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Evaluation of a 2D diode array for IMRT quality assurance

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Abstract

Background and purpose: The QA of intensity modulated radiotherapy (IMRT) dosimetry is a laborious task. The goal of this work is to evaluate the dosimetric characteristics of a new 2D diode array (MapCheck from Sun Nuclear Corporation, Melbourne, Florida) and assess the role it can play in routine IMRT QA.

Material and methods: Fundamental properties of the MapCheck such as reproducibility, linearity and temperature dependence are studied for high-energy photon beams. The accuracy of the correction for difference of diode sensitivity is also assessed. The diode array is benchmarked against film and ion chambers for conventional and IMRT treatments. The MapCheck sensitivity to multileaf collimator position errors is determined.

Results: The diode array response is linear with dose up to 295 cGy. All diodes are calibrated to within ± 1% of each other, and mostly within ± 0.5%. The MapCheck readings are reproducible to within a maximum SD of ± 0.15%. A temperature dependence of 0.57%/°C was noted and should be taken into account for absolute dosimetric measurement. Clinical performance of the MapCheck for relative and absolute dosimetry is demonstrated with seven beam (6 MV) head and neck IMRT plans, and compares well with film and ion chamber measurements. Comparison to calculated dose maps demonstrates that the planning system model underestimates the dose gradients in the penumbra region.

Conclusions: The MapCheck offers the dosimetric characteristics required for performing both relative and absolute dose measurements. Its use in the clinic can simplify and reduce the IMRT QA workload.

Keywords: Intensity modulated radiation therapy; Quality assurance; Diode array

1. Introduction

The potential improvement of tumor local control with dose escalation and decrease of side effects with better sparing of critical organs have contributed to the eager incorporation of intensity modulated radiation therapy (IMRT) techniques by the radiation therapy community. Clinical implementation of IMRT, however, has been hindered by the lack of efficient tools and methods for dosimetry verification and quality assurance (QA). Typically, the QA process consists of verifying the absolute dose delivered to a reference point, and also the relative planar isodose distribution. The latter task is more involved and performed using two general approaches: integrated dosimetry [11,13,15,17–19,22,27] and individual beam dosimetry [1,3,12,23,27]. Integrated dosimetry consists of measuring the relative composite dose distribution in one or more selected planes of a (often cylindrical) phantom. In the individual beam approach, the relative dose distribution is measured on a plane perpendicular to the central axis of each beam in a flat phantom. The integrated dose approach provides direct information on the composite dose distribution and is more efficient. On the other hand, the individual beam approach allows for a more comprehensive analysis and can lead to a better understanding of the sources of error in the planning and delivery process. In both cases, films are generally used as relative 2D dosimeter of choice. IMRT film dosimetry can be very tedious, particularly when repeat QA measurements need to be made.

A new 2D diode array has been developed for routine QA of planar IMRT dosimetry (MapCheck from Sun Nuclear) [10]. This device contains 445 n-type diodes distributed over an area of $22 \times 22\ \mathrm{cm}^2$. The diode spacing is 7.07 mm in the $10 \times 10\ \mathrm{cm}^2$ central portion of the detector and increases to 14.14 mm outside of this area. Illustration of

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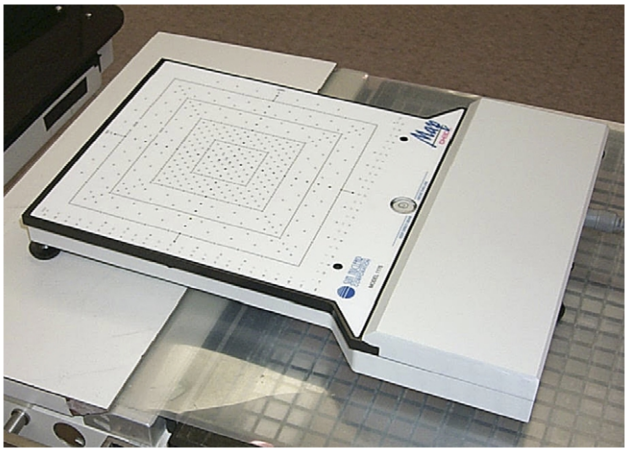

Fig. 1. Two-dimensional diode array (MapCheck).

the diode array is given in Fig. 1. The MapCheck can make both relative and absolute dose measurements simultaneously and therefore greatly simplify and reduce the QA workload. This device is however not designed to achieve composite beam dosimetry at non-normal incidence due to the diode directional response. Many properties of the MapCheck device need to be thoroughly understood before it can be applied for accurate IMRT verification. In this paper, we characterize and validate several of the basic MapCheck dosimetric properties shown by Jursinic and Nelms [10], such as diode linearity with dose, dose rate response, reproducibility with time and temperature fluctuations. In addition, measurements of conventional and IMRT relative beam dosimetry were made with the diode array and compared with those made with film and ion chamber. The potential use of MapCheck as an absolute dosimeter is demonstrated. The sensitivity of the MapCheck measurements to multileaf collimator (MLC) positioning errors is also assessed. Finally, we discuss the issues of setting MapCheck tolerance criteria when comparing measurements and calculations for IMRT beams.

2. Methods and materials

2.1. Theory of operation

The dose deposited in the MapCheck by a high-energy photon beam is measured by integrating the current generated in each diode over the irradiation period. Each individual MapCheck diode is $0.8 \times 0.8\ \mathrm{mm}^2$. The diode plane has a 2 cm thick water-equivalent buildup material and a 2.3 cm thick water-equivalent backscattering material. This inherent scattering material replaces, to a certain extent, the usual shielding added around diodes to flatten their response to the low energy scattered photons. According to the manufacturer, the MapCheck diodes are radiation hardened and exhibit a sensitivity degradation of about 2.6%/kGy delivered with a 10 MeV electron beam.

The MapCheck is calibrated for radiation measurement with the diode outputs corrected for their variations in radiation sensitivity. This is achieved by a six-step calibration process designed by the manufacturer. The MapCheck calibration can be done in any high-energy photon beam. The result of the calibration is a file containing an individual correction factor for each diode. During a measurement session, the MapCheck is leveled on the accelerator couch and its center is aligned with the center of the beam utilizing the beam crosshair. The output of the MapCheck is sent to a graphical software interface for display and analysis on a PC. A background correction is also required prior to a measurement session, to account for cable and diode noise in the absence of radiation.

2.2. Calibration and reproducibility

We verified the accuracy of the MapCheck calibration method by subtracting measurements of a 6 MV photon beam (Elekta Precise, Crawley, UK) acquired at 0 and 180° rotation of the detector array. For each detector orientation, six MapCheck readings were acquired and averaged. The field size was $25 \times 25\ \mathrm{cm}^2$ at 100 cm source-to-surface distance (SSD) and 5 cm buildup was used. One hundred MUs were delivered per reading. The two matrices of average dose measurements were appropriately rotated for subtraction.

The diode array reproducibility over a measurement session was evaluated by calculating the SD of 15 consecutive readings made by each MapCheck diode. These measurements were acquired with 5 cm of water-equivalent buildup at a SSD of 100 cm. Photon beams of 6 and 18 MV (SL20, Elekta, Crawley, UK) at a field size of $25 \times 25\ \mathrm{cm}^2$ were used to deliver 60 MUs per reading. A Farmer chamber placed in solid water at 1.5 cm under the MapCheck was used to measure the stability of the beam on the central axis. The reproducibility of dosimetry using Kodak XV films was also measured in similar conditions for comparison.

2.3. Linearity, pulse rate and dose rate response

Note that the measurements of linearity, pulse and dose rates dependence, and output factor were made only with the central diode of the device because the MapCheck exhibits a uniform inter-diode response once calibrated, as will be shown in Section 3.

Measurements were made using 6 and 18 MV photon beams (SL20, Elekta, Crawley, UK) at the standard 5 cm buildup and 100 cm SSD geometry. The dose linearity response of the MapCheck central diode was evaluated by measuring its output for beam deliveries of 1–450 MUs. The Elekta linear accelerators allow the user to select different repetition rates by varying the number of radiation pulses per second. Therefore, the pulse rate dependence of the same diode was determined by measuring its response at a constant dose (100 MU) delivered with repetition rate ranging from 50 to 600 MU/min. The diode response to the dose per pulse, or dose rate, was also evaluated at a constant machine repetition rate of 400 MU/min and output of 100 MUs. The dose rate was varied by changing the SSD from 75 to 135 cm, with 5 cm buildup. The MapCheck results were referenced to the measurements made with a Farmer ion chamber under the same irradiation conditions.

2.4. Output factor comparison

The MapCheck central diode was used to measure the relative dose output for various square field sizes ranging from 1×1 to $25 \times 25\ \mathrm{cm}^2$ for 6 and 18 MV beams, respectively. These measurements were done with a buildup of 10 cm and a source to buildup distance of 90 cm. The relative output factors derived from these measurements were compared to the measurements made with a Farmer chamber (PTW 30006) and a pinpoint chamber (PTW 31006) in the same conditions.

2.5. Temperature effect

Temperature dependence was measured for two individual MapCheck n-type diodes provided by the manufacturer. The diodes were immersed in a cold water bath at a depth of 1.5 cm. The source to water distance was 100 cm. A laboratory water heater-circulator attached to the reservoir was used to slowly increase the water temperature from 10 to 40 °C at a rate of approximately 0.25 °C/min. A thermocouple attached to the diode capsules was used to monitor the diode temperature. A 6 MV photon beam delivered an output of 100 MU to the diodes after every 5 °C rise in temperature. Before each irradiation and measurement, the water heating system was turned off for 10–15 min in order for the temperature in the diode capsule to reach equilibrium. The charges produced by both diodes are collected simultaneously with a two-channel electrometer.

2.6. Clinical application

For absolute dosimetry, the MapCheck is calibrated, for a given photon energy, by delivering 100 cGy to the unit with a field size of $10 \times 10\ \mathrm{cm}^2$ and a SSD of 100 cm. The MapCheck software then calculates a (central) diode output to dose conversion factor. The conversion factor and the inter-diode responses are saved in files that can be loaded when the MapCheck is used for subsequent dose measurements at specific photon energy. For relative isodose distribution delivered by any given beam, 'reference' measured or calculated dose maps can be loaded into the MapCheck software for comparison with dose maps measured with MapCheck. The reference dose map can be shifted manually to optimize alignment with the MapCheck dose map. The quality of the match between the two dose maps is evaluated by determining the number of diodes that satisfy a relative dose difference tolerance and a distance to agreement tolerance set by the user.

Initial clinical testing of the MapCheck involved simple comparisons of 6 and 18 MV open and 60° wedged field profiles measured with an IC10 ion chamber (Scanditronix-Wellhofer, Bartell, TN), films and MapCheck. The ion chamber profiles were scanned in a water tank, whereas the film and MapCheck measurements were obtained in solid water. The buildup thickness was 5 cm and the SSD was 100 cm. The MapCheck profiles were obtained with the diagonal diodes aligned with the collimator crosshair to achieve maximum spatial resolution. The films were digitized with a Vidar 12-bit scanner and processed using the RIT software (Radiological Imaging Technology, Colorado Springs, CO) at a resolution of 0.423 mm. A median filter (3×3 pixels) was used to smooth the film data. For the open beam profiles, the MapCheck results were compared to the ion chamber measurements for low gradient areas inside and outside of the beam. The MapCheck results were compared with film measurements in the penumbra region where high-spatial resolution was needed. Comparison of the 60° wedge profiles was performed to evaluate MapCheck's response to beam hardened dosimetry.

The relative dosimetry performances of the MapCheck for IMRT QA were evaluated by comparing the MapCheck measurements to film results for a head and neck IMRT treatment containing seven beams. This plan contained an average of 9 segments/beam and the average field size was $14 \times 17\ \mathrm{cm}^2$. MapCheck measurements were also compared to the calculated dose maps obtained with Pinnacle^3 (Philips Medical System—Radiotherapy).

Both the MapCheck and the film dose maps were obtained with 5 cm of buildup and at a SSD of 90 cm. All irradiations were delivered at 0° gantry angle in order to simplify setup. Both film and calculated dose maps were loaded into the MapCheck software for comparison. The film results were down sampled to a $1 \times 1\ \mathrm{mm}^2$ resolution grid by the MapCheck software. The Pinnacle^3 dose maps were calculated at the same resolution. After the user normalizes the diode array and reference dose maps to a selected dose point, the software application calculates the number of diodes, which satisfy the dose difference tolerance and distance to agreement criteria selected by the user.

The accuracy of the MapCheck absolute dose measurements was verified by comparing its readings to the doses measured with a pinpoint chamber (PTW 31006) for the seven IMRT irradiations in solid water. For each beam, the point of measurement is chosen to coincide with the normalization point used for the relative dose comparison. The absolute calibration of the diode array is performed just prior to these measurements to eliminate all possible temperature dependence effects.

The last MapCheck clinical test consisted of verifying its sensitivity to MLC positioning errors. This was achieved by modifying another clinical seven-beam head and neck IMRT plan where all MLC segments were contracted and expanded by 1 and 2 mm, respectively. This plan had an average of 9 segments/beam and with an average field size of $17 \times 20\ \text{cm}^2$. Each of the contracted and the expanded beams were delivered to the MapCheck. For a given beam, the unmodified, contracted and the expanded deliveries measured with MapCheck were compared with the calculated dose map. The MapCheck sensitivity to the MLC positioning error was evaluated by the variation of the number of diodes that did not satisfy the dose and distance to agreement tolerances specified by the user.

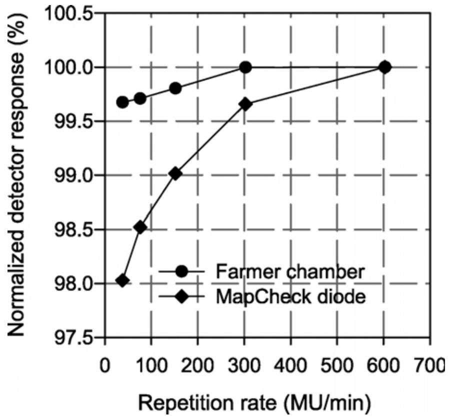

Fig. 2. Pulse rate dependence of the central diode of the MapCheck in a 6 MV photon beam. The pulse rate dependence of a Farmer ion chamber placed 1.5 cm under the diode array is also shown.

3. Results

3.1. Calibration and reproducibility

The accuracy of the correction for difference in radiation sensitivity of the 445 MapCheck diodes was verified by subtracting measurements of a 6 MV photon beam acquired at 0 and 180° rotation of the diode array. The discrepancies observed vary from -0.6% to 0.8% with more than 85% of the diodes within $\pm 0.4\%$. It is important to mention that stability of the calibration is affected by the stability of the radiation beam used for the calibration process. The symmetry stability of the calibration beam was about 0.1%. When the calibration beam stability was arbitrarily degraded to 0.3%, the discrepancies between the rotated readings increased to $\pm 1.2\%$.

The maximum SD for each MapCheck diode and for 15 consecutive measurements is $\pm 0.15\%$. These measurements included not only the reproducibility of the detector but also the reproducibility of the beam output between measurements. SD of the 15 reference ion chamber readings is 0.04% compared to that of 0.06% of the central MapCheck diode. Almost identical results were obtained for an 18 MV photon beam. In comparison, the maximum SD of 15 Kodak XV film measurements using 45 MU exposures is $\pm 1.7\%$ in the open portion (80%) of the field, in agreement with published data [2,14].

3.2. Linearity, pulse rate and dose rate response

The diode response is linear with dose and demonstrates a slightly higher sensitivity for 18 MV photons than for 6 MV. The slopes of the best linear fit for 6 and 18 MV photon beams are 11 094.6 and 11 854.1 counts/Gy with regression coefficients of 0.99999 and 0.99995, respectively. The diode saturates at 2.95 and 2.76 Gy for 6 and 18 MV, respectively, due to the capacitor size used in our MapCheck integrator circuit.

The pulse rate dependence of the central diode for a 6 MV photon beam and repetition rate ranging from 50 to 600 MU/min is shown in Fig. 2. The response of a Farmer ion chamber using the same irradiation conditions is also shown. Both curves are normalized to the measurements at maximum dose rate. The diode exhibits a monotonically increasing sensitivity variation of 2% with increasing pulse repetition rate. The Farmer chamber exhibits $<0.5\%$ variation, attributable to the variation of dose delivery of the linear accelerator as a function of the selected repetition rate. We have verified that this unexpected diode behavior is not due to a variation of MapCheck integrator response as function of the exposure time by repeating all measurements with constant irradiation time. The results are identical to the ones presented in Fig. 2. Similar results are also obtained for the diode and the chamber for 18 MV photon beam. The basic mechanism of the MapCheck behavior is not resolved at the present time and is under investigation.

Pulse rate dependence of the diode should not be a concern for IMRT QA because all treatments are generally delivered with the same repetition rate. The diode's dependence on dose rate needs to be examined, as dose delivered to a point will vary with field size or IMRT segments. The ratios of the relative doses measured with the MapCheck central diode and a Farmer ion chamber in the same irradiation conditions ($10 \times 10\ \text{cm}^2$, 5 cm depth and 2.5 cm of backscattering material) for SSD of 75–135 cm are presented in Fig. 3. This change in SSD corresponds to a change in dose rate from 6.50 to 2.10 Gy/min. These dose rates are obtained by correcting the nominal dose rate of 4 Gy/min (SSD 100 cm, $10 \times 10\ \text{cm}^2$, $d_{\max}$) with the inverse square law and the proper TMR. The results are normalized to the measurements at 95 cm SSD. The plotted data are averages of three diode and three Farmer readings, respectively. (The error bars correspond to the sum of the relative diode and Farmer reading errors in quadrature.) The

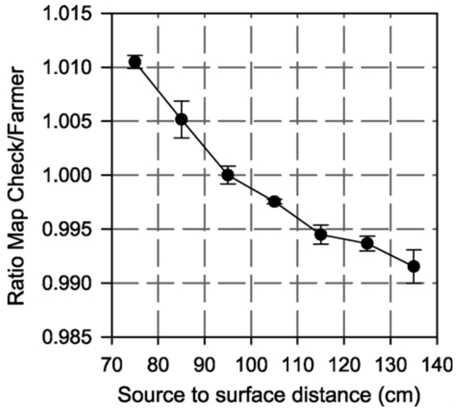

Fig. 3. The ratio of relative doses measured with the MapCheck central diode and a Farmer ion chamber in the same irradiation conditions as function of the source-to-surface distance (SSD). The dose rate seen by the detectors is varied by changing the SSD from 75 to 135 cm.

diode sensitivity varies from 1.05 to −0.85% for SSD from 75 to 135 cm, respectively. These results fall within the range of published data for different n- and p-type silicon diodes [4,6,8–10,25,26].

3.3. Output factor comparison

The output factors of a 6 MV photon beam measured for different field sizes with the MapCheck central diode, a Farmer chamber (PTW30006) and a pinpoint chamber (PTW31006) are presented in Fig. 4. The results are normalized with respect to that for a $10 \times 10\ \mathrm{cm}^2$ field. For field sizes equal to $4 \times 4\ \mathrm{cm}^2$ and larger, MapCheck and Farmer results agree generally to within 1%. At $25 \times 25\ \mathrm{cm}^2$, where the field size exceeds the diode array, the MapCheck underestimates the output factor by 1.2%. For field size smaller than $4 \times 4\ \mathrm{cm}^2$, the Farmer chamber underestimates the output factor due to the volume averaging effect. The output factors measured with the MapCheck diode and the pinpoint chamber agree to within 2% for field sizes down to $2 \times 2\ \mathrm{cm}^2$. For the $1 \times 1\ \mathrm{cm}^2$ field, the pinpoint chamber output factor is 13.3% lower than that measured with the MapCheck. For such small field dimensions, the 2 mm diameter by 5 mm length of pinpoint chamber seems less suitable than the $0.8 \times 0.8\ \mathrm{mm}^2$ MapCheck diode for dose measurements. For small field sizes, output factors measured with MapCheck agree to within 2% of published data for 6 MV photon beam (Elekta linear accelerator) measured with a diamond detector or calculated with Monte Carlo simulation [7].

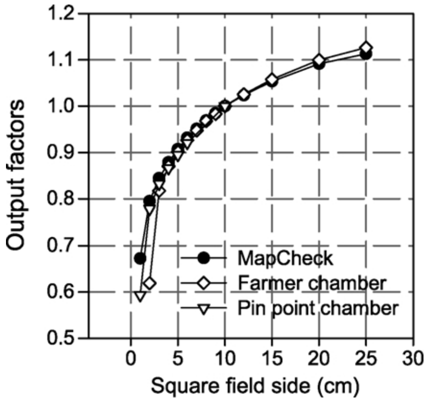

Fig. 4. Output factors of a 6 MV photon beam measured with the central diode of the MapCheck, a Farmer (PTW30006) and a pinpoint chamber (PTW31006). The results are normalized for the $10 \times 10\ \mathrm{cm}^2$ field size.

3.4. Temperature effect

The results for two individual MapCheck diodes demonstrate a linear increase of sensitivity with temperature. The two diodes exhibit a slight difference in temperature dependence, with temperature coefficients equal to 0.52 and 0.57%/°C, respectively. These results fall within the range of diode temperature coefficients published in the literature (−0.1 to 0.6%/°C) [10,16,20,24]. For room temperatures from 18 to 25 °C, the diodes show an average sensitivity increase of about 4%. Diode temperature dependence is not corrected for by the MapCheck hardware or software. The absolute calibration of the MapCheck should be repeated if the room temperature differs from the calibration condition by more than ±1 °C in order to achieve high-accuracy absolute dose measurements.

3.5. Clinical application

Profiles of 10×10 and $20 \times 20\ \mathrm{cm}^2$ field have been measured with an IC10 ion chamber, films and MapCheck. The IC10 ion chamber and MapCheck results for both field sizes agree to within ±1% in the low-dose gradient regions inside and outside of the field. The film profiles are noisier and agree with the chamber measurements to within ±3% in the low gradient area. The film data were not excessively smoothed in order to preserve the sharpness of the profile in the penumbra region. In the high-dose gradient region, the volume averaging effect degrades the ion chamber profiles. Discrepancies greater than 1.5 mm distance to agreement are observed between the ion chamber and the film measurements in the high-gradient regions. The limited resolution of the MapCheck means that often only one or two measurement points will be in the 20–80% penumbra region. The diode readings are accurate also in the high-dose gradient region and match well with the film profiles. The MapCheck results are less sensitive to volume averaging effect or low energy scattered photon. The diode array readings also appear to be insensitive to beam hardening produced by a 60° wedge (Fig. 5). The ion chamber and MapCheck profiles of the wedged field agree well over the open portion of the field. The discrepancy between both curves reaches 5% at the tip of the profile, mainly due to the poorer spatial resolution of the chamber.

The MapCheck performance for relative dosimetry of IMRT fields was evaluated based on a seven beam, 6 MV

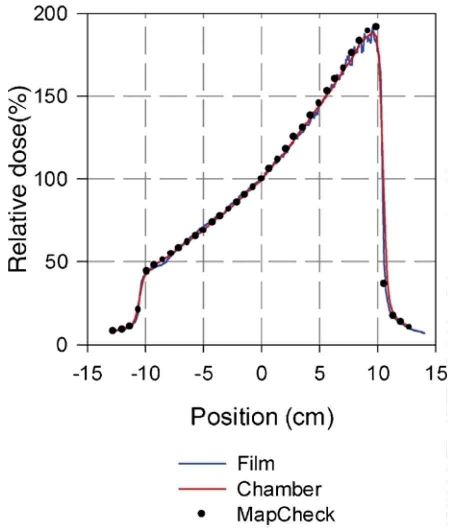

Fig. 5. Inplane profiles of a 20 × 20 cm^2 60° wedged field (6 MV) measured with the MapCheck, an IC10 ion chamber and films.

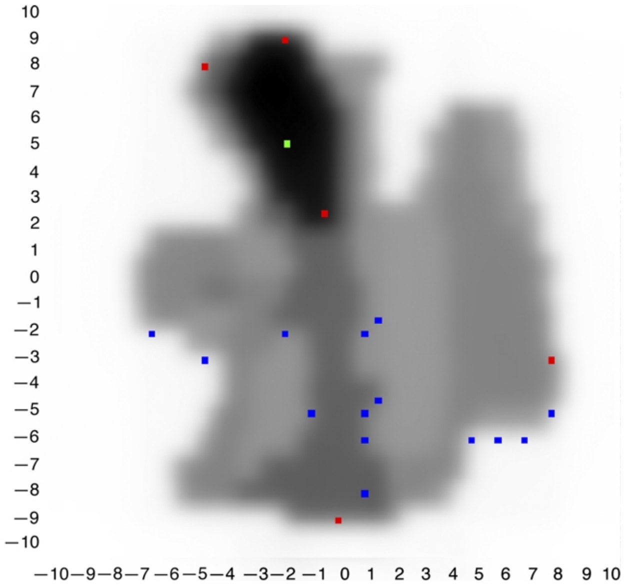

Fig. 7. Screen capture of a section of the MapCheck interface. The film or the calculated dose map is shown in gray scale in the background with the failing diodes in overlay. Diodes are displayed in red or blue to represent positive or negative discrepancy, respectively. The green diode represents the normalization point. The tolerances used in this example are 3% and 2 mm.

head and neck IMRT plan. The agreements between MapCheck with film, and MapCheck with Pinnacle dose maps are evaluated for dose differences of 3 and 5% and distances to agreement of 1 and 2 mm. For the seven IMRT beams, Fig. 6 shows the average percentage of diodes, which agrees within the specified tolerances. The error bars on the graph represent ± 1 SD on the percentage of diodes satisfying the tolerances. Fig. 7 shows a screen capture of a section of the MapCheck interface where the film or the calculated dose map is shown in gray scale in the background overlaid with the failed diodes (blue or red diodes for negative and positive differences, respectively). For a tolerance of 3% dose difference and 2 mm distance to agreement (denoted 3%/2 mm), 99.6% of the diodes agree with the film measurements. The percentage of diodes in agreement with the film decreases to 99.0 and 95.6% for tighter tolerances of 5%/1 mm and 3%/1 mm, respectively. These results demonstrate excellent agreement between MapCheck and film measurements. The percentage of diodes in agreement with the treatment plan calculated dose maps ranges from 96.4, 90 and 83.4% for the tolerance of 3%/2 mm, 5%/1 mm and 3%/1 mm, respectively. The failed diodes are located mainly in regions of high-dose gradient. This disagreement is due in part to the modeling of the penumbra in the planning system. The same type of discrepancies was observed between film measurements and Pinnacle calculations in the high-dose gradient regions. Our Pinnacle^3 calculations underestimate the gradient in the penumbra region because its beam model has been based on beam profiles acquired with a 6 mm diameter ion chamber. The improvement of the Pinnacle^3 model based on profiles measured with a high-resolution scanning diode to achieve better agreement in the beam penumbra is under investigation.

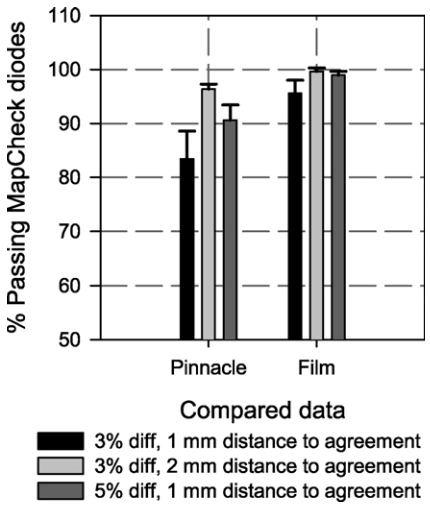

Fig. 6. Comparison between 2D MapCheck measurements, film and Pinnacle dose maps for a seven-beam head and neck IMRT plan. The histogram shows the number of diodes, which agree with the film and the calculated dose, respectively (within given dose difference and distance to agreement tolerances).

Absolute dose measurements are also achieved with the MapCheck and a pinpoint chamber (PTW31006) for the previous IMRT plan. The MapCheck results are systematically higher than the chamber readings and the discrepancy between both detectors ranges from 0 to 3.2%. The chamber is believed to underestimate slightly the dose due to a lack of sensitivity. In fact, for segments, which block the measurement point, the small chamber does not record any signal whereas the diode array detects the radiation transmission through the collimator. For certain beams where the normalization point is located on a narrow dose peak, the volume averaging effect can also explain in part the lower dose seen by the ion chamber.

The sensitivity of the diode array for MLC positioning errors was investigated using another seven-beam head and neck IMRT plan. Fig. 8 shows the results of the comparison of MapCheck and Pinnacle^3 dose maps as percentage of diodes within tolerance. On average, 92.3% of the MapCheck diode readings agree with the unmodified dose map for a tolerance set at 3%/2 mm. For the 1 mm contracted and expanded MLC deliveries, the percentage of diodes in agreement with the unmodified Pinnacle^3 dose maps decreases to 83.3 and 91.9%, respectively, at 3%/2 mm tolerance. The agreement decreases further to 75.4 and 80.5% for the 2 mm contracted and expanded MLC deliveries, respectively. The error bars on the graph in Fig. 8 represent ± 1 SD on the percentage of diodes satisfying the tolerances. In all cases, the failed diodes are mainly located in regions of high-dose gradient. As expected, for the contracted plans, the failed diodes showed lower dose than the unmodified calculated dose maps. The opposite was observed for the expanded plans. In multiple segment delivery, the effect of the systematic MLC position errors is emphasized by the presence of multiple field edges and can be detected by the MapCheck even if the spacing between the diodes is larger than the MLC position error. Fig. 8 shows that the difference in MapCheck agreement was noticeably smaller for a 1 mm MLC expansion than for a 1 mm MLC contraction. The results suggest that the MLC itself might have been initially calibrated to produce fields that were smaller than intended such that the expected discrepancies were not observed when the MLC segments were enlarged by 1 mm. The magnitude of the calibration error also appears to be less than 1 mm. Our results demonstrate that, with a properly designed set of QA measurements, the diode array can detect a systematic MLC position error of the order of 1 mm in all the MLC leaves.

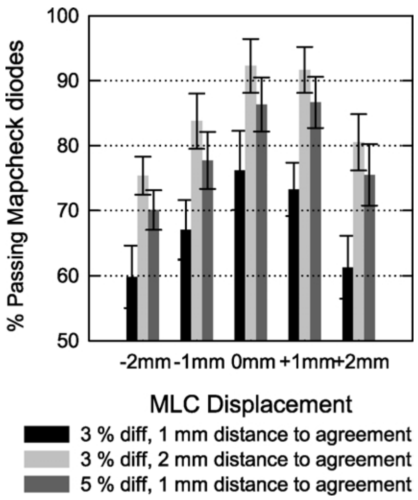

Fig. 8. Comparison between 2D MapCheck measurements and Pinnacle dose maps for a seven-beam head and neck IMRT plan. The histogram shows the number of diodes, which agree with the calculated dose (within given dose difference and distance to agreement tolerances) for induced MLC positioning errors of ± 1 and ± 2 mm.

4. Discussion and conclusions

Our results demonstrate that the MapCheck can be used to accurately and efficiently verify the dosimetry of IMRT treatment delivery. The setting of MapCheck comparison tolerance criteria is challenging and needs to take into account the uncertainties of the MapCheck measurements, the MLC calibration, radiation delivery and treatment plan dose calculation. Van Dyke et al. [21] and the AAPM task group 53 [5] suggest criteria of 3% of dose difference and 4 and 3 mm, respectively, for dosimetry of conformal therapy beam. At present, in our institution, the tolerances between measurements and calculations are set at 3%/2 mm. The percentage of diode failing these criteria can reach up to 15% and is due mainly to the modeling of the penumbra in our planning system. The disagreement between the measured and calculated dose maps increases generally with the number of segments per beam and with the use of small segments (<2 cm^2) delivering an appreciable fraction of the MUs. In our practice, we try to eliminate these small segments during the planning process by limiting the minimum segment size and by reviewing all segments before submitting the plan to the physician for review. After MapCheck measurement, the physician and the physicist inspect the position of the failed diodes with respect to the location of the target and organs at risk. The decision to go ahead with the plan, to modify it or to change the delivery method is then made. Methods to improve the agreement between planned and measured IMRT delivery are currently under investigation. A new image-based procedure has been implemented in our clinic to achieve MLC calibration to within ± 0.5 mm. The re-modeling of the penumbra in our planning system based on high-resolution measurements should also improve the match between the calculated and the measured dose maps.

In the light of our results, we conclude that the diode array presents the required characteristics for performing dosimetry of conventional and IMRT deliveries. The ability of the MapCheck to simultaneously perform both relative and absolute dose measurements can simplify and reduce the IMRT QA workload. Furthermore, its interface makes the comparison to planning data easy and efficient. The definition of the acceptable tolerances for dosimetry comparison is challenging, but provides a meaningful approach to quantify IMRT QA.

Acknowledgements

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