Original Article

The Design of an Audit Test for ^{60}Co Brachytherapy Treatment Planning System

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Abstract

Background: Auditing the treatment planning system (TPS) software for a radiotherapy unit is of paramount importance in any radiation therapy department. A Plexiglas phantom was proposed to measure the ionization of ^{60}Co high dose rate (HDR) source and compare dose points in the planning system for auditing and verifying TPS. **Methods:** Auditing was performed using a Plexiglas phantom in an end-to-end test, and relative dose points were detected by a farmer-type ionization chamber and compared with the relative dose of similar points in TPS. The audit results were determined as pass optimal level (<3.3%), pass action level (between 3.3% and 5%), and out of tolerance (>5%). **Results:** The comparison of the collected data revealed that 80% of the measured values were ≤5% in the pass level, and 20% of the points were out of tolerance (between 5% and 6.99%). **Conclusion:** This study documented the appropriateness of the dosimetry audit test and this phantom design for the HDR brachytherapy TPS.

Keywords: *Audit, brachytherapy, dosimetry, Plexiglas phantom, radiotherapy*

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Introduction

One of the advantages of high dose rate (HDR) brachytherapy (BT) is short treatment time because of the high specific activity of the source. Radiotherapy centers worldwide have started using ^{60}Co sources as an alternative to ^{192}Ir. The ^{60}Co source is more cost-effective than^{192}Ir, and it has become popular because its longer half-life and mono-energetic radiation spectrum.[1-3]

In BT, determining accurate dose distribution in the treated volume is desirable. The dose calculation of BT is in accordance with the TG-43 U-1 report.[4] The total uncertainty in the delivered dose by BT is estimated to be between 5% and 10%, depending on the application, which is mainly derived physically and clinically.[5]

An audit is a crucial tool for verifying treatment planning system (TPS) modeling, treatment dose delivery, and quality assurance (QA) in radiation therapy planning. The audit guidelines provide valuable data improving quality and safety in the treatment process.[6-8]

Uncertainties aroused by imaging, treatment planning, dose delivery, and anatomical variations are the sources of errors in BT as such, it is of paramount importance to identify these uncertainties, their magnitude, and their impact on the patient's overall uncertainty in dose delivery.[9]

Some errors such as applicator reconstruction uncertainties, which lead to the inaccurate definition of the source dwell positions, and the high amount of prescribed dose (or estimating dwell times) cannot be detected by traditional methods such as a radiographic film or QA tools for mechanical source positions because they do not include the applicator reconstruction process. Accordingly, it is necessary to directly compare dose distribution between TPS and measurement points under the same condition as a clinical practice. To this end, we must have an "end-to-end" program for audit and QA dosimetry simulating a clinically treated organ. To minimize misadministration, an appropriate audit and QA need to be introduced and guarantee the accuracy of BT treatment.[10-17]

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Several BT dosimetry audits have been published over the last several years, in which various detectors and phantom designs have been adopted; however, there is no simple, comprehensive audit method available.[18] This study aimed to evaluate the accuracy of calculated dose distribution by the TPS of HDR-BT unit by using a simple homemade phantom and farmer ionization chamber, accessible in most radiation therapy centers, in a three-dimensional (3D) space.

Materials and Methods

Afterloading unit and treatment planning system

All measurements were performed in the BT ward of the clinical radiation oncology department, Golestan Hospital, Ahvaz, Iran. The afterloading machine Eckert and Ziegler BEBIG GmbH HDR system used with TPS named HDR plus, with TG43 U-1 formalism dose calculation and inverse planning optimization algorithm. This system uses a single ^{60}Co source, which moves in a stepping way and locates in planned dwell positions for planned dwell times in a tip to end of applicator direction, through either a single or series of transfer tubes connected to the patient applicators.

- A: Phantom from anterior view and holes used for chamber placement
- B: Holes A and B and their measurement points (their depth from anterior surface of phantom, 50 and 70 mm) and small holes for needle insertion from a lateral view
- C: Hole C and its measurement points.

Phantom

Measurements were performed by a phantom constructed from Plexiglas by the in-house design with a cube shape and 100 mm × 100 mm × 100 mm dimensions and nine cylindrical holes for chamber placement (9-mm diameter). It is fully illustrated in Figure 1, and the anterior view of the phantom is shown in Figure 2a. The size of the phantom is selected based on the clinical range of BT (local treatment).[14] For the applicator insertion, there is an array of 20 small holes with 2.2-mm diameters between chamber holes on the entire phantom surface, which are 11 mm away from each other. Eight stainless steel needles were used for being connected to the after-loading machine. Only eight of these holes were used based on the computed tomography (CT) scan imaging in phantom. Needle tips were placed in the 85-mm depth from the anterior surface of the phantom into small holes [Figure 2].

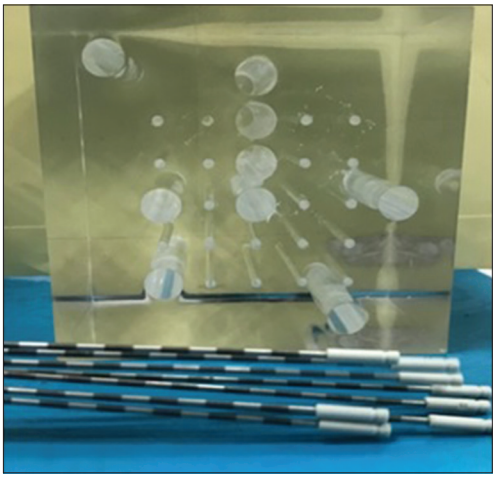

Figure 1: Anterior view from the surface of phantom and applied needles

Procedure for high dose rate brachytherapy dosimetry audit

The routine operating procedures utilized for the phantom similar to patients, including CT scan protocol, data transfer, planning process, plan export to multisource system, and dose delivery of the plan.

Applicator insertion and computed tomography scan procedure

To perform audits, stainless steel applicator needles used for routine interstitial implants were inserted into the designed small holes of the plexiglass phantom, as shown in Figure 2a. The CT scan was performed using the normal BT CT scan protocol with 0.2 cm slice thickness, and the CT scan images were then exported to TPS.

Treatment planning procedure

According to the clinical protocols, the applicators reconstructed the CT images. A virtual clinical target volume (CTV) around the contoured needles represents CTV. CTV segmentation in this study aimed for the auto-activation of dwell positions by using an inverse planning algorithm for three Gy prescribed doses. Six control points at three-chamber holes (namely A, B, and C with both 50 and 70 mm depths from the anterior surface of the phantom) were defined for the CT planning of the phantom [as shown in Figure 2b and c]. Using such a design for the concerned points, it is possible to evaluate dose distribution in three dimensions. The absolute and relative doses of the points were recorded as , representing

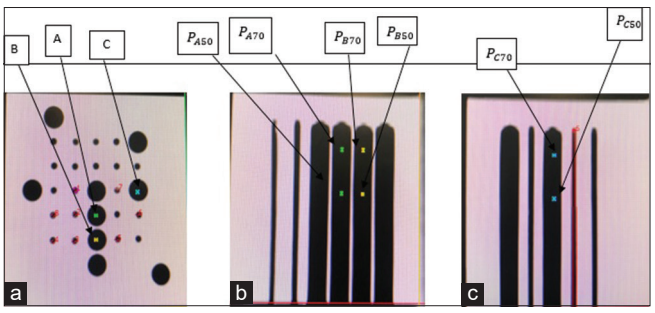

Figure 2: Phantom structure and needle insertions into a phantom and holes for chamber placement. These views are axial (a) and Coronal view (b and c) of a phantom taken from computed tomography scan planning of the phantom. $P_{x,y}$ is the point defined in hole x and depth y (mm) from the anterior surface of the phantom

a measured point located in hole x with depth y from the anterior surface of the phantom [Table 1].

Audit measurements

Before conducting the audit test, the QA tests of the BEBIG multisource revealed that the unit was reliable and reproducible. The measurements were made by farmer chamber (scanditronix, IBA) calibrated at Iran secondary standard dosimetry laboratory, with the calibration certificate No. 97020257. The dosimetry chamber was placed inside three holes (holes A, B, and C) in the phantom, with each hole in both 50 and 70 mm depths, similar to TPS control points definition. The empty small holes and other empty chamber holes were filled with water to provide a homogeneous media, according to the TG43 U-1 assumption. Finally, the plan was delivered by the multisource machine 18 times (three times for each position in the phantom), and the magnitude of ionization produced in the sensitive volume of chamber was recorded at each measurement point and relevant doses calculated for the points by TPS. The measurement results of the six points are shown in Table 1.

Results

The reference value of air-kerma rate in TG-43 U-1 dose calculation was extracted from the TPS library (=16145.4 cGycm^{2} $^{h-1}$).

The absolute and percentage doses of six defined points were recorded according to the TPS dose calculation. In this study, the relative ratios of doses at different points were calculated for TPS and the measurement data separately. Table 1 shows TPS dose points and measurements using Farmer chamber calculated for six points.

Table 1: Treatment planning system doses and percentage doses and the measured ionization values of six points in phantom

Dosimeter placement	Dosimetry depth (mm)	Audit measurement (nC)	TPS dose (Gy)	TPS percentage dose (%)
Hole A	5 ($P_{A,50}$)	65.29	3.255	108.5
	7 ($P_{A,70}$)	55.98	2.919	97.3
Hole B	5 ($P_{B,50}$)	62.26	3.054	101.8
	7 ($P_{B,70}$)	51.35	2.61	87.0
Hole C	5 ($P_{c,50}$)	55.91	2.847	94.9
	7 ($P_{c,70}$)	43.5	2.031	76.7

TPS – Treatment planning system

The relative difference error (RDE) between these two values for ratios from TPS and measurement was used to evaluate the TPS dose calculation accuracy. Table 2 shows the ratio of paired points from TPS value and measured values. The table also presents the RDE values between TPS calculation and phantom measurement. TPS shows the ratio of readings in TPS for two arbitrary points of TPS dose distribution, and *M* indicates the ratio of readings of similar points in the chamber setup. *M* and TPS are compared for each ratio, and the RDEs indicate the inaccuracy of TPS dos calculation in the proposed audit test. Audit results were determined as pass optimal level (RDE<3.3%), pass action level (RDE between 3.3% and 5%), and out of tolerance (RDE >5%).

Discussion

This study aimed to introduce a feasible audit program in ^{60}Co HDR BT. TG-43 U-1 dose calculation formalism assumes that all media is water, in which the small holes and chamber holes of the phantom filled with water reduce the origin of errors between measurement and TPS calculations.

Farmer ionization chamber has 0.6 cc measurement sensitivity, and because of this relatively large volume, it is not a suitable instrument to measure an absolute dose point in high gradient regions of dose distribution in BT. This is while the relative values between every two points in TPS and measurement in this trial are compared, and any error in chamber reading, which depends on the volume of the chamber and the setup of measurement, was almost eliminated (as the definition of the relative dose in external radiation therapy).

The farmer ionization chamber can be used in absolute dosimetry external beam radiation therapy because of its ionization volume. Here, this instrument is proposed to measure the relative dose of ionization and the relative dose for similar points in treatment planning. In this study, the distance of all the measurement points from the source is >1 cm, and the relative dose measurement with farmer under this condition (distance >5 mm) is allowed.[19] Accordingly, this design and setup propose an audit phantom, not applicable for absolute dose measurement. The attitude behind this design and the selection of chamber type was to perform relative measurements and compare them with the ratio of similar point doses from TPS and each other.

Table 2: Ratios between paired measurements point based on treatment planning system and M parameters and relevant relative difference error

Parameter	Ratio of points														
	P_{A50}/P_{A70}	P_{A50}/P_{B50}	P_{A50}/P_{B70}	P_{A50}/P_{C50}	P_{A50}/P_{C70}	P_{A70}/P_{B50}	P_{A70}/P_{B70}	P_{A70}/P_{C50}	P_{A70}/P_{C70}	P_{B50}/P_{B70}	P_{B50}/P_{C50}	P_{B50}/P_{C70}	P_{B70}/P_{C50}	P_{B70}/P_{C70}	P_{C50}/P_{C70}
M	1.17	1.05	1.27	1.17	1.5	0.9	1.09	1	1.29	1.21	1.11	1.43	0.92	1.18	1.29
TPS	1.12	1.07	1.25	1.14	1.41	0.96	1.12	1.03	1.27	1.17	1.07	1.33	0.92	1.13	1.24
RDE (%)	4.27	−1.9	1.6	2.6	6	−6.6	−2.75	−3	1.55	3.3	3.6	6.99	0	4.23	3.9

TPS – Treatment planning system; RDE – Relative difference error

Phantom design is one of the significant differences in different studies, which might have influenced the findings. In this research, the phantom dimensions were selected based on the practical range of BT techniques; however, in the TG-43 parameters and other theoretical assumptions, the medium in BT is assumed to be infinite. Accordingly, it can be considered as one of the sources of error in absolute dose measurement and can be partly eliminated because of calculating the relative values for each two-measurement value. In general, any uncertainty in measurement, including phantom type, chamber, and the design and setup of the phantom for all the measurement points, are almost identical while using their relative values. The positions for measurement points were selected randomly; however, they were in the localized target volume.

Our findings suggest RDE <5%. Similar to our findings, Diez *et al*. observed such discrepancies with gel dosimetry measurements among three holes (between 0.4% and 4.9%).[16] Ochoa *et al*. used the water phantom for measurements in Brazilian centers and reported the value of 3%.[15] In another study by Haworth *et al*., all the dosimetry values, except for one value where the dwell position was incorrectly applied, were 4.5% of the predicted value.[20] The source types and dose calculation algorithm might have caused the differences in different studies regarding the ranges. Lehmann *et al*. defined three deviation domains (<3.3%, between 3.3% and 5%, and >5% as pass optimal level, pass action level, and out of tolerance level, respectively). They found out that the audit pass rate for their measurements was 87%, while 53% was considered as optimal.[21] In Japanese Clinical Oncology Group clinical trials, all differences between the measured and planned doses at the measurement points were <3%.[22] The expanded uncertainty in point dose comparison using the described experimental techniques was estimated to be 5%. While the UK BT dosimetry audit was designed to use the BRachytherapy Applicator Dosimetry (BRAD) phantom to evaluate dose distribution, in combination with an alanine phantom to evaluate source strength, the agreement between the measured dose and prescribed dose was encouraging based on the limited set of pilot audit results.[23] Casey *et al*. reported that the total dose measurement uncertainty rates of the system were 2.4% and 2.5% for the Nucletron and Varian sources, respectively.[14]

In our study, 80% of measurements showed a pass rate (between 3% and 5%). This consistency of this finding with those of the aforementioned researches indicates that the end-to-end 3D dosimetry audits remain relevant. This is 20% of values in this study were set as out of tolerance because of the source type, measurement algorithm, dwell position effects on dosimetry values, and the number of measurement points or after-loaders.

Conclusion

The findings indicate that this development of an audit test with Farmer ionization chamber is an acceptable and appropriate approach for HDR-BT-TPS auditing, which would reduce errors in the treatment dose delivery.

Disclosure

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None.

Conflicts of interest

There are no conflicts of interest.

References

1. Gurjar OP, Batra M, Bagdare P, Kaushik S, Tyagi A, Naik A, *et al*. Dosimetric analysis of Co-60 source based high dose rate (HDR) brachytherapy: A case series of ten patients with carcinoma of the uterine cervix. Rep Pract Oncol Radiother 2016;21:201-6.
2. Sinnatamby M, Nagarajan V, Sathyanarayana RK, Karunanidhi G, Singhavajala V. Study of the dosimetric differences between (192)Ir and (60)Co sources of high dose rate brachytherapy for breast interstitial implant. Rep Pract Oncol Radiother 2016;21:453-9.
3. Rejab M, Wong JH, Jamalludin Z, Jong WL, Malik RA, Wan Ishak WZ, *et al*. Dosimetric characterisation of the optically-stimulated luminescence dosimeter in cobalt-60 high dose rate brachytherapy system. Australas Phys Eng Sci Med 2018;41:475-85.
4. Rivard MJ, Coursey BM, DeWerd LA, Hanson WF, Huq MS, Ibbott GS, *et al*. Update of AAPM task group no. 43 report: A revised AAPM protocol for brachytherapy dose calculations. Med Phys 2004;31:633-74.
5. Tedgren ÅC, Bengtsson E, Hedtjärn H, Johansson Å, Karlsson L, Lamm IL, *et al*. Experience from long-term monitoring of RAKR ratios in 192Ir brachytherapy. Radiother Oncol 2008;89:217-21.
6. Clark CH, Jornet N, Muren LP. The role of dosimetry audit in achieving high quality radiotherapy. Phys Imaging Radiat Oncol 2018;5:85-7.
7. Palmer AL, Bradley DA, Nisbet A. Dosimetric audit in brachytherapy. Br J Radiol 2014;87:20140105-20140105.
8. Pasler M, Hernandez V, Jornet N, Clark CH, *et al*. Novel methodologies for dosimetry audits: Adapting to advanced radiotherapy techniques. Phys Imaging Radiat Oncol 2018;5:76-84.
9. Kirisits C, Rivard MJ, Baltas D, Ballester F, De Brabandere M, van der Laarse R, *et al*. Review of clinical brachytherapy uncertainties: Analysis guidelines of GEC-ESTRO and the AAPM. Radiother Oncol 2014;110:199-212.
10. Gholami S, Mirzaei H, Jabbary Arfaee A, Jaberi R, Nedaie H, Mahdavi SR, *et al*. A novel phantom design for brachytherapy quality assurance. Int J Radiat Res 2016;14:67-71.
11. Palmer AL, Bidmead M, Nisbet A. A survey of quality control practices for high dose rate (HDR) and pulsed dose rate (PDR) brachytherapy in the United Kingdom. J Contemp Brachyther 2012;4:232-40.

12. Palmer A, Mzenda B. Performance assessment of the BEBIG MultiSource high dose rate brachytherapy treatment unit. Phys Med Biol 2009;54:7417-34.
13. Okamoto H, Nakamura S, Nishioka S, Iijima K, Wakita A, Abe Y, *et al*. Independent assessment of source position for gynecological applicator in high-dose-rate brachytherapy. J Contemp Brachyther 2017;9:477-86.
14. Casey KE, Alvarez P, Kry SF, Howell RM, Lawyer A, Followill D. Development and implementation of a remote audit tool for high dose rate (HDR) Ir-192 brachytherapy using optically stimulated luminescence dosimetry. Med Phys 2013;40:112102.
15. Ochoa R, Gómez F, Ferreira IH, Gutt F, de Almeida CE. Design of a phantom for the quality control of high dose rate 192Ir source used in brachytherapy. Radiother Oncol 2007;82:222-8.
16. Diez P, Aird EG, Sander T, Gouldstone CA, Sharpe PH, Lee CD, *et al*. A multicentre audit of HDR/PDR brachytherapy absolute dosimetry in association with the INTERLACE trial (NCT015662405). Phys Med Biol 2017;62:8832-49.
17. Krause F, Risske F, Bohn S, Delaperriere M, Dunst J, Siebert FA. End-to-end test for computed tomography-based high-dose-rate brachytherapy. J Contemp Brachyther 2018;10:551.
18. Palmer AL, Diez P, Laura Gandon 3, Andrea Wynn-Jones 3, Peter Bownes 3, Chris Leeet al. A multicentre "end to end" dosimetry audit for cervix HDR brachytherapy treatment. Radiother Oncol 2015;114:264-71.
19. Hill R, Mo Z, Haque M, Baldock C. An evaluation of ionization chambers for the relative dosimetry of kilovoltage x-ray beams. Med Phys 2009;36:3971-81.
20. Haworth A, Wilfert L, Butler D, Ebert MA, Todd S, Bucci J, *et al*. Australasian brachytherapy audit: Results of the "end-to-end" dosimetry pilot study. J Med Imaging Radiat Oncol 2013;57:490-8.
21. Lehmann AA, Dunn L, Shaw M, Kenny J, Keehan S, Supple J, *et al*. Dosimetric end-to-end tests in a national audit of 3D conformal radiotherapy. Phys Imaging Radiat Oncol 2018;6:5-11.
22. Nakamura M, Minemura T, Ishikura S, Nishio T, Narita Y, Nishimura Y. An on-site audit system for dosimetry credentialing of intensity-modulated radiotherapy in Japanese Clinical Oncology Group (JCOG) clinical trials. Phys Med 2016;32:987-91.
23. Clark CH, Aird EG, Bolton S, Miles EA, Nisbet A, Snaith JA, *et al*. Radiotherapy dosimetry audit: Three decades of improving standards and accuracy in UK clinical practice and trials. Br J Radiol 2015;88:20150251.