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Original Article

Developing a Verification and Training Phantom for Gynecological Brachytherapy System

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Abstract

Introduction
Dosimetric accuracy is a major issue in the quality assurance (QA) program for treatment planning systems (TPS). An important contribution to this process has been a proper dosimetry method to guarantee the accuracy of delivered dose to the tumor. In brachytherapy (BT) of gynecological (Gyn) cancer it is usual to insert a combination of tandem and ovoid applicators with a complicated geometry which makes their dosimetry verification difficult and important. Therefore, evaluation and verification of dose distribution is necessary for accurate dose delivery to the patients.
Materials and Methods
The solid phantom was made from Perspex slabs as a tool for intracavitary brachytherapy dosimetric QA. Film dosimetry (EDR2) was done for a combination of ovoid and tandem applicators introduced by Flexitron brachytherapy system. Treatment planning was also done with Flexiplan 3D-TPS to irradiate films sandwiched between phantom slabs. Isodose curves obtained from treatment planning system and the films were compared with each other in 2D and 3D manners.
Results
The brachytherapy solid phantom was constructed with slabs. It was possible to insert tandems and ovoids loaded with radioactive source of Ir-192 subsequently. Relative error was 3-8.6% and average relative error was 5.08% in comparison with the films and TPS isodose curves.
Conclusion
Our results showed that the difference between TPS and the measurements is well within the acceptable boundaries and below the action level according to AAPM TG.45. Our findings showed that this phantom after minor corrections can be used as a method of choice for inter-comparison analysis of TPS and to fill the existing gap for accurate QA program in intracavitary brachytherapy. The constructed phantom also showed that it can be a valuable tool for verification of accurate dose delivery to the patients as well as training for brachytherapy residents and physics students.

Keywords: Film Dosimetry, GYN Brachytherapy Phantom, Quality Assurance

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1. Introduction

In brachytherapy (BT) of gynecological (Gyn) cancer, the aim is to insert radioactive sources in endometrium and vagina to deliver boost dose to primary target volume and minimize radiation to normal organs. Many factors such as rapid dose fall-off near the sources and difficulties in localizing the tumor and normal organs make it difficult to reach this purpose. At present, Ir-192 sources with different arrangements are used in Gyn intracavity applicators. There are programs to calculate dose rate in different points or irradiated volume, but there is yet uncertainty in dosimetry because of applicators complicated geometry [1]. During intracavity treatment, the position of source is determine by applicator geometry and physical treatment planning including selection of applicator type and dwell positions and times according to the source strength to deliver the dose to desired volume [2]. Physical treatment planning and ensuring its accurate performance as well as understanding the abilities, potentials and limitations of the system are the most important parts of the BT procedure [3].

Finding a practical dosimetric method, leads us to the design and construction of a suitable solid phantom to obtain three-dimensional dose distribution, while using the tandem and ovoid applicators. Present work reports a newly developed phantom for insertion of Gyn applicators with capability of doing film dosimetry for the purpose of TPS dosimetry verification in a three-dimensional manner, and teaching physical intracavity BT procedure.

2. Materials and Methods

The phantom has been made for medium size ovoid (2.5 cm diameter) and 5 cm tandem (60º curvature) applicators [4]. In order to build this transportable gynecological solid phantom, Perspex material with near water equivalent density was used to simulate the soft tissues in the pelvic cavity (Figure 1) [5]. This phantom consists of one stand and two container boxes with approximate weight of four kilograms to hold Perspex slabs firm in place.

The main container is made from 2 mm thick Perspex slabs and represents the pelvic cavity where the applicators can be inserted (Figure 1). The dimensions of this container are 17 cm length, 14 cm width, and 10 cm height. Each slab was precisely engraved by laser beam according to the applicator geometry at different levels. In one end, a hollow-like cavity was formed in which the gynecological applicators could be inserted with a minimum maneuver. During irradiation, extra slabs were used to surround the phantom to provide full scatter condition. The applicators were inserted from the front side of the phantom as it was shown in the Figure1. The lower container was filled with 2 mm simple slabs. The length and width of this container is the same as the main container, but the height is different (Figure 1).

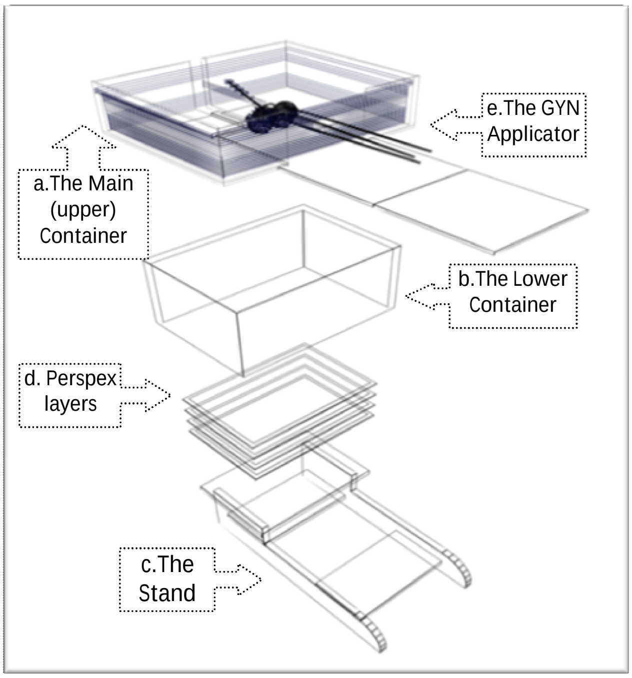

Figure 1. Preliminary plan of portable solid slab phantom constructed in the present work. Different components and layers of the phantom are shown according to the design: a) upper (main) container, b) lower container, c) stand, d) Perspex slabs, and e) Gyn applicator (combination of two ovoids and a tandem inserted in the phantom.

Radiographic film (Extended Dose Range – EDR2, Eastman Kodak Company, Rochester, NYd) was used for 3D dosimetry. After calibration, films were sandwiched between slabs from the lowest surface of the ovoid up to the tip of the tandem applicators. Each film was perforated according to the shape of the lower slab repeated for all films in the upper container. Extra Perspex slabs were used on the back and both lateral sides of the phantom in order to provide full scatter condition (Figure 2). Planning was done using the Flexiplan 3D planning system and then the Ir-192 sources were remotely loaded into the applicators by means of Flexitron [4] using an after-loading device to irradiate the films. A prescribed dose of 2 Gy was delivered to the anatomical points of A that geometrically are situated 2 cm above ovoid and 2 cm lateral to tandem applicators. Final setup is shown in Figure 2. Matlab software version 7.6.0 (R2008a) was used for mapping isodoses obtained from the films. Isodoses resulted from film dosimetry were compared with TPS isodoses in different points in 2D and 3D manner.

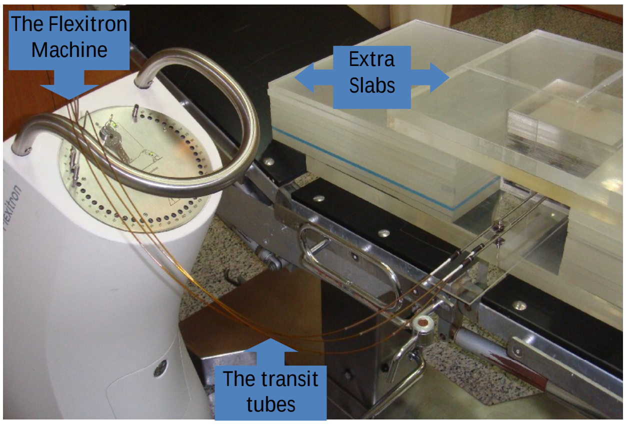

Figure 2. Irradiation setup: Slab phantom is connected to the Flexitron HDR machine by three transit tubes two for ovoids and a tandem applicator. To obtain full scatter condition slabs were also added around the phantom.

3. Results

The designed solid phantom was constructed using 17 laser shaped slabs. Films were sandwiched between their appropriate layers of phantom and exposure was done after connecting the inserted applicators to the BT machine. Dwelling times and positions of the single Ir-192 source were planned for delivery of 2 Gy dose to the point A. After processing and scanning the films, following images were obtained. (Figure 3a, b).

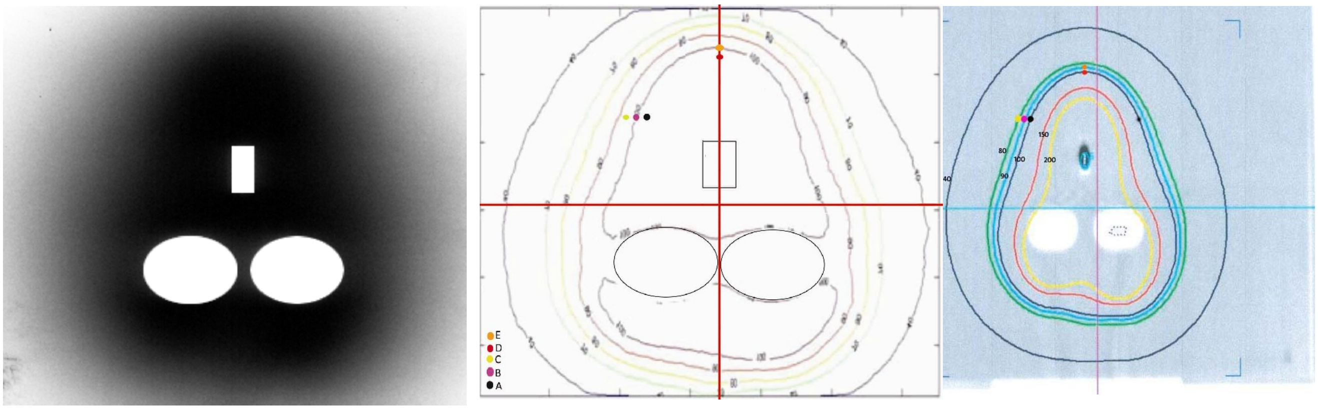

Figure 3. Irradiated film after processing and isodose distribution from film dosimetry: a) the processed film from dose distribution between slabs number 12 and 13 at the level of Ovoid and Tandem applicators. b) Isodose distribution of corresponding film, and c) Isodoses distribution from Flexiplan for the same plan.

Dose distribution from each film was mapped at different distances relative to the position of the applicators. Dose map on the films was compared with the isodose map obtained from the planning system for appropriate points (Figure 3c). The film and dose maps in Figure 3 corresponding to the plane that goes through the ovoid and a part of tandem are depicted in coronal view. Results in the Tables 1 to 5 show percentage dose for five different points within dose distribution area on both the films and planning report data on the typical plane and this procedure was repeated for all films at different planes. The points were located on both X and Z axes on isodoses of 100, 90, and 80 percent which were closer to the applicator. The average relative error was obtained to be equal to 5.08% for film dosimetry.

Table 1. The result of dose percent at five different points on typical film and planning report. These measurements were done on the sixth cut of the phantom.

Points of interest	X (cm)	Y (cm)	Z (cm)	Dose (%) Flexiplan	Dose (%) film	Relative Error (%)
A	0.7	0	2	100	100	0
B	1	0	2	90	95	5
C	1.5	0	2	80	90	11
D	0	0	2.1	100	98	2
E	0	0	2.4	90	91	2
Average relative errors of the sixth plane						4

Table 2. The result of dose percent at five different points on typical film and planning report. These measurements were done on the ninth cut of the phantom.

Points of interest	X (cm)	Y (cm)	Z (cm)	Dose (%) Flexiplan	Dose (%) film	Relative Error (%)
A	2.3	0	2	100	100	0
B	2.5	0	2	90	95	5
C	2.8	0	2	80	80	0
D	0	0	3.4	100	110	9
E	0	0	3.6	90	100	5
Average relative errors of the ninth plane						3.8

Table 3. The result of dose percent at five different points on typical film and planning report. These measurements were done on the twelth cut of the phantom.

Points of interest	X (cm)	Y (cm)	Z (cm)	Dose (%) Flexiplan	Dose (%) film	Relative Error (%)
A	1.9	0	2	100	105	4
B	2.1	0	2	90	100	10
C	2.4	0	2	80	95	15
D	0	0	4.3	100	105	4
E	0	0	4.5	90	100	10
Average relative errors of the twelth plane						8.6

Table 4. The result of dose percent at five different points on typical film and planning report. These measurements were done on the thirteenth cut of the phantom.

Points of interest	X (cm)	Y (cm)	Z (cm)	Dose (%) Flexiplan	Dose (%) film	Relative Error (%)
A	1.8	0	2	100	90	10
B	2	0	2	90	85	5
C	2.2	0	2	80	80	0
D	0	0	3.4	100	105	4
E	0	0	3.5	90	100	11
Average relative errors of thirteenth plane						6

Table 5. The result of dose percent at five different points on typical film and planning report. These measurements were done on the fifteenth cut of the phantom.

Points of interest	X (cm)	Y (cm)	Z (cm)	Dose (%) Flexiplan	Dose (%) film	Relative Error (%)
A	2.6	0	2	100	100	0
B	2.8	0	2	90	95	5
C	3	0	2	80	85	5
D	0	0	4.8	100	100	0
E	0	0	4.9	90	95	5
Average relative errors of the fifteenth plane						3

This phantom provides the possibility of dosimetry for different source arrangements which usually come from treatment planning system. It is also suitable for definition of different geometrical points like A, B, and virtual reference points in anterior wall of rectum and bladder. In addition, this phantom can also be used for measurement of dose distribution in a non-specific condition as a part of quality assurance (QA) program for verification of TPS dose calculation in Gyn BT by means of tandem and ovoid applicators.

4. Discussion

Gyn BT requires insertion of both tandem and ovoid applicators in endometrium and cervix of uterus respectively to provide appropriate pear shape dose distribution for the primary volume target [6]. In this study, the appropriate 3D TPS dose distribution to determine dwell times and positions of Ir-192 sources was done and the accuracy of treatment planning using dose distribution map of film dosimeters was evaluated and compared with TPS output.

Differences between results of treatment planning and film measurements might be due to the TPS calculation method in which a uniform water equivalent phantom is assumed. This is further supported by the findings of Meigooni et al. [7] and Lewis et al [8]. Also our results are in line with those of Hill et al. [9] who studied transmission values of Perspex and water. However, in our experiment, measurements were done within a solid phantom with approximate density 1.17- 1.20 (gr/cm^3). These two environments have 19% differences in density and 9% differences in effective atomic number. Because of the low energy of the photons and great contribution of Compton in the reaction, small changes in atomic number does not change photons transport noticeably. However, density differences can be effective in attenuation of the two different environments. According to the recommendation of TG-43, if the desired source is low energy photon emitter and measurement environment is not liquid water, for solid water and similar water substitutes, it is required to use solid-to-liquid water conversion correction ranging within 5% to 15% in the 1–5 cm interval. Because some of the low atomic number (Z) media such as polystyrene, polymethylmethacrylate, or plastic water generally have more uniform and better-characterized compositions, these media may be possible candidates for future low-energy photon-emitting brachytherapy dosimetry studies. However, values for their plastic-to-water conversion coefficients, are expected to be larger than corresponding solid water corrections [10].

Moreover, some observed differences may be a result of dosimeters limitations. In case of film dosimetry, the accumulation of dust, dirt, chemicals, and even skin fat can introduce artifacts. The power and type of safelight should be designed so that the fogging effect is minimized [11]. Film contains silver bromide grains and both silver and bromine are high atomic number materials and X-ray interactions within these materials differ from materials with low atomic number such as soft tissues or water. Therefore, relative dose response strongly depends on relative photoelectric contribution and X-ray energy. Dose response dependense to energy because of changes in photoelectric mass absorption coefficient with Z^2 is noticeable in energies less than 400 keV [11]. Film scanner also reported to have an error in less than 1% of cases due to scanner inhomogeneity and warm-up effect of the scanner lamp which can be reduced by doing a pre-scan scanning. This results the presence of less than 2% total error because of the film and scanner systems [12].

In addition, a part of disagreement may be due to the position of the films between the slabs. We used tape at the cutting edge of the films to tighten them against the light. Because of the thickness, in some of the parts, full contact was not possible to achieve between film and slabs that resulted in the presence of air gap. The TPS calculation algorithm cannot detect the gaps in spite of their presence. The air gaps affect dose distribution on the dosimetry system but it is not detected by the planning system.

Gyn applicators within a special intracavity phantom can be recognized as a new device for studying and applying different planning techniques in HDR brachytherapy. In comparison with other Gyn phantoms, film dosimeter has its own advantages and gives us the possibility of dose mapping and obtaining isodose lines in different planes within the phantom. Ion chamber dosimeters that are mostly used in the available phantoms are not able to show the isodose curves and they can just be used for point dosimetry [12- 14]. In addition, film embedded in the phantom has not the limitation of other three-dimensional dosimeters (e.g. gel dosimeter) such as sensitivity to temperature and oxygenation as well as long time required to be read [15]. Moreover, Perspex material used in phantom construction does not have the problems during transport, set up, and filling water tanks in water phantoms [16].

In order to use the phantom for different sizes of Gyn applicators, upper component of the phantom has to be changed and this is the major disadvantage of this phantom. However, it can be a useful device for assessment of different treatment planning techniques and dosimetric calculations. It is possible to use this phantom for developing and implementating QA criteria.

This phantom provides the possibility to perform dosimetry for different source arrangements which usually come from treatment planning system. It is also suitable for defining different geometrical points such as A, B, and reference points of some body parts such as bladder and rectum in clinical situations. In addition, this phantom can also be used for measuring dose distribution in a non-specific condition as a part of QA program for verification of TPS dose calculations in Gyn brachytherapy by means of tandem and ovoid applicators.

5. Conclusion

A gynecologic brachytherapy phantom can be used for training BT in the clinical setting and showed to be a valuable tool for QA program as well as verification of treatment planning system even for non-standard conditions. Films with their high spatial resolution ability can be a dosimeter of choice for verification and QA of TPSs. Results of this work provide a good evidence for agreement in dose distribution in a definite clinical condition regarding doses to the reference points with a non-significant difference in accuracy.

According to the AAPM TG46 recommendation which declared an uncertainty of 15% in the delivery of prescribed dose as a more realistic level for intracavitary brachytherapy, (Hanson et al., 1991) [17], results of measurements in this phantom are seen within the acceptable boundaries. It is consistent with one of the QA aims that is achieving a desired level of accuracy and precision in the dose delivery.

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