A simple quality assurance method to check dwell times in high dose rate (HDR) remote after loading intracavitary applications

Abstract

Calculated dwell times for approved treatment plans are usually uploaded from treatment planning system (TPS) to the control console of remote after loading High Dose Rate (HDR) brachytherapy machines for treatment execution. These TPS dwell times needs validation, also to check correctness of applications. In the event of image transfer problems, the patients' treatment cannot be cancelled, when they are on a fixed protocol of treatments. An attempt was made to arrive at 'dwell times' by manually calculated tables.

Published Monte-Carlo doserate table for single HDR Iridium-192 source from Ir-192 source manufacturers were referred. By a manual method, contributions of doses for Manchester Points A and B from Intra-Uterine (IU) tandem and Intra-vaginal (IV) ovoids, for standard irradiation geometry are generated. To validate the use of these tables, the dwell times of retrospective patient records in the department were verified.

Manually calculated dwell times for intra-cavitary treatments for different combinations of dwell positions are found to be accurate within a mean deviation $\pm 5\%$ for the treatments. This method will help in busy radiotherapy departments for rapid check of dwell times obtained from TPS, before executing treatments.

Keywords: high dose rate brachytherapy, dwell times, remote afterloading, quality assurance

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Introduction

High doserate remote after loading (RAL) systems using high intensity point sources with Iridium-192 for intra-cavitary and interstitial brachy-therapy have been in vogue since 1970s, replacing the long time used low dose rate systems. In the recent past, to take advantage of large half life, and to overcome repeated source loadings/import problems of Ir-192, high intensity remote after loaders with Cobalt-60 miniature source are becoming popular during this decade. These HDR brachy machines are interfaced to dedicated treatment planning systems (TPS), with algorithms for dose distribution, loading weightages, optimization and calculation of dwell times in pre-selected dwell positions of the high intensity single source. The activity specifications, dose planning algorithms, calculation methods, standardization and clinical applications are well documented in many protocols.^{1,2} To correlate Air Kerma Strength (AKS) of the source, calibration methods of sources with high accuracy well type ionization chambers, were outlined.³ Guidelines for quality assurance procedures of these HDR remote after loaders are well laid out in India,⁴ and maintained under regulatory control by Statutory Authority.

More than 400 remote high intensity remote after-loaders (RAL) are operational in large countries like India; Iridum-192 RALs are large in number. For treatments of carcinoma uterine cervix, breast conservation treatments for carcinoma breast and soft tissue sarcoma fractionated HDR doses are delivered. X-ray orthogonal radiographs (for 2D planning) and Computerized Tomography (CT scans) (for 3D Planning) are the localization methods followed in the radiotherapy departments. In some departments Magnetic Resonance Imaging (MRI) compatible applicators are used for MR localization protocols. Dwell times at temporary transit pellet position for each fraction are

mainly decided by the existing 'source activity' of Ir-192 miniature source pellet, and planned number of positions in the treatment plan and dose prescription to a 'reference point'. In practice, in most of the institutions, CT scan is carried out in the first fraction, and the plan is copied for treatment delivery in subsequent fractions. A target volume dose delivery was recommended in intracavitary brachytherapy instead of dose to specific points^{5,6} because the reference points mostly may not be reproducible in different clinical tumour volume patterns. In carcinoma of uterine cervix a reference point 'Point A' was originally defined as 2 cm superior to the lateral vaginal fornix and 2 cm lateral to the cervical canal. A later definition⁷ continues to be still in clinical use to have 'reference point, Point A' defined to be 2 cm superior to the external cervical OS (or cervical end of the tandem) and 2cm lateral to the cervical canal, which is in addition to volume dose prescriptions, as recommended by ICRU reports.^{5,6}

Some of the TPS computers do not have software for localization of implants using orthogonal X-Ray reconstruction methods. Sometimes, due to non-availability of CT machine slots, or problems in data transfer from CT to TPS, or planning system have some software issues, the planned fractions cannot be delivered, especially in remotely located clinics. As the 'source activity' falls at the rate of 1% day, and involvement of high strengths of Ir-192 sources, no manual calculations and delivery of dose is recommended for HDR brachytherapy by local regulatory authorities. At present there are a few methods existing to check TPS calculated dwell times,⁸⁻¹⁰ for further exporting to the treatment machine. A manual look up table method for a medium dose rate (MDR) RAL for IU-IV applicator for caesium-137 pellet sources at 0.25 inter-pellet loadings had a concept to describe pellet co-ordinates.¹¹ This led us to generate a 'look up table in the department' using available point dose-rates for Ir-192 HDR high intensity source.

Materials and methods

Machine

A MicroSelectron HDR Brachytherapy system, supplied by M/s Nucletron makes use of mHDR-v2 Iridium-192 high intensity source, 4.5mm Total Length(TL), 3.6mm Active Length (AL) source material, outer diameter 0.9mm with outer dimension AISI 316L steel encapsulation on active Ir-192 core of 0.65mm dia. This is connected by welding to stainless steel wire of 0.7mm diameter leading to a source cable. One of such machine is operational in our department since 2012. It is 6 channel type older models, where the patient's applicator is connectable by an indexer through source catheters. Nominal activity of 370 GBq (apparent activity 10Ci) imported source (Mallinkrodt AG, Netherlands) is loaded at a frequency of every 6 months.

Applicators

Applicators are provided along with the machine, made up of light weight stainless steel to which single source dwells at programmable inter-space lengths of about 2.5 mm. Pellet positions usually are localized in check films using a marker catheter, which contains tungsten pellet at selected positions. The geometry of source positioning is such that first source centre corresponds to 9mm for the Intra Uterine Tube (IUT) and 7mm in the ovoid applicators. The last source centre will correspond to 9th, 13th, 17th, 21st, 25th positions in the IUT for 4cm, 5cm, 6cm and 7cm intra-uterine lengths from external OS marker. 60° angulation of ovoids with respect to vertical plane, ensures pellet positions 4,3,2,1 and 5,6,7,8 positioned towards or away from the Z plane containing Manchester Point A (Figure 1).

Figure 1 Geometry of IU Tube and Ovoids, and A,B Reference Points.

Treatment planning system (TPS) calculations

This machine is connected to Oncentra TPS along with film scanner, and CT scanner patient data could be loaded through a CD reader drive, by DICOM compatibility. The calculation of dose rate by the TPS is based on Monte-Carlo (MC) aided dosimetry table of values for a point HDR Ir-192 source¹²⁻¹⁴ as recommended by earlier dosimetry codes^{1,2} used in MicroSelectron. Similar (MC) table was found for Flexisource Ir-192 source¹⁵ also, both tables has agreement in dose rates within 1%.

Generation of a look up table

Dose rates for different dwell positions (for IU Tandem) for straight applicator

The absolute dose-rate table $D(x,y)$ for a single source {(Nucletron mHDR-v2),⁸⁻¹⁰ Flexisource¹¹ indicate fall of dose rates along X axis two quadrants for right hand side two quadrants (0 to 7cm) along the source Y axis both +ve and -ve directions(-7 cm to +7 cm). Same table data gives different pellet contributions at specified point, if the central perpendicular axis is moved up or down by 0.25cm increments. By this method, the calculated values of dose rates in cGy/h (for "Unit Air Kerma Strength" brachytherapy source) is indirectly generated in the form of a departmental table for various dwell positions in the central tandem applicator (connectable to channel 3).

Dose rates from different dwell positions (for IV Ovoids)

The earlier conceptual method⁸ indicated the source co-ordinates of the dwell positions for similar 0.25 cm inter-pellet centers, in ovoid source trains. Standard separations for Fletcher-Suit applicator ovoid centers are 15mm, 20mm, 25mm and 30mm respectively for semi-small, small, medium and large ovoids set. The X co-ordinates of 'Manchester Points A, B' are 2cm and 5cm. of The y axis for plane containing 'Manchester Points A, B' is 2cm, from origin and y axis for central plane of ovoid's are -0.75, -1.0, -1.25 and -1.5cm with respect to origin. As the ovoid's are at 60° angulated, the co-ordinates of 5,6,7,8 downward pellet positions are $y=0.25\sin30^\circ$, $z=0.25\cos30^\circ$; $y=0.5\sin30^\circ$, $z=0.5\cos30^\circ$; $y=0.75\sin30^\circ$, $z=0.75\cos30^\circ$; $y=1.0\sin30^\circ$, $z=1.0\cos30^\circ$ away and below origin level. Considering the Y plane passing through the centre point between dwell positions 4, 5 in the ovoid, the 4,3,2,1 make in Z co-ordinates. $-0.125\sin30^\circ$, $-0.375\sin30^\circ$, $-0.625\sin30^\circ$, and $-0.875\sin30^\circ$ and 5,6,7,8 make $+0.125\sin30^\circ$, $+0.375\sin30^\circ$, $+0.625\sin30^\circ$, and $+0.875\sin30^\circ$. The z co-ordinates of the dwell positions 4,3,2,1 correspond to $-0.125\cos30^\circ$, $-0.375\cos30^\circ$, $-0.625\cos30^\circ$ and $-0.825\cos30^\circ$ and for 5,6,7,8 they correspond to $+0.125\cos30^\circ$, $+0.375\cos30^\circ$, $+0.625\cos30^\circ$ and $+0.825\cos30^\circ$. For calculation of dose rates at Left Point A from Left and Right ovoids, standard positions of the ovoids are taken, assuming that variation due to proximal and distal positions of two ovoids compensate in dose delivery at Point A. For pellet positions 1,2,3,4 upward pellet positions in ovoids similar y, z co-ordinates could be calculated towards and below origin level. Left Ovoid will be nearer to Left Point A, and Right Ovoid will be far away to Left Point A. If symmetry of both ovoids is assumed, Left Point A and Right Point A will be receiving similar contributions from opposite ovoids. About 4% correction (a factor 0.960) on dose rate is taken as multiplication factor to correct for 'anisotropy' in the ovoid dwell positions for angulated pellet orientations. Using x,y,z radial distances of Points Left A and B, doserates for individual ovoid pellet dwell positions Unit Air Kerma Strength U are referred and tabulated.

Results

Table 1 gives the contributed dose rates from various dwell positions at perpendicular 2cm and 5cm distant points, from reference pellet level, at 0.25 cm away from each other. The dose rates are mirror image for the same dwell positions on the lower, opposite side also, from the reference pellet, at zero position. The above dose rates in cGy/h when applied to the various dwell positions in the tandem applicator (Channel No.3) for 7cm, 6cm, 5cm and 4cm will

have Point A, B plane ($x=2, y=2, z=0$) occurring at 17,13,9,5 pellet positions respectively. Therefore, Table 2 indicates the resultant dose rate contributions from various dwell positions for tandem applicator. It is clear from Table 2 that as the Tandem length increases from 4

cm to 7 cm, the last pellet position is 13,17,21,25 respectively; and contribution from 1st pellet position increases as the tandem length decreases, as Point A plane occurring at 17,13,9,5 pellet levels.

Table 1 Dose rates at locations 2cm and 5cm lateral points- for 0.25cm interval dwell positions (in cGy/h per Unit Air Kerma Strength)

Dist	0	-1	-2	-3	-4	-5	-6	-7	-8	-9	-10	-11	-12
2cm	0.282	0.278	0.265	0.246	0.223	0.199	0.176	0.155	0.135	0.12	0.104	0.092	0.08
5cm	0.045	0.045	0.044	0.043	0.043	0.042	0.041	0.039	0.038	0.036	0.035	0.033	0.032

Table 2 Point A, B dose rates for Unit Air Kerma Strength (U) for different Tandem lengths and respective dwell positions

S No.	Dwell positions of pellets at 0.25cm interspacing in the tandem applicator				Point A D/R from each Pellet in cGy/h	Point B D/R From each pellet in cGy/h
	7 cm IUT	6cm IUT	5cm IUT	4cm IUT		
1	1	-----	-----	-----	0.0336	0.0208
2	2	-----	-----	-----	0.042	0.0233
3	3	-----	-----	-----	0.0504	0.0259
4	4	-----	-----	-----	0.0653	0.0289
5	5	1	-----	-----	0.0803	0.0319
6	6	2	-----	-----	0.0922	0.0334
7	7	3	-----	-----	0.104	0.0349
8	8	4	-----	-----	0.12	0.0364
9	9	5	1	-----	0.135	0.0379
10	10	6	2	-----	0.155	0.0392
11	11	7	3	-----	0.176	0.0406
12	12	8	4	-----	0.199	0.0416
13	13	9	5	1	0.223	0.0427
14	14	10	6	2	0.246	0.0435
15	15	11	7	3	0.265	0.0441
16	16	12	8	4	0.278	0.0445
17	17	13	9	5	0.282	0.0446
18	18	14	10	6	0.278	0.0445
19	19	15	11	7	0.265	0.0441
20	20	16	12	8	0.246	0.0435
21	21	17	13	9	0.223	0.0427
22	22	18	14	10	0.199	0.0416
23	23	19	15	11	0.176	0.0406
24	24	20	16	12	0.155	0.0392
25	25	21	17	13	0.135	0.0379

For contributions of dose rates to Points A and B from intra-vaginal ovoids (IV ovoid applicators) the calculated radial distances from 1 to 8 pellet positions and different ovoid diameters are summarized in Table 3. These dose rates correspond to symmetric placement of the ovoid centers with respect to 'Internal Os' position. Any asymmetry in their placement will increase the contribution from nearest ovoid, as well as get decreased contribution from far away ovoid, thereby when both contributions are added; the error in placement is likely reduced. The manually calculated dwell times were in agreement with

Oncentra TPS calculated and executed by the MicroSelectron HDR machine (Table 4) (The deviations in 33 random cases were within Mean±SD -3.6±7.1%). Close scrutiny of the isodose distributions in cases with deviations >10% against calculations, it was found that the geometry of ovoid placement was more asymmetric, and also difference between Left and Right Point A doserates were more. It is also seen from Table 4, that in these cases, the estimated dwell times were less than actually executed by the machine, implying that Ovoids were far away requiring meaner dwell time to deliver the dose of 8 Gy.

Table 3 Dose rates to Point A(cGy/h) from intra-vaginal ovoids applicator Per Unit Air Kerma Strength(AKS)

Description of Ovoids/ Seperation/Dwell. Position	Calculated Dose Rate cGy/h at Point A			
	Left Side		Right Side	
	Point A	Point B	Point A	Point B
Semi-Small I	0.127	0.0446	0.091	0.0296
Ovoids 2	0.12	0.0443	0.091	0.0294
Sep.15mm 3	0.115	0.0442	0.091	0.0294
4	0.115	0.044	0.086	0.029
5	0.11	0.0418	0.082	0.0274
6	0.108	0.041	0.077	0.0264
7	0.106	0.0392	0.067	0.0254
8	0.091	0.0384	0.058	0.0244
Small I	0.13	0.048	0.082	0.027
Ovoids 2	0.128	0.047	0.077	0.0266
Sep.20mm 3	0.125	0.047	0.077	0.0266
4	0.12	0.0464	0.077	0.026
5	0.11	0.0442	0.071	0.0246
6	0.109	0.043	0.048	0.024
7	0.108	0.0418	0.048	0.0226
8	0.104	0.0406	0.048	0.022
Medium I	0.113	0.0508	0.058	0.0246
Ovoids 2	0.111	0.0498	0.05	0.024
Sep.25mm 3	0.11	0.0492	0.048	0.0238
4	0.109	0.0488	0.048	0.0236
5	0.096	0.0464	0.043	0.022
6	0.09	0.0452	0.043	0.0216
7	0.082	0.0442	0.04	0.021
8	0.082	0.043	0.04	0.0202
Large I	0.106	0.0534	0.04	0.0216
Ovoids 2	0.096	0.0526	0.04	0.0216
Sep.30mm 3	0.091	0.0524	0.04	0.021
4	0.091	0.0516	0.04	0.021
5	0.082	0.0488	0.036	0.02
6	0.077	0.0478	0.036	0.02
7	0.067	0.0466	0.036	0.02
8	0.067	0.045	0.035	0.02

Table 4 Calculated dose rates and comparison with Oncentra planning system dwell times

No	Hosp. No	Apparent activity	Number of Dw. pos tandem & ovoids		Weightages in channels			TPS dwell times per Dw.Pos. sec 1.0 weight	Manual dwell times sec 1.0 weight	Deviation %
		Ci	Ch ₃	Ch ₂ - Ch ₁	Ch ₃	Ch ₂	Ch ₁			
1	3093/17	1.416	7	03-03	1	0.78	0.78	248.2	261.5	5.3
2	2013/18	6.984	9	03-03	1	1	1	54.5	53.1	-2.6
3	1806/18	1.381	8	03-03	1	1	1	241.2	255.1	5.8
4	246/18	2.424	8	03-03	1	1	1	167.3	148.6	-11.3
5	460/18	6.626	6	03-03	1	1	1	52.2	55.9	7.1
6	2548/14	0.743	8	03-03	1	1	1	463.2	469.4	1.3
7	1103/19	5.563	8	03-03	1	1	1	70.6	70.2	-0.6
8	279/12	2.35	8	07-07	1	0.62	0.15	124.2	134.6	8.3
9	520/14-1	3.372	12	05-05	0.14	1	0.39	338.6	310.4	-8.4
10	520/14-2	3.845	8	03-03	0.05	1	0.08	558.1	533.4	-4.5
11	2961/17	1.312	7	03-03	1	1	1	317.2	295.9	-6.8
12	3098/17	1.288	6	03-03	1	1	1	297.3	287.8	-3.8
13	390/18	7.483	6	03-03	1	1	1	50.8	48.4	-4.7
14	469/18	5.138	7	03-03	1	1	1	68	67.5	-0.7
15	672/18	4.677	7	03-03	1	1	1	91	88.8	-2.4
16	1274/18	3.014	8	03-03	1	1	1	123	118.5	-3.7
17	1293/18	2.872	8	03-03	1	1	1	141.5	132.6	-6.4
18	993/18	3.399	7	03-03	1	1	1	117.2	110.2	-6
19	1384/18	2.843	8	04-04	1	1	1	134.2	125.6	-6.4
20	2651/18	6.54	7	03-03	1	1	1	52	54.2	4.2
21	972/19	1.891	7	03-03	1	1	1	194.5	183.6	-6.7
22	376/19	2.005	7	03-03	1	1	1	206.8	182.9	-11.5
23	393/19	2.04	8	03-03	1	1	1	220.3	176.5	-20
24	441/19	2.041	6	03-03	1	1	1	213.3	180.1	-15.6
25	3380/18	3.523	7	03-03	1	1	1	105.1	98.2	-6.5
26	3387/18	3.651	8	03-03	1	1	1	84.3	87.6	3.9
27	183/19	3.903	8	03-03	1	1	1	111	97.6	-12.2
28	2583/17	2.099	8	03-03	1	1	1	178.2	174.2	-2.3
29	2310/17	2.262	8	03-03	1	0.8	0.8	175.9	176.5	0.3
30	2462/17	2.138	8	03-03	1	1	1	188.9	178.1	-5.8
31	1458/14	2.498	12	05-05	0.11	0.06	1	657.1	623.4	-5.3
32	2875/18	5.795	7	03-03	1 diff	1 diff	1 diff	63.2	55	-13
33	275/12	0.303	11	03-05	0.43	1	0.14	188.9	210.3	11.3
Mean±SD										
										-3.6±7.1%

Discussion

As the Oncentra dedicated Planning System has the calculation algorithm based on standard dose rate table, and our present point dose calculations are based on the same dose-rate table applying theoretical co-ordinates for contributions to Point A, a good agreement is expected. It is seen from Table 4 that manually calculated times are agreed well with the TPS calculated dwell times. The simple method designed in the department is able to calculate the dwell times very accurately. In brachy-therapy agreement within 10% is fairly good, because we are able to check the execution of treatment as a quality assurance. Check films will show asymmetry in placement of ovoids with respect to tandem, and also the distances from centre of ovoids might have been altered due to packing. The present work showing good agreement, explains that extra contribution by one ovoid to each point A gets compensating for the fall of dose from other ovoid. We recommend this method for validating the computer TPS calculated dwell times, and also could be used to treat the patients even if there are problems encountered for localization of applicators at rare occasions. Standard geometry does not account for deviations in Tandem angulations and unsymmetrical ovoid placements (variability due to vaginal packing by different doctors). It is assumed that contributions to Left A and Right A are averaged in reality. Ovoid pellet distances vary from 2.9cm to 5.8 cm to both side Point A's radially. Based on placement of ovoid angles, the slanted source might produce upto $\pm 5\%$ maximum anisotropy effects, which explains that TPS calculated timings, are on higher side (less dose rates in reality). Maximum of 30° inclination in the source is encountered in ovoid dwell positions, and therefore a constant value of correction 0.960 on calculated dose is incorporated in the ovoid pellet contributions. In actual applications, if the Cartesian coordinate geometry differs in treatment planners' inaccurate feeding of the applicator, there may be large deviations. In actual situations, when the dwell times calculated from look up tables grossly shows variations (as in Table 4 calculated entries S.No. 22,23,24,27,32) with respect to treatment planning system, it was observed that the actual application in the patient is much deviating from the standard geometry (may be due to disease patterns, and asymmetric placement of ovoids). However, it can be seen from Table 4 that none of the calculations gone beyond 15% deviations, validating the efficacy of present look up tables. If the patient develops any treatment related complications, we can calculate and check the actual dose delivered to the patient within 10%, because we have documented value of source activity on a past date, as well as recorded dwell times noted in the treatment registers. Scrutiny of patient data in the past 5 years, it was found that in the loading patterns in tandem and ovoids there were no systematic protocol followed. It is recommended that brachytherapy planners will make use of this look up table during routine applications in intracavitary HDR brachytherapy. It is highlighted that this manual method once helped us to locate wrong Oncentra TPS calculated time, which was unusually higher than expected from this look of table (varying by a factor more than 4). Close scrutiny of parameters revealed that for a new source, an entry of numerical 'source apparent activity' was made for the Air Kerma Rate (AKR); making a systematic error of 408.2%. However, correct treatment was delivered by the machine computer, because it has in memory the true activity and AKR. This method appears to be valid for any model Ir-192 HDR, because the point dose rate contributions beyond 1 cm from central axis is not much variable.

We compared the present work against previously available reports.⁸⁻¹⁰ It is highlighted that one method had used a flexible

intraoperative template⁸ for checking Point A doserates for variable combinations of dwell positions, second method⁹ has developed a method applicable only for vaginal applicators, and thirdly a computational method¹⁰ was described to check the planned HDR treatment by an independent software departmental software. Present method is based on a fixed look up table with pre-calculated dose rates to specified points by assuming reproducible co-ordinates of dwell positions. Radiographic verifications localize actual dwell positions of source *in-situ*, but in Table 4 their agreement with calculated dose rates agreed within 4% mean deviations, which shows that the prediction of doserates by the look up table is fairly accurate. As we routinely check our dwell times by this simple method in the department, it is felt that this might be useful for other busy HDR brachytherapy departments also.

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Conflicts of interest

Author declares that there is no conflict of interest.

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