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Abstract

A treatment planning system IMRT beam model is usually validated using phantom-based measurement, however this will not detect errors related to patient anatomy and inhomogeneity. In this study a secondary treatment system (CMS XIO) was used as a 3D dosimeter to verify an IMRT beam model recently commissioned in a Philips Pinnacle treatment planning system. Data sets from three head-neck and two prostate patients previously treated were utilised. The IMRT plans for these patients were planned in Pinnacle and transferred to XIO. The dose at each voxel in the patient volume was calculated in both XIO and Pinnacle. The 2D dose gamma maps for three orthogonal planes passing through the isocenter were calculated with a criteria of 3%/3mm. The mean gamma pass rate for all patients was 96.86% with maximum and minimum values of 99.6% and 95%. One coronal dose plane at 5.5 cm depth in the phantom was also measured and compared with dose calculated by the Pinnacle IMRT beam model using same gamma criteria. The measured mean gamma pass rate for this coronal plane dose was 96.7% with maximum and minimum of 98.41% and 95.3%. This was comparable with the gamma map pass rates for the three orthogonal dose planes calculated by XIO for the patient data. A secondary treatment planning system was shown to provide a supplementary verification tool based on calculation-based 3D dosimetry using patient anatomy.

Keywords

planning, validation, system, imrt, 3d, dosimeter, beam, model, secondary, treatment

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Validation of an IMRT beam model using a secondary treatment planning system as a 3D dosimeter

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Abstract. A treatment planning system IMRT beam model is usually validated using phantom-based measurement, however this will not detect errors related to patient anatomy and inhomogeneity. In this study a secondary treatment system (CMS XIO) was used as a 3D dosimeter to verify an IMRT beam model recently commissioned in a Philips Pinnacle treatment planning system. Data sets from three head-neck and two prostate patients previously treated were utilised. The IMRT plans for these patients were planned in Pinnacle and transferred to XIO. The dose at each voxel in the patient volume was calculated in both XIO and Pinnacle. The 2D dose gamma maps for three orthogonal planes passing through the isocenter were calculated with a criteria of 3%/3mm. The mean gamma pass rate for all patients was 96.86% with maximum and minimum values of 99.6% and 95%. One coronal dose plane at 5.5 cm depth in the phantom was also measured and compared with dose calculated by the Pinnacle IMRT beam model using same gamma criteria. The measured mean gamma pass rate for this coronal plane dose was 96.7% with maximum and minimum of 98.41% and 95.3%. This was comparable with the gamma map pass rates for the three orthogonal dose planes calculated by XIO for the patient data. A secondary treatment planning system was shown to provide a supplementary verification tool based on calculation-based 3D dosimetry using patient anatomy.

1. Introduction

Intensity modulated radiotherapy (IMRT) has been used as a routine treatment technique in many centres since the first IMRT treatment was delivered in 1996 [1]. It is critical that the treatment planning system (TPS) IMRT beam model is fully commissioned before it is released for clinical use. AAPM TG 119 includes a set of test cases for this purpose [2]. These tests were recommended to be performed using a square water equivalent phantom with artificial targets and organs at risk (OAR) drawn on CT images. These tests, however, cannot detect errors related to patient anatomy as these structures are unable to represent real patient anatomy. For example, test No.12 involves simulating a prostate treatment. The prostate clinical target volume (CTV) and rectum are represented by roughly ellipsoidal volumes with posterior concavity and a cylinder with diameter of 1.5 cm, respectively. In reality, the CTVs and OARs are complicated and vary from patient to patient, especially for head-neck cases.

As a component of commissioning tests, it is desirable to verify the IMRT beam model within patient anatomy. However, it is very difficult to directly measure the dose inside patients. This can be achieved using an independent calculation-based method which has been previously verified. One study showed that the beam model in a TPS could be verified using a full Monte Carlo calculation instead of phantom-based measurement [3]. Recently in our department, an IMRT beam model was commissioned for the Philips Pinnacle TPS. The purpose of this study was to evaluate the suitability of using a secondary commercial TPS to verify an IMRT beam model considering true patient anatomy and inhomogeneity as a supplemental test to phantom-based measurement verification.

2. Materials and Methods

To verify an IMRT beam model for an Elekta Synergy linear accelerator, considering true patient anatomy and inhomogeneity a process was developed and analysed for transferring patient data and generated treatment plans including all beam sizes, shapes and weights from the Pinnacle TPS which was being commissioned, to a CMS XIO TPS which had been utilized in our department for IMRT treatment planning for a number of years.

2.1. CMS XIO as a 3D dose calculator

CMS XIO is a three-dimensional (3D) TPS for external beam radiotherapy able to calculate dose to each voxel in a patient volume. A superposition algorithm is utilized in this system, in which the total energy fluence of the primary beam in the patient volume is first calculated and then convolved with a kernel that takes into account the transport of secondary photons and electrons within the given patient anatomy. The accuracy of this algorithm meets the current requirements for radiotherapy and has been verified by measurements and full Monte Carlo calculations [4, 5]. In our department, XIO has been used for IMRT planning and treatment since 2008.

Using this XiO TPS 310 IMRT patients have been planned and treated on Elekta linear accelerators (Linac) within our department. For each patient, an ion chamber point dose measurement was undertaken using the CIRS phantom. The plane dose was also measured at 5.4 cm depth in a water equivalent square phantom using a chamber array (I'mRT Matrix). The gamma map comparing TPS and measurement was analyzed using 3%/3mm criteria. The maximum and minimum difference to date between measured and XIO calculated point dose is 2.8 % and 0.3 % with a mean value of 1.35 %. The mean gamma pass rate is 96.7 %. The maximum and minimum pass rates are 95.3 % and 99.2 %, respectively. These patient specific quality assurance results with phantom provided an extensive verification of XIO against the IMRT delivery system. In this investigation, XIO was used as an independent 3D dose calculator for verifying the Elekta IMRT beam model commissioned in Pinnacle.

2.2. Calculation of Pinnacle IMRT plans in XIO

To verify the IMRT beam model in Pinnacle using XIO, five typical datasets from previous patients were utilised. Three of them were head-neck and two were prostate cases. The patient CT data set and associated radiotherapy (RT) structures were first imported into Pinnacle. An IMRT plan was generated for each patient using the Pinnacle Elekta IMRT beam model following current clinical protocols. Each plan was reviewed and considered acceptable by the treating radiation oncologist. The same patient CT data and RT structures were then transferred from Pinnacle to XIO using DICOM, thus ensuring plan objects such as interest points, weight point and isocenter have the same coordinates for Pinnacle and XIO.

XIO does not have a function or interface that allows direct importing of a Pinnacle IMRT plan. To overcome this in-house software was developed. The Pinnacle IMRT plan was first exported as a RTP file. The in house software then converted the RTP file for the Pinnacle IMRT plan into a tel.1 as required by XIO, enabling patient datasets to be set-up and viewed in XIO with the exact plan details e in Pinnacle. No additional optimization or plan adjustment was undertaken in XIO. The 3D dose distribution was calculated in XIO using the same calculation settings as those in Pinnacle. The calculation grid used was 2 mm and the calculation volume was chosen to be large enough to cover the entire patient volume. The 3D dose distributions calculated in XIO were exported in DICOM format and compared with Pinnacle calculated dose distributions.

A 2D gamma map for three orthogonal planes passing through the isocenter was calculated for each patient dataset comparing Pinnacle and XiO calculated dose distributions. A gamma map analysis criteria of 3%/3 mm was used as recommended by AAPM TG 119 for IMRT beam model commissioning and used by most radiotherapy centres for measurement-based patient-specific QA [2]. Dose for one coronal plane at 5.4 cm depth in a water equivalent square phantom using the I'mRT Matrix was also measured for each patient Pinnacle IMRT plan. The measured dose was compared with the same dose plane calculated in the phantom by Pinnacle using the Pinnacle IMRT model.

3. Results and Discussion

An example 3D dose cube calculated by XIO and Pinnacle using the commissioned IMRT beam model for one head-neck patient is shown in figure 1. The 2D gamma map for one coronal plane passing through the isocenter was also calculated. The gamma analysis passed for all pixels except for a very small area near the patient surface, which was also indicated by a 2D dose profile comparison in the same dose plane. The failure of the gamma analysis near the patient surface is mainly due to the difference in the electron contamination model used by XIO and Pinnacle.

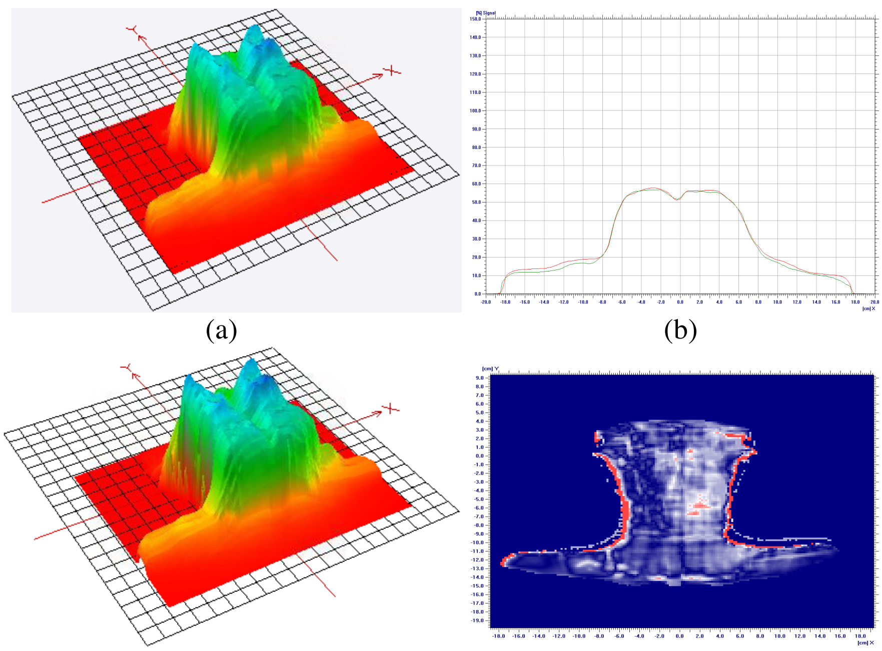

Figure1. Comparison of a coronal dose plane for a 3D dose distribution in patient anatomy for one head-neck patient: (a) The dose to patient calculated by XIO (c) The dose in patient calculated using the Elekta IMRT beam model by Pinnacle (b) A dose profile passing through isocenter in the coronal plane (d) The gamma map for the coronal plane passing through isocenter.

Table 1 shows the gamma pass rate for the three orthogonal planes passing through the isocenter for all patient datasets. The first three patients were head-neck and the last two prostate cases. The average gamma pass rate for all beams and all patients was 96.86%. The maximum and minimum gamma pass rates were 99.6% and 94.3%, respectively. Table 2 presents the gamma pass rate for one coronal plane dose measured at 5.4 cm depth in a water equivalent phantom against the same plane dose calculated by Pinnacle. The gamma map was calculated for each IMRT beam for all patients. The average gamma pass rate for this measured coronal plane dose for five patients was 96.7% with minimum and maximum gamma pass rates of 95.3% and 98.41%, respectively. The verification results using XIO as a 3D dosimeter for verifying the IMRT beam model in Pinnacle were comparable to results measured using the phantom.

Table 1. Gamma pass rates for three orthogonal planes passing through isocenter comparing Pinnacle and XiO calculated plans

	Gamma pass rate (%)		
Patient #	Transverse plane	Sagittal plane	Coronal plane
1	96.5	94.9	94.3
2	95.0	95.7	96.1
3	99.6	98.6	96.0
4	98.3	97.0	97.6
5	97.4	97.6	98.3

Table 2. Measured gamma pass rate for one coronal plane at 5.4 cm depth using a square solid water phantom and compared with Pinnacle calculated plans

	Gamma pass rate for each Pinnacle IMRT beam (%)							
	beam #							
Patient #	1	2	3	4	5	6	7	Mean pass rate (%)
1	95.9	97.6	95.8	96.2	97.4	98.4	96.6	97
2	96.92	96.84	95.51	97.31	95.3			96.4
3	96.04	95.93	95.83	97.07	96.95	97.87	96.74	96.5
4	97.1	96.75	96.21	97.04	96.21	98.41	97.76	97.1
5	95.53	97.02	96.1	95.96	98.23			97

The advantage of using a secondary commercial TPS for verifying an IMRT beam model is that it is a calculation-based 3D dosimetry. The dose at each voxel in the patient volume can be obtained. Realistic complicated inhomogeneities in real patient anatomy, often regions where limitations in treatment planning systems are seen can be analysed.

4. Conclusion

A process for using a secondary treatment planning system as a 3D dosimeter to verify an IMRT beam model has been developed and verified. This provides an alternative method for verifying an IMRT beam model based on true patient anatomy. The methodology presented here can be applied to other commercial treatment systems.

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