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Evaluation and validation of the machine performance check application for TrueBeam 2.5 Linac

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Abstract

Aim: To evaluate the Machine Performance Check (MPC) 1.1 application for TrueBeam 2.5 and to establish MPC application as a comprehensive daily QA tool after verification. **Methodology:** An automated daily Quality check application MPC using IsoCal Phantom provided by Varian Medical System (VMS) to perform the essential tests such as beam consistency that is dosimetric performance and mechanical check were performed on TrueBeam. The data was collected over a period of four months (84 days). MPC acquired data consists of a series of generation of images using MV and kV at various gantry, collimator, and couch positions. The collected data is analyzed for daily reproducibility as well as comparison with ion chamber measurements. **Findings:** The results showed that the reproducibility of MPC was less than the tolerance values for the respective mechanical parameters. The MPC measured isocenter with mean value of 0.35 mm is within tolerance. The Beam Consistency showed that over a period of four months, the mean value of output measurement of 6 MV photon beam as measured by the MPC and Farmer Type Chamber FC65-G differ by less than 1%. It is evident that the MPC proved to be fast and easy to use QA tool for daily checking of machine performance. But it is evident from present study that, inter comparison with a Farmer Type chamber is needed, if the MPC has to replace the other QA tools.

Keywords: MPC; QA; Linear Accelerator; EPID AS1000

1 Introduction

During the past two decades, there is continuous improvement in the treatment technology to treat Cancer Patients. The Treatment technology includes Treatment Planning Systems (TPS) and delivery of treatment through Linear Accelerator (Linac) equipped with state-of-the-art hardware and software technologies. Therefore, robust Quality Assurance (QA) is needed to check the equipment for any error as well as to comply with countries regulatory requirements[1,2].

There are various types of QA tools available in the market[3] Which may be supplied by vendor along with treatment machine or may be purchased separately. The main requirement for any QA equipment & procedure is that it should take minimum time to set, minimum time to perform and provide the complete result within minimum possible time. The result should be available online and offline for review.

Gao et al.[4] evaluated the IsoCal Geometric Calibration System (2014) and Clivio, A et al.[5] evaaluated the Pre Release MPC version (2015) on TrueBeam 2.0. Bhatt, C. P. et al.[6] evaluated the MPC on TrueBeam 2.0 (2017). The present study evaluates the MPC application 1.1 for TrueBeam 2.5 and aims to verify it.

2 Materials & Methods

2.1 The linear accelerator TrueBeam 2.5

Is used with Machine Performance Check (MPC) Internal Software Version 1.1.16.0 supplied by Varian Medical Systems, Inc. Palo Alto, USA. The TrueBeam 2.5 is equipped with three flat photon beams viz. 6 MV, 10 MV and 15 MV and two flattening filter free (FFF) photon beam viz. 6 MV FFF and 10 MV FFF. The Multi Leaf Collimator (MLC) with 120 Leaves (120MLC – Radiation Oncology Version). The MLC system has 40 Leaves (20 Pairs) with leaf width of 0.5 cm and outer pair has 20 Leaves (10 Leaves) leaf width of 1.0 cm. at Isocenter. The TrueBeam 2.5 is equipped with MV as well as kV Imaging Modalities. The MV Imager is Electronic Portal Imaging Device (EPID) with As1000 (Amorphous Silicon Type Flat Panel).

2.2 Machine performance check application

The MPC Ver 1.1 is an automated application having predefined protocols for performing a set of daily QA tests on TrueBeam2.5 Linear Accelerator. The MPC bracket was used to firmly mount the IsoCalphantom to the couch top (Figure 1). The bracket was positioned at the notches (Blue Arrows) indicated on the bracket label. Accurate positioning of the phantom was ensured by three defined points touching the couch top (Red Arrows) (Figure 2).

The application consists of Hardware Part that is IsoCal Phantom (IsoCal Phantom Assembly B501687R01B1506679) and software part that is Desktop Application.

The IsoCal Phantom is a hollow cylinder of 23cm Outer Diameter & Inner Diameter is 19.6 cm and height 24.5+0.5 cm with 16 Tungsten-carbide spheres (of 4mm diameter) embedded on the surface of the phantom to form a standard geometrical pattern.

Configuration of MPC: This was the most important part of the MPC Setup. Prior to acquiring the FIRST MPC CHECKS, a reference couch position was set using IsoCal Phantom and Alignment of IsoCal phantom to the isocenter using the lasers and light field. Also, each Beam energy was measured with the help of Ion Chamber and thereafter it was acquired for each beam energy. The particular beam energy was selected and baseline was set. The baseline value was indicated by a gray icon. Future consistency test was compared against the baseline values.

For performing the QA, The IsoCal Phantom was fixed on Couch through a fixation assembly (Varian Phantom Holder Assembly P1000854004D1515) at predefined position according to a type of Couch (Type VARIAN IGRT Couch Top; Index Position Used is H2(Fig. 2). We checked the grooves on the IsoCal Phantom with Laser for any tilting with the Couch Top. It helps in Correct positioning and tilt free placement of IsoCal Phantom. The MPC software application was activated through TrueBeam2.5 Console Menu (Major Mode Screen) by clicking on the MPC Icon.

At the Initial Screen of the MPC application, the default energy was shown. In this case the Default Energy was 6MV Photon. After the prepare button was pressewd; the Collimator, Gantry and Imaging Devices – MV Imager and kV Imager started moving for deployment at Pre-Defined Position. The Couch moved out. It took about a minute to perform this step. After this the MPC was ready for QA.

As soon as Beam ON was pressed, the QA procedure was started. The total Monitor Unit (MU) delivered was 217 MU. The total images acquired were 40. These images were processed and analyzed with built in MPC software using pre-defined protocol and result was shown after the completion of QA procedure.

In total 28 MV Images and 12 kV Images were acquired. The first two images were related to beam profile check. The Third Image was related to MLC Check. The Image No 4 to Image 8 was related to beam center check. Afterwards the couch moves inside i.e. IsoCal is positioned below the Collimator. The image no. 9 to image no. 32 were taken in various positions of Gantry and Collimator. The image no 33 to image no. 40 were related to Couch Check. The couch was moved up in image no. 35 and No 36. In image no. 37 and 38, the Couch was moved lateral. Again, couch was brought to default lateral position. In image no. 39 and 40, the couch is rotated by 10° to take images.

This QA took less than five minutes to complete and thereafter the result was displayed on the monitor in the form of colored rectangular box. PASS (GREEN TICK) i.e. all the values are within threshold values, PASS BUT NEAR TOLERANCE (AMBER

TICK) i.e. pass of test with certain values are near to fail values and fAIL (RED TICK) i.e. Test has failed. The detailed result window was displayed with values calculated from measurement and threshold values on clicking the rectangular box.

The result was shown on the screen and was divided into the following Heading.

Isocenter An important characteristic of the radiotherapy machine is the position and size of the treatment isocenter. The isocenter is defined as the ideal intersection point of the beam central axis over a full gantry rotation. The isocenter is determined, in MPC, using the IsoCal geometric phantom, which is located in the beam during the check. The central beam axis, in MPC, is defined by the center of rotation of the highest priority collimating device that is the MLC.

The treatment isocenter was determined using acquisitions on eight representative gantry angles (0, 45, 90, 135, 180, 225, 270, 315)^0 IEC61217[(7)].

Size: The size of the treatment isocenter is defined as the maximum distance of a beam's central axis from the idealized isocenter.

Imager Projection Offset: 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.

Beam Consistency: The Beam Consistency is very important in Radiotherapy. MPC used EPID to evaluate beam consistency. This factor was relative in nature i.e. to say a baseline value has to be previously defined and checked and recalibrated at regular intervals.

The beam check was performed using an uncorrected, jaw-collimated, symmetric field size (18cm X 18cm) beam image at Gantry 0° (IEC61217). Thereafter, a Ratio Image was calculated between the baselines and the respective beam image on the day of check i.e. current Image with respect to the baseline image. To reduce the impact of jaw positioning, the beam characteristic output and uniformity are evaluated on an inner area of the field (13.3cm X 13.3cm).

The two values viz. output change and uniformity change were evaluated on the basis of ratio image. The output change represents the average percentage change in detector response in the central area of the image. The Uniformity change represents the total percentage change in detector response in the central area of the imager i.e. the variation between the two imager pixels with the lowest and highest ratios.

The Center Shift describes the relative shift of the field center, defined by a jaw-collimated field, with respect to the baseline values. The field center was established through detection of the jaw edges in the beam image. The center shift represents a summary value on the precision of the beam steering system, the collimation and MV imaging system.

Collimation: The positional accuracy of the collimation system was determined using static field evaluations at Gantry position 0° IEC61217.

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 (40 leaves only of each bank out of 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.

Jaws Offset (for Jaw X1, X2, Y1, Y2) was the distance of the jaw edges from the center of rotation of the MLCs were detected on a symmetric 18 cm field.

Rotation Offset of Jaw was the maximum deviation of the nominal versus actual collimator rotation angle observable through an MLC comb pattern acquired for five collimator rotation angles.

Gantry: The Absolute positioning accuracy was defined as the coincidence of the couch's vertical axis with the central beam axis at gantry 0° IEC61217.

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 (0, 45, 90, 135, 180, 225, 270, 315)^{0}IEC61217.

Couch: This tests the positioning accuracy of the available couch motions.

The Lateral menu describes the positioning accuracy of the lateral couch movement on a 5cm travel range (IEC 61217) positive direction (to the right).

The Longitudinal test describes the positioning accuracy of the longitudinal movement on 5cm travel range (IEC61217) negative direction (away from gantry).

The Vertical test describes vertical movement on couch axis on a 15 cm travel range (IEC61217) positive direction (upward). The Rotation menu describes the positioning accuracy of the couch on a 10° travel range (IEC61217) positive direction (top view Counter Clock Wise). Rotation Induces Couch shift describes the offset of the center of rotation determined through all available couch rotation axes from the treatment isocenter.

The MPC was done over the period of four months (84 days). The basis for selecting the four-month period is that every four month the Preventive Maintenance and Inspection (PMI) is done by the service engineer of VMS. Thus, as soon as PMI was done, the QA was started and continued up to next PMI.

Machine Output: The output of the TrueBeam was set to 1cGy=1MU for 6 MV photon energy at its respective d_{max} for a 10 cm X 10 cm field size. The machine output measurement of TrueBeam 2.5was performed every 15 days to check for any variation. A FC65-G Farmer Type Ion Chamber (S.No. 4146 Part No. DS04-000 supplied By IBA) of active volume 0.65 cm^3 with Dose 1 Electrometer (S. No. 22512 supplied By IBA) and Water Equivalent RW3 plate and Adapter Plate (S. No. 14750 Part No. DA74-000) supplied by IBA Dosimetry, Germany, was used for Machine Output Measurement [8].

The source to surface distance on top of the RW3 plate is 100 cm and the FC65-G chamber was inserted into the Adapter Plate such that it was at 10 cm depth. The results are tabulated in Table 3.

3 Results

The MPC everyday compared the values with the values acquired on day 1. The results were shown in terms of Mean Values and Standard Deviation. This was done because of the absolute values of some of the measured parameters were quite small (<1mm or <0.10°) and evaluating in terms of percentage will not provide correct interpretation [6].

The processed data is given in Table 1 - MPC report for 6 MV Photon Beam, Table 2 - MLC Leaf Shifting Bank A and Bank B. The trends are also shown in the graphical form, Figures 3, 4, 5, 6, 7, 8 and 9 for various Groups.

4 Discussion

The QA of the Linac is the important procedure in the radiation oncology center. In the MPC, for each parameter a base line value was used by the software to compare with the measured value. During Installation and Commissioning of the TrueBeam 2.5, the MPC Value for the isocenter was acquired as per Varian Medical System Protocol and served as the Benchmark for the MPC Values.

Before starting of the study, the output was measured. Thereafter, during the entire study period, the output of the TrueBeam 2.5 was never 'tuned' or adjusted. But output of the TrueBeam 2.5 was measured regularly and the results revealed that it was within tolerance as per TRS398 [8] protocol.

Gao et al. (2014) [4] evaluated the accuracy and reproducibility of the IsoCal Geometric Calibration System for different Varian Medical Systems C – Series Linac equipped with On Board Imager (OBI) and EPID using Collimator Plate and IsoCal Phantom. The authors found that unlike other phantom based calibration methods e.g. Varian Cube and Winston Lutz Method, the IsoCal Calibration method does not require the phantom center to be positioned exactly at the treatment isocenter or mechanical Isocenter, instead, the IsoCal algorithm determines the treatment isocenter and calculates the distance between the treatment isocenter and the IsoCal Phantom center, thereby eliminating setup error.

Li, Y et al. (2018) [9] compared the usage of MPC on Halcyon and TrueBeam. Authors also compared MPC with IC profiler results by introducing intentional errors. The authors observed that if the MPC test was failed, Halcyon prevented the treatment. But this type of mechanism was absent in TrueBeam that is treatment can be delivered even if MPC fails.

The alignment of the On-Board Imager (OBI) X-ray tube is important for ensuring imaging to treatment isocenter coincidence, which in turn is important for accurate Image Guided Radiation Therapy (IGRT). Barnes et al. (2018) [10] evaluated OBI X-Ray tube alignment procedure in relation to MPC. The authors discussed the new procedure and examined the clinical significance of X-Ray tube misalignment. The MPC method was found to have high repeatability and to be quick and easy to setup, fast to perform and precise. Therefore authors recommended MPC as the preferred method of X-Ray tube alignment for Varian Medical Systems engineers.

Clivio et al. [5] in their study used the Pre-Release Version of MPC with TrueBeam 2.0 using all the energies available that is 6, 10 and 15MV and 6 and 10 MV FFF beams. It was not clear why authors performed Geometric Checks separately for each energy. The authors used the independent checks, to verify the results obtained. The authors mentioned in their paper that this is not intended to be one to one test relative to MPC, but want to compare and discuss two different methodologies for checking the Linac performance. Clivio et al performed for 10 repetitions. In the MPC prerelease version acquisition consists of a set of 39 images. For Beam consistency checks, authors used PTW StarCheck.

Bhatt et al. [6] reported 39 Planar Images and used 6MV photon beam for their MPC. Authors used F65 (most Probable FC65, C may be typo error) with Dose 1 electrometer and solid phantom (SP33). As compared to the Clivio et al. [5],Bhatt et al. [6] performed a very long term consistency of MPC for 195 days spread over 10 months.

In the present study, Geometric Checks are related to default energy and predefined acquisition that consists of 40 images.

Isocenter: 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 2.5, 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 (±0.5mm) then the isocenter test should be verified by independent sources.

Clivio et al.[5] obtained isocenter size (mm) for 6MV, 0.34±0.01,whereas Bhatt et al.[6]obtained 0.384±0.011. In the present study, isocenter size by MPC method is 0.35±0.02 which is within the range of two studies.

Clivio et al.[5] obtained 0.17±0.03mm and 0.32±0.02mm for MV and kV imager projection offset. The corresponding values in the present study were 0.17±0.05mm and 0.24±0.04mm. The values are in close agreement with values obtained by Clivio et al. Further, a low value is important for matching as well as essential for CBCT image quality.

Beam Consistency Check: The Beam Consistency checks for the present study are reported in Table 3 as the mean values of the 9 repetitions where as Standard Deviation represents the uncertainty in measurement.

Clivio et al.[5], for 6 MV Photon beam reported the following value for the Beam Output Change 0.15±0.13 with MPC, 0.40±0.40 with independent verification, whereas Bhatt et al.[6],in (2017) reported the following value in with 0.228±0.449 with MPC,-0.315±0.514 with independent verification. In the present study, for 6 MV Photon the corresponding values are 0.83±0.71 with MPC, 1.18±0.33 with independent verification. The values obtained in the present study are within tolerance. But as compared with Clivio and Bhatt, the values were on the higher side. We should cross verify the same using some other QA device or Ionisation Chamber to find the reason for the same as Armoogum K et al.[11] reported in 2018. Armoogum K et al.[11](2018), studied the long term stability of the TrueBeam 2.5 with MPC for a year (279 days data). Authors performed beam consistency check for 6MV and 10MV photons. The independent verification of beam output was done with Farmer Type Ionization Chamber in solid Water. The authors performed independent check using Sun Nuclear daily check QA3 device. Authors reported that MPC consistently measures the output lower (-1.08%) than the QA3 device. Whereas QA3 and Farmer Chamber Output are almost same. Also, MPC with Farmer difference -1.26%. Authors tuned the output thrice to bring TrueBeam Machine under tolerance measurement.

For 6 MV Photon, the values reported by Clivio et al.[5] for beam uniformity was 0.77±0.20, while Bhatt et al.[6] reported the value 0.914±0.360. In the present study, the corresponding values was 0.40±0.11. As compared to the value obtained by Clivio et al[5] and Bhatt et al.[6] this value is more towards the base line value.

For Center Shift using MPC, Clivio et al.[5] reported the value of 0.04±0.02, Bhatt et at 0.147±0.072. The values obtained in the present study for Center Shift is 0.15±0.04 which was in close agreement with the values obtained by Bhatt et al.[6]

Collimator: For 6MV, MLC Max Offset Values for Bank A, Bank B using MPC reported by different studies are -0.35±0.03 mm, 0.44±0.02 mm (Clivio et al.[5]), -0.231±0.036 mm, 0.531±0.020 mm (Bhatt et al.[6]). The value obtained in the present study is -0.27±0.02 mm, -0.18±0.03 mm respectively. As we observe for Bank A MLC Max Offset values are in close range of Clivio et al.[5] values whereas for Bank B MLC Max Offset values are near to benchmark values.

The Collimator Jaws X1, X2, Y1, Y2 values obtained by different studies using MPC are 0.01±0.01, 0.06±0.02, -1.02±0.05, 0.87±0.04 mm (Clivio et al[5]), -0.008±0.027, 0.615±0.021, -0.352±0.017, 0.260±0.084 mm (Bhatt et al[6]), -0.80±0.06, -0.73±0.03, 0.18±0.06, 0.26±0.05 mm in the current study.

For MLC leaves, Clivio et al.[5] confirmed the accurate leaf positioning and its consistency. The independent checks for MLC positioning showed no detectable deviation. Table 2 shows shift not larger than 0.5mm in the present study which is in close agreement with Clivio et al.[5] The maximum offsets of the leaf bank A and bank B were also within the tolerance values.

Clivio et al.[5] discussed the limitation of MPC regard to MLC and Jaw Offsets. According to authors Single Comb like pattern is not providing enough data to evaluate the MLC and Jaw Offset. At least bigger field size, another circular pattern, and collimator rotation will provide the better result for evaluation was required for better study.

The Gantry's positional accuracy were -0.09±0.02°, 0.08±0.0° (Clivio et al.[5] and -0.106±0.018°, 0.051±0.056° (Bhatt et al.[6])for Absolute and Relative movement of gantry respectively. The value obtained in the present studywere-0.13±.02°, -0.14±.0°. The measured values are in range as obtained by different authors.

The Couch movement accuracy were -0.06±0.02, 0.14±0.02, -0.34±0.01, 0.00±0.01, 0.37±0.02 reported by Clivio et al.[5] whereas Bhatt et al[6]reported 0.014±0.030, 0.001±0.023, -0.012±0.038, 0.089±0.007, 0.261±0.041 for Couch lateral (mm), longitudinal (mm), vertical (mm), rotation (in degree) and rotation induced couch shift movement (mm). In addition, because of additional facility of 6DOF Couch (6 Degree of Freedom Couch supplied by VMS) the Couch Pitch, and Couch Roll movement were -0.024±0.006° and -0.035±0.007° respectively. The value obtained in the present study are 0.05±0.06 (mm), 0.14±0.04 (mm), 0.12±0.03 (mm), 0.12±0.04 (degree °), 0.06±0.02 (mm) in lateral, longitudinal, vertical, rotation and rotation induced couch shift respectively. The measured values in the present study were in range as obtained by different authors.

5 Conclusion

From the present study, we conclude that MPC though it takes less time to set, easy to use and provide reproducible data but the variation in output as compared with Farmer Chamber Measurements require attention. Thus, in addition to MPC, regular measurement with Farmer Type Chamber is recommended on regular basis. Third Party QA Tools if available should be used in conjunction with MPC to understand the results better.

Conflict of Interest

The authors declare that they have no conflicts of interest. The authors alone are responsible for the content and writing of the paper. No Financial Aid or Grant is received for from any Institution for conducting this study.

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Appendix

Table 1. MPC report for 6MV photon

Area	Parameter	Value (Mean±S.D)	Threshold Value
Isocenter	Isocenter Size [mm]	0.35± 0.02	±0.50mm
	Isocenter MV Offset [mm]	0.17±0.05	±0.50mm
	Isocenter kV Offset [mm]	0.24±0.04	±0.50mm
Beam	Output Change [%]	0.83±0.71	±2.00%
	Uniformity Change [%]	0.40±0.11	±2.00%
	Center Shift [mm]	0.15±0.04	±0.50mm
Collimator	MLC Max Offset A [mm]	-0.270±0.02	±1.00 mm
	MLC Max Offset B [mm]	-0.18±0.03	±1.00 mm
	MLC Mean Offset A [mm]	-0.16±0.02	±1.00 mm
	MLC Mean Offset B [mm]	0.06±0.02	±1.00 mm
	Jaw X1 [mm]	-0.80±0.06	±1.00 mM
	Jaw X2 [mm]	-0.73±0.03	±1.00 mm
	Jaw Y1 [mm]	0.18±0.06	±2.00 mm
	Jaw Y2 [mm]	0.26±0.05	±2.00 mm
	Rotation Offset [°]	-0.80±0.06	±0.50°
Gantry	Gantry Absolute [°]	-0.13±0.02	±0.30°
	Gantry Relative [°]	-0.14±0.01	±0.30°
Couch	Lateral [mm]	0.05±0.06	±0.70 mm
	Longitudinal [mm]	0.14±0.04	±0.70 mm
	Vertical [mm]	0.12±0.03	±1.20 mm
	Rotation [°]	0.12±0.04	±0.40 °
	Rotation Induced Couch Shift [mm]	0.06±0.02	±0.75 mm

Table 2: MLC leaves

MLC Leaf No.	MLC Bank A Value (Mean±S.D) mm	MLC Bank B Value (Mean±S.D) mm	Threshold Value
11	-0.14±0.02	-0.16±0.03	±1.00 mm
12	-0.22±0.02	0.08±0.02	±1.00 mm
13	-0.10±0.02	-0.14±0.02	±1.00 mm
14	-0.26±0.02	0.01±0.02	±1.00 mm
15	-0.14±0.02	-0.17±0.03	±1.00 mm
16	-0.21±0.02	0.06±0.02	±1.00 mm
17	-0.12±0.02	-0.14±0.02	±1.00 mm
18	-0.21±0.02	0.03±0.02	±1.00 mm
19	-0.19±0.02	-0.17±0.03	±1.00 mm
20	-0.21±0.02	0.04±0.02	±1.00 mm
21	-0.11±0.02	-0.15±0.03	±1.00 mm
22	-0.27±0.02	-0.02±0.02	±1.00 mm
23	-0.12±0.02	-0.18±0.03	±1.00 mm
24	-0.24±0.02	0.05±0.03	±1.00 mm
25	-0.08±0.02	-0.15±0.02	±1.00 mm
26	-0.22±0.02	0.02±0.02	±1.00 mm
27	-0.12±0.02	-0.17±0.03	±1.00 mm
28	-0.23±0.02	0.02±0.03	±1.00 mm
29	-0.10±0.02	-0.14±0.02	±1.00 mm
30	-0.24±0.02	0.00±0.02	±1.00 mm
31	-0.13±0.02	-0.17±0.02	±1.00 mm

Continued on next page

Table 2 continued

32	-0.23±0.02	0.02±0.02	±1.00 mm
33	-0.07±0.02	-0.15±0.02	±1.00 mm
34	-0.21±0.02	0.02±0.02	±1.00 mm
35	-0.15±0.02	-0.16±0.03	±1.00 mm
36	-0.21±0.02	0.00±0.02	±1.00 mm
37	-0.11±0.02	-0.16±0.02	±1.00 mm
38	-0.23±0.02	-0.02±0.02	±1.00 mm
39	-0.12±0.02	-0.16±0.02	±1.00 mm
40	-0.16±0.02	0.04±0.03	±1.00 mm
41	-0.06±0.02	-0.13±0.02	±1.00 mm
42	-0.22±0.02	0.01±0.02	±1.00 mm
43	-0.10±0.02	-0.13±0.03	±1.00 mm
44	-0.17±0.02	0.05±0.02	±1.00 mm
45	-0.06±0.02	-0.14±0.02	±1.00 mm
46	-0.17±0.02	0.01±0.02	±1.00 mm
47	-0.06±0.02	-0.12±0.02	±1.00 mm
48	0.15±0.02	0.07±0.02	±1.00 mm
49	0.01±0.02	-0.09±0.02	±1.00 mm
50	-0.16±0.02	0.07±0.02	±1.00 mm

Table 3. Output measurement

Output measurement method	Clivio et al Mean ±S.D.	Present study Mean ±S.D.	Threshold Value
Ion chamber	0.40±0.40	1.18±0.33	±2.00%
MPC	0.15±0.13	0.83±0.71	±2.00%

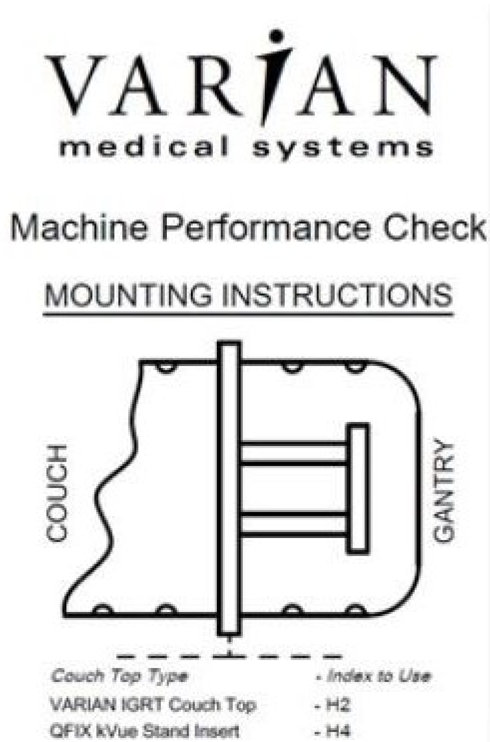

Fig 1. Positioning the IsoCal Phantom

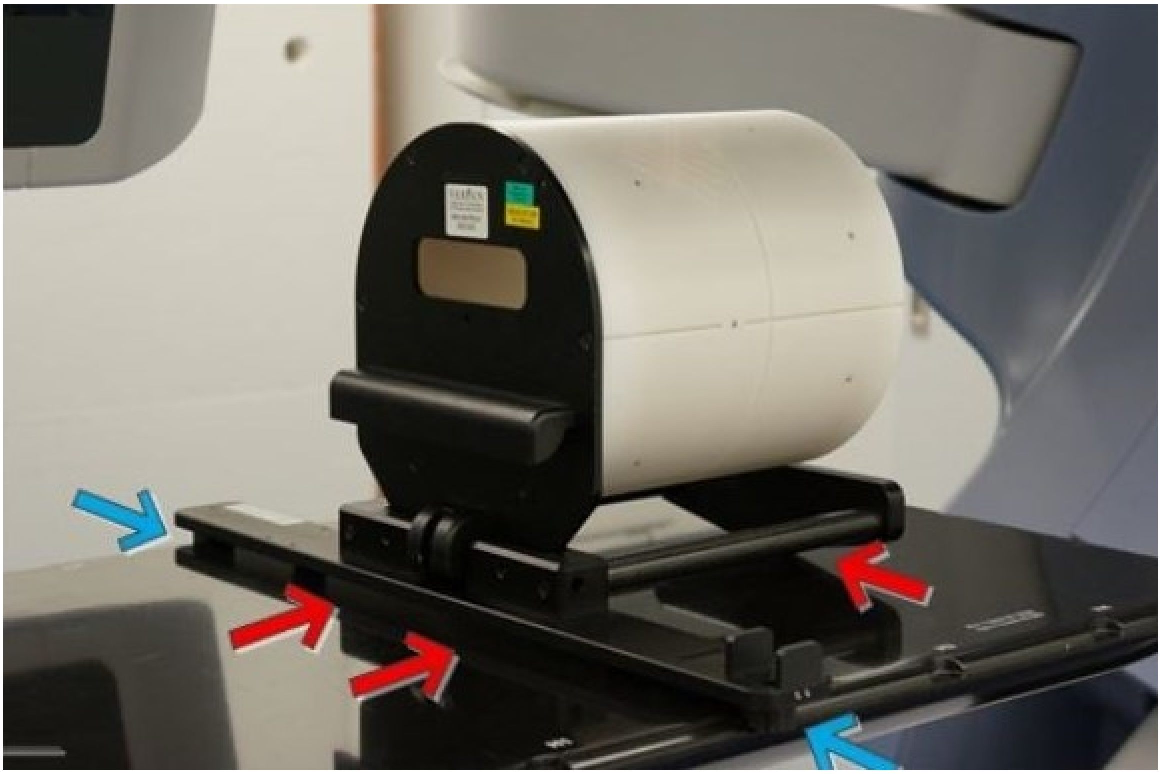

Fig 2. Mounting the IsoCal Phantom

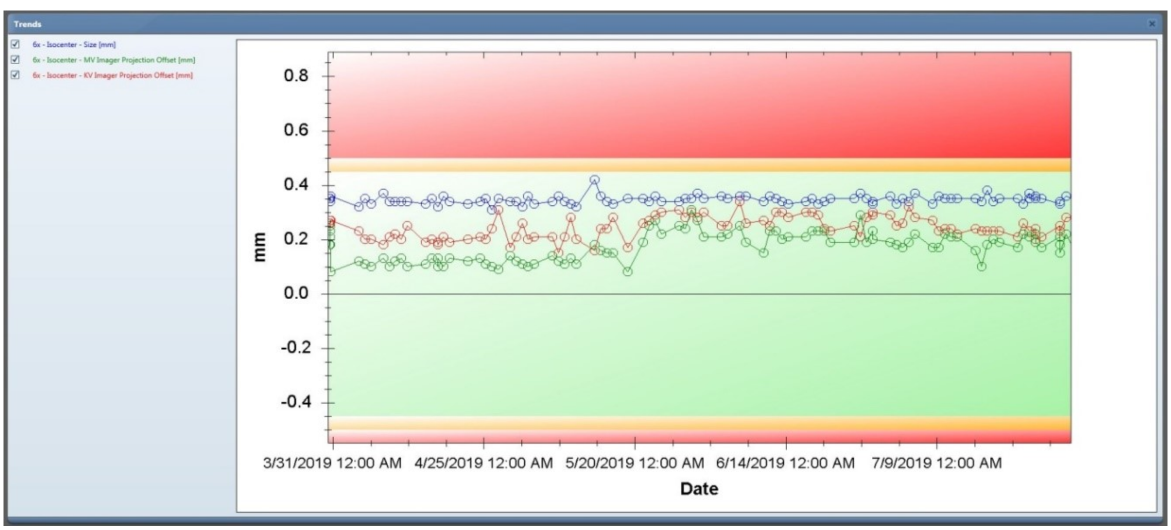

Fig 3. Data trends – isocenter group

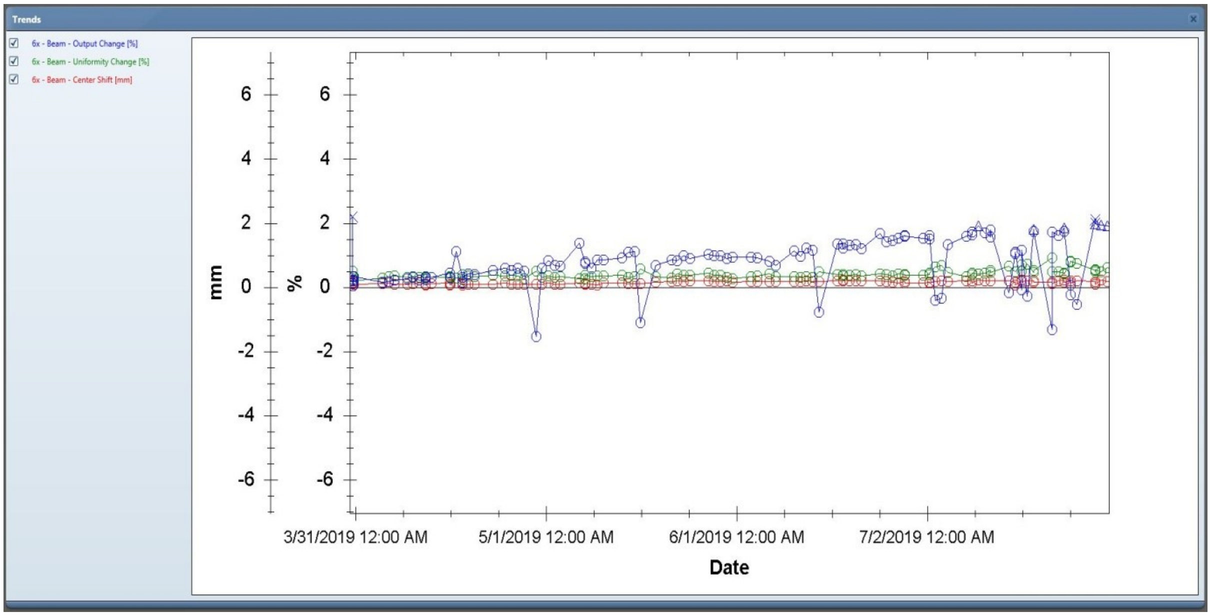

Fig 4. Data trends – beam measurement group

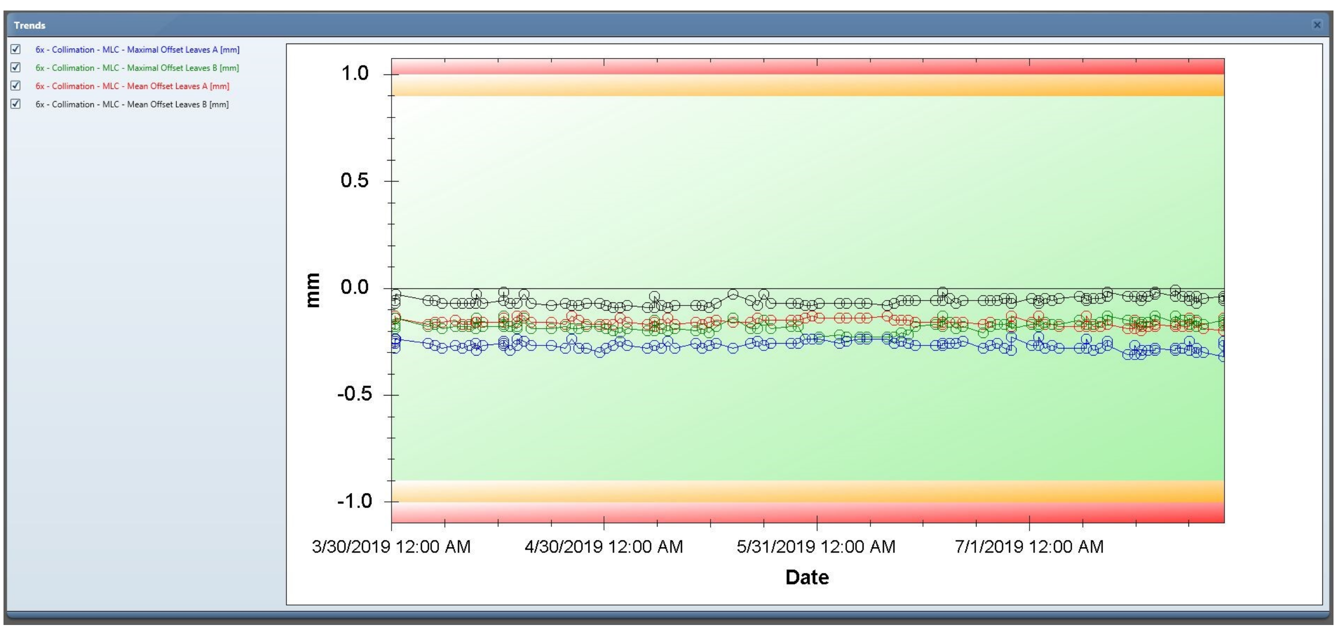

Fig 5. Data trends – Collimation MLC group

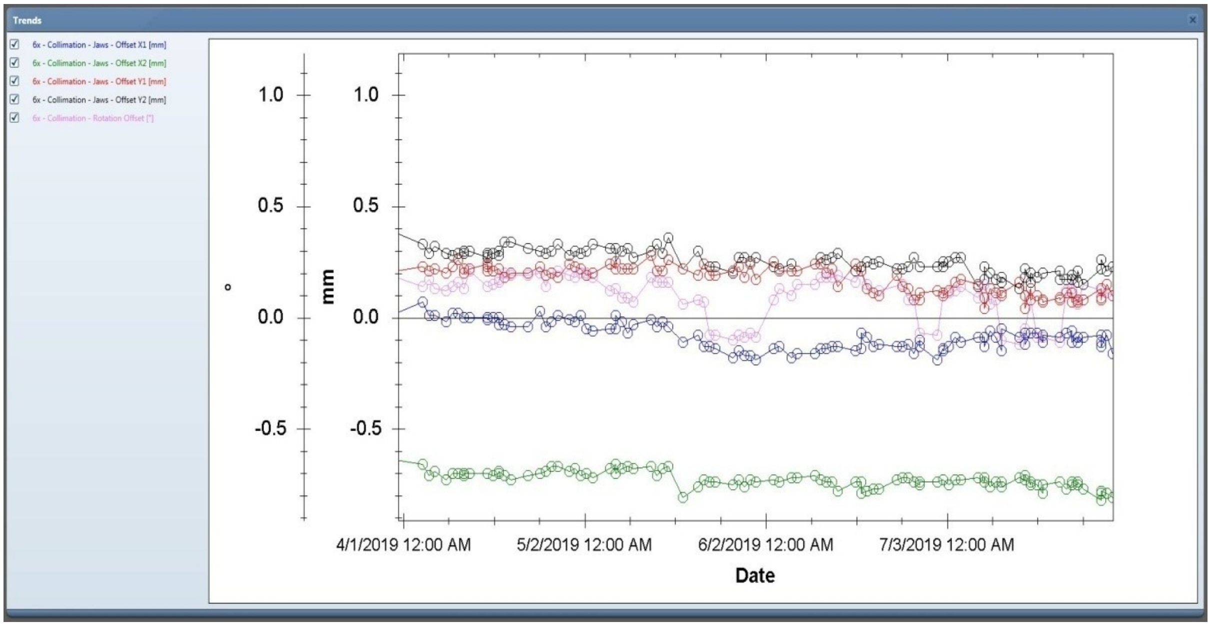

Fig 6. Data trends – Collimation Jaws Group

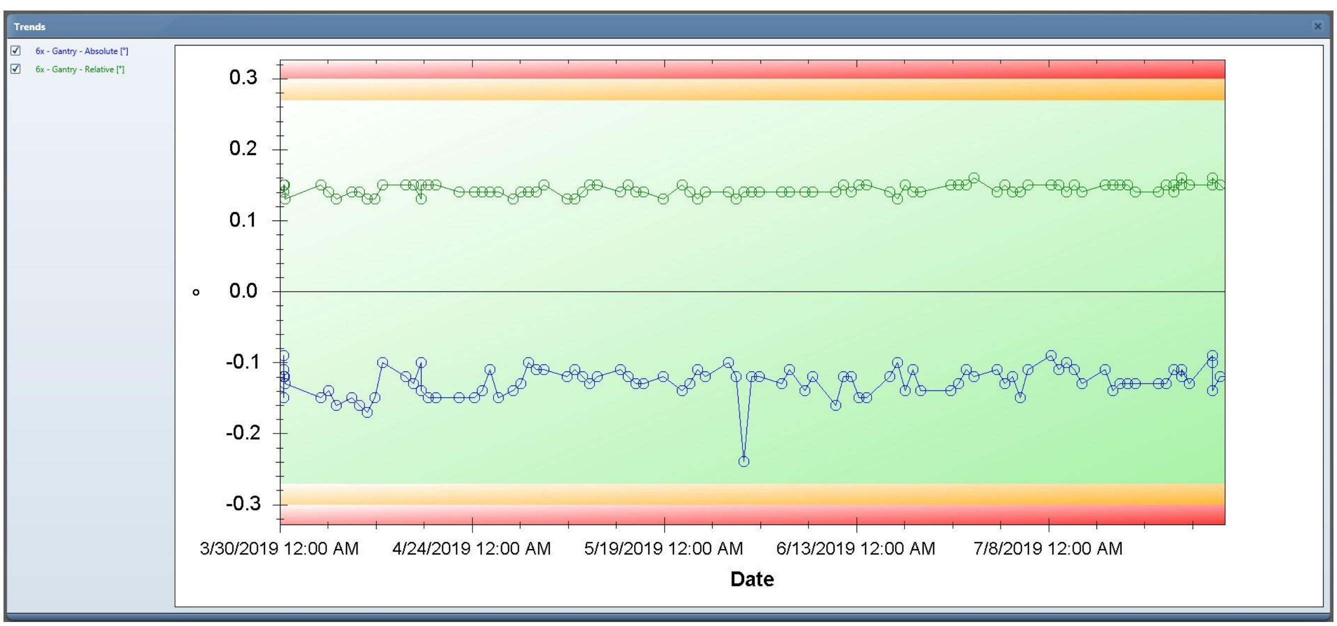

Fig 7. Data trends - gantry

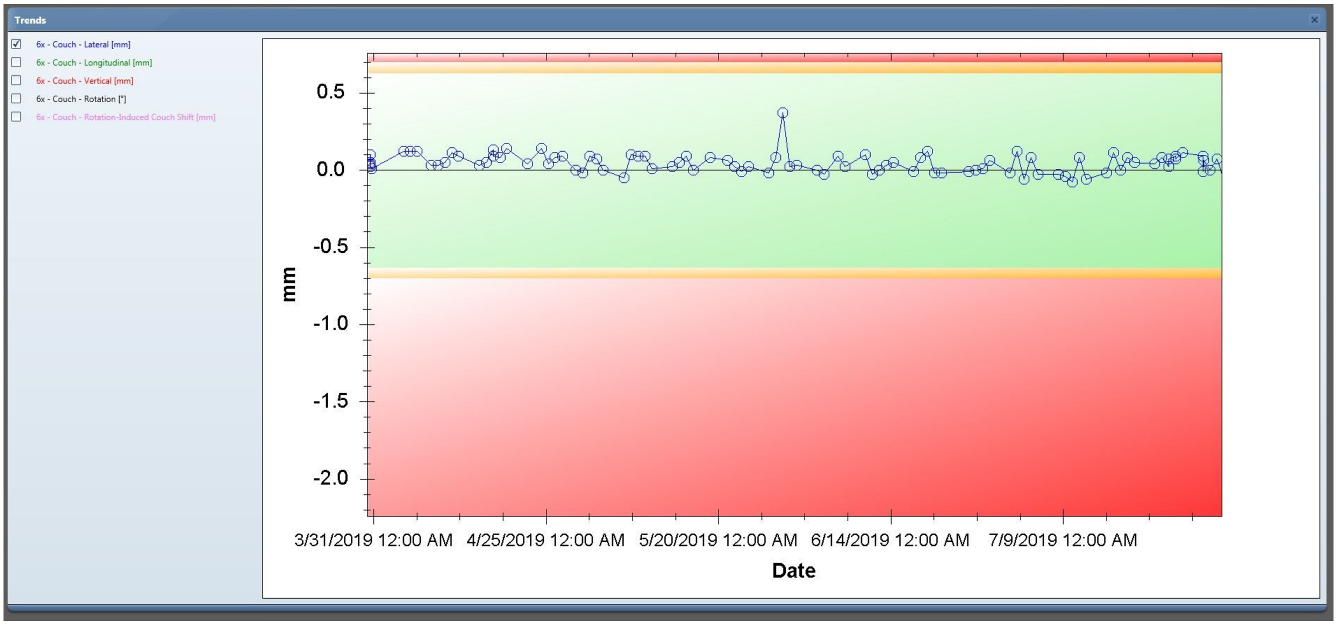

Fig 8. Data trends – couch lateral movements

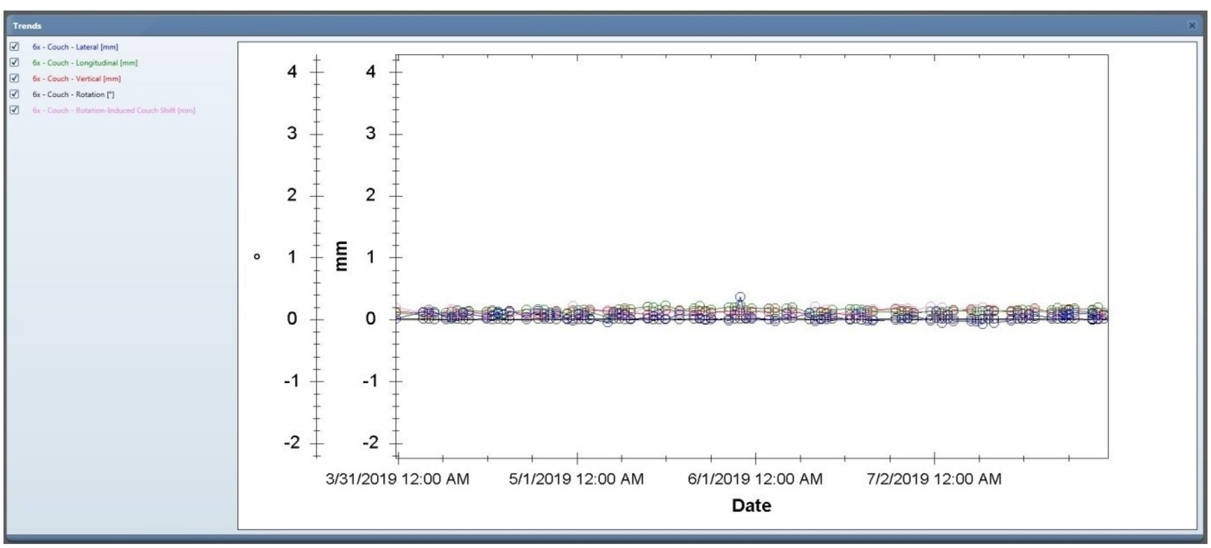

Fig 9. Data trends - COUCH