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Original article

Determining The Accuracy of Dwell Position by Using Electron Energy with Gafchromic Film in High Dose Rate Brachytherapy Systems

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Abstract

Due to the general lack of darkroom and film processing equipment in many clinics, it is no longer possible to use radiation sensitive Xomat V radiographic film for High Dose Rate brachytherapy quality assurance. An alternative is to use radio chromic film that does not require processing. The aim of this study is to develop and clinically test the GafChromic film-based brachytherapy Quality Assurance (QA) system using different electron energies. As an electron source (6 MeV-9 MeV-12 MeV -15 MeV -18 MeV) (Elekta Synergy® Platform linear accelerator, Varian GM plus IX (Varian Medical Systems, Inc.USA), Varian brand cylinder, ring and tandem double ovoid applicators, RTQA2 and EBT3 GafChromic film were used. In RTQA2 films, images are obtained at high electron energies (12 MeV and above) at 300 Monitor Unit (MU), while images are obtained at all energies at 700 MU in irradiation using different electron energies and MUs. For the desired image quality depending on the material of the applicator used, it was determined that the image clarity increased as the energy, field size and MUs increased. In EBT3, the desired image could be obtained at 18 MeV and 2500 MU. It is possible to obtain the desired image quality by using high-energy electrons, especially RTQA2 Gafchromic film, in determining the accuracy of the dwell position in brachytherapy. Since it has been determined that this method can be used easily in quality control tests, we think that this method is suitable for clinical use when necessary.

Keywords: Brachytherapy, Dwell Position, Electron Energy, RTQA2-EBT3 Models Gafchromic Film.

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INTRODUCTION

In suitable cancer patients (gynecology, breast, prostate, etc.), High Dose Rate (HDR) brachytherapy methods are frequently used as a boost dose together with both radical therapy and external beam therapy. Correct treatment of patients is only possible with a correct application, which is possible with the quality control of both the device and the equipment used from the installation of the brachytherapy device. This can only be achieved by applying this program completely after the quality control program has been established in accordance with the protocols throughout the clinical use of the device. Therefore, each institution should develop an appropriate Quality Control (QC) program for resources and equipment [1].

In addition to the complexity and sensitivity of the application, due to the use of radioactive sources, a routine QC program in brachytherapy should be established and strictly implemented in terms of both the correct treatment of the patient and the radiation safety of patients, hospital staff and the society. It uses an Iridium-192 (^{192}Ir) source with a nominal activity of 10 Ci. When the half-life of ^{192}Ir is short (74 days), there are four or more radioactive source changes per year in after loading devices depending on the source activity loaded into the device.

After a source change, source activity needs to be verified with an ion chamber with the appropriate calibration from the official institution to the source. In addition, the quality assurance of the positional accuracy of the welding motion mechanism is carried out by radiographic film. In brachytherapy, uncertainties occur in the calculation of the absolute dose [2,3] and the effect of inhomogeneity [4-6] the mechanical accuracy of the welding motion and the targeted dose for the overall treatment process depending on this accuracy. The mechanical accuracy of the welding movement is of great importance in terms of irradiation of the right place during treatment. AAPM Task Group 40 and Task Group No. 56 specify that the welding positioning error rate tolerance should not exceed ±1 mm [7,8]. ESTRO Booklet No. 8 ±2 mm states that a dwell positioning error should be corrected [1].

In short, it should be ensured that the dose given for the High Dose Rate (HDR) brachytherapy program is correct and reliable. This depends on the effectiveness of the radioactive source when treatment is applied with appropriate length of the source connecting tubes and catheters, the correct and reliable position of the source waiting positions according to the patient anatomy, the correct and reliable dwell time in each, the waiting position and the linearity of the timer [9].

One of the changes that has occurred in the last few years is that many clinics around the world no longer have dark rooms and film processing equipment. As a result, it is no longer possible to use Xomat V radiographic film for HDR brachytherapy Quality Assurance (QA), which requires radiation-sensitive, enveloped bathing. There are different suggestions for this and the most accepted is the use of radio chromic film, which does not require processing [10]. The high dose response curve of these films, which is difficult to use. Although this problem can be overcome by using Gafcromic films (XR-QA2) commercially produced for CT calibration, centers are not able to access CT calibration films from time to time, since it is the only company worldwide (Ashland-USA) to manufacture these films.

In theory, many clinics where brachytherapy devices are available also have linear accelerator devices. Radio chromic films are frequently used for QA of these devices. Using these films in brachytherapy systems, it is possible to detect the source dwell position. Weld location accuracy is done in two stages. The first is to obtain the image of the applicators with a quality that can see the dummy sources after the dummy source is placed into the used applicators. The second is to provide the source positions and irradiate the dummy sources under the same conditions without disturbing the set-up. It should be noted that this overlap should be less than 1 mm in order not to cause dose error in the patient.

Gafchromic film is a radiation sensitive microcrystalline monomer. After the monomer was spread on the gelatin matrix, it was coated on the polyester film base. It is the tissue equivalent. As a result of the interaction of the monomer component with radiation, the polymerization reaction begins and the color polymer is formed as a result. The color change (blue color) in the polymer increases in proportion to the amount of absorbed radiation. This color change is proportional to the radiation intensity. Calibration strips are obtained by detecting the colors given by a certain amount of radiation. It can be used both visually and as a film dosimeter. In our study, we benefited from the visual features of these films.

The aim of this study is to investigate whether the dwell position accuracy can be determined by using radio chromic films used in routine linear accelerator quality control and different electron energy stages in linear accelerator for image and whether it is possible to use the method in practical clinical routine.

MATERIAL and METHOD

The applicators used in the Varian GM plus IX (Varian Medical Systems, Inc.USA) after loading brachytherapy device were included in the study to determine the accuracy of the dwell position (cylinder, tandem + ovoid set and ring set).

Device Feature

Elekta Synergy® Platform linear accelerator (Elekta Oncology Systems, Crawley, UK) device was used as the electron source. Electron energies available in the device (6 MeV -9 MeV -12 MeV -15 MeV -18 MeV) and different MU values were used as electron energy. Electron subjects were not used during irradiation since it was thought to open up an area as long as the applicator and these areas could not be reached with the standard 20x20 cm electron cones available in the center. The collimator aperture was provided by the photon master collimators. A 30x2 cm field size opening was used for the cylinder, and 10x10 cm for the ring applicator and tandem.

Set-up

1. A 5 cm RW3 type (White Polystyrene, IBA-Belgium) solid phantom was placed on the Elekta Synergy Platform device table. First, RTQA2 films were used.

RTQA2 films: It has a structure that can measure a wide dynamic range between 0.02 Gy and 8 Gy, does not require a bath, has close to tissue equivalent, has a high spatial resolution, can be used in room light, is resistant to water and temperatures up to 70°C. These films are used for position verification in radiotherapy, mechanical QA and HDR systems.

2. The EBT3 films used have symmetrical structure and anti-Newtonian ring coatings. The dose error is 1% or less. The dynamic range of these films is 0.1 to 20 Gy.

RTQA2 10X10" Gafchromic film was cut in the size of the irradiated applicator on the solid phantoms placed for scattering and setup smoothness, and placed in the center of the irradiation area by fixing it with a plaster. SSD on RTQA2 Gafchromic film placed on the phantom 250 mm long rigid guide tube with code GM11011180 at 100 cm was positioned in the center of the field. To prevent scattering and extra darkening and to clarify the dummy view, the applicator was defined by the primary photon jaws according to their dimensions. A dummy source was placed in the guide tube and fixed with tape to prevent it from moving in the straight axis. Since the cone dimensions were not sufficient to provide the available areas in the device, the cone was canceled in the irradiation service mode. In the linear accelerator, 300 MU irradiation was made by changing the film for each of the 6 MeV -9 MeV -12 MeV -15 MeV -18 MeV electron energies. Using the same set-up conditions, the procedure was repeated for the roller, tandem-ovoid set and ring set applicators used in the application. In addition, under the same setup conditions, irradiations were repeated by giving 700 MU for all energies. In order to ensure image clarity, irradiation was performed using 1400MU, 2000 MU, 3000 MU under the same setup conditions at 6 MeV electron energy. After the irradiation of the films, the irradiation conditions and time were noted on the film, and the irradiated films were kept in a black envelope under appropriate storage conditions. In terms of clarity, the films were visually evaluated after 16 hours. EBT3s were irradiated at 2500 MU at only 15 MeV and 18 MeV electron energies.

RESULT and DISCUSSION

Cylindrical applicator: It is an applicator consisting of Polyarylsulfone (PPSU) and a guide tube of Polyaryletheretherketone (PEEK)/Titan. PPSU is basically a thermally stable thermoplastic consisting of phenyl and biphenyl groups bonded with ether and sulfone groups. This material has high resistance to high and low temperatures, impact resistance and resistance to chemicals and solvents. The guide tube, Polyaryletheretherketone (PEEK)/Titan, is a hybrid structure. The image of the irradiations made at 300 MU and 700 MU 12 MeV, 15 MeV and 18 MeV electron energies in the area opened to x=30 and y=2 cm at all energies in the cylinder applicator can be seen in Figure 1. In the irradiation with EBT3 film, the best image was obtained at 18 MeV and 2500 MU.

The ring tandem applicator set (60°) consists of Polyaryletheretherketone (PEEK) /Titan as in the cylinder applicator, which has the same structural feature. The ring tandem applicator (60°) was first irradiated with 300 MU in a 10x10cm area with RTQA2 film. Images were acquired starting from 12 MeV at 300 MU. At 700 MU, at 9 MeV , 12 MeV, 15 MeV and 18 MeV energies except 6 MeV, especially at 12 MeV and higher (15 MeV and 18 MeV) energies, the desired weld location was determined in both the ring and the tandem applicators. Desired image quality could not be achieved in 700 MU irradiation or 6 MeV electrons. In the EBT3 film, however, an image of 2500 MU was obtained at only 15 MeV and 18 MeV energies (Figure 2). Tandem double ovoid applicator features: the ovoid parts are made of acetyl and the intrauterine tandem part is made of titanium. In the tandem double ovoid application, the desired quality image could not be obtained with RTQA2 films at 300 MU and 700 MU in the ovoid and the irradiation dose was increased with 700 MU and 1500 MU at 18 MeV. In the tandem applicator, the desired image could be obtained at 9 MeV, 12 MeV, 15 MeV and 18 MeV at 700 MU. In Figure 3, there are 700 MU and 1500 MU images of RTQA2 films at 18 MeV energy. In addition, the comparison of the 30x2 cm field size with the irradiation made by increasing the field size (30x30cm) at 15 MeV at 300 MU and 700 MU, as an example, is shown in Figure 4.1400 MU, 2000 MU, 2500 MU and 3000 MU irradiations were repeated to improve the image quality at 6 MeV electrons. The image obtained at 3000 MU is shown in figure 5.

Results

When RTQA2 films are used, the image of dummy sources is formed from 9 MeV in the irradiation made at 300 MU 6 MeV,9 MeV.12 MeV,15 MeV,18 MeV electron energy, in the area opened in the cylinder applicator at all energies x=30 and y=2 cm. It was very clear at 15 MeV and 18 MeV, when 700 MU was given under the same set-up conditions. It was determined that all dammy sources were clearly seen, including 6 MeV, even though the film background was darker (Figure 1). 300 MU and 700 MU are seen at energies of 12 MeV and above.

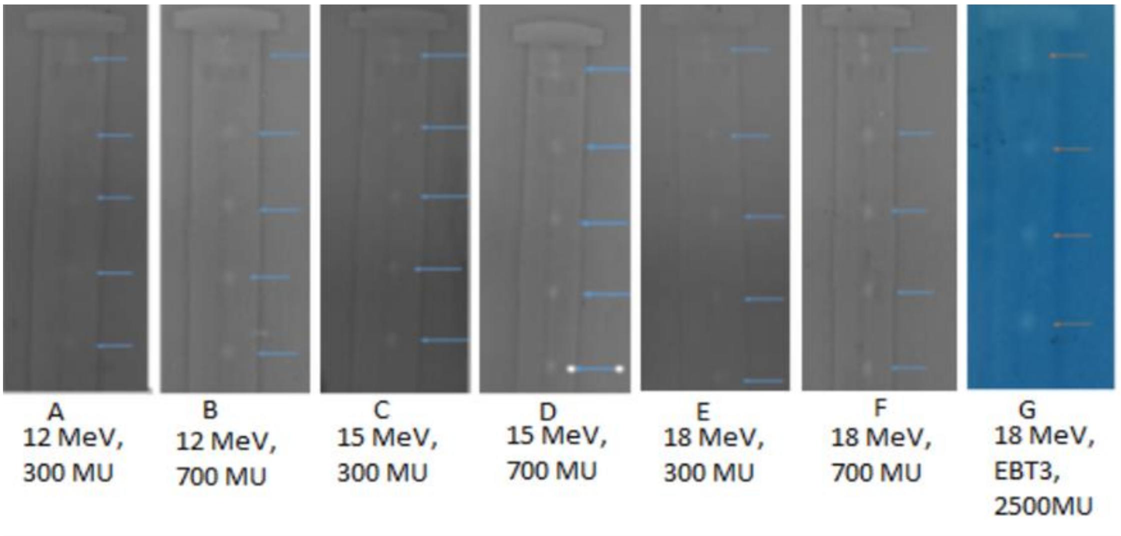

Figure 1:RTQA2 film,300 MU (A-12 MeV,C-15 MeV,E-18 MeV) and 700 MU (B-12 MeV,D-15 MeV,F-18 MeV), field 30x2 cm, G- EBT3 film, 18 MeV, 2500 MU

When the ring tandem applicator (60°) was irradiated with 300 MU in a 10x10cm size, the image could not be obtained. Also, at 700 MU, at 9 MeV, 12 MeV, 15 MeV and 18 MeV energies, especially at 15 MeV and 18 MeV energies, the desired dwell position was determined in both the ring applicator and the tandem applicator as in Figure 2.

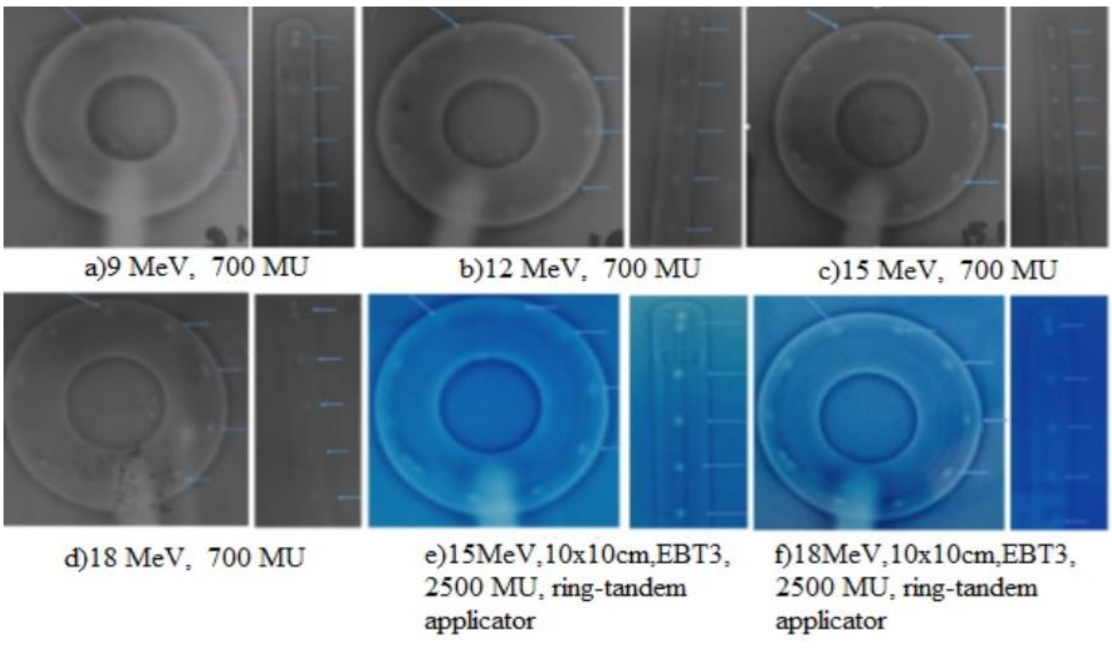

Figure 2: RTQA2 film with cylindrical applicator and 60° tandem at 700 MU different energies (a-d). 10x10 area aperture is used to obtain the vision of the radiation. e) At 15 MeV, 250 MU, EBT3 vision f) at 18 MeV 250 MU and EBT3 vision

In the tandem double ovoid application, the desired quality image of 300 MU could not be obtained in the ovoid. At 700 MU, an image was obtained at 18 MeV in a 20x20 field (Figure 3). A clear image was obtained at 1500 MU at 18 MeV.

In the tandem applicator, the desired image was obtained at 9 MeV , 12 MeV and 15 MeV at 700 MU. The clear image at 700 and 1500 MU irradiations for 18 MeV energy, in which both tandem and ovoid appears, is available in Figure3.

In addition, as seen in Figure 4, in 300 MU and 700 MU irradiations with 30x2 cm and 30x30cm field sizes at 15 MeV energy, where the clear image is taken by taking the cylinder applicator as an example, the image sharpness increases as the field size increases.

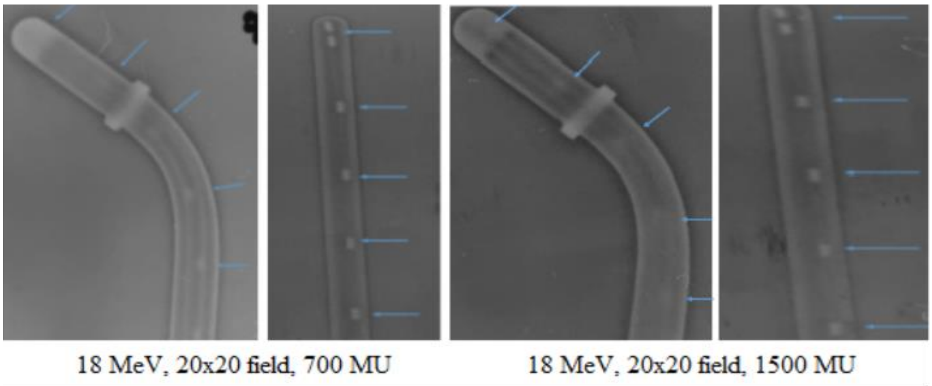

Figure 3: Applicators in tandem-ovoid applications at different 18 MeV and MU vision

When it comes to obtaining images at low energies (6MeV), it is possible to obtain images by increasing the MU (Figure 5). Similarly, if an image cannot be obtained from 100 cm of the Source-Skin-Distance (SSD), it is possible to obtain a clear image by replacing the SSD.

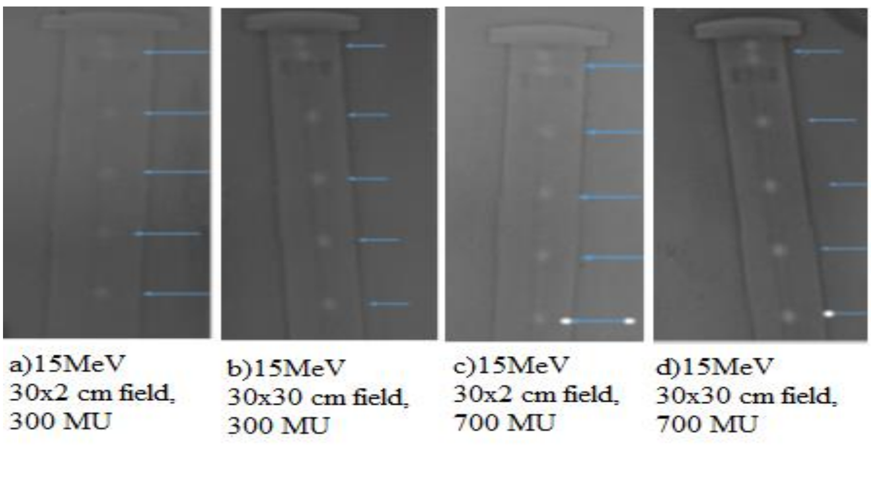

Figure 4: Effect of different field sizes on the image when energy and MU are constant.

By using the SSD differently from the standard SSD and increasing the MU, the desired image clarity can be achieved according to the applicators to be used.

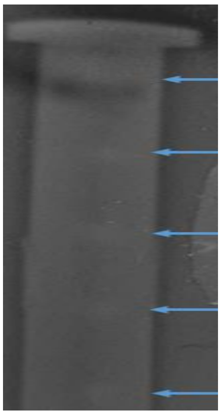

Figure 5: 30x2 cm 6 MeV, 3000 MU

Discussion

Since the beginning of the 2000s, depending on the development of technology, rapid developments in planning systems and imaging systems have generated a patient-based, established quality control program in external treatment. The absence of a patient-specific QA process in brachytherapy contradicts external radiotherapy techniques (IMRT, VMAT, etc.) Like external therapy in brachytherapy, it can have steep dose gradients in the transition to tissues. In recent years, adaptive brachytherapy applications have made widespread use of various image guidance techniques. As a result, new challenges have emerged for brachytherapy QA programs [11,12]. Brachytherapy practices include procedures performed by different professionals (radiation oncologists, radiation physicists, dosimetrists, nurses, and treatment technicians). It is possible that one of them can be a potential source of error and a chain of treatment errors that may occur due to this. Possible errors in the process of brachytherapy procedures, starting from quality control to treatment, can sometimes lead to serious irreversible problems in treatment. Since brachytherapy treatments are usually administered in fractions, the possible side effects due to errors may increase further [13].

For a high dose rate (HDR) brachytherapy treatment, it must be ensured that the dose given is correct and reliable. This can only be achieved by the effectiveness of the radioactive source, the length of the source connecting tubes and catheters, the correct and reliable positions of the source waiting positions, the correct and reliable residence time in each. The ^{192}Ir source has a half-life of 74 days, requiring replacement of the iridium source approximately four times a year to maintain acceptable dose rates and treatment times. Quarterly QA testing for HDR is recommended in the TG 56 report. This corresponds to approximately the change in resources [14]. After source replacement, source activity should be verified with appropriate cylindrical and well-type ion chambers with a secondary or primary laboratory calibrated calibration coefficient. Subsequently, the quality control procedures necessary to determine the positional accuracy of the welding motion mechanism are provided by radiographic film [15].

The use of radio chromic films for quality control and dose measurements in brachytherapy extends to studies by Sayeg and Gregory [16] who measured surface dose rates with high-dose-rate (HDR) beta-particle ophthalmic applicators. Evans et al. [17] introduced a QA check in 2007 for source positioning using radio chromic instead of conventional radiographic film. One of the changes that has occurred over the last 20 years is that many clinics around the world no longer have dark rooms and film processing equipment. As a result, the use of radiographic film for HDR brachytherapy quality assurance is no longer possible. An alternative is to use radio chromic film [18]. Because these films have high irradiation dose ranges, they are difficult to irradiate with normal C-arm X-ray, plain radiography or Computed tomography (CT). For this, we looked at the effect of different electron energies on the calibration films in terms of practicality, in line with clinical possibilities. In terms of clarity, it was observed that the desired image quality was obtained at energies above 12 MeV, especially at 15 MeV and 18 MeV energies. Taran Paulsen Hellebust and colleagues (2010) say that the desired quality image can be achieved with MR images in their work [19]. Wachowicz et al. (2006), in their study, stated that although the titanium material is MRI compatible, it reveals sensitivity artifacts in the images [20]. Some of the applicators we use are also made of titanium or hybrid alloys containing titanium, according to the catalogue. Especially at high energy (15 MeV and 18 MeV) electron energies, the desired image quality was achieved in RTQA2 films without artifacts. In EBT3 films, a similar image was obtained at 2,500 MU only at energies above 15 MeV.

CONCLUSION

In brachytherapy weld localization tests, RTQA2 films are very effective in providing source localizations depending on the material of the applicator used. In terms of practicality and routine clinical use, RTQA2 films can be easily used for brachytherapy source localization in the applicator in routine practice, with irradiation of 700 MU at 12 MeV and above energies, especially at 15 MeV and 18 MeV electron energies, and at 18 MeV 2500 MU in EBT 3 films. This method was incorporated into the clinical practice procedure, to be used as needed.

When necessary, it is possible to obtain the desired source positioning image with electron energy by looking at the dose-response relationship of the films and adjusting the energy, MU, SSD and field sizes.

Additional Statement

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- Throughout the entire process of the article, IJIASR's research and publication ethics principles were followed.
- These authors declare that there is no conflict of interest.
- These authors share first authorship

REFERENCES

[1]. ESTRO-BOOKLET NO. 8. A practical guide to quality control of brachytherapy equipment. *Edited by:* Jack Venselaar, José Pérez-Calatayud. *European Guidelines for Quality Assurance in Radiotherapy, ESTRO Booklet No.8,* 2004 – First edition. ISBN 90-804532-8©2004 by ESTRO

[2]. Rivard MJ, Coursey BM, DeWerd LA et al. Update of AAPM Task Group No. 43 Report: a revised AAPM protocol for brachytherapy dose calculations. *Med Phys* 2004;31: 633–74. https://doi.org/10.1118/1.1646040

[3]. Rivard MJ, Butler WM, DeWerd LA et al. Supplement to the 2004 update of the AAPM Task Group No. 43 Report. *Med Phys* 2007; 34:2187–2205. https://doi.org/10.1118/1.27367 90.

[4]. Daskalov GM, Kirov AS, Williamson JF. Analytical approach to heterogeneity correction factor calculation for brachytherapy. *Med Phys* 1998; 25:722–35. https://doi.org/10.1118/ 1.598254.

[5]. Chandola RM, Tiwari S, Kowar MK et al. Effect of inhomogeneities and source position on dose distribution of nucletron high dose rate Ir-192 brachytherapy source by Monte Carlo simulation. *J Cancer Res Ther* 2010; 6:54–77. https://doi.org/10.4103/0973-1482.63567.

[6]. Uniyal SC, Naithani UC, Sharma SD et al. Radiochromic film dosimetry of rectal inhomogeneity and applicator attenuation in high dose rate brachytherapy of uterine cervix. *J Appl Clin Med Phys* 2012; 13:66–75. https://doi.org/10.1120/jacmp.v13i1.3654.

[7]. Kutcher J, Coia L, Gillin M et al. Comprehensive QA for Radiation Oncology: Report of AAPM Radiation Therapy Committee Task Group 40, AAPM Report No. 46. *American Association of Physicists in Medicine American Institute of Physics (AAPM),* New York, 1994. https://onlinelibrary.wiley.com/doi/full/10.1118/1.597316%0Ahttps://onlinelibrary.wiley.com/doi/abs/10.1118/1.597316%0Ahttps://aapm.onlinelibrary.wiley.com/doi/10.1118/1.597316.

[8]. Nath R, Anderson LL, Meli J et al. Code of practice for brachytherapy physics: Report of the AAPM Radiation Therapy Committee Task Group No. 56. *Med Phys* 1997; 24:1557–98. https://doi.org/ 10.1118/1.597966.

[9]. Jursinic PA.Quality Assurance Measurements for High-Dose-Rate Brachytherapy without Film. *J Appl Clin Med Phys* 2014;15(1):246–61.https://doi.org/10.1120/jacmp.v15i1.4586.

[10]. Niroomand RA, Blackwell CR, Coursey BM, et al. Radiochromic Film Dosimetry: Recommendations of AAPM Radiation Therapy Committee Task Group 55. *Med Phys* 1998; 25(11): 2093–2115. https://doi.org/10.1118/1.598407.

[11] Williamson, J F. 'Current Brachytherapy Quality Assurance Guidance: Does It Meet the Challenges of Emerging Image-Guided Technologies?' *Int J Radiat Oncol Biol Phys* 2008;71 (1 SUPPL.): 18–22. https://doi.org/10.1016/j.ijrobp.2007. 07.2388.

[12] Cormack RA. Quality assurance issues for computed tomography, ultrasound, and magnetic resonance imaging-guided brachytherapy. *Int J Radiat Oncol Biol Phys* 2008;71:136-141. https://doi.org/10.1016/j.ijrobp.2007.07.2389.

[13] Thomadsen B, Lin S W, Laemmrich P, et al. Analysis of Treatment Delivery Errors in Brachytherapy Using Formal Risk Analysis Techniques. *Int J Radiat Oncol Biol Phys* 2003;57(5):1492–1508. https://doi.org/10.1016/S03603016(03) 01622-5.

[14].Ravinder N, Lowell LA. Code of practice for brachytherapy physics: Report of the AAPM Radiation Therapy Committee Task Group No. 56, *Med Phys 1997*; Vol. 24, No. 10, doi.org/10.1118/1.597966

[15]. DeWerd L A., Jursinic P, Kitchen R, et al Quality Assurance Tool for High Dose Rate Brachytherapy. *Med Phys* 1995; 22 (4): 435–40. https://doi.org/10.1118/1.597469.

[16] Sayeg, J. A., and R. C. Gregory. A New Method for Characterizing Beta-Ray Ophthalmic Applicator Sources. *Med Phys* 1991;18 (3): 453–61. https://doi.org/10.1118/1.596693.

[17] Evans, M. D.C., S. Devic, and E. B. Podgorsak. High Dose-Rate Brachytherapy Source Position Quality Assurance Using Radiochromic Film. *Med Dosimetry* 2007;32 (1): 13–15. https://doi.org/10.1016/j.meddos.2006.10.001

[18]. Niroomand-Rad A, Blackwell CR, Coursey BM, et al.Radiochromic Film Dosimetry: Recommendations of AAPM Radiation Therapy Committee Task Group 55. *Med Phys* 1998; 25 (11): 2093–2115. https://doi.org/10.1118/1.598407.

[19]. Hellebust, TP, Kirisits C, Berger D, et al. 'Recommendations from Gynaecological (GYN) GEC-ESTRO Working Group: Considerations and Pitfalls in Commissioning and Applicator Reconstruction in 3D Image-Based Treatment Planning of Cervix Cancer Brachytherapy'. *Radiot and Oncol* 2010; 96 (2): 153–60. https://doi.org/10.1016/j.radonc.2010. 06.004.

[20]. Wachowicz K, Thomas SD, Fallone BG. Characterization of the Susceptibility Artifact around a Prostate Brachytherapy Seed in MRI. *Med Phys* 2006; 33 (12): 4459–67. https://doi.org/10.1118/1.2364052.