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VOLUME COMPUTED TOMOGRAPHY AIR KERMA INDEX AND IMAGE QUALITY EVALUATION IN BRAZIL

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The aim of this study was to evaluate the image quality of 29 computed tomography (CT) scanners in Brazil and to perform estimations of patient dose and image quality of common CT examinations at these equipment. The volume CT air kerma indexes (C_{VOL}) were estimated, using normalised weighted air kerma indexes, supplied by the ImPACT group. The image quality tests were performed using the phantom and accreditation protocol from the American College of Radiology (ACR). The C_{VOL} values for head scans varied between 8.7 and 108 mGy. The Hi-res chest examinations presented C_{VOL} values varying from 0.4 to 32 mGy. For abdominal scans, the estimated C_{VOL} values varied between 4.1 and 94 mGy. This wide variation of air kerma between different centres is related to the scanner type and also to the scanning parameters. The results also showed that the image quality did not attend all ACR CT accreditation requirements.

INTRODUCTION

Computed tomography (CT) is an important diagnostic imaging method and has been widely used in Brazil. It is based on the acquisition of thin axial images of the patient body, resulting in little overlap of anatomical structures, better contrast and spatial resolution than conventional radiography. The disadvantage is that the patient dose in CT procedures is much higher than any conventional radiologic procedure. According to UNSCEAR 2000[1], CT scans represent 34 % of the annual collective dose of all X-ray diagnostic procedures.

The currently recommended quantities for CT dosimetry are the volume CT air kerma index (C_{VOL}). The C_{VOL} is determined from the weighted CT air kerma index (C_W) and is a useful indicator of CT dose, considering specific information about each acquisition protocol[2–4].

In CT dosimetry, apart from estimations of C_{VOL}, it is also important to evaluate the image quality, which depends on image acquiring parameters, such as slice thickness, gantry rotation time, table axial increment or helical pitch, reconstructions algorithms, etc.

The aim of this work was to evaluate the CT image quality and to estimate the C_{VOL} for routine CT examinations performed in Curitiba, Recife and Rio de Janeiro, Brazil.

MATERIALS AND METHODS

In this work, 29 CT scanners located in the Brazilian cities (and States) of Curitiba (Paraná), Recife (Pernambuco) and Rio de Janeiro (Rio de Janeiro) were evaluated. Table 1 shows the model, type and installation year of each scanner evaluated.

Routine scanning parameters for adults were collected for head, high-resolution chest and abdomen examinations. The following parameters were registered: tube voltage and current, gantry rotation time, total beam collimation, slice thickness and pitch (or increment, for sequential scans). It should be noted that the institution 8 makes only head scans and institution 9 does not perform abdominal scans.

Volume CT air kerma indexes were calculated for the examinations performed by dividing the weighted C_W by the pitch factor (p). The pitch is the ratio between the distance moved by the patient support table per rotation and the total beam width (number of slices per rotation multiplied by the slice thickness).

For axial scans, C_{VOL} can be calculated by multiplying the C_W value by the ratio between the beam width and the scan increment[4]. The C_W values were obtained from the weighted CT air kerma index ($_nC_W$), normalised to milliamperes per second, as given by the ImPACT CT Patient Dose Calculator[5] for each CT scanner.

Table 1. Main characteristics of the evaluated CT scanners.

Institution	Manufacturer, model and type (installation year)
1	GE HiSpeed FX/I, SSCT (NI)
2	Siemens Emotion, SSCT (2004)
3	GE HiSpeed FX/I, SSCT (2006)
4	Philips Brilliance P40, MSCT (2007)
5	Toshiba Aquilion 64, MSCT (2007)
6	Elscint SeleCT SP, SSCT (NI)
7	Philips CT Aura, SSCT (2001)
8	Toshiba Auklet, SSCT (2001)
9	GE HiSpeed FX/I, SSCT (2003)
10	GE HiSpeed FX/I, SSCT (2003)
11	Toshiba Asteion, SSCT (2003)
12	Siemens Sensation 64, MSCT (2006)
13	Picker PQ 2000, SSCT (1995)
14	GE Pro Speed, SSCT (1996)
15	GE Pro Speed, SSCT (1997)
16	Elscint 2400, SSCT (1998)
17	GE Light, SSCT (2000)
18	Philips Ultra Z, SSCT (2000)
19	GE Light S, SSCT (2000)
20	GE HiSpeed, SSCT (2001)
21	Siemens Sprit, SSCT (2001)
22	Philips Mx8000 16, MSCT (2002)
23	Siemens AR Star, SSCT (2003)
24	Siemens AR Star, SSCT (2003)
25	GE Light Speed 16x, MSCT (2006)
26	Siemens Sensation 16, MSCT (2006)
27	Philips Brillance 6X, MSCT (2007)
28	Siemens AR SP, SSCT (2007)
29	Philips Mx8000 16, MSCT (2007)

Institutions from 1 to 5 are located in Curitiba, from 6 to 12, in Recife and the others, in Rio de Janeiro. SSCT, single-slice CT scanner; MSCT, multislice CT scanner; NI, not informed.

The ${}_{n}C_{W}$ values are normalised to 100 mA s and depend on the following specifications: scan model, phantom (head or body), tube voltage and beam collimation.

To evaluate the image quality at all institutions, the ACR CT accreditation phantom, manufactured by Gammex, was used and is shown in Figure 1. The phantom is a solid cylinder containing four modules and has been designed to examine a broad range of image quality parameters, included in the ACR CT accreditation program[6]. For the image acquisitions, the phantom was positioned at the centre of the CT gantry, aligned with the use of the scanner's laser indicators, and the parameters, routinely used at the centres for the examinations of head (brain), adult abdomen and high-resolution chest, were selected for testing.

Module 1 is used to evaluate the slice thickness and CT number calibration. It contains five cylinders made from different materials. Using circular regions of interest (ROIs), it was possible to evaluate the CT number corresponding to each material, compared with the phantom reference CT numbers for each material.

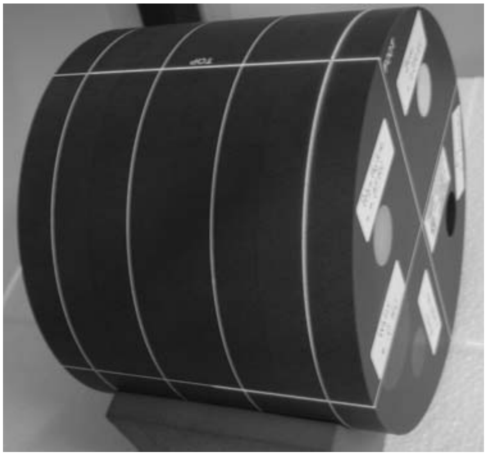

Figure 1. ACR CT accreditation phantom Gammex 464[6].

To evaluate the low-contrast resolution, the image at the centre of Module 2 was analysed. There are sets with four cylinders each in this region, with the diameters from 2 to 6 mm. The cylinder set with 6 mm should always be clearly visualised.

CT number uniformity, image noise and the presence of artefacts were evaluated based on the image of Module 3. Five circular ROIs were defined, one being located at the centre of the image and four towards the edges. The uniformity value was calculated as absolute value of the difference between the ROI at the centre of the CT image and the ROI at the edge point. Image noise was measured as the standard deviation (in Hounsfield units, HU) of a central ROI in a homogeneous phantom.

Finally, Module 4 was used to evaluate the high-contrast spatial resolution through observation of bar patterns with different spatial frequencies. Patterns corresponding to 5 and 6 lp cm^{-1} (lines pairs per cm) should at least be clearly visible for abdominal and high-resolution chest parameters, respectively.

RESULTS

Volume CT air kerma estimation

The C_{VOL} values for routine head scans were estimated for the whole examination. The estimated values for six SSCT scanners (all from Rio de Janeiro) and for three MSCT scanners, shown in Figure 2, are higher than the UK reference levels[2], which are 55 mGy for examinations performed with

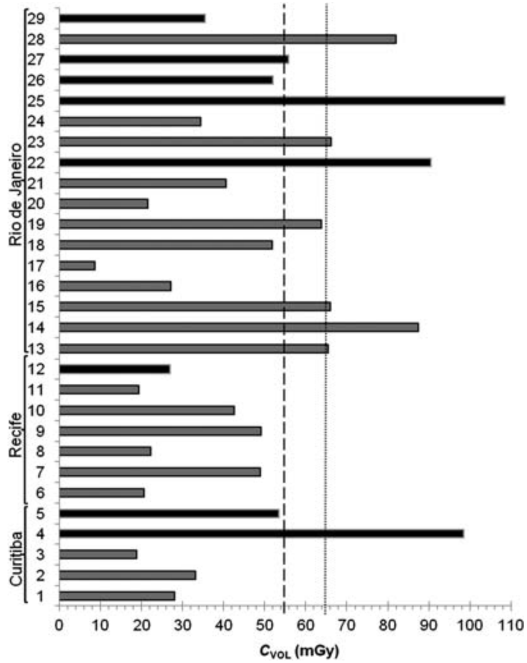

Figure 2. Estimated C_{VOL} for head examinations performed at the evaluated institutions. The gray bars show the C_{VOL} values estimated for SSCT scanners and the black bars for MSCT scanners. The dashed line represents the UK reference level for SSCT scanners and the dotted gray line the reference level for MSCT scanners[2].

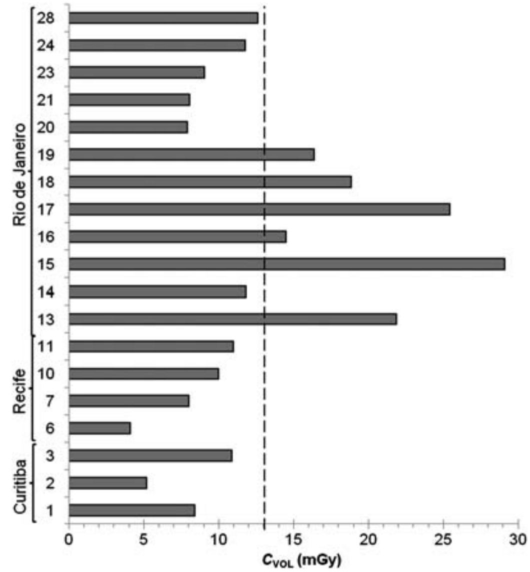

Figure 3. Estimated C_{VOL} for abdomen examinations. The dashed line represents the UK reference level for SSCT scanners[2].

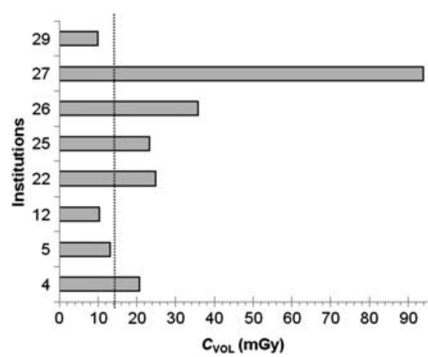

Figure 4. Estimated C_{VOL} for multislice abdomen examinations. The dashed line represents the UK MSCT reference level[2].

single-slice CT scanners (SSCT) and 65 mGy for multi-slice CT scanners (MSCT).

The lowest C_{VOL} value for head scans (8.67 mGy) was observed at institution 17 (GE HiLight, SSCT) and the highest value (108.45 mGy) at institution 25 (GE LightSpeed 16, MSCT).

For MSCT scanners, only the examinations performed at institutions 4, 22 and 25 presented C_{VOL} higher than the reference level: 98.5, 90.5 and 108.4 mGy, respectively.

For high-resolution chest examinations, it was observed that 13 institutions (3 with MSCT) presented the C_{VOL} values higher than the 3 and 7 mGy reference levels, for SSCT and MSCT, respectively.

Figure 3 shows the distributions of C_{VOL} values calculated for abdominal examinations performed at the evaluated institutions with SSCT scanners. Figure 4 shows the values for MSCT scanners.

The UK reference C_{VOL} values for abdomen and pelvis examinations are 13 mGy for SSCT and 14 mGy for MSCT scanners[2]. It can be observed that 32 % of the SSCT scanners and 62 % of the MSCT scanners presented C_{VOL} values higher than the reference levels of UK. In Brazil, at the moment there are no diagnostic reference levels for CT examinations.

Image Quality

Table 2 shows the image quality parameters evaluated, the ACR acceptance criteria for each parameter and the percentage of scanners that attend these criteria. The percentage of adequate result for all image quality tests for each scanner is shown in Figure 5.

The results show that the image quality parameter that lowest comply with the ACR requirements is

Table 2. Image quality parameters evaluated, ACR acceptance criteria and percentage of scanners attending the requirements for each parameter.

Image quality parameters	CT examination technique	ACR criteria	% of adequate scanners
CT number calibration			
Polyethylene	Abdomen	−107 to −67 HU	24
Water		−7 to 7 HU	
Acrylic		110 to 130 HU	
Bone		850 to 970 HU	
Air		−1005 to −970 HU	
CT number × ST	Abdomen	−7 to 7 HU	69
CT number × kV_p	Abdomen	−7 to 7 HU	76
Slice thickness	Abdomen	Difference ≤1.5 mm	86
Low-contrast resolution	Abdomen; brain	≤6 mm	86
Uniformity	Abdomen	<5 HU	97
Spatial resolution	Abdomen	≥5 lp cm^{-1}	79
	Hi-res chest	≥6 lp cm^{-1}	

ST, slice thickness.

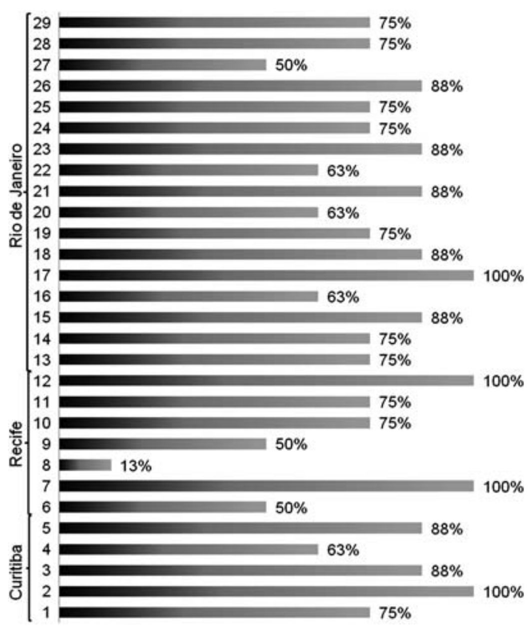

Figure 5. Graph showing the percentage of ACR phantom adequate results to each evaluated CT scanners.

the CT number. In fact, it is observed that only 24 % of all scanners comply with the ACR requirements for this analysis. On the other hand, CT number uniformity was adequate to 97 % of the scanners. The other parameters presented adequate results from 69 to 86 % of the CT scanners and the average image noise value was 5.64 ±2.95 HU.

The results also show that only four CT scanners located at institutions 2, 7, 12 and 17 attain all the ACR requirements for image quality and 14 % of all evaluated CT scanners presented adequate results higher than 90 % of the ACR phantom requirements. The institutions 6, 8 and 27 comply only with a minimum of 50 % (or less) of the ACR requirements. Special emphasis is given to institution 8 (Toshiba Auklet, SSCT), which failed at 87 % of the ACR tests. This scanner presented one of the lowest C_{VOL} values for routine head examinations and the higher image noise among all scanners.

DISCUSSION

The C_{VOL} values determined in this work for head, high-resolution chest and abdomen CT examinations were higher than the reference levels for some of the evaluated SSCT and MSCT scanners.

Two MSCT scanners, from institutions 4 and 5, presented C_{VOL} values of about 4.5 times higher than the UK reference levels for high-resolution chest examinations. It is important to notice that, for the other examinations, the scanner at institution 5 presented C_{VOL} values lower than the reference level. It shall be observed that, at these institutions (and institution 25), the high-resolution chest examinations are performed using the routine chest acquisition parameters, which means that, in these cases, the high-resolution chest examination is only an image reconstruction of the routine chest acquisition, avoiding the need of irradiating the patients twice.

On the other hand, it was observed that the C_{VOL} values for head examinations performed at institutions 5, 12, 26, 27 and 29, which have MSCT scanners, were lower than those found for some single-slice CT scanners. This result is in accordance with information given in the ICRP 102[3], which states that the MSCT is not necessarily higher than the dose delivered by SSCT scanners, depending on the selected parameters.

This wide variation observed in the estimated C_{VOL} values is probably caused by the variation in the scanning parameters between institutions. As an example, the institutions 1, 3, 9 and 10, all with the same CT scanner model (GE HiSpeed FX/i) presented different C_{VOL} values and different image quality results. This result reflects the fact that, in several institutions, quality assurance programmes and optimisation protocols are not implemented.

Confirming this conclusion, the majority of the CT scanners showed poor image quality and many other inadequacies compared with the ACR requirements (<15 % of the scanners presented adequate results to all ACR requirements).

The CT scanners responsible for some of the lowest C_{VOL} values had the worst image quality. It is known that several image quality parameters (specially the image noise) are inversely proportional to the radiation dose delivered[3]. Relatively high image noises could be observed at scanners with very low C_{VOL} values (institutions 5, 8, 11 and 21). This problem could be solved with increases in the current–time product (mA s) selected, after a more accurate optimisation study, which should include subjective image quality evaluations.

On the other hand, the scanner at institution 17 complies with all ACR requirements and provides one of the lowest C_{VOL} values for head scans, indicating the optimisation of the head scanning parameters. In spite of this result, the same institution is responsible for a high C_{VOL} value delivered for abdominal scans (almost twice the reference levels).

These results indicate the need to review the acquisition protocols selected at these institutions, aiming to improve the image quality and to maintain the C_{VOL} values as low as reasonably achievable.

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