Quality Assurance of a Diagnostic CT Machine

Aim:

To perform the Quality Assurance tests of a Diagnostic CT Machine.

Equipment Required:

1. Diagnostic CT Machine
2. CT QA Kit
3. Water/ Slab Phantoms

Theory:

A Quality Assurance (QA) program in diagnostic radiology is a set of protocols and procedures that ensures that the diagnostic images are sufficiently high quality and provide adequate diagnostic information with the lowest possible cost and the least possible exposure of the patient to radiation. A QA program of imaging equipment used in diagnostic radiology (Ex. X-ray radiography unit, Fluoroscopy unit, Computed Tomography unit, etc.) should address the image quality and geometry, including laser/couch and other geometric alignments. If CT images are used for radiotherapy treatment planning, the consistency of the electron density values across the CT, treatment planning system (TPS), and digitally reconstructed radiographs (DRRs) should also be verified.

Quality assurance testing ensures two important tenets of radiation protection:

- The dose received by the patient for diagnosis is optimized.
- Good image quality facilitates proper diagnosis, thus justifying the radiation exposure to the patient.

When new equipment is installed, acceptance testing at the customer's end for the first time and periodic QA of this equipment are mandatory requirements per AERB guidelines. The quality assurance tests for CT equipment fall into four categories

1. Mechanical tests
2. Tests for High-Frequency generators
3. Image Quality Parameters
4. Radiation Safety

1. Mechanical Tests

a. Alignment of the table to gantry:

To ensure the long axis of the table is horizontally aligned with a vertical line through the scanner rotational axis. Mismatch to these criteria will cause image artifacts, especially for bulky patients, if the patient extends out of the volume of interest (VOI). Tolerance is ±5mm of the table midline.

b. Gantry tilt: Accuracy of the tilt indicators

Most CT scanners accomplish non-orthogonal scans by tilting the gantry with some angle. If the tilt is not accurate, the gantry may hit the patient for some extreme clinical conditions.

The accuracy of the displayed gantry tilt can be assessed by supporting envelope-wrapped X-ray film at the gantry end of the patient table. The film must be held vertically (tapping into a Perspex block) to parallel the sagittal plane and intersect scan and coronal planes at right angles. Then, three axial exposures are made using the same film:

- One for the maximum superior gantry tilt
- One for the maximum inferior gantry tilt
- One at 0 gantry tilt

The three scan planes should be visible on the developed film. Also, the angles $\theta 1$ and $\theta 2$ between scan planes at maximum tilt relative to that 0° tilt should equal tilt angles displayed on the gantry. Tolerance is the manufacturer's specification or ± 2°.

c. Table Indexing Accuracy:

A ruler or tape measure placed alongside the table can be used to check that the degree of couch movement indicated on the gantry agrees with the actual distance moved. A load of approximately 70-80 Kg should be placed on the table to simulate a patient's weight.

2. Tests for High-Frequency Generators

a. Accuracy of operating potential (kVp)

The applied kilovoltage affects the quality and quantity of X-rays reaching the image receptor (Detector) and, hence, the contrast and density of the radiograph. Since any variation from the set kVp can affect the quality of the radiograph, the kVp settings must be checked periodically.

b. Accuracy of timer

If the exposure time of the x-ray diagnostic unit is not in order, the radiograph can be underexposed or overexposed. There may be a change in the adequate tissue contrast resolution in the image.

c. *Total filtration*

A minimum filtration must be added to the X-ray tube to remove low-energy components from the X-ray beam. These low-energy components do not contribute to image formation but result in unnecessary patient exposure. If the filtration is too high, the attenuation will be greater, and image contrast will be reduced. Therefore, the total filtration for the x-ray tube should be optimum for patient safety and image quality. For this purpose, the regulatory body (AERB) recommends total filtration for X-ray machines for different maximum-rated tube potentials. Total filtration includes inherent filtration and added filtration. Hence, total filtration evaluation is necessary to verify whether the added filtration is adequate. If not adequate, additional filtration must be provided for the x-ray tube.

d. *Linearity of radiation output (mA/mAs linearity)*

Keeping the kVp and time constant, the radiation output is measured at different mA stations. Each mA station reading is averaged, and the coefficient of linearity (COL) is evaluated from average mR/ mAs or mGy/ mAs (X) as follows

Coefficient of linearity (COL) = $\frac{X_{max} - X_{min}}{X_{max} + X_{min}}$ (Tolerance: CoL< 0.1)

e. *Reproducibility of radiation output*

Keeping fixed mA and time, radiation output is measured at various available kVp stations. The average of mR/mAs (mGy/mAs) is calculated (X). Consistency at each kVp station is checked by evaluating the coefficient of variation. The coefficient of variation should not exceed 0.05.

Coefficient of Variation (COV) = = $\frac{1}{X} \frac{1}{n-1} \sum (X - X_i)^2$ (Tolerance: CoV < 0.05)

Image Quality tests

1. Slice thickness

2. High contrast resolution

The high contrast resolution determines the minimum size of detail visualized in the plane of the slice with a contrast > 10%. It is affected by:

- The reconstruction algorithm
- Detector width
- Effective slice thickness
- Object to detector distance
- X-ray tube focal spot size

There exist two broad categories of measurement techniques:

- Those involving analysis of the point spread function, usually by calculation of the modulation transfer function (MTF)
- Those involving either objective analysis or visual assessment of images of resolution bar phantom.

  The resolution is the spatial frequency (in line pairs/cm) at which the modulation falls to 50%, 10%, or 2% MTF. The number of line pairs per cm visible in the image is approximately equivalent to the 2% value of the MTF.

  This result can then be compared with the 2% MTF if this is quoted in the manufacturer's specification.

3. *Low contrast resolution*

   Low contrast resolution is quoted in specification documentation as the smallest visible object at a given contrast for a given dose. The low contrast resolution determines the size of detail that can be visibly reproduced when there is only a small difference in density relative to the surrounding area.

4. *CT number accuracy and uniformity*

   Test phantoms of a standardized human shape or test objects of a particular shape, size, and structure are used for calibration and evaluation of the performances of CT scanners (supplied by the manufacturer). They should allow for the parameters to be checked: CT number uniformity, linearity, noise, spatial resolution, low contrast resolution, slice thickness, positioning of the couch, etc.

   - Accuracy: CT number depends on tube voltage, filtration, and object thickness/attenuation. CT number of water is, by definition, equal to 0. The Measured CT number should be $< \pm 4$ HU in the central ROI.

   - Uniformity: It relates to the fact that the CT number of each pixel in the image of a homogeneous object should be the same over various regions. The difference in the CT number between a peripheral and a central region of a homogeneous test object should be $< \pm 4$ HU. CT number uniformity can be assessed by placing four additional ROI (N, E, S, and W) at positions near the edge of the image of a uniform phantom. The mean CT number is then noted for these four regions, as well as the central one. The deviation from the central value should be calculated.

5. *CT number linearity*

It concerns the linear relationship between the calculated CT number and the linear attenuation coefficient of each element of the object. Deviations from linearity should be < ± 4 HU. CT number linearity is assessed using a phantom containing inserts of a number of different materials (materials should cover a wide range of CT numbers.

6. *Noise*

It is the local statistical fluctuation (standard deviation) of CT numbers of a homogeneous Region Of Interest (ROI). It strongly affects the low contrast resolution. Noise is dependent on the radiation dose. Image noise should be measured over an area of about 10% of the cross-sectional area of the test object.

Noise is generally assessed using cylindrical phantoms, either filled with water or made up of a tissue-equivalent material. Once an axial image of the phantom has been acquired, noise is obtained from the standard deviation in CT number in a region of interest (ROI) placed centrally within the image.

Noise figures given in manufacturers' specifications are quoted for a specific phantom (e.g. manufacturer's QA phantom) and specified scan parameters. These conditions must be matched exactly for the measurements/acceptance test.

Radiation Safety

1. *Radiation dose test (Measurement of Computed Tomography Dose Index, CTDI)*

Patient dose from a CT scan is assessed by measuring CTDI. Pencil ionization chambers of 10cm in length are used for this measurement. Two CT dosimetry phantoms are commonly used. A 15cm long, 16cm diameter transparent acrylic cylinder is used for "head" protocol measurements. A 15cm long and 32cm diameter cylinder is used for "body" measurements. Five to nine holes are strategically placed in the phantoms to accept the pencil ionization chamber.

The body phantom is placed on the patient's table, and the head phantom is supported on the headrest. Phantoms are aligned and centered at the scan isocenter. The ion chamber is inserted into either the central or one of the peripheral cavities of the phantom (all other cavities being filled with Perspex rods). Dose measurements at the center are used to calculate the central CTDI. Peripheral CTDI is measured in at least four positions around the phantom so as to achieve a true average.

Central and peripheral CTDI's are used to calculate weighted CTDI, CTDIw:

$$CTDI_w = \frac{1}{3} CTDI_c + \frac{2}{3} CTDI_p$$

Where $CTDI_c$ = CTDI measured at the center of the phantoms

$CTDI_p$ = CTDI measured at the periphery of the phantoms

CTDIw can be compared against diagnostic reference levels for standard scan examinations.

2. *Measurement of radiation leakage level*

As per the AERB Safety Code on Diagnostic X-ray Equipment and installations, every housing for medical diagnostic X-ray equipment shall be so constructed that the leakage radiation through the protective tube housing in any direction shall not exceed an air kerma of 1.0mGy (about 114mR) in one hour at a distance of 1.0m from the x-ray target. The measurement conditions are given below.

1. Averaged over an area not larger than 100 cm^2
2. No linear dimension greater than 20cm
3. Operating at maximum rated kVp and for the maximum rated current at that kVp.

The radiation leakage measurement is carried out with an ionization radiation survey meter. To check the leakage radiation, the collimator of the tube housing is fully closed. The operating time should be greater than the time constant of the survey meter. The exposure rate at one meter from the target is measured at different locations (anode side, cathode side, front back, and top) from the tube housing and collimator. For the maximum leakage rate (mR/h) for both tube housing and collimator, leakage in one hour is computed on the basis of the machine's workload. 180mA-min in one hour is taken as the maximum workload of a diagnostic machine. Hence, leakage in one hour will be:

Maximum leakage (mR/60min) x 180mA-min in one hour / Applied mA

3. *Radiation Protection Survey*

A radiation protection survey is a series of measurements of radiation levels at various locations around the diagnostic X-ray machine installation. This is done to check whether the radiation levels around the installation are within the permissible limits mandated by the Competent Authority (AERB). A pressurized ion chamber-based survey meter is used to measure the radiation levels.

*AERB data sheet is given below. Perform the experiment and fill the details in the sheet.

PERIODIC QUALITY ASSURANCE TEST REPORT FOR COMPUTED TOMOGRAPHY EQUIPMENT

1. **Radiation Profile Width/Slice thickness:**

Exposure parameters: kVp: mAs:

Applied Slice Thickness (mm)	Measured density profile width (FWHM)	Slice thickness	Tolerance
		Less than 1 mm	0.5 mm
		1 mm to 2 mm	±50 %
		Above 2 mm	±1 mm

2. **Measurement of operating potential:**

Set kV	mA station-1 (60 mA)	mA station-2 (80 mA)	mA station-3 (100 mA)	Average kVp	Tolerance
					± 2 kVp

3. **Timer Accuracy:**

Set Time (ms)	Observed Time (ms)	% Error	Tolerance
			± 10 %

4. **Measurement of mAs linearity**

Operating parameters: kVp: Slice thickness:

Output in µGy				µGy/mAs (X)	COL	Tolerance
mAs	I	II	III			

5. **Output Consistency**

Operating parameters: mAs: Slice thickness:

kVp	Output (mGy)					Mean (X)	COV
	1	2	3	4	5		
80							
100							
120							

6. Measurement of Computed Tomography Dose Index (CTDI)

Use a pencil ionization chamber connected to a suitable electrometer in conjunction with a head/body phantom. Measure the dose in the axial and peripheral cavities of the phantom for typical techniques. Take the readings for at least three kV_p settings.

Operating parameters: kVp: mAs: Slice thickness:

	Head (mGy/mAs)	Body (mGy/mAs)
Axial Dose ($CTDI_c$)		
Peripheral Dose ($CTDI_p$)		
Mean Peripheral dose ($CTDI_{p(mean)}$)		
Weighted CTDI ($CTDI_w$) $\boldsymbol{CTDI_w = \frac{1}{3} CTDI_c + \frac{2}{3} CTDI_p}$		
Tolerance	± 20% of the quoted value	± 40% of the quoted value

7. Low contrast resolution

Use low contrast resolution test phantom.

Operating parameters: kVp: mAs: Slice thickness: Window width:

Result:

Low contrast resolution: ------------ mm at ---------- % contrast difference

Tolerance: 5.0 mm at 1% contrast difference (minimum)
2.5 mm at 0.5 % contrast difference (expected)

8. High contrast resolution

Use high contrast resolution test phantom.

Operating Parameters: kVp: mAs: Slice thickness: Window width:

Use a high-resolution algorithm.

Result:

Size of the smallest resolvable bar/hole pattern: ----------mm (--------lp/cm).

Tolerance: At 10% contrast difference, the 1.6 mm (≈6.25 lp/cm) bar/hole pattern should be resolved

9. Radiation leakage levels from X-ray tube housing at 1 M from the focus

Operating Potential (kV) (Maximum kV)	mAs	Time

Radiation Leakage Level (mR/hr)			
Front(cathode)	Back (Anode)	Left	Right

Max leakage = $\frac{500\ mA\ \min\ in\ one\ hour\ X----Max\ leakage\ mR/hr}{60\ X----mA\ used\ for\ measurement}$ (mR in one hour)

Upper limit: Leakage radiation level at 1 meter from the focus should be ≤ 115 mR in one hour.

10. <u>Details of Radiation protection Survey of the installation</u>

Date of radiation protection survey:
Whether the radiation survey meter used for the survey has a valid calibration certificate: Yes/No

Applied Current (mA)	Applied Voltage (kV)	Exposure time (s)	Workload:

Provide the measured maximum radiation level (mR/hr) at different locations

Location	Max. Radiation level (mR/hr)
Control console (Operator Position)	
Outside the patient entrance door	
Behind Windows (if applicable)	
Patient Waiting Area	

Maximum Radiation level/week (mR/wk) = $\frac{---mA\frac{min}{week}\ X---Max.\ radiation\ level\ (mR/hr)}{60\ X----mA\ used\ for\ measurment}$

<u>Permissible limit</u>

For location of Radiation Worker: 20 mSv in a year (40mR/week)
For location of Member of Public: 1mSv in a year (2mR/week)