

Physical and Dynamic Wedges in Radiotherapy for Rectal Cancer: a Dosimetric Comparison

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Background: Wedges are frequently used in radiotherapy to modify the isodose distribution by compensating dose inhomogeneity. In this study, we compared the dosimetry of physical wedges (PWs) and evaluate dynamic wedges (EDWs) used in radiotherapy for rectal cancer. Two wedge angles of 45° and 60° were used for the physical and dynamic wedges due to the large separation in the pelvis contour. **Material Methods:** A Varian 2100 C/D linear accelerator was used to utilize the mix beam treatment flair using the 6 and 15 MV. Treatment plans using the above wedges for thirty patients were made on the Eclipse treatment planning system. Mean monitor unit, plan normalization value, maximum and minimum doses in the planning target volume (PTV), dose conformity index, dose homogeneity index and uniformity index were determined for each treatment plan. The average dose coverage for the PTV with EDW and PW plans were compared. **Results:** The PTV received prescription doses of 100.9±0.74%, 101.01±1.63% for the EDW (45°, 60°) compared to 101.2±1.65%, 101.3±1.33% for the PW (45°, 60°). Homogeneity indices were (0.11±0.02%, 0.11±0.05%) for the EDW (45°, 60°), and (0.15±0.1%, 0.16±0.11%) for the PWs respectively. The EDW at 45° had a better target coverage with a higher conformity index value of 0.98 ± 0.01 compared to the other wedges. A statistically significant ($p < 0.01$) difference was noticeable in the plan normalization values and fewer monitor units were found using the EDW at 45°. **Conclusions:** We conclude that the EDW at 45° results in an improvement to the plan evaluation parameters presented and thus increases dose efficacy for radiotherapy of rectal cancer.

Key words: homogeneity index, conformity index, uniformity index, plan normalization.

Introduction

Physical (PW) and dynamic wedges are commonly applied to obtain homogeneous dose distribution in the planning target volume (PTV) [1]. Dynamic and physical (hard) wedges are used in 3D conformal radiotherapy in order to improve dose distribution in patients. Unlike wedge factors for PWs that depend on wedge material and thickness, wedge factors for dynamic wedges such as Varian enhanced dynamic wedges (EDWs) depend on the relationship between the position of the moving jaw and the delivered monitor units (MUs) [2].

Wedge shaped isodoses are used for common clinical situations such as slope patient surfaces, regions of interesting beams and irregular shaped tumor volumes. These isodoses have been achieved by many methods.

PWs were constructed in house for cobalt and other early accelerator machines [3-4].

The dosimetry and commissioning of wedges were studied by different groups. Varatharaj et al [6] discussed dosimetric characteristics of a physical and EDW in their work, and resulted in the fact that complete knowledge of the dosimetric characteristics is crucial in the proper choice of wedge systems. Moyed et al [7] investigated the implementation and verification of virtual wedges in a radiotherapy treatment planning system and demonstrated that it is possible to include constraints checking on the delivery of virtual wedge implementation. The efficiency of the treatment planning process is improved by including these constraints checking on the virtual wedge implementation.

Sendón Del Río et al [8] suggested a model that explored the observed behavior of virtual wedge factors and confirmed a strong dependence of virtual wedge factors on the dosimetric board. An explanation has been given on how the balance between different contributions is responsible for virtual wedge factors values. Dennis et al [9] suggested that it is necessary to have knowledge of dosimetric parameters for the treatment planning of the enhancement of dynamic wedge. These dosimetric parameters and their applications

are evaluated and compared with open and wedge field dosimetric parameters.

Recent radiotherapy delivery techniques such as intensity modulated radiotherapy (IMRT), volumetric radiations modulated arc radiotherapy and proton therapy etc are popular in a large number of cancer centers/hospitals within a reasonable time frame. In the meantime, most of these techniques are only available in a small number of large centers/hospitals. However, the wedge technique is still very common in radiotherapy as there is still a big population depending on this technique. Wedges are more common as a comprehensive tool to control the intensity of the beam and hence to guarantee a desired dose distribution for the final approval of treatment planning. EDWs are further developed as beam modification accessories, but at the same time require extra care in quality assurance and dose calculation procedures.

The aim of this study is to compare the quality of the physical and dynamic wedges using dose-volume indices such as the dose conformity index, the dose homogeneity index and the dose uniformity index. According to the literature these indices have not been studied for wedge comparison. Dosimetric parameters such as mean MU, plan normalization value and dose volume histogram (DVH) tools such as maximum and minimum doses in the PTV are also discussed in this study.

Materials and methods

A Varian 2100 C/D linear accelerator (Varian Medical System, Palo Alto, CA) was used to generate radiation beams. All rectal treatment plans were generated on the Eclipse treatment planning system (version 6.5) having pencil beam algorithms to calculate MUs and dose distributions. Absolute dose measurements were performed with a cylindrical ionization chamber N30001 (PTW Freiburg Germany), which was calibrated at dosimetry calibration laboratory "PINSTECH" (Pakistan institute of Nuclear sciences and technology). In our clinic the calibrated output is adjusted to be 1cGy = MU to water with a field size of (10 cm × 10 cm) and source to surface distance (SSD) of 100 cm with detector at a depth of maximum dose.

Thirty patients were chosen for the analysis. All patients were planned to receive three-field conformal radiotherapy. By taking CT-simulation in prone position the field orientations used for the MUs delivery were posterior and two laterals. The energy utilized to deliver MUs from posterior and both lateral fields were 6 and 15 MV, respectively. The percentage depth doses (PDDs) of x-rays at depth of 10 cm were 66.6% and 77.8% for both energies respectively. These measured at SSD of 100 cm, according to the TG-51 protocol [10]. Weights of both lateral beams were adjusted according to the dose coverage.

All dosimetric parameters were appraised qualitatively and quantitatively using standard dose volume coverage, dose homogeneity, dose uniformity and dose conformity. Target

planning coverage was evaluated as the percentage of PTV receiving at least 95% of the prescribed dose $TV_{95(\%)}$. Dose uniformity was judged quantitatively by uniformity index (UI) was defined as:

$$UI = \frac{D_5}{D_{95}},$$

where $D_{5\%}$ and $D_{95\%}$ are the minimum doses delivered to 5% and 95% respectively of the PTV.

Dose homogeneity was assessed quantitatively using the dose homogeneity index (HI) as:

$$HI = \frac{D_{1\%} - D_{99\%}}{\text{prescription dose}},$$

where $D_{1\%}$ and $D_{99\%}$ are the doses delivered to 1% and 99% volume respectively of the PTV [11-13]. Smaller HI corresponds to a more homogenous dose distribution in the PTV. The conformation of target planning coverage was estimated using the Conformity index (CI) as defined by the formula:

$$CI = \frac{\text{ref Isodose Volume}}{\text{Target Volume}}.$$

The 95% isodose volume was taken as a reference volume of the PTV [14-15]. The CI value varies between (0 and 1) and a value 1 is for an ideal plan.

In addition, the mean and maximum doses to the PTV, and the dose to 1% of target volume $D_{1\%}$ were calculated to appraise target coverage, the values of above parameters of all cases planned for PWs and EDWs at wedge angles of 45° and 60° were compared with the help of dose volume histograms (DVH).

For all cases, the dose prescription was 180 cGy with 28 fractions. The statistical package for social sciences (SPSS) was used for all treatment plans. Statistical tests for all comparisons were performed using the *F*-test which was used to find out the response of all dose parameters by differentiating significance and non-significance behavior. After checking significance, standard deviation (SD) was applied for choosing the best wedge on the basis of low value of SD.

Results

Comparisons of treatment plans using EDWs at angles of 45°, 60° and PWs with the same angle for all cases were performed. To trim down the risk of toxicity, no plan was acknowledged with a hot spot along the bladder and rectal walls as these areas receive a substantial radiation dose. The dose distribution for the patients along transversal, frontal and sagittal planes are shown in Fig. 1 for EDW (45°, 60°) and Fig. 2 for PW (45°, 60°) for the same patient.

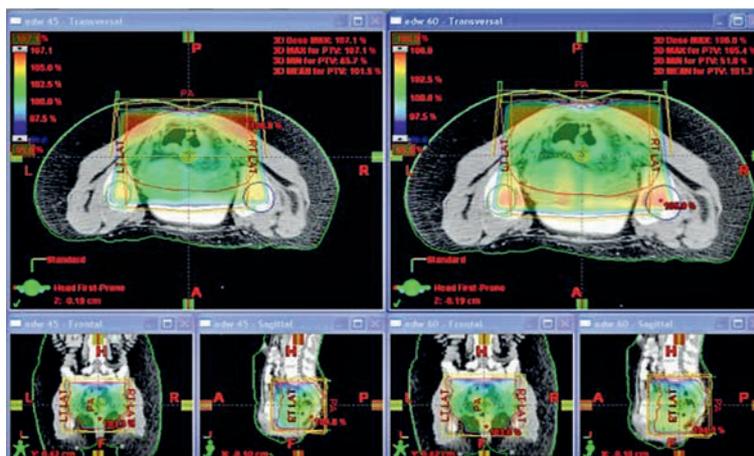


Fig. 1. Dose distribution in transversal, sagittal and frontal view of EDW at (45°, 60°)

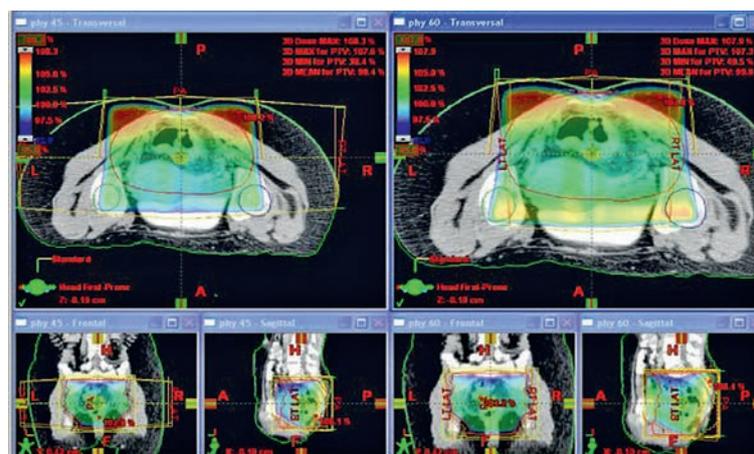


Fig. 2. Dose distribution in transversal, sagittal and frontal view of PW at (45°, 60°)

The maximum, minimum, mean doses in cGy and volume in cm^3 of the PTV were also calculated and analyzed for each patient using both wedges. The PTV received not more than 108% of the prescribed dose; however EDW 45° plans illustrated fewer amount of doses than all additional wedges up to 106%. It was also found that the mean dose for the PTV was also less in EDW 45° and it endows with a higher dose to 1% volume than the rest of the wedges. The coverage was also the best for the EDW 45° plans, as shown in Table I.

The CI for the PTV was comparable among all wedges under consideration and results showed that CI for EDW 45° was better than other wedges, i.e. EDW 45° plans are able to produce sharper and stiff dose distribution around the PTV (Fig. 3).

Higher and noticeable values of plan normalization were found while using EDWs and as extracted from Table 1 show that EDW 45° has average higher values of plan normalization representing efficient dose coverage. Smaller values of UI correspond to a more uniform dose in

the PTV. It has been observed that UI for EDW 45° plans were collectively lower than other wedges. Minute values of HI using EDW 45° showed best response in delivering homogeneous dose distribution to the PTV than other wedges. It means EDW 45° plans offer more homogeneous dose distribution than other wedges. The average lower values of UI, HI, D_{mean} , D_{max} and higher values of CI, $D_{1\%}$, $TV_{95\%}$ indicates that EDW 45° has better converge than other wedges as shown in Fig. 3 and Table I.

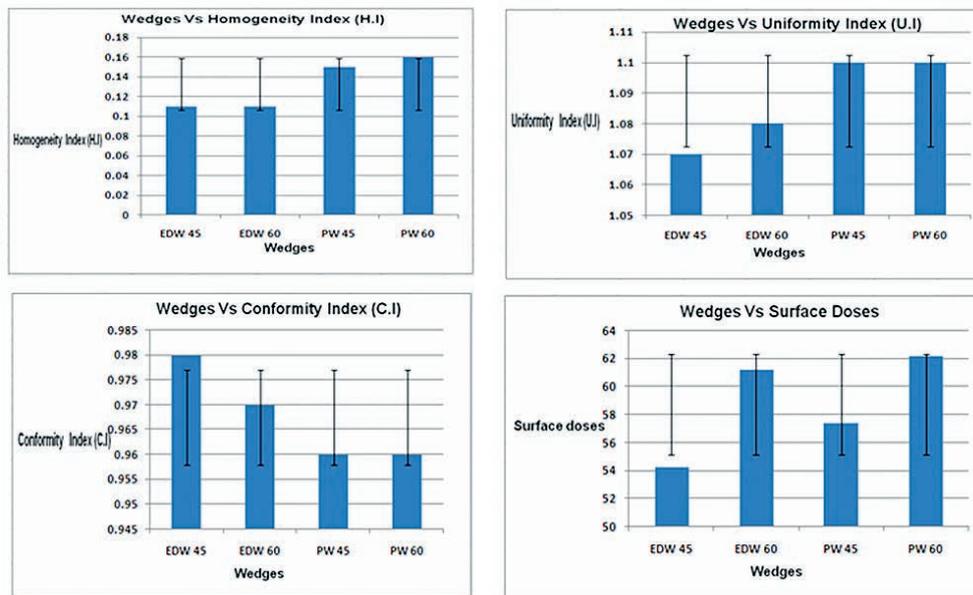
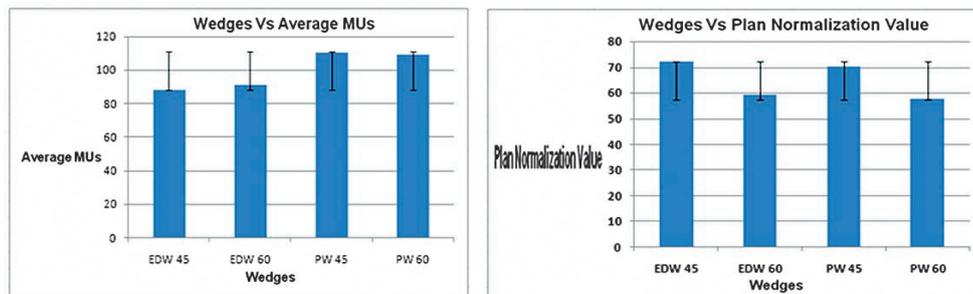
The MUs required to deliver each plan was recorded for all patients. It is clearly shown in Fig. 4 and Table I that less MU delivered in case of the EDW 45° than other edges. Minimum Surface doses appeared with EDW 45° than other wedges as shown in Fig 3 and Table I. Statistically highly significant behavior is shown by MUs ($p < 0.01$).

The dose volume histogram (DVH) analyses of EDW 45°, 60° and PW 45°, 60° plans for the PTV as illustrated in Fig. 5 for the same patient. To enhance the results, statistical analysis i.e. the F -test has been applied to find p-value (probability). A p-value of $p < 0.05$ is considered statistically significant.

Table I. Comparison of the average dose parameters of 30 patients among different wedges

Parameters	Enhance 45 ⁰	Enhance 60 ⁰	Physical 45 ⁰	Physical 60 ⁰	F-value	Probability
D _{mean}	100.9±0.74	101.01±1.63	101.2±1.65	101.3±1.33	0.56 ^{NS}	0.6409
D _{max}	106.8±1.7	107.1±2	107.5±1.8	108.3±2.6	3.12*	0.0287
D _{1%}	104.5±1.2	105.4±1.4	106.5±1.9	106.5±1.8	10.99**	0.0013
TV _{95%}	97.1±1.5	96.7±3.8	93.6±9.8	95.4±5.7	3.14*	0.0279
UI	1.07±0.02	1.08±0.05	1.1±0.13	1.1±0.08	1.77 ^{NS}	0.1576
CI	0.98±0.01	0.97±0.03	0.96±0.03	0.96±0.03	2.83*	0.0417
HI	0.11±0.02	0.11±0.05	0.15±0.1	0.16±0.11	1.08 ^{NS}	0.3694
Monitor Unit (MUs)	87.87±3.92	91.16±3.91	110.30±4.87	108.94±4.13	231**	0.0025
Plan normalization value	72.2±9.05	59.23±5.71	70.19±9.21	57.7±6.28	26.3**	0.0014
Surface Doses	54.2±2.4	61.1±2.9	57.3±2.8	62.1±2.5	13.8**	0.016

D_{mean} = Mean dose, D_{max} = Maximum dose, D_{1%} = dose to 1% of target volume; TV_{95%} = dose to 95% of target volume; UI = Uniformity index; CI = Conformity Index; HI = Homogeneity Index; * = Significant (p<0.05); ** = Highly Significant (p<0.01); NS = Non significant (p>0.05);

**Fig. 3.** Effect of wedges on dosimetric parameters such as Conformity Index (CI), Homogeneity Index (HI), Uniformity Index (UI), and Surface doses.**Fig. 4.** Illustration of MUs and plane Normalization value for Physical and Enhance Dynamic Wedges

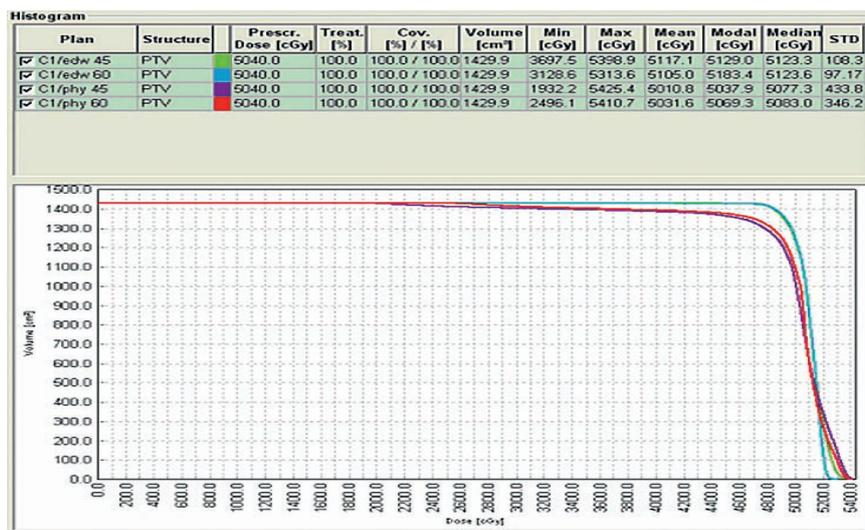


Fig. 5. Comparison of DVH of EDW 45o, 60o and PW 45o, 60o planes of the PTV.

Discussion

Results of the Monte Carlo study showed that 30% increase in mean photon energy was found due to the effect of beam hardening for the PW 45°, neither this mean-energy increase nor such dose reduction was found for the EDW 45°. These dosimetric differences between EDWs and PWs are significant and clearly affect the clinical use of these beams [16].

We compare the different outcomes in patients treated for rectal cancer using PWs and EDWs 45° and 60°. These wedge angles were used because of a large separation of the patient's pelvis contour. MU plays a vital role in measuring the output of the treatment machine. Highly statistical behavior was formed by all wedges and results in fewer MU delivered by the EDW 45°. It was also reported that EDWs use less MUs than PWs [17].

Privileged and conspicuous plan normalization values were found while using EDW. The elevated mean plan normalization value is 87.87, better dose to $D_{1\%}$ was 104.5 cGy and smaller MUs results, EDW 45° with highly significant behavior ($p < 0.01$) than others wedges. It was also reported that the number of MU to deliver a particular dose with the EDW field is less than that of the PW field due to a change in the wedge factor. Other dosimetric characteristics, such as the profile and isodose of EDW, closely match with that of the PW [18]. Our results agree with these studies that fewer MUs deliver in EDWs than PWs as shown in Fig. 4 and Table I.

Surface dose distributions from a dual energy linear accelerator can appreciably affect the treatment techniques of patients with radiosensitive critical structures, which need to be protected. It was found in this study that EDW 45° showed less surface doses than PWs as shown in Fig. 3 and Table I. It was reported that PW limited in size, high density, and

high atomic number materials creates low-energy electron and photon scattering which increase surfaces doses in PWs than EDWs [19-20]. Overall practically, the implementation of EDW in radiation therapy treatments provides clinicians with efficient tool for the conformal radiotherapy treatment planning than hard wedges [21].

In a clinical setting, PTV coverage is the major optimization objective. PTV coverage was assessed using the minimum, maximum, and mean doses. Maximum doses for the EDW 45°, EDW 60°, PW 45°, PW 60° are 106.8 ± 1.7 cGy, 107.1 ± 2 cGy, 107.5 ± 1.8 cGy and 108.3 ± 2.6 cGy, respectively, and is statistically significant. SD was low and is 1.75 for EDW 45° than other wedges.

With EDW 45o treatments reduce mean dose, $D_{\text{mean}} = 100.98 \pm 0.14$ cGy was delivered, when compared with other wedges as shown in Table I. This reduction may be small but helps in reducing the toxicity. In our study the mean and less values of dose coverage parameters such as D_{mean} (100.98 ± 0.14) cGy, D_{max} (106.8 ± 1.7) cGy, $D1$ (104.5 ± 1.2) cGy and $TV_{95\%}$ (97.1 ± 1.5) cGy emphasized the competent behavior of the EDW 45°. The average low values of D_{max} and higher values of $TV_{95\%}$ shows better and statistically significant results ($p < 0.05$) for the EDW 45° than other wedges. Lower SD values of D_{mean} (0.74), $D1$ (1.2), $TV_{95\%}$ (1.52) for EDW 45° confirm that this wedge is better than the rest of wedges.

CI is used to evaluate the clinical authentication of better treatments. Improved CI may be helpful in delivering higher doses to PTV without delivering more doses to surrounding normal tissues. It was reported that IMRT plans give significant enhancement of dose conformity to PTV on the base of higher value of CI compared to both plans [22]. In our study CI exposed comparable results among wedges showing p -value = 0.0417. The EDW 45° achieved high value of CI 0.98 ± 0.01 as compared to rest of the wedges. This was clearly shown in Fig 1 and Table I that EDW 45° gives a

considerable improvement of dose conformity to PTV with higher value of CI than other wedges.

Non-significant behavior was shown by Dmean, UI and HI indicates that any wedge can be good for coverage but collectively it is depicted from the above measured dose coverage parameters that the EDW45° delivered maximum dose to PTV, good CI for the treatment planning of rectum patients.

Conclusion

In this study, the PTVs from EDW 45° plans showed efficient and noteworthy improvement in terms of target coverage and homogeneity compared to other wedges. With less hot spot and high dose conformity in the target volume confirms a better 3D dose distribution in the PTV using the EDW 45°. Our study has shown the feasibility of achieving the desired dose distribution with EDW 45° plans. Collectively, this study suggests a dosimetric benefit of EDW 45° over other wedges and indicates the importance of EDW 45° in the treatment of rectum patients.

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