Commissioning of CT Simulator-Acceptance Testing and Quality Assurance

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Abstract

This study evaluated the clinical use of a newly installed computed tomography (CT) simulator (GE Hangwei Medical Systems Co. Ltd, China) in the Department of Radiation Oncology (Figure 3). Licensing was granted by the Atomic Energy Regulatory Board (AERB), Government of India[3]. A pencil ionization chamber connected to a suitable electrometer, along with a head/body phantom, was used to measure doses in the axial and peripheral cavities of the phantom for typical techniques.

Image quality parameters such as the Hounsfield unit (HU) value of water, noise level, homogeneity, presence of artifacts, spatial resolution, contrast, and slice thickness were assessed using a CT performance phantom. All test items were evaluated to ensure they met the required tolerance levels. CT calibration curves, representing the relationship between CT number and relative electron density, were obtained for dose calculations in the treatment planning system. The positional accuracy of the lasers was also verified. The volume CT dose indices (CTDIvol) were 15.74 mGy for the head phantom and 8.11 mGy for the body phantom. The HU accuracy, noise level, and homogeneity for the CT simulator were -2 HU, 10% of the specified value, and 1 HU, respectively. A high contrast resolution test phantom was used to assess spatial resolution, with the smallest resolvable bar/hole pattern being 0.6 mm (8.3333 lp/cm). The CT simulator demonstrated comparable performance and was deemed acceptable for clinical use.

Keywords: Computed Tomography, CT simulator, Acceptance test, Volume CT Dose Index (CTDIvol), Radiotherapy Planning, Image Quality Evaluation, Radiation Oncology

Introduction

Since the late 1970s, computed tomography (CT) has played a pivotal role in radiotherapy planning, offering significant advantages in areas such as patient positioning, target delineation, treatment beam arrangement, and dose calculation. Unlike standard diagnostic CT scanners, CT simulators are typically designed with a wider bore (greater than 80 cm) to accommodate larger patients, breast cancer patients with their ipsilateral arm at a 90° angle, and individuals using specialized immobilization devices. Additionally, these simulators are equipped with a flat-bed couch and a moving laser system, which are essential for ensuring precise treatment simulation. Before conducting patient simulations, it is vital to validate the performance and characteristics of a radiation oncology-specific CT scanner to guarantee accuracy.

Under the American College of Radiology (ACR)[2,7] CT accreditation program, U.S. institutions utilizing CT devices are required to submit clinical and phantom images, dose measurements, and scanning protocols. The accreditation process assesses various image quality factors, including CT number accuracy, low-contrast resolution, image uniformity, and the volume CT dose index (CTDIvol). The acceptance thresholds for CTDIvol are set at 80 mGy for adult head scans and 30 mGy for abdominal scans. In Europe, a reference level of 60 mGy for the weighted CTDI is recommended[8] for routine head protocols. In India, the Atomic

Energy Regulatory Board (AERB) mandates that the tolerance for the Weighted Computed Tomography Dose Index (CTDIw) in a CT simulator should remain within ±20% of the manufacturer's specified value. Acceptance testing examines factors such as spatial resolution, low-contrast resolution, linearity, image noise, and artifact presence, along with the CTDI for each plug position. Although CTDIvol does not directly represent patient dose, it serves as a valuable tool for verifying and monitoring imaging doses. While noise is frequently identified as the primary factor influencing image quality and diagnostic accuracy, other quality metrics should also be taken into account when evaluating CT scanners.Our institute recently installed the GE Medical System Discovery RT wide bore (80 cm) CT simulator. The aim of this study was to assess the image quality and radiation dose of this CT simulator to ensure its clinical acceptance for use in radiotherapy planning.

Materials and Methods

Our institute recently installed a wide bore (80 cm) CT Simulator, the Discovery RT CT system (GE Hangwei Medical Systems Co. Ltd, China), for radiotherapy simulations[1]. The Atomic Energy Regulatory Board (AERB) granted licensing approval following the submission of detailed acceptance testing, installation, quality assurance (QA), and radiation survey reports.

1. Scan parameters and computed tomography dose index[4,5]

The scan parameters were assessed to verify that the kV and mAs selected by users are accurately delivered by the CT simulator. Slice thickness (mm) was measured using the ACR CT Accreditation Phantom, while the accuracy of the operating potential (kV) was evaluated with a Radcal Accu-Gold+ kV meter. The timer accuracy (seconds) was determined using a Fluke Biomedical 35080M Digital Timer, which precisely measures exposure time. The mA/mAs linearity (CoL) was analyzed using an ionization chamber and electrometer (PTW UNIDOS E Universal Dosimeter) by comparing outputs at various settings.

To ensure consistent radiation output under identical conditions, the reproducibility of output was measured and expressed as the Coefficient of Variation (CoV), utilizing the ionization chamber and electrometer (PTW UNIDOS E Universal Dosimeter). Total filtration was assessed to confirm appropriate X-ray beam filtration, optimizing patient dose reduction while maintaining image quality. A non-invasive X-ray beam quality analyzer (Radcal Accu-Gold) was used for this purpose, simultaneously measuring dose, dose rate, half-value layer, and total filtration. Scan parameters are detailed in Table 1. CTDI values were obtained using dedicated head and body CTDI phantoms, with individual plug positions assessed to ensure measurements fell within the acceptable range (Table 2).

2. Image quality

The CT Performance Phantom (GE HealthCare, Figure 1a) was scanned to assess image quality. This phantom contains a contrast test object, a CT number linearity insert, a resolution insert, and a slice thickness insert. The scan was performed using 120 kVp, 250 mAs, and a 10 mm slice thickness, with images reconstructed using a standard algorithm. The evaluation criteria included Hounsfield unit (HU) accuracy for water, noise level, homogeneity, artifact presence, spatial resolution, contrast, and slice thickness. The HU of water and noise level were determined using the mean and standard deviation of 4×4 cm^2 regions of interest (ROI) in water. The acceptable HU range for water is -7 HU to 7 HU, while noise should remain below 7 HU. Homogeneity, calculated as the standard deviation of HU across four ROIs, should not exceed 4 HU. Artifact presence was assessed subjectively based on visibility.

For spatial resolution (Figure 1c), the bar/hole pattern of 0.5 lp/cm should be distinguishable for a 10% contrast difference, while a resolution of 0.6 mm at 12% or 8.33 lp/cm should be achieved. The low contrast

resolution test phantom was scanned using 120 kVp, 100 mAs, a 5 mm slice thickness, a window width of 70, and a window level of 30. The low contrast resolution should detect objects of 3 mm at a 1.7% contrast difference, with an acceptance range of 5.0 mm at 1% contrast difference (minimum) and 2.5 mm at 0.5% contrast difference (expected) (Figure 1d). Slice thickness accuracy was determined by measuring the distance between aluminium strips, with a required tolerance of ±1 mm to pass the slice thickness test.

3. Hounsfield unit curves and laser position[2]

An electron density phantom (Advanced Electron Density Phantom Tissue-Equivalent CT-to-Electron Density Calibration, Sun Nuclear, Melbourne, FL) was utilized to determine the HU values corresponding to each tissue-equivalent insert (Figure 2). The phantom was scanned using a body scan protocol with 120 kVp, 213 mAs, and a 2 mm slice thickness. The generated HU-to-electron density and HU-to-physical density curves were then imported into the treatment planning system for dose calculation. Additionally, a Gammex 3 moving laser system (CT SIM+™ Precision Laser Systems, Sun Nuclear Corporation, USA) was installed, complemented by RapidSIM Software for reading and directing lasers to precise coordinates. The IsoDRIVE™ mode enables automatic transmission of treatment planning and simulation coordinates to the lasers, allowing for hands-free adjustments to facilitate patient alignment. To verify accuracy, a laser alignment phantom was positioned using the Gammex 3 laser system and scanned with 120 kV, 200 mAs, and a 1.25 mm slice thickness. The laser system's accuracy was evaluated using RapidSIM Software.

Results

1. Verification of scan parameters and Computed Tomography Dose Index[10]

The scan parameters set by users were accurately verified, with average discrepancies of 1% for kV and 0.039% for mAs. As presented in Table 1, the results of the scan parameter verification remained within the acceptable tolerance limits of ±7% for kVp and ±10% for mAs. Additionally, the CTDI measurements, shown in Table 2, confirm that the head and body CTDIs for each chamber position were within the established tolerance thresholds.

2. Image quality[6,9]

As shown in Figure 1b, the HU of water was measured at 0 HU, the noise level was 10% of the specified value, and homogeneity was 1 HU. In the spatial resolution insert image (Figure 1c), the bar/hole pattern of 0.5 lp/cm was clearly resolved for a 10% contrast difference, while a resolution of 0.6 mm at 12% or 8.33 lp/cm was achieved.

For low contrast resolution, a 3 mm object was distinguishable at a 1.7% contrast difference, meeting the expected tolerance range of 5.0 mm at 1% contrast difference (minimum) and 2.5 mm at 0.5% contrast difference (expected) (Figure 1d). The slice thickness, determined by measuring the distance between aluminum strips, was accurate within ±1 mm, passing the slice thickness test. The measured slice thickness values for the aluminum strip were 8.9 mm and 9.1 mm.

These results confirm that the CT simulator successfully met the spatial resolution assessment criteria.

3. Hounsfield unit curves and laser position verification

The phantom manufacturer provided the physical and electron density values for the designated materials. The average HU values for each region of interest (ROI) were consistent with the expected material properties, with detailed results summarized in Table 4. The corresponding HU values for each relative electron density (RED) were imported into the treatment planning system.

Laser position accuracy was evaluated in three directions using a laser verification phantom. The measured deviation between the laser position and the groove center in the images was less than 0.1 mm, confirming

precise alignment.

Figures and Tables

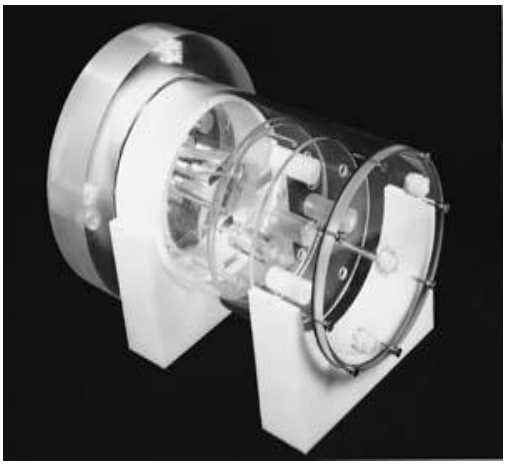

Fig. 1(a) Tissue Characterization Phantom Model 467 (GAMMEX, Middleton USA

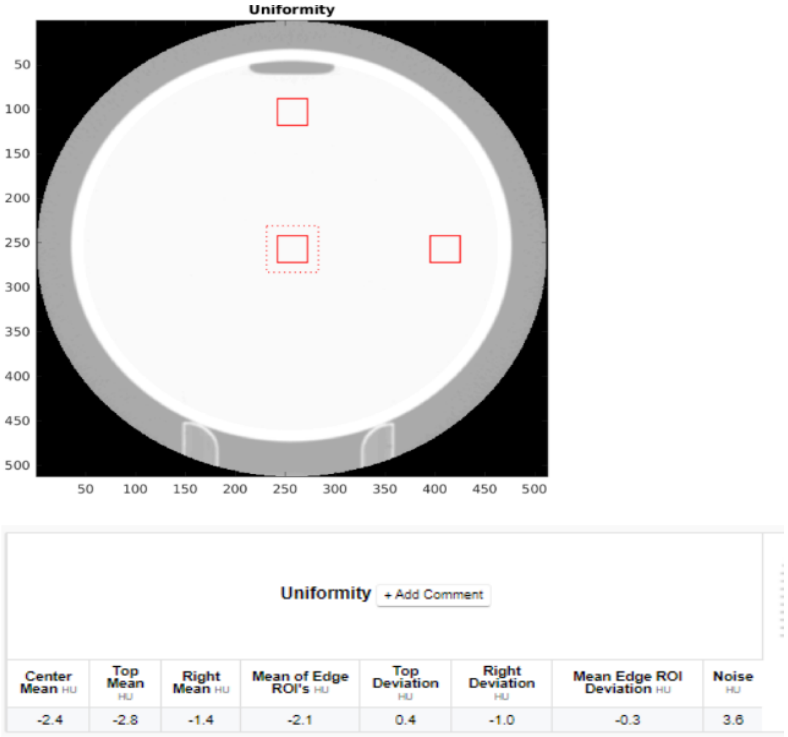

Fig.1(b) CT Slice for water Hounsfield unit (HU), noise level, homogeneity evaluation

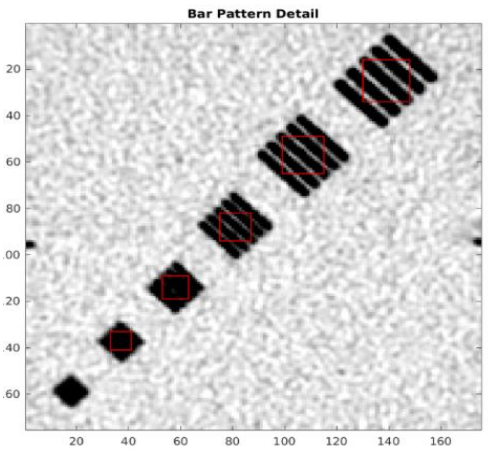

Fig.1(c) spatial resolution

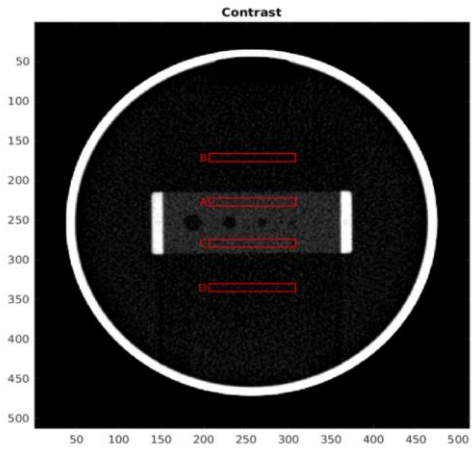

Fig.1 (d) Contrast

Table 1 Verification of scan parameters

1 Radiation Profile Width / Slice thickness Exposure parameters: kVp: 120 mAs: 100

Applied Slice thickness (mm)	Measured density profile width	Tolerance For slice thickness	
0.625	1.000	a. Less than 1 mm	0.5 mm
1.250	1.000	b. 1 mm to 2 mm	+ 50%
5.000	5.000	c. Above 2 mm	+ 1 mm

2 Measurement of operating potential

Set kV	Measured kVp				Ave kVp
	50 mA	100 mA	300mA	500 mA	
80	80.10	80.30	78.90	79.90	79.80
100	101.10	101.30	100.00	100.73	100.78
120	121.80	121.50	120.50	121.37	121.29
140	142.00	141.80	140.40	141.40	141.40

Tolerance: + 2 kVp

3 Timer Accuracy

Set Time (Sec)	Observed Time (Sec)	% Error
0.50	0.509	1.80
1.00	1.009	0.90
2.00	2.010	0.50
5.00	5.000	0.00

Tolerance: Tolerance: + 10 %

4 Measurement of mAs linearity
Operating parameters: kVp: 120 Slice thickness:10mm

mAs	Output in mGy			mGy/mAs (X)
	1	2	3	
50	1.06	1.06	1.07	0.02124
100	2.11	2.12	2.11	0.02112
300	6.31	6.31	6.32	0.02105
400	8.41	8.41	8.42	0.02103
600	13.63	13.64	13.66	0.02273

Coefficient of linearity (COL) = $\frac{X_{max} - X_{min}}{Xm + Xm;n}$ 0.03885

Tolerance in COL: + 0.1

5 Output Consistency

Operating parameters: mAs: 100 Slice thickness:10mm

kVp	Output (mGy)					Mean (X)	COV
	1	2	3	4			
80	0.69	0.70	0.69	0.69	0.69	0.692	0.00353
100	1.24	1.24	1.24	1.24	1.24	1.239	0.00127
120	1.90	1.89	1.90	1.90	1.89	1.893	0.00105
140	2.66	2.66	2.66	2.66	2.66	2.658	0.00056

Coefficient of Variation (COV) = X*' (2 [Xi - 1^2/n-1)
Tolerance in COV : + 0.05

Table 2: CTDI measured.

6. Measurement of Computed Tomography Dose Index (CTDI)

Use pencil ionization chamber connected to a suitable electrometer or TLD, in conjunction with a head/body phantom. Measure the dose in the axial and peripheral cavities of the phantom for typical techniques.

Operating parameters: kVp: 120 mAs: 100 Slice thickness :10mm

Result:		Head		Body
Axial dose	15.50	mGy/100mAs	4.71	mGy/100mAs
Peripheral dose	16.62	mGy/100mAs	10.40	mGy/100mAs
	15.52	mGy/100mAs	9.32	mGy/100mAs
	15.39	mGy/100mAs	9.21	mGy/100mAs
	15.90	mGy/100mAs	10.34	mGy/100mAs
Peripheral dose (Mean)	15.86	mGy/100mAs	9.82	mGy/100mAs
CTDIc	15.50	mGy/100mAs	4.71	mGy/100mAs
CTDIp (mean)	15.86	mGy/100mAs	9.82	mGy/100mAs

Weighted CTDI (CTDIp) = 1/3 CTDI, + 2./3 CTDIp

	CTDIw	15.74	mGy/100mAs	(Head)
		8.11	mGy/100mAs	(Body)
Quoted Value		13.94	mGy/100mAs	(Head FOV)
		7.33	mGy/100mAs	(Body FOV)

Tolerance: + 20% of the quoted value (Expected)
+ 40% of the quoted value (maximum)

7. Low contrast resolution

Use low contrast resolution test phantom.

Operating parameters: kVp: 120 mAs: 100 Slice thickness: 5mm
Window width 70 Window level 30

Result: Low contrast resolution:3mm at 1.7 % contrast difference
Tolerance: 5.0 mm at 1% contrast difference (minimum)
2.5mm at 0.5 % contrast difference (expected)

8. High contrast resolution

Use high contrast resolution test phantom.

Operating parameters: kVp: 120 mAs: 100 Slice thickness: 5mm
Use high resolution algorithm.
Window width 400 Window level 40

Result: Size of the smallest resolvable bar/hole pattern: 0.6mm (8.3333lp/cm)

Tolerance: At 10% contrast difference the size of the bar/hole pattern that could be resolvable should be 1.6 mm (» 3.12 lp/cm).

Expected high contrast resolution: 0.8 mm (» 6.25 lp/cm)

Table 3: Radiation leakage levels

9. Radiation leakage levels from X-ray tube housing at 1 M from the focus
Operating parameters: kVp: 140 mAs: 200 Sec:2
(use maximum kV available in the machine for leakage measurement)

Radiation Leakage Level (mR/hr)				
	Front(Cathode)	Back (Anode)	Left	Right
Tube	6.46	0.76	0.06	0.09

$$\text{Max leakage} = \frac{500 \text{ X Max leakage mR/hr}}{60 \text{ X mA used for measurement}}$$

Maximum radiation leakage from tube = 0.5386667 mR in one hour
0.0047 mGy in one hour

Result:

Maximum radiation leakage at 1 meter from the focus for workload of 500 mAmin in one hour is 0.5387 mR

Recommended upper limit: Leakage radiation level at 1 meter from the focus should be < 115 mR in one hour.

Table 4: Physical characteristics and HU acquired during the clinical commissioning stage

Material Name	Physical density(g/cm^3)	Relative Electron Density	Mean HU
HE General Adipose	0.955	0.944	-70.8
HE Breast	0.981	0.967	-40.1
Lung	0.45	0.435	-500.8
HE CT Solid Water	1.021	0.997	2.4
Titanium	4.512	3.745	3071
HE Brain	1.05	1.024	-0.6
HE Cortical Bone	1.926	1.777	1148.1
Lung	0.29	0.28	-675.1
CaCO3-50% Bone	1.557	1.46	711.4
HE Liver	1.08	1.054	61
Aluminium	2.71	2.357	1811.3
Stainless Steel	8	6.726	3071
HE True Water	1	1.021	0

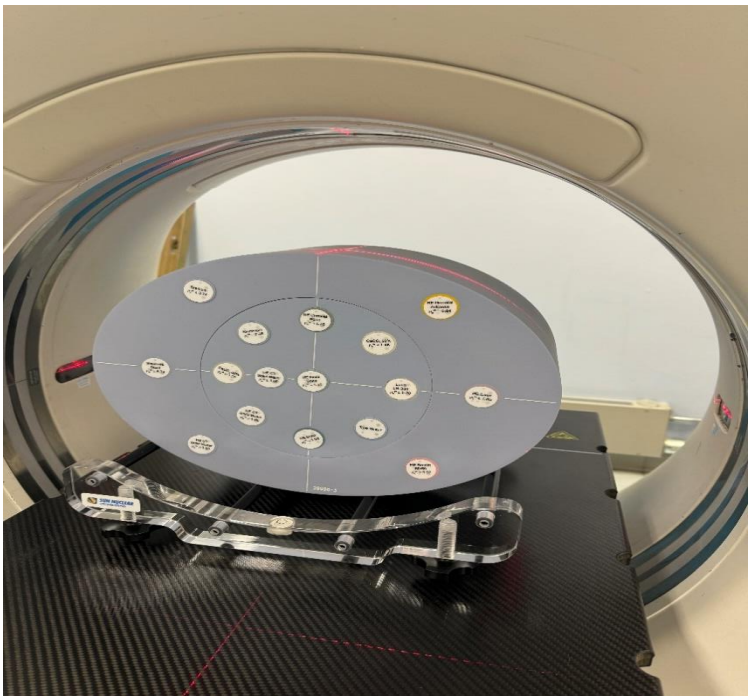

Fig.2 Advanced Electron Density PhantomTissue- Sun Nuclear.

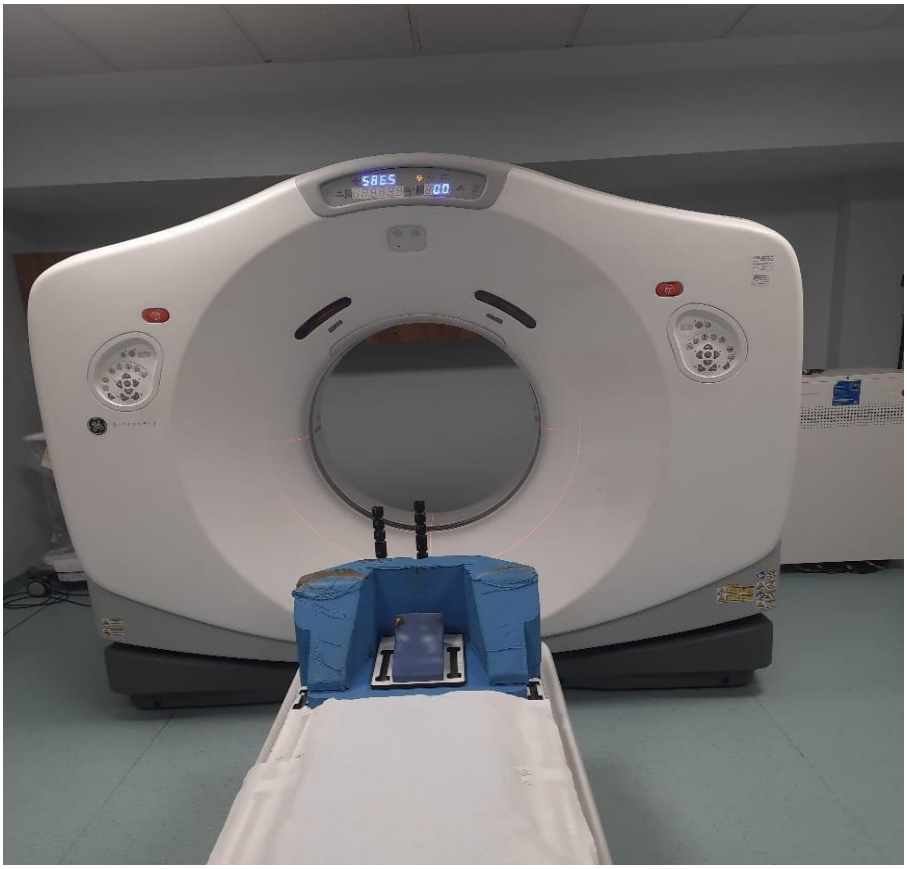

Fig.3-GE Discovery RT Wide bore CT Simulator

Discussion

The Atomic Energy Regulatory Board (AERB) granted licensing approval for the newly installed CT simulator after all test parameters were confirmed to be within acceptable tolerance limits. While CTDI is not recommended as a direct surrogate for patient doses due to its inability to account for individual body

size and composition, it remains essential for estimating more precise dose metrics, such as size-specific dose estimates.

The ACR[7] accreditation program sets CTDIvol tolerance levels at 80 mGy for a head phantom and 30 mGy for a body phantom. Using the formula CTDIvol = (1/3 × CTDIcenter) + (2/3 × CTDIperiphery), the measured CTDIvol values were 15.74 mGy for the head phantom and 8.11 mGy for the body phantom, both well within the specified tolerance limits.

HU uniformity, noise level, and homogeneity were all within the required tolerance limits[9]. Given that noise level plays a crucial role in overall image quality, it directly impacts lesion detectability. Studies on image quality across various CT scanners have shown that increased noise levels result in a lower contrast-to-noise ratio. Therefore, implementing stricter criteria for noise levels is a reasonable approach to maintaining image quality.

A CT calibration curve, which defines the relationship between HU values and their corresponding relative electron density (RED), is essential for accurate dose calculations, as megavoltage photon beams primarily interact through Compton scattering. Although CT numbers are proportional to the linear attenuation coefficient, individual scanners may exhibit variations. Therefore, HU values for each material should be specifically measured for a given scanner, typically during the commissioning process.

Maintaining HU consistency for specific tissues is critical, as variations can impact dose distribution. In general, changes of ±20 HU for soft tissue and ±50 HU for lung and bone can result in a 1% change in dose distribution. The newly installed CT simulator exhibited stable HU values, with a maximum deviation of just 2 HU. As this difference is negligible and falls within the acceptable tolerance for HU consistency, a single CT calibration curve, averaging both HU values, was applied in the treatment planning system.

In short, the installation, acceptance testing, and commissioning of the new CT simulator were successfully completed. Although all test results met the required acceptance criteria, regular quality assurance by medical physicists remains essential. Ongoing system monitoring is crucial to ensuring the long-term performance and reliability of the CT simulator in the radiation oncology department.

Conclusion

The clinical implementation of the newly installed CT simulator was validated through thorough image quality assessments and dose measurements. These evaluations confirmed that the simulator meets required standards and performs on par with existing systems. The results demonstrated its ability to produce high-quality images and accurate dose calculations, ensuring its suitability for radiotherapy planning. As a result, the CT simulator has been approved for clinical use, providing confidence in its reliability and effectiveness in a clinical setting.

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