadeh A, Mihandoost E, Masoumbeigi M, Salimian M, Mohseni M. Measurement of Entrance Skin Dose and Calculation of Effective

Dose for Common Diagnostic X-Ray Examinations in Kashan, Iran. Glob J Health Sci. 2015 Feb 24;7(5).

8. Ofori K, Gordon SW, Akrobortu E, Ampene AA, Darko EO. Estimation of adult patient doses for selected X-ray diagnostic examinations. J Radiat Res Appl Sci. 2014 Oct;7(4):459–62.

9. Panahi F, Mohammadi M, Naserpour F, Hassanpour N, Gholami M. Entrance dose determination and effective dose calculation in chest and skull radiographies: an experimental and computational study. International Journal of Radiation Research. 2021 Oct 1;19(4):899–906.

10. APPENDIX F: PCXMC—A PC-BASED MONTE CARLO PROGRAM FOR CALCULATING PATIENT DOSES IN MEDICAL X-RAY EXAMINATIONS. J ICRU [Internet]. 2005 Apr;5(2):100–2. Available from: https://doi.org/10.1093/jicru/ndi034

11. Chougule A. Scattered radiation dose to cornea of cancer patients of head and neck region treated by EBRT. 2015 Apr;

12. Khelassi-Toutaoui N, Berkani Y, Tsapaki V, Toutaoui AEK, Merad A, Frahi-Amroun A, et al. Experimental evaluation of PCXMC and prepare codes used in conventional radiology. Radiat Prot Dosimetry [Internet]. 2008 Apr;131(3):374–8. Available from: http://dx.doi.org/10.1093/rpd/ncn183

13. PCXMC 2.0 SUPPLEMENTARY PROGRAMS USER'S GUIDE. 2012 Apr;

14. Validation and Estimation of Entrance Surface Doses for Five Diagnostic Radiography Examinations Using Monte Carlo Simulation Authors.

15. Scarboro SB, Cody DD, Stingo FC, Alvarez P, Followill DS, Court LE, et al. Calibration strategies for use of the nanoDot OSLD in CT applications. J Appl Clin Med Phys [Internet]. 2018 Apr;20(1):331–9. Available from: https://doi.org/10.1002/acm2.12491

16. Kadir ABA, Priharti W, Samat S, Dolah MT. OSLD energy response performance and dose accuracy at 24 - 1250 keV: Comparison with TLD-100H and TLD-100. AIP Conf Proc [Internet]. 2013 Apr; Available from: https://doi.org/10. 1063/1.4858638

17. Kulkarni A, Akhilesh P, Sharma SD. Measurement of patient skin dose and establishment of local diagnostic reference levels for interventional cardiology procedures. Radiation Protection and Environment [Internet]. 2019 Apr;42(1):28. Available from: https://doi.org/10.4103/rpe .rpe_8_19

18. Satharasinghe D, Jeyasugiththan J, Wanninayake WMNMB, Pallewatte A, Samarasinghe RANKK. Patient size as a parameter for determining Diagnostic Reference Levels for paediatric Computed Tomography (CT) procedures. Physica Medica [Internet]. 2022 Apr;102:55–65. Available from: https://doi.org/10.1016/j.ejmp.2022.09.004