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Evaluation of Consistency of Flattening Filter Free Beam using Automated and Image-Based Tool

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Abstract

Aim: Analysis of consistency of True Beam for Six months using Automated and Integrated Image-Based tool.

Methods and materials: Data acquisition comprises a series of 40 images (12 KV and 28 MV Images) acquired at predefined positions without and with ISOCAL phantom in the beam and with predefined MLC pattern settings. Machine Performance Check utilizes a series of KV and MV images of the ISOCAL phantom to assess: Treatment isocenter size and its coincidence with MV and KV imager, positioning accuracy of the imaging systems, accuracy of collimator and gantry angles, accuracy of jaw and MLC leaf positions, accuracy of couch positioning. Six months data was taken and calculated maximum, minimum and average of each parameter.

Results: Results were analyzed for 6MV photon beam. Treatment isocenter size was between 0.53 mm and 0.33 mm (threshold of ± 0.50 mm). Coincidence of MV and KV imaging isocenters was within 0.49 mm to 0.14 mm and 0.36 mm to 0.16 mm. Positioning accuracy of MLC was within 0.3 mm to 0.37 mm; accuracy of jaws in mm was within -0.91 to -0.93, -0.02 to -0.94, 0.12 to -0.19, and 0.42 to 0.14 for X_1, X_2, Y_1 and Y_2 jaws respectively. Absolute gantry accuracy was within 0.1 to -0.06 and relative gantry accuracy was with in 0.12 and -0.1 degrees respectively. Couch accuracy for lateral, longitudinal, vertical, rotation, rotation induced couch shift in mm was within -0.4 to - 0.66 , -0.07 to -0.25, -0.06 to -0.18, 0.01 to -0.09, and 0.63 to 0.29 respectively.

Conclusion: Analysis of our six months data shown that the consistency of True Beam is satisfactory. Its values are in close agreement with the routine QA programme in our department and satisfy all recommendations under

Keywords: ISOCAL phantom; Mechanical performance test; Isocenter; Gantry; Collimator and MLCs

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Introduction

In order to ensure the medical prescription and the safe fulfillment of that prescription as regard to dose to the target volume, together with minimal dose to the adjacent normal tissue, minimal exposure of personnel, and adequate patient monitoring aimed at determining the end result of the treatment. The world health organization (WHO) [1] introduced quality assurance in the radiation therapy. The international Organization for standardization (ISO) [2] defines the quality assurance as all those planned and systematic actions necessary to provide adequate confidence that a structure, system or component will perform satisfactorily in service, will satisfy the requirement for quality. The AAPM task group (TG) 142 [3] was published by September 2009 as an update and completion of Task Group (TG) 40 [4] to give recommendations on all machine parts, adding the newer ancillary delivery technology like dynamic, intensity modulated radiation therapy, or stereotactic radio surgery (SRS) or stereotactic body radiation therapy (SBRT) as well as the imaging devices that nowadays form an integral part linear accelerator: X-ray imaging, photon portal imaging, Cone Beam Computed Tomography (CBCT). The AAPM task group report 142 has not yet included the recommendation for the new linear accelerators of the flattening filter free mode (FFF beams), the flattening filter free beams have very high dose rates and bell-shaped lateral profiles increased their use for the stereotactic treatments. Such profiles, so different in shape from the corresponding flattened ones, faced to the need of evaluating profile parameters that cannot be identical to the standard flattened beam parameters, but should keep the same concept and could be used in the same way as analogous for standard fields [5].

The TrueBeam 2.0 platform Varian (Varian Medical Systems, Palo Alto, CA, USA) has released machine performance check (MPC) application. The Varian MPC application is a fully integrated, automated KV- and MV- image based tool for verify and assessing the performance of TrueBeam critical functions. The MPC has been divided into categories: The beam consistency checks and the geometric checks. In the present study, the consistency of Flattening Filter Free (FFF) was evaluated with the aid of an automated and integrated imaging-based tool i.e., MPC. The MPC utilizes a series of KV- and MV- images of the IsoCal phantom to assess: treatment isocentre size and its coincidence with KV- and MV- imager, positioning accuracy of the imaging system, accuracy of collimator and gantry angles, accuracy of jaw and leaf positions, and accuracy of couch positioning. For the present study the preliminary test with MPC were performed for 6 MV photon beam energy available on our Truebeam unit to evaluate the consistency of the FFF photon beam.

Materials and Methods

The measurements of the present study were performed on Single Varian (Varian Medical Systems, Palo Alto, CA, USA) TrueBeam 2.0 STx linac with aS1200 EPID with six degrees of freedom couch in order to evaluate the consistency of TrueBeam with the aid of an automated and integrated image-based tool (MPC), running both flattened and flattening filter free (FFF) 6MV beams. The Mechanical Performance Check (MPC) is a new TrueBeam major mode, designed to have machine performance check in five minutes. It makes use of a dedicated phantom and associated software, the IsoCal, an automated geometric calibrated system for on-board imaging and MV imaging systems. The IsoCal Phantom is a hallow cylinder 23 cm in diameter and length with 16 tungsten carbide bearing balls each of diameter 4mm. The aS1200 EPID makes use of a 43 × 43 $(cm)^2$ panel with backscatter absorber plate between the detection panel and positioning arm. The detector matrix is 1280 × 1280 with a smaller 1190 × 1190 pixel region employed for Dosimetry (Integrated) imaging mode providing a 0.34 mm resolution when EPID is at 150 cm source to detector distance (SSD) as it is used for MPC tests.

Isocal setup and procedure

The first test requires the use of the IsoCal tray, which is mounted onto the head of the linac. The test is conducted by rotating the collimator at eight 45-degree intervals and taking MV images for each of the four intervals. IsoCal's software then determines the location of the steel pin at the center of the tray across the eight images. Based on the steel pin locations from the eight images, the program can calculate the error of the beam center from the collimator rotation.

The next test requires the use of the IsoCal phantom with both the MV imaging system and kV imaging system. The phantom is first fixed at the end of the couch at H_2 position and positioned at the room's isocenter using the room lasers. The operator then performs IsoCal's initial alignment check using the imagers. This initial check is to verify that the phantom is within 5 mm of the isocenter and will fail if it determines that this value has been exceeded. The operator will then ensure that the phantom is within the 5 mm tolerance and run the check again before the program will run fully. Once in the full IsoCal programming, the linac gantry rotates a full 360 degrees and takes 120 images throughout the entire rotation with the main beam and MV imager using a 6 MV beam. When this is complete, the couch is set at a small angle, usually less than ten degrees, and the gantry rotation process is repeated. After the MV images are completed the EPID is folded away and the CBCT based kV imaging system is brought out to conduct the kV verification. The CBCT is used here to produce planar images, rather than its usual function of producing 3D clinical images, replicating the two-dimensional (2D) image format produced by the EPID of the MV imaging system. Once again, the gantry is rotated a full 360 degrees and produces 120 images using the kV imaging system. The measurement setup described above is shown in **Figure 1**. The operator enters into the MPC mode at the True beam console to initiate the procedure that takes places automatically and acquires a series of MV and kV images, moving the machine and imaging system to the already predefined positions **(Figure 1)**.

Figure 1 The IsoCal phantom being mounted to the couch during an isocenter verification test.

All the images are then uploaded to the IsoCal software which will automatically track the ball bearing's (BB) movement and calculate the variety of machine parameters for verification. For machine verification to be accepted the parameters must be within the tolerances that Varian specifies in the program. An example of some parameters is the isocenter size calculated from the MV imager and the kV imager. The two calculated values are different but related such that both are needed to ensure the isocenter size is within the combined 0.5 mm tolerance.

MPC geometric checks

The MPC geometric tests utilizes a series of kV and 6 MV images of the IsoCal phantom situated in specific bracket on the IGRT couch to top assess: treatment/radiation isocentre size, coincidence of MV and kV isocentres, accuracy of gantry and collimator angles, accuracy and jaw MLC positions, and accuracy of couch positioning including pitch and roll. All the measurements are highly automated and the user is simply required to set up the IsoCal phantom and bracket onto the treatment couch at position H_2 and to beam on. For the geometric tests, the system makes all the required motions automatically and beams on when all is in position. Images are automatically analyzed on the TrueBeam console and results are presented with pass/fail criteria applied as shown in the **Figure 2**. Functionality for presenting trends in the results is also available in the package [6,7].

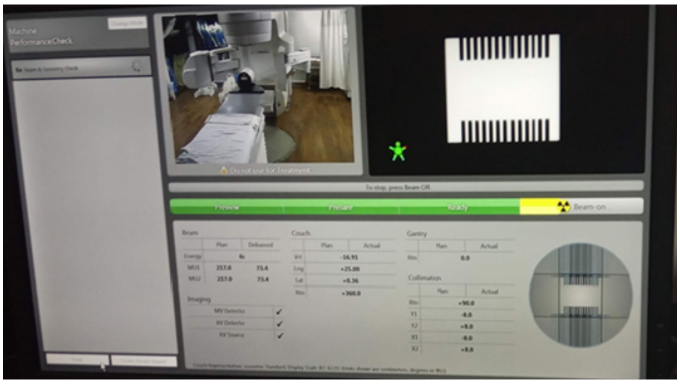

Figure 2 The leave tips from the MLCs centerline using a static comb pattern with alternating leaves.

In order to evaluate the short-term repeatability, MPC was run successively five times and measurement was performed after introducing a deliberate error in the phantom alignment to determine whether the phantom setup affected the measurement. This was achieved by introducing packing between the phantom and its mount to introduce an approximate 20 rotation in the phantom.

Further, to verify the long-term stability of the MPC measurements and sensitivity to maintenance activity, 6 months of daily data was recorded for the kV source offset (tangential and axial) and for the kV imager offset, along with a record of dates where relevant linac maintenance events occurred. The average values with minimum and maximum of the kV source off set and kV imager offset data were calculated for each period between maintenance events to assess both the magnitude of the changes caused by the maintenance events and the stability of the X ray tube alignment between events according to MPC [8].

Measurement methods

Isocenter: A vital parameter of a radiation therapy treatment unit is the position and size of the isocenter. The isocenter is defined as the ideal intersection point of the beam central axis over a full gantry rotation and size of the treatment isocenter is defined as the maximum distance of a beam's central axis from the idealized isocenter. The treatment isocenter is then determined using acquisitions with the IsoCal phantom on eight gantry angles (00, (45)0, (90)0, (135)0, (180)0, (225)0, (270)0, (315)0), representative for the full gantry rotation (gantry angles 00 and (45)0) IEC 61217 [9].

The imager (kV and MV) projection offset represents the maximum distance of the imager center (kV and MV) from the projection of the treatment isocenter. The imager projection offset is a measure of the correctness of the IsoCal calibration **(Table 1)**.

Table 1: Beam and geometry check.

Beam & geometry check Tuesday, February 05, 2019, 8.12 AM (No baseline)			
Beam delivery		Processing	
		Value	Thresholds
Isocenter		✓	
Size		+0.48 mm ✓	± 0.50 mm
MV imager projection offset		+0.25 mm ✓	± 0.50 mm
KV imager projection offset		+0.20 mm ✓	
Collimation		✓	
> MLC		✓	
> Jaws		✓	
Rotation offset		+0.07* ✓	± 0.50*
Gantry		✓	
Absolute		+0.08* ✓	± 0.30*
Relative		+0.11* ✓	± 0.30*
Couch		✓	
Lateral		0.65 mm ✓	± 0.70 mm
Longitudinal		-0.11 mm ✓	± 0.70 mm
Vertical		-0.10 mm ✓	± 1.20 mm
Rotation		0.00* ✓	± 0.40*
Rotation-induced coach shift		+0.53 mm ✓	± 0.75 mm
Note: Display scale IEC 61217 units shown or millimetres or degrees			

MLC position evaluation: The MPC MLC test utilizes a static MLC Comb pattern whereby alternating leaves are set at either 5 mm or 3.5 mm. The leaf positions are measured using EPID and the position of each leaf is determined relative to the collimator rotation axis determined from series of collimator rotated MLC fields. The MPC reports from both the mean and maximum measured offset for each MLC bank. As such, the measurement is not influenced by the EPID panel. The tolerance for MPC is ± 1 mm.

Collimator: The evaluation of positional accuracy of the collimator system was performed by using static field evaluation at gantry position 00. The MLC menu consists of the following sub measurements: Maximal Offset Leaves A Bank, Maximal Offset Leaves B Bank, Mean Offset Leaves A Bank, Mean Offset Leaves B Bank, Individual Leaves Bank A and Bank B (60 leaves from each Bank). The positional accuracy of each leaf was measured as the distance of the MLC leaves tip from the MLCs centerline using a static comb pattern with alternating leaves, as shown in the **Figure 2.**

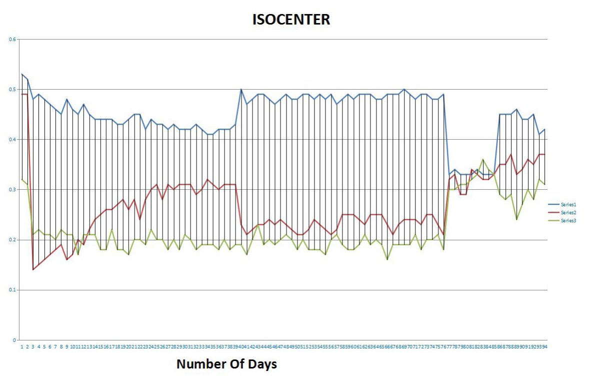

Figure 3 Graphical representation of data trends- Isocenter group. Note: Series 1- Size, Series 2-MV imager offset, Series 3-KV imager offset.

The MPC check of jaw positioning is performed using an 18 × 18 cm^2 field. Jaw edges are detected on the EPID and the result is calculated as the distance between the measured jaw edge and the centre of rotation of the MLC, which is determined from a series of collimator rotated MLC defined fields. As such, the measurement is not influenced by the absolute positioning of the EPID panel. For jaw positioning QA, the beam central axis is determined from the average field centre of two 10 × 10 cm^2 fields at 1800 opposed collimator angles. The resulting centre pixel position is dependent only on the EPID panel positioning and the focal spot position of the beam. Because of the collimator rotation the effect of jaw positioning is removed. Using the measured centre pixel as reference the position of the field edges are measured from a 20 × 20 cm^2 jaw defined field and compared to expected.

Gantry: The Absolute positioning accuracy was defined as the coincidence of the couch's vertical axis with the central beam axis at gantry 0^0.The Relative positioning accuracy was the maximum offset between the angle determined by the MV imaging system and the nominal gantry angle i.e. the values are compared for eight representative gantry angles 00,450,900,1350,1800,2250,2700,3150.

Couch: MPC measures the positioning accuracy of the different couch axes with respect to a reference position (established as the fixed room coordinate system using MV and kV images with the IsoCal phantom). Subsequently, the couch axes are moved and the actual distances are determined.

1. Lateral: describes the positioning accuracy of the lateral couch axis on a 5 cm travel range.
2. Longitudinal: describes the positioning accuracy of the longitudinal couch axis on a 5 cm travel range.
3. Vertical: describes the positioning accuracy of the vertical couch axis on a 15 cm travel range.
4. Rotation: describes the positioning accuracy of the patient support angle on a 100 travel range.
5. Pitch and Roll: describes the positioning accuracy of the patient pitch and roll angles on a 30 travel range (only for Perfect Pitch couch top, not evaluated in the current study).
6. Rotation-Induced Couch Shift: describes the distance between the center of rotation of the couch, determined through a motion on the rotational axes, and the treatment isocenter **(Figure 2)**.

Baseline: MPC does not use any external equipment for measuring dosimetric properties of the beam, but it is based on the concept of baseline data. A reference state of the machine is marked as baseline, with which subsequent acquisitions are compared to. Being a relative evaluation in its nature, a baseline acquisition has to precede any check. A baseline should be acquired only when the dosimetric performance of the beam is verified by independent means (e.g. ion chamber measurements). The baselines used in the current work refer to the first acquisition with MPC, prior to the 10 repetitions.

Beam consistency checks:

To evaluate the beam constancy, MPC uses an uncorrected MV portal image (i.e. not corrected for the flood field) of a symmetric, jaw-collimated (18 × 18 cm^2) field at gantry 00. Ratio images are calculated between the baseline and the image of the checking beam for each energy. To reduce the impact of the jaw positioning, the following parameters are evaluated on a central area of 13.3 × 13.3 cm^2 of the ratio image field.

On beam output change: It represents the average percentage variation in detector response as mean of the ratio between the beam check acquisition and the baseline data, in the central area of the imager. For this evaluation, high frequency noise is filtered from the ratio image.

Beam uniformity change: It represents the percentage variation of the uniformity between the current and the baseline image. The uniformity is defined as the difference between the two pixels with the lowest and the highest ratio in the central area of the imager. It is not an evaluation of the beam symmetry. For this evaluation, high frequency noise is filtered from the ratio image.

Beam center shift: It describes the relative shift of the field center, defined by a jaw-collimated field, with respect to the baseline. The field center is found through detection of the jaw edges in the beam image. This shift accounts for the precision of the beam steering system, the collimation and the MV imaging system **(Tables 2-6).**

Results and Discussions

The MPC geometric checks were performed for isocenter, MLC position evaluation, collimator, gantry and couch. The results are presented in terms of average values, maximum and minimum for isocenter, MLC position evaluation, collimator, gantry and couch in **Tables 2-6** respectively. The comb-like pattern presented in the **Figure 2** of the acquired KV and MV images with and without the Isocal in the beam as discussed in the materials and methods section is shown in the **Figure 2**. For each parameter a threshold value is used by the MPC software that represents the corresponding specification of the TrueBeam unit. The trends are shown graphically in the **Figures 3-6**.

The WHO introduced the QA program in radiation therapy in order to ensure that the treatment unit performs satisfactorily. The MPC being a fully automatic and integrated KV and MV image based tool for assessing the performance of the Varian TrueBeam unit. In the MPC, for each parameter a base line is used by the software to compare the measured values. In the present study, Geometric Checks are related to default energy and predefined acquisition that consists of 40 images.

The isocenter is the Benchmark for all values and therefore it has to be measured accurately. At the time of installation and commissioning of TrueBeam, the acceptance test was performed with Varian Medical System Isolock software tool. The MPC value for the isocenter was fixed on that day. If the measured value surpassed the tolerance value (± 0.5 mm) then the isocenter test should be verified by independent sources. In our study the isocenter size ranges from 0.53 mm to 0.33 mm with an average of 0.44 mm. The Table 3 presents the maximal offset of leaves. The maximum offset of leaf bank A and leaf bank B are within the tolerance. The Collimator Jaws X_1, X_2, Y_1, Y_2 values obtained is shown in the Table 4. All the parameters obtained by our MPC checks are within the threshold limit. The gantry Positional accuracy was measured with MPC and is shown in the Table 5. The absolute and relative values of gantry ranges from 0.1 mm to 0.06 mm with an average value 0.049 mm and for relative the average value was found to be 0.051 mm. All the parameters were found within the threshold value of (± 0.30)0. The couch lateral, longitudinal, vertical, rotation and rotational induced shifts are shown in the Table 6. All the parameters were found within the threshold values. The beam consistency was within ± 2%.

The results of our study were in the close agreement with the research literature presented by several research groups across the globe. Clivio et al. [10], Nigam et al. [11] and Bhatt et al. [12] evaluated the Machine performance by using the MPC and our results are in agreement with these studies **(Figures 3-6).**

Table 2: The MPC report of Isocenter for 6 MV Photons.

Parameters Isocenter	Evaluation	Threshold (mm)	Maximum (mm)	Minimum (mm)	Average (mm)
Size	Close within thresholds	± 0.50	0.53	0.33	0.44
MV imager Offset	Within thresholds	± 0.50	0.49	0.14	0.26
KV imager Offset	Within thresholds	± 0.50	0.36	0.16	0.21

Table 3: The MPC report for MLC leave bank A and B.

Parameters	Evaluation	Threshold (mm)	Maximum (mm)	Minimum (mm)	Average (mm)
	Within thresholds				
Maximal offset leaves A	Within thresholds	± 1.00	0.7	-0.54	-0.42
Maximal offset leaves B	Within thresholds	± 1.00	0.29	-0.58	-0.33
Mean offset leaves A	Within thresholds	± 1.00	-0.15	-0.44	-0.34
Mean offset leaves B	Within thresholds	± 1.00	0.05	-0.3	-0.04

Table 4: The MPC report for jaw offset parameters.

Parameters Jaws	Evaluation	Threshold (mm)	Maximum (mm)	Minimum (mm)	Average (mm)
Offset X_1	Within thresholds	± 1.00	0.93	-0.91	0.80
Offset X_2	Within thresholds	± 1.00	-0.02	-0.94	-0.63
Offset Y_1	Within thresholds	± 2.00	0.12	-0.19	-0.05
Offset Y_2	Within thresholds	± 2.00	0.42	0.14	0.29
Rotation offset	Within thresholds	± 0.50	0.09	-0.29	0.006

Table 5: The MPC report for gantry.

Parameters	Evaluation	Threshold (mm)	Maximum (mm)	Minimum (mm)	Average (mm)
Gantry	Within thresholds				
Absolute	Within thresholds	± 0.30°	0.1	-0.06	0.049
Relative	Within thresholds	± 0.30°	0.12	-0.1	0.051

Table 6: The MPC report for couch lateral, longitudinal, vertical and rotational parameters.

Parameters	Evaluation	Threshold (mm)	Maximum (mm)	Minimum (mm)	Average (mm)
Couch					
Lateral	Within thresholds	± 0.70	-0.4	-0.66	-0.56
Longitudinal	Within thresholds	± 0.70	-0.07	-0.25	-0.13
Vertical	Within thresholds	± 1.20	-0.06	-0.18	-0.11
Rotation (°)	Within thresholds	± 0.40	0.01	-0.09	-0.01
Rotation induced couch shift	Within thresholds	± 0.75	0.63	0.29	0.49

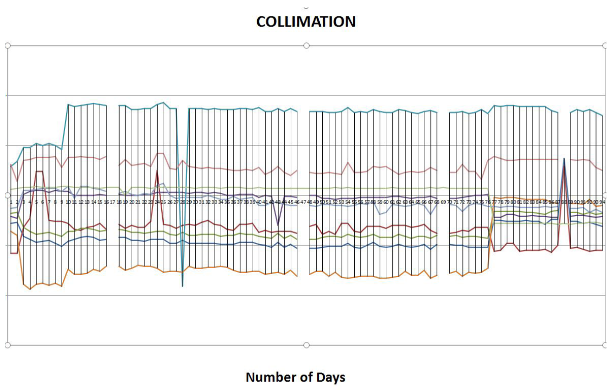

Figure 4 Graphical representation of data trends – Collimator and Jaw offset. Note: JAWS Series 1-Maximal offset leaves A, Series 2-Maximal offset leaves B, Series 3-Mean offset leaves A, Series 4-Mean offset leaves B, Series 5-Offset X1, Series 6-Offset X2, Series 7-Offset Y1, Series 8-Offset Y2, Series 9-Rotation Offset.

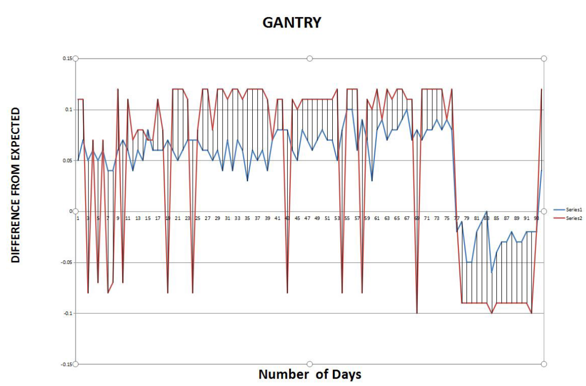

Figure 5 Graphical representation of data trends – Gantry. Note: Series 1-Absolute, Series 2-Relative.

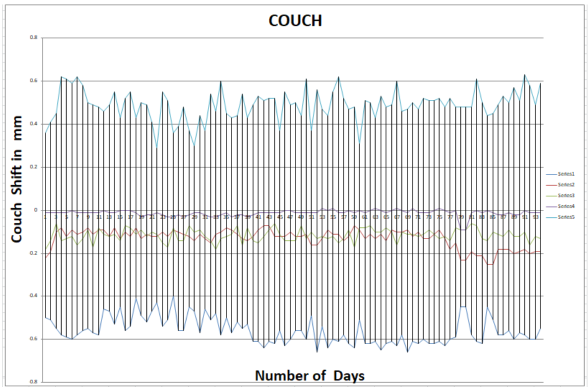

Figure 6 Graphical representation of data trends – Couch. Note: Series 1-Lateral, Series 2-Longitudinal, Series 3-Vertical, Series 4-Rotational, Series 5-Rotation Induced couch shift.

The results of our study were in the close agreement with the research literature presented by several research groups across the globe. Clivio et al. [10], Nigam et al. [11] and Bhatt et al. [12] evaluated the Machine performance by using the MPC and our results are in agreement with these studies **(Figures 3-6).**

Conclusion

To We conclude from our study of consistency of TrueBeam for six months using automated and integrated image based tool that the MPC is a reliable, quick and easy to use method for verifying the machine performance on both geometric and dosemetric aspects. Further, we infer from our study that the consistency of the TrueBeam is satisfactory and the value are in close agreement with the routine QA programme of our department and satisfy all the recommendation of TG-142.

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