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Establishing Diagnostic Reference Level for Computed Tomography Examination in Madagascar

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Abstract: The doses received by the patient during Computed Tomography (CT) examination are relatively significant compared with the doses received by patients undergoing classic X-ray examinations. Owing to this, each country should adopt a consistent policy to optimize the doses delivered to the patient during CT examination. One of the available options for the dose optimization is the implementation of the Diagnostic Reference Levels (DRLs) to evaluate thedose delivered to the patient and to guide the operators for the choice of parameters during CT examinations. Actually, Madagascar hasn't got yet his own DRLs, so that the International Atomic Energy Agency (IAEA) or other international existing DRLs are used to fill this gap. The present study was performed to analyze the feasibility of setting (DRLs) atnational level. The study is a part of an IAEA Project entitled "Strengthening Technical Capabilities for Patient and Occupational Radiation Protection in Member States", RAF9053. For this purpose, three public and private hospitals using computed tomography were selected. The patient dose assessment was performed by determining the Computed Tomography Dose Index (CTDI), Multiple Scan Average Dose (MSAD), Dose Length Product (DLP) and Effective dose (E) for an adult chest and skull CT examination. Pencil ionization chamber was used, having an active length of 100 mm, connected with an electrometer (RAD-CHECK). The system was calibrated through the Secondary Standard Dosimetry Laboratory of Madagascar (SSDL-Madagascar) before the measurements campaign. To simulate the patient presence, two types of Polymethylmethacrylate (PMMA) phantoms were used. The first, having 32 cm diameter was used to replace an adult body patient, and the second phantom, having 16 cm diameter simulate the head of an adult patient. The results were compared with the International Diagnostic Reference Level which is chosen for this study. It has beenestablished that the obtained values are similar to the existing DRLs. Measurements performed during this study can be useful for the patient dose optimization and considered as the first and main step for the National Diagnostic Reference Level setting for Computed Tomography in Madagascar.

Keywords: Computed Tomography, CTDI, DLP, DRLs, Patient Dose

1. Introduction

The use of ionizing radiations increases in medical field, especially in medical imaging. This fact participates considerably to the collective effective dose evolution, so special care should be taken; among the medical imaging is the Computed Tomography (CT) examination. Actually, the elevation of more reliable and more precise diagnostic demand engenders the augmentation of the number of performed CT examinations and then the augmentation of the doses delivered in this field. The Radiation Protection is generally based on three principles: justification, optimization and dose limitation [3]. Justification means that the benefit provided by the use of the ionizing radiations is significant compared with other techniques, and any other method than using ionizing radiations are available.Optimization implies that the dose delivered to the patient should be *As Low As Reasonably Achievable*, according to the ALARA principle

[1,2,3,4]. Nevertheless, the obtained images should be adequate to the diagnosis requirement and respond to the treatment need to avoid the repetition of the examination. The last principle (dose limitation) is not applicable to the medical field as the obtained benefit should outweigh largely the risk associated by the use of ionizing radiations.

To insure the effectiveness of the dose optimization, a National Diagnostic Reference Level (DRLs) should be implemented. The Diagnostic Reference Level (DRLs) is a great tool to follow-up the dose delivered to the patient, to detect bad practices and to promote the dose optimization culture to reduce as low as reasonably achievable the dose delivered to the patient. The availability of DRLs on national level participates largely to the protection of the patient against the side effect of ionizing radiations as these values were established according the general context (CT available in the country) and the morphology in general of the citizens of this country (average mass, averageheight,...).

For the realization of this work, three pilot facilities located in Antananarivo (Capital of Madagascar) were selected. Some quantities were evaluated for this study which can be divided into two groups: local quantities and integral quantities. The first group includestheWeighted Computed Tomography Dose Index ($CTDI_w$) and Multiple Scan Average Dose (MSAD). These two quantities represent the delivered exposition dose inside the limits of the irradiated body region. The second group includes the Dose Length Product (DLP) and the effective dose (E) which in contrast to the first group, taking into accounts the extent of the irradiation for the entire body region being irradiated.

The $CTDI_w$ is a dose indicator for a single slice. Some of the chosen reference organizations use this quantity to be a reference. Whenever, actually in practice several adjacent slices are scanned simultaneously instead of a single slice. For this case the dose received for the central slice will be largely affected by the contribution of the other slices in its neighborhood. That's way some other international organization adopt MSAD which take into account the contribution of the neighbor slices to be a reference instead of the $CTDI_w$. That is for example the case for the IAEA [3].

The DLP and E, can be used as risk indicators [4]. DLP is used to estimate the value of the effective dose to the patient without taking into account the tissue weighting factor.The Effective dose E, evaluates the total risk regarding to the radiation sensitivity of the part of the body being irradiated [4,5].

2. Materials and Methods

The main goal of this work is to study the feasibility of the implementation of the DRLs throughout a comparative study between existing DRLs of some international organizations and the measured doses delivered to the patients for the three pilot centers by using an ionization chamber, type pencil connected to an electrometer. Specific phantoms for Computed Tomography were used for the dose measurements.

For this study, four international organizations were chosen to be a reference: European Commission (EC), National Radiological Protection Board (NRPB), American Association of Physicists in Medicine (AAPM) [5] and International Atomic Energy Agency (IAEA) [3] which are among the most used DRLs in the world.

Choice of computed tomography center

Before measurements, a series of quality control of the CT equipment was done for some centers in the capital of Madagascar (Antananarivo). Three of them were chosen to participate in the pilot project: one facility was public and two private. The chosen computed tomography equipment satisfies the quality control testing according the Radiation Measurements, Inc (RMI) procedures [11] and received the major part of the patient in the capital of Madagascar. The following list of test was realized during the quality control, other than the standard tests using RMI test tools, specified by the figure N°1:

- Location of plan and thickness of cut,
- Resolution in the plan of cut,
- Exposure uniformity and beam path.

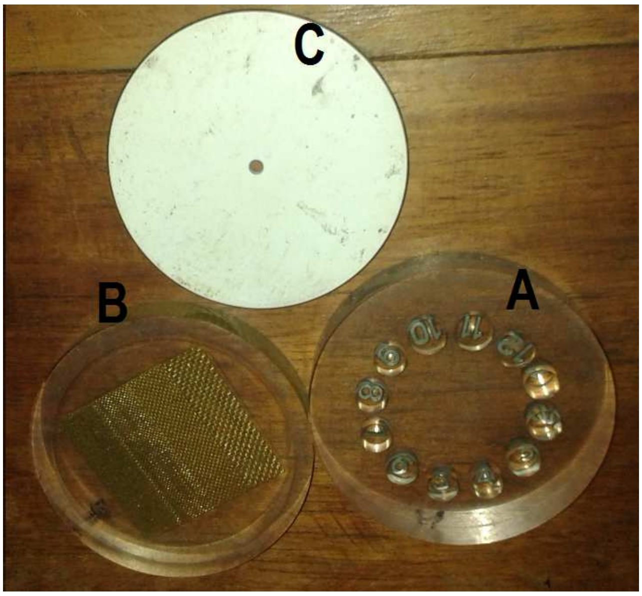

Figure 1. *RMI kits for the thickness of cut location (A), resolution in the plan of cut (B) and exposure uniformity and beam path(C).*

Calibration of the detector

The dosimetry system used for this project was an ionization chamber, type pencil connected to an electrometer, type RAD-CHECK. The dosimeter was calibrated through the Secondary Standard Dosimetry Laboratory of Madagascar (SSDL-INSTN Madagascar) to determine the direct factor converting the exposition in roentgen (R) to KERMA (Kinetic Energy Realized to Material) in milligray (mGy). The whole was irradiated with a Cs-137 source following the standard protocolsof calibration at a distance of 1 meter (figure n°2 and figure n°3). The KERMA was measured, first using the standard of the SSDL, and then using the detector under calibration (ionization chamber type pencil connected with the electrometer RAD-CHECK). The calibration factor was determined, considering the detector under calibration response versus the given value by the SSDL standard. The calibration factor of the chamber connected with the electrometer was calculated according the following equation, taking into account the uncertainty of the SSDL standardand eventual uncertainty sources during the calibration procedure.

$$CC = \frac{Q \times N_K}{E_R} \tag{1}$$

where, Q (nC) is the mean of the collected charges measured by the ionization chamber used as reference instrument, N_K the calibration factor of the reference ionization chamber and E_R the mean value given by the instrument under calibration (ionization chamber type pencil connected to the electrometer RAD-CHECK).CC is expressed directly in $mGy.R^{-1}$

Figure 2. *Experimental device for the irradiation of the reference instrument in the SSDL-Madagascar.*

Figure 3. *Experimental device for the irradiation of the reference instrument in the SSDL-Madagascar.*

Patient Dosimetry

The patient dosimetry consists of the estimation of the exposition dose delivered to the patient during the CT examination. It was performed according to the American Protocol [5]. Head and body polymethylmethacrylate (PMMA) dosimetry phantoms, having respectively 16 and 32 cm diameters were used to simulate the head and the body, especially the chest of the patient being irradiated. The ionizing chamber type pencilwas inserted into the phantom holes according to the drilling positions specified by the figure n° 6.

Figure 4. *Electrometer RAD-CHECK connected to to the ionization chamber.*

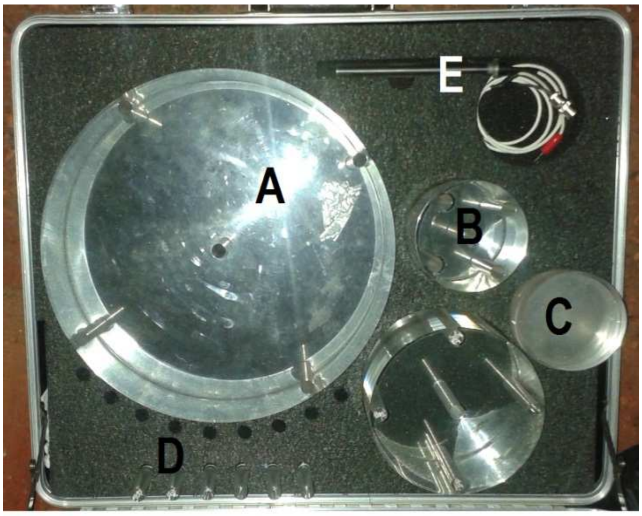

Figure 5. *PMMA used for body and head phantoms (A,C), PMMA used as spacers, PMMA used to plug the unused holes (D), ionization chamber, type pencil (E).*

The measurements consist of the $CTDI_w$, MSAD, DLP and E determination, for common examinations of chest and skull versus the chosen parameters used by the operator. For the determination of the two local quantities ($CTDI_{100}$ and MSAD), the following equations were used:

$$CTDI_{100} = \frac{1}{N \times T} \int_{-50mm}^{50mm} D(z)dz \tag{2}$$

$$MSAD = \frac{1}{p} \times CTDI_{100} \tag{3}$$

Where N represents the slice number used for the examination, T is the thickness of the slice, expressed in mm and D(z) the dose profile following the z axis, expressed in milligray (mGy). The overlapping of slices is quantified by the pitch factor (p).

The $CTDI_{100}$ (mGy) represents the dose profile measured by the pencil ionization chamber having a sensitive length of 100 mm. Phantoms were positioned in the center of the gantry by using laser beam, specified by the figure N°7. The $CTDI_{100}$ is defined by the equation (1) and can be evaluated from the following equation:

$$CTDI_{100} = \frac{k_{T,P} \times 100 \times E_R \times CC}{N \times T} \quad (4)$$

Where $k_{T,P}$ is the correction factor for the temperature and pressure, E_R (R) the electrometer (RAD-CHECK) reading and CC the appropriate conversion factor from roentgen to mGy.

$k_{T,P}$ is calculated by the following equation

$$k_{T,P} = \left(\frac{T°C + 273.2}{20°C + 273.2} \right) \times \left(\frac{(101.3)}{P} \right) \quad (5)$$

T°C and P represent respectively the temperature and the pressure during the measurements.

The weighted CTDI ($CTDI_w$) is calculated by considering the contribution of doses around the drilling position occupied by the ionization chamber into the polymethylmethacrylate (PMMA) holes of the phantom.

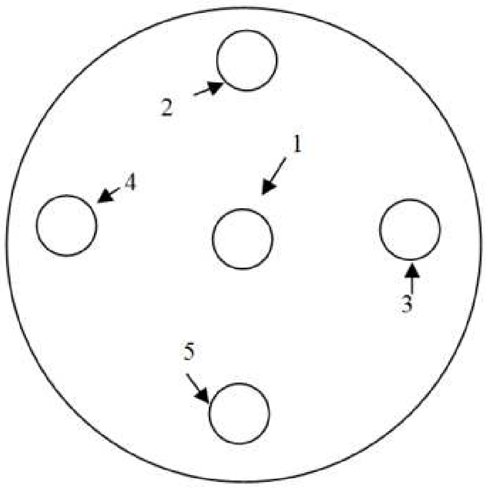

Figure 6. *Drilling position of the PMMA.*

The CTDI vary across the field of view (FOV). The CTDI are different from the surface than the center of the FOV. To take into account this difference, it is convenient to use the weighted CTDI instead of the single CTDI. The $CTDI_w$, generalize the value of the CTDI by both from the surface and the center of the view. The $CTDI_w$ was calculated using the following equation:

$$CTDI_w = \frac{1}{3} CTDI_1 + \frac{2}{3} \left[\frac{1}{4} \sum_{i=2}^{5} CTD_i \right] \quad (6)$$

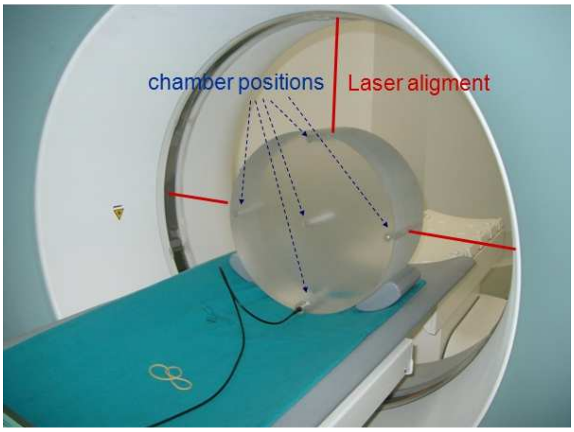

Figure 7. *Positioning of the ionization chamber and the phantom PMMAin the axis of the gantry during the measurements.*

$CTDI_{VOL}$ and DLP can be obtained by using the Formulation n°6 and n°7

$$CTDI_{VOL}(mGy) = \frac{1}{p} \times CTDI_W \quad (7)$$

$$DLP(mGy.cm) = CTDI_{VOL} \times scan\,length \quad (8)$$

The scan length can be obtained by subtracting the end position and the start position of the scan, which is available both in n the gantry and in the comment during the examination. The dose length product is expressed in mGy.cm

The potential biological effect from radiation depends not only on the radiation dose to the tissue or organ, but depends also to the radiation sensitivity of the irradiated tissue or organ being irradiated. The same exposition dose doesn't engender the same effect for two different organs [7,9]. That's why the use of effective dose is necessary. The effective dose is defined as the product of the Dose Length Product to the k factor.The effective dose E is expressed in mSv.

$$E = k \times DLP \quad (9)$$

Where k is the converting factor for the dose length product to the effective dose (E) is expressed on $mSv.mGy^{-1}.cm^{-1}$. The following table, extract of the publication n° 87 of the International Commission on Radiation Protection (ICPR) gives the values of k used for head and chest CT examination.

Table 1. *k factor for head and chest CT examination.*

Region of the body	k ($mSv.mGy^{-1}.cm^{-1}$)
Head	0.0023
Chest	0.017

3. Results and Discussions

Tables 2, 3 and 4 show the results of $CTDI_w$, MSAD, DLP and E of skull and chest examinations for the three centers versus the parameters used for each type of examination. Table 5 gives the reference values from International organizations: EC, NRPB, AAPM and IAEA.

Table 2. *Exposure parameters, CTDIw, MSAD, DLP and E results for the Center n°1.*

Examination	kV	mAs	Slice number	Slice width (mm)	Pitch	Scan length (cm)	$CTDI_w$ (mGy)	MSAD (mGy)	DLP (mGy.cm)	E (mSv)
Skull	130	220	39	4	0.55	15	32.5	59.1	487.4	1.1
Chest	130	84	38	5	1	40	9.4	9.4	374.5	6.4

Table 3. *Exposure parameters, CTDIw, MSAD, DLP and E results for the Center n°2.*

Examination	kV	mAs	Slice number	Slice width (mm)	Pitch	Scan length (cm)	$CTDI_w$ (mGy)	MSAD (mGy)	DLP (mGy.cm)	E (mSv)
Skull	120	300	36	2.5	1.25	15	35.9	28.7	539.1	1.2
Chest	120	200	96	3.2	1	40	5.4	5.4	215.0	3.7

Table 4. *Exposure parameters, CTDIw and DLP results for the Center n°3.*

Examination	kV	mAs	Slice number	Slice width (mm)	Pitch	Scan length (cm)	$CTDI_w$ (mGy)	MSAD (mGy)	DLP (mGy.cm)	E (mSv)
Skull	110	107	20	5	0.75	15	32.9	43.9	493.2	1.1
Chest	110	193	51	3	0.75	40	5.3	7.1	212.1	3.6

Table 5. *Dose reference levels for computed tomography for a typical adult patient.*

	EC		NRPB		AAPM		IAEA	
	$CTDI_w$ (mGy)	DLP (mGy.cm)	$CTDI_w$ (mGy)	DLP (mGy.cm)	$CTDI_w$ (mGy)	DLP (mGy.cm)	MASD (mGy)	DLP (mGy.cm)
Skull	60	1050	60	1050	60	-	50	-
Chest	30	650	30	650	40	-	35	-

The $CTDI_w$ and MSAD, as a local quantities change with the used parameters particularly, the choice of high voltage, the used charge (mAs per slice), number and thickness of slice (collimation) and the pitch factor which quantify the contribution of the neighbor slices on the considered slice. As dose indicator for one slice, it was established that the slice exposure increases with the high voltage, the used charge per slice and the slices overlapping, (for the case where the pitch factor is less than one, the MSAD increases considerably compared to the $CTDI_W$ due to the overlapping of the slice). Pitch factor should be chosen according to the clinical indication.

Sometimes, the $CTDI_W$ and MSAD are low (low dose for a single slice), but the integral quantities (PDL and E) are significant, owing that the explored distance is high. It is verified by the equation number 8 and number 9. The operator should insure to scan only the part of the patient to be scanned.

Values of the $CTDI_w$ are affected widely by the choice of the collimation (N×T), verified by equation n°3. That is the case of the Center n° two for a chest examination in which the used collimation is bigger than the other centers (even the used mAs is high, the dose delivered to the slice is low.

- All the realized measurements are similar to the proposed guidance levels (EC, NRPB, AAPM and IAEA). As the three centers are accompanied during all the project, the dose delivered to the patients are even low than the chosen references.

4. Conclusion

- The dose received by patient undergoing Computed Tomography examination is significant. The present work which is done for three computed tomography centers confirms that there is a large variation in the choice of the parameters used to a current examination so then the dose received by the patient are largely different for a same examination type but using different parameters. Stakeholders on radiological societies, especially on computed tomography should be encouraged to balancethe protection of the patient and the diagnostic need. A minimum radiation doses that provide adequate diagnostic information for standard clinical questions should be established to reach this goal. That's way the implementation of a national Dose Reference Levels is suitable for patient dose optimization.

- Care must be taken for the choice of examination parameters to insure that the patient dose is optimized as the delivered dose to the patient change versus the examination parameters.

- The dose received by the patient increases with the scan length distance, high voltage, charge per slice, field of view, collimation and pitch. These quantities should be chosen according to the examination requirement.

- The similarity of the results of the performed measurements for the pilot centers and the other international organizations DRLs which were used to be a reference affirm that the present work is useful and valid to the implementation of the DRLs for the Computed Tomography examination for Madagascar.- It can be seen from this study that for dose optimization, a dose guidelines should be established for each country and each current procedures to be a real guide for Radiologist, Radiographers and medical physicists during a computed tomography screening.

- This preliminary study was only performed for three Computed Tomography facilities among eleven recorded in

Madagascar. The obtained results, when developed for all existing center in Madagascar can be useful to establish DRLs at a national level so actions are underway to extend measurements for all existing facilities in Madagascar.

- The present work is only focused on a chest and skull adult dosesstudied; survey of practice in other current adult patient and pediatric Computed Tomography will be performed in the near future.

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