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Dosimetric comparison of single and double collimator stereotactic body radiotherapy plans using Cyber Knife for carcinoma prostate

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► ***Original article***

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ABSTRACT

Purpose: This study was conducted to evaluate single collimator (SC) and double collimator (DC) plans with respect to dosimetric analysis, calculated dose delivery to OAR and treatment time in carcinoma prostate patients treated with cyberknife. ***Materials and Methods:*** A retrospective study was conducted among twenty low and intermediate risk carcinoma prostate previously treated with Cyberknife. PTV was created and OARs were delineated. The prescribed dose was set as 37.5 Gy in 5 fractions and a base plan (BP), followed by three reduction plans (time, beam and node) were generated for both single and double collimators with sequential optimization module. The SC and DC plans were compared for the above-said variables. The mean differences were compared using paired t-test. A p-value of <0.05 was taken as statistically significant. ***Results:*** The median age of the patients was 63 years. DC plans had tighter isodose lines. The means of minimum doses did not vary significantly across the plans but the mean and maximum doses, PTV D2 and V95 means were significantly higher in single collimator plan. The mean CI and HI values were better in DC plans. The doses to OAR were comparable in both single and double collimator plans in terms of maximum doses. The mean doses received by OAR's were significantly lesser in DC plans.SC plans resulted in lesser beams, nodes, MU and treatment time. ***Conclusion:*** Double collimator plans were better in producing good dosimetric results and reduced OAR doses with lesser estimated treatment efficiency.

Keywords: *Cyberknife, sequential optimization, prostate, fixed collimators.*

INTRODUCTION

Prostate cancer is the second most common cancer and the fifth leading cause of cancer-associated death in men. There have been 1.3 million new cases of prostate cancer and 359,000 associated deaths estimated worldwide in 2018. The incidence rates are found to be high in Australia, New Zealand, Northern and Western Europe (Norway, Sweden, Ireland) and North America (particularly in the United States) however, mortality rates are elevated in the Sub-Saharan Africa regions (E.g. Benin, South Africa, Zambia, and Zimbabwe) as well as the Caribbean (Barbados, Jamaica, and Haiti) [1]. Based on the data of population-based cancer registries, prostate is the second leading site of cancer in Delhi, Kolkata, Nagpur, and Thiruvananthapuram and is a 3rd common cancer in Bangalore (3rd most common cancer). From 2008 to 2012, the age-adjusted incidence rate for the in Mumbai, Chennai, Barshi, and Bengaluru registries was 8.9, 6.1, 2.0 and 8.3 per 100,000 population respectively [2,3]. Data regarding the true incidence of prostate cancer is limited in India [4].

Stereotactic Body Radiation Therapy (SBRT) has been one of the recommended treatment

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modalities in the treatment of very low, low and favorable or good prognostic intermediate-risk prostate cancer [5, 6]. The concept of Stereotactic radiosurgery (SRS) from being limited to treating intracranial lesions non-invasively initially has developed over time when the Gamma Knife radiosurgery system developed in 1972, which necessitated using invasive frames eliminating the advantage of fractionating treatment. Then the conventional linear accelerators were in place which helped intracranial SRS to expand greatly. However, it had deficiencies in terms of poor or absent image guidance, limited treatment configurations and was mainly limited to intracranial targets like the Gamma Knife and could not address the problems of patient movement and target motion for extra-cranial sites. Cyberknife (CK) in 2001, which was designed specifically to deliver stereotactic radiosurgery, overcame the main limitations of conventional linear accelerators [7].

Cyberknife, a frameless whole-body image-guided robotic radiosurgery system has a 6MV linear accelerator mounted on a computer-controlled robotic arm and an orthogonal pair of diagnostic X-ray imaging devices. Using 1200 points in the room, it can irradiate the target [8]. The low α/β values in prostate cancer support hypofractionated radiation therapy that helps in producing good tumor control and reducing rates of complication in the surrounding organs at risk (OAR) [9,10]. The most commonly prescribed dose delivered to the prostate gland range between 35 to 36.25 Gy in 5 fractions. Thus resulting in an EQD2 of 70 Gy for late effects (α/β = 3 Gy) and 85 Gy for tumor effects (α/β = 1.5 Gy) [5, 10].

A typical conventional fixed circular collimator (CC) system in cyberknife consists of 10 different diameters ranging from 0.5 to 6 cm controls the beam size and generates hundreds of non-isocentric and non-coplanar circular radiation beams. The beams create a highly conformal dose distribution by pointing to the edge of the target, resulting in a very low dose to OAR [11].

Evidence in the treatment of smaller targets like trigeminal ganglion in trigeminal neuralgia suggests that there is a higher dose delivery to the brain stem (OAR) in single collimator plans of bigger size compared to bi-collimator plans [12]. In the era of multileaf collimators and IRIS collimators, there are very limited studies on comparing the effect of single and double collimators thus arises a need for designing treatment plans which may be a cost-effective alternative in avoiding the dose spillage to the OAR. With this background, this study was proposed with an objective function for plan quality evaluation in terms of dosimetric analysis, calculated dose delivery to OAR and treatment time using single and double collimators in carcinoma prostate patients treated with cyberknife.

MATERIALS AND METHODS

Twenty patients who were diagnosed with low and intermediate-risk carcinoma prostate already treated with CyberKnife G4 Model from April 2018 to October 2018 were retrospectively analyzed.

To compare minimum, maximum and mean doses to PTV, conformity index and homogeneity index between single and double collimator plans. To compare duration of treatment, number of nodes, beams and MU and doses to the OAR between the created single and double collimator plans.

CT and MRI data sets of previously treated 20 patients were imported and registration was done in Mimvista contouring station. The entire prostate gland along with the tumor was contoured as GTV, 0.3 cm margin given around GTV to create PTV. Organs at risks (OARs) such as urinary bladder, rectum, penile bulb, small bowel, and bilateral femoral heads were also delineated. The CT data and RT structures were imported into CyberKnife treatment planning system, called Multiplan treatment planning system 4.6 (Accuray, Sunnyvale, USA). Ray tracing algorithm was selected for dose calculations. Gold fiducials were identified in the planning CT and DRR images were aligned. Anterior Organ at Risk (AOAR) was created from the bladder volume with a margin of 10 mm

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from PTV. Similarly, Posterior Organ at Risk (POAR) was generated from the rectum with a margin of 10 mm from PTV. AOAR and POAR were used to reduce the bladder and rectum dose. The prescribed dose to target was set as 37.5 Gy in 5 fractions.

The cyberknife treatment plan was generated in the sequential optimization module. Four symmetric shells were created (3, 9, 18 and 36 mm) around PTV to achieve the conformal dose gradient away from the target. The initial treatment plan i.e., base plan (BP) was generated with a single collimator. The sizes of the collimator were chosen depending on the size of the tumor in table 1. Total monitor unit (MU) was restricted to 37500 MU. MU per beam and MU per node were set at 750 MU and 1125 MU respectively and 95% of the target would receive the prescribed dose. Utilizing the node, time and beam reduction tools in the sequential optimization module, three reduction plans were generated with respect to time, beam and node [Time Reduction (TR), Beam Reduction (BR) and Node Reduction (NR)]. To evaluate the difference in the effects of single v/s double collimators, treatment plans were generated with the same optimization goals for the same set of patients even for the double collimator, thus generating eight plans for each patient resulting in 160 plans for the study. All the plans were generated in such a way that the desired dose constraint objectives were fulfilled.

The plan quality evaluation was done by comparing the dosimetric results obtained from the cumulative dose-volume histograms (DVH) of SC and DC plans. The PTVs were evaluated for mean doses, D98%, D2%, V95%. Conformity index was calculated using equation (1)

$$CI = (TV_{PIV}/PIV) \times (TV_{PIV}/TV) \quad (1)$$

Where in, V_{PIV} represents the volume of PTV receiving the prescription dose; PIV represents prescription isodose volume and TV represents target volume. Homogeneity index was calculated using the formula in eq. (2)

$$HI = \text{Maximum dose}/\text{Prescription dose} \quad (2)$$

Where the maximum dose was 100% isodose.

The mean, maximum dose, and the dose volumes V75%, V50%, V25%, were analyzed for bladder and rectum. D5%, D1% and mean dose were compared for bilateral femoral heads.

The maximum and mean doses to penile bulb were also recorded.

Plan efficiency was determined using the treatment delivery parameters such as the number of node positions, beams, MU and estimated treatment time per fraction.

Point dose measurements were done for all 8 plans for five randomly selected patients. For point dose measurements, verification plans were created on SRS baby blue phantom with 0.016 cc pinpoint ion chamber. The calculated TPS dose was taken as reference for all measurements and variation from the measured dose was noted.

Table 1. Different sizes of fixed collimator used in the plans.

Patient	Single collimator	Double collimator
1	35	35,10
2	40	40,10
3	35	35,10
4	35	35,10
5	40	40,12.5
6	35	35,10
7	35	35,10
8	35	35,10
9	35	35,10
10	30	30,10
11	40	40,12.5
12	35	35,15
13	40	40,20
14	50	50,20
15	40	40,25
16	35	35,12.5
17	50	50,30
18	40	40,20
19	35	35,20
20	40	40,25

Data entry and statistical analysis

The data were entered into Microsoft excel and the results were expressed in means and proportions. The mean differences in single versus double collimator plans for the

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dosimetric variables were compared using paired t-test. The analysis was done using SPSS version 16.0. A *p*-value of <0.05 was taken as statistically significant.

RESULTS

The median age of the patients was 63 years, ranging between 52 to 73 years. 85% of patients had PTV volume between 51 to 150 cc shown in table 2.

Table 2. Patient and tumor characteristics.

Characteristics	Descriptives
Median age in years (Range)	63 (52-73)
PTV volume in cm^3	**n (%)**
< 50	01 (5.0)
51- 100	10 (50.0)
101-150	07 (35.0)
>150	02 (10.0)
T-stage	
T1c	2
T2a	5
T2b	4
T2c	9
Gleason score	
5	2
6	11
7	7
PSA ng/ml	12.8±5.2

The mean prescription isodose line in single and double collimators were 81.7±1.3% and 83.9±2.8% for the base plan (BP), 81.3±1.4% and 83.6±2.5% for time reduction (TR) plan, 81.5±1.3% and 83.8±2.7% for the node reduction (NR) plan and 81.1±1.3% and 83.7±2.6% for beam reduction (BR) plan respectively. The single and double collimator plans did not vary significantly in the means of calculated minimum dose to PTV (P>0.05). The means of maximum and mean dose to PTV was significantly higher in single collimator plans compared to double collimator plans (P<0.05). Conformity index (CI) was significantly lesser in double collimator plans compared to single collimator plans indicating better conformity in double collimator plans. Homogeneity index (HI) confirmed that the dosage distribution in the plans with double collimator plans was more homogeneous with a mean of 1.19 compared to single collimator wherein, the mean was 1.23. This difference was statistically significant with a value of P<0.05, table 3.

The mean PTV D2 doses were significantly higher in single collimator plans and D98 were noted to be significantly higher in double collimator plans (P<0.05) except for beam reduction (P >0.05) as shown in figure 1. The mean target dose distribution for the volumes of V95%, V110%, and V115% was better in DC plans when compared with SC plans (P<0.05) (figure 2).

Table 3. Target dose distribution analysis for both single and double collimator plans.

PTV	Single Collimator (SC) v/s Double Collimator (DC)							
	Base Plan		Time Reduction		Node Reduction		Beam Reduction	
	SC	DC	SC	DC	SC	DC	SC	DC
Minimum dose (Gy)	31.37±2.27	32.13±1.97	31.39±2.13	32.11±1.37	31.34±2.24	31.96±2.42	31.38±2.49	32.41±1.36
t-value (*P*-value)	-1.43 (0.17)		-1.53 (0.14)		-1.09 (0.28)		-1.95 (0.07)	
Maximum dose (Gy)	45.94±0.73	44.74±1.46	46.19±0.82	44.92±1.29	46.02±0.71	44.79±1.42	46.38±0.89	44.85±1.36
t-value (*P*-value)	3.89 (0.001)*		5.17 (<0.001)*		4.13 (0.001)*		6.12 (<0.001)*	
Mean dose (Gy)	41.36±0.93	40.70±0.71	41.22±0.43	40.71±0.64	41.24±0.46	40.73±0.70	41.46±0.74	40.69±0.66
t-value (*P*-value)	2.96 (0.008)*		4.12 (0.001)*		3.82 (0.001)*		4.78 (<0.001)*	
Conformity index	1.34±0.07	1.26±0.05	1.32±0.08	1.24±0.06	1.34±0.07	1.26±0.06	1.33±0.08	1.24±0.05
t-value (*P*-value)	5.45 (<0.001)*		4.97 (<0.001)*		6.09 (<0.001)*		6.24 (<0.001)*	
Homogeneity index	1.23±0.03	1.19±0.04	1.23±0.03	1.19±0.04	1.23±0.03	1.19±0.04	1.23±0.03	1.19±0.04
t-value (*P*-value)	3.77 (0.001)*		5.34 (<0.001)*		4.11 (0.001)*		(<0.001)*	

*indicates statistically significant difference.

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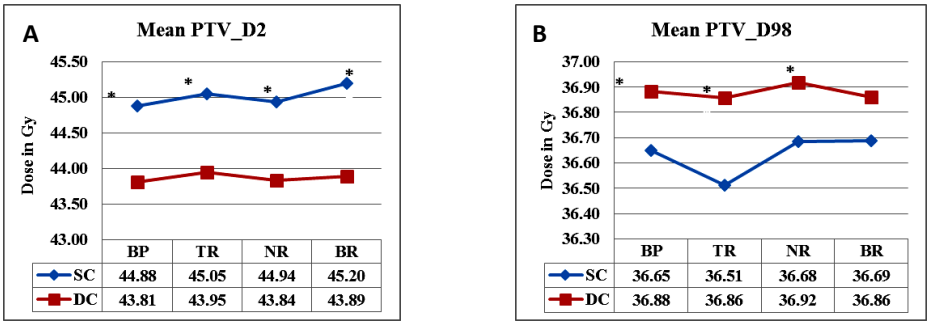

Figure 1. Mean D2 **(A)** and D98 **(B)** dose distribution of PTV for Base Plan (BP) Time Reduction (TR), Beam Reduction (BR) and Node Reduction (NR) plans in Single collimator (SC) and Double Collimators (DC).

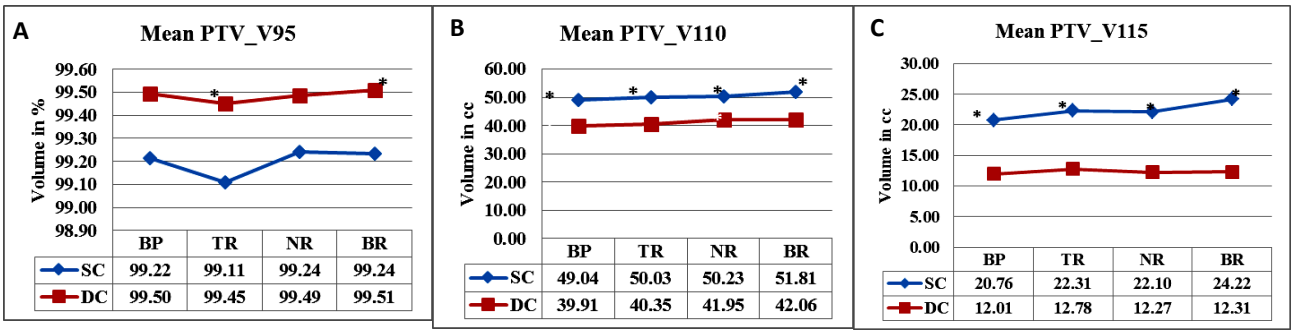

Figure 2. Mean dose distribution of PTV for V95 **(A)**, V110 **(B)** and V115 **(C)** for Base Plan (BP) Time Reduction (TR), Beam Reduction (BR) and Node Reduction (NR) plans in Single collimator (SC) and Double Collimators (DC).

The means of mean dose to the bladder in SC plans was 18.24 ± 5.00 Gy, 18.13±4.78 Gy, 18.25±4.94 Gy, and 18.12±4.91Gy whereas for DC plans it was 17.01±5.04 Gy, 17.08±4.92 Gy, 17.17±5.04 Gy and 17.07±4.88 Gy for BP, TR, NR, and BR respectively. The means of doses received by 1% of the bladder volume and the mean doses received were significantly lesser for double collimator plans compared to single collimator plans (P<0.05). The means of maximum dose, V25%, V50% and V75% to bladder did not vary significantly between single and double collimator plans (P>0.05) except for V50% wherein the volume receiving 50% of the dose in the base plan was significantly lesser in double collimator plans (P<0.05), table 5.

The means of mean doses to the rectum were 18.59±5.05 Gy, 18.13±4.89 Gy, 18.59±5.05 Gy and 18.37±4.96 Gy for SC plans and 17.55±4.95 Gy, 17.29±4.94Gy, 17.57±4.91Gy and 17.02±5.15 Gy for DC plans for BP, TR, NR, and BR respectively. The means of mean doses to the rectum were significantly higher with base plan, node and beam reduction plans with single collimator however time reduction plans did not differ with the use of single or double collimators. The mean of maximum doses received by 1% of the rectal volume, V25%, V50%, and V75% did not vary significantly between single and double collimator plans (P>0.05) except for V75% wherein the volume receiving 75% of the dose in the plans with beam and time reductions were significantly lesser in single collimator plans (P<0.05), table 5.

The mean of maximum dose to the right femur in SC plans was 17.37±3.74 Gy, 16.94±3.86 Gy, 17.42±3.84 Gy, and 17.15±3.66 Gy whereas for DC plans it was 15.64± 4.97 Gy, 16.55±3.16 Gy, 16.61±3.42 Gy, and 14.91±4.11Gy for BP, TR, NR, and BR respectively. The mean of maximum doses to Left femur in SC plans was 17.31±3.56 Gy, 16.88±3.51 Gy, 17.26±3.74Gy, and 17.04±3.49 Gy whereas for DC plans it was 15.80±4.69 Gy, 16.82±3.65 Gy, 16.14±3.17 Gy, and 17.08±4.95 Gy for BP, TR, NR, and BR respectively. The means of mean and maximum doses, means of

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doses received by 1% and 5% of the left and right femur volumes did not vary significantly between single and double collimator plans (P>0.05) except for maximum dose, D1% and D5% which was significantly lesser in double collimator plans with node reduction (P<0.05) in left femur and maximum dose alone in right femur table 6.

The mean D1% and mean doses of penile bulb were significantly lesser across all reduction plans and base plan with double collimators (P<0.05). However, the mean of the maximum doses did not differ in either of the single or double collimator plans (P>0.05) table 6.

The mean duration of treatment in minutes were significantly higher in double collimator plans (SC v/s DC: BP-49 v/s 57, TR- 42v/s 50, NR- 47v/s 56, BR-43 v/s 51). The mean number of beams (SC v/s DC: BP-234 v/s 258, TR-172 v/s 187; NR-232 v/s 254, BR-174 v/s 196) and nodes (SC v/s DC: BP-79 v/s 82, TR-68 v/s 73; NR-68 v/s 72, BR-71 v/s 77) were higher in double collimator plans. It was significant across all reduction and base plans (P<0.05) except for TR plan with respect to number of total beams (P>0.05), table 4. The total MU (SC v/s DC: BP- 34177.53 v/s 36716.24, TR-33954.21 v/s 36604.46, NR-34176.17 v/s 36714.26, BR- 34275.89 v/s 36619.49) were also significantly higher for double collimator plans compared to single collimator plans (P<0.05), table 4.

Dose deviation between the TPS calculated and measured values for SBRT verification plans was well within the tolerance of ±3%.

Table 4. Comparison of treatment time, total beams, number of nodes and MU.

PTV	Single Collimator (SC) v/s Double Collimator (DC)							
	Base Plan		Time Reduction		Node Reduction		Beam Reduction	
	SC	DC	SC	DC	SC	DC	SC	DC
Treatment time (mins)	49.00± 5.20	57.75± 5.80	42.55± 4.79	50.65± 4.66	47.75± 5.23	56.65± 6.05	43.30± 4.87	51.20± 5.33
t-value (*P*-value)	-7.28 (<0.001)*		-6.23 (<0.001)*		-7.11 (<0.001)*		-7.66 (<0.001)*	
Total Beams	233.70± 49.27	258.15± 46.75	171.85± 43.64	187.10± 33.48	231.75± 48.59	254.25± 49.62	174.25± 40.28	195.90± 38.78
t-value (*P*-value)	-3.04 (0.007)*		-1.55 (0.14)		-2.55 (0.02)*		-3.48 (0.003)*	
Total no. of nodes	79.35± 5.67	82.45± 4.65	68.45± 7.49	73.20± 5.80	68.10± 7.77	72.25± 4.91	71.20± 7.63	77.00± 6.37
t-value (*P*-value)	-3.16 (0.005)*		-2.95 (0.008)*		-1.48 (0.004)*		-4.75 (<0.001)*	
Total MU	34177.53± 2176.64	36716.24± 734.25	33954.21± 2377.79	36604.46± 816.61	34176.17± 02249.53	36714.26± 772.24	34275.89± 2361.38	36619.49± 782.33
t-value (*P*-value)	-5.17 (<0.001)*		-4.88 (<0.001)*		-5.03 (<0.001)*		-4.42 (<0.001)*	

Table 5. Comparison of dose received by the anterior and posterior OARs.

OAR	Plan	Mean differences						
		D1%	Maximum Dose	Mean Dose	V75%	V50%	V25%	D1cc
Bladder	SBP v/s DBP	0.48*	0.23	1.23*	-0.19	2.07*	2.63	-
	STR v/s DTR	0.41*	0.33	1.04*	-0.44	1.43	2.13	-
	SNR v/s DNR	0.31*	0.21	1.08*	-0.09	3.28	2.54	-
	SBR v/s DBR	0.45*	0.22	1.05*	-0.40	1.45	2.18	-
Rectum	SBP v/s DBP	0.08	0.009	1.04*	-1.38	2.25	2.88	0.21
	STR v/s DTR	0.23	-0.41	0.84	-2.51*	1.04	1.63	-0.26
	SNR v/s DNR	0.07	-0.002	1.03*	-1.59	2.52	1.42	0.12
	SBR v/s DBR	0.13	0.08	1.35*	-2.08*	1.98	2.40	0.33

SBP – Single Collimator Base Plan; DBP – Double Collimator Base Plan; STR – Single Collimator with Time reduction DTR – Double Collimators with Time Reduction; SNR - Single Collimator with Node reduction; DNR – Double Collimators with Node Reduction; SBR - Single Collimator with Beam reduction; DBR – Double Collimators with Beam Reduction;
* indicates paired differences to be statistically significant (P<0.05).

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Table 4. Comparison of treatment time, total beams, number of nodes and MU.

OAR	Plan	Mean differences			
		Mean Dose	Maximum Dose	D1%	D5%
Rt Femur	SBP v/s DBP	-0.01	1.74	0.42	0.12
	STR v/s DTR	0.02	0.40	0.13	-0.05
	SNR v/s DNR	0.09	0.81*	0.21	0.09
	SBR v/s DBR	0.16	2.23	0.59	0.29
Lt Femur	SBP v/s DBP	0.03	1.50	0.53	0.37
	STR v/s DTR	0.14	0.06	0.04	0.15
	SNR v/s DNR	0.36*	1.13*	0.79*	0.55
	SBR v/s DBR	0.27	-0.04	0.34	0.26
Penile Bulb	SBP v/s DBP	2.09*	0.74	0.91*	-
	STR v/s DTR	1.76*	0.74	0.88	-
	SNR v/s DNR	1.96*	0.73	0.81*	-
	SBR v/s DBR	2.97*	1.01*	1.11*	-

SBP – Single Collimator Base Plan; DBP – Double Collimator Base Plan; STR – Single Collimator with Time reduction DTR – Double Collimators with Time Reduction; SNR - Single Collimator with Node reduction; DNR – Double Collimators with Node Reduction; SBR - Single Collimator with Beam reduction; DBR – Double Collimators with Beam Reduction;
* indicates paired differences to be statistically significant (P<0.05).

DISCUSSION

CyberKnife can deliver high-dose radiation to the target and minimal dose to the neighboring critical structures. However, it has a long treatment time and methods to shorten that without compromising on the dose distribution parameters are challenging to enhance the utility of Cyber Knife [13]. It is an established fact the usage of double collimators in the cyberknife increases the treatment time due to necessity in the physical change of the collimator and once again starting the treatment process after changing the collimator. Hence to elicit the efficacy of double collimator versus single collimator plans the current study was conducted.

The median age of the patients was 63 years, ranging between 52 to 73 years and it is known that more than three-quarter of the cases occur in men aged more than 65 years of age [14]. Sudahar H *et al*., in their study reported an average volume of the PTV as 71.7 cm^3 which is slightly lower compared to the current study wherein it was 98.17 cm^3 and the creation of PTV volume varies with the different institutions and the physicians planning it. It also varies as different planning systems measure target volumes in different ways [15].

Double collimators had tighter isodose lines compared to single collimator plans indicating better CI implying better quality plans in double collimators [16]. Though the means of minimum doses did not vary significantly across the plans, the mean and maximum doses, PTV D2 and V95 means were significantly higher in single collimator plans caused by hot-spot dose within the target.[17] The means of minimum dose estimated to PTV in either single or double collimator with no significant difference were between 31.34 -32.41 Gy and the means of maximum dose in DC plans were between 44.74 to 44.92 Gy. In the DC plans, the CI mean values were 1.24 (TR, BR) and 1.26 (BP, NR) respectively and HI mean values were 1.19 in all the reduction and base plans. Similarly in a study by Murai T *et al*., while comparing multi-leaf collimator plans (MLC) v/s conventional circular collimator (CC) plans, the mean minimum and maximum doses in CC plans were 34 Gy and 40.8 Gy and the mean CI and HI values were 1.29 and 1.12 respectively which were comparable to the current study except for the mean value of maximum dose to the PTV which was higher in our study and it may be due to different planning systems and the margins given in the planning [11]. The conformity index value greater than one in the current study

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shows that irradiated volume exceeds the target volume and covers part of the healthy tissue which is seen in both SC and DC plans, however, it is better in DC plans [18]. The ideal value of HI is said to be 1, however, the values are more than 1 in both SC and DC plans and the value is said to increase as the plan becomes less homogeneous thus indicating better homogeneity in DC plans in this study [19].

D98% were noted to be significantly higher in double collimator plans except for beam reduction similarly Sudahar H *et al*., also found higher D98% in double collimator plans [12]. Larger the number of MUs longer is the treatment time [20]; it is noted that reduction of number of nodes, beams, and MUs result in decreased treatment time [21] and however in the current study SC plans resulted in lesser beams, nodes, and MU hence increasing the treatment time in the DC plans.

SC plans in this study have a higher overall dose to the target volume which may lead to increase dose spillage to the surrounding structures increasing the unnecessary radiation-induced toxicity caused by hot-spot dose [17]. Similarly in the current study there is a significant dose to OAR in SC plans in terms of means of doses received by 1% of the bladder volume, the mean doses received and V50% in base plan; mean of mean doses to rectum; means of maximum dose, D1% and D5% with node reduction in left femur and maximum dose alone in right femur; means of D1% of the penile bulb receiving the dose and mean of mean doses except for time reduction plan. Sudahar H *et al*., also have found similar results when comparing dose delivery to the OAR in single and double collimator plans [12]. Murai T *et al*., in CC plans with two collimators has also found an estimated mean of maximum dose to bladder and rectum as 40.2 Gy and 38.7 Gy respectively which is similar to the current study finding where-in the mean values of maximum doses to bladder in DC plans was between 39.4 to 39.8 Gy and 38.4 to 38.7 Gy to the rectum respectively [11]. The mean V50% bladder (DC plans) in the current study was between 27.9 to 29.5 and rectum was 33.5 to 35.1 which were lesser when compared to the mean V50% in a study by Murai T *et al*., where it was 42.3 (bladder) and 26.5 (rectum) and the difference may be due to different planning systems, the dose constraints set and the margins given in the planning [11]. In addition to it, dose constraints set for each OAR during the optimization of the radiation plans as per RTOG-0938 recommendations, explain that there was no significant difference in the doses to OAR between single and double collimator plans except for few events as described above.

There are very few literatures existing in the current Indian setting on the dosimetric comparison of single and double collimators and this is one such study. However, it is limited by small sample size and no clinical effects have been recorded which are of concern in eliciting the safety and efficacy of SBRT among clinical cases but CI logically is considered to correlate with good post-treatment results [22]. Another limitation of the study is the fact that in SBRT planning the dosimetric results is somewhat planner dependent, although all the treatment plans were generated by experienced planners. The optimization criteria used in different planning systems can as well vary [23]. Although the technique of CC is successful, treatment time remain long because of the inherent limitations of using CCs and for the prostate tumors, target motion increases during longer treatment times increasing the improbability in the dose distribution [11].

CONCLUSION

The mean of maximum and mean doses estimated to PTV were better in DC plans when compared with SC plans. Even CI and HI were superior in DC plans. SC plans demonstrated significant reductions in the number of nodes, beams, estimated treatment time and total MUs. The doses to OAR were comparable in both SC and DC plans in terms of maximum doses except for femurs and penile bulb in node and beam reduction plans respectively which were significantly lesser in DC plans. The mean doses received by the surrounding OAR were significantly lesser in DC plans with the exception of left femur in all plans barring node

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reduction. However clinically, mean doses received by the anterior and posterior OAR and maximum dose received by the femurs and penile bulb in all situations can be considered more important clinically. Thus double collimator plans were better in producing good dosimetric results and reduced OAR doses with lesser estimated treatment efficiency. The authors would like to further confirm the results with real-time dose delivery during the clinical practice and further studies on the same among other study populations and different tumor sites where SBRT is feasible are also warranted.

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

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