Reference Levels of Radiation Dose for Imaging in Pediatrics

Niveles de referencia de dosis de radiación para la toma de imágenes en pediatría

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Key words (MeSH)
Multidetector computed tomography
Radiation protection
Radiation dosage

Palabras clave (DeCS)
Tomografía computarizada multidetector
Protección radiológica
Dosis de radiación

Summary

Introduction: Due to the characteristics and challenges of the pediatric population regarding radiation, the use of adequate doses of radiation is a duty of medical diagnostic centers. For this reason, the Dose Reference Levels (DRL) have been established in many countries to optimize and monitor the protocols of each institution. In Colombia there are no studies in this subject. ***Objective:*** To show the DRLs used in a university hospital of high complexity in the modalities of computed tomography (CT), radiography and fluoroscopy and to compare them with international standards. ***Methodology:*** Retrospective descriptive trial between 2018 and 2019. We analyzed dose length product (DLP) data for skull, chest, abdomen, and high-resolution chest CT (HRCT); and dose area product (DAP) for chest, abdomen, bone, and fluoroscopy radiography by age groups. ***Results:*** Data were collected for a total of 780 patients. 360 x-rays, 100 fluoroscopy and 320 tomography scans. Reference levels of radiation dose used in the hospital were found to be low compared to European guidelines of 2018 reference levels. DRLs are described for each study and age group. ***Conclusion:*** It was demonstrated that at the hospital where the study was conducted, reference levels of radiation in the pediatric population are low. This work can serve as a national reference.

Resumen

Introducción: El uso de dosis adecuadas de radiación en pacientes pediátricos es un deber de los centros de diagnóstico médico debido a las características y retos que implica esta población. Por lo anterior, se han establecido unos niveles internacionales de referencia de dosis (DRL, del inglés *dose reference level*) para optimizar y comparar los protocolos de cada institución. En Colombia no se cuenta con estudios al respecto. ***Objetivo:*** Mostrar los DRL utilizados en un hospital universitario de alta complejidad en las modalidades de tomografía computarizada (TC), radiografía y fluoroscopia y compararlos con los estándares internacionales. ***Metodología:*** Estudio descriptivo retrospectivo realizado entre 2018 y 2019. Se analizaron datos de producto dosis longitud (DLP) para TC de cráneo, tórax, abdomen y TC de tórax de alta resolución (TACAR); y producto dosis área (DAP) para radiografía de tórax, abdomen, huesos y fluoroscopia por grupos etarios. ***Resultados:*** Se obtuvieron los datos de 780 pacientes: 360 radiografías, 100 de fluoroscopia y 320 tomografías. Se encontró que los niveles de referencia de dosis de radiación usados en el hospital son bajos, comparados con guías europeas de 2018 de niveles de referencia. Se describen DRL para cada estudio y grupo etario. ***Conclusión:*** Se demostró que en el hospital donde hizo el estudio los niveles de referencia de radiación en la población pediátrica son bajos. El presente trabajo puede servir como referente nacional.

Introduction

Images, as a diagnostic tool, have become a fundamental part of the approach to patients, as they facilitate the approach to various pathologies and their treatment. This, in turn, has led to a marked increase in exposure to ionizing radiation.

Computed tomography (CT) is the main contributor to the radiation burden, but although fluoroscopy and conventional radiography also use radiation, they still play an essential role in pediatric radiology (1-4). Because radiation is potentially harmful, any unnecessary exposure should be avoided, so the International Commission on Radiological Protection (ICRP) created the ALARA (as low as reasonably achievable) principle to radiation (5, 6). Since children are ten times more sensitive to the effects of radiation, they have greater tissue radiosensitivity, higher cumulative dose because they have higher mitotic rates, and longer life expectancy during which these effects may manifest themselves (1, 3, 4, 7, 8).

Likewise, the amount of radiation used in the examinations can be modified considerably due to the variation in the size and weight of pediatric patients, so adapting the protocols used in adults is not a viable option (7, 9).

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The ICRP introduced in 1996 the diagnostic reference levels (DRLs) (10, 11) which have since been used to optimize and monitor the radiation levels to which patients are exposed. This concept is fundamental and has been reviewed by multiple international institutions (11-16). These values help to guide if the patient's radiation dose is unusually high. They are not a limit, but help to optimize and compare the protocols of each institution (7).

The ICRP recommendation is that DRLs for the pediatric population should be adjusted for weight or size and that this adjustment, in turn, should help in optimizing the use of radiation without interfering with the quality of diagnostic information (7).

Only a few countries have established their DRLs for pediatric examinations. The European guidelines on reference dose levels published in 2018 contain basic recommendations on how to establish and use DRLs for pediatric X-ray examinations and procedures, which include defining local, national, and European DRLs, the examinations for which DRLs should be established, using weight and age groups, and providing a dose reference for each group and type of image (17).

For its part, in Spain an agreement was published in 2018 between the Nuclear Safety Council and the University of Malaga to carry out a survey of the radiological procedures used in Spanish healthcare centers, their frequency and the doses received by patients and the population. In that publication, they determined the typical doses given to patients and proposed reference values for the procedures; however, an analysis focused on the pediatric population was not made (18).

In France, in early 2020, David Célier and collaborators published two studies evaluating pediatric patient imaging dose and a proposal for updated reference levels for that country. For tomography, they showed that the exposure levels were much lower than in previous surveys and were among the lowest values published at present. When evaluating X-rays and fluoroscopic examinations, they observed a remarkable variability in radiation dose, especially in fluoroscopy (11, 19).

In our country, despite the fact that Decree 482 of 2018 of the Ministry of Health and Social Protection regulated the use of ionizing radiation producers (20), there are no updated publications on standardized dose reference values for each type of diagnostic modality in the pediatric population. In 2012, a study by the National University was published in which reference doses for chest radiography in children were studied (21). This publication provides a guide to standardize the values; however, at the moment there is no updated information or data for other diagnostic modalities. Therefore, the objective of this research is to show the DRLs used in the institution to which the authors belong, in the CT, radiography and fluoroscopy modalities and to compare them with international standards.

Methods

This is a retrospective descriptive cross-sectional study, conducted between 2018 and 2019, at a university hospital. Information from the PACS (Picture Archiving and Communication System, Impax AGFA) was collected by searching by age group. Five groups were created: neonates (0-31 days, under 1 month), infants (1 month to < 3 years), preschoolers (3 to < 6 years), school children (6 to < 10 years), and adolescents (10 to 15 years, 11 months, and 29 days). Twenty studies for each age group were assigned to each procedure: radiographs - anteroposterior chest (AP), AP abdomen, AP and lateral bone studies, fluoroscopy studies (video-deglution, cystourethrography, bowel transit and esophageal, stomach and duodenum studies), single skull CT, chest CT with contrast medium, abdomen CT with contrast medium, and CAT scan.

In the neonatal group, it was not possible to collect the number of patients in the bone x-ray procedures and none of the tomography procedures.

The tomography studies were performed on Siemens Biograph mCT and Somatom Definition tomographs, both 64-slice and incorporating the CARE Dose4D dose modulation system, which achieves significant dose reductions with dose modulation according to the size and shape of the patient, generating optimal image quality with fixed kV of 110-120 in the skull, 80 in the chest, 100 in

the abdomen and leaving the mAs under the CARE Dose4D system, in fixed TACAR kV of 100 and fixed mAs of 20 and 35. In all patients it was performed without sedation and in the vast majority, a single tomographic phase.

The X-ray equipment used in the generation of pediatric images are digital direct radiology equipment, models Luminos Fusión and Multix MP from Siemens, equipped with a DAP (dose area product) dose meter, IBA models 120-131 ZK and 120-131 IS, respectively. Fluoro Save" "image capture" technique was used for fluoroscopy studies, i.e., no X-ray exposure, saving the fluoroscopic image.

The tomographs and X-ray equipment were subjected to quality controls by the institution's medical physicist, for verification of the parameters of kV, mAs, exposure time, filtration, automatic exposure control and dosimetric conditions.

The diagnostic reference levels for the tomography were the dose length product (DLP) and the effective dose; for the X-ray studies the dose area product (DAP) was recorded, when it is more than one projection, the total dose by arithmetic sum. The equipment shows these values in the patient's protocols once the studies are completed, except for the effective dose in CT, which was calculated from the DLP multiplied by the conversion factor for the anatomical region explored, based on the kV used and the patient's age using table 5 of Radiology 2010 (22).

Statistical Analysis

Of the total number of patients (n = 44), 43 had a single kidney injury, while one patient had 3 injuries (Figure 2). The statistical analysis was performed according to ICRP recommendations (5), which define that the DRLs for diagnostic procedures should be established as the rounded value of the third quartile of the median value distribution. For each type of tomography, the median and third quartile of the DLP and mGy effective dose values were calculated and, in turn, the data were divided and analyzed for each age group with a number of 20 patients, as recommended by European guidelines (23).

For radiography and fluoroscopy, the median and third quartile of the dose area product were calculated, and the analysis by age group was also performed with 20 patients per exam and age.

Results

Se Data were collected for a total of 780 patients: 360 x-rays, 100 fluoroscopy studies and 320 tomography scans. Since data such as weight and height were not available, only age was taken into account for group distribution. All 780 studies were included for analysis.

Table 1 shows, for each type of radiography and fluoroscopy studies and for each age group, the median and third quartile of the DAP value, where it can be identified that radiation levels increase with the age of the patient and that they are higher in the studies

of fluoroscopy.

Table 2 shows the median and third quartiles of the LDL and effective dose values for head, chest, CT and abdominal scans for each age group. For each CT scan only one phase was performed, and again it is identified that the radiation levels increase with the age of the patient.

Table 1. Results in radiography and fluoroscopy in the Hospital

Procedure	Age group	mGy.cm²	
Chest X-ray	< 1 month 1 month - < 3 years 3- < 6 years 6- < 10 years 10 - < 16 years	Medium 13 19 17 51 52	3er Quarter 35 36 26 67 78
Abdominal X-ray	< 1 month 1 month - < 3 years 3- < 6 years 6- < 10 years 10 - < 16 years	Medium 21 22 112 106 300	3er Quarter 37 40 145 127 459
AP Bone X-ray, Lateral	1 month - < 3 years 3- < 6 years 6- < 10 years 10 - < 16 years 1 month - < 3 years 3- < 6 years 6- < 10 years 10 - < 16 years	Medium 17 18 29 26 16 15 31 25	3er Quarter 30 35 42 51 21 29 42 53
Fluoroscopy	< 1 month 1 month - < 3 years 3- < 6 years 6- < 10 years 10 - < 16 years	Medium 154 203 540 284 499	3er Quarter 178 314 786 670 903

Table 2. DLP results and effective dose (mGy) in Hospital CT

Procedure	Age group	DLP		mGy	
Cranial CT	1 month - < 3 years 3- < 6 years 6- < 10 years 10 - <16 years	Medium 182 244.5 301 414.5	3er Quarter 236.5 263.75 342.75 514	Medium 1.015 0.855 0.8 0.785	3er Quarter 1.327 0.922 0.9 0.972
TACAR	1 month - < 3 years 3- < 6 years 6- < 10 years 10 - <16 years	Medium 17.5 18.5 48 65.5	3er Quarter 21.25 26.25 55.75 79.5	Medium 0.8 0.54 1.1 1.035	3er Quarter 1.075 0.675 1.317 1.45
Chest CT	1 month - < 3 years 3- < 6 years 6- < 10 years 10 - <16 years	Medium 10.5 10.5 27.5 182	3er Quarter 20.25 22 60 268	Medium 0.075 0.37 0.6 5.5	3er Quarter 1.325 0.687 1.225 5.75
Abdominal CT	1 month - < 3 years 3- < 6 years 6- < 10 years 10 - <16 years	Medium 32.5 51 78.5 404	3er Quarter 50.25 66 129 609	Medium 1.205 1.265 1.8 6.075	3er Quarter 2.45 2.275 2.87 9.21

Discussion

El The use of low-dose radiation in pediatrics is a must for different medical diagnostic centers, especially since the 2001 ALARA conference (6), where leaders in imaging, medical physics, radiation biology, engineering, and regulatory agencies participated to address radiation risks, especially in tomography, and strategies to reduce the dose (24, 25).

Since then there has been increased concern about the issue and currently there is sufficient evidence worldwide about radiation values for different studies, primarily in the adult population (26-30). However, in pediatrics the data are scarce, especially in Colombia, where there is only one study in which dose levels were reported for chest radiography (21). It is important to note that there are no guidelines setting levels for national use with which to compare.

Due to the impact that radiation can have and the greater sensitivity of children to it, it is necessary that the different countries and diagnostic imaging centers have their reference values to compare with the standards in the world. Different publications have emphasized that this should be a goal to be achieved (9, 14, 23, 31).

It is important to keep in mind that the DRLs are values that help guide if the patient's dose is unusually high, there are no lower limits, and they must be adjusted to optimize the use of radiation without interfering with the quality of the diagnostic information (7).

For this reason, this paper presents typical dose values or radiation dose levels for the studies that are most frequently performed in the pediatric radiology service. The analysis of the median and third quartile of DLP and effective dose in tomography and of DAP in radiography and fluoroscopy was made.

It was found that in the different age groups the patients are exposed to low doses of radiation, but these do not interfere with the quality of the diagnostic information, according to the criteria of the radiologist who interpreted the studies, without repetition or difficulty in making diagnoses or contributing conclusions.

The comparison was made with international standards, with special emphasis on the European guidelines for reference levels in pediatrics published in 2018 (23) and with the multicenter studies by Célier and collaborators for reference levels for France published in 2020 (11, 19), due to the lack of national guidelines for comparison.

It was observed that the DRLs used at the Pablo Tobón Uribe Hospital are lower in most studies and age groups. Table 3 shows the comparison of DRLs for CT with medium and third quartiles between the Hospital vs. France (11,19) and the European guidelines (23), all of which are referenced by different age groups. This information is also illustrated in Figures 1, 2 and 3.

With regard to cranial CT, the Hospital's levels are 34.3% and 37.9%, lower than the French and European levels, respectively. In CT of the thorax they are 36.15% and 47% lower.

With regard to CT scans of the abdomen in children under 10 years of age, at the Hospital the radiation dose is 36.15% lower than in France; however, in children over 10 years of age the DRLs are 62% higher. This could be due to the fact that in the French study they included patients only up to the age of 14, while in this work, up to the age of 16. When comparing all age groups for abdominal CT with European guidelines, the Hospital remains below with 41% less in the doses.

The use of low doses in the Hospital is attributed to the fact that CT scans are performed in a single phase with fixed kV, as described, and using the lower mAs of the CARE Dose4D system.

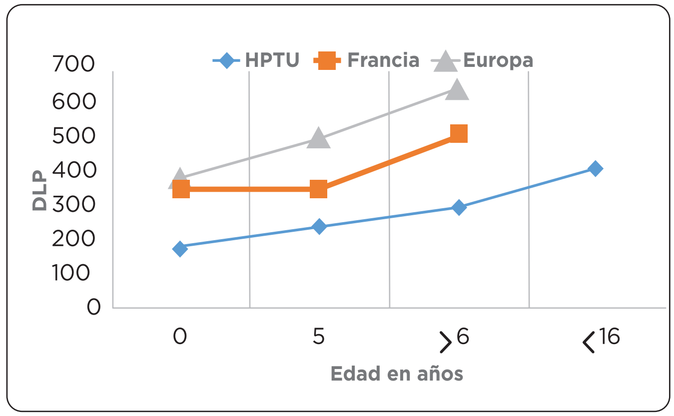

Figure 1. Comparison of doses used in head CT.

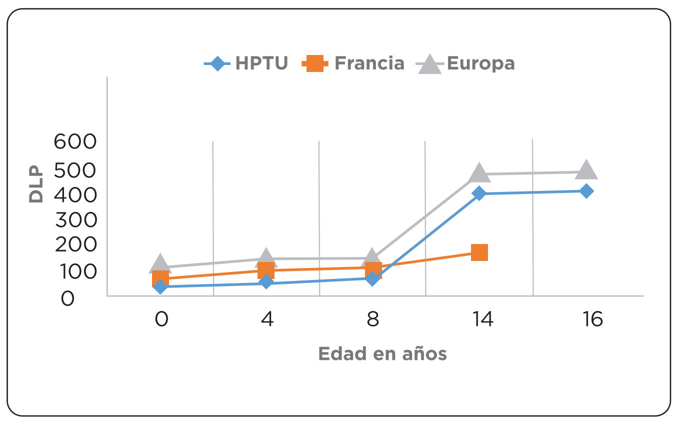

Figure 2. Comparison of doses used in abdominal CT.

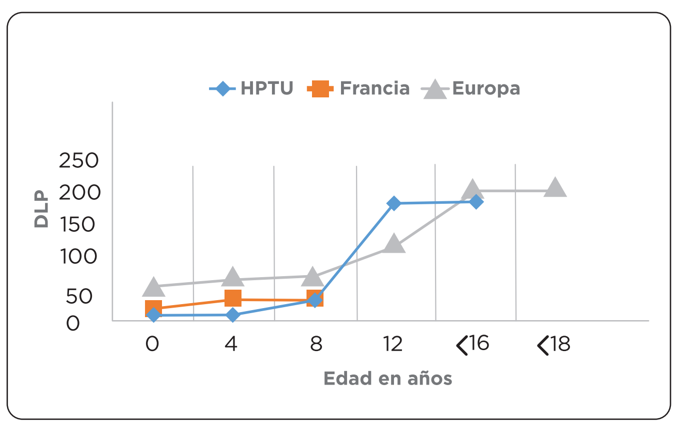

Figure 3. Comparison of doses used in chest CT.

Table 3. DLP comparison in tomography

	University Hospital HPTU			France			European Guides	
Procedure	Age group	DLP		Age group	DLP		Age group	DLP
Cranial CT	1 month - < 3 years 3 - < 6 years 6 - < 10 years 10 - < 16 years	Medium 182 244.5 301 414.5	3er Quarter 236.5 263.75 342.75 514	1 < 6 years > 6 years	Medium 360 510	3er Quarter 450 530	0 - < 3 months 3 months - < 1 year 1- < 6 years > 6 years	Medium 300 385 505 650
Chest CT	1 month - < 3 years 3 - < 6 years 6 - < 10 years 10 - < 16 years	Medium 10.5 10.5 27.5 182	3er Quarter 20.25 22 60 268	1 month - < 4 years 4- < 10 years	Medium 18 34	3er Quarter 20 36	1 month - < 4 years 4 - < 10 years 10- < 14 years 14- < 18 years	Medium 50 70 115 200
Abdominal CT	1 month - < 3 years 3 - < 6 years 6 - < 10 years 10 - < 16 years	Medium 32.5 51 78.5 404	3er Quarter 50.25 66 129 609	1 month - < 4 years 4 - < 10 years 10 - < 14 years	Medium 53 90 150	3er Quarter 71 92 170	1 month - < 4 years 4 - < 10 years 10- < 14 years 14- < 18 years	Medium 120 150 210 480

Table 4. Comparison in radiography and fluoroscopy

	University Hospital HPTU			France			European Guides	
Procedure	Age group	mGy.cm2		Age group	mGy.cm2		Age group	mGy.cm2
Thoracic X-Ray	< 1 month 1 month - < 3 years 3 - < 6 years 6 - < 10 years 10 - < 16 years	Medium 13 19 17 51 52	3er Quarter 35 36 26 67 78	< 1 month 1 month - < 4 years 4 - < 10 years	Medium 6 12 22	3er Quarter 8.3 15 35	< 1 month 1 month - < 4 years 4 - < 10 years 10 - < 14 years 14 - < 18 years	Medium 15 22 50 70 87
Abdominal X-ray	< 1 month 1 month - < 3 years 3 - < 6 years 6 - < 10 years 10 - < 16 years	Medium 21 22 112 106 300	3er Quarter 37 40 145 127 459	1 month - < 4 years 4 - < 10 years	Medium 42 180	3er Quarter 60 220	< 1 month 1 month - < 4 years 4 - < 10 years 10 - < 14 years 14 - < 18 years	Medium 45 150 250 475 700
Fluoroscopy	< 1 month 1 month - < 3 years 3 - < 6 years 6 - < 10 years 10 - < 16 years	Medium 154 203 540 284 499	3er Quarter 178 314 786 670 903	< 1 month 1 month - < 4 years	Medium 100 200	3er Quarter 290 360	< 1 month 1 month - <4 years 4 - < 10 years 10 - < 14 years	Medium 300 700 800 750

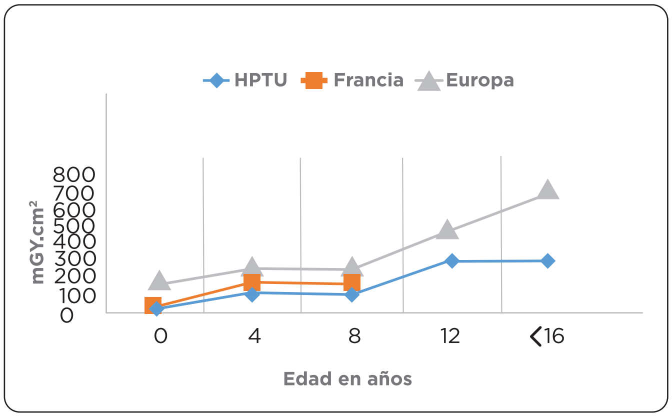

Figure 4. Comparison of doses used in abdominal radiography.

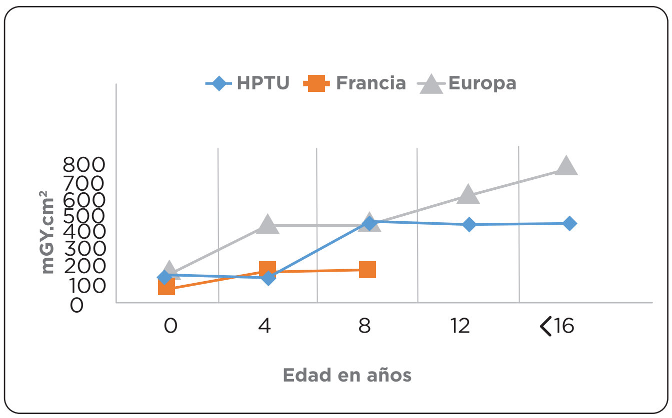

Figure 5. Comparison of doses used in chest radiography.

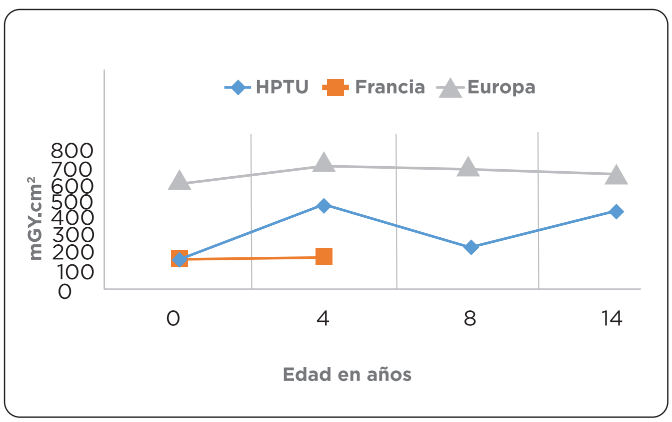

Figure 6. Comparison of doses used in fluoroscopy.

Table 4 and Figures 4, 5 and 6 present the comparison of DRL for radiography and fluoroscopy, in which it is evident that HPTU uses even lower radiation doses than international standards. In abdominal radiography it is 41.2% and 56% below the French multicenter study and European guidelines, respectively. However, in chest radiography and in fluoroscopy it has higher DRL, 46.8% and 15.9%, respectively, compared to the French, but 13.7% and 64.3% below the European guidelines, so the dose used in the Hospital is still much lower, compared to the European guidelines.

The low doses in radiography and fluoroscopy are due to the fact that, as far as possible, the repetition of projections is avoided when the image achieved provides the necessary diagnostic information. Additionally, in fluoroscopy, acquisitions are limited. Shields are not used either, because they can obscure structures that need to be evaluated, which would lead to repeated studies and this, in turn, increases the radiation dose.

With what has been described, it is demonstrated that in the HPTU the levels of radiation in the pediatric population are low —even compared to international references—, but it is guaranteed that the quality of the diagnostic information is preserved.

Among the limitations of the study are its retrospective nature and the fact that the anthropometric data of the patients was not available, so it was not possible to perform an analysis of reference levels by weight, as recommended by the ICRP and European guidelines; however, the age groups proposed by them were taken into account. Another important limitation is the lack of objective evaluation of the image quality, since the study was based on the subjective vision of the radiologist doctor, on the non-repetition of images, without complements or description in the radiological report of technical limitations due to the low dose to give diagnoses.

In conclusion, the information presented shows that HPTU offers low doses to the pediatric population, in most groups, even below European and French standards. This study could serve as a national reference and is a guide and a start for other institutions to set their protocols and reference levels of radiation dose.

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Received for evaluation: March 20, 2020
Accepted for publication: May 14, 2020