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2D linear array device as a quality assurance tool in brachytherapy applications

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ABSTRACT

Background: External beam radiotherapy and brachytherapy plays a vital role in the management of cancer cervix. High dose rate brachytherapy is being presently used worldwide for the brachytherapy applications. At present, 2-Dimensional linear array detectors are the most common QA tool used for pretreatment patient specific quality assurance in external beam radiotherapy alone and till date no dedicated brachytherapy tool is available. An attempt has been made to explore the feasibility of using 2 dimensional linear array, Imatrixx as a QA tool for brachytherapy. ***Materials and Methods***: Reference treatment plans are generated by Plato treatment planning system using the images of Imatrix acquired with Siemens CT simulator. The efficacy of Imatrixx as a QA tool for intracavitary treatment plan verification, dwell position and dwell time accuracy verification are studied. ***Results:*** The length and the widths along with the area of the reference isodose curves of the intracavitary treatment plans generated by Plato Planning system and measured with Imatrixx is compared. The difference in area of the reference isodose curve is found to vary from -0.59 cm2 to 4.59 cm^2. The estimated user correction factor for Iridium-192 energy, 0.38 MeV is 1.090 with a standard deviation of ±0.0211. Machine related QA such as dwell position and dwell time were measured with Imatrixx with an accuracy of 0.5 mm and 0.02 s respectively. ***Conclusion:*** Results shows that the 2-Dimensional linear array, Imatrixx can be used with accepted accuracy for both machine and patient specific quality assurance in brachytherapy treatments.

Keywords: *Brachytherapy, HDR QA tool, linear array, Imatrixx, patient specific QA.*

INTRODUCTION

Cervical cancer is the most common cancer among women in developing countries. Nearly 5 lakh new cases of cancer cervix are detected annually all over the world. Radiotherapy is an important modality in the treatment of cervical cancer. Both external beam radiotherapy and brachytherapy are used in the management of cervical cancer. Brachytherapy has the advantage of very high dose delivery to the tumor tissue along with reduction of dose to organs at risk because of rapid dose fall-off [(1)]. As per Onal *et al.* [(2)] the CT-plan is superior to the conventional plan in target volume coverage and appropriate evaluation of OARs, as the conventional plan overestimates tumor doses and underestimates OAR doses in brachytherapy. The High Dose Rate (HDR) systems which is used in the brachytherapy dose delivery uses either a Cobalt -60 or Iridium-192 source. With the help of the three dimensional treatment planning systems, it is possible to optimize the treatment dwell position and dwell time to achieve the required dose distribution. In HDR, treatment is to be delivered in few minutes and so a small change in dwell position or dwell time will introduce a lot of error in the treatment delivery. Therefore brachytherapy treatment delivery demands stringent QA tests

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for the HDR unit and for the patient treatment plan, to achieve the desired clinical outcomes [3,4,5]. Commonly films are used to carry out the verification of HDR treatment plans, dwell position and dwell time accuracy. Uniyal *et al*. [6] have studied the dosimetric accuracy of treatment plans in high dose rate (HDR) brachytherapy by using Gafchromic EBT2 film and demonstrated the adequacy of dose calculations of a commercial treatment planning system (TPS) in a homogenous medium like cervix. Other than films, several authors have tried different methods to verify the dwell position and dwell time accuracy. Van't Riet *et al*. [7] used X-ray flouroscopic images and Duan *et al*. [8] used a pinhole camera to capture the autoradiographic image of the active ^{192}Ir source. However, images produced with these methods were either of poor quality or contained no patient anatomic information. Centers providing IMRT treatments usually have a linear array detector to carry out the Patient Specific Quality Assurance for external beam treatments. 2D linear array device is a user friendly device that can measure very small changes and is also capable of measuring dose gradients encountered in brachytherapy. An attempt has been made in this work to find out the feasibility of using 2-Dimensional array detector to perform HDR dosimetry of virtual patient plan verification and quality assurance of HDR unit.

MATERIALS AND METHODS

The microselectron HDR unit equipped with 18 channels and loaded with maximum activity of 10 Ci is used in this study. The 2-D ionization chamber array studied in this work is the ImRT ImatriXX array provided with Omnipro ImRT software version 1.7b and the virtual patient plans are created using Plato treatment planning system version 14.0 .

Treatment plan verification

Three flexible implant catheters were placed on the ImatriXX. The central catheter is placed along the y-axis such that the tip is 6 cm above the origin of the ImatriXX device and the lateral catheters are placed at 1 cm on either side of the central catheter. The tip of the lateral catheters is made to coincide with X-axis of the ImatriXX. This setup mimics the Fletcher Gyneac applicator with a central tandem and two ovoid separated from it at a distance of 1 cm. This setup was scanned with Somatom Emotion Duo CT simulator with a slice thickness of 3 mm and the scanned images were sent to Plato treatment planning system. The Plato insight module was used in the planning of these CT slices. Prescription points namely RA,LA were chosen such that they represent point- A and RB, LB represent point -B in intracavitary planning of cervical cancer as per ICRU 38. RA and LA were 2 cm above the origin and 2 cm lateral to the right and left side of the central catheter respectively. RB and LB were specified such that they were 2 cm above the origin and 5 cm lateral to the central catheter on the right and left side of it. The isodose distribution is generated and the ImatriXX was irradiated, with the same arrangement of catheters, the setup of which is shown in figure 1 in the microselectron HDR unit. The same procedure is repeated for different separations of 4, 5, 6 cm between the ovoids and various central tandem lengths of 4 and 5 cm as these are the usually encountered separations and central tandem length at our centre. A total of 12 measurements were carried out for various combination of central tandem length and ovoid separation. The ImatriXX was calibrated in linear accelerator for 6 MV photon beams to get uniform response for all detectors. This energy is not comparable to the energy of emission of Iridium-192 isotope (0.38 MeV), for which the Imatrixx was used. In order to obtain a correction factor for the energy of 0.38 MeV, the prescription dose to the points RA and LA are increased from 2 to 8 Gy and the ratio of the TPS planned and IMatriXX measured dose are estimated. The average of the estimated values are taken as the correction factor for the energy of 0.38 MeV. The length and the width along with the area of the 100 % isodose distribution planned by TPS is compared with ImatriXX measured length, width and area. The measured

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data were statistically analyzed using Chi square test.

Dwell position accuracy

Autoradiograph using films is the method available to check the dwell position accuracy of the HDR unit and in this work ImatriXX is used to carry out the same. A single catheter was placed along the Y-axis of the detector. The 26 dwell positions were selected for various combination of separations and step size. The separations of 20, 30, 50, 60 and 100 mm for step sizes of 2.5, 5, 10 mm available in the machine, were planned. The ImatriXX is irradiated with the above plans and the accuracy of the dwell positions were studied. The dose profiles and the acquired images were used for the estimation of dwell separations and the difference in the planned and measured distance between the dwell positions.

Dwell time accuracy

The same setup as used for dwell position accuracy verification was used for the verification of dwell time accuracy. Step size of 10 mm was used and different dwell positions with dwell time of 1s are planned. The ImatriXX was irradiated for different dwell positions and the dwell time is measured using the field view list in the omni-pro software. The dwell time accuracy was confirmed by repeating the measurements for five different dwell positions.

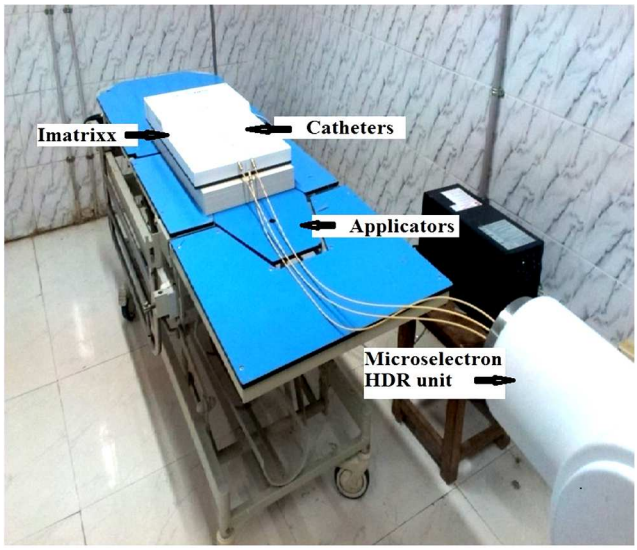

Figure 1. Experimental setup of Imatrixx for virtual patient plan verification

RESULTS

The area of the reference isodose surface is estimated from the Plato TPS and ImatriXX. The difference in area is found to vary from -0.59 cm^2 to 4.59 cm^2 and the results are shown in table 1 and the distribution of difference in area is graphically represented in figure 2. The Chi square test with 11 degrees of freedom yielded a result of $p<0.05$. The user correction factor for Iridium-192 energy 0.38 MeV is estimated when compared to the calibration of ImatriXX with 6 MV photon beam and is shown in table 2.

Dwell position accuracy is verified for 26 dwell positions for various step sizes of 2.5, 5, 10 mm. The average of the difference between the planned distance between the dwell positions and that measured along with standard deviation are shown in table 3, and is represented graphically in figure 3. The dose profiles and the acquired images for 30mm, 50mm dwell position separations are shown in figure 4.

Dwell time accuracy was verified using the field view option by measuring the time between the snap shots. The difference between the dwell time planned and measured is found to be 0.02 s, the data for which is show in table 4.

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Table 1. Difference in area between the Plato calculated and Imatrixx acquired for 100 % isodose surface for various catheter lengths.

Distance between ovoids in cm	Difference in area (cm^2)		
	Catheter Length: 4.0cm	Catheter Length: 5.0cm	Catheter Length: 6.0cm
2.0	-0.59	-0.19	-1.16
4.0	1.00	-1.30	0.42
5.0	-0.84	-1.84	4.59
6.0	1.21	4.97	-0.17

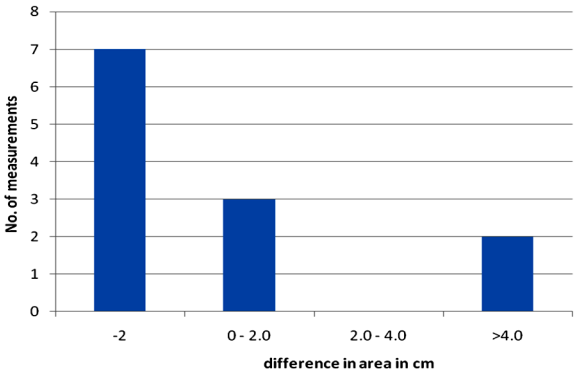

Figure 2. Distribution of difference in planned and measured treatment area.

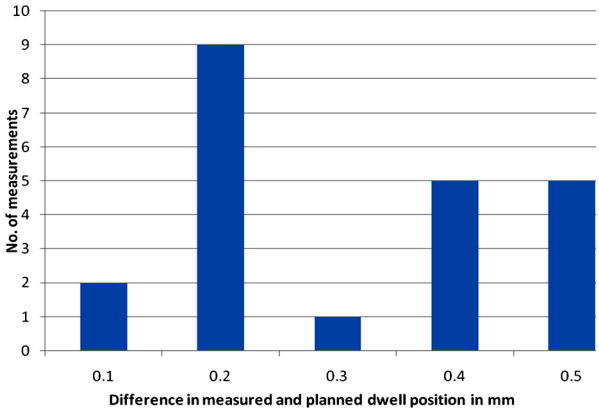

Figure 3. Distribution of difference in planned and measured dwell position length.

Table 2. Correction factors calculated for reference points RA and LA for various catheter lengths.

Dose in Gy	Correction factor			
	Catheter length :5.0 cm		Catheter length :6.0 cm	
	RA	LA	RA	LA
2.0	1.11±0.015	1.07±0.006	1.07±0.025	1.10±0.010
4.0	1.11±0.015	1.08±0.010	1.07±0.010	1.11±0.011
6.0	1.11±0.025	1.08±0.023	1.08±0.015	1.11±0.010
8.0	1.11±0.015	1.07±0.010	1.07±0.020	1.11±0.026
Average correction factor with standard deviation :1.090 ± 0.0211				

Table 4. Verification of dwell time using Imatrixx.

Dwell positions	Snap shots	Planned time (s)	Measured Time (s)
1	50	1	1.00
2	49	1	0.98
3	49	1	0.98
4	49	1	0.98
5	49	1	0.98
Average with std. deviation :0.984 ± 0.008944			

Table 3. Dwell position accuracy verification.

Step sizes	Planned distance between dwell position(mm)	Average measured distance between dwell position(mm) with standard deviation
2.5, 5.0, 10.0 mm	20	20.02±0.325
	30	29.96±0.338
	50	49.6±0.000
	60	59.37±0.400
	100	100.03±0.404

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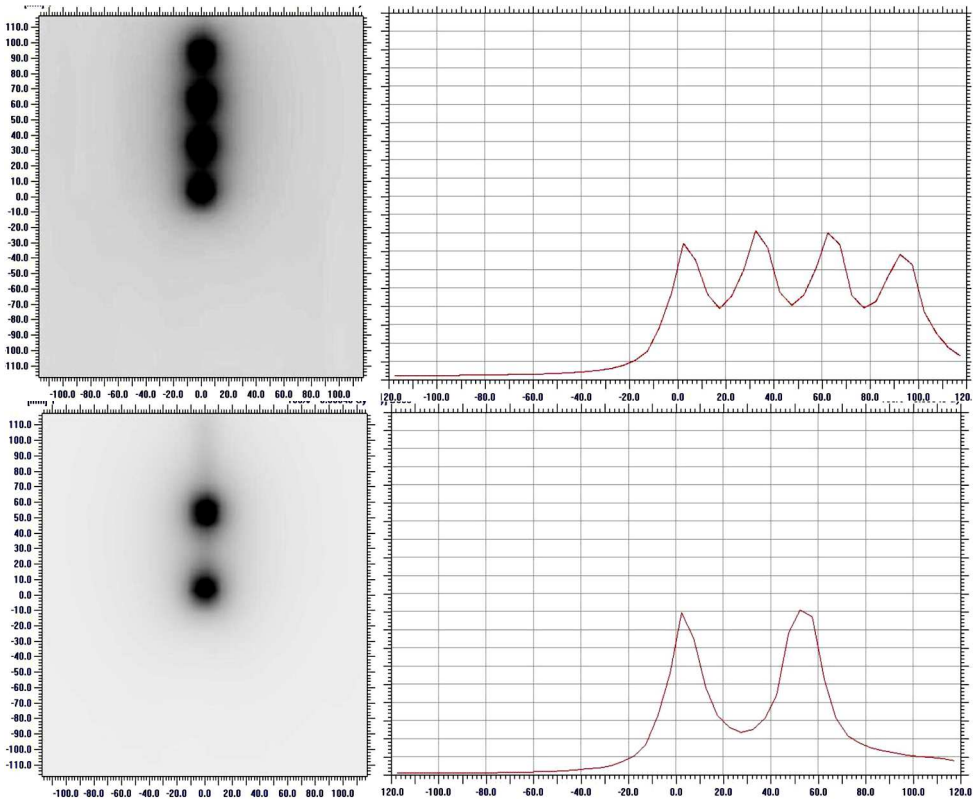

Figure 4. Acquired image and dose profile for 30 mm and 50 mm dwell separation.

DISCUSSION

The area of the reference isodose surface is estimated from the Plato TPS and Matrix. The difference in area is found to vary from -0.59 cm^2 to 4.59 cm^2 with a standard deviation of ±1.918 and the results of statistical analysis using chi square test with $p<0.05$ proves that the Imatrixx can be effectively used for the verification of patient treatment plan generated by the Treatment planning system. The distribution of the measurements of the difference in area is shown in figure 2. The distribution shows that nearly 58% of the difference in area between the planned and measured were in the range of -2 to 0 cm^2. This confirms the fact that the treatment area matches with the planned area within acceptable limits. The correction factor has to be found out for the energy for which the Imatrixx is to be used. When the IMatrixx calibrated in 6 MV photon beam is used and as the dose prescribed in the TPS for Point RA and LA were increased from 2 to 8 Gy, we observed a constant ratio in the TPS prescribed and Imatrixx measured dose. The user correction factor for Iridium-192 energy, 0.38 MeV was estimated and found to be between 1. 07 to 1.11, when compared to the calibration of ImatriXX with 6 MV photon and the mean correction factor was estimated to be 1.090 with a standard deviation of ±0.0211. With this correction factor, the % deviation between the estimated and the measured dose varies from -2.19 to -1.38 %. Yewondwossen has reported a variation of around 3.7% for the maximum mean difference between TPS calculated and 2-D array measured dose [9]. Our results correlate well with the published data and is within the acceptable tolerance range of radiotherapy practice which is usually ±3% [10]. The above results show that ImatriXX can be effectively used as QA tool for patient plan and point dose verification.

Auto radiograph using the films is the common mode of verification of dwell position accuracy. The dwell position accuracy is verified

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visually and it may be affected by film blurring as reported in literature [11].The 2-d linear array is tried for the Dwell position accuracy verification. The Imatrixx is irradiated for the various dwell positions as programmed and that measured difference in separation ranges from 0.1 to 0.5 mm. The dose profiles and the integrated images acquired in Imatrixx gives an apparent peak for the irradiated dwell position which makes the measurements easy to perform compared to films. Manikandan *et al.* have reported a mean dwell positional accuracy of -0.45 mm [12] using ImatriXX. Our results on dwell postion accuracy shows that nearly 40 % of the measurements are within 0.2 mm variation. All the measurements are within the acceptable range of ±1 mm.

Dwell time accuracy was verified using the field view option and measuring the time between the snap shots. The difference between the dwell time planned and measured was found to be 0.02 s which is well within the tolerance limit of ±1 s.

CONCLUSION

The efficacy of the 2-D linear array ImatriXX was tested and the results show that the array can be effectively used as Quality assurance tool for patient plan verification in brachytherapy and for HDR machine Quality assurance.

***Conflicts of interest*:** *Declared none.*

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