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UNCERTAINTY OF MEASUREMENT ABSORBED DOSE BY GAFCHROMIC EBT3 DOSIMETER FOR CLINICAL ELECTRON AND PHOTON BEAMS OF MEDICAL ACCELERATORS

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Abstract

Purpose: Investigation of the relative errors of absorbed dose measurement based on polymer films Gafchromic EBT3 for clinical electron and photon beams of medical accelerators.

Material and methods: Polymer Gafchromic EBT3 films were calibrated using different radiation beams, namely photon and electron beams of Elekta Axesse medical accelerator with beam energy equal to 10 MV and 10 MeV, correspondingly, and electron beam of a betatron for intraoperative radiotherapy with beam energy equal to 6 MeV. The film pieces were irradiated by the uniform dose field in the dose range from 0.5 to 40 Gy. The dose value was controlled by cylindrical ionization chamber on Elekta Axesse accelerator and by the Markus parallel-plate ionization chamber on betatron. The irradiated films were scanned using Epson Perfection V750 Pro flatbed scanner in 16 bit RGB color mode with 150 dpi resolution. The red and green channels were used for further analysis. The central part of each film was used for calculation of average values of net optical density and its root-mean-square. As a result, the calibration curves, i.e. dependence on the reference absorbed dose measured by ionization chamber on the net optical density were constructed taking into account uncertainties of dose measurement and optical density measurement.

Results: The relative uncertainty for the dose measurement lies within 7 % for low doses (less than 1 Gy) and within 4 % for higher doses. The green channel is less sensitive to the radiation, but its relative uncertainty values are in general 1–2 % lower than the ones for the red channel. The use of different calibration sources results in different calibration curves with difference up to ± 6 % for the green channel.

Conclusion: The polymer Gafchromic EBT3 films can be used for absorbed dose measurement for the doses not less than 0.5 Gy. For lower dose values the dose measurement uncertainty caused by statistical reasons amounts 15 %. For dose values of about 1 Gy and higher the dose measurement uncertainty amounts 5 % that allows to use the films for transverse and longitudinal prescription treatment dose distribution measurement with very high spatial resolution.

Key words: *radiation therapy, Gafchromic EBT3 film, clinical dosimetry, medical accelerators, absorbed dose, uncertainties*

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Introduction

Radiation therapy is widely used for treatment of malignant tumors all over the world. The development of radiation therapy is based on the development of dose delivery techniques that include Intensity Modulated Radiation Therapy and Volumetric Modulated Arc Therapy. These techniques allow high-quality dose delivery that results in possibility to carry out hypofractionated radiation therapy. This fractionation type is effective for example in the cases of prostate carcinomas [1] or lung cancer [2]. IMRT and VMAT techniques are also effective in the case of irradiation of brain [3] or liver metastases [2]. Each dosimetric treatment plan which use high gradient dose fields should be verified before implementation and patient treatment. One of the widely used ways to check the treatment plan quality is based on the using of radiochromic polymer films that have the best spatial resolution among all dosimeters used in the medical physics. The typical spatial resolution of the polymer films is about 0.1 mm. That is why radiochromic dosimetric films are widely used in clinical dosimetry of photon, electron and proton beams mainly for obtaining of dose spatial distributions of a radiotherapy device. Such films are not exposed by the visible light that makes them more reliable in routine operation. In 2011 third generation of radiochromic film Gafchromic EBT3 was presented. The film is a tissue-equivalent dosimeter with the dose measurement range 0.1–20 Gy according to the manufacture specification [4]. The film has low energy dependence and could be used for dosimetry of both electron and photon beams.

The main question that appears while operating any dosimetric system is its measurement uncertainty. According to the International Committee on Radiation Units the clinical dose delivered to the patient should lie in the range $D^{+5\%}_{-7\%}$ (D is the prescribed dose) resulting in the demand to clinical dosimetry be more accurate than ±5 %. Measurement uncertainties of the main types of ionization chambers ("golden standard") could be found in the international dosimetric protocols TRS-398 and TG-51 [5, 6]. For the ionization chambers the uncertainty values lie in the range 1.5–3.6 % depending on the radiation type and quality.

The possible sources of errors in the dose measurement using Gafchromic EBT3 film were analyzed by J. Sorriaux et al. [7]. In the cited reference the dose measurement uncertainty was estimated to be equal to 0.55 % neglecting the local inhomogeneity of the film. Up to the best of our knowledge there were no investigations of the dose measurement uncertainties caused by local inhomogeneity (non-uniformity) of the dosimetric system based on the Gafchromic EBT3 film. Investigation of the previous generation of the film, Gafchromic EBT2, showed that the film local inhomogeneity was equal to 3.7 % while the uncertainty of the absorbed dose obtained using calibration curve counted more than 6 % [8]. According to the manufacture information the film uniformity is better than 3 % in the dose range 0.1–10 Gy [4]. It was also stated that for dose values more than 10 Gy the uncertainty may increase.

In the clinical practice the films are used for measurement of highly gradient transverse beam distributions [9]. In this case it is hard to estimate the value of dose measurement uncertainties caused by random reasons that include both film non-uniformity and statistical errors that appear in detector during film scanning. However, the value of the possible dose measurement uncertainties could be estimated during irradiation of the film by the flat field during film calibration routine. In this case one could rather simply calculate the statistical uncertainty of the dose measurement from calibration curve. In spite of the fact that Gafchromic EBT3 film non-uniformity and scanner statistical error could be calculated separately in our opinion in clinical practice understanding of the whole system is more reliable.

In this paper we present our investigation of the dose measurement uncertainties of dosimetric system that consisted of Gafchromic EBT3 film and Epson Perfection V750 scanner. In our investigation we used three different treatment beams, namely 10 MV photons (doses up to 40 Gy), 10 MeV and 6 MeV electrons (doses up to 30 Gy). The investigation of the film response to the MeV electron beam irradiation was carried out due to our interest to intraoperative radiotherapy (IORT). The delivered dose for this treatment modality amounts 10–22 Gy per single fraction according to Ref. [10].

Material and methods

Gafchromic EBT3 film

Gafchromic EBT3 polymer films are widely used as a reliable secondary dosimeter due to the facts that film effective atomic number (Z_{eff}^{EBT} = 6.84) is close to the water one (Z_{eff}^{water} =7.3); the film is self-developing and the spatial resolution lies in the sub-millimeter range while using flatbed scanner [4, 11].

Interaction of the ionizing radiation with the film results in the film darkening that could be expressed using net optical density value:

$$NetOD = \log\frac{PV_{before} - PV_{bckg}}{PV_{after} - PV_{bckg}} \qquad (1)$$

where PV is the pixel value as read by the scanner, and indexes *before*, *after* и *bckg* denotes film before irradiation, after irradiation and scanner background caused mainly by dark current [12]. The film darkening is caused by polymerization of the monomers in it under irradiation that defines the maximal achievable spatial resolution and time that is needed for film processing.

The Gafchromic EBT3 film consists of a single active layer with nominal thickness equal to 28 μm that is situated between two protective polyester layers with nominal thicknesses equal to 12 μm each. Thus, the third generation of the film is insensitive to the film overturn upside down during the scanning procedure according to [13]. The film characteristics could vary from a batch to a batch that should be taken into account. During our experimental study we used the films with the batch number № 04041202.

Calibration routine

Because of film non-uniformity each pixel could darken to a different value during film irradiation. Stochastic process during scanning procedure adds uncertainty to each pixel value. It is hardly possible to predict the exact value of this uncertainty during the measurement of the dose spatial distribution of the highly gradient field. However, it is still possible to estimate the expected uncertainty value of the whole system while irradiating the films by the uniform flat fields. In our research we combined Gafchromic EBT3 calibration procedure that assumes the use of flat fields with estimation of the measured dose uncertainty caused by the film non-uniformity and scanner processes. In our assumption such an approach could help a lot to have at least a feeling of relative dose error expected during the film irradiation by the arbitrary fields.

The film calibration procedure is needed to assign the absorbed dose with the film net optical density. One should be aware that each particular dosimetric system that includes radiation source, radiation conditions, detectors, scanner model could have different reply and in the most of the cases should be calibrated as a whole system. Change of any component may result in a necessity of new calibration. In the case of the film dosimetry one could use different color channels (red, green, blue) that usually have different reaction to the irradiation. This is the basis of multichannel dosimetry that is widely developed these days [14]. However, in our work we used red and green channels of the film separately for better understanding of their difference that should be taken into account during multichannel dosimetry.

Procedure of the film calibration can be divided into two stages. At the first step the radiation source is calibrated using the ionization chamber following the routines described in protocols TRS-398 or TG-51 [5, 6]. At the second step the characterized radiation source is used for irradiation of the film pieces that should be situated at the same conditions as the ionization chamber before. One of the conditions of the film calibration routine is its irradiation in the flat field that is at least twice larger than the film size in order to avoid penumbra influence. The fact that the film is irradiated by the flat field allows combining film calibration and relative dose uncertainty evaluation.

During our experiments we irradiated film pieces 5×5 cm² using the field size 10×10 cm². The irradiated film pieces were scanned in transmission regime 24 hours after the irradiation in order to finish self-development process. The scanning was carried out at 150 dpi resolution and the color depth was chosen to be equal to 48-bit (16-bit per color channel using RGB mode). Region of interest (ROI) was used for obtaining of data for calibration curve. Following Refs. [15–17] the ROI was chosen to be equal to 1×1 cm² in the center of the field resulting in approximately 3600 pixels that were used for calibration. This ROI was also used for estimation of statistical uncertainty of the measured pixel value.

Net optical density was obtained from averaged pixel value ($\overline{PV_i}$) taken from the scanned film ROI basing on Eq. (1). Knowledge of pixel value standard deviation (σ_{PV_i}) allows obtaining uncertainty of the net optical density σ_{NetOD} in the following form:

$$\sigma_{NetOD} = \sqrt{\sum_i \left(\frac{\sigma_{PV_i}}{\sigma_{x_i}}\right)^2 \Delta x_i^2} \qquad (2)$$

where x_i are the variables in the Eq. (1) and Δx_i^2 are their uncertainties.

Dependence of the absorbed dose on film net optical density, namely the calibration curve could be described by the following equation [12]:

$$D_{fit} = a \times NetOD + b \times (NetOD)^n \qquad (3)$$

where a,b,n are the free fit parameters.

The uncertainty of the dose definition based on calibration curve is given by the following equation [12]:

$$\sigma_{D_{fit}} = \left[NetOD^2 \times \sigma_a^2 + NetOD^{2n} \times \sigma_b^2 + \right.$$
$$+ (b \times NetOD^n \times \log NetOD)^2 \times \sigma_n^2 +$$
$$\left. + (a + n \times b \times NetOD^{n-1})^2 \times \sigma_{NetOD}^2\right]^{0.5} \qquad (4)$$

where σ_a, σ_b and σ_n are the uncertainties of the fit parameters a,b,n respectively.

Algorithm of uncertainty calculation

The scanned data treatment program code was developed using Wolfram Mathematica software [17].

The film calibration routine assumes irradiation of the film pieces by the flat field. This fact allows us to estimate the statistical changes in the film darkening due to random reasons both is the film and in the scanned image. The following algorithm has been developed:

1. The starting point of the data treatment was the scanned film pieces in the 48-bit TIFF format. In our experiment each film piece was irradiated by the known dose D_{ref} and scanned before irradiation and 24 hours after the irradiation. Thus, the sets of values $PV_{after,i}$, $PV_{before,i}$ at each i-th pixel of the film within the whole film piece were obtained. The values of PV_{bckg} and $\sigma_{PV_{bckg}}$ were obtained at advance from the scanning of the dark field (the scanner lamp was closed by the opaque screen).

2. As the next step the ROI was defined. The average pixel values and their uncertainties were calculated within ROI resulting in average values $\overline{PV_{after}}$ and $\overline{PV_{before}}$, as well as their standard deviations $\sigma_{PV_{after}}$ and $\sigma_{PV_{before}}$. While calculating the standard deviations the points within ROI where $\overline{PV} - 5\sigma_{PV} < PV_i < \overline{PV} + 5\sigma_{PV}$ were not taken into account in order to avoid standard deviation overestimation due to artifacts. Such values were changed by the mean value of two nearest pixels. The cleaning procedure was iterative and two iterations were enough in our case.

3. Basing on obtained pixel values the average *NetOD* value and its standard deviation σ_{NetOD} were obtained.

4. Experimental calibration curve (dependence of D_{ref} on *NetOD*) was fitted by Eq. (3), resulted in fit parameters a,b,n and their uncertainties. The fit was based on the least squares algorithm using Wolfram Mathematica built-in function NonlinearModelFit based on Levenberg–Marquardt algorithm.

5. The film pieces irradiated during the calibration procedure were assumed to be irradiated by the unknown dose D_{fit}. Based on the film *NetOD* value and calibration curve the dose of irradiation D_{fit} was calculated. Based on the fit uncertainties obtained earlier and σ_{NetOD} value the dose uncertainty σ_{Dfit} was calculated using Eq. (4). The relative dose uncertainty σ_{Dfit} / D_{fit} was the main point of interest that described the expected error values caused by combination of the local film inhomogeneity, stochastic scanning processes and random reasons.

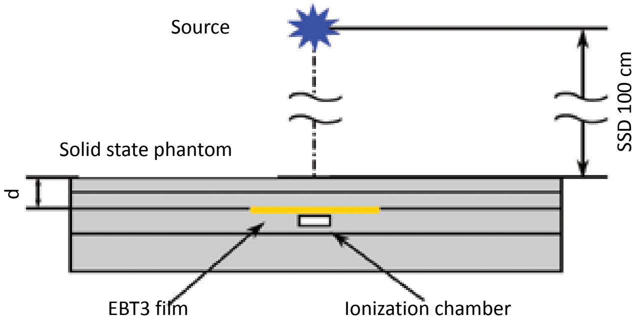

Fig. 1. Film irradiation scheme used both at the Elekta Axesse accelerator for electron and photon beams and at the betatron

Experimental equipment

Experimental irradiation of the Gafchromic EBT3 films was carried out using 10 MV photon beam and 10 MeV electron beam of the Elekta Axesse accelerator (Meshalkin National Medical Research Center, Novosibirsk, Russia) and 6 MeV electron beam of betatron for IORT (Tomsk Polytechnic University, Tomsk, Russia).

Elekta Axesse irradiation procedure

The films were irradiated by 10 MV photon beam in the dose range 0.5–40 Gy and by the 10 MeV electron beam in the dose range 0.5–30 Gy. Fig. 1 shows the general irradiation scheme used both at Elekta Axesse accelerator for electron and photon beams and at IORT betatron.

The film pieces with sizes 5×5 cm² were irradiated in the standard conditions: field size was equal to 10×10 cm², and Source-Axis Distance (SAD) amounted 100 cm. The accelerator dose rate was equal to 460 ± 50 MU/min, resulting in 4.6 ± 0.5 Gy/min. Each film piece was irradiated perpendicular to the beam axis in the solid state phantom MatriXX (Ser.No.13042, IBA Dosimetry, Germany) [18].

Due to the fact that Elekta Axesse accelerator was calibrated earlier with respect to dose depth distributions the irradiation dose was controlled by internal dosimeter (MU values). The reference dose was measured using clinical dosimeter DOSE1 (DOSE-1) [19] and cylinder ionization chamber Farmer FC65-P (S/N 2519).

The dose depth distribution maximum at 10 MV photon beam was situated at d = 2.6 cm depth in the solid phantom. For 10 MeV electron beam the same value amounted d = 2.2 cm. The film pieces were situated at these depths.

In order to obtain reference doses from ionization chamber D_{ref} all routine procedures were carried out according to TRS-398 and TG-51 protocols [5, 6]. For the 10 MV photon beam the value $\%dd(10)_x$ = 73 % and $TPR_{10.20}$ = 0.738 resulting in k_Q = 0.985 both for TG-51 and TRS-398 protocols. In the case of 10 MeV electron beam the beam quality factor R_{50} = 4.33 g/cm² resulting in $k_Q^{TRS-398}$ = 0.898 according to TRS-398 [5] and k_Q^{TG-51} = 0.894 according to TG-51 [6]. Since the difference is less than 0.5 % we decided to use the quality factor value defined by TRS-398 protocol.

Betatron irradiation procedure

For the film irradiation 6 MeV betatron developed at Tomsk Polytechnic University for IORT was used. The calibration of the betatron was carried out using UNIDOS-E dosimeter (PTW Freirburg, Germany) [20], plane-parallel ionization chamber PTW 23343 Freirburg Markus PTW Freirburg, Germany) [21] and solid state phantom RW3 Slap Phantom T29672 [22]. Due to the fact that the internal dose control unit had not been developed up to the experiment, the irradiation dose was controlled by irradiation time. At the first stage the dose was measured by ionization chamber versus time and at the second stage the films were irradiated during the same time using the ionization chamber to control dose stability. The irradiation scheme is shown in Fig. 1. The difference was the presence of applicator with diameter 8 cm installed between radiation output window and phantom surface.

The films were irradiated in the dose range 1–25 Gy. The dose depth distribution maximum in the solid stated phantom was situated at the depth d = 1.0 cm. The beam quality factor R_{50} = 2.2 g/cm² resulting in $k_Q^{TRS-398}$ = 0.924 according to TRS-398 [5] and k_Q^{TG-51} = 0.941 according to TG-51 [6]. Due to the significant difference in the values we decided to use the mean value of k_Q quality factor equal to k_Q = 0.933. Significant difference of the k_Q values obtained from the same dose depth curve using different protocols is very interesting. However, investigation of this fact is out of the scope of this paper.

Scanner

For the film scanning Epson Perfection V750 Pro scanner was used [23]. The films were scanned at 150 dpi resolution in 48-bit color mode. The scanner background average values and their uncertainties amounted: $PV^r_{bckg} = 570 \pm 80$, $PV^g_{bckg} = 630 \pm 81$, $PV^b_{bckg} = 540 \pm 66$. Indexes r, g, b define «red», «green» and «blue», respectively. Uncertainty values are given at confidence interval p = 0.95.

Results

Photon beam of Elekta Axesse accelerator

During the film calibration at 10 MV photon beam of Elekta Axesse accelerator the following calibration fitting equations for red and green channels were obtained:

$$D^r_{fit}(x) = (11.8 \pm 0.6) \times x + (79 \pm 3.8) \times x^{(6.3\pm0.3)}$$
$$D^g_{fit}(x) = (16.9 \pm 0.5) \times x + (30 \pm 0.4) \times x^{(2.7\pm0.07)} \quad (5)$$

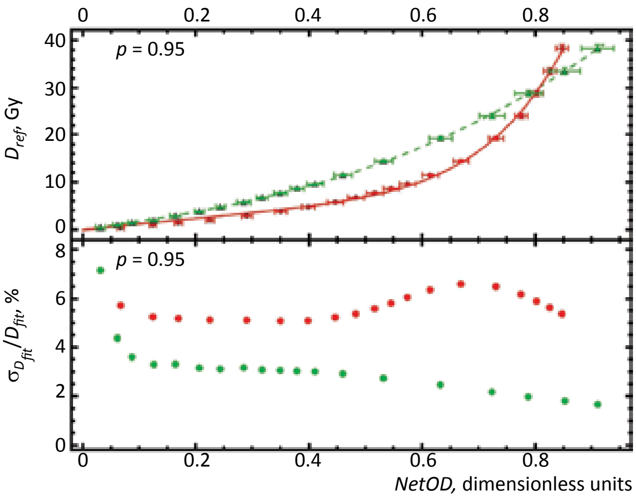

Fig. 2. Calibration dependences and fitting curves according to Eq. (5) obtained at 10 MV photon beam of Elekta Axesse (upper plot). Relative uncertainty of absorbed dose calculated from calibration curves Eq. (5) (lower plot). Red dots – red channel, green dots – green channel, lines – fit curves

Fig. 2 shows the experimental calibration dependences and calibration curves given by Eq. (5). The error bars in dose values were assumed to be 2 % according to TRS-398 [5]. Error bars in *NetOD* values were calculated at confidence interval $p = 0.95$.

Fig. 2 and uncertainty values in Eq. (5) shows that green channel better fits the experimental data.

Lower plot in Fig. 2 shows the dependence of relative dose uncertainty on net optical density for both red and green channels at confidence interval $p = 0.95$ that was calculated using Eq. (4). In Fig. 2 one can see that the values of relative dose uncertainty lie within 7 % level for both channels. For red channel uncertainty varies in the range 5–7 % for the whole range of *NetOD* values. For green range the dose uncertainty decreases with increase of *NetOD* values and lies within 5 % range for doses larger than 1 Gy.

Electron beam of Elekta Axesse accelerator

During the film calibration at 10 MeV electron beam of Elekta Axesse accelerator the following calibration fitting equations for red and green channels were obtained:

$$\begin{aligned} D_{fit}^{r}(x) &= (10.2 \pm 0.3) \times x + (56 \pm 2) \times x^{(4.8 \pm 0.16)} \\ D_{fit}^{g}(x) &= (16.2 \pm 0.3) \times x + (29 \pm 0.2) \times x^{(2.46 \pm 0.05)} \end{aligned} \quad (6)$$

Fig. 3 shows the experimental calibration dependences and calibration curves given by Eq. (6). The error bars in dose values were assumed to be 2 % according to TRS-398 [5]. Error bars in *NetOD* values were calculated at confidence interval $p = 0.95$.

Lower plot in Fig. 3 shows the dependence of relative dose uncertainty level on net optical density for both red and green channels at confidence interval $p = 0.95$. In Fig. 3 one can see that the values of relative dose uncertainty lie within 7 % level for both channels. For red channel uncertainty varies in the range 3.5–5 % for the whole range of *NetOD* values. For green range the dose uncertainty decreases with increase of *NetOD* values and lies within 4 % range for doses larger than 1 Gy.

Electron beam of betatron

During the film calibration at 6 MeV electron beam of betatron the following calibration fitting equations for red and green channels were obtained:

$$\begin{aligned} D_{fit}^{r}(x) &= (10.3 \pm 0.3) \times x + (59.2 \pm 2.6) \times x^{(4.61 \pm 0.16)} \\ D_{fit}^{g}(x) &= (16.5 \pm 0.5) \times x + (34.2 \pm 0.7) \times x^{(2.59 \pm 0.09)} \end{aligned} \quad (7)$$

Fig. 4 shows the experimental calibration dependences and calibration curves given by Eq. (7). Error bars in *NetOD* values were calculated at confidence interval $p = 0.95$.

Lower plot in Fig. 4 shows the dependence of relative dose uncertainty level on net optical density for both red and green channels at confidence interval $p = 0.95$. In Fig. 4 one can see that the values of relative dose uncertainty lie within 5.2 % level for both channels. For red channel uncertainty varies in the range 3.5–5 % for the whole range of *NetOD* values. For green range the dose uncertainty decreases with increase of *NetOD* values and lies within 4 % range for doses larger than 1 Gy.

Comparison of calibration curves

In order to compare film response to different kinds of radiation the dependences of curves ratios were plotted versus *NetOD* values. Fig. 5 shows comparison of calibration curves obtained at electron (10 MeV) and photon (10 MV) beams of Elekta Axesse accelerator taking into account the uncertainties of calibration both for red and green channels.

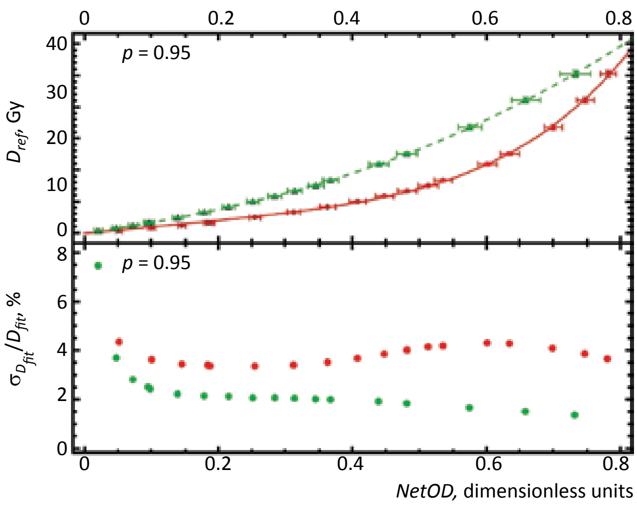

Fig. 3. Calibration dependences and fitting curves according to Eq. (6) obtained at 10 MeV electron beam of Elekta Axesse (upper plot). Relative uncertainty of absorbed dose calculated from calibration curves Eq. (6) (lower plot). Red dots – red channel, green dots – green channel, lines – fit curves

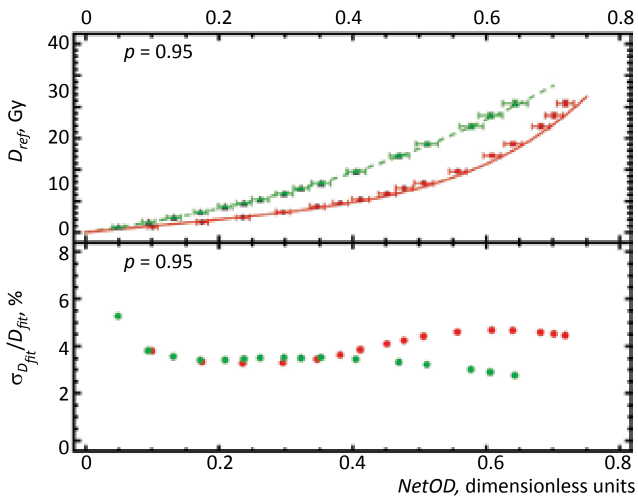

Fig. 4. Calibration dependences and fitting curves according to Eq. (7) obtained at 6 MeV electron beam of IORT betatron (upper plot). Relative uncertainty of absorbed dose calculated from calibration curves Eq. (7) (lower plot). Red dots – red channel, green dots – green channel, lines – fit curves)

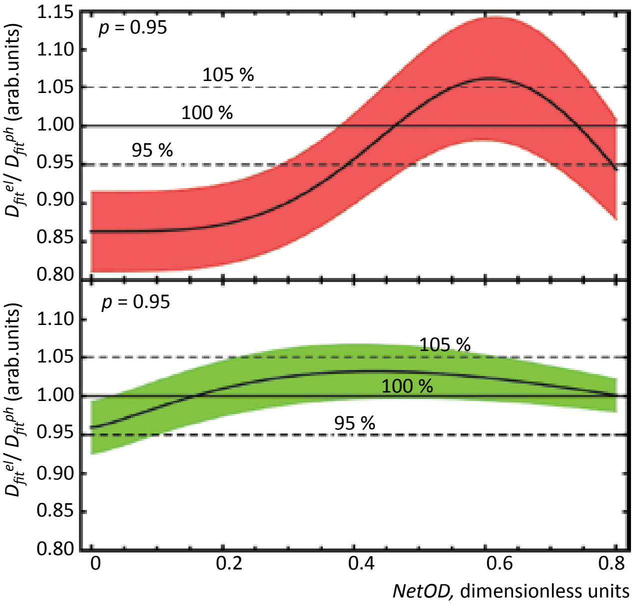

Fig. 5. Ratio of calibration curves obtained at 10 MeV electron beam and 10 MV photon beam of Elekta Axesse accelerator. Color region show uncertainty region due to uncertainties of calibration curves. Upper plot – red channel, lower plot – green channel

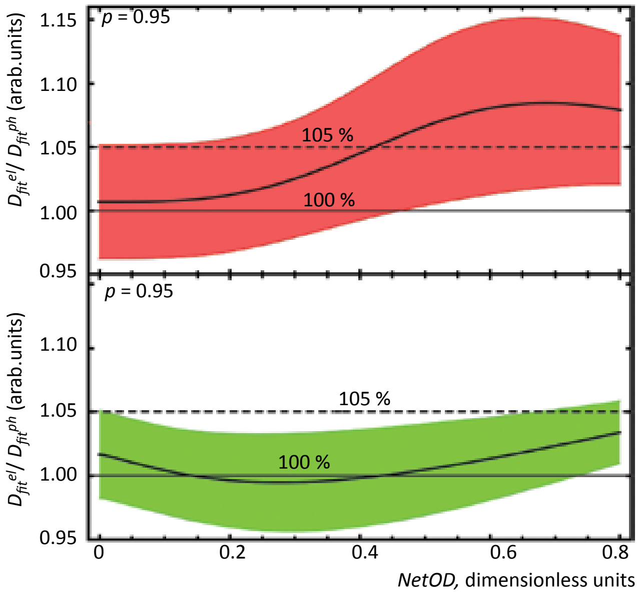

Fig. 6. Ratio of calibration curves obtained at 10 MeV electron beam of Elekta Axesse accelerator and 6 MeV electron beam of IORT betatron. Color region show uncertainty region due to uncertainties of calibration curves. Upper plot – red channel, lower plot – green channel

In Fig. 5 one can see that ratio of calibration curves for the red channel lies in the range 0.86–1.06, and maximal uncertainty value amounts ±8 % in the range of net optical density values *NetOD* ≃ 0.6. Green channel coincidence is better resulting in the ratio values 0.96–1.04 and maximal uncertainty ±4 % (*NetOD* ≃ 0.5).

Fig. 6 shows comparison of calibration curves obtained at electron beams of Elekta Axesse accelerator (10 MeV) and electron beam of betatron (6 MeV) taking into account the uncertainties of calibration both for red and green channels.

In Fig. 6 one can see that ratio of calibration curves lies in the range 0.96–1.09 for the red channel, and in the range 0.96–1.06 for the green one.

Discussion

Polymer radiochromic film Gafchromic EBT3 was calibrated at electron and photon beams of two different accelerators. The uncertainties of the absorbed dose values calculated from the measured *NetOD* values using calibration curves (D_{fit}) were obtained taking into account statistical distribution of the measured PV within ROI.

The results of film calibration both at electron (10 MeV) and photon (10 MV) beams of Elekta Axesse linear accelerator show that the film response to different kinds of radiation is similar i.e. there is no significant difference between calibration curves for electron and photon beams. Both calibration curves were fitted well by the curve type, described by Eq. (3). The results of film calibration at electron beams of different energy (10 MeV and 6 MeV) show that the film response to different particle energy is similar i.e. there is no significant difference between calibration curves.

In comparison with results of Gafchromic EBT2 film obtained in Ref. [8] our results show that Gafchromic EBT3 film dose measurement uncertainties are less than Gafchromic EBT2 ones being within 5 %. Obtained uncertainties of unknown dose measurement show that film green channel is better while irradiating films to the dose values higher that 1 Gy due to the fact that uncertainty values lie within 4 % range (at $p = 0.95$). Such uncertainty level allows to use the film for absolute dose measurement. In our opinion the difference between red and green channels should be taken into account while using film multichannel dosimetry.

If one irradiates a film by the dose equal to 1 Gy the following uncertainties values could be obtained. Uncertainties caused by fitting curve error: ΔD_r^{ph} = ±5 %, ΔD_g^{ph} = ±3 %, ΔD_r^{el} = ±3.2 %, ΔD_g^{el} = ±1.8 %. If one additionally takes into account statistical distribution within ROI the following uncertainty values could be obtained: ΔD_r^{ph} = ± 5.5 %, ΔD_g^{ph} = ±4.5 %, ΔD_r^{el} = ±3.7 %, ΔD_g^{el} = ± 3.2 %. Such high level of local inhomogeneity uncertainty does not allow measuring absorbed doses less than 10 cGy (uncertainty amounts 15 %). Uncertainty values for the doses larger than 20 Gy lie within 5 % that extends manufacturer information.

Conclusion

The polymer Gafchromic EBT3 films could be used for absorbed dose measurement for the doses not less than 0.5 Gy. For lower dose values the dose measurement uncertainty caused by statistical reasons amounts 15 %. For dose values of about 1 Gy and higher the dose measurement uncertainty amounts 5 % that allows to use the films for transverse and longitudinal prescription treatment dose distribution measurement with very high spatial resolution.

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Неопределенности поглощенной дозы, измеренной дозиметром Gafchromic EBT3 на клинических электронных и фотонных пучках медицинских ускорителей*

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Реферат

Цель: Исследовать величины относительных неопределенностей в измерении поглощенной дозы с помощью радиохромных полимерных пленок Gafchromic EBT3 для клинических электронных и фотонных пучков медицинских ускорителей.

Материал и методы: Полимерные пленки Gafchromic EBT3 калибровались на фотонном и электронном пучках медицинского ускорителя Elekta Axesse с энергией 10 МВ и 10 МэВ соответственно, а также на электронном пучке бетатрона для интраоперационной лучевой терапии с энергией пучка 6 МэВ. Пленки облучались в однородном дозном поле в диапазоне доз от 0,5 до 40 Гр. Величина поглощенной дозы в процессе калибровки контролировалась цилиндрической ионизационной камерой на линейном ускорителе Elekta Axesse и с помощью плоскопараллельной ионизационной камеры типа Markus на бетатроне. Облученные пленки сканировались с помощью планшетного сканера Epson Perfection V750 Pro с глубиной цвета 16 бит на канал (цветовая модель RGB) при пространственном разрешении 150 точек на дюйм (dpi). Для дальнейшего анализа использовались только красный и зеленый цветовые каналы. Для расчета средней величины чистой оптической плотности и ее среднеквадратичного отклонения исследовалась центральная часть каждой из пленок. При построении калибровочной кривой пленки, т.е. зависимости референсной поглощенной дозы, измеренной ионизационной камерой, от чистой оптической плотности, использовались неопределенности измеренной дозы и оптической плотности.

Результаты: Относительная неопределенность измеренной с помощью пленки дозы лежит в пределах 7 % для низких значений доз (менее 1 Гр) и в пределах 4 % для высоких значений доз. Зеленый канал цветности оказался менее чувствительным к ионизирующему излучению, однако величина относительной неопределенности оказалось в среднем на 1–2 % ниже, чем у красного канала. Использование разных источников излучения для калибровки привело к разным калибровочным кривым с разницей до ± 6 % (для зеленого канала).

Заключение: Полимерные пленки Gafchromic EBT3 могут быть использованы для измерения значений поглощенной дозы не менее 0,5 Гр. Для более низких значений дозы неопределенность измеренных значений, обусловленная статистическими причинами, составляет более 15 %. При значениях дозы порядка 1 Гр и более, неопределенность измерений дозы составляет 5 %, что позволяет использовать пленки для измерения поперечного и продольного распределения дозы с очень высоким пространственным разрешением.

Ключевые слова: *лучевая терапия, пленки Gafchromic EBT3, клиническая дозиметрия, медицинские ускорители, поглощенная доза, неопределенности*

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