Importance of Dose Reference Level in Pediatric Computed Tomography

Bastos, C. O.[1],Assis, B. S.[1,3], Nascimento, M. R[1], HAMANN, J H.[1,4] , Chaves, T. O.[2,4] and Peixoto, J. G.P[1]

[1] Instituto de Radioproteção e Dosimetria, Rio de Janeiro, Av. Salvador Allende, 3773 - Barra da Tijuca 22780-160, Brazil

[2] Instituto Fernandes Figueira, Rio de Janeiro, Av. Rui Barbosa, 716 - Flamengo 22250-020, Brazil

[3] Universidade Federal Fluminense, Rio de Janeiro, Av. Gal. Milton Tavares de Souza, s/nº – Campus da Praia Vermelha 24210-346, Brazil

[4] Complexo Hospital de Clínicas - Universidade Federal do Paraná, CHC - UFPR, Brasil.

bastos.c1999@gmail.com

Abstract. Radiation dosimetry is vital in minimizing health risks associated with ionizing radiation, especially for pediatric patients who are more sensitive and at higher risk. Chest radiography and computed tomography (CT) are common procedures for diagnosing pediatric patients, but the distribution of radiation dose in CT is different and often results in higher effective doses. To ensure patient safety, the As Low As Reasonably Achievable (ALARA) principle should be followed, and diagnostic Reference Levels (DRLs) should be established. DRLs serve as crucial tools to optimize dose and achieve high-quality diagnostic imaging while minimizing radiation risks. This article focuses on studying the variables for the verification, validation, and creation of a dose reference level in CT for pediatric patients in Rio de Janeiro, Brazil. International standards such as ICRP 135 and Radiation Protection N° 185 are used as references. The study considers factors such as weight, height, age, scan time, number of images, CTDIvol, collimation, and beam energy. The procedures analyzed are divided into head, chest, and abdomen. Probability models, specifically the T-Student Distribution method, will be used to analyze the data and determine diagnostic reference levels. Excel and Python will be used for data analysis and statistical tests. The expected results include the determination of specific diagnostic reference levels for pediatric CT in Rio de Janeiro, reducing the risk of cancer induction, and minimizing excessive doses. In conclusion, establishing dose reference levels for pediatric CT is crucial for radiological protection. Specialized DRLs that consider the unique characteristics of pediatric patients are necessary to ensure optimized dose and radioprotection for all pediatric groups undergoing CT.

1. INTRODUCTION

Ionizing radiation dosimetry is directly and indirectly related to what we call radiological quantities, with the main function of minimizing health risks related to its application. When we approach biological organisms, the effects caused by ionizing radiation, according to Roh, C (2020)., are due to the deposition of energy to cellular targets directly or involving highly reactive free radicals. Those products of the interaction could damage DNA, RNA, proteins, lipids, carbohydrates and many metabolites leading to various pathological diseases[1].

When analysing studies related to pediatric patients, a greater radiosensitivity of these individuals is evident, especially when we talk about the neonatal phase that is from the day of birth to the twenty-eighth day of life[2]. For these patients, the risks associated with exposure to ionizing radiation is similar to found in prenatal patients in the last trimester of the gestational period[3], but variations in the period of birth can directly influence the observed pattern of radiosensitivity in individuals, as is the case of premature individuals, especially those who are below the thirty-seventh week, which makes them if so, more radiosensitive than the others[4,5]. Other factors such as weight, body measurements and age directly influence the individual dose[6].

About 60% of pedriatic patients exposures are related to chest radiography[6], and the use of these x-ray systems is present in neonatal intensive care units. In this sense, it is essential that the ALARA principle is widely used[7], making the doses of these individuals as small as possible so that the expected image results can be obtained without unnecessary radiation dose to the patient[8]

Therefore, the establishment of diagnostic Reference Levels (DRLs) becomes a crucial tool to raise awareness of issues related to dose optimization[9], consequently obtaining diagnostic benefits and achievable doses[10].

Computed tomography (CT) is also of paramount importance for the diagnosis of these patients, but as well as conventional X rays, it is important to be aware of exposure[11], since when we treat about this pediatric population, 5-10% of CT exams are performed in this group[12]

Thus, it is necessary to use the standards of national and international agencies, as well as exclusive radiation protection plans for the use in these patients[13], so that the carcinogenic effects of exposure to low-level ionizing radiation, that were previously stated by scientific society as a major concern can be even more minimized[13,14]. With smaller doses, the risk of cancers such as leukemia,which is most commonly observed in children and is historically one of the first types of cancer associated with ionizing radiation, will also be reduced[15].

In order to increasingly preserve these very radiosensitive individuals, standards such as ICRP 135 and Radiation Protection N°185 evaluates the importance of dose reference levels, especially when talking about radiation protection in imaging exams, which is the case of computed tomography[17,20].

1.2 Computed Tomography

Computed tomography is a non-invasive procedure that uses ionizing radiation to produce detailed images from transmitted x-ray through the human body for . It procedures related to patient diagnosis.

When analyzing image formation, computed tomography brings crucial information for the diagnosis, since it has a low contrast and, in turn, its performance in cases of density differentials, it ends up having great prominence in the image transmission process, as this ends up not having the so-called object superposition mainly due to the double collimation made in the equipment beams, as well as its image that is received through slices providing a more detailed image[16].

The dose distribution in computed tomography is completely different from that of conventional radiology, as tube rotation generates a more uniform dose throughout the tomographic section. (MAIA, A.F.,)[16]. However, with the rotation more slice images are produced increasing effective dose.

While a x-ray chest exam in adults provides an average about 0.10 mSv, the tomography of the same region is about 5.5 mSv[29]. (Kroft, Lucia J.M et all, 2019)
For the construction of a DRL referring to computed tomography, some factors are crucial, in achieving greater precision in measurements: as tomography time, number of images, CTDIvol, collimation, tube voltage (kV) anodic current (mA) and pitch. These parameters aligned with the patient variables described in topic 3, can lead DRLs to be obtained with greater precision and thus, investigate the biological effects from ionizing radiation.
Both volume computed tomography dose index (CTDIvol) and dose length product (DLP) are recommended quantities for setting DRLs. The shape is relevant for the patient dose per slice while the latter is relevant for the patient absorbed dose for the complete CT procedure. Both quantities together enable analysis of the scan length, for instance in the study of the reasons for exceeding a DRL. In modern CT scanners, both CTDIvol and DLP are available from the console and can also be automatically retrieved from the radiation dose structured reports for automatic dose management. Besides CTDIvol, a Size-Specific Dose Estimate, when available, can be used as a DRL metric for body CT examinations (Radiation protection no. 185) [17].
The dose to which the patient is subjected during the CT examination is estimated using the CTDIvol (Computed Tomography Dose Index), which represents the dose index in computed tomography, informed for each examination and previously calibrated using simulators. This value is not the patient's dose, which directly reflects the risk, but an indicator that characterizes the radiation exposure in CT used to compare with practice. Another parameter stored by the CT equipment is the DLP (Dose-Length Product). This theoretical quantity is defined as the product between the CTDIvol and the irradiated length in the patient(Friedrich,Q. B. et all, 2015).

1.3 Dose Reference Levels

When we talk about biological effects in pediatric patients, especially those who are in the first years of life, we must keep in mind that they end up being the most radiosensitive among patients.
Therefore, studies regarding the reference levels of dose for tomography in pediatric patients become essential, so that cellular, histological, system and whole body effects are avoided. New paths and possibilities must be treated and analysed to decrease the dose experienced by these individuals.This approach is known as ALARA (As Low As Reasonably Achievable) principle of keeping radiation levels as low as reasonably achievable, taking into account all radiological protection guidelines and using monitoring and dose evaluation in order to maintain the limits established by existing standards. which directs the serious and committed multidisciplinary work of radiological protection.
DRLs are used, in a way, by Ordinance 453, edited by the Brazilian Ministry of Health, as a dose parameter for X ray and CT exams, so that, when measured in equipment, the value acquired must be close to that stipulated by the cited regulation.Worth remembering that currently the RDC 611 of March 2022 ends up being the standard currently used for radiological protection parameters, and before such topics were covered by Ordinance 453. Significantly higher or lower values should be investigated, as a way to restrain practices that lead to an excess dose or provide an image quality below the essential for a quality exam (SAVI, M. B. M. B, 2014)[18]. Thus, DRLs are a monitoring tool that aims to attract the attention of professionals and authorities responsible for the dose delivered to patients, helping to identify opportunities for optimizing protocols and practices. (Seraphim et al, 2020)[19]

Optimisation of paediatric imaging is of particular importance because the risk of harmful radiation effects is greater in children than in adults, and they have a longer life expectancy during which these effects may manifest. Moreover, the smaller body size of most children compared with adults means that more organs are likely to be within or near the primary beam, so precise collimation is both more important and more difficult (ICRP, 2013b)(ICRP 135, 2017)[20,21].

The dose used for pediatric exams ends up varying due to several factors. To guarantee a DRL, data referring to patients become fundamental to provide greater accuracy: such as weight, height, age, sex of the individual and body thickness. Some of these variables can be seen in Table 1.

Unlike what was previously proposed, the DRLs in their current model use the weight of the pediatric individual as a factor of greater reliability, since in the past, patient age has been used to define groups of children for the purpose of establishing paediatric DRLs. Typically, ages of 0 (neonate), 1, 5, 10, and 15 years[20]. So, in some situations only the age bands are available for evaluation, in this case can be used if age is the only available measure.

Description	Weight group (kg)	Age group based on weight-for-age charts	Most common age groups used for the previous national DRLs (years)
Neonate	<5	<1 month	0
Infant, toddler, and early childhood	5–<15	1 month to <4 years	1
Middle childhood	15–<30	4–<10 years	5
Early adolescence	30–<50	10–<14 years	10
Late adolescence	50–<80	14–<18 years	15

Table 1: Weight grouping for paediatric diagnostic reference levels (DRLs) recommended by the European Guidelines on DRLs for Paediatric Imaging and approximate equivalent ages (EC, 2016), and age groups used for earlier surveys. (ICRP 135, 2017)[20].

Another point to be observed is that some anatomical regions end up being more commonly observed in computed tomography procedures, namely the head, chest and abdomen. Some irradiated areas are shown in table 2.

Anatomical region	**Procedure**
Head	Routine Paranasal sinuses Inner ear/internal auditory meatus Ventricular size (shunt)
Neck	Neck
Chest	Chest
	Cardiovascular CT angiography
Abdomen	Abdomen (upper abdomen)
	Abdomen+pelvis
Trunk	Whole body CT in trauma
Spine	Cervical spine
	Thoracic spine
	Lumbar spine

Table 2: CT exams that require DRLs definition(Radiation protection no. 185, 2018)[17].

An important consideration for the determination of CTDIvol and DLP, as well as for the setting of DRLs in terms of these quantities, is the calibration of the CT console readings. The calibration uses standard cylindrical CT phantoms, with either 16 cm or 32 cm diameters shown in the table 3.("head" and "body" phantoms; IEC, 2002, IAEA, 2013). In some scanners the calibration phantom size used is different in paediatric body CT protocols. In recording and reporting patient dose values, it is therefore essential to state the phantom size (diameter either 16 or 32 cm) used in the calibration of the console value. Consequently, the CTDIvol and DLP values should also always be specified together with the size of the calibration phantom. It is recommended that CTDIvol and DLP are determined for a 32 cm phantom for all paediatric body CT examinations (chest, abdomen, trunk and spine) and for a 16 cm phantom for paediatric head CT examinations (Radiation protection no. 185, 2018)[17].

Computed tomography			
Exam	Age or weight group	**EDRL**	
		$CTDI_{vol}$, mGy	**DLP, mGy cm**
Head	0-<3 months	24	300
	3 months-<1 y	28	385
	1-<6 y	40	505
	≥6 y	50	650
Thorax	<5 kg	1,4	35
	5-<15 kg	1,8	50
	15-<30 kg	2,7	70
	30-<50 kg	3,7	115
	50-<80 kg	5,4	200
Abdomen	<5 kg		45
	5-<15 kg	3,5	120
	15-<30 kg	5,4	150
	30-<50 kg	7,3	210
	50-<80 kg	13	480

Table 3: European DRLs for computed tomography. EDRLs for head CT refer to 16 cm phantom and EDRLs for thorax and abdomen for 32 cm phantom. DRLs refer to a complete routine CT examination (one scan series) (Radiation protection no. 185, 2018)[17]

1.4 Radiosensitivity

Currently, the risk of radiation-induced cancer is a stochastic risk with a non-linear dose model (Bunick et all)[22]. Pearce et al.2012, demonstrated a two- to three-fold increase in the incidence of leukemia and brain tumors in individuals exposed to radiation in childhood[23]. Mathews 2013, and others showed that there was a 24% increase in the overall incidence of cancer in individuals exposed to CT radiation, especially when exposure occurred in minors[24]. Miglioretti et al. estimated that one year of performing pediatric CT in the United States could induce more than 4800 neoplasms in the future. (PERIN, I et all, 2022)[26].

Children, who have many years left to live are more likely than adults to develop radiation-induced cancer; also, as future parents, they are at risk for passing on radiation-induced genetic defects to the next generation (Alzen, G.,2011)[27]. This effect is called stochastic effect, this in turn has its occurrence proportional to the dose that the patient was submitted, allowing the biological effects of this pediatric

individual being both somatic and hereditary, in the case mentioned above, it is a hereditary effect, since we are not talking about the individual in question, but its subsequent offspring.

In this case, it is so much important to remember in cellular radiosensitivity had the cell specialization (in this case, the cell that has less specialization, have more radiosensitivity in and cells in the process of mitosis (proliferative state). The moment in the cell cycle process is also an important factor, the G1 and S moments become more resistant than the cells that are in the process of mitosis or in the G2 phase.(Bastos, C.O.,2020)[30].

Among the tissues that are more sensitive to ionizing radiation, hematopoietic tissues and reproductive cells, young bone and epithelium of the digestive tract, skin, and muscle, and nervous tissue, respectively, can be highlighted in terms of sensitivity (Bastos, C.O.,2020)[30].

Children's and adolescents' tissues also have a higher water content than adult tissues. This means that more radiation is absorbed and dispersed, so a higher dose is needed to penetrate a layer of tissue of the same thickness(Alzen, G.,2011) [27]. In addition, because they are individuals of small body proportion, when we consider the groups in the early years of pediatrics, the exposure of organs close to the irradiated tissue ends up becoming another important issue..Because of this, factors such as device collimation must be carefully defined.

Because they are individuals of small body proportion, when we consider the groups in the early years of pediatrics, an exposure of organs close to the irradiated tissue makes a difference in the location of tissues and also the difference in location of tissues and organs, which have different ratios than those found in adults. An example of an area commonly covered by a CT scan is the rib cage. The rib cage has a rounded appearance at birth, as the anteroposterior and transverse diameters are very close (in adults this ratio is 1:3) and the longitudinal axis is short, with chest circumference similar to abdominal circumference and horizontal ribs. During the first two years, the circumference start to differentiate itself and the thoracic circumference becomes increasingly larger than the abdominal (GARDNER; GRAY; O'RAHILLY, 1971; LATARJET; LIARD, 1993; ROHEN,YOKOSHI; LUTJEN-DRECOL, 2007) (Teixeira, P.T., 2008)[28].

2. OBJECTIVE:

To conduct a study of the important variables for a future verification, validation, and creation of a dose reference level in computed tomography based on the ecotype of pediatric patients located in the state of Rio de Janeiro/RJ, aiming at radioprotection in order to minimize the biological effects of ionizing radiation. It is worth noting that the entire study will be based on the international standards ICRP 135 and Radiation Protection No. 185.

3. MATERIALS AND METHODS

Due to issues related to the standardization of the exposure of these individuals, this research has been divided into parts so far.

3.1 Standards

The standards used as the basis for this work, mentioned earlier, have become fundamental for characterizing the dose reference level. When it comes to pediatric patients, factors such as weight, height, body dryness, and age are crucial for greater precision in establishing a dose reference level. According to European Commission Radiation Protection Standard No. 185, the weight and age criteria follow the following pattern: Weight groups for body exams: < 5 kg, 5 - < 15 kg, 15 - < 30 kg, 30 - < 50 kg, 50 - < 80 kg. The recommended first weight group (< 5 kg or neonates) applies to

newborn babies but does not apply to those in incubators. Age groups for head exams: 0 - < 3 months, 3 months - < 1 y, 1 - < 6 y, ≥ 6 y (Radiation Protection No. 185, 2018)[17].

3.2 Variables

Regarding the variables, they were divided into two topics: the CT scanner and the collection of patient data, in order to establish thresholds in this study. It's important to note that all data related to the variables will be collected later in the database at the research site, where such request will be submitted to a research ethics committee.

3.2.1 CT Scanner

As for the CT scanner, the variables that are essential for conducting the study are: scan time, number of images taken, information about the equipment operator, CTDIvol, image acquisition date, collimation of the equipment used, and beam energy in kV.

3.2.2 Patient

When considering patient variables, factors such as weight in kilograms, height in centimeters, age in years or months (for individuals under 1 year of age), gender of the individual undergoing the procedure, and body thickness are crucial for greater accuracy in determining the absorbed dose in these biological systems. Information regarding the division of groups by weight and age can be seen in Table 4 extracted from Radiation Protection Standard N° 185. Another crucial aspect will be the division of the procedures to be analyzed, which will consist of three groups: head, chest, and abdomen.

Recommended weight groups (intervals) for *body* examinations	**Recommended age groups (intervals) for *head* examinations**
< 5 kg	0 - < 3 months
5 - < 15 kg	3 months - < 1 y
15 - < 30 kg	1- < 6 y
30 - < 50 kg	≥ 6 y
50 - < 80 kg	

Table 4: Recommendation of groups according to weight and age for body and head exams in pediatric patients.

3.3 Probability

Among the probability models, for this work, the method approached in the T-Student Distribution will be used. The test will be divided into 6 parts to obtain a result, which are:

1) Determination of the null hypothesis (H0) and the alternative hypothesis (H1) for the comparison of the doses;
2) Collection of data regarding the doses received by each patient, which will be divided into 3 main groups: head, chest, and abdomen. After this process, a new division will be made according to the patient's variables, described in subsection 3.2.2;
3) Calculation of the mean and standard deviation of the doses for each group of patients;
4) Determination of the degrees of freedom;
5) Consultation of the T-Student distribution table;
6) Comparison of the data obtained by the statistical model with the values from the table for the validation of the null hypothesis.

3.4 Software

Among the chosen softwares to work with, Excel will be used in conjunction with Python programming language.

3.4.1 Excel

The data related to the groups will be divided into separate columns according to the sample size, using patient variables. After calculating the mean, standard deviation, and sample size for each group, the software will perform the t-test to obtain the necessary values for interpreting the data.

3.4.2 Python

The numpy and scipy libraries will be installed, which are necessary as an initial step. After the installation process, the importation will be done. After this moment, the data obtained from pediatric patients' tomography scans will be inserted, using arrays from numpy. This command will be repeated according to the obtained sample size. In addition, the mean, standard deviation, and sample size will be calculated for each group, and finally, the ttest_ind function from scipy will be used to perform the T-student test.

4. EXPECTED RESULTS

Among the expected results for this work, the determination of diagnostic reference levels (DRL) for pediatric tomography exams is one of them, aiming at the ecotype of the state of Rio de Janeiro/RJ, thus contributing to the creation of a regional DRL. Another crucial point will be the reduction of dose and the risk of cancer induction in patients undergoing pediatric tomography procedures, so that excessive doses do not affect these more radiation-sensitive patients.

5. CONCLUSION

Thus, it is possible to denote the importance of dose reference levels for pediatric patients, as they are more radiosensitive individuals and with different characteristics than those observed in adults, their DRLs must be specialized and, therefore, radiological protection these individuals may , in turn, be increasingly encompassing for all pediatric groups by computed tomography.

6. ACKNOWLEDMENT

I would like to thank the Institute of Radiation Protection and Dosimetry, as well as the Fernandes Figueira Institute, for providing all the intellectual support so that this article could be written, the Nuclear Energy Commission, for the support offered, CAPES for granting the master's schoolarship, to my supervisor and co-supervisor for helping throughout the research development process and to the IRTech research group.

7. REFERENCES

[1] . Roh, C. (2018). *Metabolomics in Radiation-Induced Biological Dosimetry: A Mini Review and a Polyamine Study. Biomolecules, 8(2), 34.* doi:10.3390/biom8020034

[2] . Rana, B. S., Kumar, S., Sandhu, I. S., & Singh, N. P. (2018). DOSIMETRY OF ADULT AND PEDIATRIC PATIENTS FOR COMMON DIGITAL RADIOGRAPHY EXAMINATIONS. Radiation Protection Dosimetry, 179(4), 349–357. doi:10.1093/rpd/ncx293

[3] . Mattsson, S., Leide-Svegborn, S., & Andersson, M. (2021). *X-Ray and Molecular Imaging During Pregnancy and Breastfeeding—When Should We be Worried? Radiation Protection Dosimetry.* doi:10.1093/rpd/ncab041

[4] . Gislason-Lee, A. J. (2021). Patient X-ray exposure and ALARA in the neonatal intensive care unit: Global patterns. Pediatrics & Neonatology, 62(1), 3–10. doi:10.1016/j.pedneo.2020.10.009
[5] . Schäfer, S. B., Papst, S., Fiebich, M., Rudolph, C., de Laffolie, J., & Krombach, G. A. (2019). *Modification of chest radiography exposure parameters using a neonatal chest phantom. Pediatric Radiology.* doi:10.1007/s00247-019-04522-1
[6] . Asada, Y., & Ichikawa, T. (2019). *Consideration of diagnostic reference levels for pediatric chest X-ray examinations. Radiological Physics and Technology.* doi:10.1007/s12194-019-00533-7
[7] . Hinojos-Armendáriz, V. I., Mejía-Rosales, S. J., & Franco-Cabrera, M. C. (2018). Optimisation of radiation dose and image quality in mobile neonatal chest radiography. Radiography, 24(2), 104–109. doi:10.1016/j.radi.2017.09.004
[8] . Flint, K., Bottenus, N., Bradway, D., McNally, P., Ellestad, S., & Trahey, G. (2020). *An Automated ALARA Method for Ultrasound. Journal of Ultrasound in Medicine, 40(9), 1863–1877.* doi:10.1002/jum.15570
[9] . Célier, D., Roch, P., Etard, C., Ducou Le Pointe, H., & Brisse, H. J. (2019). *Multicentre survey on patient dose in paediatric imaging and proposal for updated diagnostic reference levels for France. Part 1: computed tomography. European Radiology.* doi:10.1007/s00330-019-06405-3
[10] . Tsapaki, V. (2020). *Radiation dose optimization in diagnostic and interventional radiology: Current issues and future perspectives. Physica Medica, 79, 16–21.* doi:10.1016/j.ejmp.2020.09.015
[11] . Kesminiene, A., & Cardis, E. (2018). *Cancer risk from paediatric computed tomography scanning: implications for radiation protection in medicine. Annals of the ICRP, 014664531875623.* doi:10.1177/0146645318756236
[12] . Bashier, E. H., & Suliman, I. I. (2018). *RADIATION DOSE DETERMINATION IN ABDOMINAL CT EXAMINATIONS OF CHILDREN AT SUDANESE HOSPITALS USING SIZE-SPECIFIC DOSE ESTIMATES. Radiation Protection Dosimetry.* doi:10.1093/rpd/ncy164
[13] . Lowe, S. A. (2019). *Ionizing radiation for maternal medical indications. Prenatal Diagnosis.* doi:10.1002/pd.5592
[14] . Callahan, M. J., MacDougall, R. D., Bixby, S. D., Voss, S. D., Robertson, R. L., & Cravero, J. P. (2017). *Ionizing radiation from computed tomography versus anesthesia for magnetic resonance imaging in infants and children: patient safety considerations. Pediatric Radiology, 48(1), 21–30.* doi:10.1007/s00247-017-4023-6
[15] . Kosik, P., Durdik, M., Jakl, L., Skorvaga, M., Markova, E., Vesela, G., … Belyaev, I. (2020). *DNA damage response and preleukemic fusion genes induced by ionizing radiation in umbilical cord blood hematopoietic stem cells. Scientific Reports, 10(1).* doi:10.1038/s41598-020-70657-z
[16] MAIA, A.F., PADRONIZAÇÃO DE FEIXES E METODOLOGIA DOSIMÉTRICA EM TOMOGRAFIA COMPUTADORIZADA , IPEN, 2005. available in<http://pelicano.ipen.br/PosG30/TextoCompleto/Ana%20Figueiredo%20Maia_D.pdf>
[17] Radiation protection no. 185 European guidelines on diagnostic reference levels for paediatric imaging.
[18] SAVI, M. B. M. B, ESTUDO DOS NÍVEIS DE REFERÊNCIA DE DIAGNÓSTICO PARA PROCEDIMENTOS DE TOMOGRAFIA COMPUTADORIZADA NO ESTADO DE SANTA CATARINA, Universidade Federal de Santa Catarina, 2014. available in<https://repositorio.ufsc.br/bitstream/handle/123456789/123260/326189.pdf?sequence=1&isAllowed=y>
[19] Seraphim et al, Definição de Níveis de Referência em Diagnóstico do Serviço de Medicina

Nuclear do Hospital de Clínicas de Porto Alegre, 2020, available in < https://www.bjrs.org.br/revista/index.php/REVISTA/article/view/1208/627>
[20] ICRP, 2017. Diagnostic reference levels in medical imaging. ICRP Publication 135. Ann. ICRP 46.
[21] ICRP, 2013b Protection in Medicine
[22] Bunick A. P., Schelin H. R., Paschuk S. A., Filipov, D., Milhoretto, E., Deniak, Silva J. C. V., Simulação de Kerma-ar na profundidade pulmonar na água, e Kerma-ar na superfície de entrada da pele em pacientes neonatos submetidos a radiografias do tórax AP, 2019, available in < https://sbpr.org.br/revista/index.php/REVISTA/article/view/938/550>
[23] Pearce MS, Salotti JA, Little MP, McHugh K, Lee C, Kim KP, et al. Radiation exposure from CT scans in childhood and subsequent risk of leukaemia and brain tumours: a retrospective cohort study. Lancet. 2012;380(9840):499-505. Available from: doi: 10.1016/S0140-6736(12)60815-0. » https://doi.org/10.1016/S0140-6736(12)60815-0
[24] Mathews JD, Forsythe AV, Brady Z, Butler MW, Goergen SK, Byrnes GB, et al. Cancer risk in 680 000 people exposed to computed tomography scans in childhood or adolescence: data linkage study of 11 million Australians. BMJ. 2013;346:f2360-f2360. doi: 10.1136/bmj.f2360.» https://doi.org/10.1136/bmj.f2360
[25] Miglioretti DL, Johnson E, Williams A, Greenlee RT, Weinmann S, Solberg LI, et al. The use of computed tomography in pediatrics and the associated radiation exposure and estimated cancer risk. JAMA Pediatr. 2013;167(8):700. doi: 10.1001/jamapediatrics.2013.311.
» https://doi.org/10.1001/jamapediatrics.2013.311
[26] PERIN, I.,GUETTER C. R.,KLÜPPEL, L. E.,FACHIN,C. G. e PIMENTEL, S. K. Tomografia computadorizada na avaliação do trauma abdominal pediátrico https://doi.org/10.1590/0100-6991e-20223246, 2022, available in <https://www.scielo.br/j/rcbc/a/skYCTvsmwJsbtFnypfCkyzQ/?lang=pt&lng=pt&nrm=iso&tlng=pt#>
[27] Alzen, G. and Benz-Bohm, G., Radiation Protection in Pediatric Radiology, 2011, available in <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3132617/>
[28] Teixeira, P.T., ANATOMIA DO RECÉM NASCIDO E DA CRIANÇA: CARACTERÍSTICAS GERAIS, 2008, available in https://www.redalyc.org/pdf/260/26012806006.pdf
[29] Kroft, Lucia J.M. MD, PhD; van der Velden, Levinia MSc; Girón, Irene Hernández PhD; Roelofs, Joost J.H. RT; de Roos, Albert MD, PhD; Geleijns, Jacob PhD, Added Value of Ultra–low-dose Computed Tomography, Dose Equivalent to Chest X-Ray Radiography, for Diagnosing Chest Pathology, 2019, DOI: 10.1097/RTI.0000000000000404, available in https://journals.lww.com/thoracicimaging/Fulltext/2019/05000/Added_Value_of_Ultra_low_dose_Computed_Tomography,.6.aspx
[30] Bárbara Q. Friedrich1 , Alexandre S. Capaverde1 , Stefânia Vanni1 , Carolina F. S. Mazzola1 , Ana M. Marques da Silva2 , Dose em exames de crânio e tórax de Tomografia Computadorizada Pediátrica: uma Revisão Bibliográfica, 2015 available in https://repositorio.pucrs.br/dspace/bitstream/10923/12026/2/Dose_em_exames_de_cranio_e_torax_de_Tomografia_Computadorizada_Pediatrica_uma_Revisao_Bibliografica.pdf
[31] Bastosa,C.O., Nascimento,M.R., Peixotob, J.G. Biological effects of Body Scanner equipment, 2020, available in