Ionization chamber array for patient specific VMAT, Tomotherapy and IMRT QA

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Abstract. The evaluation between measured and calculated dose is essential in the patient specific quality assurance procedures for intensity modulated radiation therapy. The high complexity of volumetric arc radiotherapy, Tomotherapy and intensity modulated radiation therapy deliveries attributed to the dynamic and synchronization requirements of such techniques require new methods and potentially new tools for the quality assurance of such techniques. Studies evaluating the dosimetric performance of EDR2 film and a 2D ionization chamber array quality assurance device have been performed in our institution. Our results showed that differences between the detector systems are small. The respective gamma index histograms showed that when 3% dose difference and 3mm distance to agreement are used, more than 90% of the evaluated points were within the tolerance criteria.

1. Introduction

Volumetric modulated arc therapy (VMAT) is a novel extension of conventional intensity-modulated radiotherapy (cIMRT), in which an optimized three-dimensional dose distribution may be delivered in a single gantry rotation. VMAT is the predecessor to RapidArc (Varian Medical System). Leaf positions and segment weights (control points) are directly optimized, and a variable dose rate is used. RapidArc incorporates capabilities such as variable dose-rate, variable gantry speed, and accurate and fast dynamic multileaf collimators (DMLC), to optimize dose conformality, delivery efficiency, accuracy and reliability. Tests have been designed that evaluate RapidArc performance in a stepwise manner. The accuracy of DMLC position during gantry rotation, the ability to vary and control the dose-rate and gantry speed and, the combined use of variable DMLC speed and dose-rate can be independently tested. Similar to IMRT with static gantry angles and set dose rate, the RapidArc deliveries require patient specific QA. The evaluation between measured and calculated dose is essential in the patient specific quality assurance procedures for intensity modulated radiation therapy. The high complexity of volumetric arc radiotherapy delivery attributed to the dynamic and synchronization requirements of such delivery require new methods and potentially new tools for the quality assurance of such techniques. Studies evaluating the dosimetric performance of EDR2 film and commercially available quality assurance devices have been performed in our institution. Among the commercially available 2D array detector devices, based on either diode or ionization chamber arrays[1-3] show excellent characteristics in terms of linearity, repeatability, and independence from dose rate effects while at the same time have limited spatial resolution, due to the discrete although parse number of detectors available when compared to film. (figure1) Poppe et al.,[3] analyzed the influence of those parameters on accuracy of IMRT dose measurements and concluded that dose variations in realistic IMRT dose distributions contain very little, if any, spatial frequency components.
Spezi et al.[4] show that the PTW Seven29 array can detect leaf positional errors down to 1mm and also spatial resolution has been discussed by others for I'matrixx[5] and Delta4 array[6-7]. Since, our goal of the study is not to characterize or evaluate the different detector arrays which can be been found elsewhere.

2. Materials and Methods

2.1. PTW 2D Array and Octavius phantom

The PTW seven29 2D-Array consists of 729 vented plane-parallel ionization chambers with a 0.6g/cm$^2$ graphite wall arranged in a 27 x 27 matrix covering an area of 27 cm x 27 cm. Each single chamber is air-filled with a cross section of 5mm x 5mm and height of 5mm. The chambers are separated from each other by 5mm. The distance between the centers of adjacent chambers is 10mm. The 2D array surrounding material is made up of polymethyl methacrylate (PMMA). The measuring system consists of the chamber array itself, which also accommodates part of the electronic devices, the array interface, and a data acquisition board for the personal computer. A dedicated phantom for the QA of rotational treatments focusing primarily on the use of the Seven29 2D ion chamber array, called Octavius was used during measurements. Octavius is made of polystyrene (physical density 1.04 g/cm$^3$, relative electron density 1.00), and is 32cm wide and has a length of 32 cm. A 30 x 30 x 2.2 cm$^3$ central cavity allows the user to insert the 2D ion chamber array into the phantom. The position of the cavity is such that when the 2D array is inserted, the plane through the middle of the ion chambers goes through the center of the phantom. The measurement ranges for PTW Seven29 as specified by manufacturer are 200 mGy – 1000 Gy and 500mGy min$^{-1}$ to 8 Gy min$^{-1}$. The 2D array is calibrated for absolute dosimetry in a Co$^{60}$ photon beam at the PTW secondary standard dosimetry laboratory. An on-site cross calibration factor correcting for the quality of the beam can be measured and used by the detector acquisition software. In this work the detector array was used in absolute dose measuring mode and dose values were corrected for daily variation of linac output.

2.2. Dose Verification

2D detector arrays have two limitations of their geometrical resolution, the size of the single detector and the centre-to-centre distance between the detectors. In the case of the PTW Seven29 the first limitation has been dealt with by adjusting the dose verification routine to the measurement process. The measured values are compared to the convolution product of the calculated dose distribution and the single-detector lateral response function, and the width of this response function is sufficiently small to enable the detection of 1 mm MLC misalignments. The second limitation has been dealt with by taking two frames of each dose distribution with a step width of 5 mm in between, so that a sampling frequency of 0.2 mm$^{-1}$ is achieved in the direction of the shift. This may be generalized by applying the 5 mm shift in two dimensions. Applying the Nyquist theorem to the measured values of realistic dose distributions, it has been shown[8] that the sampling frequency of 0.2 mm$^{-1}$ is appropriate. Due to the optimized MLC-adapted geometry of the PTW Seven29, the required 5 mm shift between two frames of the same dose distribution can be easily and precisely achieved.

3. Results - CTRC experience with PTW Seven29

Our results showed that differences between the film and the PTW Seven29 measurements of IMRT, RapidArc and Tomotherapy patient specific QAs are small (Table 1). The respective gamma index
histograms showed that when 3% dose difference and 3mm distance to agreement are used, more than 90% of the evaluated points were within the tolerance criteria. The agreement as reflected through gamma index passing rates was higher on average for the Seven29 2D array compared to the film measurements.

Accurate dose validation is a key component in the successful delivery of patient treatments. The PTW Seven29 with Octavius is accurate with the clinical criterion of 3% and 3 mm and is also accurate with more stringent criteria, 2% and 2 mm, for clinically used field widths and pitches. With more obscure settings of 1.06 cm FW and pitch of 2, higher discrepancies were observed using more stringent criteria. The Seven29/Octavius and the film measurements are comparable in performance based on average gamma passing percents. Based on these measurements however, the Seven29/Octavius gives better results when using the clinical passing criteria of 3%, 3 mm as well as the more stringent 2% and 2 mm when comparing QA plans with helical TomoTherapy.

| PLAN NO | SITE  | RapidArc | IMRT     | Tomotherapy |
|---------|-------|----------|----------|-------------|
|         | Site  | Film     | PTW Seven29 | Site        | Film | PTW Seven29 | Site  | Film      | PTW Seven29 |
| 1       | Brain | 91.69    | 94.55     | Brain       | 98.24 | 96         | Pancreas | 94.6      | 100.00     |
| 2       | Brain | 99.34    | 98.9      | H&N         | 98.21 | 96.96      | Prostate | 99.7      | 99.90      |
| 3       | H&N   | 94.38    | 95.79     | Liver       | 97.32 | 96.19      | Anus     | 98.4      | 100.00     |
| 4       | Liver | 99.99    | 99.78     | Lung        | 93.62 | 97.47      | Prostate | 96.4      | 99.70      |
| 5       | Lung  | 99.63    | 98.7      | Prostate    | 99.55 | 97.49      | Prostate | 98.9      | 99.90      |
| 6       | Lung  | 99.87    | 99.95     | Prostate    | 94.92 | 98.13      | Prostate | 95.1      | 100.00     |
| 7       | Prostate | 94.95   | 96.05     | Prostate    | 96.72 | 96.77      | Pelvis   | 98.2      | 99.90      |
| 8       | Prostate | 98.79   | 97.94     | Prostate    | 98.47 | 97.74      | Pelvis   | 95.1      | 97.70      |
| 9       | Prostate | 94.24   | 96.78     | Prostate    | 97.94 | 97.88      | Prostate | 96.6      | 99.30      |
| 10      | Prostate | 93.98   | 96.2      | Prostate    | 99.63 | 99.96      | Prostate | 91.2      | 96.60      |
| 11      | Prostate | 98.37   | 97.81     | Prostate    |         |            |         | 97.5      | 100.00     |
| 12      | Prostate | 99.11   | 98.42     |             |         |            | Liver    | 92        | 97.60      |
| 13      | Prostate | 92.93   | 99.45     |             |         |            | Larynx   | 95        | 96.20      |
| 14      | Prostate | 99.23   | 99.78     |             |         |            | Spine    | 94.3      | 96.80      |
| 15      | Spine  | 96.76    | 98.72     |             |         |            | Hypopharynx | 97.5 | 93.40 |
| Average |       | 96.88    | 97.92     | Average     | 97.46  | 97.46      | Average  | 96.03     | 98.47      |

4. Conclusions

Although rotational radiotherapy treatments are increasingly used, the developed technology is relatively new and requires careful monitoring and verification. For the verification of these treatment methods, the Seven29 2D ion chamber array provides an overall accuracy comparable to that of single ion chamber measurements when it is used in combination with the Octavius phantom. This phantom contains a compensation cavity to rectify the different collection efficiency when the array is irradiated from the rear. This QA method facilitates the pretreatment verification process by providing on-line absolute 2D dose information.

The availability of 2D arrays for patient specific quality assurance has provided another established method of accurately validating precise, measured dose distributions. The ability of current 2D array technology to provide stable and reproducible results as shown in multiple published literature, validates the future role of 2D arrays as a robust dosimeter. Current 2D ionization array systems such as the PTW Seven29, eliminate the need of film and ion chamber-based dose validation and further
shorten the time associated with dose validation due to their ability of instantaneously reading, processing and analyzing the data.

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