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Evaluation of depth dose characteristics of superficial X-rays machine using different kVp and applicators diameter

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Background: Radiotherapy Treatment Planning requires different dosimetric quantities as input in order to calculate a desired dose distribution. This study has been focused to evaluate the depth dose characteristics of superficial X-rays being used for radiotherapy treatment. ***Materials and Methods:*** Computerized 3-D water phantom of multi-data system was used. The measurements were made through PTW (Physikalirsch-Technische Werkstalten) farmer type NT-30006 waterproof ionization chamber of 0.6cc, and PTW electrometer for digital dose rate reading in Gy/min using five different diameter applicators and filters at five different values of accelerating potentials (kVps). ***Results:*** The dose rate at various kVp X-ray beams was observed to decrease significantly with increasing depth in water phantom for all applicator diameters from 98% (at 0.1cm depth) down to 43% (at 2cm i.e. reference condition). The dose rate increases by increasing the value of kVp with a maximum at 150 kVp (1.6 and 0.93 Gy/min for respective applicator diameters 2.5cm and 10cm). Applicator with 2.5cm diameter demonstrates better dose rate at 85kVp at different depths. PDD decreases lower than 50% for all combination of applicators and kVps at/or above 2cm depth so these measurements should not be considered for treatment planning. ***Conclusion:*** Higher energy X-rays are suggested to be used for applicators of higher diameters and smaller energy X-rays for applicators having smaller diameters. **Iran. J. Radiat. Res., 2011; 9(3): 159-166**

Keywords: *Radiotherapy treatment, Pantak Therapax SXT-150, depth dose, applicators diameter, kVp, superficial X-ray machine.*

INTRODUCTION

Superficial kilovoltage X-rays have a lot of applications in radiotherapy, such as treatment of basal or squamous cell carcinomas of the skin and the palliative irradiation of bone metastases (1), for the treatment of cancers at or close to the skin surface due to maximum dose absorption close to such areas (2,3). Superficial X-rays are equally effective to control nonmelanomatous skin tumours (4). Various tumour types and/or conditions show different reactions to a particular dose of radiation. A slight over dose may damage the normal tissues while a too low dose may make the treatment less effective (5). Perfect quantity and facts of dose delivered during superficial X-ray radiotherapy is, therefore, required for patient dose evaluation (6).

Applicators are useful in superficial radiotherapy to treat curved areas of the skin e.g. forehead (1). Applicators used with kVp X-ray units usually produce low energy electrons that can interfere with the dose measurements at phantom surface (1,7). Increasing kVp will increase the penetrability of the X-ray beam and therefore increases the exposure of phantom since it increases the number of X-rays, which have sufficient energy to penetrate the phantom. Different sizes/diameters of applicators are useful for the evaluation of secure patient dose at various depths and areas. Depth-doses depend upon half-value layer, which may be associated with a wide range of tube peak voltages kVps (8). The absorbed dose distributions for the clinically used combinations of X-ray energies and applicators can be obtained from measurements in water phantom. This information may be useful as input in a treatment planning for

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radiotherapy [8] and incorporation in dosimetry protocols (IAEA [9], Klevenhagen *et al* [10], Ma *et al* [11], and NCS [12]).

To determine the absorbed dose at positions other than 2cm (reference depth) in the water phantom or for different applicator diameters and kVp, relative dosimetry data including percentage depth dose curves and output factors are useful. A comparison of depth dose measurements [13] has shown variations due to the use of a variety of phantom materials other than only real water [14, 15], therefore, it is recommended that measurements should be made in real water [16]. Hill *et al.* [17] studied the behavior of chambers using X-ray beams from 80–150 kVp and recommended the use of the parallel plate ionization chambers to determine depth dose data to give correct dose information close to the surface and at depth in the water phantom. Hill *et al.*[2] studied depth doses in water and relative detector response (in Solid Water and in air) for various X-ray beams (75, 100, 180 kVp) using different applicators diameter with Pantak DXT300. They observed maximum deviation of 4.7% and 5.8% for 75 kVp X-ray beam with 2cm applicator diameter at 2mm and 20mm depths respectively. Munck af Rosenschöld *et al.*[18] compared various kVp dosimetry protocols by the IAEA (TRS-277 and TRS-398) [9], IPEMB[16] and NCS[12] experimentally in four clinical beams having potentials of 30, 80, 120 and 200 kVp, with half-value layers ranging from 0.6 mm Al to 1 mm Cu and found fairly good agreement, i.e. within 1-2%. Evans *et al.*[1] used Gulmay D3300 kilovoltage X-ray therapy unit with various applicator sizes and diameters and noted that the variation of absorbed dose with stand-off distance from the applicator base followed the inverse-square law for all tested combinations of beam tube potential (kVp) and applicator. Performance assessment and beam characteristics for Pantak Therapax SXT-150 X-ray therapy unit has been studied by Natto[19] and Jurado *et al.*[20] through beam quality, central axis depth dose and field uniformity for several applicator sizes and focal skin distances (FSDs) with the tube operating between 80 and 150 kVp accelerating potential. Natto[19] compared his results with those calculated using Monte Carlo code-MCNP and noted good agreement between experimental and calculated results for various combination of beam quality and applicators, whereas Jurado *et al.*[20] compared their results with those of British Journal of Radiology (BJR) supplement 25[9]. The present study is also performed on Pantak Therapax SXT-150 X-ray therapy unit available at BINO, Pakistan for its calibration and performance assessment for various applicator sizes, filters at different acceleration potentials (kVp) to provide the accurate determination of depth doses for secure treatment planning. The present depth dose data was compared with that of Jurado *et al.* [20] with only small deviations and discussed using available literature.

MATERIALS AND METHODS

This work has been carried out using Therapax SXT 150, kilovoltage therapy unit that encompasses low and medium energy X -ray beams as defined in the IAEA TRS-398 protocol[9]. Components of the unit include a microprocessor based control console, a HT generator and control system, a cooling water system, a mobile tube stand, a metal ceramic X-ray tube, a set of filters and a set of applicators. For modification of the beam quality additional filters have been used. The system allows eight different combinations of tube potential, tube current and added filtration. An extra specific filter is provided for warm-up. Filters are recognized by the system on inserting added filtration into the tube head, by automatically setting the tube potential and tube current. Filter specific characteristics (listed in table 1) were chosen to provide beam qualities capable of covering a wide range of situations found in clinical practice.

Beam sizes were established by stainless steel applicators fixed at the tube head.

Table 2 shows the characteristics of the nine available applicators. Dose rate and beam characteristics of the Therapax SXT 150 have been explored to fulfill the objectives of this work. Dose determination was carried out in accordance with the International Atomic Energy Agency (IAEA) TRS-398 protocol [9], based on standards of absorbed dose to water under reference conditions as shown in table 3.

A PTW 10001 UNIDOS electrometer (Physikalirsch - Technische Werkstalten, Freiburg, Germany) was connected to the PTW Type NT-30006 plane-parallel chamber which is assumed quite suitable for low-energy X-ray dosimetry. The calibration was performed in standards of absorbed dose to water at four different radiation qualities covering the range of low-energy X -rays.

Table 1. Filters characteristics.

Filter No.	kVp	mAs	Added filtration
4	80	8.0	0.8 mmAl
5	85	4.0	2.0 mmAl
6	100	10.5	1.8 mmAl + 1.0 mmCu
7	120	11.2	1.1 mmAl + 0.3 mmCu
8	150	13.2	0.2 mmAl + 1.0 mmCu
Warm-up	150	13.2	5 mmPb

Table 2. Applicators characteristics.

Shape	FSD (cm)	Diameter Φ (cm)
Cylindrical	15	2.0
Cylindrical	15	2.5
Cylindrical	15	4.0
Cylindrical	15	5.0
Conic	25	10.0

Measurements were carried out at the highest tube voltage and current (150 kVp and 20 mA) using the warm-up filter to minimize any scattered radiation. The areas of maximum leakage were identified using therapy verification films wrapped around the tube head and performing a 10 min exposure. The tube head leakage was measured using the chamber at distances of 5 cm and 1 m from these points of maximum leakage.

Timer accuracy and linearity with dose were checked. Timer response is independent of the filter and the applicator. Therefore, filters 4, 5,6,7,8 and the 2.0, 2.5, 4.0, 5.0, 10.0 cm diameter applicators were chosen to perform the measurements.

Accuracy was checked using a digital electrometer. Exposures with a timer selection of 1.35 min were performed; using the electrometer to measure the time elapsed between the console time display showing 0.45 min and 1.45 min. These measurements were carried out starting the electrometer when the irradiation was running in order to avoid the delay from when the start button is pushed until the timer starts counting. Linearity of the timer with dose was assessed by performing exposures with a timer selection of 0.45 min to 4.25 min, measuring the output with the PTW ionization chamber in the water phantom.

Dose rate measurements were carried out for each filter–applicator combination at least three times to evaluate the average dose rate. Dose rate normalization was performed at the depth of maximum dose

Table 3. Reference conditions used in the determination of absorbed dose rate to water.

	Lower-energy filters	Medium-energy filters
Phantom	water	water
Chamber	PTW Type NT-30006	PTW Type NT-30006
Measurement depth	Phantom surface	Phantom surface
Position of reference point of chamber	At the measurement depth of 3cm	At the measurement depth of 3cm
Applicator diameter (Φ)	2.5cm	10.0cm

coinciding with the surface for these beam qualities [20].

For low-energy X-ray beams, measurements were made using the PTW NT-30006 chamber and the water phantom. Measurements were performed from the surface to a depth with a dose rate value of about 10–15%, in steps of 0.1cm to 3cm (smaller steps in the higher dose gradient zone).

RESULTS

The intention of present research was to investigate the depths dose characteristics of superficial X-rays, by exercising all degrees of freedom. So the effects of possible parameters, which may affect the dose rate/ depth, have been exercised. At the first instance the effect of applicator on dose rate have been noted, and later on research was diverted to the effect of kVp for a constant applicator diameter.

Effect of applicators diameter

The absorbed dose rate has been determined from the precise measurements of timer scale at a depth of 2cm (reference condition) in water phantom and the results are presented in table 4. The present absorbed dose rates determined using various filters for 10cm applicator diameter have been compared with those of Jurado *et al.* [20], also shown in table 4, indicating only a small difference in the range -0.34 to +0.22.

Dose rate at different depths in water phantom, using different applictor diameters and constant kVp have been measured. Dose rate has been found maximum at phantom surface, and decreased with depth. Figure 1 shows the depth dose characteristics for filter No. 5 (2mm Al) using different applicators diameter. The decrease in dose rate with depth is found much significant (~60-70%).

It is also clear from figure 1 that although dose rate falls with increasing depth but the curve for each applicator is different indicating the effect of applicator on dose rate. The maximum dose rate (which always occurs for minimum depth) increases with increasing applicator diameter (see figure 1).

The dose rate data for filter No. 5 and at accelerating potential of 80 kVp using the 2.5, 4.0 and 5.0cm diameter applicators were compared with the published data of Jurado *et al.* [20] for the same radiotherapy machine (Pantak Therapax SXT 150) as depicted in table 5. The %differences were found within +4.92, +8.94 and +12.71 at dose depth of 1cm and within -1.12, -0.41 and -8.00 respectively at dose depth of 2cm in water phantom. But for same filter 5 and at same 80kVp using applicator of 2.0cm diameter, the %difference was -4.07 and +3.53 respectively at dose depth of 1 and 2cm. The maximum difference in local dose between measured and published data was

Table 4. Comparison of experimental and published [20] data for absorbed dose rate to water in reference conditions.

Filters	Φ = 10 cm applicator at 2cm depth		
	Experimental D_w (Gy/min)	Published [20] D_w (Gy/min)	Difference
5	0.63	0.97	-0.34
6	0.83	1.00	-0.17
7	0.88	1.04	-0.16
8	0.99	0.77	+0.22

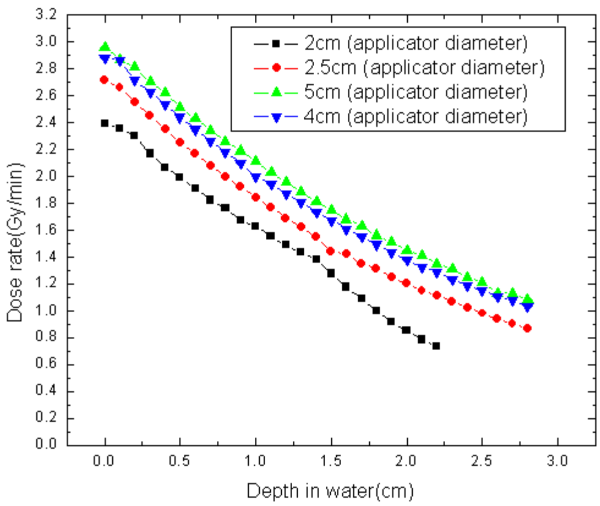

Figure 1. Depth dose rate for X-ray beams using different applicator diameter, plotted as a function of depth in water.

Table 5. Comparison of published [20] and experimental dose data at two different depths using filter No. 5 at accelerating potential of 80 kVp.

Dose Depths (cm)	Applicator diameter (cm)	Published data[20] (P)	Experimental data (E)	%Difference (E-P)*100/E
1.0	2.0	56.2	54.0	-4.07
	2.5	58.0	61.0	+4.92
	4.0	60.1	66.0	+8.94
	5.0	61.1	70.0	+12.71
2.0	2.0	43.7	45.3	+3.53
	2.5	45.2	44.7	-1.12
	4.0	48.6	48.4	-0.41
	5.0	51.2	47.5	-8.00

about -8.00% and +12.71% at 1 to 2cm depths in water phantom.

Effect of kVp

The explorations of depth dose characteristics have been extended by changing kVps to note the effect on dose rate at different depths for constant applicator diameter. This investigation has been made for two different applicator diameters 10cm and 2.5 cm, and results are presented in figures 2 and 3 respectively.

This feature may explain, at least in part, the patterns of 80kVp to 150kVp depth doses where the smallest applicator diameter 2.5cm consistently shows greater depth dose values at 80kVp than those at 85kVp to, 150kVp. It can be seen that dose rate decreases with depth, although it is dissimilar for different kVps (see figures 2, 3). The dose rate at 150kVp decreases with depth as shown in figures 2 and 3, but the decrease is not much significant when compared with the case of dose rate at low kVp (i.e. 80 kVp).

The equivalent depth dose comparison for the low (80 kVp) and medium (150 kVp) energy beams using 10cm applicator diameter are listed in table 6. The maximum difference in local dose at 1 cm depth is approximately -16.34% at low energy (80 kVp) but at 150 kVp the difference is not much significant (-4.34% at 3cm depth). Table 7 depicts the equivalent depth dose comparison for the low (85 and 100 kVp) energy beams using 2.5cm applicator diameter. The present depth dose data are higher at 85kVp as compared to that of Jurado *et al.* [20] and a maximum difference in local dose at 3 cm depth is approximately

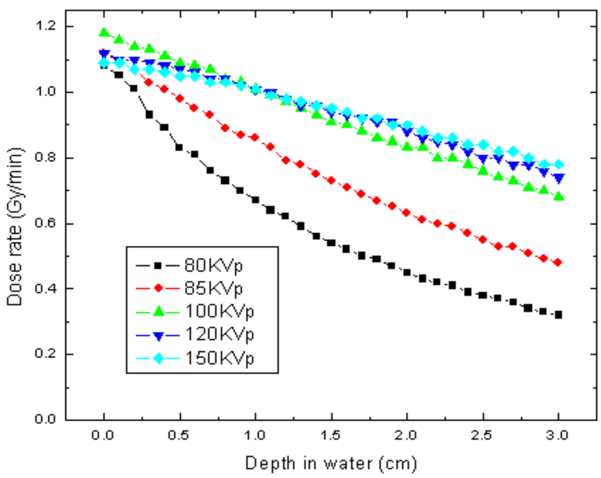

Figure 2. Depth dose characteristics of X-ray beams for 10cm applicator diameter.

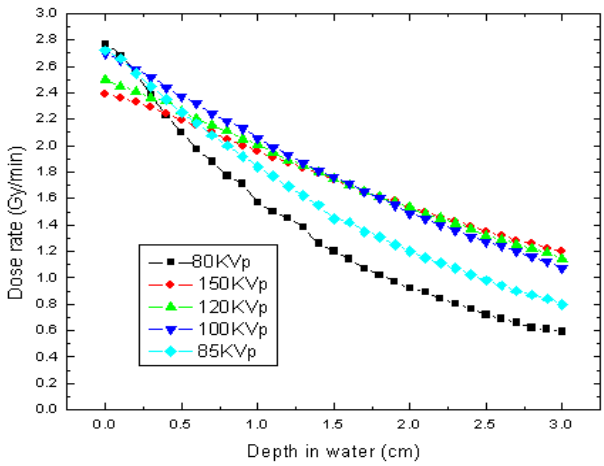

Figure 3. Depth dose characteristics of X-ray beams for 2.5cm applicator diameter.

Table 6. Comparison of published [20] and experimental dose data measured at two different kVps at various depths using 10cm applicator diameter.

Tube potential (kVp)	Depth (cm)	Φ = 10 cm applicator		
		Experimental	Published[20]	%Difference
80	1	67.5	76.5	-16.34
	2	56.2	58.9	-4.80
	3	40.4	45.7	-13.11
150	1	92.5	94.3	-1.94
	2	82.7	84.6	-2.29
	3	71.3	74.4	-4.34

Table 7. Comparison of published [20] and experimental dose data measured at two different kVps at various depths using 2.5cm applicator diameter.

Tube potential (kVp)	Depth (cm)	Φ = 2.5 cm applicator		
		Experimental	Published[20]	%Difference
85	1	82.4	76.0	+7.77
	2	64.6	56.8	+12.07
	3	49.3	41.8	+15.21
100	1	80.4	79.6	+0.99
	2	61.6	62.3	-1.14
	3	45.2	47.1	-4.20

+15.21% while at 100 kVp the difference is not much significant (<-4.20% at 3cm depth).

DISCUSSION

Clinical treatments need advice on techniques for measuring depth doses, applicator factors for small field sizes and dose fall off with increasing focus-to-surface distance (FSD) on kilovoltage X-ray machines [16]. For the Therapax SXT 150 clinical X-ray unit, lateral dose profiles at several depths and depth dose distributions were measured and compared with results from the same radiotherapy machine (Pantak Therapax SXT 150) by Jurado *et al.* [20] with applicators and kVps. To make dose measurements reliable, normalization of the depth-dose distributions was performed at a depth of 2 cm (the reference point in dosimetry protocols such as NCS [12], Klevenhagen *et al.* [10], Ma *et al.* [11] for X-rays with energy from 80 to 150 kVp). The same reference point was used for the whole data set to ensure that uncertainties with surface dosimetry could not introduce into the results and any normalization of the beam data. The quality of the X-ray beam was found quite comparable and satisfactory as evident from absorbed dose rate measurements.

The dose rate was found to increase with beam energy. As higher-energy beams possess greater penetrating power they deliver a higher depth dose. The FSD does not give accurate inverse-square law correction for output at extended FSDs under all clinical conditions. For small field sizes, the inverse-square law correction underestimates the change in output with FSD. Scatter photons from the applicator have no contribution in dose rate because they are attenuated by the filter and the photon scatter from water phantom will contribute to the dose. So the deviations from the inverse-square law is caused by an additional decrease in output because of the loss of X-ray beams scattered from the sides of applicator in air and in phantom[16] and it is more significant for small field sizes and low photon energies. Measurements by Aukett *et al.* [22] have also shown that for some applicator designs deviations may be significant particularly for smaller applicators.

Figure 1 shows the relation between dose rate and depth in water with change of applicator diameter keeping kVp, filter thickness and mAs constant. On increasing the applicator diameter, dose rate increases and the X-ray penetrate to a longer depth in water phantom. With increasing field size more scattered photons contribute to the dose at greater depths, resulting in a less steep depth-dose profile[8]. Filter 5 having thickness 2mmAl and applicators having diameters 2.0cm to 5.0cm demonstrate % depth dose (PDD) at 2cm depth only between 44.7 to 48.4% so for 2 cm depth treatment filter 5 and applicators diameter 2.0, 2.5, 4.0 and 5.0cm should not be used for treatment otherwise cancer part will be spare. Jurado *et al.* [20] also observed similar results as depicted in table 5. Also shown in table 5 some %differences in the dose rate data, such differences are expected because PDD data of Jurado *et al.* [20] may be taken at different tubes currents, added filtration and detectors/chambers. Aukett *et al.* [22] studied applicator factors with ionization chambers using 50 and 100kVp X-rays and found %differences within ±2 for cylindrical and parallel plate chambers. Rosser [23,24] also noted %difference of ±4 between several ionization chambers. Ehringfeld *et al.* [25] also experienced uncertainity of ±1.5% between various ionization chambers. Therefore, it can be said that the present dose rate data is uncertain within the observed range.

An initial effort to produce a single profiled filter to obtain better stability of the maximum 5 cm diameter applicator was not successful and also to achieve an improvement at the smaller applicator diameters. This indicated the need for a composite filter profiled to suit each individual applicator size [5].

In figures 2 and 3 plots show that dose rate values are superior for 150kVp (with applicator Φ=10 cm), because they correspond to a harder beam as compared to lower kVps [26]. The dose rate falls off rapidly to its minimum value, but the fall off for high kVp is quite different than that at low kVp. This feature may explain patterns of 80 to 150 kVp depth doses where the smaller applicator (Φ=2.5cm) yielded consistently greater depth dose values at low kVp. The equivalent depth dose comparison for the low (80 - 100kVp) and medium (150 kVp) energy beams using 10cm and 2.5cm applicator diameters are listed in tables 6 and 7 showing some uncertainties with the already published data [20]. Along with different tubes currents and added filtrations, X-ray beam quality may also be a cause of this difference. It is, however, noted that the uncertainty at low kVp (80-85) is higher but shows improvement on increasing the X-ray beam energy. Similar kind of variations were also experienced by Klevenhagen *et al.* [10], who noted maximum deviation of 23.2% at a depth of 0.2 cm and 12.9% at a depth of 0.3 cm at 75 kVp X-ray beam and observed an improvement in the dosimetric agreement on increasing the X-ray beam energy, the maximum deviation was 2.2% for 300 kVp X-ray beam. This could be accepted as satisfactory agreement since the accuracy of the data did not directly affect output dosimetry at these qualities [17], and the data can be used clinically for guidance only.

CONCLUSION

The present investigations demonstrate the depth dose evaluation of superficial X-rays by varying different parameters. It helps treatment planners to choose the optimum set of treatment parameters. For this purpose, a complete setup (primary electron energy with possible high-voltage ripple, focal spot size, target, inherent filtration, applicators and additional filtration) must be modeled accurately in order to be able to reproduce the measured dose distributions. The dose rate at various kVp X-ray beams was found to decrease with depth in water phantom, for all applicator diameters. The dose rate increases by increasing the value of kVp with maximum at 150kVp. Applicator having diameter 2.5cm gives better dose rate at 85 kVp at different depths. At 3cm depth PDD decreases lower than 50% at all kVps and so should not be used for treatment.

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