Benchmarking a New Circular Cone-based Radiosurgery System against Clinically Tested Radiosurgery System on the same Novel Digital Linear Accelerator Platform

Dayananda Shamurailatpam Sharma, P Shaju[1], Mayur B Sawant, Suryakant Kaushik

Department of Medical Physics, Apollo Proton Cancer Centre, Chennai, Tamil Nadu, [1]Department of Radiation Oncology, Kokilaben Dhirubhai Ambani Hospital and Medical Research Institute, Mumbai, Maharashtra, India

Abstract

Objective: To examine the dosimetric characteristics of circular cones, the accuracy of dose modeling and overall treatment delivery of two radiosurgery systems integrated on a linear accelerator (Linac). **Materials and Methods:** The dosimetric characteristics of circular cones (4-17.5 mm) from Varian (VC) and BrainLAB (BLC) were measured for 6 MV flattening filter free beam from Edge linac using stereotactic field diode and 0.65 cc ionization chamber following established protocols. The Eclipse and iPlan modeled dose distribution for VCs and BLCs were validated with EBT3-film measurement. End-to-end tests were performed using stereotactic phantom having PTW 60008 diode connected to a Dose-1 electrometer. **Results:** The depth at dose maximum, TRP_{10}^{20} and dose at 10cm depth of the same size VC and BLC agree within ± 0.7 mm, ± 0.71% and ± 0.81% respectively. Full width at half maximum (FWHM) of any cone beyond 15 mm depth increases at 1% of nominal cone size per 10 mm depth. The penumbra of 4mm and 17.5mm VC at 15 mm depth was 1.1 mm and 1.50 mm. At 300 mm depth, penumbra increased by around 0.4 mm for 4 mm cone and up to 1 mm for cone size ≥12.5 mm. The VCs penumbra values were within ±1mm of the corresponding BLCs. Scatter factors for VCs varies from 0.609 to 0.841 and were within ± 1.0% of corresponding values of BLCs. Agreement between the Eclipse and iPlan computed dose fluence and the EBT3-film measured dose fluence was >98% (γ: 1%@1 mm), and the absolute dose difference was ≤ 2.2%, except for the 4 mm cone in which it was >96% and ≤4.83%. Target localization using cone-beam computed tomography was accurate within ± 0.8 mm and ± 0.3° in translation and rotation. The end-to-end dose delivery accuracy for both radiosurgery systems was within ± 3.62%. **Conclusion:** The dosimetric characteristics of Varian and BLC cones of same diameter was comparable. Both Eclipse and iPlan cone planning system modeled dose fluences agree well with the EBT3 film measurement. The end-to-end tests revealed an excellent target localization accuracy of Edge linac with satisfactory and comparable absolute dose agreement between Varian and BLC radiosurgery systems and hence these can be interchanged on edge linac.

Keywords: Comparison, cone, dosimetry, end-to-end, measurement, radiosurgery, validation

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Introduction

Stereotactic radiosurgery (SRS) employing miniature circular cone mounted on linear accelerator (linac) remains efficient and effective technique for small to very small spherical cranial tumor, including trigeminal neuralgia,[1] owing to its sharp penumbra characteristics. The ability of new generation linac, which enables delivery of sharper penumbra beam at very high dose rate using flattening filter free (FFF) technology within sub-millimeter spatial resolution, guaranteed by six-dimensional correction strategy using on-line volumetric image guidance, further enhances its application to frameless SRS. However, ensuring the administration of an accurate dose to small targets continues to be challenging since the accuracy of the measured beam data used in the treatment planning system (TPS) is crucial to the dose delivery from such small fields.[2-5] The commissioning of TPS with poor beam quality,

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Address for correspondence: Dr. Dayananda Shamurailatpam Sharma, Department of Medical Physics, Apollo Proton Cancer Centre, 100 Feet Road Tharamani, Chennai - 400 053, Tamil Nadu, India. E-mail: drdayananda_s@apollohospitals.com

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incorrectly measured or extrapolated beam data can result in systematic error in dose delivery which subsequently may lead to erroneous patient treatments and radiation incidents or accidents.[6]

Additionally, detector characteristics, position uncertainties, beams steering stability, and lack of lateral electronic equilibrium are the key factors that hinder the measurement of accurate beam data from small photon fields,[5,7,8] and remain active areas of research. Several studies[9-14] have reported significantly large variation in the beam data, particularly output factor for the very small fields, when measurement was performed using different dedicated detectors and formalism. Therefore, measurement of accurate and reproducible beam data and validation of the dose modeled by the TPS is of paramount importance for successful implementation of radiosurgery program. Citing the severity of consequences one could expect from an inaccurately commissioned new radiosurgery system, it is imperative to compare its dosimetric characteristics and overall performance with a clinically tested radiosurgery system.

Recently, Varian medical system introduced a novel radiosurgery system "Edge" for both intracranial and extracranial tumor. In this study, we have investigated dosimetric characteristic of newly developed stereotactic circular cones from Varian and compared it with another time-tested commercial cones on the same linac. Two different TPS were commissioned independently for cone-based stereotactic planning. End-to-end tests of the integrated radiosurgery system were carried out independently to assess the overall accuracy of the radiosurgery process. To the best of our knowledge, this is the first comparative report on the comprehensive characterization, commissioning, and validation of two radiosurgery system on the same linear accelerator.

Materials and Methods

Edge radiosurgery system

The Edge Radiosurgery system (Varian Medical System, Palo Alto, CA) comprises of a fine beam isocenter digital Linac, a new Perfect Pitch 6° couch, high-intensity FFF mode for radiosurgery (1400 monitor unit (MU)/min for 6 MV and 2400 MU/min for 10 MV), 2.5 MV portal imager for treatment portal verification, onboard kV imaging systems for two-dimensional, three-dimensional (3D), and four-dimensional image acquisition and Calypso tracking system. The isocentric accuracy of Edge linac measured during commissioning was 0.267 mm radius under gantry, collimator, and couch rotation and were reproducible within ± 0.011 mm. This system supports both frame and frameless approaches to patient immobilization. Small, sharp and focused radiosurgery beam is produced using either in-built HD120 multileaf collimator (MLC) or add-on circular cones. The physical and dosimetric characteristic of the similar HD120 MLC has been reported for application in radiosurgery and intensity modulated radiotherapy (IMRT).[15] The new circular cones from Varian, referred as Varian cones (VCs) hereafter, are available in seven diameters of 4, 5, 7.5, 10, 12.5, 15 and 17.5 mm respectively. These are made of tungsten and showed a maximum leakage of 0.2%. The mounting of cone was aligned with isocenter within ± 0.013 mm and reproducible within an accuracy of ± 0.004 mm. The Integrated Conical Collimator Verification and Interlock (ICVI) system provides an automated and electronic correlation of planned cone size with the physical cone mounted in the linac. This is especially crucial in light of the recent radiation accident that was reportedly caused by the incorrect cone size insertion. Eclipse cone planning (V13.6) provides planning and dose calculation for treatments utilizing stereotactic cones. It uses a fast superposition convolution algorithm for dose calculation. SRS cone planning can be performed using either static non-coplanar beam or non-coplanar arc.

BrainLAB radiosurgery system

Another commercial radiosurgery system, BrainLAB (BLC) (BLC AG, Feldkirchen, Germany) investigated in this study comprises of circular cones having 4, 6, 7.5, 10, 12.5 and 15 mm diameter and iPlan TPS (V1.4). These BLC cones can be mounted on Edge linac using the BLC collimator mount accessory attached on the accessory mount slot provided on collimator face of Edge. The isocentric clearance of Edge linac after mounting both models of cones (Varian and BLC) remain the same. The only shortcoming from safety view point is that ICVI does not recognize the BLC diameter and hence no interlocks are provided for the insertion of wrong size on the linac. The iPlan circular cone planning system employs the pencil beam algorithm. It makes use of a tissue-maximum ratio derived from measured percentage depth-dose (PDD) curves, off-axis ratios (OARs), and scatter factors (S_t). The algorithm accounts for heterogeneities in the depth dimension by means of radiological depths determined from the computed tomography (CT) scan. The algorithm assumes secondary scatter is of limited importance and does not explicitly account for it in the dose calculation.

Beam data acquisition

Beam data measurements were carried out for 6 MV FFF beam from Edge linac using high resolution stereotactic field diode (SFD) and blue phantom radiation field analyser (RFA). OmniPro Accept software was used for the precise positioning of the detector, data collection and analysis. Absolute dose measurement was made using calibrated FC-65 ionization chamber and Dose 1 electrometer following IAEA TRS 398 protocol.[16] All the dosimeteric equipment, detectors and software used in this study were from IBA (IBA Dosimetry, Nuremberg, Germany). Beam data measurement were grouped into two categories; (a) basic beam data for VC and BLC under similar set-up condition, (b) beam data acquisition as per the requirement of Eclipse and iPlan treatment planning algorithm.[17,18]

Basic beam data for Varian and BrainLAB cones

Beam data measurement of circular cones always begins with the accurate centering of SFD by means of in-line and cross-line profile measurements at dose maximum (d_{max}) and 20 cm depth using 4 mm circular cone. In the first set, PDD curves, OARs and S_t were measured for each VC size at target to surface distance (TSD) of 100 cm. In all the measurements, the jaws size was set at 6 cm × 6 cm as recommended by the manufacturer.[17] For each VC size, OARs were measured at 1.5, 5, 10 and 20 cm depth. S_t were measured at 5 cm depth with TSD of 100 cm using "daisy-chain" strategy.[10] In this formalism the output measured for a small circular cone using SFD is linked to nominal linac output measured by calibrated ionization chamber (FC 65G) and electrometer (dose 1) through an intermediate field size of 4 cm × 4 cm as described by Sharma *et al*.[14] The same set of measurement was repeated by replacing VC system with BLC system. The corresponding dosimetric data were compared from the same physical nominal cone sizes.

Beam data acquisition for commissioning of treatment planning system

In the second set of data acquisition, beam data were acquired for each cone size, cone model and TPS combination for 6 MV FFF beam on Edge linac following TPS supplier recommendations. Eclipse cone planning algorithm demands nominal linac output measured at d_{max} (1.5 cm), PDD curves measured at 100 cm TSD, OARs at 5 cm depth for different TSD of 90, 100 and 110 cm and S_t at 5 cm depth with TSD of 100 cm. The nominal linac output measured at 10 cm depth (D_{10}) and TSD of 100 cm was then converted to d_{max} (1.5 cm). Although, Varian recommend direct normalization at 10 cm × 10 cm for S_t, we have adopted "daisy-chain" strategy based on the result of investigation by Sharma *et al*.[14] The S_t were then converted to the geometry expected by Eclipse, isocentric set-up and 1.5 cm depth, using PDD ratios. Whereas, in case of iPlan cone planning algorithm, beam data measurement were carried out following the recommendation prescribed in Technical Reference Guide Rev. 1.8 BLC Physics.[16] Unlike the previous measurements, jaws size was set at 1.4 cm × 1.4 cm for cone size ≤8 mm and 2.0 cm × 2.0 cm for cone size of up to 17.5 mm. Similar to the beam data measurement of Eclipse cone planning, for each cone size the OAR, PDD and S_t were measured using SFD in a Blue Phantom RFA. PDD for all BLC were measured with 100 cm TSD. The OAR measurements were made at 92.5 cm TSD and at a depth of 7.5 cm. The S_t were measured following "daisy chain" strategy and following the geometrical set-up recommended in the technical reference guide. The same nominal linac output measured during the beam data generation of Eclipse cone planning system was used for BLC cone planning configuration also. All the measured data were processed and converted to the format required by the respective TPSs.

Validation of treatment planning system

The processed beam data were then configured into the respective TPSs following manufacturer recommendations. Successful dosimetric configuration of both the TPSs (Eclipse and iPlan) was first validated using film dosimetry. For this, test plans were created for each cone size and cone model separately on Eclipse and iPlan TPS using the same CT dataset of solid plastic slab phantom (SP34; density: 1.03 g cm^{-3}: IBA Dosimetry, Nuremberg, Germany) at fixed gantry angle of 0°. The MU required to deliver 5 Gy at D_{10} and TSD of 90 cm were calculated from each cone size and cone model in the respective TPS (VCs in Eclipse and BLCs in iPlan). Measurement from each treatment plan was performed on Edge linac using Gafchromic EBT3 films (International Specialty Products, Wayne, USA) following general recommendations outlined in the AAPM TG-55 report.[19] Each exposed film was scanned in transmission mode using Epson 10,000XL flatbed scanner (SEIKO Epson Co, Japan) in 48 bit RGB with a scanner resolution of 400 dpi. Optical density (OD) was measured prior to exposure to quantify the background image and 48 hours following the exposure, after which the latent image had stabilized. VeriSoft (V 7.0.1.30, PTW-Freiburg, Germany) was used to analyze the exposed films. The pixel values measured for the red channel of the scanner were used to calculate the net OD for each film piece and these were converted to absorbed dose (in cGy) using a pre-measured net OD-to-dose calibration curve. The field width, penumbra width and absolute dose were measured from each of the irradiated film and compared against the TPS calculated values. TPS calculated and EBT3 film measured planar dose distribution from each cone size and model were also compared using Gamma index analysis set for 1% dose difference at 1mm (1%@1mm). Gamma index criteria of 1%@1 mm was chosen as a stringent criterion in view of the reported uncertainty associated to film dosimetry (AAPM TG-55). A lower threshold of 10% of the maximum dose was also chosen during the gamma index analysis.

End-to-end test

End-to-end tests were carried out to assess the overall accuracy of the radiosurgery process which includes CT simulation, treatment planning, 3D image-based target localization, and final treatment delivery using a stereotactic phantom (StereoPHAN; SunNuclear cooperation, USA). StereoPHAN with PTW 60008 diode (PTW, Freiburg, Germany) inserted in it using a customized adapter was CT scanned at 1 mm slice thickness. The PTW 60008 diode has an active volume of 0.03 mm^3, diameter of 1.13 mm and length of 0.03 mm. The CT datasets were separately transferred to Eclipse and iPlan Cone planning system. The center of the active volume of the PTW 60008 diode detector was identified in both the TPS using the manufacturer specified technical data and radiological CT image. Target localization was carried out using the traditional three marker point methods. Single arc plan of complete 360° gantry rotation was created for each cone size and cone model with isocenter set at the center of the active volume of PTW 60008 diode. The total number of MU require to deliver 10 Gy at isocenter were calculated at 1 mm × 1 mm grid resolution from each plan. Prior to dose measurement from the treatment plan, PTW

60008 was cross calibrated against calibrated reference FC65 ionization chamber at the same beam quality and field size.

The phantom along with PTW 60008 diode connected to Dose 1 electrometer was set-up on the Perfect Pitch treatment couch of Edge radiosurgery system using calibrated room lasers as if it is done for a patient [Figure 1]. Cone-beam CT image of the StereoPHAN was acquired and any deviation in the set-up was corrected in six dimensions. Once the position of the isocenter is localized, the phantom was irradiated from each plan (cone size/cone model) and corresponding dose was measured which subsequently were compared with the TPS calculated dose.

Results

Dosimetric comparison of Varian and BrainLAB cones

The depth at d_{max}, beam quality (TRP_{10}^{20}) and dose at 10 cm depth (D_{10}) extracted from the measured PDD of every cone size and model are summarized in Table 1. As expected, d_{max}, TRP_{10}^{20} and D_{10} increases with increase in cone diameter for both cone models. The d_{max}, TRP_{10}^{20} and D_{10} of same diameter cones from Varian and BLC agree within ± 0.7 mm, ±0.71% and ± 0.81% respectively. The comparison of central axis normalized cross profiles from same nominal sized VCs and BLCs at a representative depth (10 cm), showed very good overall agreement as depicted in Figure 2. The radiation field size represented by the full width at half maximum (FWHM) and radiation penumbra measured as the lateral separation of 80% and 20% dose extracted from the measured profiles of every cone sizes and types at various depths are shown in Figure 3. The FWHM measured from the cross profile at 1.5 cm depth (d_{max} for 6MV FFF and 10 cm × 10 cm field) of various cones sizes from both Varian and BLC agrees within ± 0.1 mm of the manufacturer specified cone size. For similar cone sizes, the FWHM values from VCs agrees well with that of BLCs. After d_{max}, FWHM of any cone increases at the rate of around 1% of the cone size per centimeter increase in depth. The increase in FWHM at deeper depths is consistently less by up to 0.4 mm in VCs as compare to corresponding cone size from BLC. Table 2 represents the radiation penumbra (mean of left and right) measured for every cone sizes from both the manufacturers and at different measurement depths. As expected, the 80%-20% radiation penumbra width increases with cone size and depth of measurement. For the VCs, the penumbra at 15 mm depth increases from 1.1 mm for 4 mm cone to 1.50 mm for 17.5 mm cone. As the depth increases from 15 mm to 300 mm, the penumbra also increases by around 0.4 mm for 4 mm cone and up to 1 mm for cone size ≥ 12.5 mm. The penumbra width measured from the BLCs is consistent to within ± 0.1 mm of the corresponding cone size from Varian. The S_t of Varain and BLC cones measured for 6MV FFF beam under identical conditions of 100 cm TSD and at D_{10} are shown in Figure 4. The S_t (standard deviation) value from VCs ranges from 0.609 (±0.002) for 4 mm cone to 0.841 (±0.006) for 17.5 mm cone. The agreement of S_t value between similar cone sizes of Varian and BLC were within ± 1.0%.

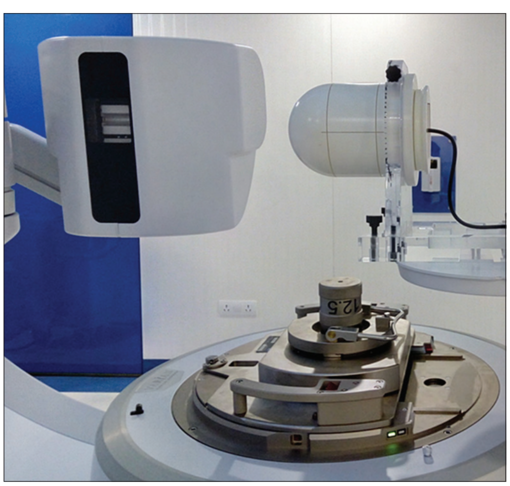

Figure 1: Set-up for absolute point dose measurement using StereoPHAN during the end-to-end test

Validation of Eclipse and iPlan cone planning system

The comparison of the TPS modeled and EBT3 film measured planar dose distribution at D_{10} is shown in Figure 5 (Figure 5a for Varian Radiosurgery system; Figure 5b for BLC radiosurgery system) for a representative cone size of 10 mm. Whereas, Figure 6 represents Gamma values analyzed for 1% dose difference at 1 mm distance to agreement for every cone size. An excellent agreement between TPS calculated and EBT3 film measured dose distribution were observed for all the cone sizes and both the radiosurgery systems. For all evaluation criteria, more than 98% of points within the radiation fields pass even the most stringent evaluation criteria of 1% dose difference at 1 mm except for the 4 mm cone size. The minimum gamma value for the 4 mm cone size under 1% dose difference at 1 mm evaluation criteria was 96.1 for Varian radiosurgery system as compared to 97.3 from BLC radiosurgery system.

Table 1: Comparison of the central axis depth dose parameters; depth at dose maximum, beam quality (TRP_{10}^{20}) and dose at 10 cm depth extracted from the measured percentage depth-dose of every cones from Varian and BrainLAB

Cone diameter (mm)	D_{max} (mm)		TRP_{10}^{20}		D_{10} cm (%)	
	BLC	VC	BLC	VC	BLC	VC
4	7.3	7.7	0.559	0.563	49.7	50.1
5	NA	8.0	NA	0.563	NA	50.9
6	9.3	NA	0.560	NA	50.2	NA
7.5	9.2	9.6	0.574	0.571	51.2	51.5
10	10.3	11.0	0.572	0.576	52.5	52.8
12.5	11.5	11.1	0.576	0.579	53.1	53.0
15	12.1	11.8	0.577	0.581	53.5	53.9
17.5	NA	12.3	NA	0.581	NA	54.5

VC: Varian cone, BLC: BrainLAB cone, NA: Not available

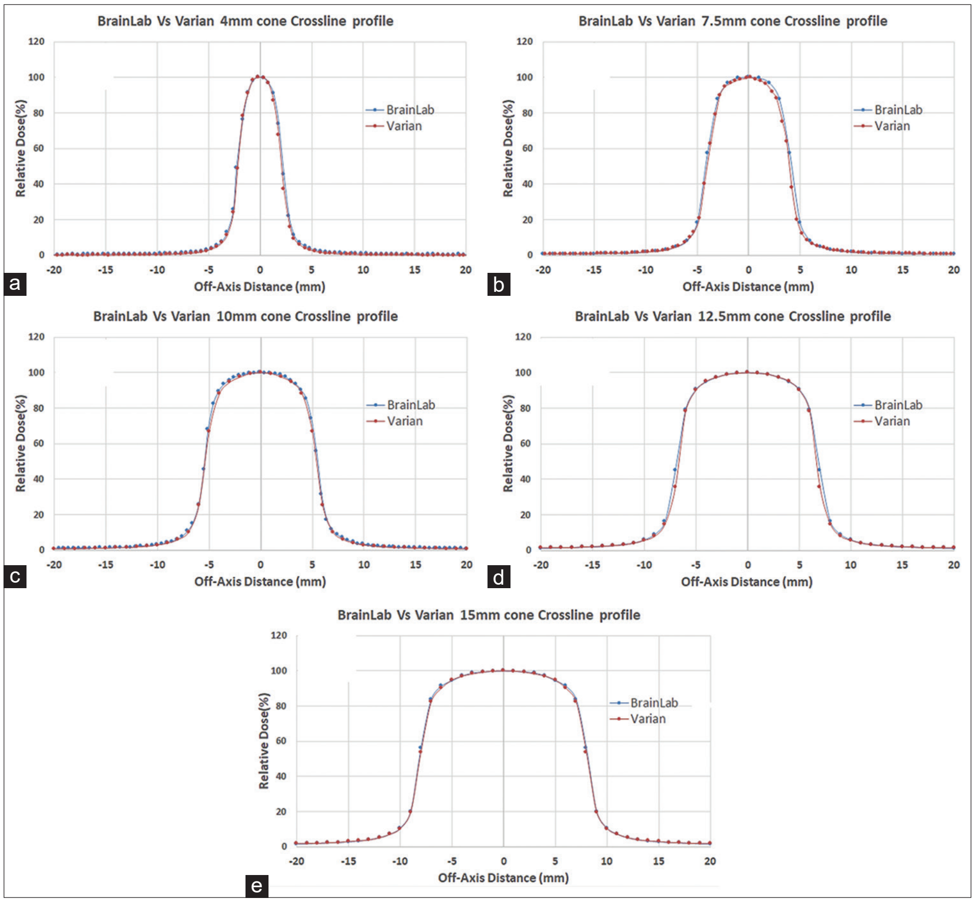

Figure 2: Comparative crossline-profiles of same cone size (a) 4 mm, (b) 7.5 mm, (c) 10 mm, (d) 12.5 mm and (e) 15 mm, from Varian and BrainLAB measured at a representative depth of 10 cm for 6 MV FFF beam on edge linac. The curves are normalized to 100% on the central axis. FFF: Flattening filter free

Table 2: Variation of radiation penumbra (mean of left and right) measured for all cone size from Varian and BrainLAB with depth of measurements

Depth (mm)	Radiation penumbra measured for cones of different diameter (mm)												
	BLC						VC						
	4	6	7.5	10	12.5	15	4	5	7.5	10	12.5	15	17.5
15	1.10	1.15	1.25	1.35	1.45	1.45	1.10	1.10	1.25	1.35	1.40	1.40	1.50
50	1.15	1.30	1.40	1.50	1.55	1.65	1.20	1.15	1.40	1.50	1.45	1.60	1.65
100	1.30	1.45	1.50	1.60	1.80	1.75	1.25	1.25	1.50	1.60	1.70	1.85	1.75
200	1.50	1.70	1.80	1.95	2.05	2.10	1.40	1.50	1.80	2.00	2.10	2.15	2.15
300	1.55	1.85	2.10	2.30	2.45	2.35	1.50	1.75	2.05	2.25	2.40	2.40	2.50

VC: Varian cone, BLC: BrainLAB cone

The variation in the absolute dose calculated by the TPSs and measured with EBT3 films for each cone size and cone model are shown in Table 3. In case of Varian radiosurgery system, Eclipse cone TPS calculated and EBT3 measured dose agrees within ± 2.2% for all cone sizes except for the 4 mm cone size wherein EBT3 film measurement underestimate by 4.1% compared to TPS calculated dose. For the BLC radiosurgery system, EBT3 film measurement underestimate compared to iPlan TPS calculated dose for all cone sizes ranging from 0.32% to 4.83% for the smallest 4 mm cone.

End-to-end verification using StereoPHAN three-dimensional head phantom

The target localization accuracy as verified using cone beam CT was within ± 0.8 mm in any of the translational axis and ± 0.3° in any of the three rotations. Table 4 represents the end-to-end test result showing the percentage deviation between TPS calculated absolute dose from various plans and corresponding PTW60008 diode measured absolute dose for the two radiosurgery systems i.e., Varian (Eclipse cone TPS for VCs) and BLC (iPlan TPS for BLC). In general, the pattern of dose variation between TPS calculated and PTW60008 diode measurement was very similar for both the radiosurgery systems and for all cone sizes. For all the treatment plans created either in Eclipse cone planning or iPlan TPS using cone sizes bigger than or equal to 10 mm, the PTW60008 diode measurement underestimate the dose by up to 1.98% compared to TPS calculated dose. However, for the treatment plans using cone sizes <10 mm, PTW60008 diode measured dose was more than TPS calculated dose by up to 3.62% for the smallest cone size of 4 mm.

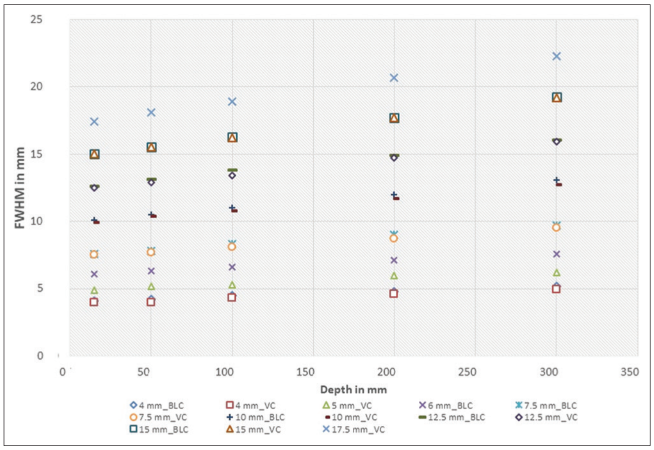

Figure 3: Variation in the radiation field size represented by the FWHM with depth for various cone sizes from Varian and BrainLAB. Same cone sizes from Varian and BrainLAB shows similar results. VC: Varian cone, BLC: BrainLAB cone, FWHM: Full width at half maximum

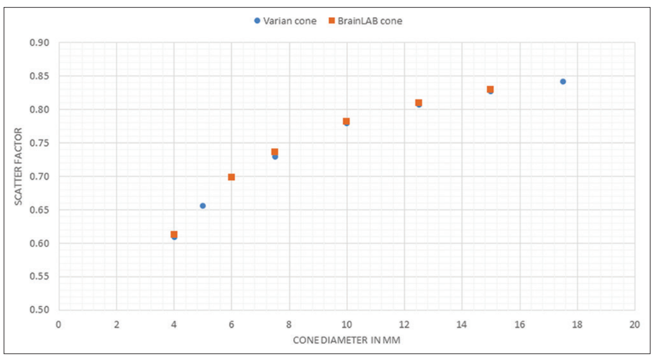

Figure 4: Scatter factor (S_t) of Varian and BrainLAB cones measured for 6MV FFF beam under identical conditions. FFF: Flattening filter free

Discussion

The present study focuses on the comparison, commissioning and validation of cone-based SRS technique, and hence the isocentric accuracy, cone positioning accuracy, reproducibility and radiation leakage through cones were quoted while describing the Edge radiosurgery system. We also did a comprehensive characterization of each component/functionality of Edge linac for clinical implementation of advanced radiotherapy techniques such as IMRT, volumetric modulated arc therapy, SRS/stereotactic radiotherapy/stereotactic body radiation therapy (SBRT) using high-definition MLC. The performance of Edge linac was characterized following the recommendations of AAPM TG report 106,[20] manufacturer recommended protocols and AAPM-RSS guideline[21] and the results were well within the tolerance limits specified in AAPM-RSS guideline.[21] Although few published data[3,4,9-14] are available on the dosimetric characteristics of SRS cones, the same is limited when small SRS cones are integrated with FFF beam in the newly emerging linear accelerators. The commissioning and validation of BLC[22] and Varian[23] Radiosurgery systems on two different linacs have been reported in two separate studies. In this study we have compared the dosimetric characteristics of BLC and recently available Varian circular cones on the same Edge linac using the same beam quality.

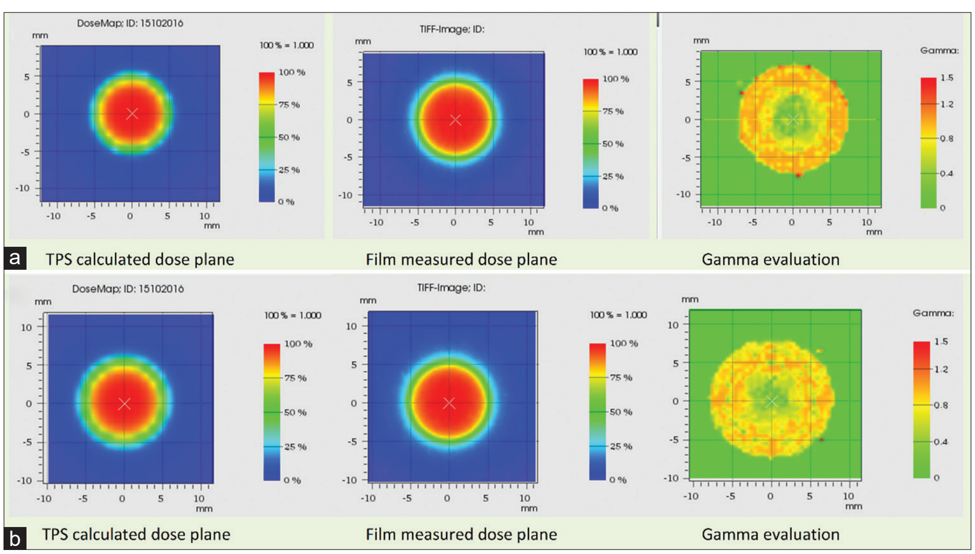

Figure 5: Comparison of TPS modeled and EBT3 film measured planar dose distribution from (a) Varian radiosurgery system and (b) BrainLAB radiosurgery system, at 10 cm depth for a representative cone size of 10 mm, using gamma analysis set at 1% dose difference at 1 mm. TPS: Treatment planning system

Table 3: Percentage deviation between treatment planning system calculated and EBT3 film measured absolute dose for two radiosurgery systems i.e., Varian (Eclipse cone treatment planning system for Varian cones) and BrainLAB (iPlan treatment planning system for BrainLAB cones)

Plan name	Cone (VC/BLC) diameter (mm)	Percent deviation between EBT3 film measured and TPS (Eclipse and iPlan) calculated dose for two radiosurgery system	
		VC	BLC
P1_4 mm cone	4	−4.08	−4.83
P2_5 mm cone	5	−2.16	-
P3_6 mm cone	6	-	−2.42
P4_7.5 mm cone	7.5	−1.76	−1.37
P5_10 mm cone	10	−2.10	−1.93
P6_12.5 mm cone	12.5	2.16	−0.32
P7_15 mm cone	15	1.95	−1.48
P8_17.5 mm cone	17.5	1.52	-

Measurement Setup: EBT3 film at 10 cm depth in a solid water phantom with a fixed gantry angle. TPS: Treatment planning system, VC: Varian cone, BLC: BrainLAB cone

Table 4: End-to-end test result showing the percentage deviation between treatment planning system calculated absolute dose from various plans and PTW60008 diode measured absolute dose for two radiosurgery systems i.e., Varian (Eclipse cone treatment planning system for Varian) and BrainLAB (iPlan treatment planning system for BLC cones)

Plan name	Cone (VC/BLC) diameter (mm)	Percent deviation between PTW60008 diode measured and TPS calculated dose for two radiosurgery system	
		VC	BLC
P1_360 Arc_4 mm cone	4	3.62	3.49
P2_360 Arc_5 mm cone	5	2.82	-
P3_360 Arc_6 mm cone	6	-	2.66
P4_360 Arc_7.5 mm cone	7.5	1.19	1.43
P5_360 Arc_10 mm cone	10	−1.53	−1.98
P6_360 Arc_12.5 mm cone	12.5	−1.94	−1.02
P7_360 Arc_15 mm cone	15	−1.97	−1.89
P8_360 Arc_17.5 mm cone	17.5	−1.82	-

Measurement Setup: PTW60008 diode at the center of StereoPhan for all the treatment plans with full 360 degree arc. TPS: Treatment planning system, VC: Varian cone, BLC: BrainLAB cone

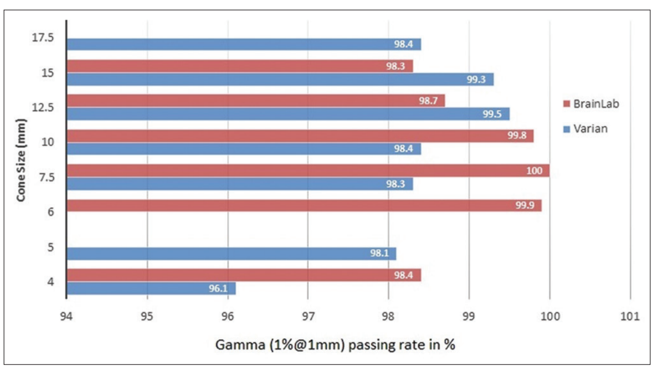

Figure 6: Gamma (1% dose difference at 1 mm distance) analysis values resulted from the comparison of EBT3 measured planar dose distribution and corresponding dose distribution from various cones calculated by Eclipse cone TPS and iPlan TPS. TPS: Treatment planning system

Also, two different TPSs (iPlan and Eclipse cone planning) were commissioned and validated on the same linac. This study not only provide us a more realistic comparison of a time tested (BLC) and new (Varian) radiosurgery systems but also offer us an opportunity to test the applicability of either of the system based on personnel preference or in case of system malfunction and hence more flexibility in our ongoing radiosurgery program. To our knowledge, we have not came across any similar study. Hence our data will be compared with the closest publication.[22,23]

Choice of an appropriate detector is of paramount importance in small field dosimetry as the accuracy of the beam data is highly influenced by the characteristics of the detector.[3-5,7-14] Special attention is needed particularly for scatter factor measurement due to significantly large variation reported from several studies.[9-14] So far, there is no ideal commercial detector available for small field dosimetry.[5,7] Moreover, the methodology and adopted formalism also influence largely the accuracy of scatter factor.[8-14] Sharma *et al*.[14] has recently reported the influence of various commercial detector design, methodology and adopted formalism on scatter factor measurement. Based on this recent publication, we have chosen SFD for the basic beam data measurement and "daisy chaining" as the formalism for scatter factor measurement. No attempt has been made to apply the correction factor.

The observed increase in the central axis depth dose parameters (d_{max}, TRP_{10}^{20} and D_{10}), penumbra and scatter factor with increasing cone sizes are in agreement with previous publications.[9-14,22,23] Our measured values of d_{max} are in agreement with the values reported by Wiant *et al*.[22] for similar 6MV FFF beam and BLC cones on TrueBeam STx linac. For same cone sizes from Varian and BrianLAB, the maximum variation in d_{max} (0.7 mm), TRP_{10}^{20} (±0.72%), and D_{10} (0.81) observed in PDD characteristics of 6MV FFF beam are within the tolerance limit of ± 1% specified in AAPM-RSS guideline.[21] Excellent agreement (within ± 0.1 mm) was observed between manufacturers specified and measured cone sizes of both models. Wiant *et al*.[22] reported a variation ranging from 0.2 mm to 0.4 mm between BLC specified and measured FWHM of cone of 4–15 mm diameter on TrueBeam STx. Beam divergence from VCs was marginally better at deeper depths although may not be significant. Above all, excellent agreement of penumbra (±0.1 mm) and S_t (±1.1%) values between same cone sizes of Varian and BLC demonstrate that the dosimetric characteristics of these cones are similar and hence are interchangeable.

The excellent agreement between the TPS modeled and EBT3 film measured dose fluence under the stringent gamma analysis threshold of 1% dose difference at 1 mm demonstrates the high level of accuracy of the measured beam profiles for both cone models and sizes. However, the comparatively higher variance in the absolute dose recorded may be partially explained by the increased measurement uncertainty in film dosimetry and the inherent variation in the output factor measurement between SF3 diode and EBT3 film.[15,18] We used the PTW60008 diode for absolute dose verification in end-to-end test as it was precisely adapted to a stereotactic phantom using the adapter supplied by the manufacturer and it also served as a cross-check for the output factor measured using SFD. For cones larger than or equal to 10 mm, the difference between the TPS modeled and the PTW60008 measured dose was <2%, which is within the acceptable measurement error for absolute dose as per TRS398.[15] However, large deviation of up to 3.62% was observed for the smallest cone of 4 mm, which is primarily due to the inherent sources of errors associated with the small field output factor measurement and may be partly with the dose calculation algorithm.

Conclusion

The dosimetric characteristics of Varian and BLC cones of similar diameter are comparable. Both Eclipse and iPlan cone planning system modeled dose fluence agrees excellently well with EBT3 film measurement. End-to-end test revealed an excellent target localization accuracy of Edge linac with satisfactory and comparable absolute dose agreement for both Varian and BLC radiosurgery systems and hence can be interchanged on Edge linac.

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Conflicts of interest

There are no conflicts of interest.

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