

A method to enhance 2D ion chamber array patient specific quality assurance for IMRT

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Abstract Gamma index comparison has been established as a method for patient specific quality assurance in IMRT. Detector arrays can replace radiographic film systems to record 2D dose distributions and fulfill quality assurance requirements. These electronic devices present spatial resolution disadvantages with respect to films. This handicap can be partially overcome with a multiple acquisition sequence of adjacent 2D dose distributions. The detector spatial response influence can also be taken into account through the convolution of the calculated dose with the detector spatial response. A methodology that employs both approaches could allow for enhancements of the quality assurance procedure. 35 beams from different step and shoot IMRT plans were delivered on a phantom. 2D dose distributions were recorded with a PTW-729 ion chamber array for individual beams, following the multiple acquisition methodology. 2D dose distributions were also recorded on radiographic films. Measured dose distributions with films and with the PTW-729 array were processed with the software RITv5.2 for Gamma index

comparison with calculated doses. Calculated dose was also convolved with the ion chamber 2D response and the Gamma index comparisons with the 2D dose distribution measured with the PTW-729 array was repeated. $3.7 \pm 2.7\%$ of points surpassed the accepted Gamma index when using radiographic films compared with calculated dose, with a minimum of 0.67 and a maximum of 13.27. With the PTW-729 multiple acquisition methodology compared with calculated dose, $4.1 \pm 1.3\%$ of points surpassed the accepted Gamma index, with a minimum of 1.44 and a maximum of 11.26. With the PTW- multiple acquisition methodology compared with convolved calculated dose, $2.7 \pm 1.3\%$ of points surpassed the accepted Gamma index, with a minimum of 0.42 and a maximum of 5.75. The results obtained in this work suggest that the comparison of merged adjacent dose distributions with convolved calculated dose represents an enhancement in the methodology for IMRT patient specific quality assurance with the PTW-729 ion chamber array.

Keywords Patient specific IMRT quality assurance · PTW-729 ion chamber array · Multiple acquisition sequence · Detector spatial response

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Introduction

Patient specific quality assurance (QA) is routinely recommended for intensity modulated radiotherapy (IMRT). The measurement of dose distribution for individual beams is a recommended, regular method in many radiation therapy facilities [1–4]. Individual beam intensities can be measured with a radiographic film or a 2D detector array inserted into a phantom. The quality of the agreement

between calculated and measured dose can be quantified through the Gamma index calculation [4–6].

The availability of 2D detector array devices favors digital methodologies for the QA of patient specific IMRT plans [7–22]. These devices have a number of electronic detectors distributed over a surface. The spatial resolution of a detector array is inevitably worse than a radiographic film due to the size of detectors and their spatial distribution.

Size and spacing between detectors in the PTW-729 ion chamber array allow the implementation of a multiple acquisition sequence, which consists of four measurements of a given field with three 5 mm-shifts of the device. It is thus possible to achieve better spatial resolution, as reported by Spezi et al. [12]. This procedure is to be referred in the remainder of this paper as Merge.

On the other hand, some authors have shown the importance of considering the influence of the detector geometry and dimensions in the incident dose readings [10, 13, 14]. Poppe et al. proposed the convolution of the calculated 2D dose distribution with the ion chamber response function, before applying the Gamma index comparison. This function characterizes the ion chamber's 2D response to irradiation with a slit beam. They showed that a better agreement can be obtained between a dose profile measured with a semiconductor dosimeter (“gold standard”) and the same dose profile measured with a PTW-2D array, taking into account the detector spatial response function [13]. Herzen et al. compared calculated dose profiles from an IMRT pyramidal dose distribution with measurements with a MatriXX 2D array. They considered the detector lateral response, and concluded that the array is a suitable device for 2D dose verification [10]. Gago-Arias et al. also evaluated three 2D detector arrays, taking into account both measured and Monte Carlo response functions. Using IMRT treatments they compared the arrays performances with film measurements in terms of the Gamma index and concluded that the arrays fulfill IMRT verification requirements [14]. Asuni et al. also derived the 2D response function for the ion chamber of a detector array from the chamber's line spread function. Then they convolved the incident fluencies of two IMRT plans with the response function and compared the obtained dose distribution with measured doses. They concluded that their device measures IMRT fields accurately within acceptable tolerance [21].

However, a simple straightforward irradiation of a detector array like PTW-729 and the convolution method alone cannot resolve details having spatial frequencies higher than 1 cm^{-1} .

The purpose of this work was to implement and test a methodology that incorporates both the Merge option, as described by Spezi et al. [12] and the convolution of the

calculated dose with the detector's spatial response function, as described by Poppe et al. [13] for the patient specific QA in IMRT plans with the PTW-729 ion chamber array. Several IMRT plans were thus evaluated with the Gamma index calculation. Gamma index comparisons were also performed with the PTW-729 ion chamber array using only the Merge option, and using the traditional film methodology.

Methods

A 6 MV beam from a Primus linear accelerator (Siemens Medical Solution, Inc., Concord, CA) equipped with a 82 leaf MLC OPTIFOCUS (Siemens Medical Solution, Inc., Concord, CA) was used to deliver the step and shoot IMRT treatment plans. The plans were generated with the TPS Konrad (Siemens Medical Solution) and sent to the linac with the R&V system LANTIS (Siemens Medical Solution). The average number of segments per plan was 13, with a minimum of 8 and a maximum of 22.

In order to calculate 2D dose distributions corresponding to every beam, a solid water phantom (RW3, PTW-Freiburg, Germany) was scanned. Radiographic film X-Omat V Ready Pack (Eastman Kodak Company, Rochester, NY) was used to determine the dose. The films were inserted into the phantom at a depth of 2 cm and with 5 cm for backscattering. The procedure for film dosimetry was carried out following the recommendations of the AAPM TG-69 [23].

The 2D dose matrices were calculated at the measurement depth and sent to a PC with the quality assurance software RITv5.2 (Radiological Imaging Technology, Colorado Springs, CO). The matrices had a grid spacing of $2 \times 2 \text{ mm}^2$. IMRT beams were delivered individually, with gantry at 0° , pointing down and in the step and shoot modality. After irradiated and developed, the films were scanned with a Vidar scanner, VXR-16 Dosimetry Pro Advantage (VIDAR System Corporation, Rendon, VA). Calculated and measured dose distribution were compared with the RITv5.2 software, with the Gamma index parameters set at 3% dose difference and 3 mm of distance.

The 2D ion chamber array PTW-729 (PTW-Freiburg, Germany) was also used to measure dose. The effective measuring point of the chambers in the PTW-729 is at a depth of 0.5 cm of PMMA [7]. The array was inserted in the solid water phantom to an additional depth of 1.5 cm and with 5 cm for backscattering. The IMRT beams were then delivered individually over the arrangement, with the linac gantry positioned at 0° . The Merge option was employed, consisting of four acquisitions of the same beam, with three array shiftings of 5 mm, so that the beam cross section was registered with increased resolution [12].

This arrangement was also scanned in order to calculate the dose matrix corresponding to each individual beam. Calculated dose and merged measured dose distributions were processed with the same RITv5.2 software with identical parameters for the Gamma index comparison with the parameters of 3% dose difference and 3 mm distance.

Due to their volume and scattered secondary electron response, detectors in an array show a specific spatial response [10, 13–15, 20, 21]. In one dimension, the spatial response of a PTW-729 ion chamber can be taken as a trapezoidal form with an upper width of 5 mm and a lower width of 9 mm [13, 15]. The dose calculation within the TPS used a grid spacing of 2 mm. For the purposes of this work, an adapted response function was built with values equivalent to the mean value of the reported original function in 2 mm intervals. The 2 mm intervals were placed symmetrically with respect to the center of the original function, with an interval placed in the middle of the plateau. The 2D chamber response function was derived from the adapted linear response following the procedure of Poppe et al. [13].

The calculated dose matrices were then convolved with the 2D detector response function. In order to do this, the TPS calculated dose files were sent to a personal computer and convolved using a simple, home-made Matlab (Mathworks, Inc, version 5.1) routine. The convolved doses were then normalized so that their maximum values remained equal to those of the primary dose distribution before the convolution.

The convolved doses were introduced into the RITv5.2 for comparison with the merged measured doses. Identical parameters of 3% dose difference and 3 mm distance were employed for Gamma index calculation. Dose distributions as calculated, convolved after calculation, or measured with the PTW-729 without and with Merge, are presented in sectors a, b, c, and d in Fig. 1.

The procedure with the RIT software for dose distribution comparison requires an experienced operator to visually establish relevant points for registration. In our study all the registrations and comparisons were made by the same operator.

A total of 35 individual IMRT beams from 12 patients were included in our study. All patients who arrived in the time period set to implement the QA methodology with the PTW-729 were included, and their plans were processed with the 2D array as well as with films. The treatment sites were prostate, and head and neck. The beams for every patient were randomly selected.

An IMRT beam from a patient's treatment was excluded from our results. A very large number of points failed to meet the Gamma index passing criteria with the film-based methodology for this beam.

In order to evaluate the results obtained by different methodologies of IMRT patient specific QA, some authors have compared the results obtained with digital devices, with results obtained with radiographic film measurements [7, 19]. In our work, a student *t* test was applied to the overall results.

Results

The graphic in Fig. 2 shows the percentage of points that surpass the limit Gamma value of 1 for the three methods of IMRT plan evaluation. In the comparison of the calculated dose and that measured with radiographic film, the mean value of the percentage of points that surpassed the limit Gamma value of 1, was 3.5, with a standard deviation of 2.6 (minimum, 0.67; maximum, 13.27). The largest and most common disagreements were situated in high dose gradient areas.

In the comparison between the calculated dose and that measured with the ion chamber array with Merge, the mean value of the percentage of points that surpassed the limit Gamma value was 4.4, with a standard deviation of 1.8. (minimum, 1.44; maximum, 11.26). As in the previous case, the largest disagreements were situated in high dose gradient areas. The difference between this second mean value and the first had some statistical significance ($t = 0.0496$).

When comparing the convolved calculated dose and the dose measured with the ion chamber array with Merge, the mean value of the percentage of points that surpassed the limit Gamma value was 2.7, with a standard deviation of 1.3. (minimum, 0.42; maximum, 5.75) As in previous cases, the largest disagreements were situated in high dose gradient areas. This third mean value is lower than the first, with statistical significance for the student *t* test of 0.0451. The statistical significance of this value with the second is much higher ($t = 9.7 \times 10^{-6}$).

Figure 3 illustrates the result differences between the comparisons of a merged measured dose with the corresponding calculated dose (a) or with the convolved calculated dose (b).

Discussion

Measurement of 2D dose distribution from individual beams is an established methodology for the IMRT patient-specific QA [1, 2, 4]. The conventional, film-based procedure of quality assurance fulfills the role of 2D verification. 2D detector arrays as the PTW-729 are an advantageous alternative technique, with the potential for enhancing verification procedures [2, 7–14, 16–21]. However, even in the case of diode arrays, spatial resolution is

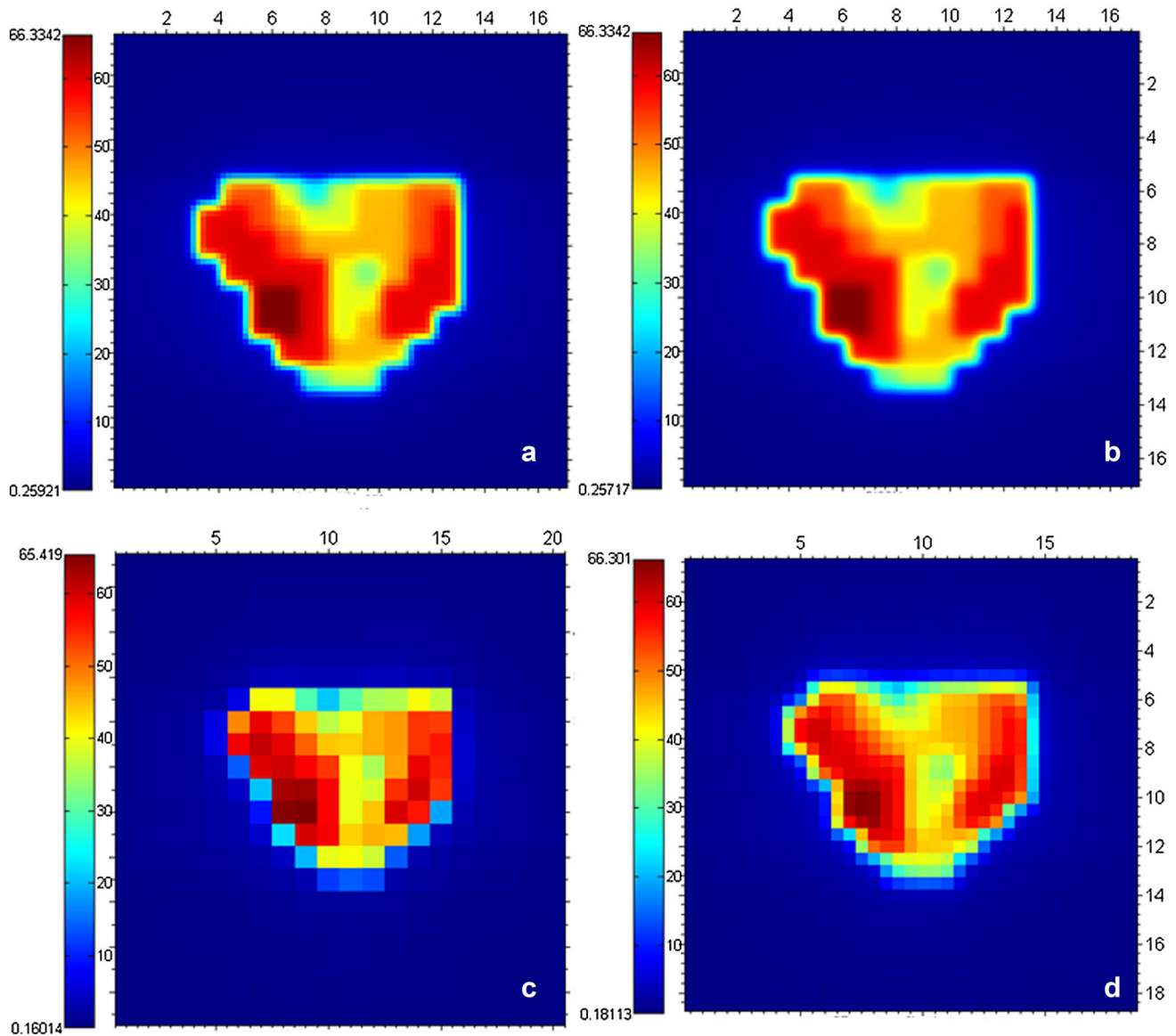


Fig. 1 Dose maps for Gamma index comparison

poorer than that achievable with radiographic films. Increased cost limits the number of detectors in the array and their minimum size.

Several authors have discussed the advantages of improved sampling resolution in QA 2D measurements [12, 17, 18, 20]. The Merge option with the PTW-729 ion chamber array increases sampling resolution without additional material costs [12, 17, 18]. The Octavius Detector 1500 constitutes an evolution of the PTW-729 with the possibility to increase the spatial sampling frequency and the coverage of a dose distribution with the sensitive areas of ion chambers by merging only two measurements [20].

In this work, the comparison between calculated dose and that measured with the PTW-729 array with the Merge option produced acceptable results for clinical practice [4].

These results showed a larger number of points that surpassed the limit Gamma value when compared to results achieved with the film-based methodology. The difference had some statistical significance.

Determination of differences between calculated and detector arrays measured doses faces another limitation. The volume of the cubic ion chamber introduces an averaging of the dose over the detector volume, as explained above. This effect is given by the detector geometry and affects its spatial response.

Besides volume averaging, there are other effects that influence the detector response. Bouchard et al. showed that differences in electron density between water and the detector medium, among other factors, should also be taken into account [24].

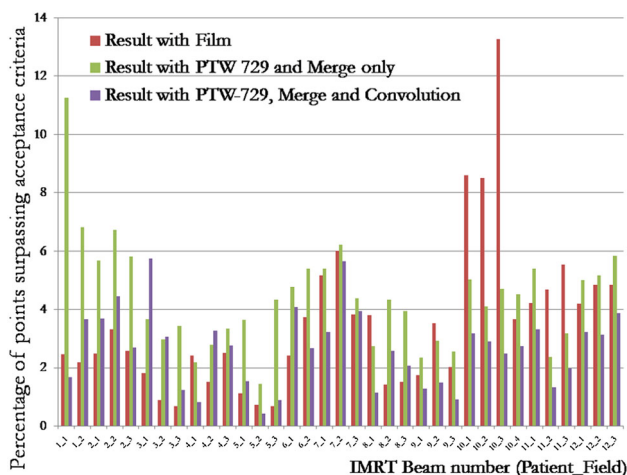


Fig. 2 Percentage of points surpassing tolerance values

As a consequence of all this, a specific smoothing of the measured 2D dose distribution is introduced. Detector response functions have been reported for a variety of devices, obtained through measurements as well as through Monte Carlo simulations [10, 13, 14, 20–22].

In this case, the convolution of the calculated dose with the detector response function is a departure of the clinical parameter, but it also reflects a particular feature of the measuring device. Values measured with the 2D array can be regarded as sample values from the convolution product of the calculated dose distribution and the detector response function [15]. According to Poppe et al. a satisfactory sampling resolution is achieved, compared with the

Nyquist frequency for convoluted IMRT typical dose distributions [15].

The novelty of this work consisted in performing both the Merge procedure and the calculated dose convolution in order to make the Gamma index comparison, for a number of cases, during the implementation of the QA procedure.

Results thus obtained in our work, compared favorably even to those attained with the traditional, film based methodology, in the sense of a better correspondence between expected and measured dose. However, if film were capable to pick up problems in beam delivery better than the PTW-729, false negatives could be obtained with the last option. This could explain the problem with the beam excluded from our analysis. Alternatively, it underscores the difficulties arising from film dosimetry, as stated by previous revisions [11, 19, 23]. A problem with the linac and the delivery of that particular beam at the time of the film measurement could also have taken place.

As noted above, in all the comparisons, the largest disagreements were situated in high dose gradient areas. This finding agrees with those found by previous authors [6].

In our opinion, these results favor the possibility of using the PTW-729 ion chamber array for patient-specific quality assurance in IMRT planning, with the Merge option and the convolution of the calculated dose.

The quality assurance procedure with the detector array is not very different from the film-based methodology with respect to the main steps of the procedure. In both cases the

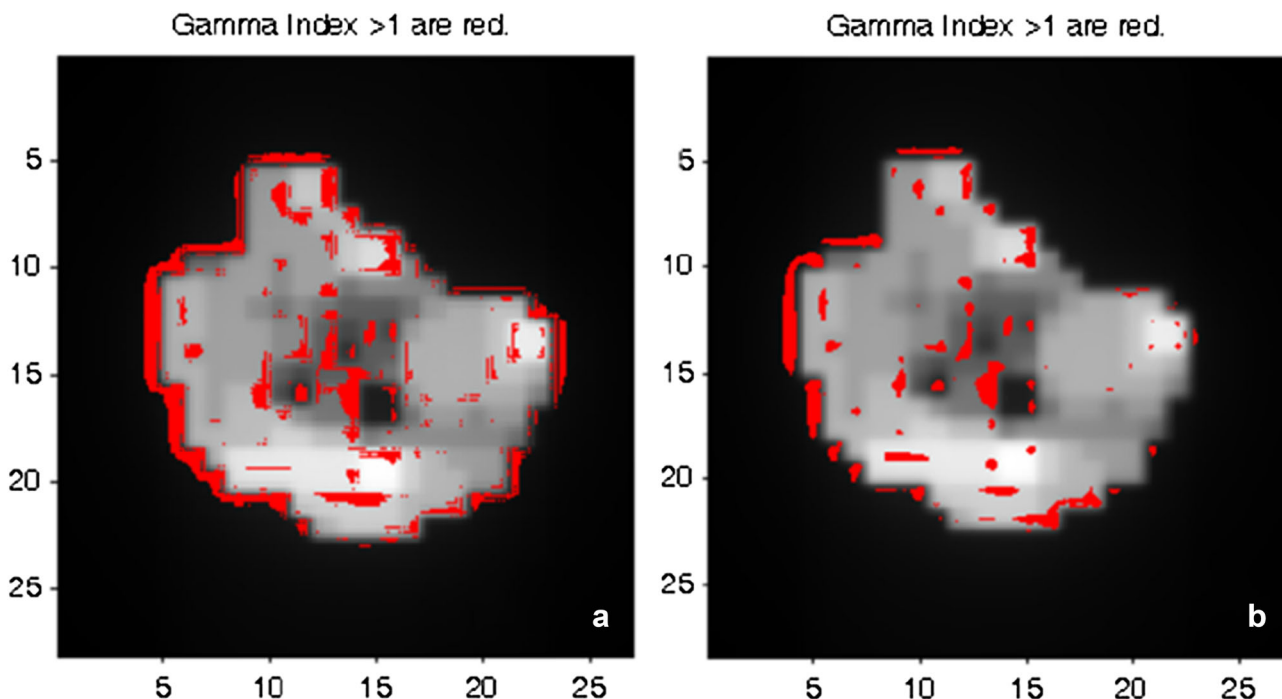


Fig. 3 Gamma analysis with the PTW-729 **a** without convolution and **b** with convolution

plan is sent to the linac with the R&V system and delivered, either on the film or the array. Extra time is needed for the Merge procedure with the detectors array, but automatic digital matrix processing can be more straightforward than with films, as noted by previous authors [10–12, 19].

As several authors point out, film dosimetry is a time- and material-consuming method that requires the continuous availability of a high-precision and stable chemical processing technique [2, 7, 10, 11, 13, 14, 23]. Radiochromic films could be used so that development of films is not needed, but it would still be necessary to scan the film, perform a calibration procedure, and maintain a constant supply of expendables [10, 25].

The convolution of the calculated dose distribution can be easily performed with a simple informatics routine in any computer language able to process numerical matrices and DICOM images. The dose comparisons with the Gamma index method can be also performed with the same standard software for quality assurance used in the department, whether the calculated dose has been convolved or not.

The visual, subjective registration of measured and calculated dose with or without convolution, may also introduce variations in the Gamma index assessment.

Finally, it is also important to consider that Gamma methodology is only a tool for IMRT QA. Even a high rate of points satisfying the Gamma index does not always ensure satisfaction of clinical goals or that the actual treatment will be adequately delivered, as some authors have pointed out [26–29]. Tolerance levels more stringent than 3% and 3 mm could be needed to detect some possible errors, especially in dynamic rotational techniques [16, 18, 28].

Conclusions

Three methods of quality assurance for individual beams in patient specific IMRT treatment plans were compared in this work. The results agree with the thesis that the comparison of the calculated dose and dose registered with the PTW-729 with the Merge option is an acceptable methodology for patient specific quality assurance.

The comparison between the dose measured with the PTW-729 with the Merge option and the convolved calculated dose yielded improved results in the Gamma analysis, as compared with the results of the comparison without the convolution. This is consistent with the influence of the detectors spatial response in 2D dose distribution measurements. Our results suggest that the PTW-729 array-based patient-specific IMRT quality assurance

enhanced procedure can be satisfactorily implemented in clinical practice.

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