Abstract

Multichannel *in vivo* dosimetry by means of Gachromic EBT3 films for patients treated with radiotherapy in the head and neck area using the VMAT technique

Introduction: The main goal of radiotherapy is to deliver the prescribed dose of ionizing radiation to the cancer tissues in an efficient, accurate and safe manner while trying to save healthy tissues and organs as much as possible. Therefore, one of the important elements in the preparation and realization of treatment is the high-quality assurance of radiotherapy. Nowadays, thanks to the continuous development of irradiation devices and computerized treatment planning systems, radiotherapy techniques become more and more advanced. Irradiation using rotational techniques with beam intensity modulation, such as VMAT (volumetric modulated arc therapy), is possible. The use of increasingly complex radiotherapy techniques makes it more and more difficult to verify the accuracy of the treatment. *In vivo* dosimetry is one of the methods that allows avoiding errors that can arise at the stage of treatment preparation. It is based on a dose measurement during the irradiation of the patient. Comparison of the measured dose with the reference value, taking into account defined tolerance levels, allows assessing whether the irradiation treatment is carried out correctly. Applied at the beginning of the irradiation, it helps to prevent systematic errors, which – if committed, could reduce the chances of recovery and increase the risk of tissue/organs damage. The most commonly used detectors for *in vivo* measurements in three-dimensional conformal radiation therapy (3D-CRT) are semiconductor detectors, which are placed on the patient's skin. These type of measurements allow detecting errors such as incorrect calibration of the therapeutic beam, application of incorrect beam energy, instability of accelerator dose output or incorrect patient positioning. Semiconductor diodes have limited use in treatment techniques such as VMAT. This is due to the fact that they have a dose rate and energy dependency of the signal. For the reason that in case of the VMAT technique it is impossible to determine the central axis of the beam and the size of the radiation field (the VMAT technique is implemented using arcs, not single fields), the correction of the measured signal on the dose rate changes is very difficult. Gafchromic EBT3 film detectors do not have such disadvantages. Therefore, the aim of this work is to investigate whether small detectors made of Gafchromic EBT3 radiochromic film are suitable for *in vivo* dosimetry during irradiation using the VMAT technique.

Aim: The aim of this work is to investigate the suitability of small detectors made of Gafchromic EBT radiochromic film for *in vivo* dosimetry during irradiation of patients using the VMAT technique for cases of tumours located in the head and neck area.

Materials and methods: Film detectors with the size of 1,0 cm x 1,5 cm were prepared for measurements, made of sheets of Gafchromic EBT3 radiochromic films by Ashland. They

are very thin (~278 μm), self-developing films that do not require a chemical development process as in case of classic X-ray films. Film darkening is a monotonically increasing the dose function. The degree of darkening expressed as optical density can be measured directly with a densitometer or can be determined from a film image after scanning the film with a suitable scanner. The film samples were calibrated for measurements in the fractional dose range for typical teleradiotherapy (0 cGy to 250 cGy) and the total dose range (0 cGy to approximately 6600 cGy). For this purpose, the film samples were placed in the RW3 solid slab phantom by PTW-Freiburg and irradiated under strictly defined conditions, using a 6 MV beam generated in the Versa HD linear accelerator by Elekta. The dose delivered to film samples was monitored with 0.6 ccm Farmer type ionization chamber by PTW-Freiburg. To calculate the optical density of the films, the irradiated samples were scanned with the EPSON EXPRESSION 10000XL flatbed scanner, recommended by the Gafchromic EBT3 film producer. Film images analysis and calculations were performed using ImageJ software [Rasband, 2018], using a user-written script. The three-channel film dosimetry method was applied to dose calculations based on the scanned films' images. For the presented methodology, the standard uncertainty of the dose measurement was calculated.

Before using the film samples for measurements on patients, the method was verified on the RW3 slab phantom and the anthropomorphic phantom (*the Alderson Rando phantom, Radiology Support Devices*). The phantoms were prepared in the same way as a typical patient. First, a CT scan was done and then there was introduced a treatment plan using the Pinnacle, Philips treatment planning system (*CC Convolution* calculation algorithm). To reduce the uncertainty, measurements were made simultaneously using two film samples wrapped in a thin, opaque foil. In order to evaluate the obtained results, a metrological compatibility test was used, taking into account standard uncertainties of measurements. The attenuation of the beam by films and measurements reproducibility by means of film samples were also investigated. After that, dose measurements for 23 patients irradiated in the head and neck area using VMAT technique were conducted. For each patient, fractional and total dose measurements were made with detectors placed in three positions (from the front of the patient, on the left and right side). Films were stuck under a 0.5 cm thick bolus, which was placed on the patient immobilization mask. To read the dose reference value from the treatment planning system, a precise location of the film samples was required. For this purpose, small markers were stuck to the two opposite corners of the film, visible on the CT images performed on the patient for treatment planning. A total of 69 fractional dose measurements and 69 total dose measurements were made.

Results: For the method of measurement with film detectors described in this work, the relative standard uncertainty of dose measurements was 2,9% and 3,5% respectively for dose measurements during one irradiation fraction and for total dose measurements. The metrological compatibility test for method validation in the RW3 slab phantom confirmed the compliance of the film samples measurements, ionization chamber measurements and the doses calculated in the treatment planning system (for all measurements $\zeta < 2$). Measurements validation conducted on anthropomorphic phantom confirmed the agreement between the dose measured with film samples and the dose calculated in the treatment planning system (for all measurements $\zeta < 2$). Measurements of the therapeutic beam attenuation by the films showed that the difference between the dose measured using ionization chamber with or without the

presence of the two films packet is a maximum of 0,7%. The measurements reproducibility, expressed as the quotient of the standard deviation and the mean value, in the slab phantom for the reference conditions, for 10 measurements, was 0,7%. For measurements on patients, the mean difference between the dose measured using the film samples and the dose at point (calculated in the treatment planning system), for the fractional dose and total dose measurements, was 4,1% and 19,0% respectively. The mean difference between the film detectors measurements and the dose calculated in the treatment planning system in the small volume, for the fractional dose and total dose measurements, was 4,3% and 19,2% respectively. In case of the fractional dose measurements, it turned out that the obtained mean differences of 4,1% and 4,3% result from inaccuracies in the calculations of the 6 MV photon beam model (implemented to the Pinnacle treatment planning system) in the dose buildup region, that is at the depth at which measurements were made. In the case of total dose measurements, the mean differences of 19,0% and 19,2% were also influenced by the limited dynamic range of the film and the large decrease in sensitivity at high radiation doses. Therefore, it is not possible to make accurate measurements of high doses beyond the optimal measuring range of the films.

The purpose of *in vivo* dosimetry is to detect an error in the dose administered to the patient. The obtained measurement result is compared with the reference value calculated in the treatment planning system. It is, therefore, necessary to determine what difference between the result of the *in vivo* dosimetry and the calculation result makes it necessary for the user to take steps in order to explain obtained discrepancy, that is so-called tolerance level. In this work, the tolerance level was determined by the method proposed in the JCGM 100:2008 report [JCGM, 2008]. When determining it, the standard uncertainty of the measurement method with film packages presented in this paper, the uncertainty of the treatment planning system calculations and the uncertainty related to the accuracy of films package positioning related to the variability of the dose distribution were taken into account. For an "average patient", the tolerance level for dose measurement during a single treatment session was 5,6%. Assuming that the presented measurement method is subject to a normal distribution, it is possible to obtain a difference in the range of ±11,1% of the dose calculated in the treatment planning system with a probability of 95,4%. This is a higher value than the tolerance levels proposed in the international recommendations [IAEA, 2013], which are 5% for simple techniques and 7% for more complex situations. However, the recommended levels were developed for the 3D conformal radiation therapy technique (3D-CRT), where the irradiation is implemented with static, large fields and measurements are made under transient charged-particle equilibrium. If the presented measurement method using small film detectors was applied to the 3D-CRT irradiation technique, the tolerance level would be 4,5% of the calculated dose. It should be emphasized that the value of the tolerance level recommended by the IAEA was determined based on clinical assumptions. The tolerance level determined in this work has a very strong metrological basis.

Conclusions: Gafchromic EBT3 films are good detectors for *in vivo* dose measurements. They allow a direct dose measurement, even in the area with the absence of charged-particle equilibrium and in the area of high dose gradient. They cause a negligible reduction of the therapeutic dose for the patient, so they can be used for many fractions of irradiation. Their applicability in *in vivo* dosimetry for total dose measurements is limited due to the large decrease in film sensitivity for high doses. However, it is reasonable to use them

for total dose measurements throughout many therapeutic sessions. as long as the total dose does not exceed 10 Gy. They can be a good tool for monitoring the course of treatment. They have good reproducibility. The standard uncertainty of dose measurement by means of films packets is at the level of uncertainty of other commercially available detectors for *in vivo* dosimetry. Measurements at a depth of 0.5 cm require individual tolerance levels for each patient due to the large variability of the dose distribution. Film detectors proved to be a good tool for validation of the treatment planning system calculations.

In vivo dosimetry using detectors made of Gafchromic EBT3 film sheets has never been applied before to measurements for the VMAT irradiation technique. A method of determining the location of film detectors on CT images using markers is unique. The simultaneous measurement with two detectors (two samples. one above the other) has never been performed before. *In vivo* dosimetry during the whole patient treatment has never been done before.

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