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CT number accuracies for different number of detector array and age of detector: A multi-center study

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Abstract

Background: The accuracy of the CT number and its linearity are important parameters in computed tomography (CT) image quality. Both parameters may depend on the number of detector arrays and the age of detector. No previous study has investigated this issue.
Purpose: The purpose of this study was to investigate the CT number accuracy of various materials in ACR 464 CT phantom images and its linearity from 55 different scanners as a function of the number of detector arrays and age of detector.
Method: This study used an accredited ACR 464 CT phantom. The phantom was scanned by 55 CT different scanners from various vendors. The CT numbers of different materials and their linearity were automatically measured using IndoQCT software from images of the phantoms. The coefficient of determination (R^2) was obtained from a graph of CT number versus material density. Information on the number of detector arrays (from 2- to 128-row array) and age of detector (from 1 to 12 years, determined from the commissioning date) were found from the Medical Physicist officer at each CT center.
Result: It was found that 6 out of the 55 scanners had a CT number linearity lower than 0.990. The CT scanners with R^2 values below this standard had a number of detector of 16- and 32-row array, and have detector ages of 3, 5, 8, 10, 11, and 18 years.
Conclusion: The accuracy of CT number and its linearity were independent of the number of detector arrays and the age of the detector. The finding suggests that quality control of the accuracy of CT number and its linearity should to be carried out periodically so that if any issues can be addressed as soon as possible.

Keywords: CT number, ACR phantom, CT-scan

Introduction

The use of computed tomography (CT) as an imaging modality increased rapidly since its first introduction in 1970[1,2]. CT utilizes x-rays as ionizing radiation to obtain images of the target area[3,4]. CT images depict different tissue attenuation within a body[5]. The difference of tissue attenuation is converted into CT numbers in Hounsfield units (HU)[6,7].

The accuracy of CT number in clinical practice is crucial[8,9], especially for diagnosis with quantitative computed tomography (QCT)[10]. CT number is used to support the process of diagnosing many diseases, such as identifying the composition of kidney stones, kidney cysts[11], osteoporosis[12], lung cancer, and anemia[10]. In addition, the accuracy of CT number also plays an important role in the field of radiotherapy. In radiotherapy, the accuracy of CT number is used to accurately perform dose planning in treatment planning systems (TPS)[11,13,14].

Every CT scanner has their own characteristics in mapping attenuation of materials[15,16], especially in materials with various effective atomic numbers and densities. Therefore, the resulting CT number may vary for each CT machine[17,18]. Considering its important role in various aspects of diagnosis, CT number accuracy is considered an important parameter of image quality and it needs to be regularly monitored to avoid patient misdiagnosis. Anam et al.[5] studied the CT number linearity of 16 CT scanners and showed a different trend of CT number accu-

Authors' contribution: A – Research concept and design, B – Collection and/or assembly of data, C – Data analysis and interpretation, D – Writing the article, E – Critical revision of the article, F – Final approval of the article.

racy in each scanner. In another study, Cropp et al.[18] conducted CT number evaluation on 36 CT scanners using the ACR CT phantom for tube voltage variations and showed that each object produced slightly different CT numbers for different CT manufacturers and tube voltage variations.

The quality of CT images may depend on the number of detector arrays and the age of the detector. To the best of our knowledge, there is no study on the accuracy of CT numbers and its linearity from various CT machines with different numbers of detector arrays and age of the detector. The purpose of this study, therefore, is to investigate the CT number accuracy of various materials on ACR CT phantom images and its linearity from 55 different scanners as functions of number of detector array and age of detector.

Method

ACR 464 CT phantom

The phantom for this study is an accredited ACR 464 CT phantom with a diameter of 20 cm. This phantom has 4 modules for image quality assessment. In this study, module #1 was the only module used. Module #1 has 5 materials with different densities, i.e., Air, Polyethylene, Acrylic, Bone, and Solid water (**Figure 1**)[19]. Each material has a minimum and maximum CT number tolerance limit according to the value recommended by ACR which has been annotated in **Figure 1**[20].

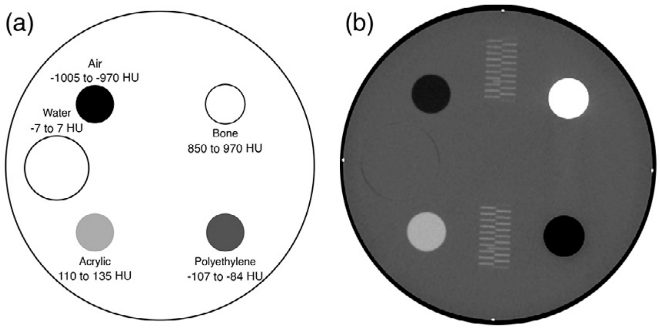

Figure 1. Design of the module #1 of ACR 464 CT phantom (a), and example of an axial image of it (b).

Data collection

A total of 55 datasets were obtained from 41 hospitals in Indonesia. This data was collected in the compliance test program from June 28, 2018 to May 15, 2024 by a survey team from Balai Pengamanan Alat dan Fasilitas Kesehatan (BPAFK) Surakarta. The survey was conducted on 19 from GE (GE Brivo CT385, Brivo CT325, BrightSpeed S, Revolution ACT, and Revolution EVO), 12 from Hitachi (Hitachi Eclos, Supria, and Scenaria), 13 from Toshiba (Toshiba Aquilion Prime, Aqulion/LB, Aquilion Lightning, Aquilion Start, Alexion, Asteion, and Activion 16), 6 from Philips (Ingenuity CT), and 5 from Siemens (Definition AS, Emotion 16, and Somatom). The parameters for image acquisition are listed in **Table 1**. The scanners have various numbers of detector arrays (**Table 2**). The detec-

Table 1. Scan parameters of 55 CT scanners

Number of Scanner	Vendor	Type	kV	mA	Revolution time (s)	FOV (mm)	Slice thickness (mm)	Mode	Pitch	Convolution kernel
2	GE	Brivo CT385	120	65-200	1-1.5	236-250	10	Axial	-	Standard
4	GE	Brivo CT325	120	60-200	1-2	214-250	10	Axial	-	Standard
4	GE	BrightSpeed S	120	100-300	1	219-225	10	Axial	-	Standard
3	GE	Revolution ACT	120	200	1	246-250	10	Axial	-	Standard
1	GE	Revolution ACTs	120	200	1	227	10	Axial	-	Soft
5	GE	Revolution EVO	120	100-300	1	204-250	10	Axial and Helical	0.969	Standard
6	Hitachi	Eclos	120	100-300	1-2	215-220	10	Axial	-	12
5	Hitachi	Supria	120	178-300	0.75-1	210-250	10	Axial	-	12
1	Hitachi	Scenaria	120	163	1	221	10	Axial		54
2	Toshiba	Aquilion Prime	120	200	1	208-227	10	Helical	0.813-0.85	FC26
1	Toshiba	Aquilion/LB	120	300	1	220	10	Helical	0.938	FC26
1	Toshiba	Aquilion Lightning	120	200	1	230	10	Helical	0.688	FC26
1	Toshiba	Aquilion Start	120	300	1	205	10	Helical	0.938	FC26
3	Toshiba	Alexion	120	150-300	1-1.5	212-235	10	Helical	0.688-1	FC26, FC64, FC68
3	Toshiba	Asteion	120	100-200	1	220-240	10	Axial and Helical	1.5	FC20, FC23, FC27
2	Toshiba	Activion 16	120	100	1	240	10	Helical	0.688	FC23
6	Philips	Ingenuity CT	100-120	194-400	0.4-0.75	203-250	10	Axial and Helical	0.276-0.399	UA and UB
1	Siemens	Definition AS	120	300	1	203	10	Helical		H31s
2	Siemens	Emotion 16	130	88-180	1.5	220-233	10	Axial and Helical	0.55	H31s
2	Siemens	Somatom	110-120	300	1	199-223	10	Axial and Helical	1	[,Br40f', ,3'] and [,J30s', ,3']

Table 2. Number of detector arrays in the scanners

Number of detector array	Vendor	Type	Number of scanner
2	GE	Brivo CT325	1
4	Toshiba	Asteion	3
8	GE	Brivo CT325	2
8	GE	BrightSpeed S	4
16	GE	Brivo CT385	1
16	GE	Brivo CT385	1
16	GE	Brivo CT325	1
16	GE	Revolution ACT	3
16	Hitachi	Eclos	6
16	Hitachi	Supria	5
16	Toshiba	Aquilion Lightning	1
16	Toshiba	Alexion	3
16	Toshiba	Activion16	1
16	Toshiba	Activion16	1
16	Siemens	Emotion 16	2
16	Siemens	Somatom	2
32	GE	Revolution ACTs	1
32	Toshiba	Aquilion Lightning	1
64	Toshiba	Aquilion Prime	2
64	Philips	Ingenuity CT	2
64	Siemens	Definition AS	1
128	GE	Revolution EVO	5
128	Hitachi	Scenaria	1
128	Toshiba	Aquilion/LB	1
128	Philips	Ingenuity CT	2
128	Philips	Ingenuity CT	2

tors have also various ages (**Table 3**). The information of the number of detector arrays (from 2- to 128- -row array) and the age of the detectors (from 1 to 18 years) was collected from the Medical Physicist officer at each CT center.

Table 3. Age of detectors

Age of detector (year)	Vendor and type	Number of scanner
<1	Siemens Emotion 16	1
1	GE Revolution ACT, GE Revolution EVO, Toshiba Asteion, Toshiba Aquilion Prime, Toshiba Aquilion Lightning, Siemens Definition AS, Siemens Emotion 16.	7
2	GE BrightSpeed S, Hitachi Supria, Toshiba Activion 16, Siemens Somatom.	4
3	GE Revolution ACT, GE Brivo CT385, Toshiba Aquilion Prime, Toshiba Aquilion Lightning, Philips Ingenuity CT.	5
4	GE BrightSpeed S, Hitachi Supria, Toshiba Asteion.	4
5	GE Brivo CT325, GE Revolution EVO, GE Revolution ACT, GE Revolution ACTs, Hitachi Eclos, Hitachi Supria, Hitachi Scenaria, Tohsiba Aquilion/LB, Toshiba Alexion, Philips Ingenuity CT.	10
6	GE Revolution EVO, Toshiba Alexion, Hitachi Supria, Philips Ingenuity CT.	4
7	GE BrightSpeed S, GE Revolution EVO, Hitachi Supria, Toshiba Alexion, Philips Ingenuity CT.	5
8	Hitachi Eclos, Philips Ingenuity CT.	3
9	Philips Ingenuity CT.	1
10	GE Brivo CT325, GE Revolution ACT, Hitachi Eclos, Toshiba Activion 16.	5
11	Toshiba Asteion, Siemens Somatom.	2
13	GE Brivo CT325, GE Brivo CT385.	2
14	GE Brivo CT325.	1
18	Hitachi Eclos.	1

CT number measurement

CT number measurement was automatically performed using IndoQCT software (**Figure 2**). The software detects the target position and place the region-of-interest (ROI) automatically. After the CT number of each material was obtained, the coefficient of determination (R^2) between CT number and material density was calculated using equation (1)[21].

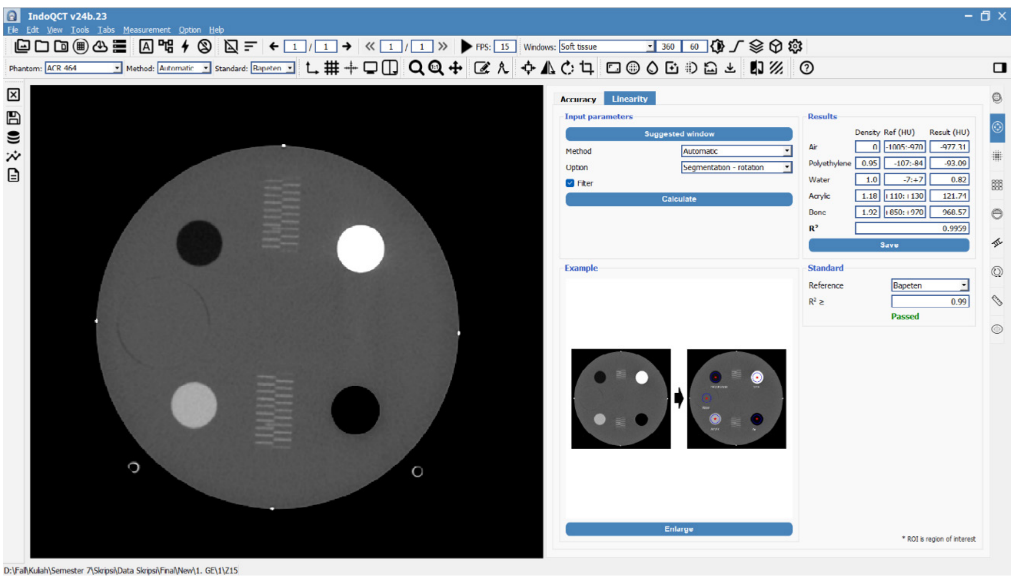

Figure 2. User interface of IndoQCT software

$$R^2 = \left(\frac{n\sum xy - \sum x \sum y}{\sqrt{[n(\sum x^2) - (\sum x)^2][n(\sum y^2) - (\sum y)^2]}} \right)^2 \quad (1)$$

where y is the CT number of the material, x is the density of the material, and n is the number of materials. The measured CT number of each material was compared with the tolerance range recommended by ACR, and the R^2 value was compared with the minimum limit set by the Indonesian regulatory body, which is 0.990[22].

Result

CT number measurement

Figure 3 shown the graphs of CT numbers of each material within the ACR CT phantom for the 55 CT scanners. For Air, there were 2 scanners with CT numbers below the minimum limit (-1000 HU), i.e., Toshiba Aquilion Lightning and Toshiba Aquilion Prime scanners with CT numbers of -1006.0 and -1006.7 HU, respectively. For Polyethylene (PE) material, there was only 1 scanner with a CT number below the limit (from -107 to -84 HU), i.e., the Philips Ingenuity CT scanner with a value of -108.0 HU. For Acrylic material, there were no scanners with a CT number out of the limit (from 130 to 145 HU). For Bone material, there were 29 scanners that produced CT numbers outside the tolerance limit range (from 850 to 970 HU), i.e., 3 of GE BrightSpeed S scanners, 4 of GE Revolution ACT, 5 of GE Revolution EVO, 5 of Hitachi Eclos scanners, 4 of Hitachi Supria, 1 of Hitachi Scenaria, 1 of Toshiba Aquilion Start scanner, 5 of Philips Ingenuity CT scanners, and 1 of Siemens Somatom scanner. The highest CT number of Bone was with the Toshiba Aquilion Start scanner with a value of 1261.2 HU, and the smallest value was with the Philips Ingenuity CT scanner with a value of 830.7 HU. For Water, no scanner produced a CT number value outside the reference range (from -7 to 7 HU). Based on the CT number measurement data, the Bone material produced the most CT numbers outside the recommended values, even though the tolerance range was the widest (i.e. 120 HU).

Figure 4 shows R^2 for the 55 CT scanners. Six scanners did not pass the CT number linearity standard (more than 0.990), i.e., 5 from Hitachi Eclos scanners, and 1 from Toshiba Aquilion Start scanner. The lowest determination coefficient value was from the Toshiba Aquilion Start scanner with a value of 0.976, and the highest value was produced by the Siemens Definition AS with a value of 0.999. Philips Ingenuity CT

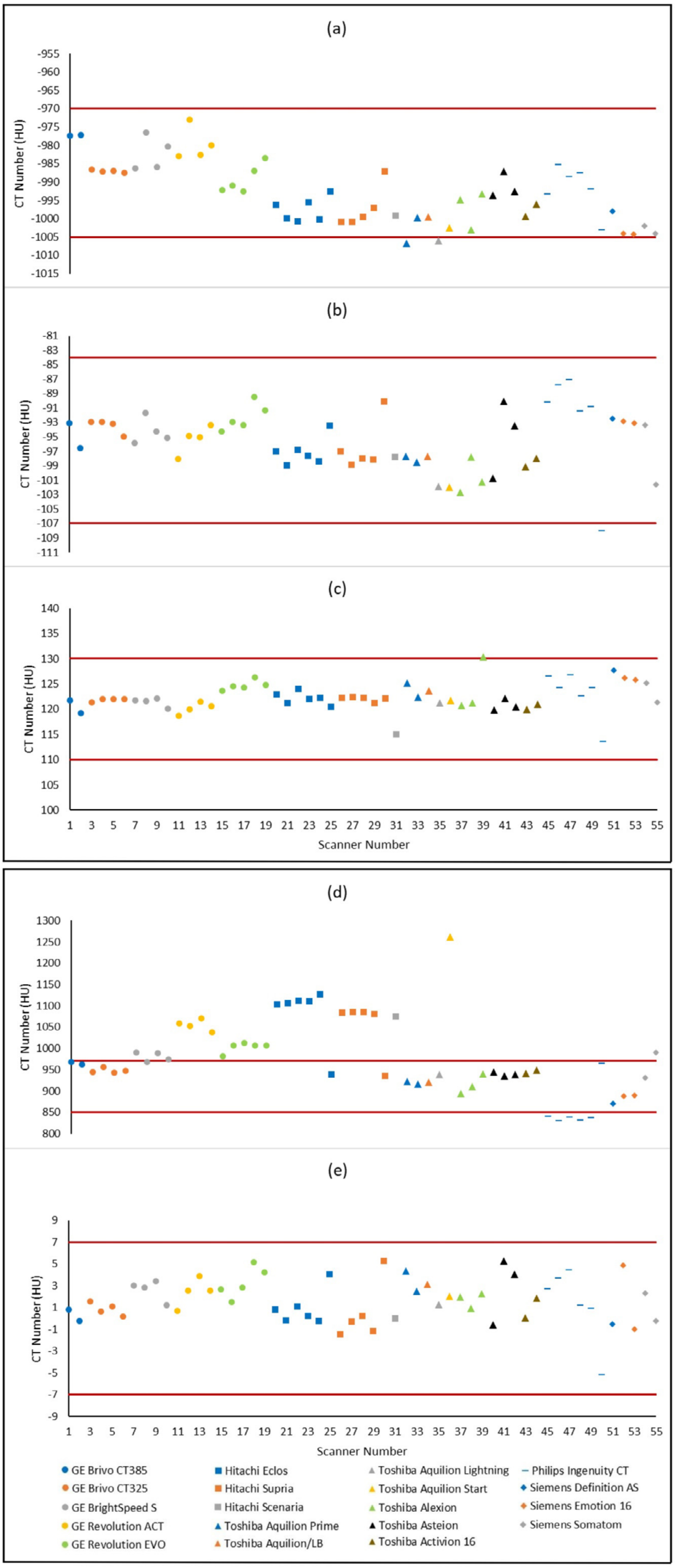

Figure 3. Graphs of CT number results of materials on the ACR CT phantom for 55 CT scanners. (a) Air, (b) Polyethylene (PE), (c) Acrylic, (d) Bone, and (e) Solid Water.

scanners were also among the scanners that obtained high linearity, i.e., 0.999.

Effect of number of detector array and age of detector

Figure 5(a) shows the relationship between the R^2 and the number of detector arrays. There were 6 CT scanners with a CT number linearity lower than 0.990. Five were 16-row array detectors and one was a 32-row array detector. We found no relationship between the R^2 value and the number of detector array. **Figure 5(b)** shows the relationship between the R^2 and age of detector. There were 6 CT scanners with a CT number linearity lower than 0.990. Each of them has a detector age of 3, 5, 8, 10, 11, and 18 years. There was no apparent relationship between the R^2 value and the age of detector.

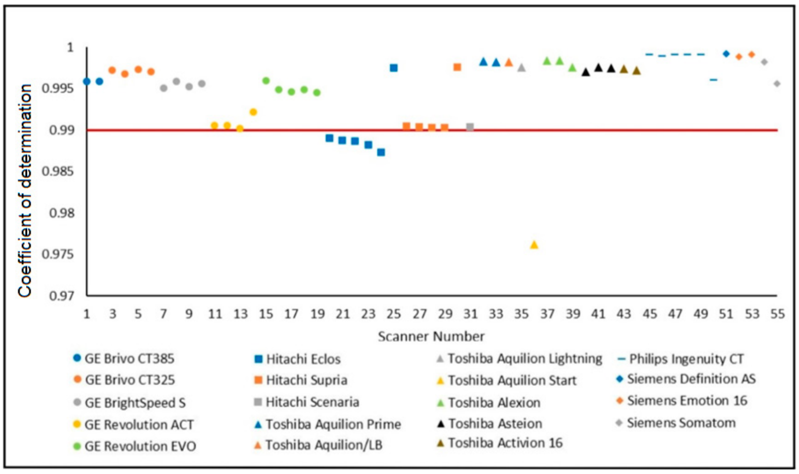

Figure 4. Graph of CT number linearity for 55 CT scanners.

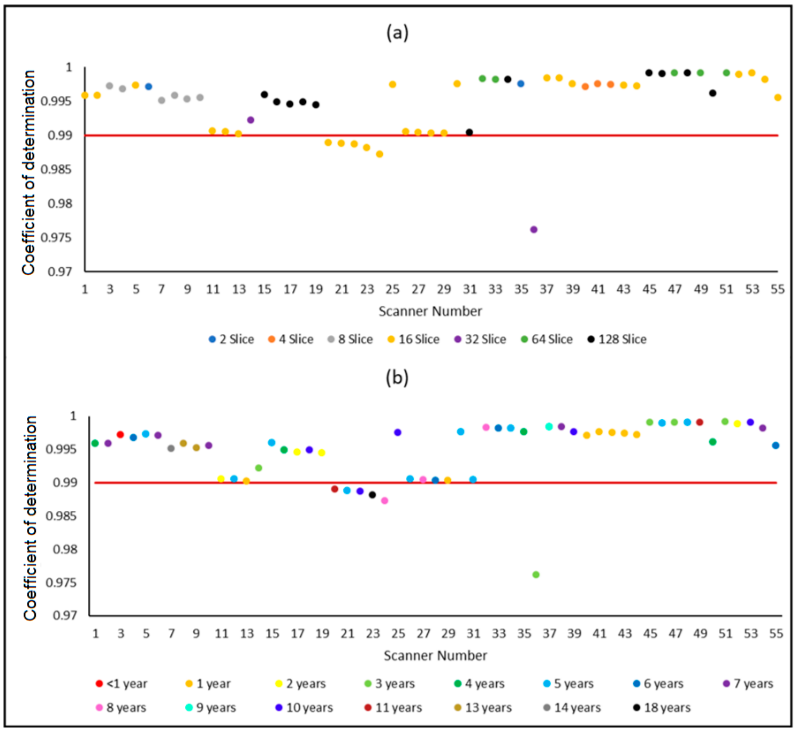

Figure 5. Graph of CT number linearity results for variation of (a) number of detector arrays, and (b) age of detector (year).

Discussion

This study was performed with the aim to evaluate the effect of number of detector arrays and age of detector on the accuracy of CT number and its linearity. This evaluation is important because the accuracy of the CT number and its linearity have a direct impact on the accuracy of diagnosis[23]. Although studies[1,18] had previously been carried out related to CT numbers on various scanners using ACR CT phantoms, there are no studies that comprehensively examined CT number accuracy and its linearity for various number of detector array and age of detector.

The accuracy of the CT number for each material in the ACR CT phantom was similar to previously reported data[10]. For water materials, there were no CT scanners whose CT number was outside the specified tolerance level. The Air, Polyethylene, Acrylic materials were only slightly out of the tolerance level. In bone material, the CT number values that are out of tolerance is much greater, i.e., 29 CT scanners out of a total of 55 CT scanners. It is noted that the CT number for bone material depends on the ratio of linear attenuation coefficients of the bone material and that on water. And the ratio of attenuation coefficients depends on beam quality. The beam quality depends on tube voltage and filtration. For some scanners, the filtration may depend on the mode (different bowtie filters for head and body modes). It is obvious, that CT numbers for bone material may differ between scanners, and between scanning protocols. There is no reason to expect it to fall within a relatively narrow, specified range. Also, there is absolutely no reason to expect linear correlation between CT numbers and density. Of course, if the material composition was constant, the CT numbers would be linear with material density. But bone differs from water. Bone contains calcium, which has a higher atomic number than hydrogen and oxygen, thus a higher probability of photoelectric effect, and higher attenuation coefficient. Hence, the bone with density of 1.9 g/cm^3 will not have a CT number of 970 HU. The CT number is expected to be higher according many other aspects.

For an in-depth analysis of the effect of scanner type on the CT number in bone material, dependency between the half value layer (HVL) value and the CT number of bone on each scanner needs to be known. However, we were unable to obtain data on the HVL value at the central axis because the data we used was retrospectively collected. This is one of the limitations of this study.

We found that the CT number accuracy and its linearity were not influenced by the number of detector arrays and age of detector. It was found that CT scanners with 2, 4, 8, 64, and

128-row array can produce coefficient of determination values above the tolerance limit. R^2 values smaller than 0.990 were only found in some 16- and 32-row arrays.

The assumption that increasing age of detector age may cause degradation in the resulting CT number was not proven. The age of detectors that were 13 and 14 years old still had accurate CT number and good linearity (above 0.990). In contrast, one of the detectors that had a linearity below 0.990 was only 3 years old. It should be noted that the CT scanners evaluated in this study are CT scanners that are still used for examinations in hospitals and undergo routine quality control (QC). Thus, it can be understood that the CT scanners must still be within tolerance limit, including their CT number linearity. If the value obtained from the QC program is outside the tolerance, repair or replacement of components must have been carried out. This also shows the importance of the routine QC program to ensure that the image quality parameters are still within the tolerance limits.

Among the limitations of the study was that the accuracy CT number and its linearity measurements were not carried out with the same input parameters. This was due to differences in the settings of several CT scanners. In fact, as reported in previous studies[18,24-27], different tube voltages have the potential to produce different CT number values. Variations in tube current do not affect the CT number[10], but low currents cause high noise in the image, so the accuracy of the CT number can be affected[23]. It is also important to note that the slice thickness used in this study was very large i.e., 10 mm. Currently, it is very rare for scans to be performed with a slice thickness of 10 mm. It is noted that the data we have is compliance test data, collected retrospectively. This large slice thickness leads to low image noise, but the potential for partial volume artifacts (PVA) is higher.

The advantage of this study is that the CT number measurements were carried out automatically so that measuring subjectivity was avoided. The segmentation results of each object on the ACR CT phantom were displayed and all showed accurate results. However, a weakness and limitations of the study is that, the number of scanners used is still quite limited at only 55 CT scanners and the data used is retrospective data so that it can't explore more deeply other parameters that want to be studied. Further studies with non-retrospective data and more scanners would provide more convincing results. In addition, it important to note that the ACR standard is testing in axial mode. In this study, we used the data from compliance tests in our country, and the tests are carried out in two modes, namely axial and sagittal. Therefore, the data we analyze is mixed between axial and helical modes.

Conclusion

Scanners with different vendors have different HU value characteristics for each material in the ACR CT phantom. The same exposure factor can produce different HU values when applied to scanners from with different vendors. Especially in bone material, deviations are very usual to happen because of the high density. The number of detector arrays (from 2 to 128-row array) and the age of the detector (from <1 to 18 years) did not have a significant influence on the accuracy of CT number and its linearity. The more important issue is to carry out quality control periodically so that any reduction of CT number accuracy and linearity can be detected as soon as possible.

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Conflict of interest

None

Reference

1. Anam C, Amilia R, Naufal A, Ali MH. Automatic measurement of CT number in the ACR CT phantom and its implementation to investigate the impact of tube voltage on the measured CT number. Radiat Phys Chem. 2023;216:111434. doi: 10.1016/j.radphyschem.2023.111434.
2. Afifi MB, Abdelrazek A, Deiab NA, Abd El-Hafez AI, El-Farrash AH. The effects of CT x-ray tube voltage and current variations on the relative electron density (RED) and CT number conversion curves. J Radiat Res Appl Sci. 2020;13(1):1–11. doi: 10.1080/16878507.2019.1693176.
3. Sadia RT, Chen J, Zhang J. CT image denoising methods for image quality improvement and radiation dose reduction. J Appl Clin Med Phys. 2024;25(2):1–17. doi: 10.1002/acm2.14270.
4. Diop AY, Diagne M, Faye NAB, Dieng MM. Feasibility study for the evaluation of doses received by organs during medical exposure for pediatric patient undergoing CT scan and estimation of the potential risk of radiation-induced cancers. Radiat Phys Chem. 2023;216:111432. doi: 10.1016/j.radphyschem.2023.111432.
5. Anam C, Amilia R, Naufal A, Budi WS, Maya AT, Dougherty G. The automated measurement of CT number linearity using an ACR accreditation phantom. Biomed Phys Eng Express. 2023;9(1):17002. doi: 10.1088/2057-1976/aca9d5.
6. Anam C, Amilia R, Naufal A, Dougherty G. Automatic measurement of CT number linearity in three types of Catphan phantoms. J Teknol. 2023;85(6):155–160. doi: 10.11113/jurnalteknologi.v85.20340.
7. Brindhaban A, Jassim O. Effect of X-ray beam energy and image reconstruction technique on computed tomography numbers of various tissue equivalent materials. Radiography. 2021;27(1):95–100. doi: 10.1016/j.radi.2020.06.017.
8. Duan X, Zhang Y. Establishing quality control action limits for CT number accuracy in spectral images using an American College of Radiology phantom. Med Phys. 2023;50(10):6071–6078. doi: 10.1002/mp.16626.

9. Dragon JM, Guha S, Salvatore MM. Hounsfield units: Future applications in clinical practice, radiomics, and artificial intelligence. Clin Imaging. 2024;110:110141. doi: 10.1016/j.clinimag.2024.110141.

10. Anam C, Amilia R, Naufal A, et al., Impact of noise level on the accuracy of automated measurement of CT number linearity on ACR CT and computational phantoms. J Biomed Phys Eng. 2023;13(4):353–362. doi: 10.31661/jbpe.v0i0.2302-1599.

11. Al-Hayek Y, Spuur K, Davidson R, Hayre C, Currie G, Zheng X. The effect of inappropriate patient centring on CT numbers and radiation dose: A survey of current practices and knowledge. Radiography. 2024;30(1):100–106. doi: 10.1016/j.radi.2023.10.009.

12. Kubon S, McLean AL, Eckardt N, et al. Early detection of aseptic bone necrosis post-cranioplasty: A retrospective CT analysis using Hounsfield units. J Cranio-Maxillofacial Surg. 2024;52(4):484–490. doi: 10.1016/j.jcms.2024.02.001.

13. Cruz-Bastida JP, Zhang R, Gomez-Cardona D, Hayes J, Li K, Chen GH. Impact of noise reduction schemes on quantitative accuracy of CT numbers. Med Phys. 2019;46(7):3013–3024. doi: 10.1002/mp.13549.

14. Davis AT, Palmer AL, Pani S, Nisbet A. Assessment of the variation in CT scanner performance (image quality and Hounsfield units) with scan parameters, for image optimisation in radiotherapy treatment planning. Phys Med. 2018;45;198–204. doi: 10.1016/j.ejmp.2017.11.036.

15. Hahn PF, Blake MA, Boland GWL. Adrenal lesions: Attenuation measurement differences between CT scanners. Radiology. 2006;240(2):458–463. doi: 10.1148/radiol.2402042120.

16. Birnbaum BA, Hindman N, Lee J, Babb JS. Multi-detector row CT attenuation measurements: Assessment of intra- and interscanner variability with an anthropomorphic body CT phantom. Radiology. 2007;242(1):109–119. doi: 10.1148/radiol.2421052066.

17. Roa AMA, Andersen HK, Martinsen ACT. CT image quality over time: Comparison of image quality for six different CT scanners over a six-year period. J Appl Clin Med Phys. 2015;16(2):350–365. doi: 10.1120/jacmp.v16i2.4972.

18. Cropp RJ, Seslija P, Tso D, Thakur Y. Scanner and kVp dependence of measured CT numbers in the ACR CT phantom. J Appl Clin Med Phys. 2013;14(6):338–349. doi: 10.1120/jacmp.v14i6.4417.

19. McCollough CH, Bruesewitz MR, McNitt-Gray MF, et al. The phantom portion of the American College of Radiology (ACR) Computed Tomography (CT) accreditation program: Practical tips, artifact examples, and pitfalls to avoid. Med Phys. 2004;31(9):2423–2442. doi: 10.1118/1.1769632.

20. ACR. Phantom testing instructions instruction manual for testing the ACR CT phantom. 2004;1–16.

21. Zarb F, Rainford L, McEntee MF. Image quality assessment tools for optimization of CT images. Radiography. 2010;16(2):147–153. doi: 10.1016/j.radi.2009.10.002.

22. BAPETEN REPUBLIK INDONESIA. Peraturan Badan Pengawas Tenaga Nuklir Republik Indonesia Nomor 2 Tahun 2Oi8 Tentang Uji Kesesuaian Pesawat Sinar-X Radiologi Diagnostik dan Inervensional. 2018;1–73. Online]. Available: https://jdih.bapeten.go.id/unggah/dokumen/peraturan/364-full(diubah).pdf

23. Kanamori H, Nakamori N, Inoue K, Takenaka E. Effects of scattered X-rays on CT images. Phys Med Biol. 1985;30(3):239–249. doi: 10.1088/0031-9155/30/3/004.

24. Alikhani B, Jamali L, Raatschen HJ, Wacker F, Werncke T. Impact of CT parameters on the physical quantities related to image quality for two MDCT scanners using the ACR accreditation phantom: A phantom study. Radiography. 2017;23(3):202–210. doi: 10.1016/j.radi.2017.03.013.

25. Das IJ, Cheng C, Cao M, Johnstone PAS. Computed tomography imaging parameters for inhomogeneity correction in radiation treatment planning. J Med Phys. 2016;41(1):3-11. doi: 10.4103/0971-6203.177277.

26. Husby E, Svendsen ED, Andersen HK, Martinsen ACT. 100 days with scans of the same Catphan phantom on the same CT scanner. J Appl Clin Med Phys. 2017;18(6):224–231. doi: 10.1002/acm2.12186.

27. Lascola KM, O'Brien RT, Wilkins PA, Clark-Price SC, Hartman SK, Mitchell MA. Qualitative and quantitative interpretation of computed tomography of the lungs in healthy neonatal foals. Am J Vet Res. 2013;74(9):1239–1246. doi: 10.2460/ajvr.74.9.1239.