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Original Article

To determine the source dwell positions of HDR brachytherapy using 2D 729 ion chamber array

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Abstract

The purpose of this study was to determine the dwell position of a high-dose-rate (HDR) brachytherapy Ir-192 source using a PTW Seven29 2D detector array. A Nucletron Microselectron HDR device and 2D array ionisation chamber, equipped with 729 ionisation chambers uniformly arranged in a 27 × 27 matrix with an active array area of $27 \times 27\ \text{cm}^2$, were used for this study. Different dwell positions were assigned in the HDR machine. Rigid interstitial needles and a vaginal applicator were positioned on the 2D array, which was then exposed according to the programmed dwell positions. Subsequently, the positional accuracy of the source position was analysed. This process was repeated for different dwell positions. The results were analysed using an in-house-developed Excel programme. Different random dwell position checks as well as dwell position measurements were performed using a radiochromic film. The dwell positions measured by the 2D array were found to be in good agreement with those measured by the film. The standard deviations between the doses obtained from the different dwell positions were 0·191828, 0·329973, 0·370632 and 0·779939, whereas the corresponding standard deviations of the doses at the vaginal cylinder were 0·60303, 0·242808, 0·242808 and 0·065309. When the planned and measured dwell positions were plotted, a linear relationship was obtained.

Keywords: afterloading; applicators; HDR brachytherapy; 2D array

INTRODUCTION

Brachytherapy is a treatment method in which sealed radioactive sources are used to deliver radiation at short distances by interstitial, intracavitary or surface application. With this mode of therapy, a high radiation dose can be delivered locally to a tumour, with rapid dose fall-off in the surrounding normal tissue. High-dose-rate (HDR) brachytherapy is a technique in which a small Ir-192 source (active length 3·5 mm and diameter 0·6 mm) can be programmed to dwell for a given time at any point in the treatment catheters.[1] It is often used in conjunction with external beam radiation therapies to boost radiation. The delivery method of HDR brachytherapy aims to achieve this radiation boost by localising high-activity radiation directly within the target volume. Therefore, it is necessary to ensure that the radiation is delivered with a highly precise dwell position and timing.[2] The success of this treatment is strongly dependent on the accuracy

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of the source measurements, specifically the measurements of source strength, dwell position and dwell time by an afterloading system that uses an electronic 2D detector array.[3] Correct identification, reconstruction and applicator position determination are critical to the success of brachytherapy.[4] The majority of currently available, traditional brachytherapy planning systems simply use summation of the pre-determined dose distribution around individual source positions based on TG43 formalism.[5] In brachytherapy, film dosimetry is typically utilised for applications in routine quality control, commissioning or auditing.[6] It is extremely important to perform adequate quality assurance checks on the equipment before treatment.[7] Brachytherapy plays an essential role in the treatment of all invasive cancers of the cervix. In radical treatment, it is usually combined with external beam treatment. It is mainly applied as an intra-cavitary procedure, and in selected cases it is complemented by interstitial implants.[8,9]

MATERIALS AND METHOD

Measurement of source dwell position using 2D array

The irradiations were performed using a Nucletron Microselectron HDR (PTW Freiburg, GmbH, Germany) afterloading device utilising Ir-192. A hollow metallic needle was connected to the afterloader via a flexible guide tube. The Nucletron Microselectron HDR Brachytherapy unit afterloader first treats the most imminent dwell position before continuing to other specified dwell positions, which are at further distances within the catheter that moves forward during the treatment, with the drum controlled from outside using a remote.

The measurements were conducted with a seven29 detector array (PTW Freiburg) containing a total of 27 × 27 cubic detectors. The edge length of each cubic detector was 5 mm. The 2D array was calibrated for absolute dosimetry with a Co-60 photon beam at the PTW Secondary Standard Dosimetry Laboratory. The 2D array acquisitions were performed with Verisoft software. It is recommended by PTW that this 2D array should be switched on a minimum of 5 minutes before a measurement is performed. It was tested whether the measured dwell position depended on the switch-on time of the detector array.[10]

First, the 2D ion chamber array was set. It was then connected to a computer. Each needle was positioned so that it coincided with the central detector of the 14th row. The experimental setup is shown in Figure 1. The needle end was about 0·5 cm from the central detector of the array. Planning was performed for different step sizes: 0·5, 1, 1·5 and 2 cm. The dwell time was set at 30 seconds with a reference length of 1,369 mm.

An interstitial needle was connected to the afterloading device using a suitable cable wire — that is, the needle was fixed to the detector surface. The needle tip was fixed on the 14th detector of the 2D array. The experimental set up is shown in Figure 1. The signal of the detector in the 14th row was evaluated to the dwell position of the source. In the HDR machine, we can set different step sizes to control the source movement. During irradiation, the source movement will be in different positions of the needle. First, we have to measure the total length of the guide wire to the needle end. The length of the transfer tube is a critical element in the overall source positioning accuracy. The measured length was 1,369 mm. Different step size were selected in the machine, such as 0·5, 1, 1·5 and 2 cm, and the dwell time was set as 30 seconds. During source movement, the source exposed radiation in corresponding values in the detector array. Verisoft provided the dose values corresponding to each detector. The dose values are presented in Figure 2. The exposure time of the source in each detector was 30 seconds. The dose values are high in the planned dwell position, and in other positions the values are less. Measurements were taken using the 16-cm interstitial rigid needle and vaginal cylinder.

Autoradiograph using radiochromic film

Gafchromic EBT2 film (International Specialty Products Corporation, Wayne, NJ, USA) consists of an active layer laminated between two polyester layers. It has a wide dose range of 1 cGy

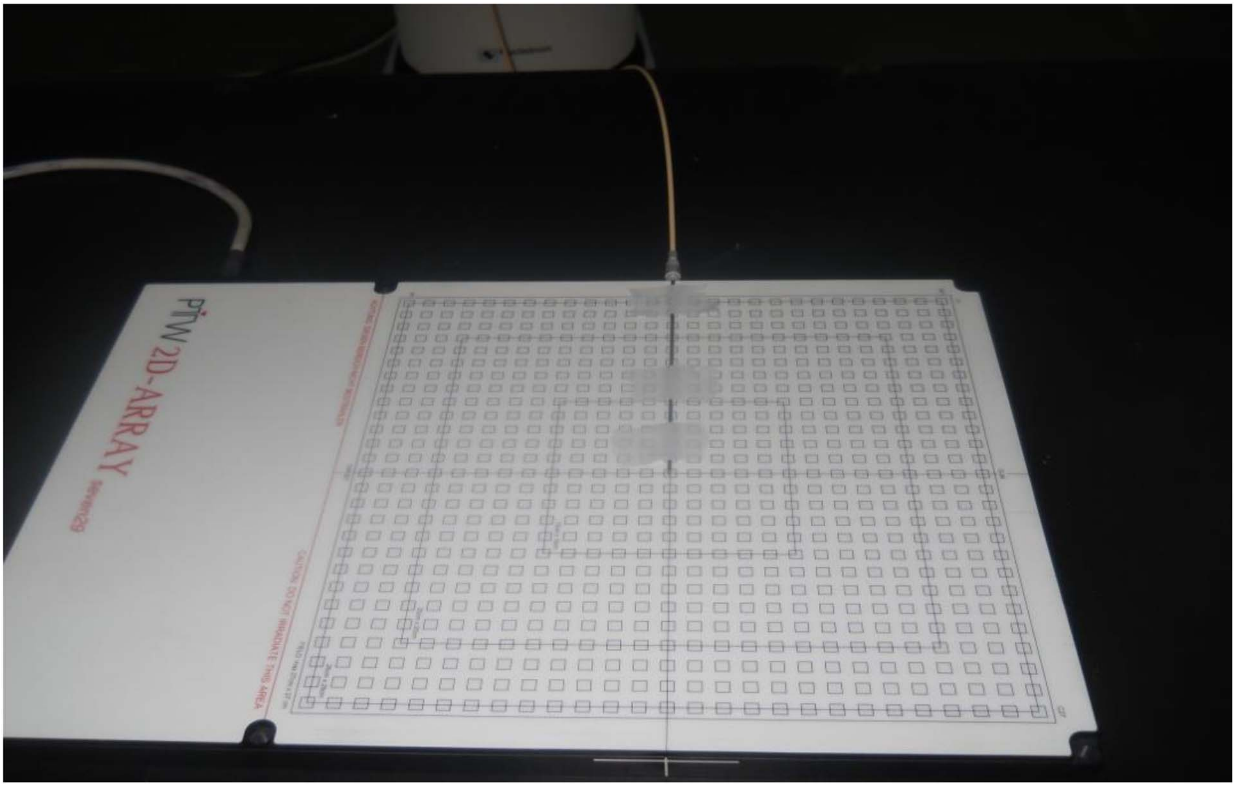
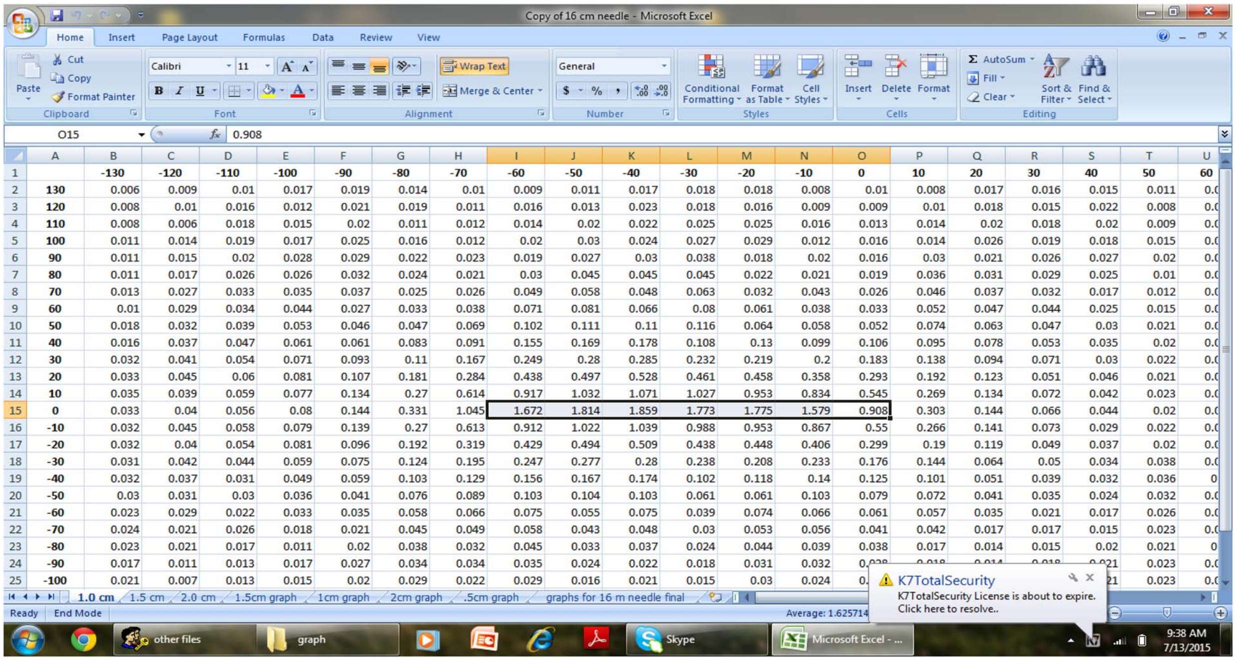


Figure 1. *Figure showing the set up of the 16-cm rigid needle.*



O15 0.908

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
1		**-130**	**-120**	**-110**	**-100**	**-90**	**-80**	**-70**	**-60**	**-50**	**-40**	**-30**	**-20**	**-10**	**0**	**10**	**20**	**30**	**40**	**50**	**60**
2	**130**	0.006	0.009	0.01	0.017	0.019	0.014	0.01	0.009	0.011	0.017	0.018	0.018	0.008	0.01	0.008	0.017	0.016	0.015	0.011	0.0
3	**120**	0.008	0.01	0.016	0.012	0.021	0.019	0.011	0.016	0.013	0.023	0.018	0.016	0.009	0.009	0.01	0.018	0.015	0.022	0.008	0.0
4	**110**	0.008	0.006	0.018	0.015	0.02	0.011	0.012	0.014	0.02	0.022	0.025	0.025	0.016	0.013	0.014	0.02	0.018	0.02	0.009	0.0
5	**100**	0.011	0.014	0.019	0.017	0.025	0.016	0.012	0.02	0.03	0.024	0.027	0.029	0.012	0.016	0.014	0.026	0.019	0.018	0.015	0.0
6	**90**	0.011	0.015	0.02	0.028	0.029	0.022	0.023	0.019	0.027	0.03	0.038	0.018	0.02	0.016	0.03	0.021	0.026	0.027	0.02	0.0
7	**80**	0.011	0.017	0.026	0.026	0.032	0.024	0.021	0.03	0.045	0.045	0.045	0.022	0.021	0.019	0.036	0.031	0.029	0.025	0.01	0.0
8	**70**	0.013	0.027	0.033	0.035	0.037	0.025	0.026	0.049	0.058	0.048	0.063	0.032	0.043	0.026	0.046	0.037	0.032	0.017	0.012	0.0
9	**60**	0.01	0.029	0.034	0.044	0.027	0.033	0.038	0.071	0.081	0.066	0.08	0.061	0.038	0.033	0.052	0.047	0.044	0.025	0.015	0.0
10	**50**	0.018	0.032	0.039	0.053	0.046	0.047	0.069	0.102	0.111	0.11	0.116	0.064	0.058	0.052	0.074	0.063	0.047	0.03	0.021	0.0
11	**40**	0.016	0.037	0.047	0.061	0.061	0.083	0.091	0.155	0.169	0.178	0.108	0.13	0.099	0.106	0.095	0.078	0.053	0.035	0.02	0.0
12	**30**	0.032	0.041	0.054	0.071	0.093	0.11	0.167	0.249	0.28	0.285	0.232	0.219	0.2	0.183	0.138	0.094	0.071	0.03	0.022	0.0
13	**20**	0.033	0.045	0.06	0.081	0.107	0.181	0.284	0.438	0.497	0.528	0.461	0.458	0.358	0.293	0.192	0.123	0.051	0.046	0.021	0.0
14	**10**	0.035	0.039	0.059	0.077	0.134	0.27	0.614	0.917	1.032	1.071	1.027	0.953	0.834	0.545	0.269	0.134	0.072	0.042	0.023	0.0
15	**0**	0.033	0.04	0.056	0.08	0.144	0.331	1.045	1.672	1.814	1.859	1.773	1.775	1.579	0.908	0.303	0.144	0.066	0.044	0.02	0.0
16	**-10**	0.032	0.045	0.058	0.079	0.139	0.27	0.613	0.912	1.022	1.039	0.988	0.953	0.867	0.55	0.266	0.141	0.073	0.029	0.022	0.0
17	**-20**	0.032	0.04	0.054	0.081	0.096	0.192	0.319	0.429	0.494	0.509	0.438	0.448	0.406	0.299	0.19	0.119	0.049	0.037	0.02	0.0
18	**-30**	0.031	0.042	0.044	0.059	0.075	0.124	0.195	0.247	0.277	0.28	0.238	0.208	0.233	0.176	0.144	0.064	0.05	0.034	0.038	0.0
19	**-40**	0.032	0.037	0.031	0.049	0.059	0.103	0.129	0.156	0.167	0.174	0.102	0.118	0.14	0.125	0.101	0.051	0.039	0.032	0.036	0
20	**-50**	0.03	0.031	0.03	0.036	0.041	0.076	0.089	0.103	0.104	0.103	0.061	0.061	0.103	0.079	0.072	0.041	0.035	0.024	0.032	0.0
21	**-60**	0.023	0.029	0.022	0.033	0.035	0.058	0.066	0.075	0.055	0.075	0.039	0.074	0.066	0.061	0.057	0.035	0.021	0.017	0.026	0.0
22	**-70**	0.024	0.021	0.026	0.018	0.021	0.045	0.049	0.058	0.043	0.048	0.03	0.053	0.056	0.041	0.042	0.017	0.017	0.015	0.023	0.0
23	**-80**	0.023	0.021	0.017	0.011	0.02	0.038	0.032	0.045	0.033	0.037	0.024	0.044	0.039	0.038	0.017	0.014	0.015	0.02	0.021	0
24	**-90**	0.017	0.011	0.013	0.017	0.027	0.034	0.034	0.035	0.024	0.022	0.018	0.031	0.032	0.038	0.018	0.014	0.018	0.021	0.023	0.0
25	**-100**	0.021	0.007	0.013	0.015	0.02	0.029	0.022	0.029	0.016	0.021	0.015	0.03	0.024	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.023	0.0

Average: 1.625714

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Figure 2. *Excel values corresponding to each detector in the 2D array.*

to 40 Gy as well as a large measurement area. Radiochromic EBT2 film develops in real time with no processing.[11] This film enables the collection of data in one plane from radiation exposure and has been used to verify dwell positioning.[12] The quality of the radiochromic film

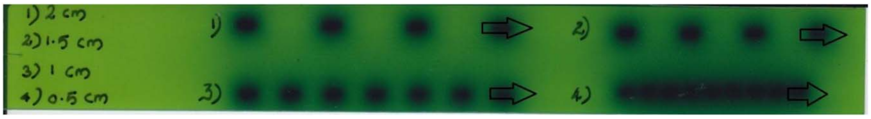

Figure 3. Autoradiograph using radiochromic film.

has improved over the last decade, as the active layer has become more uniform and the film less sensitive to ambient light. A number of recent studies have successfully used such films to evaluate dose distributions around HDR sources.[13] In this experiment, the autoradiograph was taken using EBT2 film with a 16-cm interstitial needle connected to the transfer tube. The film was handled in accordance with the recommendations outlined in the AAPM TG-55 report.[14] The needle was placed over the film strip and its position was marked on the film. Subsequently, the film was irradiated utilising the pre-defined dwell positions and a 40 seconds dwell time. The reference length was 1,369 mm, and the measurements were repeated for different step sizes, specifically 0·5, 1, 1·5 and 2 cm.

Radiochromic was used for dwell position verification. The position of tip was marked on the surface of the film. The needle was placed on the surface of the film strip, and was fixed using cello tape, with the tip of the needle marked on the surface of the film.

The needle was placed on the surface of the film strip. The sources were programmed to stop every 5 mm for intervals suitable for autoradiography — that is, the step size was displayed in the monitor as 0·5, 1, 1·5 and 2 cm. The reference length of the guide wire was 1,369 mm, and the dwell time was set to be 30 seconds. During the source movement, each programmed position exposed the film — that is, the film shows dark areas on the film strip because of the 30 seconds exposure in each position. Figure 3 shows the autoradiograph using the radiochromic film.

RESULTS

The differences between the detector responses at the planned dwell positions and those at nearby positions at which the detector responded were found to be 0·0804 for the vaginal cylinder and 0·1234 for the 16-cm needle when a 2-cm step size was used.

The dose values corresponding each source position, which is called detector response, the average differences of dose values obtained in planned dwell positions and nearby positions were found to be 0·0804 and 0·1234 for the vaginal cylinder.

Figures 4 and 5 show the planned dwell positions versus detector response for the 16-cm rigid needle and the vaginal cylinder, respectively. Tables 1 and 2 show the detector signals at each source dwell position for the vaginal cylinder and the 16-cm needle, respectively. The differences between the detector responses at the planned dwell positions and those at nearby positions at which the detector responded were found to be 0·0804 for the vaginal cylinder and 0·1234 for the 16-cm needle. The standard deviations of the differences between the doses obtained for dwell positions of 0·5, 1, 1·5 and 2 cm were 0·191828, 0·329973, 0·370632 and 0·779939, respectively, for the 16-cm needle, and 0·60303, 0·242808, 0·242808 and 0·065309, respectively, for the vaginal cylinder. Each source position was identified by the peak in the profile.

For the vaginal cylinder at dwell positions of 0·5, 1, 1·5 and 2 cm, the average doses were determined to be 0·160, 0·087, 0·0630 and 054, respectively, and the dwell time was set at 20 seconds for each dwell position. The standard deviation between the average doses for each dwell position was 0·0489. The average doses for the 16-cm needle were 0·16, 0·081, 0·075 and 0·059 for dwell positions of 0·5, 1, 1·5 and 2 cm, respectively. Figure 4 shows the autoradiograph for each of these dwell positions.

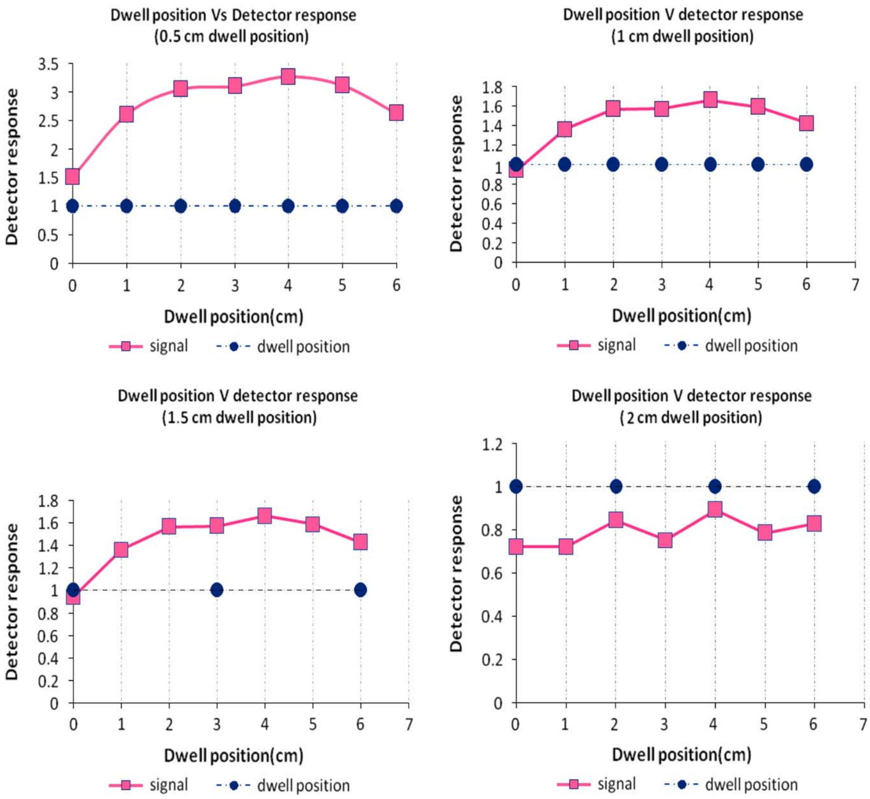

Figure 4. *Graph showing dwell position versus detector response of the 16-cm rigid needle.*

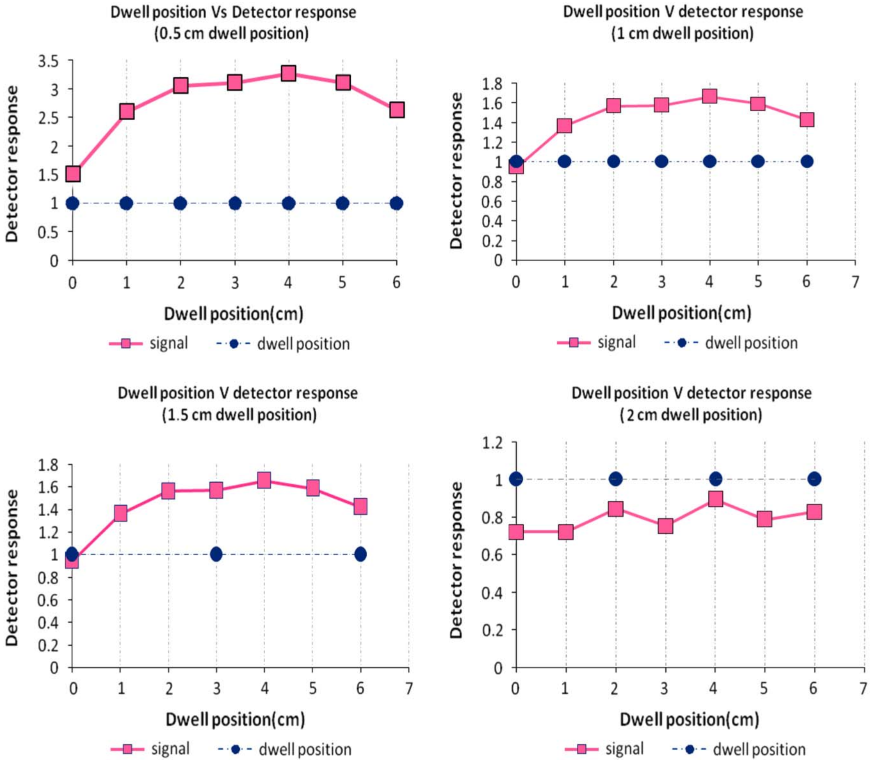

Figure 5. *Graph showing dwell position versus detector response of the vaginal cylinder.*

Table 1. *Detector signal of each source dwell position for the vaginal cylinder*

	Detector signal (vaginal cylinder) (IN Gy)						
Dwell position (cm)	**0**	**1**	**2**	**3**	**4**	**5**	**6**
0·5	1·515	2·609	3·051	3·106	3·271	3·117	2·633
1	0·945	1·363	1·564	1·571	1·659	1·589	1·424
1·5	0·806	1·135	1·349	1·178	1·289	1·373	1·145
2	0·721	0·721	0·844	0·753	0·892	0·786	0·828

Table 2. *Detector signal of each source dwell position for the 16-cm rigid needle*

	Detector signal (16 cm rigid needle) (IN Gy)						
Dwell position (cm)	**0**	**1**	**2**	**3**	**4**	**5**	**6**
0·5	1·518	3·028	3·556	3·619	3·77	3·607	3·179
1	0·908	1·579	1·775	1·773	1·859	1·814	1·62
1·5	0·806	1·135	1·349	1·178	1·289	1·373	1·145
2	0·977	0·939	1·009	0·892	0·81	0·25	0·113

DISCUSSION

Discrepancies between planned and delivered doses can significantly impact the effectiveness of a treatment. Overdosing a patient causes unnecessary exposure to healthy surrounding tissue. This effect is compounded at treatment sites that are in close proximity to sensitive organs. Nevertheless, most errors in brachytherapy have been the results of human errors rather than failures of the treatment delivery system or errors associated with treatment planning.

It was found that the measured and planned source positions matched well for both the 16 cm needle and the vaginal cylinder. It was found that the measured source position shows good agreement with the planned source positions. In the case of the vaginal cylinder, the maximum response corresponded to a 2-cm step size. 2D ion chamber array measurements showed good agreement with the film measurements. The other disadvantage of film is blurring, as reported by Rickey et al.[3] The blurring effect was more pronounced with metal applicators than with plastic catheters. This problem can be eliminated by using a 2D array.

The accuracy was checked with several tests: the measurement method shows a strict linear correlation between the source position obtained from the afterloading device and the measured source position. The dwell positions measured by gafchromic EBT2 film for step sizes of 0·5, 2 and 1·5 cm were found to be in good agreement with those measured by the 2D array.

The given graph Figures 4and 5 shows dwell position versus detector response, the straight line in the graph shows movement of source in each position — that is, planned positions — and another line shows dose values corresponding to each source positions. In zero dwell position of the source in the 14th detector, the source moved to the end of the catheter. The graph obtained was easily developed using excel programme. The dwell positions were also measured using gafchromic EBT2 film for step sizes of 0·5, 2 and 1·5 cm and were found to be in good agreement with those measured by the 2D array. From the film, we could only visually inspect the source path — that is, darkening in the film shows that the source movement accuracy corresponded within + or −1 mm, and in this study we found it to be in good agreement with the dwell position measurement obtained using 2D array.

CONCLUSION

The 2D array-based method of measuring the dwell position of an afterloading device is both fast and accurate. Furthermore, intra-cavitary test plans reproduced on the 2D array with the same applicator positions show the ideal dose distribution of the treatment planning system (TPS). Thus, utilising a 2D 729 detector array is a reliable, filmless and cost-effective method of determining dwell positions in HDR brachytherapy.

Acknowledgement

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