РАДІАЦІЙНА ФІЗИКА
RADIATION PHYSICS

УДК 539.1+616-006 https://doi.org/10.15407/jnpae2024.04.366

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EVALUATION OF myQA SRS DETECTOR FOR THE STEREOTACTIC TREATMENT PLAN VERIFICATION

Modern radiotherapy techniques involve the use of high-modulated radiation fields. Intensity Modulated Radiation Therapy and Volumetric Modulated Arc Therapy require careful quality control to ensure that the planned dose distributions can be delivered by the treatment system. Quality assurance of the patient-specific treatment plan is often performed prior to treatment, when beams are delivered to the phantom and radiation doses are checked compared to the doses provided in the treatment planning system. In this study, myQA SRS measurements were compared to the EBT3 film measurements. The resolution of the film is 25 μm. The sufficiently high resolution of the stereotactic radiosurgery (SRS) detector (0.4 mm) makes it a potential alternative to film for real-time dosimetry. Irradiation was performed on a Varian TrueBeam linear accelerator. The gamma index criteria were 3 %/3 mm, the threshold dose was 10 %, and gamma index normalization was performed using the global maximum dose. The gamma index results obtained on film and on myQA SRS gave comparable results. The passing rate of film measurements based on gamma evaluation was 89.92 % and the passing rate of myQA SRS was 82.6 %. The average gamma values for the 3 %/3 mm global gamma analysis were 0.48 for the film and 0.594 for myQA SRS. In this study, film was chosen as the reference clinical detector with the highest resolution available today. myQA SRS, designed for verification of stereotactic plans, qualitatively and quantitatively identified areas of dose mismatch.

Keywords: radiation therapy, quality assurance, detectors, radiochromic film, linear accelerator, treatment planning system, dose distribution.

1. Introduction

Radiation therapy is a long-established way of treating cancer by exposing tumors to high-energy photons. The treatment method using small fields and dose delivery with a high spatial gradient is called stereotactic body radiotherapy (SBRT). In the case of tumors localized in the brain, this type of treatment is called stereotactic radiosurgery (SRS). In the case of SRS and SBRT, the target and the surrounding tissue with a 2 - 5 mm margin are included for irradiation. Both methods can replace surgery to remove the tumor in selected cancer cases, as they totally ablate the tumor's cancer cells.

Once a stereotactic treatment plan has been created and before the physician gives final approval to the plan, it is imperative to verify the accuracy and appropriateness of real-time dose delivery. The accuracy of small-field dosimetry is highly dependent on the detectors used. Deficiency of charged particle equilibrium, detector size, detector resolution, and non-equivalence of detector material to soft tissue density are some of the effects that should be considered. An ideal detector for small field dosimetry should provide high spatial resolution, high signal-to-noise ratio, spatial uniformity, and high stability, as well as being water equivalent and easy to use clinically. Currently, there is no detector with all the required properties, so it is recommended to use several detectors to obtain clinical dosimetric data.

Modern radiotherapy techniques involve the use of high-modulated radiation fields. Intensity Modulated Radiation Therapy (IMRT) and Volumetric Modulated Arc Therapy (VMAT) require careful quality control to ensure that the planned dose distributions can be delivered by the treatment system. VMAT technique involves simultaneous rotation of the gantry, repositioning of the shielding jaws, and repositioning of the shielding tungsten leaves dynamically in order to provide uniform coverage of the planning target volume (PTV) and dose reduction to the surrounding organs at risk.

Quality control of the patient-specific treatment plan is preferably performed before radiotherapy, when treatment beams are delivered to the phantom and radiation doses are checked against the predicted doses provided in the treatment planning system (TPS) [1]. The dose distribution obtained from the measurements is compared with the reference dose distribution obtained from the TPS calculations. SRS/SBRT treatment plans require high-resolution detectors to measure and confirm the dose before treatment.

Methodology. The accuracy of dose delivery in radiosurgery has particular importance because of high doses and small radiation fields. In the case of conventional radiotherapy treatment with a field size of 10 cm × 10 cm, an error in the position of the shielding leaf Δx = 1 mm results in a geometric dose delivery error of 1 %. In the case of radiosurgery treatment, with a field size of 1 cm × 1 cm, an error in the position of a shielding leaf of Δx = 1 mm results in a geometric dose delivery error of 10 %.

The dose fluctuation ΔD = 5 % in the case of a fractionated radiotherapy treatment with a dose per fraction 2 Gy is 0.1 Gy. In the radiosurgery case, a 5 % error from a dose per fraction of 21 Gy would be 1.05 Gy. A comparative table of stereotactic radiosurgery and fractionated radiotherapy (Table 1) is presented below, showing how a slight variation in the physical parameters of the linear accelerator can affect the dose distribution within the patient.

Table 1. **Comparison of external radiation therapy types and their errors in dose delivery**

Varying parameter	Fractionated radiation therapy	Stereotactic radiosurgery
Dose per fraction	2 Gy	21 Gy
Number of fractions	30	1
Total dose	60 Gy	21 Gy
Radiation field size	100 mm × 100 mm	10 mm ×10 mm
Spatial position error of the tungsten leaf of 1 mm results in	Geometric dose delivery error of 1 %	Geometric dose delivery error of 10 %
The resulting dose deviation of 5 %	0.1 Gy	1.05 Gy

Dose fluctuation can be caused by inaccuracy of the position of the collimator leaves, the gantry angle, and the position of the jaws. In this study, two different detectors were used for dosimetric verification of the stereotactic treatment plan: EBT3 radiochromic film and myQA SRS.

The radiochromic film is the most accurate way to verify treatment plans nowadays. The resolution of the film is 25 μm. The resolution of the SRS detector is 0.4 mm, which is inferior to the film. However, myQA SRS detector has some advantages over the film in clinical application. While radiochromic films are disposable, myQA SRS can be reused an unlimited number of times. Due to the sufficiently high resolution of myQA SRS, its measurements can be compared with those of EBT3 film.

2. Experimental measurements

2.1. Measurements with radiochromic film

A calibration curve was created from 0 to 1000 cGy using 11 data points. The irradiated film was scanned 48 h post-exposure with an Epson Scanner using the triple channel method, 300 dpi resolution (corresponding to 0.35 mm pixel spacing), and no color corrections. Irradiation was performed on a Varian TrueBeam linear accelerator, and the Eclipse 16.1 TPS with the AcurosXB algorithm was used for dose calculation.

The Acuros XB (AXB) solves the linear Boltzmann transport equation by a deterministic method using discretized cross sections as radiation interacts with the voxel volumes in matter. AXB makes use of the chemical composition of each material in the volume during radiation transport. With the single beam setup in phantoms, this algorithm has already been demonstrated to achieve comparable accuracy with Monte Carlo simulations [2].

PTVs sizes were 0.55, 0.11, and 0.64 cm^3 located in the brain. A stereotactic small-field radiotherapy plan was created using VMAT fields with a coplanar beam configuration so there was no rotation of the treatment table. 6 MV-FFF (flattening filter-free) energy was used. The x-ray beam produced by the target is strongly forward peaked. The flattening filter is designed to obtain a uniform intensity beam, and a conically shaped filter is used to attenuate the beam in the center. This is usually composed of tungsten or steel or a lead/steel combination.

The patient's original treatment plan was copied onto a computed tomography (CT) image of a solid water phantom. The depth of the film was 4 cm with a backscatter of 6 cm, and the isocenter of the plan was placed in the middle of the film. After recalculation, a two-dimensional dose distribution in the plane of the film location was exported. The planned dose distribution was compared with the results of the dose distribution on the film using eFilmQA film analysis software.

2.2. Measurements with myQA SRS

The dosimetry instrument in this study is a high-resolution digital detector array system (myQA SRS, IBA dosimetry). myQA SRS base is a flat array of solid-state detectors with dimensions of 0.4 mm × 0.4 mm × 0.75 mm, which occupy an active area of 12 × 14 cm^2 [3]. The solid-state detectors provide a signal by collecting the charge released when a particle passes through a semiconductor. Appropriately implanted electrodes create an electric field in which ionization charges accumulate and produce a detectable signal. The detecting medium for

this type of detector is silicon (Si). Absorption of ionizing radiation generates pairs of charge carriers (electrons and electron-deficient species called holes) in a block of semiconductor material; the migration of these carriers under the action of a voltage represents an electrical pulse. The generated pulses are amplified, recorded, and analyzed to determine the energy and number of charged particles.

The system of myQA SRS consists of a two-dimensional detector array, a cylindrical phantom which is made of Acrylonitrile butadiene styrene plastic (material density 1.04 g cm^{-3}) with a holder for the detector array, and dose analysis software (myQA Patients, version 2.15). A two-dimensional detector array was inserted into the phantom for dose verification with an equivalent depth of 10 cm in water for the central detector. The detector consists of an array of semiconductor detectors with 105000 effective measurement points (300 × 350 pixels with a detector spacing of 0.4 mm), and the effective detection plane was 12 × 14 cm (Fig. 1).

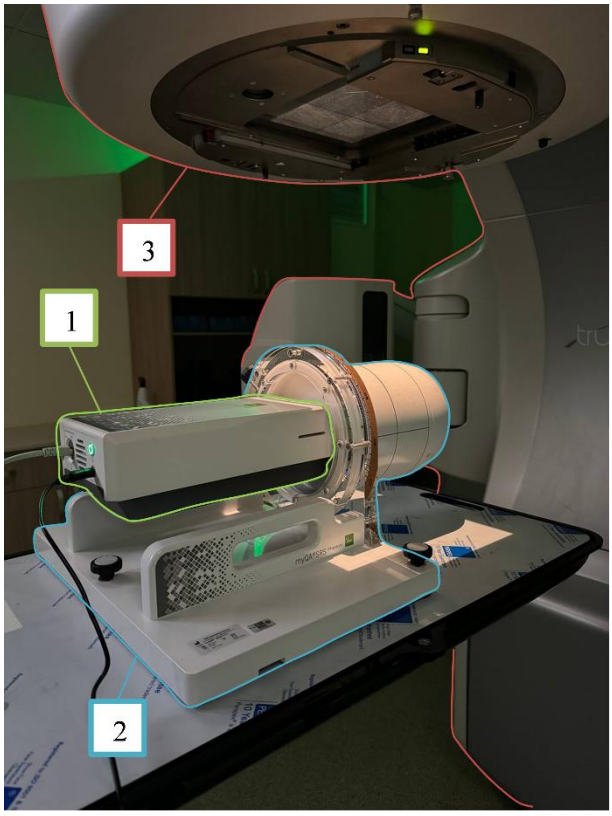


Fig. 1. Dosimetric measurements with myQA SRS on the TrueBeam STx linear accelerator. *1* – myQA SRS assembly, *2* – cylindrical phantom, *3* – Varian TrueBeam STx linac. (See color Figure on the journal website.)

myQA SRS was scanned on a CT scanner to account for all possible densities of the materials of which the phantom and detector are constructed. The CT image of the myQA SRS with the isocentre in the centre of the detector array was used to create a stereotactic treatment plan for the patient in the TPS with the same linear accelerator parameters as for the radiochromic film. The measured dose was compared with the calculated dose distribution from the TPS in the myQA Patients software.

2.3. Gamma index

The gamma index is widely used to evaluate the coincidence between the calculated and measured dose distributions by utilizing the percent dose difference (DD) and distance to agreement [4]. Regarding the calculation of the DD, there are two types of gamma index methods, which are the global and local gamma index analyses. The global gamma index analysis calculates the DDs relative to the maximum dose (or prescription dose), while the local gamma index analysis calculates the DDs relative to the doses at each evaluated point. Because the DD is a percent value, the local gamma index analysis could exaggerate the DDs in the low-dose regions, while the global gamma index method could underestimate the dose discrepancies in the low-dose regions. The gamma index γ can be defined as follows:

$$\gamma = \min_{\{r\}} \left\{ \Gamma\left(r, r_{reference}\right) \right\}, \tag{1}$$

$$\Gamma\left(r, r_{reference}\right) = \sqrt{\left(\frac{r - r_{reference}}{\Delta_{distance}}\right)^2 + \left(\frac{d - d_{reference}}{\Delta_{dose}}\right)^2}, \tag{2}$$

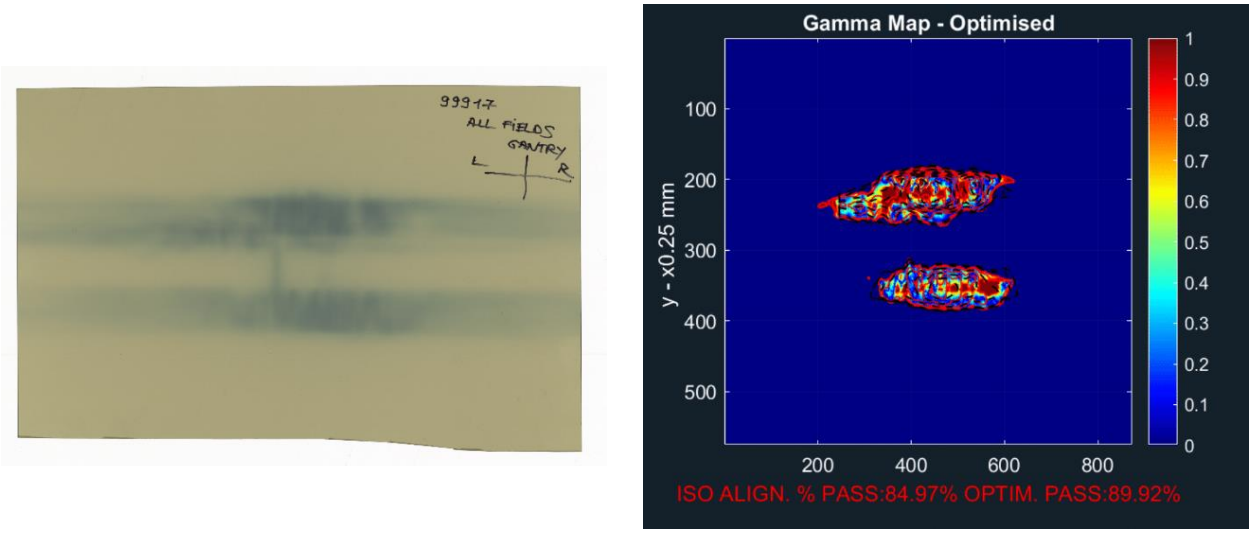
where d is the dose distribution read by the detector, $d_{reference}$ is the dose distribution computed by the TPS, Δ_{dose} and $\Delta_{distance}$ are gamma criteria measured in % and mm, respectively. The point of the measured dose distribution r is analyzed and considered to pass gamma analysis, i.e. it is the point at which the calculated dose corresponds to the real dose provided $\gamma \le 1$.

In this study, dose distributions were analyzed using the following gamma criteria: Δ_{dose} = 3 %, $\Delta_{distance}$ = 3 mm. Automatic matching with rotation correction included was used and manual correction was applied where necessary. Dose distributions from the TPS were considered as reference, and film and matrix measurements were compared to the reference.

3. Results and discussion

The dose threshold was 10 % of the maximum dose, and gamma index normalization was performed using the global maximum dose. The dose threshold should be set to exclude low-dose areas that have no or little clinical relevance but can significantly bias the analysis. This allows the gamma analysis to

ignore the large area or volume of dose points that lie in very low-dose regions which, if included, would tend to increase the passing rate when global normalization is used [5]. The result of the stereotactic plan evaluation with a total dose of 27 Gy and dose per fraction of 9 Gy using eFilmQA film analysis software is shown in Fig. 2. Three PTVs are irradiated simultaneously with the isocenter located at the geometric center between the three foci. All calculated $\gamma > 1$ are equated to 1 and are considered to be those that have not passed the analysis. All gamma above 1 are marked in red on the gamma map. In this way, it is possible to see areas of dose mismatch.



a *b*

Fig. 2. Evaluation of the treatment plan with a total dose of 27 Gy and dose per fraction of 9 Gy using eFilmQA. *a* – exposed EBT3 film on Varian TrueBeam STx linear accelerator; *b* – the result of the gamma passing rate of the film by comparing the dose distribution from TPS and the distribution on the film. (See color Figure on the journal website.)

For the same treatment plan, Fig. 3 shows the results of dose coincidence using myQA SRS with the same gamma criteria of 3 %/3 mm. The dose distribution on the top left is the detector reading, dose distribution on the bottom left is the calculation of the TPS. The histogram shows the gamma values on the x-axis and the number of pixels that have the corresponding gamma value on the y-axis. Pixels with a gamma value greater than 0.99 are considered to have failed gamma analysis. The areas of disagreement between the calculated dose and the measured dose are shown at the bottom right of the Figure. AAPM TG-218 report advises use for the gamma analysis of the global normalization with reference dose selection as a better approach, compared to the maximum dose.

The numerical description of the gamma passing rate result on myQA SRS is presented in Table 2. Delta Dose Abs – absolute DD between two datasets. Thresholds T1 and T2 are gamma values manually selected. The algorithm calculated that 27.5 % of the pixels of the two datasets have a gamma value less than 0.257, 48.5 % of the pixels of the two datasets have a gamma value between 0.257, 0.888, and 24 % of the pixels of the two datasets have gamma value greater than 0.888.

The final gamma passing rate values on two different detectors are shown in Table 3.

Table 2. **Result of gamma analysis on myQA SRS processed in myQA Patients**

Analysis Method	Gamma Index
Delta Dose Ratio	3 %
Delta Dose Abs	0.06204 Gy
Dose Error Mode	Global
Delta Distance	0.3 cm
Threshold	10 %
Average Gamma Value	0.594
Max Gamma Value	4.97
Passing Values	82.6 %
Failing Values	17.4 %
Threshold T1	0.257
Threshold T2	0.888
Values < T1	27.5 %
T1 < Values < T2	48.5 %
Values > T2	24 %

Table 3. **Gamma passing rate on film analyzed in eFilmQA and on myQA SRS analyzed in myQA Patients**

Varying parameter	eFilmQA	myQA Patients
Passing Value	89.92 %	82.6 %
Average Gamma Value	0.48	0.594

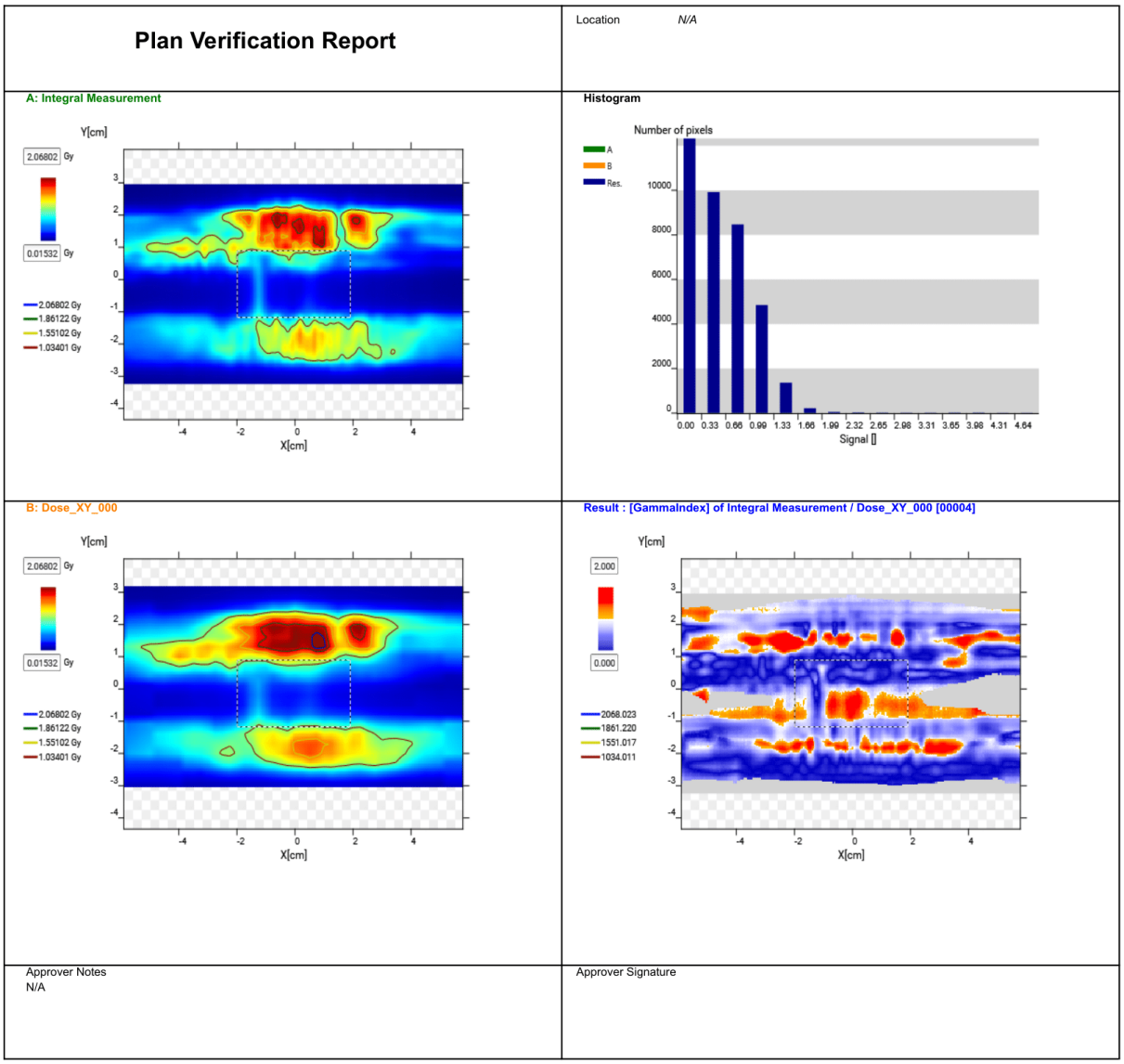


Fig. 3. Evaluation of the treatment plan with a total dose of 27 Gy and dose per fraction of 9 Gy using myQA Patients software. (See color Figure on the journal website.)

4. Conclusion

The advantage of a radiochromic film, compared to a semiconductor-based detector matrix myQA SRS, is better spatial resolution, which allows handling high dose gradients in the case of modern stereotactic plans. The disadvantage of films, compared to other detectors, is that the use of film is time-consuming. The film has to be prepared before measurement and handled very carefully. The results cannot be processed immediately after measurement, exposed films must be scanned and calibrated according to strictly defined methods.

S. James et al. [6] compared four commercially available stereotactic plan quality assurance devices and found that multi-leaf collimators positioning errors were reliably detected by high-resolution detectors, including myQA SRS, but not always detected by lower-resolution detectors.

The gamma passing rate difference between two treatment plans on two different detectors is insignificant and clinically acceptable. In clinical practice, both of these detectors can be used for verification of stereotactic treatment plans, but in terms of the functionality, simplicity, and reusability of myQA SRS, this detector is more suitable for routine application through a number of the following points:

1. saving time in analyzing the quality of the treatment plan after the measurement;
2. less probability of human error because there are no things like scanning the film on the scanner after it has been exposed;
3. it is more cost-effective to use the myQA SRS in the long run, as you buy the detector once while the number of radiochromic films needs to be renewed regularly;
4. independence from external economic factors such as availability of films at the distributor, cost of films on the market.

The research was partially supported by The National Research Foundation of Ukraine under the project “Improving Quality and Safety in Radiation Therapy for Cancer and Radiological Diagnostics” with registration number 2021.01/0211 (Science for Safety and Sustainable Development of Ukraine).

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ОЦІНКА ДЕТЕКТОРА myQA SRS ДЛЯ ВЕРИФІКАЦІЇ СТЕРЕОТАКСИЧНОГО ПЛАНУ ЛІКУВАННЯ

Сучасні методи променевої терапії передбачають використання геометрично ускладнених полів випромінювання. Променева терапія з модульованою інтенсивністю (IMRT), об’ємно-модульована дугова терапія (VMAT) вимагають ретельного контролю якості лікувального плану, щоб гарантувати, що заплановані розподіли дози можуть бути доставлені лікувальною системою. Контроль якості плану лікування проводиться до початку лікування, коли пучки доставляються на детектор і дози опромінення порівнюються з дозами, передбаченими в розрахунках системи планування лікування (TPS). У цьому дослідженні для дозиметричної перевірки стереотаксичного плану лікування використовували два різні детектори: радіохромну плівку EBT3 і myQA SRS. Роздільна здатність плівки становить 25 мкм. Досить висока роздільна здатність цифрового детектора myQA SRS (0,4 мм) робить його потенційною альтернативою плівці для дозиметрії в реальному часі. Опромінення проводилося на лінійному прискорювачі Varian TrueBeam. Критерії гамма-індексу становили 3 %/3 мм, порогова доза – 10 %, нормалізація гамма-індексу проводилася за глобальним максимумом дози. Результати гамма-індексу, отримані на плівці і на myQA SRS, були співставними. У цьому дослідженні як еталонний детектор було обрано плівку, тому що роздільна здатність цього детектора є найвищою на сьогоднішній день. Система myQA SRS, призначена для верифікації радіохірургічних планів, якісно і кількісно виявила області невідповідності доз.

Ключові слова: променева терапія, контроль якості, детектори, радіохромна плівка, лінійний прискорювач, система планування лікування, розподіл дози.

Надійшла / Received 24.09.2024