Technical Note

A Feasibility Study of Stereotactic Radiosurgery/Stereotactic body Radiotherapy/Stereotactic Ablative Radiotherapy Practice using TomoEDGE in Helical TomoTherapy for Lung, Liver, and Spine Targets

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Abstract

The primary purpose of the study is to evaluate the implementation of Helical TomoTherapy (HT) for eligible stereotactic radiosurgery/stereotactic body radiotherapy/stereotactic ablative radiotherapy (SRS/SBRT/SABR) cases using TomoEDGE option. The study focuses on reduction of treatment time without compromise in plan quality using TomoEDGE. It is a mode in HT that uses a dynamic opening of the jaws during treatment delivery to reduce the dose penumbra which otherwise is not possible with fixed jaws option. Eligible SRS/SBRT/SABR cases of lung, liver, and spine were used in this study. All planning parameters such as dose prescription to target and critical organs, pitch, and modulation factor were same in all the plans of the same patient with modifications in the field width and jaw mode. First set of plans with 2.5 cm width and second set of plans with 5 cm width were done in dynamic TomoEDGE mode. Third set of plans created with 5 cm width fixed jaw mode and fourth set of plans with 2.5 cm fixed jaw mode for comparison purpose were done. Our observations achieved that a significant milestone with reduction of up to 34.3% in treatment time of liver cases, 35.2% in lung cases, and 28.7% in spine cases was observed using dynamic TomoEDGE mode with 5 cm width, while no significant variation in the planning results compared with plans using 2.5 cm dynamic TomoEDGE option. TomoEDGE is an efficient and useful mode in TomoTherapy to reduce the treatment time with bigger field width in SRS/SBRT/SABR cases without significant changes in the plan quality.

Keywords: Stereotactic radiosurgery/stereotactic body radiotherapy/stereotactic ablative radiotherapy, TomoEDGE, TomoTherapy, treatment time

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Introduction & Objectives

A very fine intensity modulation can be planned and delivered using TomoTherapy treatment system.[1] It uses 6 MV flattening filter-free photon fan beam technology and is modulated by a binary multileaf collimator. The treatment delivery with gantry rotation and couch translation into the bore looks like a computed tomographic scan.[2] The leaves travel across the selected width in about 20 msonds. This modulation gives high degree of homogeneous and conformal dose distribution.[3] TomoTherapy was developed as an efficient technology to deliver simple to complex dose distributions for a wide variety of distinctive and convoluted lesions.[4]

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Stereotactic radiosurgery (SRS) is an established methodology for spinal lesions. Stereotactic body radiotherapy/stereotactic ablative radiotherapy (SBRT/SABR) is a highly conformal and precise high-dose delivery to extracranial lesions over few fractions to a well-defined target using a stereotactic

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frame/reference. SBRT/SABR results are encouraging as an effective option for primary and secondary lung lesions based on the available data.[5-7] Further, it is an appealing modality for patients with inoperable liver metastases.[8-10] Helical TomoTherapy (HT) can be used successfully in some of the SRS/SBRT[11-13] cases though its primary focus is not radiosurgery. The main constraint is its long treatment time[14] when compared with other techniques such as volumetric-modulated radiotherapy. HT beam is collimated to a fan width of 40 cm, and three different thicknesses (1, 2.5, and 5 cm) can be selected by tungsten collimators. Beam-on time can be reduced by using bigger field width which however results increased dose penumbra in the longitudinal direction as this parameter is proportional to field width.[15] As a result, adjacent critical structures might potentially receive higher doses and similar dosimetric results vis-à-vis small-field width plans are unachievable. The choice of big field width with fixed jaws mode had a constraint of dose penumbra effect as its dimension is proportional to field width. TomoEDGE, a technique in HT, uses a dynamic opening of the jaws during treatment delivery while the couch speed is constant, to reduce the dose penumbra.[16,17] Now, using dynamic jaws mode, we have the possibility to choose bigger field width, thereby reducing the treatment beam-on time. The main objectives of this study were to compare the dosimetric results of different treatment modes (dynamic TomoEDGE mode with 5 cm width, dynamic TomoEDGE mode with 2.5 cm width and fixed mode with 5 cm width) using plan quality metrics recommended by ICRU, RTOG, etc., and evaluate the uses of TomoEDGE (dynamic jaws mode) with bigger field width in SRS/SBRT/SABR cases of different extra cranial lesions. Though few studies have been available from other countries,[13,18] there are no Indian data. Further, to the best of our knowledge, no clinical study was ever published which includes evaluation of quality of dose coverage and dose gradient comparisons between these modes which are most important in SRS/SBRT/SABR cases.

Materials and Methods

Five SBRT liver cases, five SBRT lung cases, and four SRS spine cases each with four different plans were used in this study. Vacuum cushion (Klarity Medical, USA) was used in lung/liver cases, and thermoplastic mask (Orfit Industries, Belgium) was used in spine cases for patient setup. Planning computed tomography (CT) was done in the head first supine position using our big bore CT simulator (Philips Medical Systems, The Netherlands). 2-mm slice thickness was used in spine cases whereas 3 mm was used in lung/liver cases. Clinician drew the target and critical structures on the CT slices. 4DCT was used to create internal target volume in the cases of lung and liver. Mean planning target volume of liver cases was 30.12 ± 8.31 cc (18.6–40.1 cc), lung cases was 36.72 ± 13.37 cc (17.7–48.8 cc) and spine cases was 41.85 ± 7.98 cc (32.3–50.2 cc). All plans were done with Volo Planning System Version 5.1.2.12 (Accuray, Sunnyvale, CA, USA) as below.

- First set of plans was done using 2.5 cm width in dynamic TomoEDGE mode
- Second set of plans was created with 5 cm width with dynamic TomoEDGE mode
- Third set of plans was created with 5 cm width and fixed jaw mode for comparison purpose
- Fourth set of plans was created with 2.5 cm width and fixed jaw mode for comparison purpose.

The degree of modulation is characterized by modulation factor which is defined as the ratio of maximum to the average leaf open time. A modulation factor of 2.0 was used for all the plans. A value of 0.1 was used for another factor "pitch" which is defined as the ratio of couch travel per full gantry rotation to the field width used, for all the plans. This pitch value allows the completion of treatment in a single session.

Except change in field width and jaw mode, all other planning parameters such as dose prescription to target, critical organs, pitch, and modulation factor were same in all the plans of same patient. A median dose of 12 Gy to lung, 18 Gy to liver, and 18 Gy to spine was prescribed per fraction. A total of 200 iterations were used in all the plans. Dose–volume histograms were generated for dosimetric analysis and comparison. Currently, conformity index which describes the agreement between planning target volume and prescription isodose, homogeneity index (HI) which tells about the uniform dose distribution inside the target, gradient index which gives the dose fall off outside the target, and quality of coverage index (Q_{RTOG}) which explains the minimum isodose coverage are the most popular indices to evaluate the plan quality.[19,20] Dose received by 95% volume of the target (D_{95}) is a popular and frequently used prescribed volume dose in Radiation Therapy Oncology Group studies.[21] As per the recommendations of ICRU-83, $D_{95,}$ dose near minimum D_{98}, dose near maximum D_{2}, mean dose D_{50}, and dose HI were evaluated. Paddick conformity index (PCI), paddick gradient index (PGI), and Q_{RTOG} were also used for comparison of plans. A paired *t*-test was used to assess the statistical significance of differences in target dosimetry. A $P < 0.05$ was considered for significance.

- HI is defined[22] as $(D_{2\%} - D_{98\%})/D_{50\%}$
- $PCI = TTV^2/PTV - PIV$[22,23]

In the above equation, TTV – treated target volume by prescribed isodose line, PTV – planning target volume, and PIV – prescription isodose volume

- $PGI = V_{50}/V_{100}$[20,24,25]

In which V_{50} – volume of half of the prescription dose, V_{100} – volume of prescription dose

- $Q_{RTOG} = I_{min}/RI$[20,26]

in which I_{min} – minimum isodose surrounding the target and RI – reference isodose.

Results and Discussion

Dose color washes in sagittal, coronal, and axial sections of liver target for all the four modes are shown in Figures 1-4 and

same for spine from Figures 5-8. Similarly, for lung target, the dose wash are shown in Figures 9-12. Clear similarity in target dose distribution was observed between the four modes in all the three sites. Planning target volume dosimetry results of SBRT/SRS plans with dynamic TomoEDGE (2.5 cm width), dynamic TomoEDGE (5 cm width), and fixed jaw (2.5 and 5 cm width) mode are tabulated in Table 1. Organ at risk doses calculated by the planning system in different modes are shown in Tables 2-4 in lung, liver, and spine cases, respectively. Maximum point doses/volume doses were based on the SBRT guidelines and considered as mentioned in tables for comparison.

Dose values from DVH analysis were measured in all the plans to evaluate the quality and mentioned with standard deviations. The average D_{95} was >95% for lung and liver and was >90% for spine in all the modes. Similarly, plan evaluation results related to maximum, minimum, and mean doses are acceptable and comparable [Table 1]. Dose conformity ranged between 0.67 and 0.72 for lung, 0.7 and 0.75 for liver, and 0.63 and 0.68 for spine is similar between the three modes. Homogeneity values of all the modes of three sites of the study ranging from 0.07 to 0.15 are satisfactory. Dose gradient values ranged between 3.5 and 3.9 in all the three modes were acceptable. Q_{RTOG} ranged between 0.947 and 1.028 was good and comparable in both regular and dynamic modes in all the selected plans. *P* values were mentioned in the tables. The statistical difference of indices in all the modes found insignificant using *t*-test expect in homogeneity. An ideal value of HI is zero.[22] Lower HI indicates the more homogeneous dose distribution across the target. Ideal value for PCI has not defined but the obtained values in this study are comparable with other published studies.[13,20] Lower gradient index values are generally expected in a good plan. Acceptable values of gradient indices were observed in all the cases comparable to published,[20] and they are nearly same. If the minimum dose is nearing to the prescription dose, then Q_{RTOG} is close to unity. All Q_{RTOG} values in the study have the index >0.9 and well in agreement with RTOG guidelines.[20] Dynamic TomoEDGE (2.5 cm width) showed slightly better target dosimetry and OAR doses among four modes of our study. Dynamic TomoEDGE (5 cm width) target and OAR results are nearly equivalent to 2.5 cm width mode. Fixed mode (2.5 and 5 cm width) target dosimetric results were also comparable with other modes. The critical structures doses were observed more in fixed jaw mode as expected. The difference between 2.5 and 5 width dynamic modes of OAR doses is

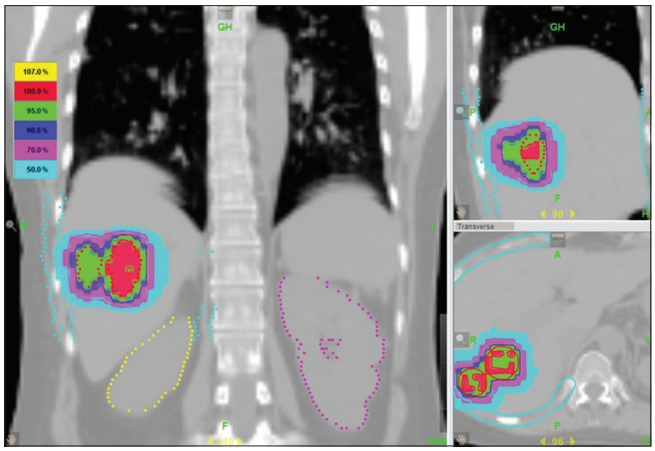

Figure 1: Liver dynamic 2.5 cm

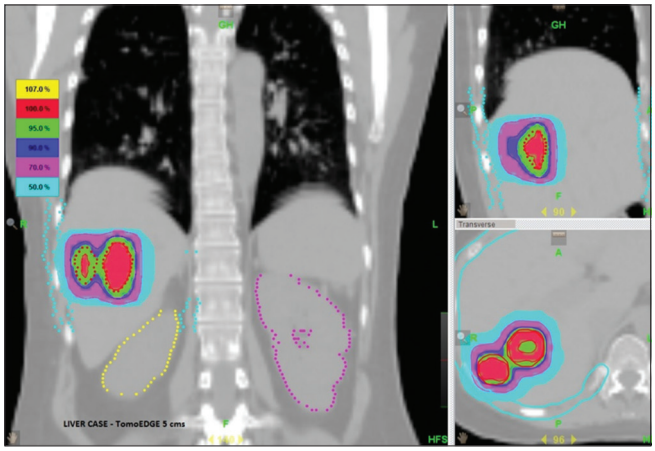

Figure 2: Liver dynamic 5 cm

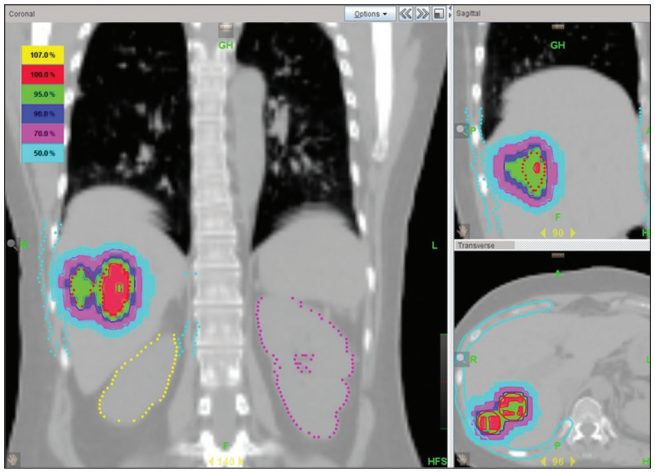

Figure 3: Liver fixed 2.5 cm

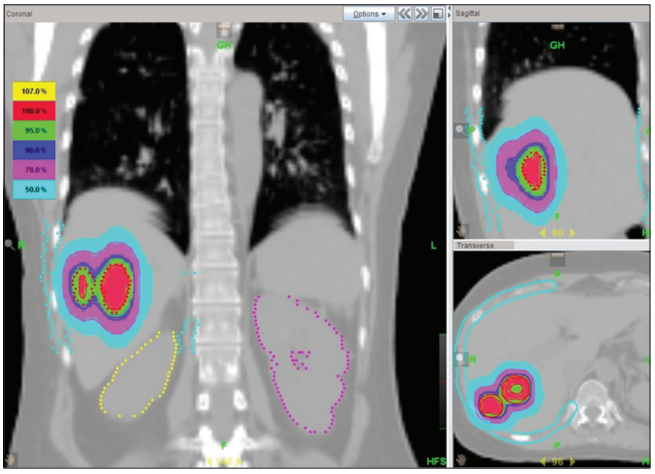

Figure 4: Liver fixed 5 cm

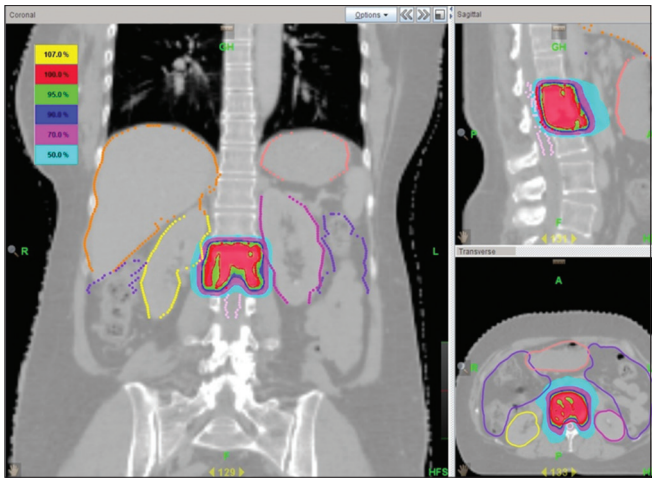

Figure 5: Spine 2.5 dynamic

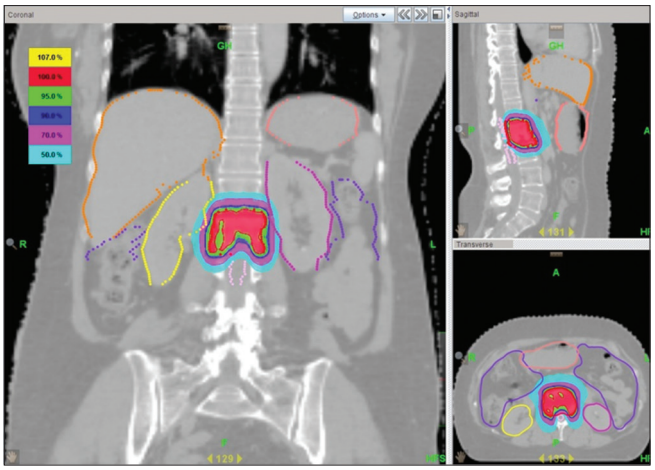

Figure 6: Spine 2.5 fixed

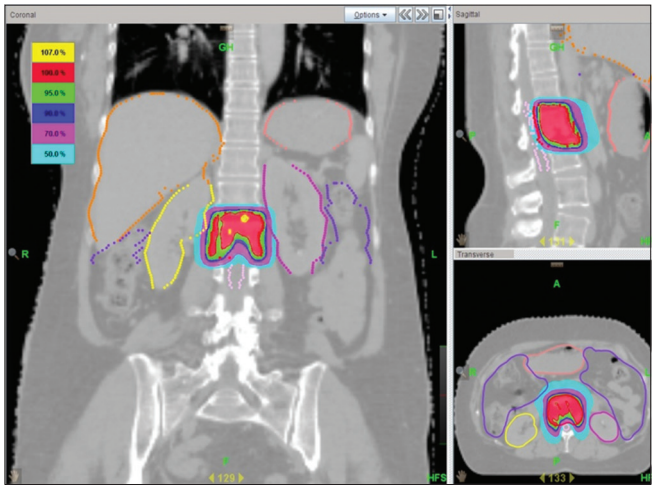

Figure 7: Spine 5 dynamic

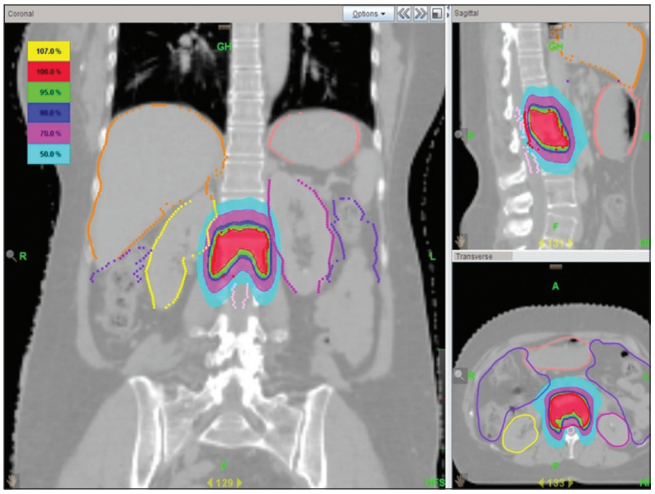

Figure 8: Spine 5 fixed

statistically insignificant [Tables 2-4] except in few cases of dynamic and fixed (5 width). The dose penumbra is produced in the superior/inferior direction due to fixed jaws. As the couch is continuously in motion, it produces a dose gradient in longitudinal direction. Hence, the critical structures which are very adjacent to the target received more doses.[27,28]

In SRS/SBRT cases where dose per fraction is very high, the planning system has limitations and it cannot calculate the final dose with higher pitches. System indicates to reduce either prescription dose or pitch. As the prescription dose is more, the pitch selection should be less in the order of 0.1–0.12 only. We achieved equivalent critical organs doses such as regular plans with higher FW using dynamic jaw mode (TomoEDGE) selection. In this mode, when the target comes in the field projected by front jaw, then the back jaw sits at the superior part of the target until it reaches its maximum. This jaw stays there while the target is moved through the fan beam until the inferior portion of the target comes in to the field. This is how the dose penumbra is reduced in this mode with big field width which gave dosimetric results similar to small width plans.

Treatment time comparison between TomoEDGE 2.5 cm and TomoEDGE 5 cm modes is shown in Figure 13.

The average treatment time of SRS/SBRT/SABR delivery using HT Dynamic TomoEDGE with 2.5 cm field width for lung, liver, and spine was 20.1 min, 19.8 min, and 20.5 min, respectively. A significant reduction of treatment beam on time up to 35.2%, 34.3%, and 28.7% for lung, liver, and spine [Figure 13], respectively, was observed with HT Dynamic TomoEDGE with 5.0 cm field width with similar planning results. This clarity is a remarkable advantage in maintaining quality plans with faster treatment delivery. Beam-on time comparison was also done with 2.5 cm width fixed jaw mode and dynamic mode. Obviously, dynamic mode beam on time should be slightly more than fixed mode if width is same. There was an average increase of [Figure 14] 5.8% beam-on time in liver cases, 8.4% in spine cases, and 4.6% in lung cases. Hence, it is clear that more advantage in the treatment time reduction with large width only.

The time required for patient set up, 3D volumetric imaging, and review/correction/approval is same for all the modes;

Table 1: Target dosimetry

Site	Prescription	Parameter	Dynamic TomoEDGE mode with 5 cm width (Gy)	Dynamic TomoEDGE mode with 2.5 cm width (Gy)	Fixed mode with 5cm width (Gy)	Fixed mode with 2.5cm width (Gy)	P value dynamic (2.5 and 5)/fixed (2.5 and 5)
PTV lung	48 Gy/4F	D_{95}	48.5±1.2	48.5±1.1	48.5±1.4	48.5±1.2	0.91/0.83
		D_{2}	48.5±1.1	48.6±1.1	48.6±1.4	48.5±1.1	0.93/0.68
		D_{98}	47.6±1.4	47.6±1.4	47.5±1.6	47.6±1.4	0.96/0.94
		D_{50}	48±0.1	48±0.1	48±0.1	48±0.1	0.97/0.94
		HI	0.07±0.008	0.07±0.006	0.07±0.008	0.07±0.007	0.91/0.96
		PCI	0.67±0.16	0.71±0.12	0.67±0.15	0.72±0.12	0.66/0.51
		PGI	3.7±0.3	3.6±0.2	3.8±0.3	3.7±0.2	0.65/0.46
		Q_{RTOG}	1.028±0.019	1.026±0.018	1.028±0.017	1.026±0.016	0.92/0.81
PTV liver	54 Gy/3F	D_{95}	52±0.8	51.7±1.2	52±0.9	51.7±1.2	0.45/0.51
		D_{2}	56.5±1.3	56.5±1.2	56.4±1.4	56.6±1.2	0.95/0.85
		D_{98}	51.4±1.2	51.9±1.2	51.4±1.2	51.8±1.2	0.39/0.53
		D_{50}	54±0.1	54±0.1	54±0.1	54±0.1	0.80/0.86
		HI	0.09±0.005	0.08±0.004	0.09±0.008	0.08±0.005	<0.05/<0.05
		PCI	0.72±0.15	0.75±0.12	0.7±0.14	0.75±0.11	0.82/0.50
		PGI	3.5±0.3	3.5±0.2	3.5±0.3	3.6±0.2	0.91/0.53
		Q_{RTOG}	0.98±0.014	0.99±0.011	0.96±0.015	0.98±0.012	0.06/<0.05
PTV spine	18 Gy/1F	D_{95}	16.5±0.8	17±0.7	15.9±0.6	17.1±0.7	0.85/0.06
		D_{2}	18.8±0.9	18.7±0.8	18.6±0.9	18.7±0.8	0.58/0.84
		D_{98}	16.1±1.2	16.6±1.1	16.5±1.2	16.5±1.1	0.66/0.64
		D_{50}	18±0.1	18±0.1	18±0.1	18±0.1	0.78/0.81
		HI	0.15±0.009	0.11±0.009	0.15±0.009	0.11±0.009	<0.05/<0.05
		PCI	0.63±0.11	0.66±0.11	0.63±0.15	0.68±0.11	0.97/0.77
		PGI	3.9±0.4	3.8±0.3	3.9±0.5	3.9±0.3	0.71/0.85
		Q_{RTOG}	0.947±0.045	0.955±0.053	0.962±0.051	0.96±0.055	0.89/0.91

Dose received by 95% volume D_{95}, Dose near minimum D_{98}, Dose near maximum D_{2}, Mean dose D_{50}. HI: Homogeneity index, PCI: Paddick conformity index, PGI: Paddick gradient index, Q_{RTOG}: Quality of coverage index, PTV: Planning target volume

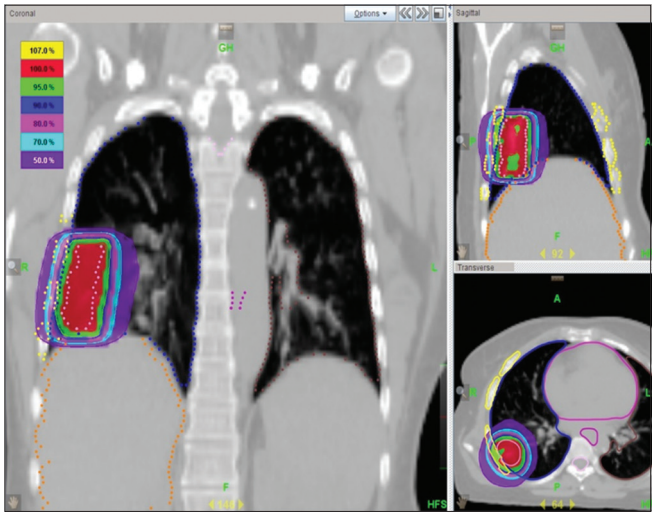

Figure 9: Lung 2.5 dynamic

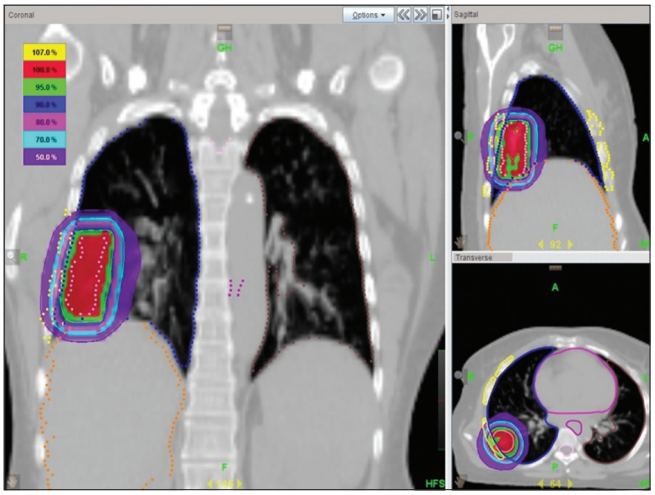

Figure 10: Lung 2.5 fixed

however, the time reduction in treatment delivery ensures patient comfort, precise, and accurate delivery, more so for SRS/SBRT/SABR treatments. This is quite useful for patients who cannot lie down more time on treatment couch. The study is conclusive in exhibiting the benefits of dynamic jaw (TomoEDGE) mode with large width for eligible SRS/SBRT/SABR treatment delivery.

Conclusion

Dynamic TomoEDGE option is an efficient and useful mode in TomoTherapy to reduce the treatment time with large field width in SRS/SBRT/SABR cases without significant changes in the plan quality. These results are encouraging for adoption of SRS/SBRT/SABR practice using HT for lung, liver, and spine targets of selective cases.

Table 2: Lung stereotactic body radiotherapy normal structure doses

OAR	Dynamic TomoEDGE mode with 5 cm width (Gy)	Dynamic TomoEDGE mode with 2.5 cm width (Gy)	Fixed mode with 5 cm width (Gy)	Fixed mode with 2.5 cm width (Gy)	*P* dynamic (2.5 and 5/dynamic and fixed (5 cm)
Spine (maximum)	10.1±1.2	10±1.2	10.5±1.2	10.2±1.2	0.89/0.69
Heart (maximum)	13.5±1.4	13.5±1.2	13.9±1.2	13.5±1.4	0.74/0.61
Oesophagus (maximum)	11±0.8	11±0.8	11.7±0.7	11±0.9	0.92/0.52

OAR: Organ at risk

Table 3: Liver stereotactic body radiotherapy normal structure doses

OAR	Dynamic TomoEDGE mode with 5 cm width (Gy)	Dynamic TomoEDGE mode with 2.5 cm width (Gy)	Fixed mode with 5 cm width (Gy)	Fixed mode with 2.5 cm width (Gy)	*P* dynamic (2.5 and 5/dynamic and fixed (5 cm)
Ribs (30 cc)	19±3.4	18±3.3	20±3.4	18.6±3.2	0.45/0.42
Spine (maximum)	10.7±4.1	10.6±3.9	11±4.2	10.6±4	0.72/0.53
Right kidney (35%)	0.9±0.3	0.7±0.3	2±0.3	1±0.3	0.29/<0.05
Left kidney (35%)	0.9±0.6	0.7±0.5	2.8±0.5	1.6±0.5	0.17/<0.05
Stomach (3 cc)	6.8±1.4	6.7±1.5	6.9±1.6	6.8±1.5	0.48/0.67
Spleen (average)	3.6±0.9	3.6±0.8	4.5±0.8	4±0.8	0.91/0.23

OAR: Organ at risk

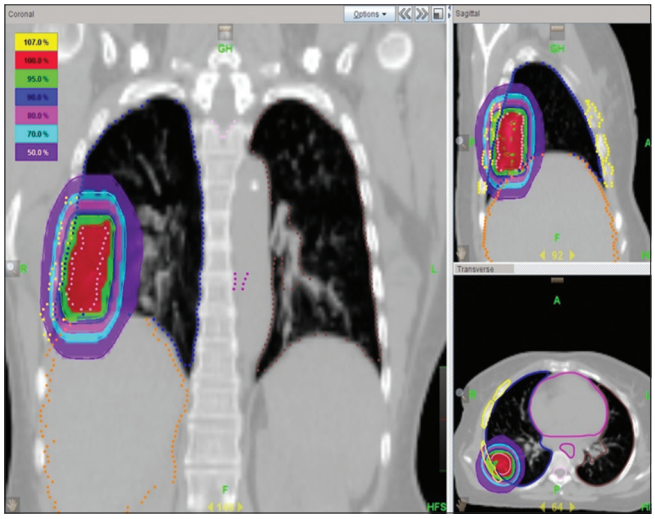

Figure 11: Lung 5 fixed

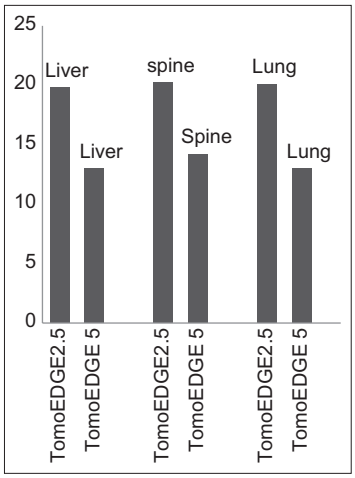

Figure 13: Beam-on time in min (Y axis) Comparison EDGE 2.5 versus 5 width

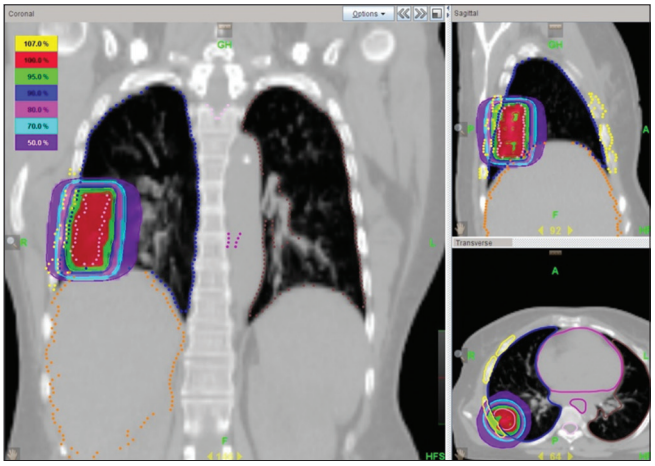

Figure 12: Lung 5 dynamic

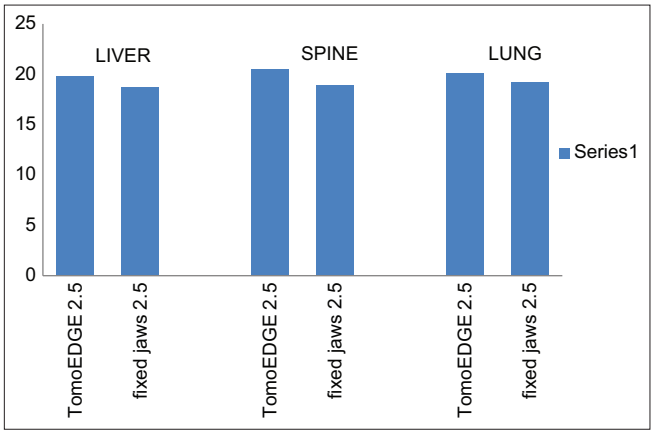

Figure 14: Beam-on time in min (Y axis) comparison Edge versus fixed jaws 2.5 width

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Nil.

Table 4: Spine stereotactic radiosurgery normal structure doses

OAR	Dynamic TomoEDGE mode with 5 cm width (Gy)	Dynamic TomoEDGE mode with 2.5 cm width (Gy)	Fixed mode with 5 cm width (Gy)	Fixed mode with 2.5 cm width (Gy)	*P* dynamic (2.5 and 5/dynamic and fixed (5 cm)
Spine (0.035 cc)	10.3±3.4	10.7±3.3	10.3±3.8	10.7±3.8	0.66/0.82
Left kidney (50% volume)	3.3±0.8	3.2±0.7	4.1±0.9	3.3±0.7	0.79/0.17
Right kidney (50% volume)	3.5±0.6	3.5±0.5	3.9±0.8	3.6±0.8	0.80/0.29
Stomach (10 cc volume)	6.5±0.5	6.5±0.6	6.8±0.5	6.5±0.6	0.97/0.85

OAR: Organ at risk

Conflicts of interest

There are no conflicts of interest.

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