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Technical Note

Evaluation of SRS MapCHECK with StereoPHAN phantom as a new pre-treatment system verification for SBRT plans

Bartlomiej Mieszko SADOWSKI[1,ABCD,*], Marta FILLMANN[1,E], Dariusz SZAŁKOWSKI[1,E], Paweł KUKOŁOWICZ[1,EF]
[1]*Department of Medical Physics, The Maria Sklodowska-Curie National Research Institute of Oncology, Poland*
[*]*Corresponding author: Bartłomiej Sadowski; bartlomiej.sadowski@pib-nio.pl*

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Abstract

Introduction: The aim of this study was to evaluate the new 2-Dimensional diode array SRS MapCHECK (SunNuclear, Melbourne, USA) with dedicated phantom StereoPHAN (SunNuclear, Melbourne, USA) for the pre-treatment verification of the stereotactic body radiotherapy (SBRT).

Material and methods: For the system, the short and mid-long stability, dose linearity with MU, angular dependence, and field size dependence (ratio of relative output factor) were measured. The results of verification for 15 pre-treatment cancer patients (5 brains, 5 lungs, and 5 livers) performed with SRS MapCHECK and EBT3 Gafchromic films were compared. All the SBRT plans were optimized with the Eclipse (v. 15.6, Varian, Palo Alto, USA) treatment planning system (TPS) using the Acuros XB (Varian, Palo Alto, USA) dose calculation algorithm and were delivered to the Varian EDGE® (Varian, Palo Alto, USA) accelerator equipped with a high-definition multileaf collimator. The 6MV flattening-filter-free beam (FFF) was used.

Results: Short and mid-long stability of SRS MapCHECK was very good (0.1%-0.2%), dose linearity with MU and dependence of the response of the detector on field size results were also acceptable (for dose linearity $R^2 = 1$ and 6% difference between microDiamond and SRS MapCHECK response for the smallest field of 1×1 cm^2). The angular dependence was very good except for the angles close to 90° and 270°. For pre-treatment plan verification, the gamma method was used with the criteria of 3% dose difference and 3 mm distance to agreement (3%/3 mm), and 2%/2 mm, 1%/1 mm, 3%/1 mm, and 2%/1 mm. The highest passing rate for all criteria was observed on the SRS MapCHECK system.

Conclusions: It is concluded that SRS MapCHECK with StereoPHAN has sufficient potential for pre-treatment verification of the SBRT plans, so that verification of stereotactic plans can be significantly accelerated.

Keywords: dosimetry; quality assurance; stereotactic radiotherapy.

Introduction

The stereotactic radiosurgery technique is widely used in the treatment of small tumors, especially in brain localization. In this technique, small tumors are usually irradiated with a high fraction dose delivered with a high dose rate. Different types of technologies are used to deliver radiation during stereotactic radiosurgery in the brain and other parts of the body. Control of treatment plans is a basic principle of good radiotherapy.[1] Nowadays, flattening filter free beams are used more and more in radiosurgery.[2,3] For some patients, if multiple lesions are present, the radiosurgery technique is performed as a simultaneous single isocenter therapy. The very high dosimetric and geometric accuracy of irradiation is desired because dosimetric and geometric errors may lead to serious consequences for the patient. The pre-treatment verification plays a very important role in the safety and efficiency of radiosurgery.[4,5] The gold standard in the verification of SBRT plans is using EBT3 Gafchromic films. This detector has many advantages, but it requires a lot of skill from the user, and unfortunately, the measurement is very time-consuming.[6,7]

Sun Nuclear developed a new 2-D array for quality assurance of treatment plans for small fields, the SRS MapCHECK (SunNuclear, Melbourne, USA), with dedicated phantom StereoPHAN (SunNuclear, Melbourne, USA).[8] This device has been already tested, and the results are described by Ahmed et al.[9] However, due to the fact that the device is not yet widely used, taking into account our experience with other dosimetry devices, we have assessed the SRS MapCHECK. In addition to the standard tests performed for new detectors, we compared the

Authors' contribution: A – Research concept and design, B – Collection and/or assembly of data, C – Data analysis and interpretation, D – Writing the article, E – Critical revision of the article, F – Final approval of the article.

results of the SRS MapCHECK control with the results of the measurements with Gafchromic Films. The results of our investigations are presented in this paper.

Materials and methods

SRS MapCHECK

SRS MapCHECK is a 2-D array of 1013 SunPoint 2 (Sun Nuclear, USA) diode detectors. The active detector volume is 0.007 mm^3. The diode detectors are located 2.2 cm below the front surface of the array. The maximum active area is 7.7 × 7.7 cm^2. For treatment plan verification, SRS MapCHECK is inserted into StereoPHAN (**Figure 1**), which is a dedicated phantom built from polymethyl methacrylate (PMMA). The system worked under software SNC Patient v8.2 (Sun Nuclear, USA). The functionality of the software allows for correcting the signal for temperature, angle, field size, and dose rate response.[8] In the measurements made by us, all corrections were applied.

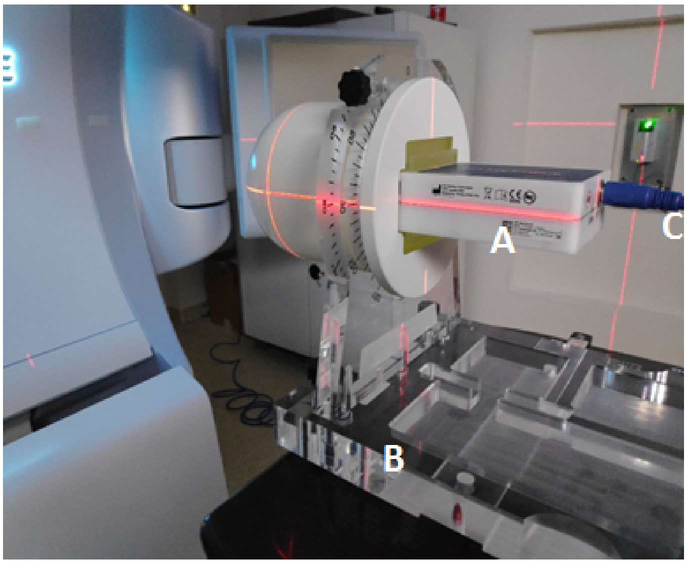

Figure 1. SRS MapCHECK (A) in StereoPHAN phantom (B) positioned at isocenter. (C) – Signal Cable.

EBT 3

Gafchromic EBT3 7.5 × 7.5 cm^2 film pieces were used (cut from 20 × 25.4 cm^2). Films were placed in a special holder for StereoPHAN, and inserted into the frontal plane. The orientation of the film was the same for all measurements. All Gafchromic films were processed and analysed at least 12 h after exposure. The films were scanned using the Epson Perfection V750 flatbed (Seiko Epson Corp., Nagano, Japan) colour scanner at a resolution of 72 dpi and 48-bit Colour. The films were scanned in the same landscape orientation. The threshold for films was 20% of the maximum dose. For the purpose of this work, we used the calibration curves scaling protocol proposed by Lewis.[10] A triple channel calibration curve for each film batch was determined separately for a range of doses between 0 and 3600 cGy. We present our results from the green channel. The films were analysed using FilmQA Pro 2016 (Ashland, USA).

Tests of SRS MapCHECK

First, SRS MapCHECK was calibrated for relative sensitivity and absolute dose. Next, several tests were performed: short and long-term stability, dose linearity, gantry angular dependence, field size dependence (ratio of relative output factor) and gamma comparison of 15 treatment plans with Gafchromic EBT3 films. All tests were performed on 6MV Flattening Filter Free (FFF) beam on EDGE accelerator (Varian, Palo Alto, USA).

A. Relative Sensitivity Calibration and Absolute Dose Calibration

Relative sensitivity calibration determines differences between SRS MapCHECK detectors. The calibration allows entering the individual correction factors for each detector. To obtain the relative sensitivity array, 10 exposures of the detector were made. The 4 exposures were made with MapCHECK installed on the table at the isocenter and exposed to a 10 × 10 cm^2 field (6 MV WFF, 200 MU) from the front (AP). Next, 4 exposures were made with MapCHECK installed on the table at the isocenter exposed to a 10 × 10 cm^2 field from the back (PA). Additionally, one AP and one PA exposure with an open 5 × 5 cm^2 field (6 MV FFF, 200 MU) were made with MapCHECK installed in the StereoPHAN. Uniformity of all fields was checked in SNC Patient. The maximum and minimum value from the uniformity field was compared for each profile. For Absolute Dose Calibration, computed tomography (CT) scans of the StereoPHAN with MapCHECK were obtained. The CT scans were exported to TPS, then original Hounsfield Units (HU) from CT were overridden with HU for PMMA for the whole tomography of the phantom. Then, in the treatment planning system (Eclipse), a dose distribution for the AP field for 5 × 5 cm^2 field, 100 MU, and 6 MV FFF beam was calculated. Calculation of dose distribution allows for converting the signal to dose for the central diode and all other detectors. For absolute dose calibration, SRS MapCHECK installed in StereoPHAN was irradiated with a 5 × 5 cm^2 beam with 100 MU. The 6 MV FFF beam was used.

B. Short and mid-long term stability

The short-term stability was checked during a 3-hour measurement session: a series of 10 measurements were taken one after another (100 MU, 5 × 5 cm^2, 6 FFF MV), and after three hours, another session of 10 measurements was carried out. From every two sessions, the average value of the signal detected by the central diode was used to calculate the dose. For these doses percentage difference was taken. For mid-long term stability, the scheme was the same as for the short-term, except that one session of 10 measurements was performed after one month. In mid-long term stability, the output of the accelerator was checked before measurement. The average values were compared.

C. Dose Linearity Dependence

Array was irradiated with 5 × 5 cm^2 field size with 50, 125, 300, 500, 700, 1200, 1500, 2000, 2500, 3000, 3500 MU. The 6MV FFF radiation was used. The signal detected by the central diode was analysed. A linear function was fitted to the data, and Pearson's correlation coefficient R^2 was calculated.

D. Gantry angular dependence

Array in StereoPHAN was irradiated with the field size of 5 × 5 cm^2 and with 100 MU for gantry angles of 0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°. The results were normalized to the central diode signal for a 0° gantry angle. Additionally, the dose distributions obtained for each angle were compared with the dose distribution obtained for the gantry angle of 0°. Dose distributions were compared with the Gamma method with 3% and 3 mm (Dose Difference (DD)/ Distance to Agreement (DTA)) with threshold of 5%.[11]

E. Field size dependence – ratio of relative output factor

The array was irradiated for different field sizes with 100 MU: 1 × 1 cm^2, 2 × 2 cm^2, 3 × 3 cm^2, 4 × 4 cm^2, 5 × 5 cm^2 (as a reference field). The value of the dose was taken from the central diode. Results were compared to the signal obtained for the reference field (5 × 5 cm^2). The results were compared (field by field) with measurements carried out with microDiamond detector (PTW-Freiburg, Germany). For microDiamond values, appropriate corrections were applied for fields ≤ 3 cm.[12]

F. Dose Rate dependence

SRS MapCHECK was irradiated two times with 100 MU for 5 × 5 cm^2 field size with different dose rates with 6 MV FFF: 400 MU/min, 600 MU/min, 800 MU/min, 1000 MU/min, 1200 MU/min, 1400 MU/min. The values of the signal of the central diode were analysed, and values are normalized to average from the 1400 MU/min value.

G. Gamma Evaluation

A pre-treatment verification of 15 SRS-SBRT plans for patients treated in our clinic (5 brains, 5 lungs, and 5 livers) were checked with the SRS MapCHECK. The treatment plans were calculated for different doses per fraction (2 Gy to 18 Gy). Equivalent sphere diameters of PTV were in the range of 1.5 cm to 5.5 cm. All these plans were prepared using Eclipse v15.6 (Varian, Palo Alto, USA) and Acuros v15.6. Verification measurements were carried-out with EBT3 Gafchromic Films and SRS MapCHECK. In this study, results of gamma global index of SRS-SBRT QA plans with MapCHECK and Gafchromic EBT3 were compared with criteria: 3%/3 mm (Dose Difference (DD)/ Distance to Agreement (DTA)), 2%/2 mm, 1%/1 mm, 3%/1 mm and 2%/1 mm.

Results

A. Relative Sensitivity Calibration and Absolute Dose Calibration

Relative sensitivity calibration was done according to the instruction described in the User Guide. Analysis of uniformity of array after relative calibration was within 0.4%. Eclipse calculated, that for 100 MU, 5 × 5 cm^2, 6FFF MV the dose at the central diode position was 78.9 cGy. This value was always used to convert the signal from the central diode to the dose during absolute dose calibration. After the calibration procedure, to check the value on the central diode, the array was irradiated with the same field. The value from the central detector was 0.3% different from the value from calibration (78.9 cGy).

B. Short and mid-long term stability

Results of short and mid-long-term stability were good. The percentage difference between averages of two consecutive measurements out of 10 measurements performed during 3h period from the central diode was -0.3%. The difference between average values from 1 month period from the central diode was 0.3%.

C. Dose Linearity

Figure 2 shows the linear dose dependence on MU. R-value is 1. Error bars are small for the resolution of the graph. Values on the Y axis are taken from the center diode. On the X axis are prescribed Monitor Units.

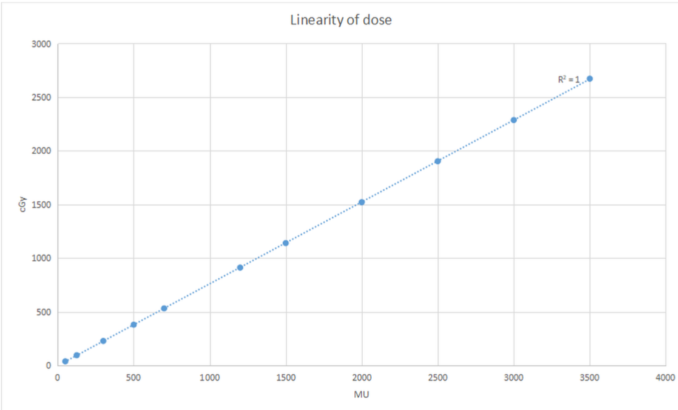

Figure 2. Linearity of dose in SRS MapCHECK..

Table 1. Result from Gantry angle dependence. Percentage difference between signal measured for a given angle and for angle 0°.

Angle	**0°**	**45°**	**90°**	**135°**	**180°**	**225°**	**270°**	**315°**	**0°**
(angle-0°)/0° [%]	–	0.3	0.7	-0.3	-0.2	0.0	-0.2	0.4	–

Table 2. Result from angular dependence – gamma global results.

Angle	**0°**	**45°**	**90°**	**135°**	**180°**	**225°**	**270°**	**315°**
Gamma 3%/3 mm, 95%<	100%	100%	79.5%	100%	100%	100%	87.6%	100%

D. Angular dependence

For angular dependence, results are shown in **Table 1**. Gamma evaluation results are shown in **Table 2**.

E. Dependence of the response of the detector on field size -Ratio of relative output factor

The results for two different detectors are shown in **Figure 3**. All measurements for field sizes were normalized to 5 × 5 cm^2 field size (reference field size). For small fields (< 3 cm), correction from TRS 483 was applied for microDiamond.

F. Dose Rate dependence

Figure 4 shows dose rate dependence. On the X axis are dose rates. On the Y axis is the ratio between values from different dose rates to standard 1400 MU/min (for 1400 MU/min value = 1). Error bars are from standard deviation.

G. Gamma Evaluation

There were created verification plans for each of the 15 treatment plans for SRS MapCHECK and Gafchromic films separately. Results for EBT 3 Gafchromic Films are shown in **Figure 5**. **Figure 6** shows results for SRS MapCHECK. On the X-axis ordinal number of the plan, the Y-axis Gamma value is in %.

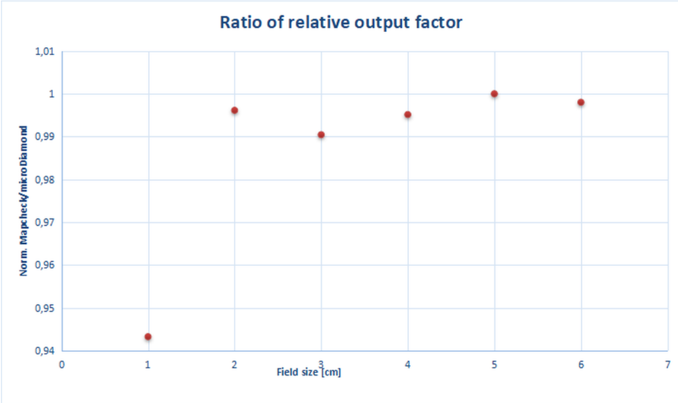

Figure 3. Field size dependence (ratio of relative output factor) for SRS MapCHECK compared to PTW microDiamond. The uncertainty of the measurement is so small that it can not be presented in the graph (uncertainty of the order of 0.001).

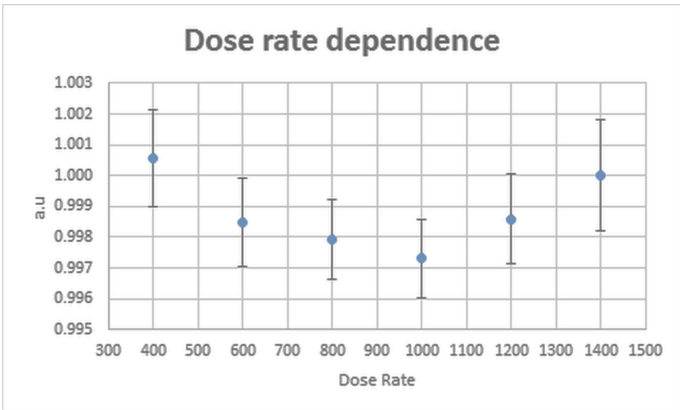

Figure 4. Dose Rate dependence for 6 MV FFF. Error bars are from absolute uncertainty.

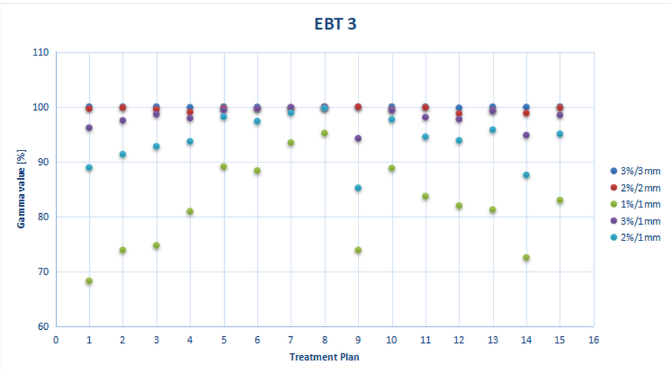

Figure 5. Gamma results for EBT 3 for 15 treatments plan. On the X-axis ordinal number of the plan, on Y-axis Gamma value in %.

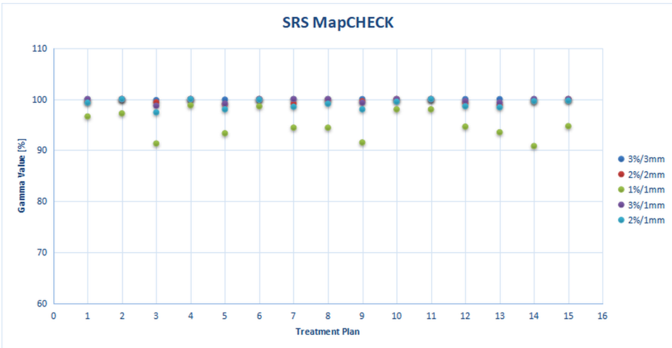

Figure 6. Gamma results for SRS MapCHECK for 15 treatments plan. On the X-axis ordinal number of the plan, on the Y-axis Gamma value in %.

Discussion

Verification of SBRT plans requires low uncertainty and high spatial resolution devices. These measurement devices should be easy to use and should deliver the result immediately after the measurement. Such a device is the SRS MapCHECK matrix, which has been in use in our clinic for a year.

The matrix was tested before being put into clinical use. The following parameters have been checked: short and mid-term stability, dose linearity, gantry angular dependence, field size dependence (ratio of relative output factor). Additionally, the results of 15 clinical plans were compared with the results obtained from measurements made on EBT 3 Gafchromic films. In this case, the Gafchromic film detector was used as a gold standard. The test results showed the high usefulness of the SRS MapCHECK. The matrix can be used to verify plans prepared for single, small targets. The small active area and the inability to rotate the matrix with the table make it impossible to use the matrix for measurements of multi-target plans.[8]

Immediately after calibration, the matrix was irradiated with the same plan that was used for calibration, and it was noticed that the signal recorded by the central diode was 0.3% higher than the calibration value. The short and medium-term stability is 0.3% (difference between average values), which is an acceptable value for this type of equipment. This is very important because the matrix can be used for 3-4 hours. The detector-dose response shows a very good match between the linear function and the results where the determination factor is close to 1. SBRT plans, where high fractional doses are often given, are also implemented with a large number of monitor units. Therefore good linearity of the detector response plays a very important role. The comparison of the SRS MapCHECK detector response with the response of the microDiamond chamber has shown a far-reaching agreement in terms of field size-Ratio of relative output factor. Only for 1 × 1 cm^2 fields, the SRS MapCHECK signal normalized to a 5 cm square field is approximately 7% smaller than that of a microDiamond. This may be due to the fact that the result for the microDiamond detector for fields ≤ 3 cm has been recalculated using a correction according to TRS 483 Report.[12] For the matrix, correction factors are recalculated automatically, and the user does not have access to the correction values (manufacture corrections applied). For the angular response of the SRS MapCHECK, as it is for 2D matrix, there was not a very good agreement with TPS for angles 270° and 90°, where the beam is parallel to the detector surface. The sensitivity of the 2D detector at these angles is worse, but already 10° degrees from these angles for 2D matrices leads to improved results.[13] This is because the radiation to the detectors located distally (in relation to the radiation source) is shielded by the detectors located proximally. This situation must be taken into account when verifying IMRT plans. The solution is to forbid IMRT fields with such angles or to rotate the matrix by 90°/270° when verifying fields with such angles. For VMAT plans, this situation is negligible because, during plan execution, the contribution to the total dose recorded by the detector for this range of angles is small in relation to the total radiation from the full rotation of the gantry. The phenomenon of dependence of the response of semiconductor detectors on the angle of the beam is known. Similar relationships were described for the 2D MatriXX matrix.[14] SRS MapCHECK shows negligible dependence on dose rate changes.

Analysis of patient plans verified with the matrix and EBT3 films shows similar values. This is particularly evident in the criteria commonly accepted for 3%/3 mm, 2%/2 mm plan analysis. The mean values for individual gamma criteria are shown in **Table 3**.

For the strict criteria such as 1%/1 mm the results obtained are better for SRS MapCHECK than for EBT3 films. This may be due to the fact that EBT3 are more sensitive to errors resulting from the scanning protocol, calibration curve, defect in the film texture itself, or due to positioning uncertainties. One may conclude that 1 mm/1% is too strict and should not be used for this method.

Table 3. Results of Gamma verification for SRS MapCHECK and EBT3.

	SRS MapCHECK				
	3%/3mm	**2%/2mm**	**1%/1mm**	**3%/1mm**	**2%/1mm**
avg	99.98%	99.62%	94.75%	99.73%	99.01%
std	0.06%	0.4%	2.41%	0.43%	0.81%
max	100.00%	99.90%	77.90%	100%	99.70%
min	97.00%	84.90%	26.00%	94.70%	77.06%
	EBT 3				
avg	99.96%	99.55%	82.22%	98.34%	94.53%
std	0.06%	0.4%	7.83%	1.43%	3.57%
max	100.00%	100.00%	98.60%	100.00%	100.00%
min	99.90%	86.60%	62.10%	98.40%	85.50%

Conclusions

The results of this study confirm that SRS MapCHECK is a good tool for the verification of SRS/SBRT dynamic treatment plans. The results of plan verifications carried out with the SRS MapCHECK and EBT3 Gafchromic films were very similar. Easy configuration, setup, and immediate result of SRS MapCHECK is a great advantage for clinical work where the short time of measurements is very crucial.

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