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Evaluation of the image quality in computed tomography: different phantoms

Avaliação da qualidade de imagem na tomografia computadorizada: diferentes fantomas

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Abstract

The aim of this paper was to compare the simulators provided by the CT manufactures and Catphan's Phantom with the American College of Radiology (ACR) computed tomography phantom. The image evaluation followed the protocols established by the manufactures of the phantoms. For slice thickness evaluation, the maximum percentage difference was 9% between the phantoms ACR and Siemens. In CT number accuracy test, the measurements of CT number of water showed a difference of 10 HU between the CT simulators. Comparing the uniformity results, the discrepancy was 11% and 55% for Siemens and Philips respectively in relation to the result obtained with the ACR phantom. The result of low contrast was the same for all phantoms. The MTF50 and MTF10 obtained with Siemens phantom was 4 and 8 pl/mm. For Catphan, 6 and 7 pl/mm. Results demonstrate that the ACR simulator was the most comprehensive and flexible to be used in several scanner models. Some simulators did not present all image quality indicators to perform a complete test.

Keywords: computed tomography, image quality, phantoms.

Resumo

O objetivo deste trabalho foi comparar os simuladores fornecidos pelos fabricantes de tomógrafos e o fantoma Catphan com o fantoma de tomografia computadorizada do Colégio Americano de Radiologia (ACR). A avaliação da imagem seguiu os protocolos estabelecidos pelos fabricantes dos fantomas. Para a avaliação da espessura de corte, a maior diferença foi de 9% entre os fantomas ACR e Siemens. No teste de exatidão do número de CT, as medidas do número de CT da água mostraram uma diferença de 10 HU entre os fantomas de CT. Comparando os resultados de uniformidade, a discrepância foi de 11% e 55 % para os fantomas da Siemens e da Philips em relação ao valor obtido com o fantoma do ACR. O resultado de baixo contraste foi o mesmo para todos os fantomas. Os valores de MTF50 e MTF10 para a resolução de alto contraste do Siemens foram 4,2 e 7,6 pl/mm e para o Catphan, 6 e 7 pl/mm. Os resultados demonstraram que o simulador do ACR foi o mais compreensivo e flexível a ser usado em diversos modelos de tomógrafos. Alguns simuladores não apresentaram dados suficientes para realizar o teste completo.

Palavras-chave: tomografia computadorizada, qualidade da imagem, fantomas.

Introduction

The optimization program includes an evaluation of the image quality. Each manufacture has developed a specific simulator for their computed tomography (CT) scanner. These phantoms present differences in the physical indicators to evaluate image quality, values of tolerance, and especially the procedure to carry out the tests. The American College of Radiology (ACR) CT phantoms have been used in an accreditation program in the USA. By applying a standard methodology, it is possible to evaluate and to compare scanners from all manufactures or models.

The minimum physical indicators recommended for the evaluation of image quality are: positioning of coach, CT number accuracy, slice width, low contrast resolution, high contrast (spatial) resolution, CT number uniformity, and noise. However, several simulators do not have these indicators to conduct a full assessment.

Despite of the increase of multi-slice scanners in Latin America, hospitals do not have personnel trained,

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instrumentation, and phantoms to implement the quality assurance program. Nowadays, the regulatory authority does not have any information about the performance of scanners of the services. Besides, countries of Latin America do not have a CT accreditation program. Consequently, there is no information about patient dose and image quality.

The aim of this paper was to compare the simulators provided by the manufactures and the Catphan's Phantom with the ACR CT Phantom. The image evaluation followed the protocol established by the manufacture of each phantom.

Materials and methods

The phantoms evaluated were provided by General Electric (GE), Siemens, Philips, Catphan 500, and ACR CT Phantom.

Image quality tests were performed in three scanners: Philips Brilliance 40, GE Light speed and Siemens Somaton, with their respective simulators and the CT ACR Phantom. Additional tests were carried out in the public hospital with Catphan 500 and ACR phantom on the scanner Picker.

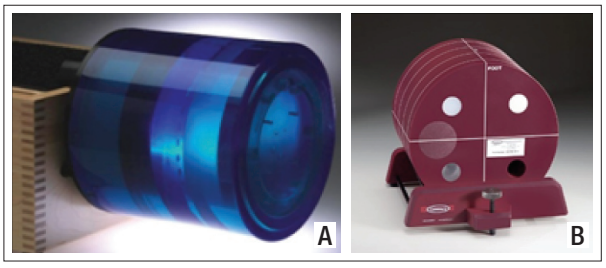

Figure 1. (a) Catphan 500; (b) ACR.

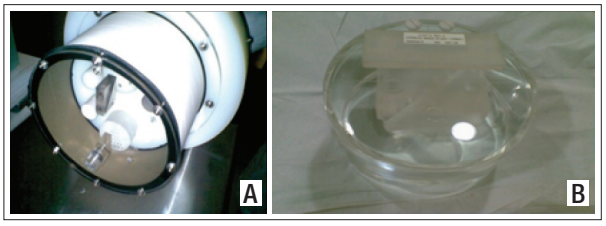

Figure 2. (a) Phantom Philips / Brilliance 40; (b) Phantom GE/ Light speed).

Table 1. Quality assurance of each manufacturer

Test QA	CAT[1]	ACR	GE	PHI[2]	SI[3]
Collimation	x	x	x	x	x
Accuracy of # CT	x	x	x*	x	x*
Pixel Size	x	-	-	-	-
High Contrast	x	x	x	x	x
Low Contrast	x	x	x	x	x
Noise and Uniformity	x	x	x	x	x
Contrast scale	x	x	x	x	x
Alignment	x	x	-	-	x
Accuracy laser light	-	-	x	-	-
x* - only water and air					

QA: quality assurance; [1]CAT: Catphan; [2]PHI: Philips; [3]SI: Siemens.

Simulators characteristics

The simulators have distinct characteristics, according to the specificity of the test performed.

The Catphan 500[1] (Figure 1a) is made in The Phantom Laboratory Incorporated, in New York. It is a solid Phantom containing four modules: CTP528, 21 line-pair high resolutions; CTP 515, sub-slice and supra-slice low contrast; CTP404, position verification, slice width, sensitometry and pixel size; CTP486, solid image uniformity module.

The ACR[2] CT accreditation phantom (Figure 1b) is a solid phantom containing four modules, constructed primarily from solid water. There are external markings (BBs) on the first and last module to allow the alignment of the phantom in the axial, coronal, and sagittal directions. Using this phantom, it is possible to evaluate alignment, CT number accuracy, slice width, low and high contrast resolution, uniformity, and noise.

The Philips Phantom[3] (Figure 2a) has two parts: head and body. The part of the head contain: physical layer, impulse response and slice width; water layer, noise and uniformity; multi-strip, contrast scale and sensitometry. The part of the body contain: a Teflon strip and water hole.

GE's Phantom (Figure 2b) for scanners of light speed series can evaluate six quality image criteria: contrast scale, resolution of high and low contrast, noise, uniformity, slice width, accuracy of laser, and linearity of CT number[4]. It is divided into three parts: resolution's block, contrast membrane, and water hole.

The Siemens' Phantom for Somaton scanners contains a number of modules suitable for testing different CT image quality characteristics, such as: slice thickness, impulse response, CT number accuracy (water and air), high and low contrast, noise and uniformity, and alignment. Table 1 presents the proposed tests by each manufacturer.

For this study, the following were compared: collimation, accuracy and linearity of CT number, evaluation of high and low contrast, noise and uniformity, and contrast scale. Therefore, they demonstrate the adequacy to a proper image quality evaluation of each phantom.

Experimental setup

Simulators were placed and aligned using light beams of the scanners. All phantoms are cylindrical; the alignment in the gantry was performed considering sagittal and coronal projections. The position was determined by specifics marks of each simulator. The evaluation followed the respective manual of the manufacture. To compare the ACR and Catphan phantoms, the head routine protocol on axial acquisition was used.

Results and discussion

Slice thickness

Siemens Somaton Phantom

Table 2 shows the results of slice thickness to ACR and Siemens phantoms on Siemens/Somaton.

In Table 2, the maximum difference between the results obtained with the phantoms was 9% for the slice width with 10 mm. In relation to nominal slice, differences were lower than 3% for Siemens and 10% for ACR.

Philips

In this study, it was possible to compare the phantoms results only for 5 mm slice thickness (Table 3), in which the result obtained was equal for both phantoms and nominal slice thickness. For 10 mm, the percentage difference between the nominal and ACR was of 46%.

CT GE Hi-Speed

In the Table 4, for nominal 3 mm slice thickness, the Phantoms GE and ACR presented the same values. For the other thicknesses (5, 7 and 10), we could only obtain the comparison with nominal values. For ACR measurements, the values for 3 and 7 mm were the same of the selected. For GE, the difference between the measured and the nominal values was 5%.

CT Picker

Table 5 presents the slice thickness measurements using Catphan and ACR phantoms. For all nominal slice thickness, the differences between the phantoms results were 5%. Comparing with the nominal value of 3 mm, the percentage difference was approximately 40%.

Table 2. Comparison of slice thickness measured with the CT Somaton phantom and ACR

Nominal slice thickness (mm)	Slice thickness measured (mm)		D (%)
	Phantom ACR	Phantom Siemens	
2	2.5	2.3	8
3	3.0	3.2	7
10	9.0	9.8	9

Table 3. Slice thickness for CT Brilliance, Philips

Slice thickness selected (mm)	Slice thickness selected measure (mm)	
	Phantom ACR	Phantom Philips
5	5	5
7	10	-

Table 4. Slice thickness for CT Hi-Speed, GE

Slice thickness selected (mm)	Slice thickness selected measure (mm)	
	Phantom ACR	Phantom GE
3	3.0	3.0
5	-	5.0
7	7.0	-
10	-	9.5

Table 5. Slice thickness for CT Picker

Slice thickness selected (mm)	Slice thickness selected measure (mm)	
	Phantom ACR	Phantom Catphan
3	2,2	2,1
5	5	5,1
10	10	10

CT number accuracy

Siemens phantoms

Table 6 presents the accuracy values of the CT number carried out with ACR and Siemens Phantoms. The Siemens Phantom only has water and air inserts. Important structures, like soft tissue and bone, are not available. For all cases, the values are in the tolerance range.

CT Brillance, Philips

Table 7 presents the results of CT number accuracy with ACR and Philips Phantoms. For polyethylene and acrylic, the results showed a difference of 14 and 2%, respectively. For water, although the values were in accordance to the tolerance, the value measured with ACR phantom was approximately 7 HU. Philips Phantom does not have a material similar to air. Therefore, with the exception of acrylic, the CT number accuracy was adequate.

CT Hi-Speed, GE

In Table 8, the results of the CT number accuracy for CT Hi-Speed from GE are presented. In this case, water is the only common material in the phantoms. The result to the discrepancy was 43% between the simulators.

Table 6. Accuracy of CT number for CT Somaton, Siemens

Material	Average number of CT (HU)		
	Phantom ACR	Phantom Siemens	Reference (HU)
Polyethylene	-90.5	-	-107 and 87
Water	0	-1.0	-7 and +7
Acrylic	126.7	-	+ 110 and 130
Bone	894.0	-	+ 850 and 970
Air	- 983.1	-999.0	- 1,005 and 970

Table 7. Accuracy of CT number for CT Brillance, Philips

Material	Average number of CT (HU)		
	Phantom ACR	Phantom Philips	Reference (HU)
Polyethylene	-81.2	- 70	- 107 and 87
Water	5.7	0	-7 and +7
Acrylic	136.6	140	+ 110 and 130
Bone	893.7	-	+ 850 and 970
Air	-973.9	-	-1,005 and 970

Table 8. Accuracy of CT number for CT Hi-Speed, GE

Material	Average number of CT (HU)		
	Phantom ACR	Phantom GE	Reference (HU)
Polyethylene	-90.4	-	- 107 and 87
water	-0.7	-0.4	- 7 and +7
Acrylic	124.9	-	+ 110 and 130
Bone	917.2	-	+ 850 and 970
Air	-985.1	-	- 1,005 and 970
Polyethyrene	-	-1,1	-

Picker

The CT numbers obtained with ACR and Catphan Phantoms are presented in Table 9. For polyethylene and air, the discrepancy between results was of 4 and 1%, respectively. The reading of water had a very high discrepancy between phantoms.

Low contrast resolution

The Siemens and ACR Phantoms contain low contrast groups of objects inside a similar background with different sizes. For both phantoms, groups with 5 and 2 mm diameter were identified applying the manuals.

For Philips Brilliance CT, we could not visualize the group of 5 mm as the manufacture in ACR and Philips.

The GE Phantoms contain a polystyrene membrane suspended in water with holes with diameters of 10, 7.5, 5, 3 and 1 mm. It was observed holes of 3 mm. The differences between CT number of the membrane and water are equal to 10 (contrast level).

In the Catphan 500, the contrast levels are measured marking region of interest (ROIs) over the largest target visualised in supra-slice, sub-slice, and in the background (Table 10). With the ACR's Phantom, inserts of 6 mm were visualized inserts by applying head's protocols. With the Catphan, the smallest diameter discernible was 5 mm for supra (0.3% contrast level) and 5 mm for sub-slice (1% contrast level).

Uniformity and noise

Table 10 presents the results of uniformity and noise according to ACR manual for all scanners.

For Siemens CT scanner using its own phantom, it was possible to evaluate only uniformity. ACR showed a uniformity of -0.6 HU and Siemens, 7.3 HU. The results were satisfactory.

The results to the Hi-Speed GE Scanner and Philips Brilliance by uniformity and noise using their own simulator were satisfactory. Nevertheless, when comparing to the ACR, the values for uniformity and noise were respectively 3.4 HU and 2.4 to GE and -1.4 HU and 4.8 to ACR. For Philips, the noise showed a difference of 16% in relation to the manufactures tolerance. Compared with the ACR, the # CT was 55% superior and the standard deviation was 20% lower.

For the Picker, the value of uniformity obtained by Catphan was 8.7 HU and 10.4 with the ACR. The maximum values of noise were 9.1 with the Catphan and 7 with ACR phantom.

High contrast resolution

Table 11 shows the results to the test of high contrast carried out with the ACR Phantom on scanners: Philips, Siemens, and Picker.[1]

Results to the CT GE using the own phantom of manufacturer presented a difference between the measured and reference value (18%) equal to 17%.

To the Siemens and Catphan phantom, the MTF method was used to quantify the values of high resolution. The results obtained for Siemens and Picker scanners were according to the manufacturer's tolerances (Tables 12 and 13).

Table 9. Accuracy of CT number for CT Picker

Material	Average number of CT (HU)		
	Phantom ACR	Phantom Catpham	Reference (HU)
Polyethylene	-98,2	-94,4	-107 and 87
Water	10,1	0	-7 and +7
Acrylic	133	120	+110 and 130
Bone	978	-	+850 and 970
Air	-974,6	-980	-1005 and 970

Table 10. Uniformity and noise – Phantom ACR

Parameter / Position	Average number of CT (HU) ± standard deviation			
	CT Siemens	CT Philips	CT GE	CT Picker
Center (C)	-0.4±5.2	3.8±6.9	-1.4±4.8	10.4±5.2
3h	-1.0±4.3	3.3±5.2	-0.7±4.2	10.7±6.3
6h	-2.3±4.7	4.1±5.5	-0.1±4.9	11,0±7,0
9h	-1.0±4.2	3.6±5.8	-0.1±4.3	10,8±4,7
12h	0.3±4.2	4.1±5.4	0.4±4.2	11.6±4.8

Table 11. High contrast resolution - Phantom ACR

Technique	Spatial frequency (pl/mm)			
	CT Siemens	CT Philips	CT Picker	Reference
Abdomen adult	6	6	-	5
Chest Hi-Resolution	8	7	-	6
Head	-	-	7	-

Table 12. High contrast resolution – CT Siemens

MTF (u)	Nominal Value (lp/cm)	Tolerance (lp/cm)	Measured value (lp/cm)	Conform
50%	4,50	0,45	4,2	y
10%	8,00	0,80	7,6	y
2%	10,00	1,00	9,6	y

Table 13. High contrast resolution – CT Picker

MTF (u) (%)	Value (lp/cm)	Tolerance (lp/cm)
60	5	±50 %
50	6	±50 %
8	7	±50 %

Conclusions

Evaluation of slice thickness showed similar results for all phantoms. For the accuracy of CT number, the water's CT number showed a very large discrepancy for all simulators. The GE and Siemens Phantoms do not have the structures to simulate soft and high materials, which are necessary to image quality evaluation. For low contrast resolution, all phantoms showed equivalent results.

For uniformity and noise, GE and Siemens phantoms presented results with a very large discrepancy in relation to ACR. However, Philips and Cathan Phantoms showed equivalent results.

Results demonstrate that the ACR simulator was the most comprehensive and flexible for use in several scanner models. It also had all the tests recommend by the International Image Quality Assurance[5].

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