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Patient-Specific Quality Assurance for SRT/SBRT Plans

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Abstract

The quality assurance of the stereotactic plans of 12 brain and lung patients was compared with one dimensional and two dimensional measurement systems. Absolute dose measurements used CC04, CC01 Razor ion chambers and EBT3 films. MatriXX Evolution and EBT3 films were used for dose fluence map measurements.

In absolute dosimetry, CC04, CC01 Razor ion chambers and EBT3 film were successful. In 12 patients' plan, differences were 0.35% with CC04, -2.09% with CC01 and 1.95% with EBT3 film. In the gamma index analysis for 12 patients, EBT3 film was obtained with 95.2% of MatriXX at 3%-3 mm, and 88.31% with MatriXX. Similar results were obtained in 2%-2 mm, 1%-1 mm and 3%-1 mm.

Ion chambers are successful in small field measurements. However, in stereotactic plans, the uncertainty in measurements increases as the dose change in the target volume is about 20-25%. Although we have performed successful QA with two-dimensional systems in stereotactic plans, more accurate results were obtained with EBT3 due to the resolution of MatriXX. In particular, the distance between two ion chambers was the main reason of uncertainties.

Keywords: SRT/SBRT QA, EBT3 and MatriXX QA, CC01 Razor QA

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1. Introduction

The improvements in radiotherapy based therapies has been increasing rapidly. In order to increase the effectiveness of the treatments, it is necessary to treat with more accurate, precise and high doses. With the developing technology, there are other uncertainties, although the devices are more precise, more comprehensive and practical. These uncertainties increase the importance of the accuracy of complex therapies. As a result, it is necessary to make dosimetric quality assurance (QA) of the plans in order to minimize the possible uncertainties and mistakes before the treatment. In treatment techniques such as intensity modulated radiation therapy (IMRT) and volumetric modulated arc therapy (VMAT), validation of the plans only by point dose control is not sufficient for a comprehensive analysis of the treatment plan. For this reason, two or three dimensional dosimetric verification of plans should be performed in IMRT, VMAT, stereotactic radiotherapy (SRT) / stereotactic body radiotherapy (SBRT) treatments. The patient-specific QA is to check whether the dose fluence map obtained from the measurements is consistent with the dose fluence map obtained from the treatment planning system (TPS). This procedure should be easy, cheap and effective for all plans of the patient. There are many dosimetry systems that can perform 1D, 2D, 3D measurements to develop patient QA. These are ion chambers, thermo luminescence dosimeter (TLD), electronic portal imaging device (EPID) radiographic film, Gafochromic film, 2D measurement systems, 3D measurement systems and gel dosimeter [1,2].

To compare measurement results with TPS, the gamma index method was developed by Low et al. (1997). In 2003, Low and Dempsy improved their current state of gamma index method and provided them to use it regularly in clinics. The gamma index method is a program that compares the measured dose flux map with the dose flux map obtained from TPS and evaluates the dose difference (DD) and distance to agreement (DTA) at any point. The dose

Table 1. Properties of ion chambers

	Full Guarded	High Uniform Spatial Resolution	Cavity Volume (cm^3)	Cavity Lenght (mm)	Cavity Radius (mm)	Wall material	Wall thickness (g/cm^3)	Central electrode material
CC01 Razor	X	X	0.01	3.6	1	C552	0.088	Graphite
CC04	X	X	0.04	3.6	2	C552	0.070	Graphite

difference is defined as the difference between the measured and calculated dose at one point. The distance to the agreement is defined as the difference between the measured dose at a point and the calculated position. These two parameters are complementary expressions. In gamma index analysis, both conditions are required [3,4].

For our 12 stereotactic treatment plan;

Absolute QA was done with CC04 and CC01 razor ion chambers and EBT3 film. And compared the results for three detectors.

QA was done in two dimensions with MatriXX and EBT3 film. The gamma index method and dose fluence maps were compared for two detectors.

2. Materials and Methods

Stereotactic plans of 12 patients were prepared with VMAT fields using 6 MV-FFF energy in non-coplanar plane. Absolute dosimetry was measured with ion chambers to verify each plan. Iba CC01 Razor (IBA Dosimetry, Germany), Iba CC04 (IBA Dosimetry, Germany), ion chambers were placed at a depth of 5 cm with a solid water equivalent phantom and scanned at Siemens Biograph mCT PET-CT (Siemens Healthcare, Erlangen, Germany). QA plans were made by transferring the plans of 12 patients to phantoms prepared with these two ion chambers. QA plans were recalculated without changing any parameters in the Monaco 5.11 (Elekta, Crawley, England) TPS. In the ion chambers measurements, the SSD was set at 95 cm.

In the Iba MatriXX Evolution (IBA Dosimetry, Germany), measurements, the holder attached to the head of the linear accelerator was placed 5 cm RW3 phantom and MatriXX was placed under it. In the film measurements, the holder attached to the head of the linear accelerator was placed 3 cm RW3 phantom and EBT3 was placed under it. In the film and MatriXX measurements, the SSD was set at 71.2 cm.

In order to perform absolute dose analysis in film measurements, EBT3 films for calibration were cut 2x2 cm^2. In the RW3 solid water equivalent phantom, 6MV-FFF was irradiated with 20 films between 0-3871 MU at a depth of 5 cm at a field size of 10x10 cm^2. The films were scanned on the Epson V800 scanner and an optical density-dose curve was created in the Mephysto mc^2 film calibration program.

CC04 and CC01 Razor Ion Chambers: Ion chambers radiotherapy and radiology are often used in dosimetry systems. Basically, the ion chambers are a collector with a central electrode and a gas-filled core in a conductive outer electrode. The interaction of the radiation with the ion pairs formed in the gas is based on the collection of these ion pairs by applying a voltage to the electrodes. Ion chambers are used for absolute dose measurements. The CC04 and CC01 ion chambers are used in small area dosimetry, in areas where the dose gradient is high, and for stereotactic treatments. Ideal dosimeter systems for measurements in water phantom or water equivalent solid phantoms. In general, they have a high resolution and are waterproof (Table 1) [5,6].

MatriXX Evolution Detector: Iba MatriXX Evolution (IBA Dosimetry, Germany), a two-dimensional planar measurement system, is used for verification of treatment plans. It is fast, effective and easy to verify IMRT and VMAT treatment plans. It is the ideal detector for areas with rapid dose gradient and fast reaction time. Gantry could be mounted with the holder so that QA's are made at real gantry angles. The MatriXX Evolution detector has 1020 ion chambers and each ion chamber has its own measuring channel. SSD: 100 cm, has an active area of 24.4 x 24.4 cm^2. The distance between two ion chambers is 7.6 mm. It is 0.08 cm^3 of each ion chamber. FFF is suitable for energies. It is the ideal dosimetric system for two or three dimensional QA.

Gafchromic EBT3 Film: Gafchromic EBT3 film (Ashland ISP Advanced Materials, Bridgewater, NJ, USA) has an active layer of 30 microns between the top and bottom polyester microspheres of 125 microns providing protection from external factors. EBT3 film is ideal for dosimetric measurements in external radiotherapy, radiosurgery and

Table 2. Results of absolute dose measurements

	CC01 Razor			CC04			EBT3 FILM		
	TPS	Measurement	%Different	TPS	Measurement	%Different	TPS	Measurement	%Different
Patient 1	5,85	5,7	2,56	5,75	5,79	-0,70	13,6	13,68	-0,58
Patient 2	3,86	3,84	0,52	3,9	3,89	0,26	9	8,96	0,42
Patient 3	13,88	14,51	-4,54	13,65	14,08	-3,15	29,68	30,04	-1,21
Patient 4	14,21	14,29	-0,56	13,99	13,8	1,36	31,97	31,73	0,75
Patient 5	24,61	24,79	-0,73	24,19	24,04	0,62	57,58	57,16	0,73
Patient 6	10,32	10,93	-5,91	10,19	10,44	-2,45	23,48	24,18	-2,98
Patient 7	13,88	14,21	-2,38	14,08	15,05	-6,89	31,9	29,94	6,1
Patient 8	27,67	28,9	-4,45	28,24	25,95	4,57	65,63	65,76	-0,2
Patient 9	28,62	30,02	-4,89	28,25	24,01	7,93	68,31	63,37	7,2
Patient 10	12,15	12,44	-2,39	12,24	12,1	1,14	28,1	26,17	6,86
Patient 11	14,45	14,69	-1,66	14,1	14,06	0,28	33,39	32,55	2,51
Patient 12	14,64	14,73	-0,61	14,5	14,32	1,24	34,38	32,96	3,85
Average	15,35	15,75	-2,09	15,26	14,79	0,35	35,59	34,71	1,95
STD	7,52	7,87	2,40	7,52	6,60	3,55	18,07	17,42	3,21

brachytherapy. The film reduces the uncertainty in the dosimetry because it does not need a bath. The dose range can be up to 10 Gy in red channels and up to 40 Gy in green channels. It has high resolution (25µm minimum). The wide and linear range of the dose-response allows the use of the IMRT, VMAT and SRT/SBRT in dosimetric evaluation of the plans, because it is water-proof and water-equivalent, it can be used in water phantom [7].

Statistical analysis of CC04, CC01 Razor and Film absolute dose measurements results were analyzed by friedman test. The results of the film and MatriXX measurements were analyzed by Wilcoxon signed-rank test.

3. Results and Discussion

The results of absolute dose measurements with ion chambers and films are shown in Table 2. The results of two-dimensional dose measurements with film and MatriXX are shown in Table 3.

In one dimensional point dose measurements, CC01 Razor, CC04 ion chambers are successful in verifying stereotactic plans. Because it has small volumes, the volume effect is minimal and similar results are obtained with high resolution films. In the three dosimetric system, even if there was a high dose gradient, the differences were smaller than the average of 3%. The results of CC04, CC01 Razor and film

Table 3. Patient QA results in two dimensions

	%3-3mm		%2-2mm		%1-1 mm		%3-1mm	
	EBT3	MatriXX	EBT3	MatriXX	EBT3	MatriXX	EBT3	MatriXX
Patient 1	100	80,6	99,7	61,3	94,5	37,6	98,2	47,5
Patient 2	96,8	90,6	84,6	90,6	57,3	59,4	68,1	75
Patient 3	95,2	94,6	91,5	80,3	73,2	44,8	75,1	59,6
Patient 4	92	90,9	86,1	72,4	59,9	39,8	64,3	58
Patient 5	95,3	85,9	57,7	67,9	36,8	37,4	38,4	56,4
Patient 6	91,3	85,2	84,4	63,8	71,1	30,7	74,7	46,9
Patient 7	94,1	100	92,1	92,3	68,6	61,5	70	69,2
Patient 8	100	82,4	98	59,6	71,6	27,1	72,2	38,5
Patient 9	99,9	84,3	96,4	68,4	74,4	35,7	85,1	52,6
Patient 10	94,8	84,3	91	57,5	70	22,7	74,1	31
Patient 11	87,2	88,7	81,2	58,4	73,6	22	73,8	38,1
Patient 12	95,8	92,1	87,9	85,3	65,9	55,8	76,3	47,5
Average	95,20	88,30	87,55	71,48	68,08	39,54	72,53	51,69
SD	3,84	5,60	11,02	12,65	13,44	13,54	13,83	12,86
P	0,015		0,015		0,005		0,015	

measurements are significant compared to friedman statistical analysis between the three systems (p:0.028).

MatriXX and EBT3 films are successful in verifying stereotactic plans. The MatriXX has 1020 ion chambers and the distance between each ion chamber is 0.5 cm. The distance between these two ion chambers cannot be measured, but dose maps are formed by the interpolation method. Despite a very rapid dose change on stereotactic planes, MatriXX is successful in measuring dose maps. Similar results were obtained with EBT3 film and MatriXX two-dimensional plan verification.

Bellec et al. (2017) used Gafcromik-EBT3 film for the plan verifications of 350 patients in the CyberKnife M6 linear accelerator. In gamma index analysis, they obtained a gamma ratio of 85% according to the criteria of 3 - 1.5 mm, they obtained average gamma values as 0.7 [8].

Pulliam et al. In a 6-year period, the 13003 IMRT-VMAT treatment plan performed the absolute dose measurement using Iba CC04 ion chamber and EDR2 film. According to the gamma index analysis in the film results, they obtained an average of 97.7% according to the 5%-3 mm criteria. When all of the 13003 treatment plans were considered; 97.7% of ion chamber measurements and 99.3% of gamma index analysis (film) were valid [9].

In SRS/SRT/SBRT, an inhomogeneous dose distribution occurs within the target volume. Generally 20% to 25% dose heterogeneity is available in the target volume. This sharp dose change leads to dosimetric difficulties.

In absolute dosimetry, CC04, CC01 Razor ion chambers and EBT3 film are successful. However, since the dose change is high, there is more uncertainty in point dose measurements. With each of the three masurement systems, there was an average difference of less than 3%.

Radiocromic films have high resolution and can be used in dosimetric measurements in areas where there is a sharp change in radiation. Radiochromic films are more useful for dose measurement in areas of high dose gradient radiation, due to the use of high doses specific to setereotactic plans, poor energy dependence, and near-tissue equivalence. The MatriXX interpolates between the measuring points, even if the distance between the ion chambers is short. If SRT/SBRT has a high dose change to a point between two ion chambers, it can lead to uncertainties in the dose fluence maps. Also, since the specific volume of ion chambers causes uncertainties, we have to accept film analyzes more accurately.

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