Commissioning of Clinac IX Trilogy Linear Accelerator for Stereotactic Radiosurgery

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Abstract

Comprehensive quality assurance (QA) and beam data acquisition has been performed for commissioning of Varian Trilogy linear accelerator for stereotactic radiosurgery (SRS). Mechanical, electrical and radiological tests were performed to check linac performance as per American Association of Physicists in Medicine (AAPM) Task Group (TG) 142. The geometric isocentre accuracy, congruence check and calibration of kV and MV imager were performed using the IsoCal QA device. The off axis ratio profiles, depth dose data and beam output factors of 6 MV SRS beam for the field sizes ranging from 2 × 2 cm² to 15 × 15 cm² were measured using SFD diode detector and cc13 semiflex ion chamber. The multileaf collimator (MLC) characterization was done in the treatment planning system (TPS) using the parameters measured with the CC13 semiflex ionisation chamber in water phantom. Dose measured with 2D ion chamber array was compared to that calculated in TPS. The maximum change in MV and kV imager isocentre was within ±0.03 cm. The variation between SFD measured and ion chamber measured beam data is in positive correlation for fields sizes down up to 2 × 2 cm². Variation in output factors is ±0.56 ± 0.05 %. The measured beam data is imported and calculated in the Eclipse TPS and is found within 1% gamma agreement index (GAI) with the Analytical Anisotropic Algorithm (AAA) model data. GAI for TPS verification QA is 97.8%, 98.5% and 98.3% respectively for fix jaw 2 × 2 cm², 5 × 5 cm² and rapid arc SRS plan. Successful modelling of the photon beam for high dose rate SRS mode is achieved for clinical treatment of patients.

Keywords: radiotherapy, commissioning, beam data, quality assurance, stereotactic radiosurgery

1. Introduction
There have been revolutionary advances in last two decades in radiotherapy technology using x-rays. New delivery techniques such as image guided Intensity Modulated Radiation Therapy (IMRT), Intensity Modulated Arc Therapy (IMAT), Stereotactic Radiosurgery / Radiotherapy (SRS/SRT) have been evolved, that uses static and dynamic MLC for shaped beam delivery and on-line imaging system for instant setup corrections. For successful application of any such techniques, it is necessary to commission the treatment unit and associated TPS. The process of commissioning a medical linear accelerator (linac) for clinical use includes comprehensive measurements of dosimetric and mechanical parameters that are mandatory for validating the treatment planning systems and selection of desired radiation modality and treatment technique intended for a patient [1,2]. Commissioning also includes testing the accuracy of acquired data, development of operational procedures, and due trainings to all concerned with the operation of the accelerator.

During commissioning of a linac for clinical use, several challenges are faced by medical physicists, including the need of accuracy and precision, a large number of testing methods, data validation techniques, time constrains and scarcity of standards. Considering the hazardous effects of radiations, the beam data should be highly specific to the treatment techniques, energy and dose calculation algorithm [3,4]. The accuracy requirements meeting global standards [5]. The commissioning data is considered as reference and has to be used by TPS for patient dose calculation. It is hence vital that the collected data be of highest quality to circumvent dosimetric errors and wrong dose prediction in the treatment plan.

In stereotactic radiosurgery high radiation doses at higher dose rates to small, stereotactically targeted tumour in one single fraction (SRS) or in small number of fractions (SRT). The size of tumour in such cases is usually not larger that 2-3 cm to avoid geometrical uncertainties and irradiation of surrounding region [6–9]. Thus, commissioning of SRS involves the dosimetry of small fields [10,11]. Unlike the dosimetry of conventional fields, which can be performed in the standard way without any special considerations, in small field dosimetry, special precautions are to be considered. Small fields are limited by radiation source occlusion, loss of lateral charged particle equilibrium and volume of available detectors for small fields [12–14][15,16]. Radiation accidents due to wrong detector selection have already been reported [4]. It is necessary to select appropriate detector and measurement parameters, to measure the beam data with utmost accuracy, to avoid dose errors to the patients.

Various authors have presented a range of detectors for use in small fields. The beam profiles and depth dose profiles can accurately be measured with ion chambers with sufficient accuracy down to 2 × 2 cm², but for the smaller fields specialised detectors are needed [17–21]. It has been shown that the ion chambers (0.13 cc, 0.015 cc, 0.009 cc, 0.007 cc) can measure output factors accurately down to 2 × 2 cm² [22,23]. Investigators have studies the role of EPID for beam profile and output factor measurement in small fields and found that it can measure beam data with sufficient accuracy up to field sizes of 2 × 2 cm² [24]. Another important aspect is the verification of measured data. Several studies have advised the use of at least a two-dimensional detector for this purpose and have validated the same for this purpose [25,26].

While commissioning a linac, MLC characterisation is a parameter of utmost importance which affects the dose optimization and calculation. Tongue and groove effects and leaf end transmission of rounded leaf edges have a considerable effect on the treatment delivery [27,28]. In IMRT and IMAT plans, where a number of small segments are delivered to produce the desired dose distribution inside the patient, their effects plays crucial role. These parameters require some sophisticated methodology and careful measurement of the desired values for their calculation. The dosimetric leaf gap (DLG) is a quantity to model the effect of rounded leaf edges, opposing leaves offset and leaves transmission of Varian MLCs [29].

End to end testing of Trilogy linear accelerator for SRS mode has been done. Mechanical, geometrical and dosimetric parameters have been tested thoroughly during commissioning. The mechanical stability of kV and MV imaging system is tested on digital platform. The quality check of TPS and associated dose calculation algorithm is performed. A process to acquire beam data for SRS
mode in Trilogy linac commissioned on Eclipse TPS (Version 11) has been presented. The techniques for beam data verification has been presented to check the accuracy of TPS dose algorithm. Current work aims to present the process that may be helpful for other institutions performing commissioning.

2. Materials and Methods

Trilogy configuration of Clinax iX (Varian Medical Systems, Palo Alto, CA) linac was commissioned for 6 MV high dose rate SRS mode. The linac is aligned isocentrically, with source to isocentre distance (SID) of 100 cm. It has two independent pairs of X and Y Jaws with maximum opening of $40 \times 40$ cm$^2$ at isocentre plane. Its millennium 120 MLC have central 40 pairs of leaves of 0.5 cm projection at isocentre plane, which enhances the conformality of dose delivery of IMRT and IMAT plans. Its outer 18 pairs of leaves are of 1 cm and outermost 2 pairs of 1.4 cm at isocentre plane. This configuration of MLC is designed for minimal tongue and groove effect. Trilogy is also equipped with an on-board imaging (OBI), real time position management™ (RPM) system for advanced Image guided radiation therapy (IGRT), tumour gating and tracking capabilities. The high dose rate of 1000 MU/min in SRS mode is a result of the special modification in the design of the beam flattening filter. The flattening filter has smaller height and diameter than the conventional design, thus makes possible the high dose rate and flat beam simultaneously for field sizes maximum up to $15 \times 15$ cm$^2$.

The dosimetric data for 6 MV SRS was acquired according to Analytical Anisotropic Algorithm (AAA) configured in Eclipse TPS (Eclipse, Version 11.0; Varian Medical Systems, Palo Alto, CA). Data acquisition follows the guidelines of AAPM TG 42, 106 and 142 [5,30,31]. BluePhantom2 (IBA Dosimetry, Germany) with a scanning range of $48 \times 48 \times 41$ cm$^3$ was used for all dosimetric measurements. The OmniPro Accept software (Version 7.4; IBA Dosimetry, Germany) was used for data acquisition, processing and analysis. The stereotactic field diode (SFD; IBA Dosimetry, Germany) with an active volume of $1.7 \times 10^{-5}$ cm$^3$ was used to acquire all the beam profiles. Same set of beam profiles and depth dose data was acquired using CC13 semiflex ionization chamber (IBA Dosimetry, Germany). The detector was aligned such that its effective point of measurement is at the depth of measurement. The diode was placed such that its active volume is perpendicular to beam central axis [32]. Initial scan to check and correct alignment with beam central axis was performed. The reference field diode (RFD; IBA Dosimetry, Germany) was placed in air between the phantom and collimator head as reference detector.

Absolute dosimetry, output factors, MLC transmission and dosimetric leaf gap (DLG) were measured using CC13 semiflex ionization chamber and SFD. All the measurements except transmission and DLG were made at 100 cm source to surface distance (SSD) and 10 cm depth. DLG was measured at 95 cm SSD, 5 cm depth for a set of dynamic MLC fields of 12 cm sweeping gap movement.

The 2D ion chamber array ImRT MATRIXX embedded in MultiCube phantom (IBA Dosimetry, Germany) with OmniPro IMRT (Version 1.7; IBA Dosimetry, Germany) was used for TPS dose verification and gamma analysis. The ion matrix has been improved in terms of spatial resolution and large area acquisition. Gafchromic (EBT3) film was used to check the accuracy of radiation isocentre of gantry and collimator and its coincidence. Isocal geometric calibration system (Varian Medical Systems, Palo Alto, CA) was used to check isocentre coincidence of kV and MV imagers with radiation isocentre. X-Lite tool was used to check the congruence of optical and radiation fields.

2.1 Mechanical Tests

The Mechanical checks were performed prior to data acquisition as a part of commissioning as per IEC and AAPM guidelines. The mechanical and radiation isocentre coincidence was checked by gantry rotation and star shot analysis on gafchromic (EBT3) films respectively. The film was placed
with its plane parallel to gantry axis of rotation for gantry isocentre keeping its center at 100 cm SID. For collimator and couch isocentre the film was placed in a plane perpendicular to central axis at 100 cm source to axis distance (SAD). In all cases, the films were sandwiched in solid water slab phantom. Each film was exposed to 100 MU for a slit size of 0.5 cm × 20 cm at various gantry and collimator angles to form a star pattern in both cases. The film was then scanned using EPSON scanner according to the guidelines of AAPM TG 55. Star shot analysis was done in OmniPro Accept.

The verification of gantry and collimator angles as an agreement between mechanical and digital readout was checked using spirit level and plumb line. The localizing lasers were verified with respect to the central axis using a local made iso-align device. The congruence of radiation and optical field was measured by placing the X-lite tool (IBA Dosimetry, Germany) and gafchromic (EBT3) film consecutively at 100 cm SAD perpendicular to beam central axis. The SSD verification was done using the solid water phantom slabs of 1cm thickness in a range of SSD from 85 cm to 115 cm.

The isocal is specially designed QA system for MV and kV imagers. It has a hollow cylindrical phantom of length and diameter of 23 cm each. The phantom has 16 ball bearings (bb) each of 4mm diameter placed in spatially defined locations. It acquires a set of MV and kV images of phantom and collimator plate at a set of gantry and collimator angles. The associated computer software then calculates the offset and respective corrections of MV and kV image panels with respect to the treatment isocentre as a function of gantry angle. The software provides a plot of the positional variations for both the imaging panels[33].

2.2 Absolute Dose and Output Factors

The absolute dose calibration was performed as per International Atomic Energy Agency (IAEA) Technical Report Series (TRS) 398 in SSD setup [34]. The beam quality was determined by measuring the beam quality index TPR20/10 and tuned for 6 MVSRS beam as per manufacturer protocol. The dose calibration was 1cGy/MU at the depth of maximum dose using FC 65-G 0.6cc farmer type ion chamber and Dose1 electrometer assembly.

2.3 Photon Beam Profiles

![Image](a) ![Image](b)

**Figure 1.** The isocal phantom along with the collimator plate. The phantom is having various ball bearings at different positions (a) and depiction of the rotation isocentre and projection centre on the imager using 6 degree of freedom of the isocal phantom and plate projections(b) from [33].

The output factors ($S_{op}$) were measured with CC13 semiflex ionization chamber and SFD at 100 cm SSD, 10 cm depth in the BluePhantom2. All data was acquired as per Eclipse beam data guide for combination of field size ranging from $2\times2\text{cm}^2$ to $15\times15\text{cm}^2$. The $S_{op}$ value for $10\times10\text{ cm}^2$ field was normalized to unity.
Crossline beam profiles and depth dose profiles for 6MV SRS mode were acquired as per requirements of Eclipse TPS for jaw defined square fields of 2 cm, 4 cm, 6 cm, 8 cm, 10 cm, 12 cm and 15 cm. The phantom was aligned with central axis at 100 cm SSD. Step size was kept 1 mm for each profile with a measurement and resolution time of 0.20 second each. The crossline profiles were taken at 1.5 cm (dmax), 5 cm, 10 cm, 20 cm and 30 cm depth in water. The raw data was normalized to 100 % at the central axis and then analyzed in OmniPro Accept software for the beam parameters as per IEC 60976, before exporting to TPS.

2.4 TPS QA

The radiation beam data acquired for 6MV SRS beam was configured in the TPS and then analyzed for its accuracy with model data. The analysis between measured and model data was done by the TPS and a gamma error histogram was generated, the tolerance limit for this is 1 %. Once the data is accepted, the agreement between the TPS calculated and delivered dose was verified by point

\[ \text{Figure 2. Radiation field analyzer setup for measurement of absolute dose data and beam profiles (a) and 2D ion chamber matrix array embedded in multicube phantom for TPS QA of Trilogy linac.} \]

dosimetry and planar dosimetry using FC 65-G ion chamber and ImRT MatriXX (IBA Dosimetry, Germany) respectively, embedded in multicube phantom (IBA Dosimetry, Germany). The data was analyzed for 3 % dose difference (DD) and 3 mm distance to agreement (DTA) criteria in OmniPro IMRT [35,36].

2.5 MLC Characterization

The leaf transmission measurement was done using CC13 semiflex ion chamber and SFD in BluePhantom2 at 100 cm SAD. The detector was placed at 5 cm depth. Absolute dose was measured for 10 cm square field defined by X and Y jaws. The leaves transmission was measured for MLC bank A and B by closing the jaw defined field by either bank of MLC one by one and average of both was taken (Rt). The dosimetric leaf gap (DLG) was measured by the manufacturer suggested method. This technique requires leaf gap measurement using seven different MLC defined field openings in dynamic mode. The DLG was calculated using the formula:

\[ \text{Rg} = \text{Rt} \left(1 - \frac{g}{120}\right) \]
\[ R_{g}' = Mg - R_g \]

where \( R_t \) is the average leaves transmission, \( g \) is constant leaves gap in any particular dynamic delivery of sweeping gap movement of range 120 mm. \( Mg \) is the initial meter reading for the leaves gap \( g \). The intercept on leaf gap axis in the plot between \( R_{g}' \) and \( g \) on gives the DLG value.

3. RESULTS

3.1 Mechanical Tests

The gantry and collimator and couch mechanical and radiation isocentre was found to be within ±1 mm diameter respectively. Maximum variation of 0.3° in the gantry angle with mechanical versus digital display was obtained at set gantry angle of 90°, similarly maximum variation of 0.2° was observed in collimator angle at 135°. The congruence between optical and radiation field was well in agreement for the range of field sizes applicable for SRS mode, the maximum variation of +1 mm was observed in X jaw for field size 15×15 cm² field. The relation between the observed and displayed SSD was also well within limit for the range of ODI tested, the maximum variation was about -2 mm at 115 cm SSD.

![Figure 3](image-url)  

*Figure 3*. Radiation isocentre verification for Gantry(a), collimator (b) and couch (c) isocentre by star shot analysis on gafchromic film. The result analysis in OmniPro software shows overall isocentre congruence within ± 1 mm diameter of sphere.

The isocal calculated maximum rotation for kV and MV imager was 0.069 degree and -0.069 degree w.r.t. the beam central axis. While the maximum shift in image locations was -0.168 cm and -0.25 cm respectively for kV and MV. The maximum change from previous calibrations was within 0.03 cm tolerance and hence no shift was applied on the imagers.

3.2 Dosimetric Tests

3.2.1 Absolute Dose and Output Factors

The beam quality index, TPR 20,10 for 6 MV SRS beam was 0.673. The absolute dose calibration of 1cGy/MU at the depth of maximum dose was achieved. The variation of output was recorded daily during the data acquisition and a maximum variation of 0.3% was found which was within tolerance values of IAEA TRS 398. The output factors were normalized to unity for 10 × 10 cm² field size and were exported to the TPS.
Figure 4. MV and kV images of isocal phantom with collimator plate at different gantry and collimator angles. The associated software automatically identify the locations of ball bearings (a). Isocal results for phantom offset showing lateral (x) and longitudinal (y) offset between projected isocentre and MV (b) and kv (c) imager centre for full gantry rotation.

3.2.2 Beam Profiles and PDDs

The data obtained was automatically plotted and tabulated in OmniPro Accept 7.4 software. The data presented here was plotted in Microsoft excel version 2013. Figure 6. a) shows beam profile for different field sizes at 100 cm SSD and 10 cm depth, gantry and collimator kept at zero-degree angle,

Table 1. The output factors measured with CC 13 and SFD for 6MV SRS beam normalized unity at 10×10cm² field size. The CC 13 measured data was used for TPS configuration.

| Field Size | 2 × 2 | 4 × 4 | 6 × 6 | 8 × 8 | 10 × 10 | 12 × 12 | 15 × 15 |
|------------|-------|-------|-------|-------|---------|---------|---------|
| CC13       | 0.851 | 0.917 | 0.955 | 0.982 | 1.000   | 1.015   | 1.035   |
| SFD diode  | 0.837 | 0.900 | 0.942 | 0.974 | 1.000   | 1.022152| 1.051   |

acquired using SDF, the data was normalized to 100% along CAX. Figure 6. b) shows depth dose profile for square fields of 2, 4, 6, 10 and 15 cm, the peak value was normalized to 100 % at the depth of maximum dose.

3.2.3 MLC Characteristics

The MLC transmission factor and dosimetric leaf gap (DLG) was measured in the RFA using CC13 ion chamber at 100 cm SAD 5 cm depth. The results for MLC data was:

1. MLC Leaf transmission factor: 0.01358
2. Dosimetric Leaf Gap (DLG):
   a) with cc 13 semiflex ion chamber: 0.135 cm
   b) with SFD diode detector: 0.076 cm

The DLG value of 0.135 was best matching with the theoretical values and satisfying the previous commissioning data. Also, the gamma passing was found to be higher with this value, hence this value was used to configure the MLC in TPS.
3.2.4 TPS QA and Gamma Analysis

To check the accuracy of TPS calculations with linac delivery, QA check was performed on ImRT MatriXX detector array (IBA Dosimetry, Germany). The measured dose was processed and collated with TPS calculated dose for same treatment plan in OmniPro-IMRT software. The gamma criteria were set to 3%, 3mm. The results of QA for both SRS STATIC and SRS ARC mode were obtained.

Figure 7. Gamma analysis of SRS rapid arc plan in OmniPro Accept. The TPS vs measured dose shows good agreement in 3%/3mm gamma criteria.
Table 2 presents the measured versus TPS predicted point dose and spatial dose agreement for jaws defined static field $2 \times 2 \text{ cm}^2$ and $5 \times 5 \text{ cm}^2$ for which GAI was 97.82% and 97.53% respectively. Figure 7 shows the measured versus TPS predicted dose profiles for SRS arc mode, the gamma index analysis result shows 98.2% passing points in 3%/3mm gamma criteria.

4. Discussions

Commissioning can be a difficult task in a running department with high patient load. The problem is further compounded when no quick reference is available for the modality under examination. In such a situation the medical physicist has to work in close collaboration with the manufacturer’s physicist for the QA and commissioning work. When, the equipment under investigation is capable of performing all types of treatments in external beam radiotherapy, it becomes more stringent to align the equipment as per the requirements of each technique and modality.

The mechanical parameters have different tolerance values for SRS treatments, thus to perform stereotactic treatments the parameters have to set in sophisticated and strict tolerance levels. In the arc mode delivery, when a large number of segments are delivered from different gantry directions around the patient and in some cases may also be non-coplanar, the accuracy of isocentre and relative positions of gantry and couch is required. We have achieved all the isocentre accuracies within 1 mm tolerance limit. Also, the geometrical positions of the imagers have been tested and found satisfactory. However, there are many factors that may further affect these parameters with the course of time. Hence these checks must be done periodically. Other than this the dosimetry for SRS differs from conventional practice. Accurate estimation of absolute dose and field output factors is necessary, which is affected by occlusion of radiation source.

Clemente[37] has discussed the role of various detectors in measurement of beam output factors using a multicenter approach. They insist on intercomparing results of different centers for more accuracy and consistency. The overlapping penumbra and dose fall off along beam edges is an issue causing errors in small field dosimetry. It is further limited by availability of detectors and decreased beam output. The detector volume effect causes dose averaging in such cases and cause wrong prediction of already decreased dose. This effect has been explained by Laub [38]

Figure 8. The TPS calculated gamma analysis of measured beam data vs model data. The beam data for full beam containing dose from all around the field sizes of interest (a) and gamma analysis for the dose inside field only, not considering the penumbra margins and region outside field. The gamma is within 1% in both cases.
where they observed significant differences amongst dose measured by different detectors in IMRT fields. Other than these, the dose in flat region of beam profile must also be looked for consistency and beam parameters like flatness and symmetry.

There have been numerous works on the commissioning of advances linear accelerators in clinic in the past, which have suggested new methods and baseline data for future. Andreo [39] has suggested use of Monte Carlo simulations for accurate modeling and verification of measured data. Several national and international organizations like IAEA, AAPM and DIN etc. keep on posting relevant guidelines on commissioning of linacs. The Medical Physicists must consider all this data while performing the commissioning QAs in clinic.

In this study, for the concerns of issues related to small field dosimetry and high dose rate, the beam data is acquired with two different detectors namely CC13 ionisation chamber and SFD diode. There is no significant variation in the beam data acquired with these detectors in the range of fields analyzed. There are little variations in the absolute dosimetry parameters like output factors, and dosimetric leaf gap acquired with SFD and CC13. Other than this, for relative dosimetry any of the detectors can be used in small fields down up to $2 \times 2 \, \text{cm}^2$.

5. Conclusion

The accept testing and commissioning is a tedious task for any radiation therapy installation. The introduction of any complete system for clinical use requires a thorough testing of all associated parameters, their consistency related accuracy. It is the responsibility of qualified medical physicists to check and maintain the standards of any such system in their clinic. The intended use of the system is to treat a cancer patient when all the auxiliary parts and subsystems are in synchrony and working accurately. However, any deficiency in any part or subsystem can lead to erroneous treatment and cause severe effects on patient health. That too, if accepted during commissioning may become a systematic error and propagate throughout the working life of the system or until detected and fixed. In SRS, where radiation dose increases manifolds to the targeted mass, any chances of error can increase the harmful effects of radiations drastically. Hence, it is very crucial to check the whole system thoroughly for electrical, mechanical and dosimetric accuracy and stability.

In this study, all mechanical and electrical parameters were thoroughly investigated and found satisfactorily within tolerance limits. Here we have presented only few tests, however the acceptance testing was performed as per global standards. The dosimetric data, crossline beam profiles, percentage depth dose data, output factors and other dosimetric parameters were measured, analyzed and successfully configured to the TPS. The calculated versus measured dose is well within agreement. The TPS, linac and other subsystems were found working in a synchrony. This data gave an insight into accurate beam modeling and hence determined the accurate and safe patient treatment.

Table 2. Table showing the TPS QA results for the 6 MV SRS beam. The TPS calculated dose compared to dose measured in plane detector array and analysed using gamma index analysis.

| Sr. No. | Plan          | Absolute Dose Variation | Gamma (GAI) $2\% / 2 \, \text{mm}$ | Gamma (GAI) $3 \% , 3 \, \text{mm}$ |
|---------|---------------|-------------------------|----------------------------------|----------------------------------|
| 1.      | $2 \times 2 \, \text{cm}^2$ Static | 0.73 $\%$              | 96.08 $\%$                     | 97.82 $\%$                     |
| 2.      | $5 \times 5 \, \text{cm}^2$ Static   | 1.57 $\%$              | 95.52 $\%$                     | 97.53 $\%$                     |
| 3.      | SRS ARC       | 1.23 $\%$              | 92.49 $\%$                     | 98.31 $\%$                     |
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