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# FEASIBILITY OF RUBY PHANTOM FOR DOSE VERIFICATION AND RADIATION ISOCENTER STABILITY FOR STEREOTACTIC RADIOSURGERY AND RADIOTHERAPY (SRS/SRT) TREATMENTS

**SAIMA ALTAF**

Lecturer, Institute of Physics (IoP), The Islamia University of Bahawalpur, Pakistan.
Email: saima.altaf@iub.edu.pk

**SAEED AHMAD BUZDAR**

Professor, Institute of Physics (IoP), the Islamia University of Bahawalpur, Pakistan.
Email: saeed.buzdar@iub.edu.pk

**SANA SALAHUDDIN**

Lecturer, Institute of Physics (IoP), The Islamia University of Bahawalpur, Pakistan.
Email: sana.sallahuldin@iub.edu.pk

**MARIA ATIQ**

Assistant Professor, Institute of Physics (IoP), The Islamia University of Bahawalpur, Pakistan.
Email: maria.atiq@iub.edu.pk

**ATIA ATIQ**

Assistant Professor, University of Education, Multan, Pakistan. Email: atia.atiq@ue.edu.pk

**KHALID IQBAL**

Principal Medical Physicist, Shoukat Khanum Memorial Cancer Hospital and Research Center Lahore, Pakistan. Email: kiqbal@skm.org.pk

**MALIK YOUNAS IMRAN**

Institute of Physics (IoP), the Islamia University of Bahawalpur, Pakistan. Email: unas105@gmail.com

**Abstract**

**Background:** Stereotactic Radiotherapy utilizes well-collimated and highly confined beams to treat the small targeted lesion demanding high levels of precision and accuracy in QA procedures. In this study, the RUBY modular QA phantom was evaluated for isocenter verification and pretreatment dose verification of SRS/SRT treatments. **Material and Method:** RUBY modular QA phantom was used for daily QA checks of geometric accuracy of radiation isocenter carried out with linac QA insert. Data was acquired for 100 days with Ruby phantom for TrueBeam linac. Isocenter verification was also done by IsoCal phantom and results were compared with Ruby phantom results. Patient-specific QA was performed for 25 SRS/SRT treatment plans using a patient QA insert with a pinpoint 3D ionization chamber as a detector. **Results:** The maximum diameter of the isocenter sphere is 1.04±0.12mm, 0.99±0.13mm, and 1.07±0.22mm for the gantry, collimator, and couch. The average isocenter offset is 0.45±0.18mm, 0.40±0.2mm, and 0.23±0.2mm for the gantry, collimator, and couch measured. The average isocenter deviation measured with the IsoCal is 0.35±0.02mm, in close agreement with the value 0.41±0.11mm measured with Ruby phantom. The point dose values accessed by the RUBY phantom agree to the expected dose within the acceptance limit of 3%. **Conclusion:** Ruby phantom is consistent, rapid, and easy to implement for daily QA checks and its results proved to agree with IsoCal phantom. RUBY phantom is also recommended for pretreatment QA SRS/SRT, using patient QA insert. The modular construction of the RUBY allows using of a single phantom to perform different QA processes for a more synchronized and harmonic QA workflow using a variety of task-specific inserts.

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**Keywords:** IsoCal Phantom, Isocenter, Quality Assurance, Ruby Phantom, TrueBeam, Stereotactic Radiosurgery, Stereotactic Radiotherapy

## 1. INTRODUCTION

Advancements in technology and Radiation physics provide the basis for high-dose, focused radiation therapy techniques demanding high levels of precision and accuracy. Modern techniques such as stereotactic radiosurgery and radiotherapy (SRS/SRT) include tumors and functional abnormalities in the brain [1]. Because of the critical nature of brain tissue, challenges arise in precisely identifying the target volume and accounting for any patient motion during treatment. SRS uses three-dimensional imaging technologies (such as CT and MRI), immobilization, localization techniques, and QA procedures to validate accurate target definition and alignment. Due to the small treatment fields and steep dose gradients involved, quality control of SRS and SRT before and during the treatment, uses cutting-edge detectors, gadgets, phantoms, and measuring algorithms [2-4]. The linac-based SRS technique consists of multiple arcs converging onto the machine isocenter, which is stereo tactically placed at the center of the imaged target volume. An ideal mechanical isocenter is a point of intersection of the rotational axis of a gantry, collimator, and couch[5]. Due to the system's several geometric inaccuracies, perfect alignment is almost difficult to obtain [6] and the isocenter also moves in the space with the movement of the mechanical component of the linac. So the machine isocenter is supposed to lie within a virtual sphere containing the isocenter of the gantry, collimator, and couch[7]. One of the critical errors that occur during the SRS/SRT treatments is the displacement of the mechanical isocenter. With more and more patients undergoing linac-based SRS, the necessity of acceptable specification of linac isocentric accuracy requires that the isocenter remain within a sphere of radius 1 mm with any combination of the gantry, collimator, and couch rotation [5, 8]. Therefore, to guarantee the treatment's high degree of geometric accuracy, it is essential to develop strategies to lower the risk of such errors through comprehensive and efficient quality assurance systems. This requires the development of strict acceptance levels.[7, 9, 10]. Several guidelines are available for practitioners to carry out the QA programs. The AAPM Task Group 101, 142 [11, 12] and joint IAEA-AAPM report TRS 483 both advise using a suitable dosimeter with a spatial resolution of around 1 mm [13, 14]. We utilize the RUBY modular QA phantom (PTW Freiburg, Germany), one basic Ruby phantom with multiple exchangeable inserts. It enables medical physicists to validate end-to-end QA of the entire radiotherapy process, from imaging and treatment planning to target, dosimetry, and delivery with a choice of “as and when” needed [15]. We practiced Linac QA insert for isocenter verification through the WL test and patient QA insert for point dose verification of SRS/SRT patients. We started using Ruby phantom for daily Linac QA testing utilizing Winston Lutz (WL) test during morning QC for isocenter verification as an independent QA system. To cross-check the newly introduced Ruby phantom’s validity we include the IsoCal method, Machine Performance Check (MPC) a machine-specific phantom. It is used to evaluate the machine’s geometric performance by fully automated measurement sequences with high accuracy using kV and MV imaging systems [16-18].

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## 2. MATERIAL AND METHODS

This study evaluates the Ruby phantom for localization of the radiation isocenter and point dose measurements of SRS/SRT plans as an independent phantom. The isocenter verification was also performed by using the IsoCal system. Linac used in this study is Varian TrueBeam (Varian Medical Systems, Palo Alto, CA) linear accelerator. Equipped with aS1200 EPID (1024 × 1024 pixels) and, 120 Leaf HD MLC (40 pairs of leaves 2.5 mm thick and 20 pairs of leaves 5 mm thick) and an entire suite of Cone-Beam CT (CBCT) imaging.

Isocenter verification was done by Ruby Phantom and Isocal Phantom. That included data acquired in 18 months from May 2020 to November 2021 on random 100 days by Ruby phantom and for 41 days (same days in which Ruby phantom QA was also performed) by IsoCal measurements.

### 2.1 Phantoms

#### 2.1.1 RUBY Phantom

The RUBY phantom (PTW Freiburg, Germany) is made up of polystyrene containing a base body and modular inserts. Ruby Phantom's QA capabilities include:

- Linac QA checks with tissue-equivalent bone structures for KV and MV imager's visibility and automatic image analysis software IsoCheck EPID, isocenter positioning accuracy by Winston-Lutz testing with the high-density radiopaque sphere at isocenter.
- Patient QA with detector insert and film inserts
- System QA checks with enhanced CT visibility by tissue-equivalent materials, end-to-end testing, and a single insert for SRS, and SRT QA. Single-point dose measurements of Patients using the same insert with different detectors.

The phantom has three sets of markers on its surface a central line of the phantom base is in black and the other two sets of lines can be used for the misalignment of the phantom in a definite manner for verification of geometric accuracy. As for the Patient QA insert, a detector can be inserted at the center of the insert for point dose measurement in the phantom. This is a homogeneous polystyrene insert that is compatible with different detectors such as ion chambers and films. In this study, PTW Pinpoint 3D S/N: 152503 ion chamber was used in conjugation with patient QA insert of Ruby Phantom.

#### 2.1.2 IsoCal Phantom

The Linac, TrueBeam (Varian Medical Systems, Palo Alto, CA) is provided with a dedicated phantom IsoCal, for geometric accuracy measures and associated software for image analysis of routine QA. The IsoCal phantom is made up of a hollow cylinder with a 23 cm diameter and length both. It contain16 ball bearings each 4mm in diameter made up of tungsten carbide. IsoCal phantom was placed in a specific bracket on the tabletop the geometric tests acquire a series of images to measure isocenter deviation, offsets of MV, and kV imager.

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## 2.2 Isocenter Verification

In every WL test, the RUBY phantom was positioned using a KV imager and room lasers (in agreement with linac cross-hair ≤1 mm) and also by aligning the radiopaque sphere at the center of the linac QA insert with the projected KV imaging isocenter. WL test was performed using a Linac QA insert which contains a ceramic ball at its center, 8 mm in diameter, and four bone equivalent cylinders. The phantom was positioned using room laser and KV CBCT. For each test a series of images were acquired using a square field of 4 cm × 4 cm, with 2.5 MV energy using 2 monitor units, rotating the gantry through 12 angles in 30-degree steps during the full rotation from 0 to 360 degrees; 12 collimator, and 5 couch angles of rotation during a full rotation of 360 degrees. The corresponding DRRs were created each image series was imported from Aria (15.6) software to analyze with the PTW IsoCheck EPID software using the minimum sphere option. IsoCheck EPID (PTW Freiburg, Germany). QA Software determines the rotational isocenters of Linac's gantry, collimator, and couch by analyzing MV images.

In IsoCal measurements, the phantom was positioned with the help of room lasers. A series of images were acquired using a square field of 4 cm × 4 cm, with 2.5 MV energy using 2 monitor units, rotating the gantry through 12 angles in 30-degree steps during the full rotation from 0 to 360 degrees, 12 collimators, and 5 couch angles during the full rotation of 360 degrees. The analysis of acquired images was done with the associated IsoCal software which returns the values of different parameters e.g. isocenter offset from the central beam, phantom position, MV, and KV imager offsets.

## 2.3 Patient QA

Patient-specific QA of 25 patients with brain tumors was done using a patient QA insert of Ruby Phantom. Planning CT and MRI for Ruby phantom was done with patient QA insert while homogenous plug filled the detector openings. 3D CT scans were performed with a flat-couch CT scanner (Toshiba, Tsx-021B, and Japan). All scans were reconstructed in 1 mm slice thickness. Magnetic resonance imaging (MRI) was performed on 1.5 Tesla (GE medical system, USA). For the registration of CT and MRI, images were imported to Eclipse treatment planning system Aria 15.6 version (Varian Medical Systems, Palo Alto, CA, USA) through DICOM. Image fusion of CT and MRI was done using the match point option in Eclipse TPS[19]. 25 SRS/SRT patients were planned with 6 MV flattened beams using Eclipse Treatment Planning System (Varian 6.5, Aria 15.6, Varian Associates, and Palo Alto, CA, USA). Plan optimization and dose calculation were done using the anisotropic analytical algorithm (AAA) algorithm. The prescribed dose of 6 SRS patients was between 12 Gy and 24 Gy (i.e. in one fraction) and for 19 SRT patients is between 12 Gy to 30 Gy in 3 or 5 fractions with a dose per fraction of 4 Gy to 9 Gy. The target volume for 6 SRS patients were ranging between 1.9 $cm^3$ to 23 $cm^3$ and for 19 SRT patients was 1.9 $cm^3$ to 63.2 $cm^3$. The treatment plans were then exported on CT/MRI fused images to create verification plans for Ruby Phantom. The RUBY phantom with the patient QA insert was positioned on the couch by CBCT using the 'fast head and neck' preset with automatic image registration in 'Bone (T & R)' mode for final positioning. The homogenous plugs were used to fill the detector openings during the CBCT

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acquisition. The treatment plans were irradiated using Varian TrueBeam (Varian Medical Systems, Palo Alto, CA) linear accelerator, and the point dose was measured with PTW Pinpoint 3D S/N: 152503 ion chamber in the RUBY phantom with the patient QA insert. The measured point dose and the calculated dose were compared. The percentage dose difference was determined using the following formula:

$$\%\text{Dose Diff} = \frac{(\text{calculated dose} - \text{expected dose})\ \text{x}\ 100}{expacted\ dose}$$

A positive dose difference indicates that the measured dose is larger than the TPS calculated dose and vice versa.

## 3. RESULTS

### 3.1 Isocenter Verification

#### 3.1.1 Ruby Phantom

Winston–Lutz test shows the deviation of the radiation field isocenter from the origin through multiple pieces of information about the geometric accuracy of radiation isocenters. It shows combined and separate image analysis for gantry collimator and couch rotations. These results can be displayed quantitatively and graphically. The analysis returns the values of different parameters e.g. diameter of the isocenter sphere, isocenter offset, their standard deviation and standard error of the mean, and the isocenter position in terms of coordinates.

**Table 1: The minimum, maximum, and mean diameters of the isosphere and isocenter offset for the gantry, collimator, and couch rotations**

| | Maximum Diameter of isocenter (mm) | Minimum Diameter of isocenter (mm) | Mean Diameter of isocenter (mm) | Isocenter Offset (mm) | Isocenter Position (mm) | |
|---|---|---|---|---|---|---|
| | | | | | Left-Right | Target-Gun |
| **Gantry** | 1.04 | 0.41 | 0.78±0.12 | 0.45±0.18 | -0.009 | 0.304 |
| **Collimator** | 0.99 | 0.39 | 0.79±0.13 | 0.40±0.20 | 0.186 | 0.240 |
| **Table** | 1.07 | 0.06 | 0.62±0.22 | 0.23±0.12 | 0.116 | 0.155 |
| **Combined** | 0.97 | 0.47 | 0.73±0.09 | 0.36±0.11 | 0.090 | 0.230 |

The diameters of the isosphere, isocenter offset, and isocenter position measured by IsoCheck EPID are presented in Table 1 for the gantry, collimator, and couch rotations separately. The standard error of the mean is 0.012mm, 0.013mm, and 0.021mm for the diameter of isocenteric sphere and 0.01mm, 0.02mm, and 0.01mm for the offset of the gantry, collimator, and couch. Evaluation of reproducibility is assessed by the standard deviation given in Table 2.

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**Table 2: Reproducibility of the rotational isocenter tests with ruby phantom based upon measurements taken over 100 days**

| Parameter | Standard Deviation | Parameter | Standard Deviation |
|---|---|---|---|
| **Diameter of Isocenter Sphere** | | **Isocenter Offset** | |
| Gantry | 0.12 mm | Gantry | 0.18 mm |
| Collimator | 0.14 mm | Collimator | 0.20 mm |
| Couch | 0.22 mm | Couch | 0.12 mm |
| **Isocenter Position** | | | |
| Left-Right | 0.27 mm | Target-Gun | 0.20 mm |

### 3.1.2 IsoCal Phantom

The offset in the radiation isocenter measured by IsoCal is shown in Fig 1. The deviation remains consistent within the range of min 0.31mm to max 0.45mm over the whole period which is well below the defined threshold of ± 0.5mm. The standard deviation is calculated to be 0.18 mm. the treatment. The largest longitudinal, lateral, and vertical offset positions were -0.05mm, 0.92mm, and 1.1 mm.

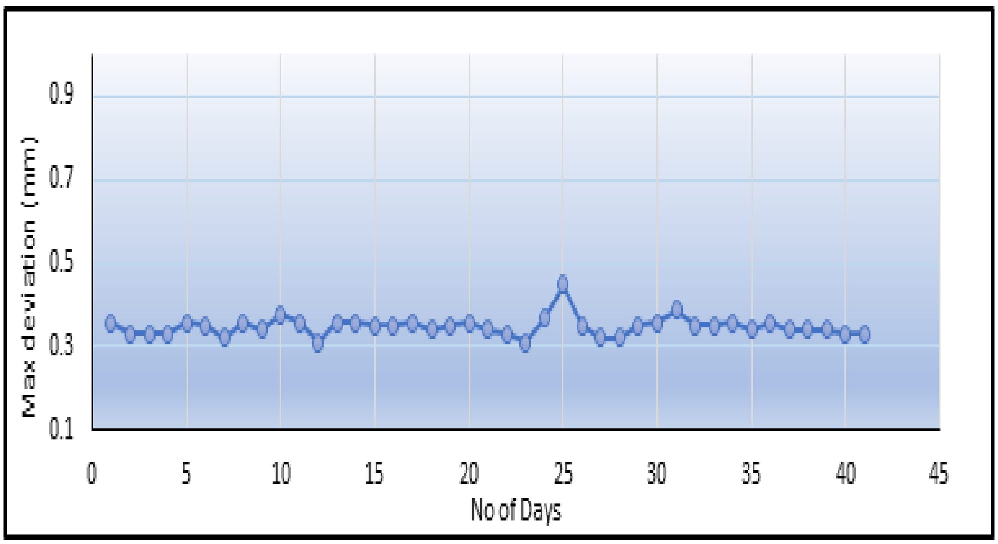


**Fig 1: Offset of Radiation isocenter gantry, collimator, and couch collectively using Ruby phantom (PTW Freiburg, Germany) on Varian TrueBeam on various days**

The average is -0.737mm, -0.105mm, -0.043mm, and the standard deviation is 0.54mm, 0.65mm, and 0.58mm. Shown in Fig 2. Maximum MV and KV imager shifts from the isocenter are measured as shown in Fig 3. The average shift in the MV imager is 0.17±0.07 mm and for the KV imager 0.16±0.08mm.

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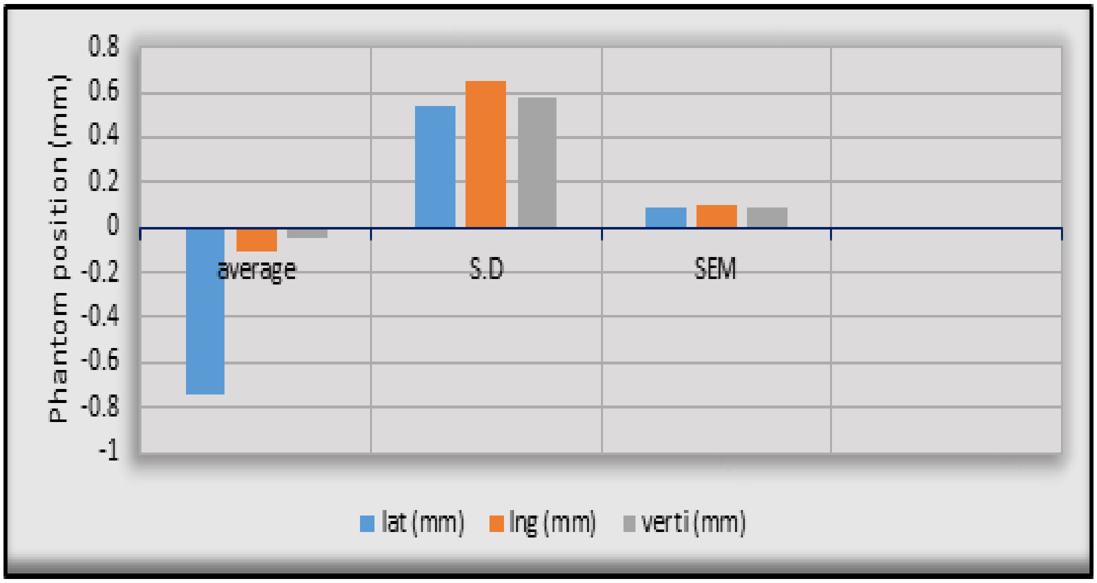


**Fig 2: Average standard Deviation and standard error of mean Lateral, longitudinal, and vertical position (mm)**

IsoCal also measures the rotational deviation of MV and KV imagers it represents the measure of the degrees by which an image is shifted from its center in that plan. The average value is 0.69±0.12° for MV and 0.015±0.0007 ° for the KV imager.

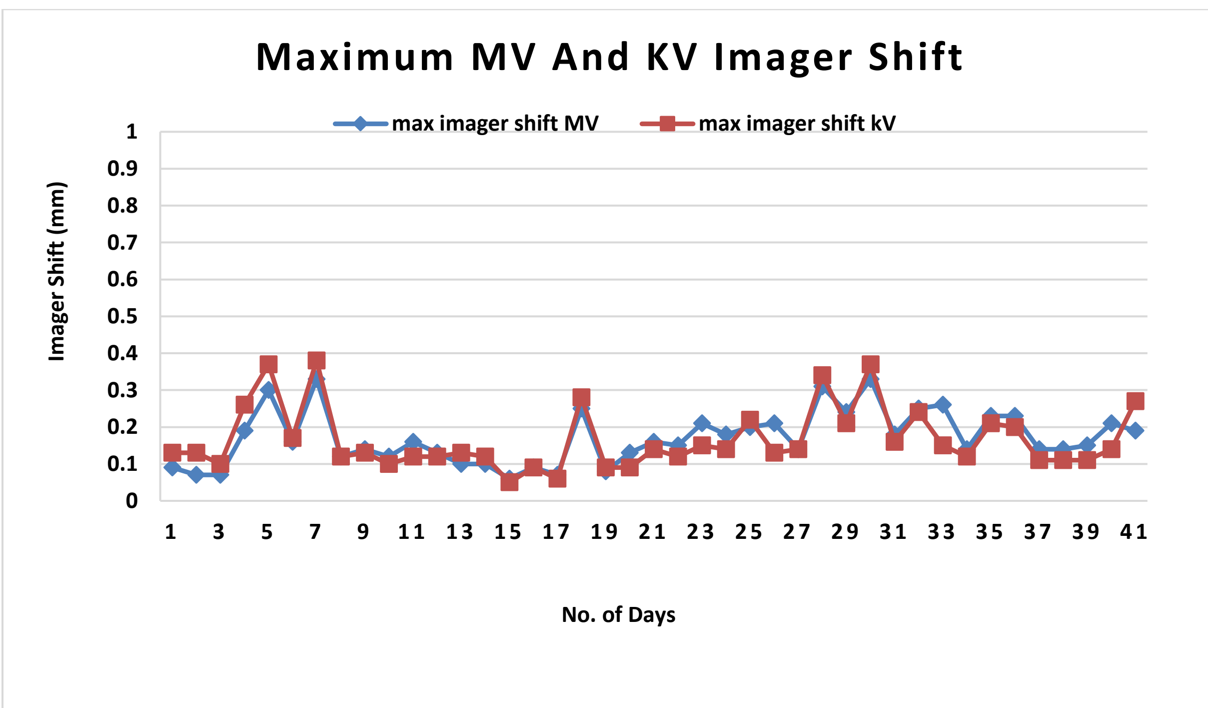


**Fig 3: Maximum MV and KV imager shifts from isocenter**

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### 3.2 Patient QA

Pre-treatment QA of 25 patients with brain tumors was done using a patient QA insert of Ruby Phantom. Point doses were measured using a pin-point 3D ionization chamber as a detector in Ruby Phantom. The results from the point dose measurements are shown in Fig. 4.

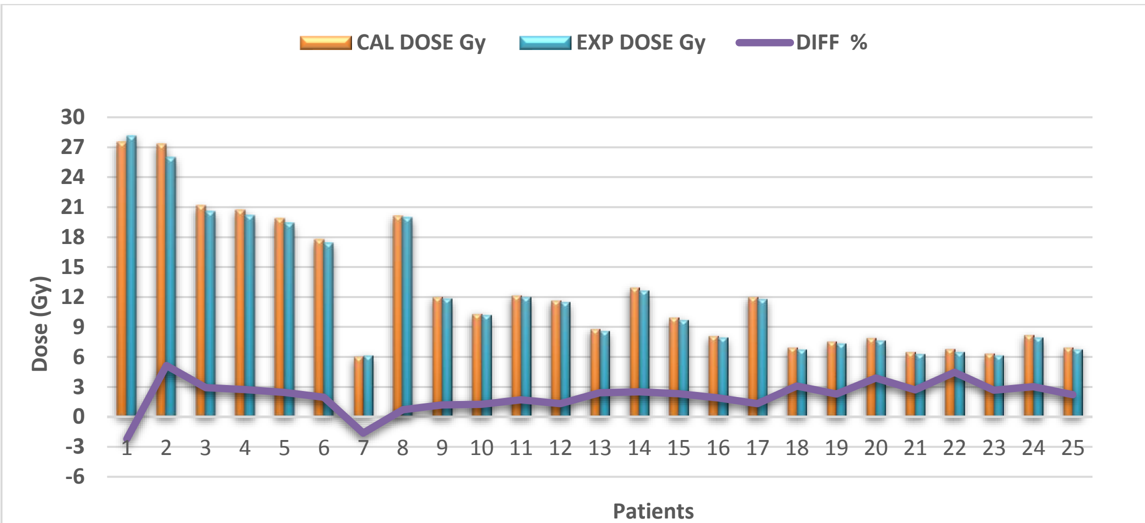


**Fig 4: Differences between the dose values calculated with the TPS and the PinPoint 3D ionization chamber measurements. Bars represent the calculated dose and expected dose while the line represents the dose difference**

The measured dose values agree with the expected values within 3%, except for plans 2, 20, and 22 where the dose difference is slightly higher. The patient with higher dose gradients was planned again and the whole QA process was repeated until the dose difference become within the acceptable limit.

## 4. DISCUSSION

Considering the high geometric accuracy and precision for isocenter localization and dose calculation are the chief goals of the SRS/SRT. This study demonstrates that the RUBY phantom with the Linac QA insert is an appropriate tool for the daily QA of isocenter verification. Results of the Ruby phantom demonstrate variation in the diameter of isocenters up to the submillimeter of accuracy Table 1. There are a few readings in which the diameter is observed to be out of the prescribed tolerance limit. As prescribed by the AAPM Task Group Report, 179 [20] the radiation isocenter should have a diameter of less than 1 mm overall. Table 1 shows the minimum, maximum, and average values of the diameter of the isocenter of the gantry collimator and couch. While the overall diameter of the isocenter sphere is also computed which ranges from a minimum of 0.49mm to a maximum of 0.97mm. Also, the standard deviation and standard error of the data show a very small deviation in values acquired daily for gantry collimator and couch rotations over the period. According to the AAPM Task Group Report, 179

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recommendations the acceptable deviation is equal to or less than 1mm between the radiation and mechanical isocenter. Results of Ruby phantom for isocenter offset are computed with IsoCheck software. The computed offsets are within the defined limits for the pass/fail criteria of the test of all rotational components (gantry, collimator, and couch) as presented in Table 1. Geometry checks were also performed by using IsoCal phantom for comparison with Ruby phantom Fig 1. The results are within the tolerance of 1mm. the comparison of results from Ruby phantom and IsoCal phantom shows no significant differences in the isocenter offset.

Another way to verify the rotational isocenter and its deviation is based on its position w.r.t origin. Calculated offset values in lateral (Left-Right) and longitudinal (Target–Gun) directions are shown in Table 1 for Ruby phantom. Results show no significant deviation in the isocenter position. IsoCal also measures the lateral, longitudinal, and vertical position of the phantom Fig 2. The vertical direction shows minimum deviation and the lateral direction shows maximum deviation. A combined average deviation of three directions shows acceptable results. The standard deviation of distance parameters should be less than one order of magnitude from 1 mm. A small deviation in values of standard deviation is the indication for reproducibility to be acceptable in the daily variations of the data. All component tests are reproducible within 0.27 mm for all parameters. Visual indication of the small spread in day-to-day variations of standard deviation is shown in Table 2 which depicts the reproducibility of geometric parameter values over the study period which depicts that clinical reality and ensures that the performance of the system is maintained at acceptable levels.

IsoCal is a useful technique for locating the image centers and the radiation isocenter. MPC analyzes and returns a pass or fail status of the result in graphical and tabular form for each test performed. According to the set tolerance level, the analysis displays a warning, for each test parameter. The MV and KV imager centers may doesn't coincide with the radiation isocenter. These centers show the shift when measured with IsoCal software. Daily shifts of MV and KV imager are shown in Fig 3. The maximum shift in the center of the KV imager is 0.38mm and in the MV imager is 0.33mm which is within the set tolerance level. Along with the offset in the imager's centers, Isocal also measured the in-plane rotation of both MV and KV imager the results show the in-plan imager shifts to be within the tolerance limit of 1° according to AAPM recommendations [21-23]

IsoCal measurements were performed to compare its results with Ruby phantom results. For comparison, the IsoCal test was performed in 41 days in which Ruby phantom tests were also performed. The results of this study depict all the parameters lie within the tolerance limit as recommended by TG 179. The average isocenter deviation measured with the IsoCal is 0.35±0.02mm is in close agreement with the values measured with the WL test using Ruby phantom which is 0.41±0.11mm (for comparison average and the standard deviation of Ruby phantom result here is calculated for 41 days in which IsoCal is performed). Schmitt et al [24] recommend a single phantom setup for dose calculation and verification, target localization, positioning workflow with CBCT, and the final dose measurement. Dose measurements were realized at the isocenter Point dose measurements carried out for 25 SRS/SRT patients are compared to the calculated

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values. The calculated dose expected dose, and % dose difference of measurements performed using RUBY phantom with Pin Point 3D chamber as the detector is represented in Fig 4. The point dose value measured by RUBY phantom agrees within ±3%, to the expected values for all volumes except for plan2, 20 and 22 where a small deviation (not more than 5%) was observed. The system QA insert is not evaluated to perform end-to-end QA in this study only linac QA and patient QA inserts are evaluated. The modular structure of the RUBY Phantom facilitates Physicists to use a single phantom to perform daily QA checks and patients specific QA. It allows a department to carry out a more synchronized and harmonic QA workflow.

## 5. CONCLUSION

The RUBY phantom did simplify the QA workflow. There is plenty of scopes for the RUBY modular QA phantom to streamline and consolidate QA checks into a single platform. Ruby phantom exhibited to be a consistent, rapid, and easy-to-implement method for checking the geometric aspects of Linac and its results proved to agree with the tests performed with IsoCal phantom. RUBY phantom is recommended to use for routine quality assurance of the isocenter. WL test in combination with Ruby phantom shortened the time and decreases the chances of human errors and hustle as it requires a one-time setup. RUBY phantom is an exciting new addition to QA tools for radiation oncology, especially for SRS treatments performed with patient QA insert. It shows agreement is better than 3% for most cases. The modular construction of the RUBY allows using a single phantom to perform different QA processes for a more synchronized and harmonic QA workflow using a variety of task-specific inserts. RUBY phantom opens the door, intending to optimize patient care and achieve a cure. The described procedures allow for safe clinical implementation in a modern radiotherapy department.

**Conflicts of Interest:** None

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