QUALITY ASSURANCE OF THE IMAGING SUBSYSTEM G4 CyberKnife. EVALUATION OF THE FLAT PANEL IMAGING CHARACTERISTICS

C.Antypas, E.Pantelis, L.Sideri, K.Verigos, A.Tzouras, N.Salvaras

IATROPOLIS CLINIC, CYBERKNIFE CENTER, ATHENS, GREECE

Introduction

A G4 CyberKnife (CK) system has been installed at Iatropolis Clinic, Athens Greece since May 2006. In CK the Target Locating System (TLS) i.e. the imaging subsystem and an imaging software is used to locate the target and then to guide the therapeutic beam to the target with sub-millimeter accuracy [1], [3]. The imaging subsystem consists of a pair of standard kilovoltage x-ray generators installed on the ceiling of the treatment room and two amorphous silicon flat panel digital detectors, called camera A and B respectively. In G4 CyberKnife®, the flat panel detectors are embedded in the floor, in orthogonal configuration. Images from both cameras are acquired for initial patient alignment and throughout the treatment. These images are fed into the image-guidance software, which uses an image registration algorithm to track the target, i.e to calculate translations and rotations of the target during the treatment delivery [2]. Consistency of the TLS is dependent on the quality of the radiographs recorded by the cameras. The aim of the project is to perform quality assurance analysis of the flat panel detectors in the imaging subsystem of the G4 CyberKnife using the QCkV-1 phantom.

Materials and Methods

The flat panel amorphous silicon detectors are situated at approximately 140cm from the isocenter (depending on the ceiling height) and at a 45˚ angle to the kV-beam central axes [2]. They consist of a 1024×1024 pixel matrix of 0.4 mm nominal pixel size. As a result of the horizontal installation, primary x-ray images suffer from a geometrical distortion of the projected object. The distortion is corrected by the image-guidance software based on the geometrical configuration of the TLS cameras. Image quality of each flat panel detector in terms of spatial resolution, contrast-to-noise ratio, image noise and geometrical distortion was evaluated using the QCkV-1 phantom (Figure 1) (Standard Imaging Inc) [4] and the PIPSPro software (Standard Imaging Inc) [5].

Figure 1

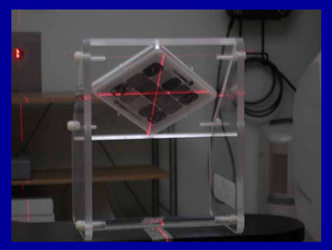

Figure 2

Measurements were taken on a daily, weekly and monthly basis to establish baseline and follow-up values of various imaging characteristics of the flat panel detectors. The QCkV-1 phantom was placed on a positioning stand especially designed for CK geometry and with four fiducials implanted for accurate and reproducible alignment (Figure 2). The phantom on the stand was CT-scanned (120kV, 2mm slice thickness) in two orthogonal orientations, appropriate for each camera. CT images were DICOM imported into Multiplan TPS and two isocentric plans with fiducial tracking were created for each orientation. Both plans were saved as phantom deliverable and loaded on SGI workstation in simulation mode. Images of the QCkv-1 phantom were acquired for each camera of the CyberKnife® system. Both corrected and uncorrected phantom images were retrieved from the CK system and fed into the PIPSPro software for QC testing [Figure 3a-b].

Uncorrected images were analyzed with the QC routine of the PIPSPro software (Figure 3a, Figure 4) in order to evaluate image characteristics of each detector.

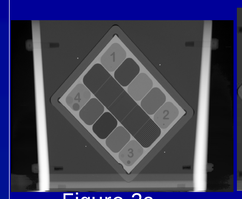

Figure 3a

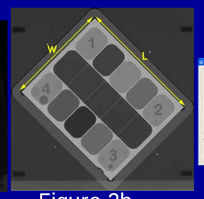

Figure 3b

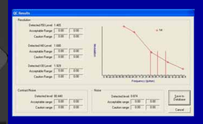

Figure 4

Spatial resolution was measured in terms of the parameters f50 which are the frequencies at 50% maximum of the relative modulation transfer function (RMTF). Contrast resolution was measured in terms of the contrast-to-noise ratio (CNR).

Geometrical distortion was quantitatively evaluated by measuring the phantom dimensions on the corrected images of the QCkV-1 phantom (Figure 3b). Phantom dimensions (Length, Width) and the ratio (L/W) were measured on the corrected images and compared with the nominal values provided by the manufacturer (Standard Imaging Inc).

Flat panel imaging characteristics were also investigated as a function of the kV settings.

Results

Image characteristics were measured using the QCkV-1 phantom and the PIPSPro software. Baseline values for spatial resolution, CNR and noise were established, averaging the initial ten measurements of each parameter, which correspond into two week time scale (Table 1).

TABLE 1

BASELINE VALUES

	Camera A	Camera B
f30	1.915±0.0062	1.908±0.0047
f40	1.672±0.0043	1.653±0.0048
f50	1.462±0.0023	1.448±0.0027
CNR	84.52±1.617	85.62±1.317
Noise	0.800±0.0165	0.780±0.0107

All image parameters measurements are presented as a deviation from the respective baseline value and on a monthly basis. Spatial resolution in terms of f50, CNR and Noise are presented in Figure 1, Figure 2 and Figure 3 respectively.

Figure 5

Figure 6

Figure 7

Geometrical distortion was quantitatively evaluated by measuring the phantom dimensions on the corrected images of the QCkV-1 phantom and using the PIPSPro software. Geometrical distortion measurements on monthly QC basis are presented in Table 2.

TABLE 2

GEOMETRICAL DISTORTION

	CAMERA A				CAMERA B			
MONTH	L (px)	W (px)	W/L	(%)	L (px)	L (px)	W/L	(%)
1	289	352	1.218	**-0.35**	292	352	1.205	**-1.37**
2	290	352	1.214	**-0.69**	289	350	1.211	**-0.91**
3	289	351	1.215	**-0.63**	291	352	1.210	**-1.03**
4	289	352	1.218	**-0.35**	294	355	1.207	**-1.21**
5	290	351	1.210	**-0.97**	289	350	1.211	**-0.91**
6	289	351	1.215	**-0.63**	289	350	1.211	**-0.91**

	L (cm)	W (cm)	W/L
NOMINAL	9	11	1.222

Flat panel imaging characteristics were also investigated as a function of the kV settings. Spatial resolution f50 and CNR as a function of kV setting are presented in Figure 8 and 9 respectively.

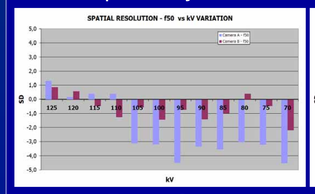

Figure 8

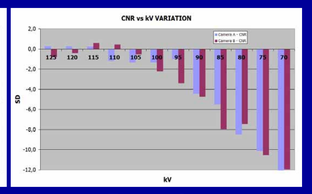

Figure 9

Discussion and Conclusions

Quality assurance analysis of the flat panel detectors in the imaging subsystem of a G4 CK system using the QCkV-1 Phantom and the PIPSPro software has been performed. Image characteristics such as Spatial Resolution f50, Contrast-to-Noise Ratio, Image Noise and Geometrical Distortion were investigated. Baseline values of the measured parameters are presented in Table 1. Spatial resolution f50 was measured 1.462lp/mm and 1.448lp/mm for Camera A and Camera B respectively. These values are in very good agreement with values reported in the literature [3].

Time dependence performance of the above parameters was found in acceptable range, i.e. variation within ±2SD with respect to the baseline values. Geometrical distortion was quantitatively evaluated using the PIPSPro software. Dimensions of the corrected QCkV-1 images revealed was found in very good agreement (within ±1.5%) with the nominal dimensions of the QCkV-1 phantom. Spatial resolution f50 and CNR were found to be independent on the kV variation within the range of CK clinical practice (100 – 125kV). However, considerable variation has been revealed in the less kV range (70 – 90kV).

QCkV-1 and PIPSPro software has been found useful in the routine Quality Assurance of the imaging subsystem of the CyberKnife.

Acknowledgements

The authors would like to thank Dr Eric DeWerd of Standard Imaging Inc for providing the QCkV-1 phantom and the PIPSPro software for this study.

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Corresponding author: **C. Antypas, cantypas@med.uoa.gr**
Iatropolis Clinic, Ethnikis Antistaseos 56, 15231 Chalandri Athens, Greece