BJRS

BRAZILIAN JOURNAL
OF
RADIATION SCIENCES
09-02 (2021) 01-17

Estimation of Absorbed Dose in Head CT scans Based on mA and mAs Modulation and Volumetric Air Kerma Index (C_{VOL}) in Petrolina/PE, Brazil

Albuquerque Júnior [a], J. S., Silva [b], E. S., Ramos, R. P.[a], Oliveira [a], R. A. P.

[a]Materials Science Research Institute, Federal University of São Francisco Valley, Juazeiro-BA, Brazil
[b]Diagnostic and Therapeutic Support Service, University Hospital Dr. Washington Antônio de Barros– HU UNIVASF, Petrolina-PE, Brazil
albuquerquefismed@gmail.com

ABSTRACT

Computed tomography (CT) represents a large percentage of radiation dose at medical exposures. Therefore, optimizing patient protection has been a practice with an important discussion. This study aims to estimate the absorbed dose in relevant organs and tissues in head CT scans in adult patients based on automatic modulation of the tube current (mA) and current-time product (mAs), and volumetric air kerma index (C_{VOL}). For that, these parameters were collected during three bimesters in two institutions with ample attendance in Petrolina/PE. One from the private sector, named institution A and another from the public sector, named institution B. Dose evaluation was performed through CALDose_XCT simulation software. The results showed that mean values of mA and mAs per bimester were lower at Institution A, where the automatic exposure control (AEC) was activated, following the guidelines of good practice in CT scans. The C_{VOL} presented mean values within the recommended levels, although at Institution B this parameter has presented greater magnitude. In simulations, institution B presented higher absorbed doses in the relevant structures, corroborating with the lower optimization of mA, mAs and C_{VOL}. This work showed the existence of the link between radiological parameters and the dose absorbed in the patient, suggesting the accomplishment of optimization studies in head CT exams.

Keywords: **head tomography; radiological parameters; relevant structures; absorbed dose.**

ISSN: 2319-0612
Accepted: 2021-06-21

1. INTRODUCTION

Computed Tomography (CT) is used in medical practice to diagnose clinical conditions and guide the appropriate medical procedure [1] quickly and accurately. On the other hand, it presents a large percentage of the dose in exposures, what brings the necessity of some measurements to optimize patient protection [2].

In many developed countries, CT is the dominant source of exposure to ionizing radiation produced by man, accounting for around 70% of contributions in the USA and the United Kingdom [3]. The National Council for the Protection and Measurement of Radiation (NCRP) of the USA showed that, despite constituting only 17% of all radiological exams, CT represents about 49% of the collective effective dose in patients [4].

According to the International Commission for Radiological Protection (ICRP 180), CT contributes an average of 57% of the collective effective dose in most European countries, demonstrating that it alone accounts for more than half of medical exposure [5].

In Brazil, according to the Supplementary Health Care Map, the number of CTs performed by a thousand beneficiaries increased by 21% between 2014 and 2016 and went from 149 in 2016 to 153 in 2017 [6,7]. In Pernambuco, taking into account all CT scanners distributed in the state, Petrolina is the third city with the largest amount [8], making it a distinguished city in terms of performing CT exams in the region.

Bearing in mind that CT is a technique that can provide high radiation doses, its use must therefore be performed safely. This work aims to estimate the absorbed dose in tissues and organs in CT scans of the head based on automatic exposure control (AEC), which modulates the current tube (mA) and the current-time product (mAs), and the volumetric air kerma index (C_{VOL}) in two computed tomography services with comprehensive care in Petrolina/PE, in order to investigate the degree of dose optimization in these exams.

2. MATERIALS AND METHODS

In order to carry out a comparison between public and private facilities with assistance in head CT scans in Petrolina/PE, two were chosen for the development of this work.

The private was named here as institution A and the public named as institution B. Institution A has a Philips CT scanner, Brilliance model of 64 channels, and institution B has a Toshiba CT scanner, model Aquillion CXL also of 64 channels.

2.1. Ethical and Legal Issues

This work was started after approval by the Research Ethics Committee (CEP) of UNIVASF, linked to the National Research Ethics Commission - CONEP for research involving human beings, with a certificate of presentation for ethical appreciation (CAAE) nº: 72193117.1.0000.5196.

2.2. Quantitative study of head CT exams in health institutions

In order to verify which routine procedure was most performed, 9223 CT scans of the head, chest and abdomen were collected through the data of tests performed in both institutions. Then, the period from October 2017 to March 2018 (six months) was adopted for the collection and, from that, it was verified which of these exams was the most frequent within this interval. The focus of this work was considered as the most frequent exam in both institutions, more specifically, the head exams. Once the number of CT scans was collected, one of them was chosen as the focus of study.

2.3. Study of parameters – mA, mAs and C_{VOL}

Before evaluating the optimization of the radiological parameters, the C_{VOL} values presented on the equipment's consoles were compared with the experimental ones. For this, C_{VOL} was calculated using a PPMA (Polymethylmethacrylate) head phantom after acquisitions using routine protocols.

These results are shown in Table 1. It is observed that the values presented show a relative deviation of less than 10% in both institutions.

Table 1: Comparison between measured values of C_{VOL} and those displayed on consoles

Institution	C_{VOL} measeure PMMA Phantom	C_{VOL} console	Relative Deviation (%)
A	29,3	32	8,4
B	49,4	52	5,0

The equipment consoles were accessed to collect the mA, mAs and C_{VOL} parameters and verify the use of the AEC in acquisition. Figure 1 illustrates the console monitor of institution B's equipment from which it was possible to extract some of this information.

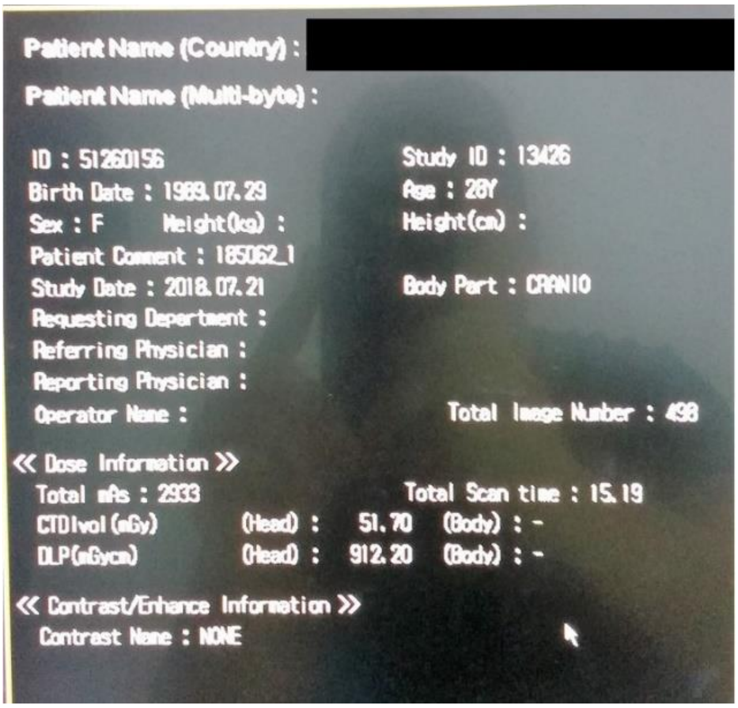

Figure 1: *Institution B equipment operating console interface.*

The radiological parameters were divided into radiographics (mA and mAs) and dosimetrics (C_{VOL}). It was possible to fill each parameter in a table after the exams were completed by the operator.

In order to verify the reproducibility of the head CT exams, the acquisition of the radiological parameters was performed during three bimesters with intervals of one month between them from October 2017 to May 2018 with the maximum number of head exams being accessed on CT system. At the end, 389 scans were obtained at the institution A and 336 at B. Thus, average and standard deviations were calculated for each parameter per bimester for both institutions.

It was also observed the existence of repetitive data to investigate the degree of agreement of the results under the same measurement conditions.

2.4. Estimated absorbed doses in organs with CALDOSE_XCT

The dosimetric study of the institutions was carried out using the Monte Carlo (MC) simulation software CALDOSE_XCT [9]. The software allows the choice of radiological parameters and the type of CT equipment that are selected from the available options, without the possibility of modification in each round of MC.

Figure 2 illustrates the CALDOSE_XCT software interface. It is possible to observe the fields for the selection of the characteristics of the phantom as well as for the filling of some radiological parameters for the dosimetric study based on the kerma in the air at the isocenter, mAs and C_{VOL}. Here, the C_{VOL} parameter was adopted to analyze the relationship between radiological parameters and doses in relevant organs in patients.

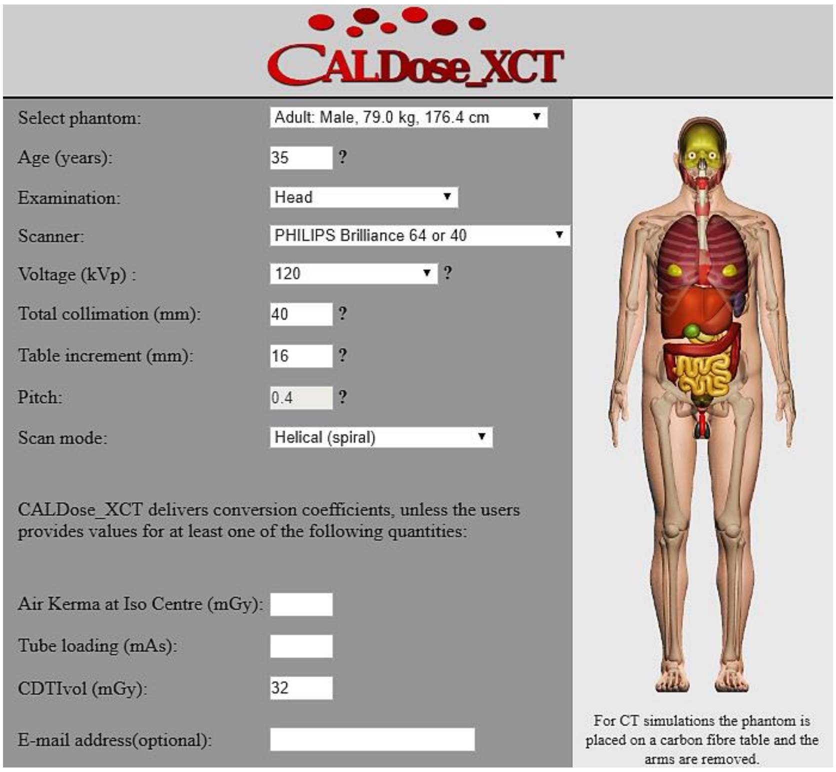

Figure 2: *CALDOSE_XCT software interface.*

In simulations of adult patients, the software has virtual phantoms to measure the absorbed dose in reference individuals, according to ICRP 89 [10], with predetermined data, such as height and body mass for men and women. In addition, it is possible to vary the age between 20 and 80 years.

In each simulation, the fields referring to the parameters were filled with the data collected from those patients who exhibited the characteristics closest to the phantoms available in the software.

In the present study, only four presented the factors closest to the software standards for individuals of both genres.

Thus, the following phantoms were used: both at Institution A and B, the statures and body masses were 176 cm and 79 kg for the male, and 164 cm and 65 kg for the female. Male individuals were considered 39 years old at Institutions A and B and female 35 years old at Institution A and 30 years old at Institution B.

The results of dosimetric calculations by MC were displayed on the software user's screen after an average time interval between 60 and 90 s, as shown in Figure 3.

```
  DATE: 01-08-2018  TIME:  9:34:59.
HEAD CT EXAMINATION FOR PHILIPS Brilliance 64 or 40
MALE ADULT PATIENT, AGE:  39.0 YEARS
BODY MASS: 79.0 KG, STANDING HEIGHT: 176.4 CM
 120 kVcp  8.0 mm Al   7 Deg  Tungsten  IPEM/SR78
MEAN SPECTRAL ENERGY:  63.4 keV
HELICAL (SPIRAL) SCAN, TABLE INCREMENT:  1.57 CM
NUMBER OF ROTATIONS:   10   PITCH:  0.39
SOURCE-TO-ISO-CENTRE DISTANCE: 57.0 cm
TOTAL FIELD SIZE AT ISO-CENTRE:  60.6 cm x   15.7 cm
BEAM WIDTH AT ISO-CENTRE:   4.0 cm    SCAN LENGTH:  15.7  cm
USER CTDIvol:    32.000 mGy

               ABSORBED DOSE

   ORGAN/TISSUE                  mGy        %
EYES                            19.77      1.51
BRAIN                           19.90      0.19
ORAL MUCOSA                     1.224      3.13
LUNGS                           0.032      4.20
MUSCLE                          0.256      0.36
SKIN (AREA COVERED BY CT BEAM)  22.40      0.46
SALIVARY GLANDS                 2.860      1.83
EXTRATHORARCIC AIRWAYS          4.684      1.25
LYMPHATIC NODES                 0.044      7.05
SKELETON AVERAGE                10.09      0.12
MAXIMUM RBM ABSORBED DOSE       17.08      0.91
MAXIMUM BSC ABSORBED DOSE       21.74      0.91
MALE WEIGHTED DOSE              0.628      0.23
```

Figure 3: *Report of absorbed doses for organs and tissues issued by the software.*

3. RESULTS AND DISCUSSION

Figure 4 shows the number of CT scans of head, chest and abdomen performed at institutions A and B from October 2017 to March 2018. It is observed that head exams are the ones that most occur in both institutions.

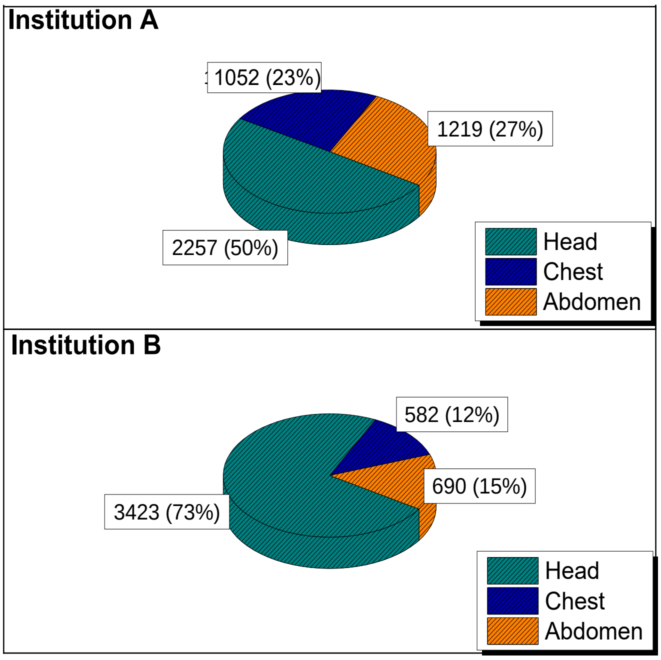

Figure 4: *Number of head, chest and abdomen exams performed at the institutions.*

Furthermore, Figure 4 reveals that head CT exams showing an important dose contribution in radiosensitive organs that come from head's structure studies. It is noteworthy that institution B has a higher demand for head CT.

Table 2 shows the average values of the mA, mAs and C_{VOL} parameters collected from routine head examinations performed at institutions A and B during the three study periods (October 2017 to May 2018).

According to Table 2, the average C_{VOL} value presented in all bimesters at Institution A is at a level below what is most common to find in head tomography exam protocols. This is because of the iDose^4 iterative reconstruction technique used by that manufacturer. The implementation of iDose^4 on the Philips CT scanner platforms allows for a significant dose reduction, preserving the image quality for a complete scan and justifying the amount presented.

Table 2: Average values of mA, mAs and C_{VOL} collected at Institutions A and B.

Bim.	Inst.	mA	mAs	C_{VOL}
1º	A	135 ± 22	101 ± 17	32 ± 4
	B	220 ± 0	165 ± 0	52 ± 0
2º	A	133 ± 16	99 ± 11	32 ± 4
	B	220 ± 0	165 ± 0	52 ± 0
3º	A	143 ± 15	117 ± 11	32 ± 4
	B	220 ± 0	165 ± 0	52 ± 0

Figure 5 (a) shows the mean values of the tube current (mA) presented in the three bimesters for head exams at institutions A and B. Figure 5 (b) shows the mean values of the current-time product (mAs) presented in the three bimesters for head exams at institutions A and B.

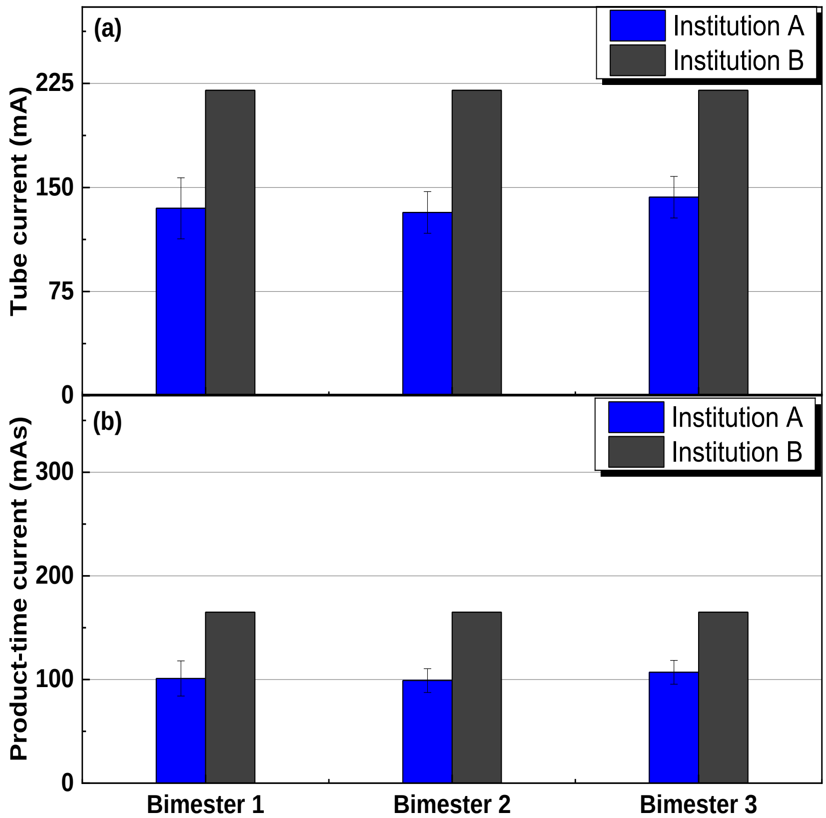

Figure 5: *Average values of mA (a) and mAs (b) in three bimesters.*

In Figure 5 (a) it is observed that there was a variation on mA between bimesters at Institution A. This is possible due to the use of automatic exposure control (AEC), which promotes automatic modulation of mA according to the individual characteristics of each patient [11]. At institution B, the average value was constant in the three bimesters, indicating the absence of mA modulation in the protocol. During acquisition, it was identified that the AEC system was not enabled for routine head acquisitions at this institution.

The AEC controls the mA values, maintaining a balance between dose and image quality. Acquisitions with the same mA will provide a constant current without considering the characteristics of the patients, which may even be influenced according to gender and age. In addition, the dose should be optimized in younger individuals, as they are more sensitive to radiation [12].

Figure 5 (b) shows that at institution A there was a small variation between bimesters of the mAs values. At Institution B, on the other hand, they were constant. It is worth mentioning that the dose increases with the variation of the mAs, showing that this parameter has a linear relationship with the dose absorbed by the patient [13].

The reduction of mAs is an attenuating method for the patient dose, which can be performed with a low mA or through the AEC applied to the examination protocol. Dose optimization can be performed depending on the mA modulation by applying AEC activation at the time of the acquisition [14,15]. The same goes for the mAs, which simply represents the product of mA per time of exposure during acquisition [16].

Depending on the manufacturer's settings, the dose reduction can be up to 60% with the use of AEC for modulation of mA and mAs [17].

Head CT should be carefully monitored to optimize the dose to the eye lens. The use of AEC, compared to the examination with fixed mAs, achieves a substantial decrease in the absorbed dose for this structure, while maintaining a good signal-to-noise ratio in the image [18].

In view of what these studies mention about dose optimization in head CT exams, it is observed that the results presented at institution A better ratify the consulted literature, even considering the recommendations of the good practice guides [2, 19].

Figure 6 shows the average values of the Volumetric Air Kerma Index (C_{VOL}) for head exams at institutions A and B during the three bimesters of the experimental period.

According to the results, it is possible to have less optimization in head CT at Institution B. Its average values of C_{VOL} per bimester are about 1.6 times higher than those of institution A.

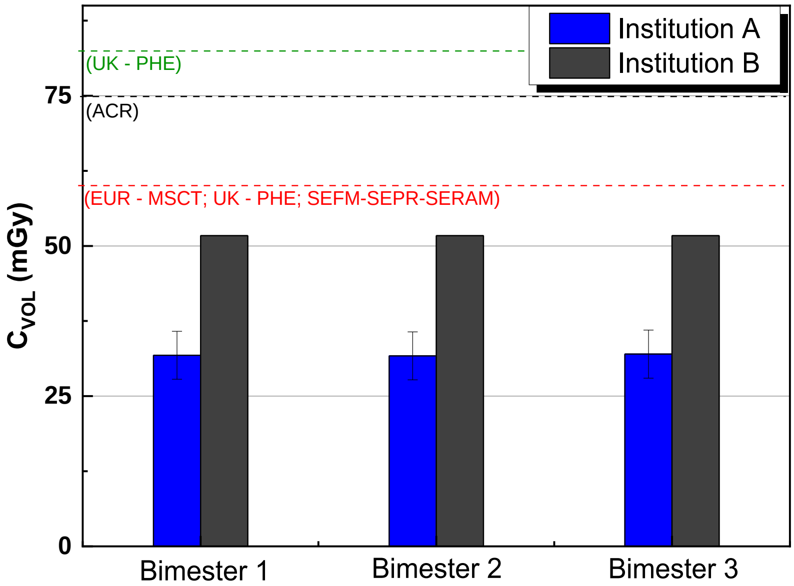

Figure 6: *Average C_{VOL} values in the three bimesters for head exams with references from the United Kingdom (green), American College of Radiology (black) and European Commission, United Kingdom and Spain (red)*

This implies in a dose increase of approximately 60%. However, it is emphasized that although the dose can always be reduced, there is a need to check the quality in terms of image resolution, contrast and noise so that confidence is maintained in the images to be studied by radiologists.

As shown in Figure 6, the was evaluated C_{VOL} according to the average values of this parameter for head CT exams at institutions A and B. The 2004 European guide [19] recommends that CT scans for brain study and for examinations of the temporal bone should have a C_{VOL} less than 60 mGy. The United Kingdom guide [3] indicates that the diagnostic reference levels (DRLs) for C_{VOL} should be less than 80 mGy in region of the posterior fossa and less than 60 mGy for brain. The ACR [20] features C_{VOL} as DRL in head CT scans of adult patients and cannot exceed 75 mGy. The Spanish protocol [21] shows that the C_{VOL} in head CT scans cannot exceed 60 mGy.

The illustration shows that C_{VOL} values, for both institutions A and B, are in accordance with the cited reference levels. The average C_{VOL} values presented by institution A in each bimester represent approximately 53% of the reference for the temporal bone according to the European guide [19] and for brain exams, according to the European, United Kingdom and the Spanish protocol guides [19, 3, 21]. As for the posterior fossa, it represents around 40% of the C_{VOL}, according to the United Kingdom guide [3], and about 43% in relation to the ACR [20].

At institution B, it was found that the average C_{VOL} value in each bimester represents around 87% of the recommendation for brain [19,3,21] and for temporal bone [19]. For posterior fossa region, the C_{VOL} value represents about 65% of the United Kingdom reference [3]. For ACR [20], this value represents around 69% of the recommended amount.

According to the results, there is less optimization in the head protocols of institution B, although the average C_{VOL} values per bimester at institution B are below the reference standards levels.

Figure 7 shows absorbed doses by some relevant structures for individuals of different genres at Institutions A and B. It is observed that institution B presented higher doses in relation to institution A. In addition, for both institutions, doses in females were higher than in males.

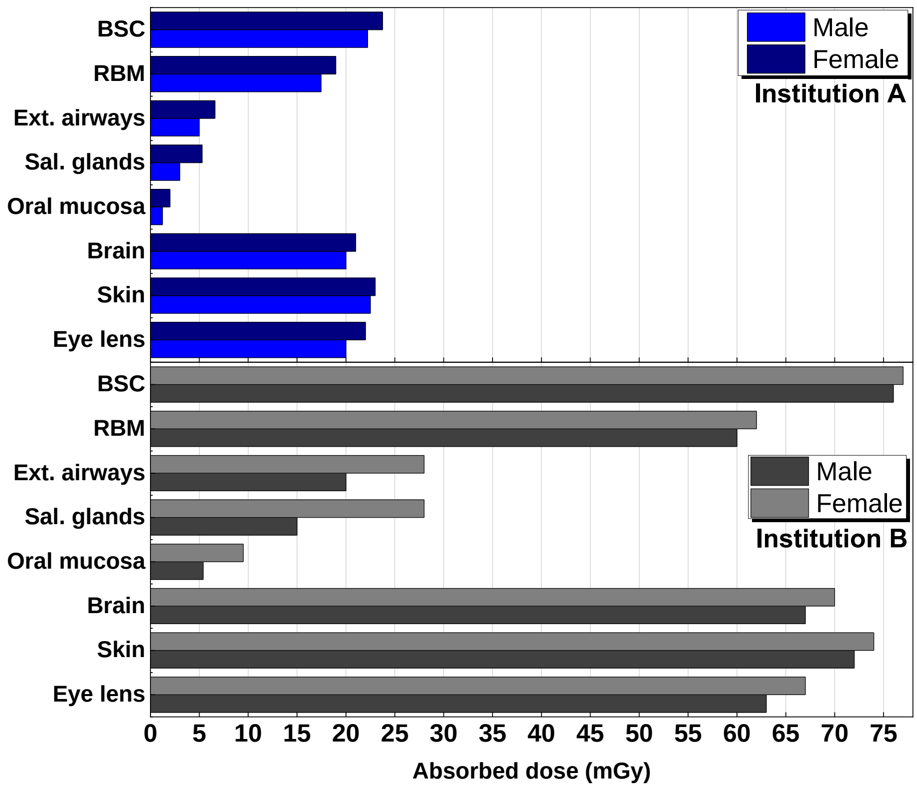

Figure 7: *Absorbed doses in relevant structures measured from C_{VOL} values at institutions A and B within the recommended limits.*

The mean values of mA and mAs at Institution A were lower than those presented by institution B due to the use of activated AEC in the head protocols, in compliance with the recommendations of IAEA [22] and ICRU [23]. This is reflected in the optimization of dose parameters, as can be seen in the results of average C_{VOL} values presented. As the activation of the AEC is not yet a consensus, that is, that it may or may not be used (even if there are still recommendations in good practice guides), it is necessary to carry out a complementary assessment of the image quality in head CT exams according to its use.

In Figure 7, it is observed that institution B presented higher doses. In addition, for both institutions, doses in females were higher than males.

Structures such as eye lens, brain, skin, bone surface cells (BSC) and red bone marrow (RBM) showed the highest absorbed doses, as they are fully inserted in the volume of the primary beam. The oral mucosa, salivary glands and extra thoracic airways are partially in the beam volume, therefore, they presented lower doses [24]. It is important to note that the risk does not depend only on the absorbed dose, but also on the biological sensitivity of the irradiated tissue or organ [25].

These results corroborate with the study of radiological parameters that showed less optimization at institution B. C_{VOL} describes the absorbed dose in axial plane of the structure in the irradiated volume, that is, its increase raises the dose in the structures. Thus, it is understood that higher doses reflect less optimization.

The absorbed doses in RBM and BSC were obtained from bones located inside the beam volume with the highest dose among the skeletal tissues. The skin also showed large doses for individuals of both genres. This may be due to the interaction of the volume of the primary beam with the portion of the irradiated structure. The tissues inside the patient's head absorb lower doses, since the beam deposits its energy in other more superficial structures.

Although the eyes are rarely regions of diagnostic interest in head CT exams, they are often included in the scan, being an area of great concern, as the eyes lens is one of the structures with the greatest biological sensitivity to radiation from the human body. Therefore, optimization of the dose on head CT is essential for its protection [26].

Sensitive cells are in the frontal region of the eye lens, absorbing higher doses, which can be affected even by the acquisition technique. In the anteroposterior (AP) projection the dosimetric values are up to 60 times greater. In addition, modulation of mA and mAs (use of AEC) can decrease the eye lens dose by more than 47% [27].

Another form of dose optimization that has been discussed is the modulation of organ-based mA (OBTCM). This technique keeps the average dose of total radiation constant, reducing direct exposure to organs such as the eye lens [26].

It is observed that at institution B the absorbed doses by the lens were about three times higher among individuals of both genres, compared to institution A.

In addition, doses were differentiated in the tissues and organs of the phantoms for men and women. This behavior is due to body structures that have different anatomical and physiological characteristics for individuals, with greater or lesser energy deposition in their structures [28].

In view of the above, institution A presented more optimized results according to the studies for head CT examinations.

4. CONCLUSION

The results obtained showed that, in both institutions studied, head tomography exams are the ones that are most frequently performed.

As for mA and mAs, institution A presented results with more optimized protocols, since the AEC was activated in the acquisitions, whereas at institution B this system was disabled.

C_{VOL} was more consistent at institution A. One of the possible influences of these results is the fact that parameters such as mA and mAs are less optimized at institution B.

The simulations in CALDOSE_XCT showed that the absorbed doses were higher at Institution B, corroborating the results of the radiological parameters in which mA, mAs and C_{VOL} were less optimized, pointing out the relationship between protocol optimization and the absorbed dose in organs and tissues.

In addition, it was observed that the dose absorption was different both between structures and between men and women, revealing that the dose absorption will depend on the individual's particularities and on the composition and structure of the tissue.

ACKNOWLEDGMENT

We would like to express our thanks and appreciation to the collaborators of this project, as well as to the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - CAPES that could make this project possible.

REFERENCES

[1] FLETCHER, J. G.; YU, L.; FIDLER, J. L.; LEVIN, D. L.; DELONE, D. R.; HOUGH, D. M.; TAKAHASHI, N.; VENKATESH, S. K.; SYKES, A. M. G.; WHITE, D.; LINDELL, R. M.; KOTSENAS, A. L.; CAMPEAU, N. G.; LEHMAN, V. T.; BARTLEY, A. C.; LENG, S.; HOLMES, D. R.; TOLEDANO, A. Y.; CARTER, R. E.; MCCOLLOUGH, C. H. Estimation of Observer Performance for Reduced Radiation Dose Levels in CT. **Academic Radiology,** v. 24, n. 7, p.876-890, 2017.

[2] EUROPEAN COMMISSION. **European Guidelines on quality criteria for computed tomography.** Luxembourg, 2000 (EUR 16262 EN).

[3] SHRIMPTON, P. C.; HILLIER, M. C.; MEESON, S.; GOLDING, S. J. **Doses from Computed Tomography (CT) Examinations in the UK.** Public Health England (PHE-CRCE-013 2011 Review). Centre for Radiation, Chemical Environmental Hazards - Public Health England: London, 2014.

[4] KANG, J. W.; DO, K. H.; HAN, K.; CHAE, E. J.; YANG, D. H.; LEE, C. W. Survey of Thoracic CT Protocols and Technical Parameters in Korean Hospitals: Changes before and after Establishment of Thoracic CT Guideline by Korean Society of Thoracic Radiology in 2008. **Journal Of Korean Medical Science,** v. 31, n. 1, p.32-37, 2016.

[5] JANBABANEZHAD, T. A., SHABESTANI-MONFARED, A., DEEVBAND M.R., ABDI, R., NABAHATI, M. Dose Assessment in Computed Tomography Examination and Establishment of Local Diagnostic Reference Levels in Mazandaran, Iran**. J Biomed Phys Eng,** p.177-184, 2015.

[6] NATIONAL SUPPLEMENTARY HEALTH AGENCY. **2016 Supplementary Health Care Map.** Rio de Janeiro, 2017.

[7] NATIONAL SUPPLEMENTARY HEALTH AGENCY. **2017 Supplementary Health Care Map.** Rio de Janeiro, 2018.

[8] CNES, Equipment consultation. **National Register of Health Institutions**. DataSus (Secretary of Health Care/MH). Available at: < http://cnes2.datasus.gov.br/Mod_Ind_Equipamento.asp>. Last accessed: 27 December 2017.

[9] CALDOSE, Calculation of Equivalent Dose in radiosensitive organs and tissues of the human body. Department of Nuclear Energy (Federal University of Pernambuco - UFPE). Available at: < http://www.caldose.org/caldose/Introducao.aspx> Last accessed: 10 January 2018.

[10] ICRP - International Commission on Radiological Protection. **Basic Anatomical and Physiological Data for Use in Radiological Protection: Reference Values. ICRP Report 89** (Oxford: Pergamon), 2002.

[11] NERSISSIAN, D. Y. **Computerized Tomography Technology and Equipment Operation.** Available at: <http://rle.dainf.ct.utfpr.edu.br/hipermidia/images/documentos/Tomografia_computadorizada_tecnologia_e_funcionamento_equipamentos.pdf>. Last accessed: 9 July 2018.

[12] BOUAOUN, A.; OMRANE, L., B.; MOGAAD, M.; KHOMSI, W., D.; ZIDI, A.; HAMMOU, A. Pediatric Head CT Exposure Doses in Tunisia: A Pilot Study Towards The Establishment of National Diagnostic Reference Levels. **Radiation Protection Dosimetry**, p.1-11, 2018.

[13] REID, J.; GAMBERONI, J.; DONG, F.; DAVROS, W. Optimization of kVp and mAs for Pediatric Low-Dose Simulated Abdominal CT: Is It Best to Base Parameter Selection on Object Circumference? **American Journal Of Roentgenology**, v. 195, n. 4, p.1015-1020, 2010.

[14] HU, L.; WANG, Y.; HOU, H.; WEI, F.; YANG, G.; CHEN, Y.. Radiation dose and image quality with abdominal computed tomography with automated dose-optimized tube voltage selection. **Journal Of International Medical Research**, v. 42, n. 4, p.1011-1017, 2014.

[15] MCDERMOTT, S.; KALRA, M. K. Low-Dose Computed Tomography for Lung Cancer Screening: The Protocol and The Dose. **Seminars In Roentgenology**, v. 52, n. 3, p.132-136, 2017.

[16] SEERAM, E. **Computed Tomography: physical principles, clinical applications and quality control.** Fourth Edition. USA, Elsevier Inc. 2016.

[17] SÖDERBERG, M.; GUNNARSSON, M. Automatic exposure control in computed tomography – an evaluation of systems from different manufacturers. **Informa Healthcare**, p. 625-634, 2010.

[18] SOOKPENG, S.; BUTDEE, C. Signal-to-noise ratio and dose to the lens of the eye for computed tomography examination of the brain using an automatic tube current modulation system. **Emergency Radiology**, v. 24, n. 3, p.233-239, 2016.

[19] BONGARTZ, G.; GOLDING, S. J.; JURIK, A. G.; LEONARDI, M.; van PERSIJN van MEERTEN, E.; RODRIGUEZ, R.; SCHNEIDER, K.; CALZADO, A.; GELEIJNS, J.; JESSEN, K. A.; PANZER, W.; SHRIMPTON, P. C.; TOSI, G. **European Guidelines for Multislice Computed Tomography**. European Commission, 2004. Available at: <http://biophysicssite.com/html/msct_quality_criteria_2004.html>. Last accessed: 27 March 2018.

[20] AMERICAN COLLEGE OF RADIOLOGY (ACR). ACR Accreditation website. **American College of Radiology CT Accreditation Program – Testing Instructions**. Available at : <https://www.acraccreditation.org/~/media/ACRAccreditation/Documents/CT/CTAccreditation-Testing-Instructions.pdf >. Revised January 6, 2017. Last accessed : 25 August 2018.

[21] SEFM-SEPR-SERAM (Spain). **Spanish Protocol SEFM-SEPR-SERAM for Quality Control in Radiodiagnosis: technical aspects.** Madrid: Senda Editorial, 2012.

[22] IAEA - International Atomic Energy Agency. **Quality Assurance Programme for Computed Tomography: Diagnostic and Therapy Applications. Human Health Series NO. 19.** Vienna: IAEA, 2012.

[23] ICRU - International Commission on Radiation Units and Measurements. **Radiation Dose and Image Quality Assessment in Computed Tomography. ICRU Report 87.** Journal of the ICRU, V. 12, 2012.

[24] GAO, Y.; QUINN, B.; MAHMOOD, U.; LONG, D.; ERDI, Y.; GERMAIN, J. S.; PANDIT-TASCAR, N.; XU, X. G.; BOLCH, W. E.; DAUER, L. T. A comparison of pediatric and adult CT organ dose estimation methods. **Bmc Medical Imaging,** v. 17, n. 1, p.2-17, 2017.

[25] ICRP - International Commission on Radiological Protection. **The 2007 Recommendations of International Commission on Radiological Protection. ICRP Report 103.** Elsevier, v. 37, 2007.

[26] LAWRENCE, S.; SEERAM, E. The Current Use and Effectiveness of Bismuth Shielding in Computed Tomography: A Systematic Review. **Radiology - Open Journal**, v. 2, n. 1, p.7-16, 2017.

[27] HUANG, Y.; ZHUO, W.; GAO, Y.; LIU, H. Monte Carlo simulation of eye lens dose reduction from CT scan using organ based tube current modulation. **Physica Medica**, v. 48, p.72-75, 2018.

[28] CASSOLA, V. F.; LIMA, V., J., M.; KRAMER, R.; KHOURY, H. J. FASH and MASH: female and male adult human phantoms based on polygon mesh surfaces. **Physics In Medicine And Biology**, v. 55, n. 1, p.133-162, 2009.