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A method for verification of treatment times for high-dose-rate intraluminal brachytherapy treatment

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Original Article

Abstract

Purpose: This study was aimed to increase the quality of high dose rate (HDR) intraluminal brachytherapy treatment. For this purpose, an easy, fast and accurate patient-specific quality assurance (QA) tool has been developed. This tool has been implemented at Bahawalpur Institute of Nuclear Medicine and Oncology (BINO), Bahawalpur, Pakistan. **Methods**: ABACUS 3.1 Treatment planning system (TPS) has been used for treatment planning and calculation of total dwell time and then results were compared with the time calculated using the proposed method. This method has been used to verify the total dwell time for different rectum applicators for relevant treatment lengths (2-7 cm) and depths (1.5-2.5 cm), different oesophagus applicators of relevant treatment lengths (6-10 cm) and depths (0.9 & 1.0 cm), and a bronchus applicator for relevant treatment lengths (4-7.5 cm) and depth (0.5 cm). **Results:** The average percentage differences between treatment time T_M with manual calculation and as calculated by the TPS is 0.32% (standard deviation 1.32%) for rectum, 0.24% (standard deviation 2.36%) for oesophagus and 1.96% (standard deviation 0.55%) for bronchus, respectively. These results advocate that the proposed method is valuable for independent verification of patient-specific treatment planning QA. **Conclusion:** The technique illustrated in the current study is an easy, simple, quick and useful for independent verification of the total dwell time for HDR intraluminal brachytherapy. Our method is able to identify human error-related planning mistakes and to evaluate the quality of treatment planning. It enhances the quality of brachytherapy treatment and reliability of the system.

Keywords: Intraluminal; Brachytherapy; Independent Method; High Dose Rate

1. Introduction

The plan is to enhance the quality of intraluminal brachytherapy treatment. For this purpose, independent verification of total dwell time for individual patient is needed. The aim of current investigation is to develop an easy, accurate, simple and independent verification method for the authentication of treatment time of treatment planning system (TPS).

Brachytherapy is a vital part of radiotherapy for the malignancies of intralumen and is frequently used with external beam radiation therapy (EBRT) for radical/palliative treatment. Several studies have suggested that control rates are considerably enhanced with EBRT and brachytherapy[1-4]. High dose rate (HDR) remote after loading intraluminal brachytherapy has been commonly used all over the world[4]. The significance of independent verification of dosimetry earlier to HDR brachytherapy treatment delivery has been acknowledged universally. Thomadsen *et al.* recognized 44 errors in HDR brachytherapy treatment in data (1980-2001) from the Nuclear Regulatory Commission and International Atomic Energy Agency[5] Guidelines[6,7] recommended the independent confirmation about the procedures for a pre-treatment

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review of the treatment planning system and the computer algorithms employed to calculate the dose distributions across the planning target volume (PTV). Techniques are required to be put into practice in order to reduce systematic and random errors in planning and treatment procedures as well. The input to treatment planning system can be provided with multimodality images (i.e. CT/MRI/Orthogonal X-rays/Ultrasound) and this software, enabled the medical physicists to maximize the dose uniformity, whilst minimizing the implant volume required to cover the target volume sufficiently as well as lessens the dose to the organs at risk. Such flexibility makes a challenge for the medical physicists for the confirmation of the optimized treatment time with manual calculation technique, which takes only a few minutes while providing a high probability of noticing considerable mistakes/errors. Actually, patients are often have to wait for the duration of treatment planning with an applicator introduced by a radiation oncologist and there is a huge amount of time pressure on the planning procedure. During that time, errors/mistakes and miscommunications may easily happened. To detect these errors, the need of patient-specific QA as well as independent verification of the key treatment planning parameter (i.e. time) are obvious and have to be performed rapidly and easily to ensure the safety and accuracy of the treatment.

The literature has reported independent authentication techniques for external beam radiation therapy[8] and HDR brachytherapy treatment planning. A number of techniques for inspection of a brachytherapy treatment plan were reported. Various methods check on single-implant[9-12] or double- implants[13, 14]. Some verify intracavitary gynecological treatments[11, 12, 15, 16], volume implants[17-21] and endobronchial brachytherapy[13, 14]. Recently many investigators have developed in-house software to compute the dose at arbitrary points [22-24]. Such software may be helpful for the commissioning of TPS, in medical practice, human errors in individual treatment planning in radiotherapy will not be recognized because of the use of the similar coordinate system, digitized applicator paths and dose point coordinates as those in the treatment planning system.

Although sufficient literature is available for verification of treatment planning time but only few studies[13, 14] are available for bronchus brachytherapy and no literature regarding rectum and oesophagus was found. It was aimed to introduce intraluminal (oesophagus, bronchus and rectum) brachytherapy in our institute. This paper presents a very quick, simple and easy patient-specific independent verification method of the treatment time (sum of all dwell times) for intraluminal brachytherapy applicators. The time needed for confirmation is in the order of 10-15 seconds if an Excel spreadsheet is available otherwise 1-2 minutes, despite the nature of applicator. A negligible additional waiting time for the patient is needed for this verification process but it provides a valuable independent confirmation.

2. Methods and Materials

Bahawalpur Institute of Nuclear Medicine and Oncology has started radiotherapy in 1998 and HDR brachytherapy was made available in October 2004. Gynecological and surface malignancies are being treated with brachytherapy. It was intended to extend our services to other sites i.e. rectum, oesophagus and bronchus. For this purpose, authentication of treatment time as calculated by TPS is needed.

ABACUS 3.1 TPS, manufactured by Varian Medical Solutions, USA is used for the current investigations. The method proposed here is therefore intended to harmonize with the ABACUS 3.1 (but it is equally applicable to other TPS, like Plato TPS etc. and off course universal in nature). All dosimetric calculations were performed for a nominal 37 GBq (10 Ci) source strength and 7 Gy as prescribed doses; it can be used for other source strengths and prescribed doses. ABACUS 3.1 has been used for treatment planning and calculation of total nominal time first and then results were compared with proposed method. Treatment planning for intraluminal (oesophagus, bronchus and rectum) brachytherapy using different available applicators was aimed to be verified with the manual planning. The factors required for the calculation are the prescribed dose, the depth of dose prescription, the length of dose prescription and source strength.

Dose delivery time was calculated manually with the equation;

$$T_M = \frac{(R_L)*(ElongationFactor)*(60\ min/hour)*(60\ sec/min)*Dose}{(Activity)*(mg/mCi)*10^6} \quad (1)$$

This equation was derived from Johns *et al.*[25] by using long and away tables and converted to Iridium based on the exposure rate constant, which indicated that the manual calculation of time requires some values as input. These values i.e. R_L and elongation factor have been derived from Johns *et al.*[25] using Table 13.3 and Figure 13.5. The R_L is the mg.hr to deliver 1000 rads to a point h cm from the center of a linear source of active length L. From Table 13.3[25], find the value of length in first column and then go right in the corresponding row, where it intersects the corresponding treatment distance that value is for R_L. The elongation factor has been determined by taking the ratio of the length of treatment/ distance of treatment (ratio of L/h). Then using Figure 13.5[25] (that looks like a Gaussian curve at the bottom of the page) ratio of L/h vs percent increase is obtained and go straight up on the graph, and look across for the percent increase in the value. Then the value we get, suppose it was 16 on the y-axis, the elongation factor is going to be 1.16 because it is a percentage increase of dose due to lateral scatter, and contribution from surrounding sources. The conversion

factor from Radium-226 to Iridium-192 is mg/mCi = 0.5648. The applicators available at XINO for rectum, esophagus and bronchus manufactured by Varian Medical Solution, USA and are compatible with Gamma Med plus HDR unit and ABACUS 3.1 TPS have been used for this study as shown in Figure 1. MS Excels, SPSS 16.0 have been used for data analysis. EndNote 5 has been used for reference management.

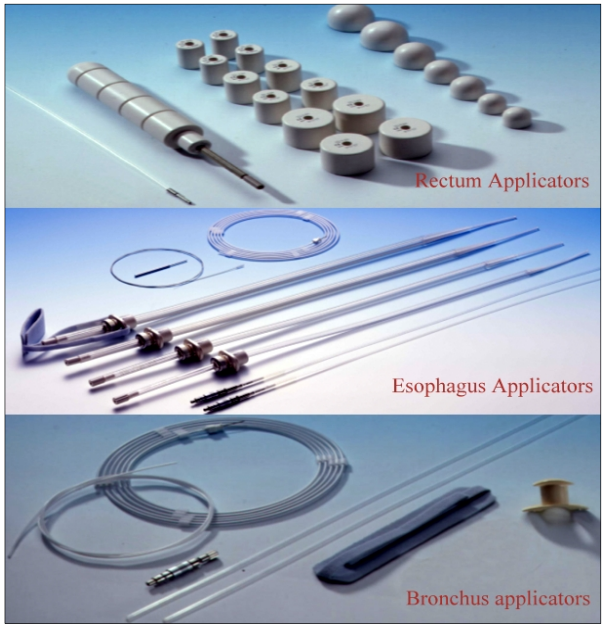

Figure 1: Different applicators for rectum, esophagus and bronchus.

2.1 Method's evaluation

To evaluate the proposed method for clinical use and validation of TPS for intraluminal applications, it was used to verify the total dwell time for three different diameters (2, 3 and 4 cm) rectum applicators for clinical relevant treatment lengths (2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 5.5, 6.0, 6.5, and 7.0 cm) and treatment depths (1.5, 2.0, and 2.5), three different diameters (8, 10 and 12 mm) oesophagus applicators for clinical relevant treatment lengths (6.0, 6.5, 7.0, 7.5, 8.0, 8.5, 9.0, 9.5 and 10.0 cm) and treatment depths (0.9 and 1.0 cm), and one (5 mm diameter) bronchus applicator for clinical relevant treatment lengths (4.0, 4.5, 5.0, 5.5, 6.0, 6.5, 7.0 and 7.5 cm) and treatment depth (0.5 cm) are available at BINOXINO.

3. Results

The objective was to confirm the total nominal time calculated by means of ABACUS TPS with the help of manual method, for different treatment lengths and treatment depths by developing and implementing a fast and accurate secondary dose calculation technique for QA of HDR treatment planning. For 10 Ci activity of Iridium-192 and 0.5648 conversion factor (Radium to Iridium), the treatment time comparison for different applicators available for rectum, esophagus and bronchus as well as percentage difference between the results of both methods for different diameters, treatment depths and lengths have been calculated and results are presented in the tables 1-3. The average percentage difference between treatment time T_M with manual calculation and as calculated by the TPS was 0.32% (standard deviation 1.32%) for rectum, 0.24% (standard deviation 2.36%) for oesophagus and 1.96% (standard deviation 0.55%) for bronchus, respectively.

Comparison between the treatment times as calculated by TPS and manual method for different rectum, oesophagus and bronchus applicators are graphically depicted in figures 2-4 respectively.

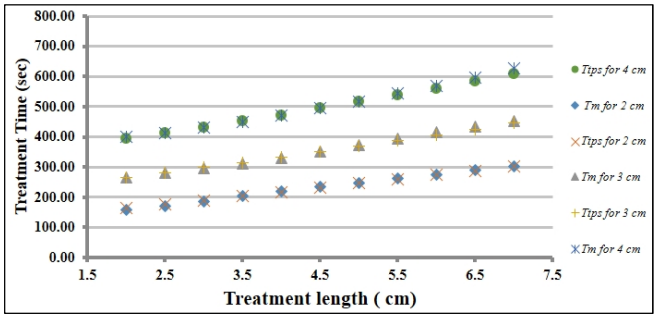

Figure 2: Comparison between the treatment times as calculated by TPS and manual method for different rectum applicators.

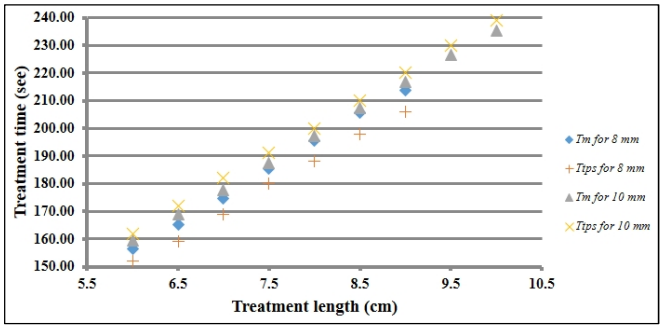

Figure 3: Comparison between the treatment times as calculated by TPS and manual method for different esophagus applicators.

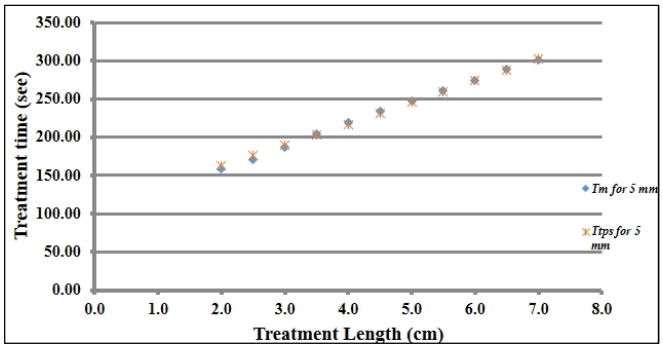

Figure 4: Comparison between the treatment times as calculated by TPS and manual method for different bronchus applicators.

Table 1: Percentage difference between total nominal time calculated by the manual method and Abacus 3.1 for available rectum applicators.

Treatment Length L (cm)	Ratio L/h	Elongation Factor	R_L	Prescribed dose (Gy)	T_M (see)	T_{TPS} (See)	% Difference
2.0 cm dia Rectum applicator, 1.5 cm Treatment height (depth)							
2.0	1.33	1.110	320.0	7.0	158.48	163	-2.85
2.5	1.67	1.130	340.0	7.0	171.42	176	-2.67
3.0	2.00	1.145	365.0	7.0	186.47	190	-1.89
3.5	2.33	1.170	391.0	7.0	204.11	203	0.54
4.0	2.67	1.180	417.0	7.0	219.55	217	1.16
4.5	3.00	1.180	444.0	7.0	233.76	231	1.18
5.0	3.33	1.180	471.0	7.0	247.98	246	0.80
5.5	3.67	1.170	500.5	7.0	261.27	260	0.49
6.0	4.00	1.160	530.0	7.0	274.31	274	0.11
6.5	4.33	1.160	559.0	7.0	289.32	288	0.46
7.0	4.67	1.150	588.0	7.0	301.70	303	-0.43
3.0 cm dia Rectum applicator, 2.0 cm Treatment height (depth)							
2.0	1.00	1.085	546.0	7.0	264.32	265	-0.26
2.5	1.25	1.100	569.0	7.0	279.26	281	-0.62
3.0	1.50	1.120	594.0	7.0	296.83	298	-0.39
3.5	1.75	1.130	620.0	7.0	312.59	315	-0.77
4.0	2.00	1.135	650.0	7.0	329.17	333	-1.16
4.5	2.25	1.150	684.0	7.0	350.96	351	-0.01
5.0	2.50	1.165	718.0	7.0	373.21	369	1.13
5.5	2.75	1.170	752.0	7.0	392.56	388	1.16
6.0	3.00	1.180	789.0	7.0	415.40	406	2.26
6.5	3.25	1.180	826.0	7.0	434.88	426	2.04
7.0	3.50	1.175	864.0	7.0	452.96	445	1.76
4.0 cm dia Rectum applicator, 2.5 cm Treatment height (depth)							
2.0	0.80	1.080	830.0	7.0	399.95	393	1.74
2.5	1.00	1.085	851.0	7.0	411.97	411	0.24
3.0	1.20	1.100	877.0	7.0	430.43	431	-0.13
3.5	1.40	1.110	905.0	7.0	448.21	451	-0.62
4.0	1.60	1.122	943.0	7.0	472.07	472	0.02
4.5	1.80	1.130	980.0	7.0	494.09	494	0.02
5.0	2.00	1.135	1018.0	7.0	515.52	516	-0.09
5.5	2.20	1.150	1060.0	7.0	543.89	539	0.90
6.0	2.40	1.160	1101.0	7.0	569.84	561	1.55
6.5	2.60	1.170	1145.0	7.0	597.72	585	2.13
7.0	2.80	1.180	1189.0	7.0	625.99	609	2.71

Table 2: Percentage difference between total nominal time calculated by the manual method and Abacus 3.1 for available bronchus applicator.

Treatment Length L (cm)	Ratio L/h	Elongation factor	R_L	Prescribed dose (Gy)	T_M (see)	T_{TPS} (See)	% Difference
5 mm dia Bronchial applicator, 0.75 cm Treatment height (depth)							
4.0	5.33	1.145	163.0	7.0	83.27	85	-2.08
4.5	6.00	1.130	179.0	7.0	90.25	92	-1.94
5.0	6.67	1.110	195.0	7.0	96.57	99	-2.51
5.5	7.33	1.095	212.0	7.0	103.58	106	-2.34
6.0	8.00	1.095	228.0	7.0	111.39	113	-1.44
6.5	8.67	1.090	244.0	7.0	118.66	121	-1.97
7.0	9.33	1.085	260.0	7.0	125.87	127	-0.90
7.5	10.00	1.070	276.0	7.0	131.76	135	-2.46

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Table 2: Percentage difference between total nominal time calculated by the manual method and Abacus 3.1 for available esophagus applicators.

T. Length L (cm)	Ratio L/h	Elongation factor	R_L	Prescribed dose (Gy)	T_M (see)	T_{TPS} (See)	% Difference
8 mm dia Esophagus applicator, 0.9 cm Treatment height (depth)							
6.0	6.67	1.110	316.0	7.0	156.50	152	2.88
6.5	7.22	1.095	338.0	7.0	165.13	159	3.71
7.0	7.78	1.090	359.0	7.0	174.59	169	3.20
7.5	8.33	1.088	382.0	7.0	185.44	180	2.93
8.0	8.89	1.085	404.0	7.0	195.58	188	3.87
8.5	9.44	1.082	426.0	7.0	205.66	198	3.72
9.0	10.00	1.070	448.0	7.0	213.88	206	3.68
10 mm dia Esophagus applicator, 1.0 cm Treatment height (depth)							
6.0	6.0	1.130	316.0	7.0	159.32	162	-1.68
6.5	6.5	1.120	338.0	7.0	168.90	172	-1.83
7.0	7.0	1.110	359.0	7.0	177.80	182	-2.36
7.5	7.5	1.100	382.0	7.0	187.48	191	-1.88
8.0	8.0	1.095	404.0	7.0	197.38	200	-1.33
8.5	8.5	1.090	426.0	7.0	207.18	210	-1.36
9.0	9.0	1.085	448.0	7.0	216.88	220	-1.44
9.5	9.5	1.08	470.0	7.0	226.48	230	-1.55
10.0	10.0	1.07	493.0	7.0	235.36	239	-1.55
12 mm dia Esophagus applicator, 1.0 cm Treatment height (depth)							
6.0	6.00	1.130	316.0	7.0	159.32	162	-1.68
6.5	6.50	1.120	338.0	7.0	168.90	172	-1.83
7.0	7.00	1.110	359.0	7.0	177.80	182	-2.36
7.5	7.50	1.100	382.0	7.0	187.48	191	-1.88
8.0	8.00	1.095	404.0	7.0	197.38	200	-1.33
8.5	8.50	1.090	426.0	7.0	207.18	210	-1.36
9.0	9.00	1.085	448.0	7.0	216.88	220	-1.44
9.5	9.50	1.08	470.0	7.0	226.48	230	-1.55
10.0	10.00	1.07	493.0	7.0	235.36	239	-1.55

4. Discussion

The results of the proposed method are in reasonably good agreement with previously published work[9]. In the literature, the reported correctness of manually calculated treatment time vary from 1% (one single catheter[9]) through 5% (volume implant[20]) up to 10% (planar implants[19]). The results of the present study are comparable to the literature[9].

The figures 2-4 show that the treatment time as calculated by both techniques is closely matched. Treatment time was increased with the increase in treatment length or depth or both.

The technique illustrated in the current study is a simple, quick and useful for HDR intraluminal brachytherapy (rectum, esophagus and bronchus) that needs no particular expertise for example developing TG43-based in-house software to verify the dose calculation i.e. the total treatment time to deliver the prescribed dose earlier to each treatment. It requires approximately one minute and hence does not considerably lengthen the patient's waiting time. The key usefulness of the second check philosophy employed in the present investigation is to gain confidence that the dose calculation is correct. Although the accurateness of dose computations is completely confirmed upon commissioning and during periodic quality assurance tests, checking the dose delivery time prior to each treatment guarantees that the correct treatment depth, treatment length, prescribe dose and the correct activity (source strength) are being used and that any bug (known or unknown) in the planning software did not affect the dose calculation.

Treatment planning is a complex as well as a time taking process in radiotherapy in general and in brachytherapy in particular that includes the applicator insertion, a complex simulation, CT/MRI or Orthogonal radiograph, transfer of simulation data to treatment planning system and then the best possible treatment plan for an individual patient. Each step is prone to one or more sources of error, so it is essential to be performed with the greatest accuracy achievable. The ambiguity in each step may influence the accuracy of subsequent steps and, therefore can have an impact on the overall treatment time. Confirmation of the total dwell time by an independent method certainly ensures the accuracy, reliability and authenticity of all component processes.

Despite its great simplicity, our method is capable to identify human error-related planning mistakes, and to evaluate the quality of treatment planning. Numerous

other independent confirmation techniques for individual treatment planning have been presented. Kumar *et al*. presented an in-house method, which calculates the dose at arbitral points[22]. Lachaine *et al*. also presented an in-house technique, which completes very quick calculation of point dose[23]. Such kinds of techniques are probably to be valuable in the commissioning of treatment planning systems and partially in individual treatment planning QA too. Though, since these methods make use of the same Cartesian coordinate system, digitized applicator paths and dose point coordinates as in the treatment planning system, they are incapable to notice human errors related with the treatment planning process, for instance set of prescription point with the incorrect coordinate, the wrong digitization of applicators, erroneous dose points or applicator points, inappropriate magnification of simulation films, or utilization of an unintended size or arrangement of applicators.

5. Conclusion

Verification of the accuracy of optimized calculations with confirmation, evaluation method is fundamental in order to guarantee the quality of treatment. This independent verification tool for confirmation of the total dwell time in TPS plan of intraluminal HDR brachytherapy presents a solid base to apply the plan for brachytherapy treatment. The average percentage differences between treatment time T_M with manual calculations and as calculated by the TPS is 0.32% (standard deviation 1.32%) for rectum, 0.24% (standard deviation 2.36%) for esophagus and 1.96% (standard deviation 0.55%) for bronchus, respectively. These results advocate that the proposed method is valuable for independent verification of patient-specific treatment planning QA. In conclusion, we have developed a very simple, trouble-free, fast and independent verification technique for intraluminal brachytherapy. It enhances the quality of brachytherapy treatment and reliability of the system.

Conflict of interest

The authors declare that they have no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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