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DEVELOP MATLAB PROGRAM AND DESIGN QC PROTOCOL FOR DENTAL CT AND GENERAL-PURPOSE CT

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Abstract

Introduction Acceptance testing is done when a new CT scanner is introduced and then annually. When QC testing is done once a year, there is a possibility that some important inaccuracies/faults would be detected later than necessary and this can compromise patient safety. In order to prevent that, a light (semi-automated) QC protocol which can be carried out weekly (or bi-weekly) by the technician is ideal. The aim of this project is to develop a MATLAB program and design a light QC protocol for a dental Cone Beam CT scanner (CBCT) and a general-purpose CT scanner.

Methods To modify validate the already existing QC protocol of CBCT and develop a new MATLAB program suitable for a general-purpose CT scanner in the existing QC framework. The main parameters that will be checked with this protocol are the calibration (correctness of HU-units) and dose parameters (Dose length product/ correct working of the automatic exposure control). CT numbers calculated from ROIs in the CT images are used to check the parameters.

Result The QC protocols for CBCT and general-purpose CT have been developed. The parameters are within acceptable/critical limits and both the scanners are working as required.

Introduction

Appropriate protocols are necessary to ensure and enhance the quality of CT scans. Since CT uses ionizing radiation with accompanied risk of tumour induction, radiation safety protocols for optimizing the dose of ionizing radiation during CT scans to reduce unnecessary radiation exposure/overdose are vital. The aim of Quality assurance (QA) or Quality control (QC) is to assure patient safety and acceptable image quality (noise level, spatial resolution, etc.) necessary for clinical diagnosis by ensuring that the CT exams being performed achieve the desired diagnostic image quality at the lowest radiation dose possible while properly exploiting the features and capabilities of the scanner being used.

The CT protocol should review and evaluate all aspects, settings and parameters of CT exam. These include acquisition parameters (rotating time, detector configuration, pitch, etc.), patient instructions (e.g., breathing instructions), the administration and amounts of contrast material (intravenous, oral, etc.), reconstruction parameters such as the width of the reconstructed image/image thickness, reconstruction algorithm/filter, use of additional image planes (e.g., sagittal or coronal planes), etc., and post-processing parameters.[1] Advanced dose reduction techniques such as automatic exposure control (e.g., tube current modulation or automatic kV selection) methods, iterative reconstruction techniques, adjustment of acquisition parameters for patient size, etc. should be considered depending on the capabilities of the scanner.[1]

This QC protocol is done when a new CT scanner is introduced (acceptance testing) and then annually. When QC testing is done once a year, there is a possibility that some important inaccuracies/faults would be detected later than necessary and this can compromise patient safety. In order to prevent that, a light (semi-automated) QC protocol which can be carried out weekly (or bi-weekly) by the technician is ideal. It is essential that this light QC protocol is simple and not time-consuming since it should not interfere with patient procedures. The aim of this project is to develop a MATLAB program and design a light QC protocol for a dental Cone Beam CT scanner (CBCT) and a general-purpose CT scanner.

Materials and Methods

The main parameters that will be checked with this protocol are the calibration (correctness of HU-units) and dose parameters (Dose length product / correct working of the automatic exposure control). Deterioration of the X-ray tube in CT scanner leads to a deviation from the required ideal X-ray spectrum which results in HU-units outside the acceptable limits. As a result, the noise level increases and the dose changes. Faults in the detector can increase image noise because of the variation in CT numbers. Wrong calibration would also cause alteration in HU-units from the reference values. Based on the results from the QC protocol, such defects can be identified. Hence any deviation in the results requires a more thorough Quality Control to find out the problems with certain aspects of the scanner. In other words, it is supposed to be a sensitive but not a very specific test.

The Martini Hospital has an existing QC framework for dose and quality control within which the QC protocols for CBCT and general CT were developed.

The already existing MATLAB program for QC protocol of cone beam (dental) CT scanner is inoperative. The code has been modified and validated, and using it, a new MATLAB program suitable for a general-purpose CT scanner has been developed.

i) Cone beam/Dental CT (flat panel CT)

<u>CT, phantom and CT image details</u>

The CBCT scanner used in the experiment is Vatech PaX-Zenith3D.

The PMMA phantom of the cone beam CT scanner with the insert and its CT image are shown below (Fig 1.1 and 1.2).

Fig 1.1. Phantom of the cone beam CT scanner[2]

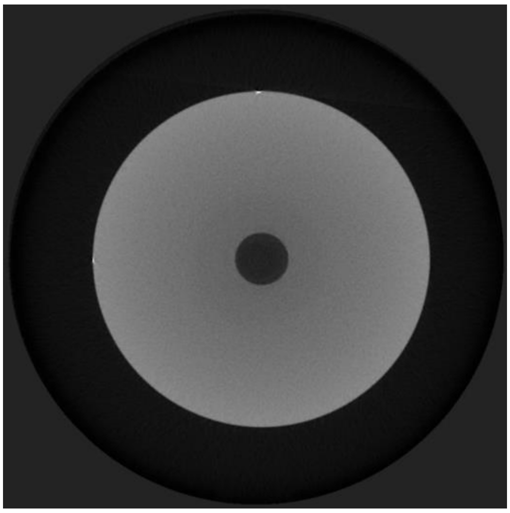

Fig 1.2. CT image of the phantom

Each scan of the phantom has 632 slices. The pixel size of the CT image is 800x800.

<u>Validation of dose parameters</u>

First the dose parameters: KVP, X-ray tube current, Slice thickness, and Image and fluoroscopy area dose product values extracted from the DICOM image (Table 1.1) are validated to check that they are within the acceptable limits.

<u>Validation of homogeneity and uniformity</u>

It is essential that approximately the same HU value is obtained for similar bony and soft tissue structures in the body. To ensure this homogeneity and image uniformity, the homogeneous areas in the phantom should have similar values in all the slices.

The initial slices (without the inserts) with homogeneous area around the centre are identified. For a selected range of slices (here, from slices 160 to 180), the Regions Of

Interest (ROI) are selected with radius R=20 in the centre and 200 pixels from the centre in the north, south, east and west of the centre (Fig 1.3).

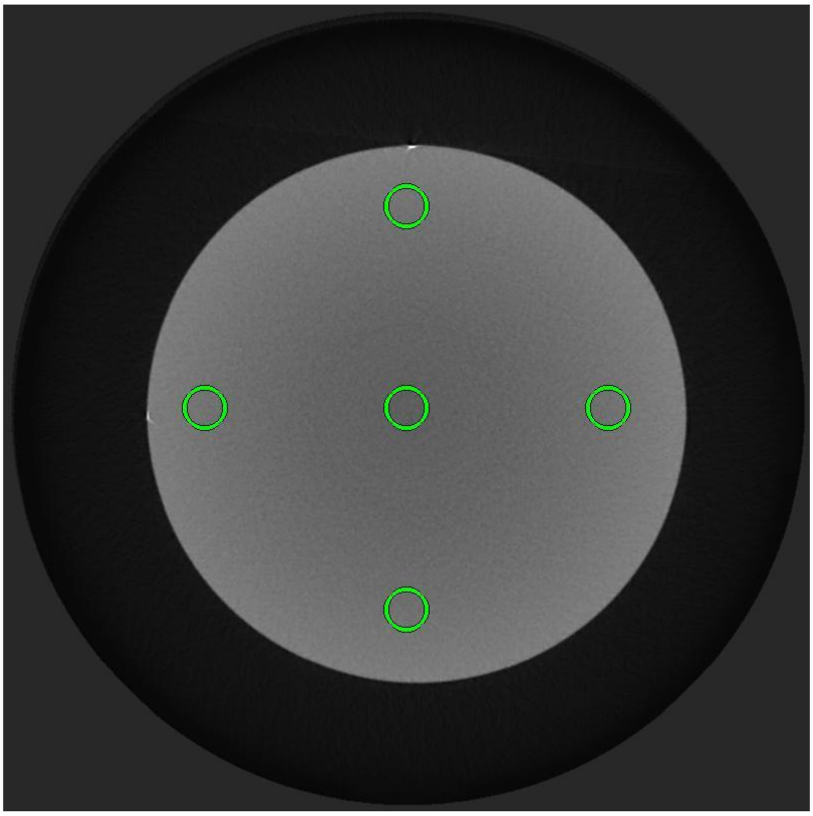

Fig 1.3. ROI in the centre and homogeneous areas around the centre

For these ROI, the mean values of CT numbers of the corresponding regions are calculated to verify the homogeneity and uniformity (Table 1.2).

For any one of the four homogeneous ROI (here, the ROI at the south of the centre), the standard deviation is calculated (Fig 1.4) to find the deviation of the CT number of the ROI in each of the 632 slices. This is used to check the image noise.

Validation of CT number of inserts

All the inserts are located within the limit: 255 to 455 slices (Fig 1.2). By identifying a huge transition in the CT number value in the consequent image slices, the presence of inserts is discovered, and the location of the five inserts are identified. For 10 slices of each insert, the mean value of the insert is calculated (Table 1.3). The mean values of the inserts are then checked if they are within the required acceptable limits.

A profile of the inserts (between slices 255 and 455) is plotted (Fig 1.5) to check the CT value of the inserts at a glance.

ii) General-purpose CT

<u>CT, phantom and CT image details</u>

The CT scanner used in the experiment is Toshiba Aquilion ONE.

The CT phantom has 5 inserts: air, delrin, acrylic resin, nylon, polypropylene (from left to right) in a water-equivalent material.

The phantom of the general-purpose CT scanner with the inserts and its CT image are shown below (Fig 2.1 and 2.2).

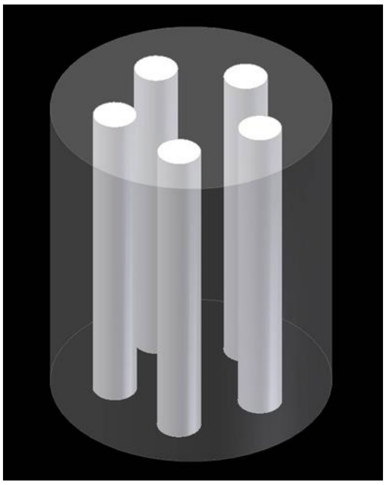

Fig 2.1. Phantom of the general-purpose CT scanner[3]

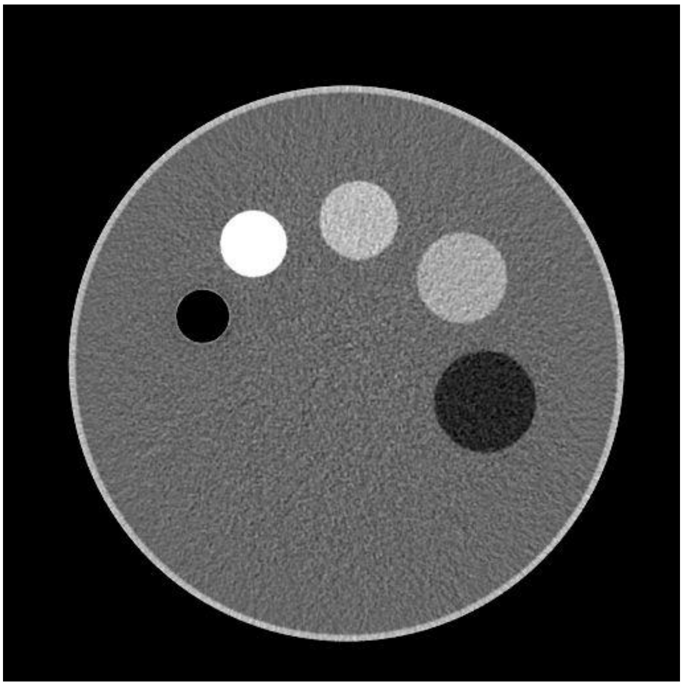

Fig 2.2. CT image of the phantom

Validation of dose parameters

First the dose parameters: KVP, X-ray tube current and Slice thickness values extracted from the DICOM image (Table 2.1) are validated to check that they are within the acceptable limits.

The ideal condition is 120kV/300 mA.

Validation of CT number of inserts

General CT scanner has a circular detector unlike cone beam CT which has flat-panel detector. In flat-panel detector, the information in each slice can be mapped to a particular detector row. So any flaw in the detector can be identified from the incorrect details in the corresponding image slice. But in circular detector, each slice has information from multiple detector arrays. So a flaw in any one (or a few) of the detector rows will be masked by the other detector arrays and can go undetected. To avoid this, axial image acquisition is performed instead of helical/spiral, i.e. the patient table is stationary. This is to ensure that any deviation in the image can be mapped to the corresponding detector row. Also, the CT numbers of the inserts from each slice is validated to check if they are within the acceptable limits. This is in contrast to the cone beam CT, where only the mean values of the inserts from the slices are validated.

The inserts are identified by a change in the pixel value corresponding to the CT number. The first slice in the list is identified with CT number greater than 375 (this is the maximum CT number corresponding to the second insert). 60 slices from this position contain all the five inserts. Five ROIs are taken in the five inserts (Fig 2.3) and the CT numbers of the ROI are plotted in a graph for the 60 slices (Fig 2.4).

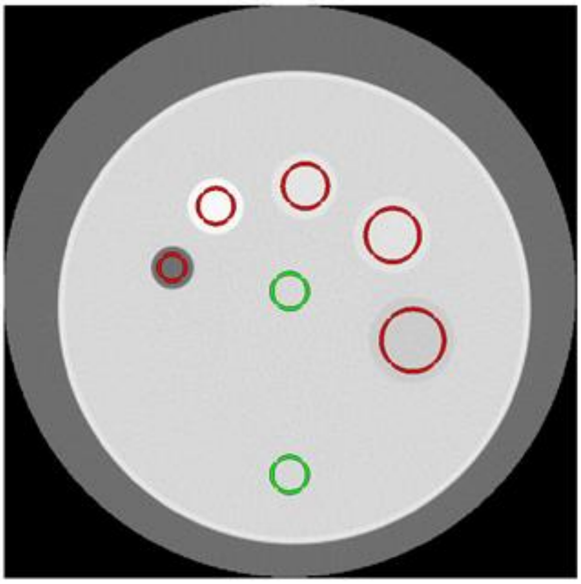

Fig 2.3. The red ROIs represent the five inserts and the green ROIs represent the homogeneous areas

The mean CT number of each insert is computed and validated (Table 2.2). From these 60 sets of CT numbers, the minimum and maximum CT numbers for each insert are identified and the difference between them is calculated to check their deviation from the reference value (Table 2.3).

Validation of homogeneity and uniformity

To check the homogeneity and uniformity, two ROIs are selected: one at the centre and one at the edge, as shown in Fig 2.3. The CT numbers of the two ROIs from the 60 slices are plotted in a graph (Fig 2.10 – 2.11). The mean values of CT numbers are calculated and they are validated to check if they are within acceptable limits (Table 2.4). The maximum and minimum CT numbers of the two ROIs and the difference between them are also determined to verify that there is no huge deviation in CT numbers from appropriate value for the same homogeneous area (Table 2.5). Since water is the main composition of tissues, it is important that the CT number of the two homogeneous ROIs do not deviate by a large margin.

Standard deviation of the CT numbers is calculated for any one of the two homogeneous ROI and plotted (Fig 2.12) to check the image noise.

Results

i) Cone beam/Dental CT (flat panel CT)

Dose parameters

Table 1.1. Dose parameters of Cone beam CT

Parameter	Measured Value	Acceptable value		Critical value		Unit
		Lower limit	Upper limit	Lower limit	Upper limit	
KVP	105	104.5	105.5	104	106	kV
X-ray tube current	4	3.5	4.5	3	5	mA
Slice thickness	0.3	0.25	0.35	0.2	0.4	mm
Image and fluoroscopy area dose product	0*	?	?	?	?	mGy cm^2

*Incorrect result from the CT scanner for reason not known (the value should not be zero).

Calibration parameter: HU-units

a) Mean CT number of the homogeneous ROI and centre ROI

Table 1.2. Mean CT number values of the four homogeneous ROI and centre ROI

Homogeneous ROI	Mean CT number	Acceptable value		Critical value	
		Lower limit	Upper limit	Lower limit	Upper limit
South	598.6	552.9	611.1	523.8	640.2
East	564.2	552.9	611.1	523.8	640.2
North	565.4	552.9	611.1	523.8	640.2
West	600.9	552.9	611.1	523.8	640.2
Centre ROI	280.5	266	294	252	308

Acceptable limit: 5% of reference value

Critical limit : 10% of reference value

For Homogeneous ROI, reference value = 582*

For Centre ROI, reference value = 280*

b) Standard deviation of the homogeneous ROI at the south (Noise)

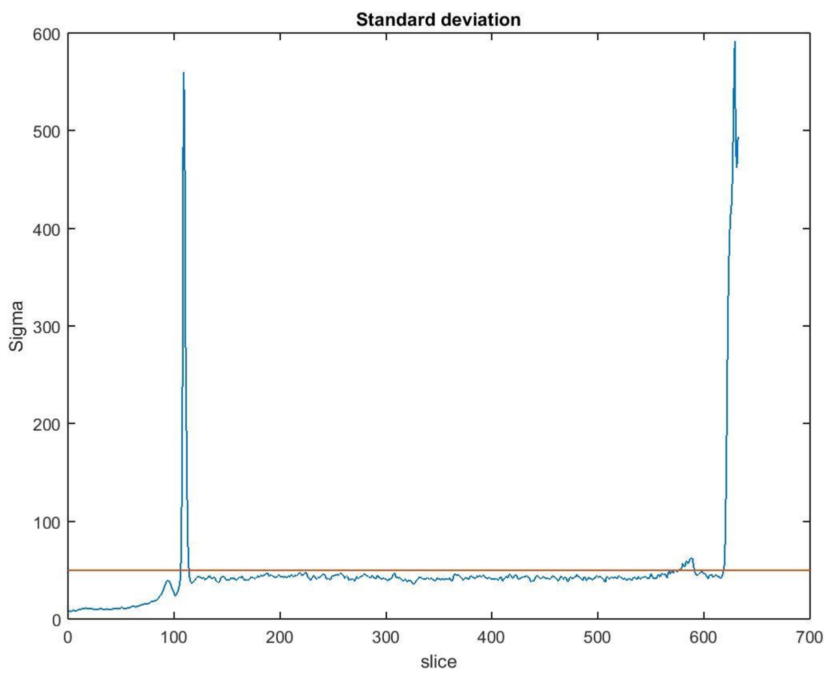

Fig 1.4. Standard deviation of the CT number in the homogeneous ROI at the south; the red line indicates the ideal deviation limit

c) Mean CT number of inserts

Table 1.3. Measured mean CT number values of the five inserts

Insert	Mean CT number	Reference value	Acceptable value		Critical value	
			Lower limit	Upper limit	Lower limit	Upper limit
Insert 1	-586.5	-586*	-615.3	-556.7	-644.6	-527.4
Insert 2	89	89*	84.5	93.4	80.1	97.9
Insert 3	429.5	429*	407.5	450.4	386.1	471.9
Insert 4	838.7	838*	796.1	879.9	754.2	921.8
Insert 5	1612.6	1612*	1531.4	1692.6	1450.8	1773.2

*Current results are taken as reference vales for future protocol checks

Acceptable limit: 5% of reference value

Critical limit : 10% of reference value

d) Profile of inserts

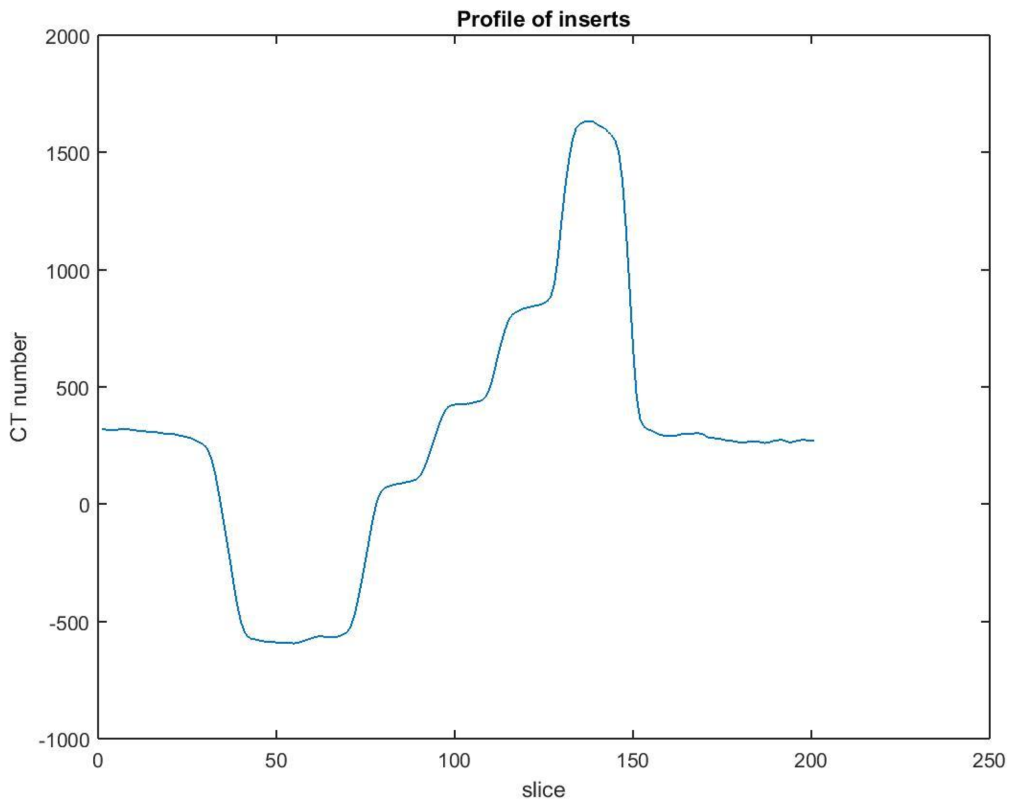

Fig 1.5. A profile of the inserts showing the change in CT number for slices with the corresponding insert

e) Output of the QC software

A sample of the output of the software is shown below (Fig 1.6).

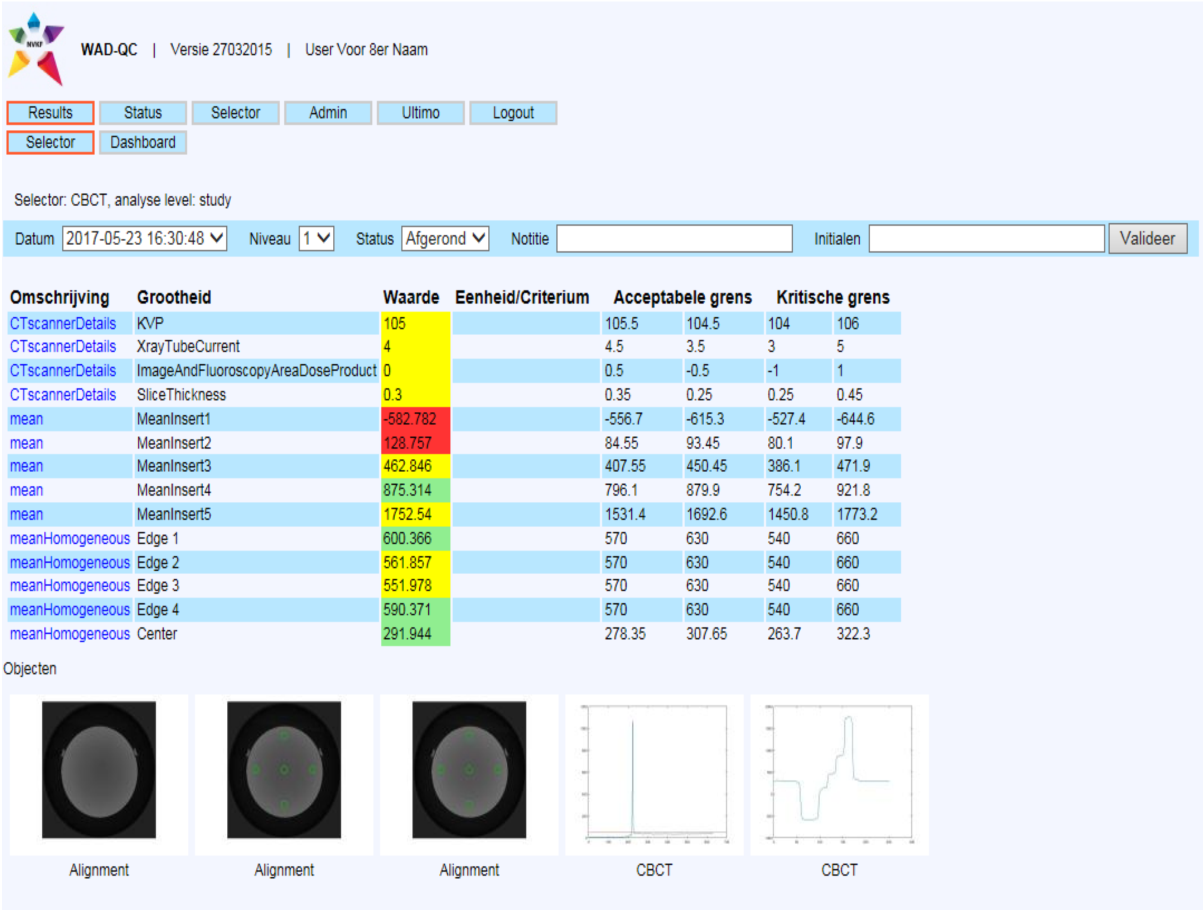

Fig 1.6. Output of the QC software: Green indicates result(s) are within the acceptable limits; orange indicates that the result(s) are outside the acceptable limits but within the critical limits; red indicates that the measured value(s) has crossed the critical limits.

ii) General-purpose CT

<u>Dose parameters</u>

Table 2.1. Dose parameters of General CT

Parameter	Measured Value	Acceptable value		Critical value		Unit
		Lower limit	Upper limit	Lower limit	Upper limit	
KVP	120	119.5	120.5	119	120	kV
X-ray tube current	330	329.5	330.5	329	331	mA
Slice thickness	2	1.5	2.5	1	3	mm

Calibration parameter: HU-units

a) CT number of inserts – mean, minimum and maximum CT numbers

Table 2.2. Calculated mean CT number of the 5 inserts

Insert	Mean CT number	Reference value	Acceptable value		Critical value	
			Lower limit	Upper limit	Lower limit	Upper limit
Insert 1	-975.5	-995	-1015	-975	-1020	-970
Insert 2	318.2	340	330	350	325	355
Insert 3	125.7	130	120	140	115	145
Insert 4	98.1	100	90	110	85	115
Insert 5	-103	-105	-115	-95	-120	-90

Reference values and acceptable limits are obtained from the CT protocol document.

Critical limit: Acceptable limit ± 5 HU

Table 2.3. Minimum and maximum CT numbers of the inserts and their absolute difference

Insert	CT number (HU)	Value
Insert 1	Minimum HU	-983.3
	Maximum HU	-975.5
	Difference	7.8
Insert 2	Minimum HU	318.1
	Maximum HU	324.5
	Difference	6.4
Insert 3	Minimum HU	125.1
	Maximum HU	128.8
	Difference	3.7
Insert 4	Minimum HU	95.8
	Maximum HU	99.8
	Difference	4
Insert 5	Minimum HU	-103.1
	Maximum HU	-101.3
	Difference	1.8

The absolute difference between the minimum and maximum CT numbers of the inserts (the 5 ROIs) from 60 slices should not exceed a particular limit, say:

Acceptable limit: 10 HU

Critical limit : 15 HU

b) Profile of inserts

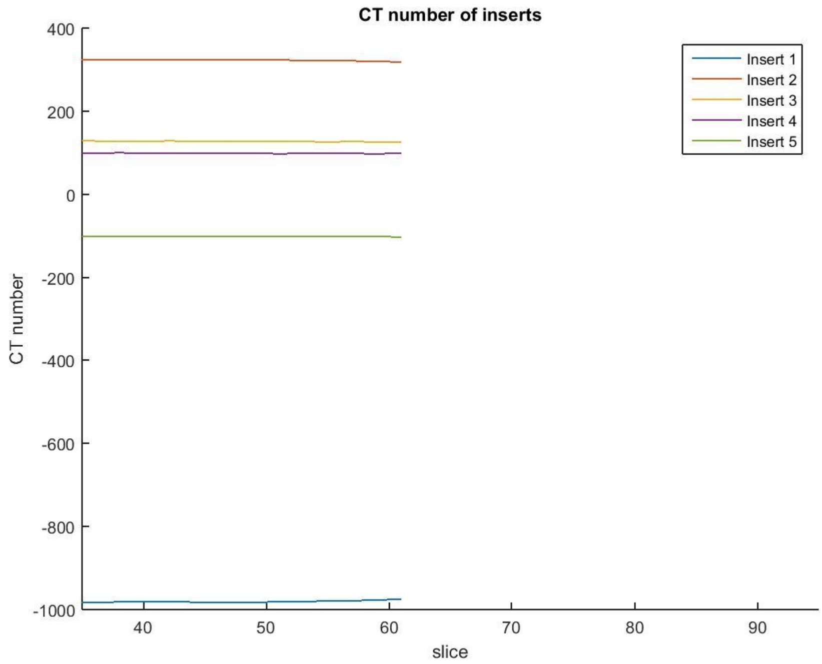

Fig 2.4. Profile of inserts showing CT number of the 5 inserts in the 60 slices

The following figures (Fig 2.5 – 2.9) show the CT number of each insert in each of the 60 slices.

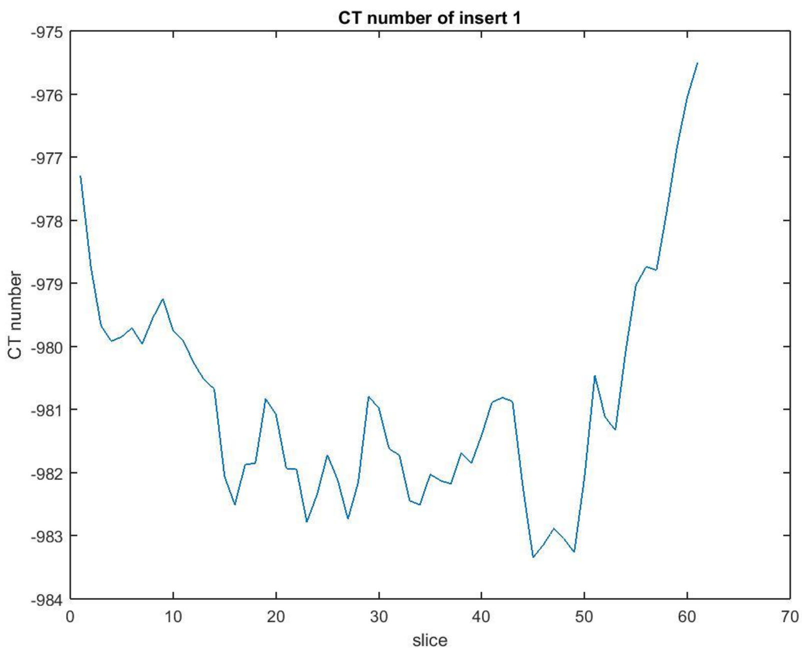

Fig 2.5. Profile of insert 1

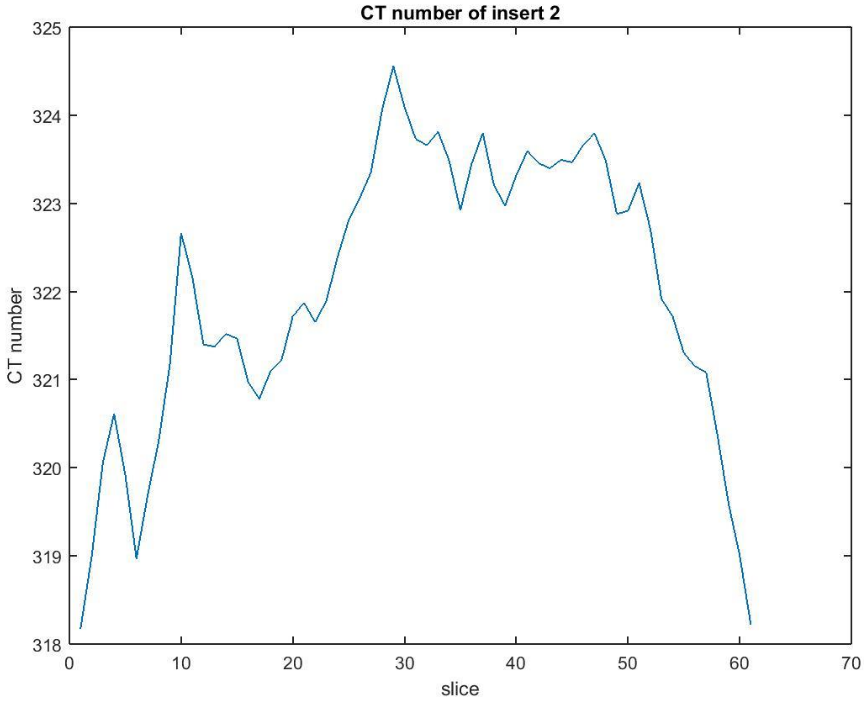

Fig 2.6. Profile of insert 2

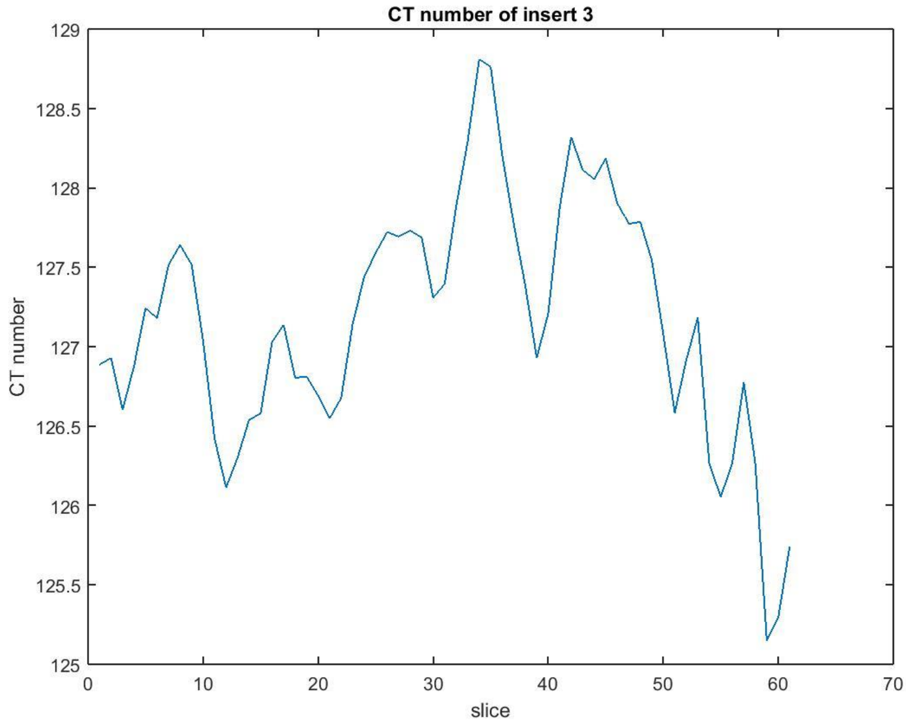

Fig 2.7. Profile of insert 3

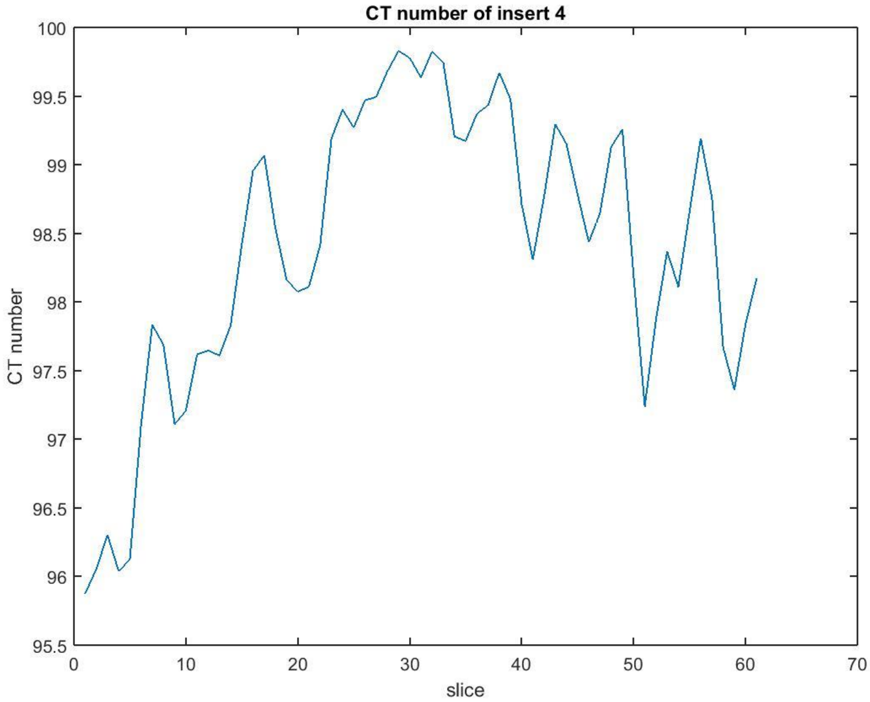

Fig 2.8. Profile of insert 4

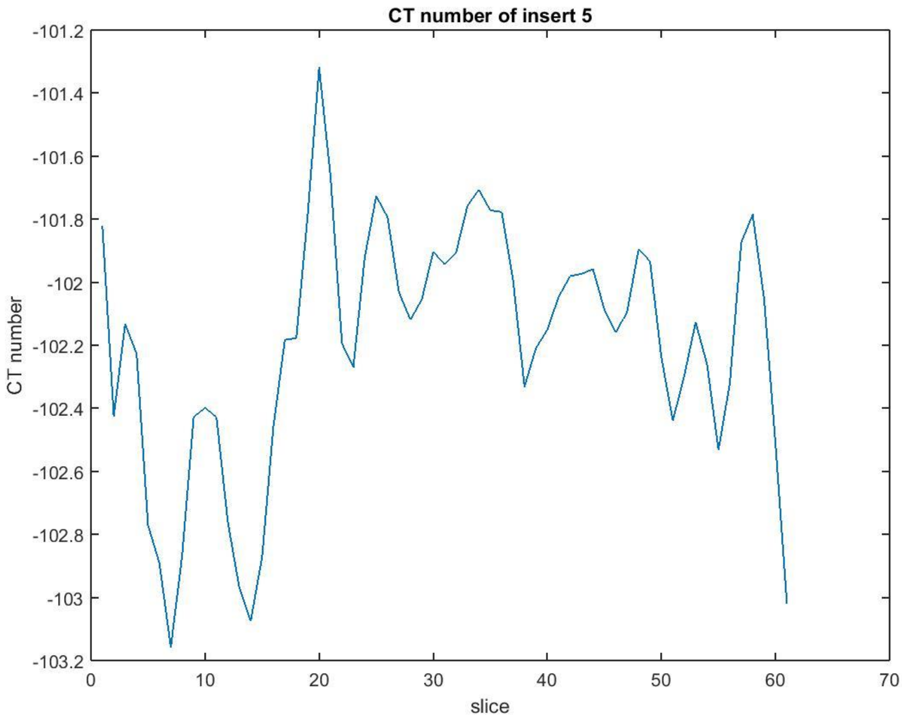

Fig 2.9. Profile of insert 5

c) CT number of the homogeneous ROI – Mean, minimum and maximum CT numbers

Table 2.4. Mean CT numbers of homogeneous ROIs

Homogeneous ROI	**Mean CT number**	**Acceptable value**		**Critical value**	
		Lower limit	**Upper limit**	**Lower limit**	**Upper limit**
Centre	-1.5	-5	5	-10	-10
Edge	0.1	-5	5	-10	-10

Reference value: 0 HU (water)

Table 2.5. Minimum and maximum HU-units of the homogeneous ROIs and their difference

Homogeneous ROI	**CT number (HU)**	**Value**
Centre	Minimum HU	-1.7
	Maximum HU	6.1
	Difference	7.8
Edge	Minimum HU	-0.1
	Maximum HU	3.8
	Difference	3.9

The absolute difference between the minimum and maximum CT numbers of the homogeneous ROIs from 60 slices should not exceed the limits:

Acceptable limit: 10 HU

Critical limit : 15 HU

The difference between CT numbers of the two ROIs in each slice can be calculated and plotted in a graph if required.

The following figures show the CT numbers of the homogeneous ROIs in the 60 slices.

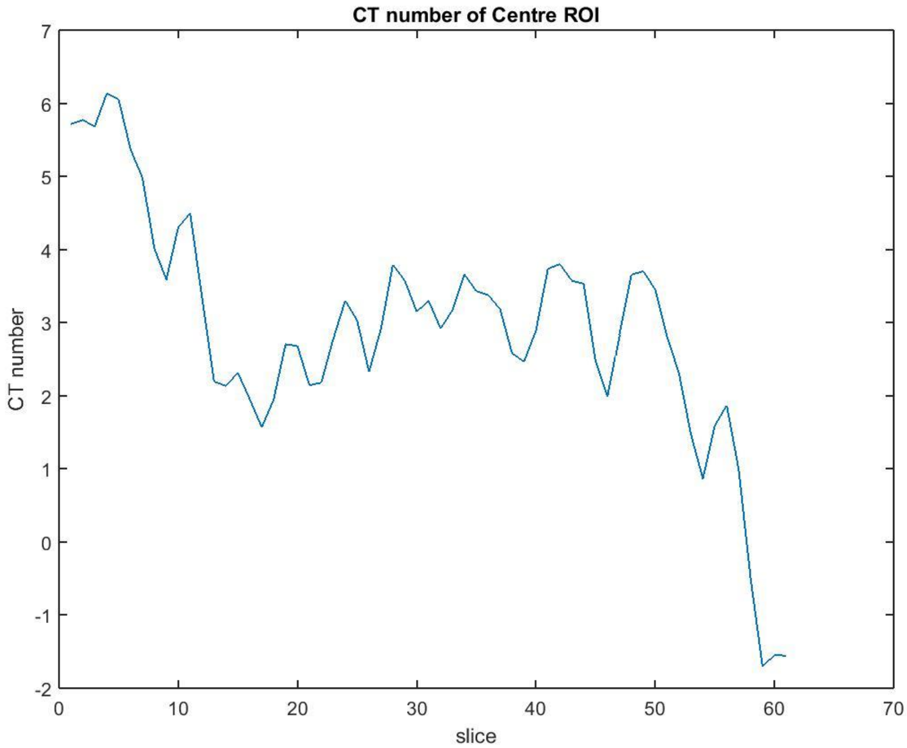

Fig 2.10. CT number of centre ROI

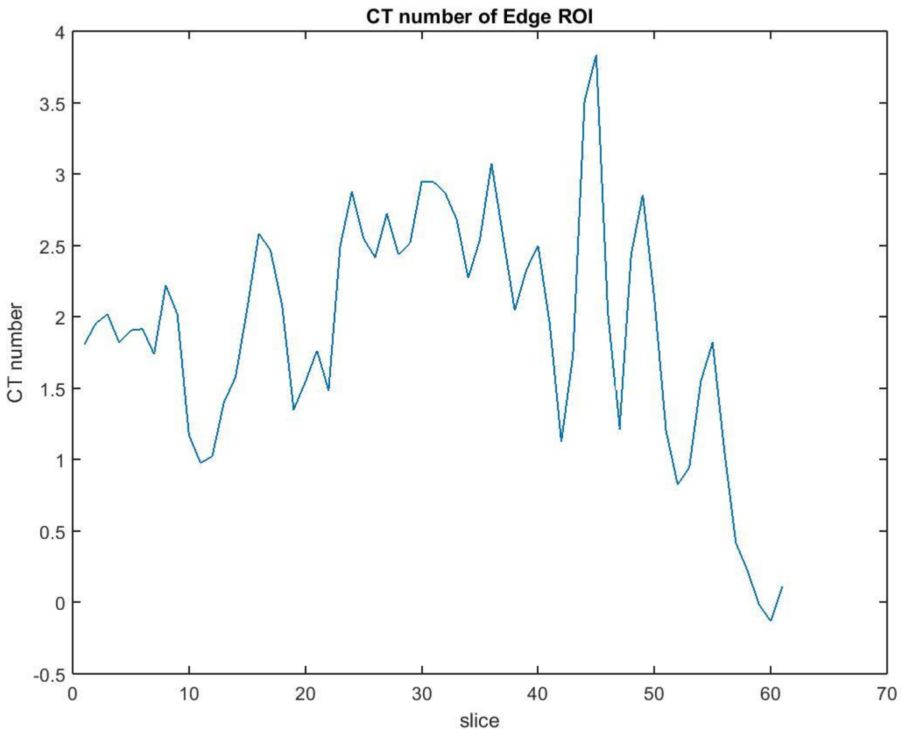

Fig 2.11. CT number of edge ROI

d) Standard deviation of the homogeneous ROI (Noise)

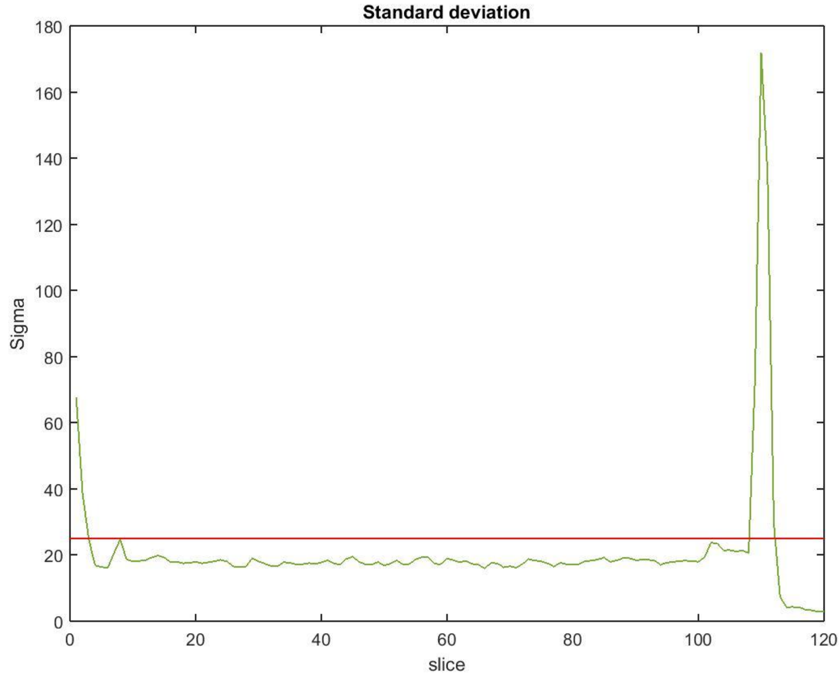

Fig 2.12. Standard deviation of the CT number in the homogeneous ROI; the red line indicates the ideal deviation limit

e) Profile of phantom

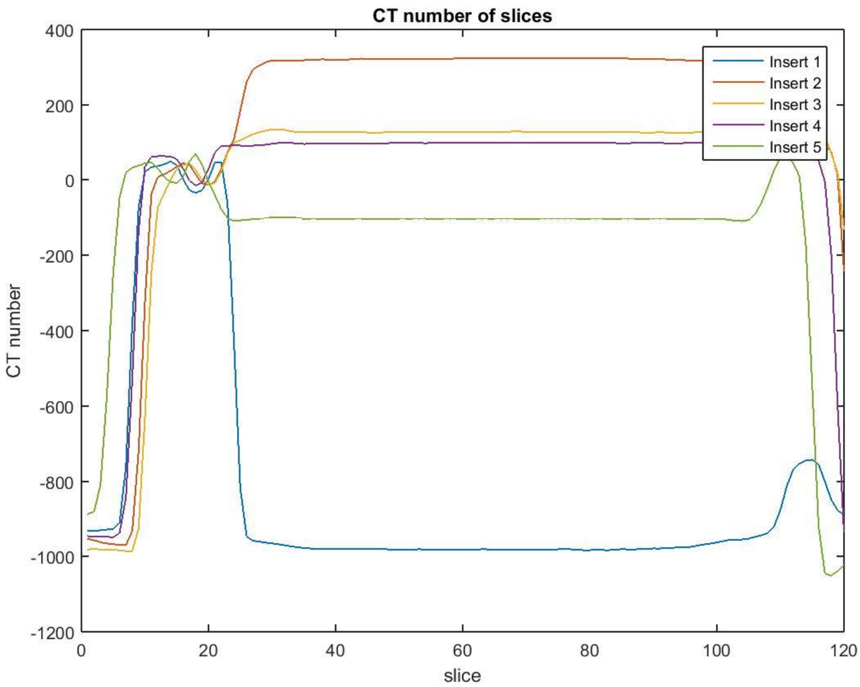

Fig 2.13. A profile of the phantom showing change in CT number with slices as the material in the phantom changes

Conclusion

i) Cone beam/Dental CT (flat panel CT)

From the results of the QC of the Cone beam CT, it can be seen all the parameters are within acceptable limits. A minor disadvantage of this QC protocol is that the protocol is correct only when the phantom is placed in the appropriate way accurately which can be a difficulty. Any slight variation in the placement of the phantom might give inaccurate results even if the CT scanner works perfectly. This can be avoided by designing a stand for the phantom such that the phantom can be placed in only the appropriate way.

ii) General-purpose CT

From the results of the QC of the General CT, it can be seen that the CT number of insert 2 is outside acceptable limits and the rest of the parameters look good. The QC is performed for one KVP value of the CT scanner. The study can be extended to a small range of voltages to check for the ideal behaviour of the scanner. Also, since the average photon energy is also dependent on the patient size, different sizes of phantom can be used to make the protocol better.

The protocol in the hospital in Drachten also measures the Contrast-to-Noise ratio. This can be calculated from the average/mean value and SD (noise). In addition to the axial scan, a helical scan is also done from which the tube current (mA) and the SD are measured for dose control by taking ROI at positions: 12, 3, 6, 9 hours and in the center of the image using a homogeneous phantom. The tube current can be directly obtained from the DICOM header in automated method.

Reference

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