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# A preliminary investigation on long-term consistency of MPC as a quick daily QA application

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*Technical Report*

## Abstract

**Purpose:** The purpose of this study was to establish Machine performance check (MPC) application as a comprehensive daily QA program in a clinical setting for a True Beam 2.0 system and investigate the first ten months (195 days) daily QA data generated by the MPC. **Methods:** An automated daily quality assurance (QA) application named machine performance check (MPC) was recently launched by Varian Medical Systems with their TrueBeam 2.0 linear accelerator (linac) system. MPC performs all the essential machine tests such as Beam Constancy Check, and Geometry Check with the use of an IsoCal phantom. There is no systematic published study on long-term consistency and validation of MPC in a clinical set-up for its acceptance as an alternative QA application. In the present study, we collected data with the MPC for over ten months (195 days) on a TrueBeam 2.0 system. The data was analysed for reproducibility and also compared with the data collected with other statndard QA devices at the time of commissioning of the TrueBeam system for validation. **Results:** The results showed that the reproducibility of MPC was at least an order of magnitude less than the tolerance values for the respective parameters and also the average measured values for all QA parameters studied. The MPC measured isocenter accuracy, and output values were close to the Winston-Lutz test (within 0.1 mm) and the ion-chamber measurements (within 0.1%), respectively. **Conclusion:** With our long term result, it is evident that the MPC could be an alternative daily QA tool. A comprehensive and long-term validation of the MPC measured values with the other standard QA methods over the ten month period will be needed before accepting MPC as a reliable QA tool.

**Keywords**: Radiotherapy, Machine Performance Check (MPC), TrueBeam 2.0, Linac QA

## 1. Introduction

In recent times a trend towards increasing use of complex dose delivery technologies such as volumetric modulated arc therapy (VMAT), flattening filter free (FFF) photon beams and on-board imaging (OBI) in modern radiotherapy centers has been witnessed. Coupled with the increase in hypo-fractionation protocols, there is a need for greater emphasis on more elaborate, and frequent quality assurance (QA) tests to ensure that the radiotherapy equipment is functioning consistently within the stated specifications. Needless to say, the tools required to implement such QA protocols should be convenient, quick and efficient. To achieve these objectives innovations have continued in QA hardware and software technologies for their wider acceptability in clinical set-ups.

An automated QA application tool named machine performance check (MPC) was introduced by Varian Medical System with their linear accelerator (linac) TrueBeam 2.0 in 2015 for clinical use. The MPC utilizes the kV and MV imaging of the linac system along with a well-established phantom (IsoCal) to perform a set of QA tests and present the results in a simple 'pass/fail' form. The recommendations of the American Association of Physicists in Medicine (AAPM) task group report 142 (TG 142) have been the basis for setting up

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the QA tests within the MPC application.[1,2] The MPC is meant for a reliable and fast system testing on a daily basis before commencing patient treatment with modalities such as intensity modulated radiotherapy (IMRT), VMAT, stereotactic radiotherapy (SRT) and stereotactic body radiotherapy (SBRT) on the treatment delivery platform.

There is a lack of literature on systematic long-term consistency evaluation and validation of the MPC in a clinical environment. Clivio *et al*. used a pre-release MPC version and performed the QA sequences on a Varian Research Beam functionality for ten repetitions (10 days).[3] We decided to systematically study the long-term performance of the clinical MPC version 1.0 MR1 on a recently commissioned TrueBeam 2.0 system. We evaluated the reproducibility of the acquired data for both dosimetric and mechanical test parameters for 195 days, spread over ten months and also compared MPC results with standard QA methods such as the Winston-Lutz for isocentric accuracy test at the time of commissioning and ion-chamber measurements for dose output on weekly basis of the TrueBeam system. We believe that our study carried out over a period of ten months in a clinical environment will help the other users to integrate the MPC in their daily QA programme with increased confidence. However, being a preliminary study the emphasis was mainly on long-term reproducibility of the results and also on ease of integration of the MPC with the departmental workflow. In the next phase of our work, we plan to validate all the MPC measured parameters with the other well-established methods over a longer period as per availability machine time in a busy clinical department.

## 2. Methods and Materials

### 2.1. TrueBeam 2.0

The TrueBeam Version 2.0 linac system with the MPC application is manufactured and supplied by Varian Medical Systems (Palo Alto, USA). The linac provides three flat and two flattening filter free (FFF) photon beam energies. It is equipped with a multileaf collimator (MLC) with 120 leaves (millenium MLC). The MLC has central 40 leaf pairs with leaf width of 0.5 cm and outer 20 pairs with leaf width of 1.0 cm at isocenter covering a field size from 0.4 × 0.4 $cm^2$ to 40 × 40 $cm^2$. The linac system has kV and MV imaging features using amorphous silicon type flat-panels. The kV imaging includes fluoroscopy and cone beam CT (CBCT) features. The Linac couch has 6-degrees of freedom namely three linear and three rotational. For additional technical specifications of the TrueBeam 2.0 system, one may refer to the relevant Varian technical catalogues.[4,5]

### 2.2. The Machine Performance Check (MPC) Application

The MPC is an automated application having pre-defined protocols for performing a set of daily QA tests. The sequence of measurements within the MPC application is initiated from the desktop of the linac console workstation. IsoCal phantom, also from Varian, is utilized to perform some of the QA tests included in the MPC protocol. The Phantom is a hollow cylinder of 23 cm diameter and height with 16 tungsten-carbide spheres (of 4 mm diameter) located in a known geometrical pattern on the surface of the phantom.[6] After mounting the IsoCal phantom on the linac couch-top using the indexing system of the couch, the MPC QA procedure needs to be activated from the TrueBeam console menu using the displayed MPC icon. The couch then moves to a known position as per the protocol, and this position is used as a reference position for the all the tests. The MPC application software lists all the scheduled checks to be performed during the session and displays instructions to be followed in a sequence. Once the photon beam energy for the tests is selected, the kV and MV detector panels get deployed at the pre-defined positions. With the switching on of the selected photon beam, the data acquisition in terms of kV and MV planar images starts for various combinations of the gantry, couch and collimator angles and field size settings.[7-10] The acquired images are instantaneously processed and analyzed for the dosimetric and geometric QA parameters.

A total of 39 planar images, both the MV and the kV ones, are acquired as per the pre-defined MPC protocol for analysis with the built-in MPC software. Of the 39 images, 12 are acquired using the kV imager with the IsoCal phantom and 27 are with the MV imager. The initial 8 MV images of the 27 images are without the IsoCal Phantom, and the rest are acquired after mounting the phantom on the couch. The first five of these MV images are utilized for beam center check and the sixth and seventh ones are for beam profile check and beam profile ratio, respectively. Four kV images acquired at gantry angle 0° and four MV images at gantry and collimator angles 0° each with the IsoCal phantom are used for the couch check. Another set of eight kV images at gantry angles 360°, 45°, 90°, 135°, 180°, 315°, 270° and 225° is acquired with the IsoCal phantom for kV isocenter measurement and a series of MV image pairs (08) at gantry angles 360°, 45°, 90°, 135°, 180°, 315°, 270° and 225° and collimator angles 0° and 90°, is acquired with the IsoCal phantom for treatment isocenter and gantry position measurement. A total of 247 MUs are delivered during the entire MPC procedure, and the procedure takes approximately 5 minutes for one photon energy. We carried out the study with 6 MV photon beam, and the data was collected for a period of ten months (195 days). The MPC QA procedure, which can be divided into two categories namely dosimetry checks and geometry checks, is described below:

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### 2.2.1. Dosimetry checks/beam consistency checks

These checks are performed with a field size of 18 × 18 $cm^2$ at 0° gantry angle utilizing a fixed number of monitor units (32 MU) without the IsoCal phantom. The planar image obtained is compared with the baseline image acquired at the time of commissioning of the linac system to estimate the deviations of various dosimetric parameters. To reduce the impact of the jaw positioning uncertainty (a geometric parameter) on the beam dosimetric parameters, the latter are estimated for an inner area of the field (13.3 × 13.3 $cm^2$) at the isocenter wherever necessary. MPC uses the high-quality MV imaging mode for acquisition, and this imaging mode is calibrated at the time of commissioning, and routinely on a monthly basis, otherwise an error message is displayed. For the beam constancy check MPC acquires a dark field and retrieve the pixel defect map, both are applied to the raw MV image. The EPID was also dosimetrically calibrated before the using MPC at the time of commissioning.

#### 2.2.1.1. Output change

It represents the average percentage change with respect to the baseline value in the detector response in the central area of the imager. As the present day electronic portal imaging device (EPID) technology has become robust and stable, the estimated output values for photon energies with it are assumed to be influenced primarily by changes in the beam characteristics.[11-14]

#### 2.2.1.2. Radiation field uniformity change

The uniformity of a photon beam is conventionally estimated from the transverse beam profiles. However, in the case of a 2D portal image, the beam uniformity is defined as the ratio of the maximum and minimum pixel intensity values observed in the inner area of the field. The change in radiation field uniformity represents the percentage variation of uniformity between the current and the baseline value. While estimating beam uniformity, the high-frequency noise is filtered.

#### 2.2.1.3. Center shift

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

### 2.2.2. Geometry checks

The geometry checks evaluate the positioning accuracy of the various mechanical axes of the TrueBeam system.

#### 2.2.2.1. Isocenter

The isocenter is defined as the ideal intersection point of the beam's central axis over the full gantry rotation. The central axis in the MPC application is defined by the center of the rotation of the highest priority collimating device, i.e. the MLC. The treatment isocenter is determined from the data acquisitions on eight representative gantry angles namely 45°, 90°, 135°, 180°, 225°, 270°, and 315°. The size of the treatment isocenter is defined as the maximum distance of the beam's central axis from the idealized isocenter.

#### 2.2.2.2. MV and kV imager offsets

The imager projection offset represents the maximum distance of the imager center from the projection of treatment isocenter localized with the help of the lead balls placed on the IsoCal phantom. A low value of imager offsets is important for CBCT image quality and image matching during IGRT process.

#### 2.2.2.3. Collimator

The positional accuracy of the collimation system is determined from the static field evaluation at 0°gantry position. The position of the individual collimator jaws is defined as the line along the edge of the steepest gradient on the acquired MV images. The jaw offset values are measured as the distance of the jaw edges from the center of rotation of the collimator, i.e., the collimator isocenter.

#### 2.2.2.4. MLC

For positional accuracy measurements of the MLC, a static comb-like pattern is acquired on the MV imager at 0° collimator and gantry angles. The positional accuracy of each MLC leaf is measured as the distance of the MLC leaf tip from the MLCs center line from this irradiation pattern. The center line is defined as the line through the center of rotation of the MLC that is perpendicular to the edges of the leaves. The leaf-banks A and B of the central 40 MLC leaf pairs alone are analyzed with the MPC. These leaf-pairs are the maximum utilized leaves for treatment delivery. The maximum and mean offset values are estimated for these two leaf-banks. Also, the rotational offset of the MLC that is defined as the maximum deviation of the nominal versus the actual collimator rotation angle observable through the edges of the MLC leaves is estimated.

#### 2.2.2.5. Gantry

The MPC evaluates two characteristics of the machine gantry positioning system namely absolute and relative errors. The absolute positioning accuracy is defined as the coincidence of the couch vertical axis with the central beam axis at 0° gantry angle. By moving the couch along its vertical couch axis, the MPC evaluates any lateral or longitudinal shift of the phantom with respect to the beam, and the treatment isocenter is recorded as the absolute gantry angle positioning error. For the relative accuracy, the angle of the gantry is evaluated as defined by MV imaging system using the geometric phantom. The relative positioning error of the gantry is the maximum offset between the angle determined by the MV imaging system and the nominal gantry angle. The values are compared for eight

representative gantry angles namely 45°, 90°, 135°, 180°, 225°, 270°, and 315°.

#### 2.2.2.6. Couch

The MPC measures the positioning accuracy of the different couch axes with respect to a reference position. The reference position is established in the fixed room coordinate system using the MV and kV images with the IsoCal phantom, and the actual travel range of the couch axes is determined in this reference system. The positional accuracies in all the directions namely lateral (5 cm), longitudinal (5 cm), vertical (15 cm), rotational (10°), pitch (3°) and roll (3°) are checked within the travel ranges mentioned in the brackets. The 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.

### 2.3. Defining the baseline values

At the time of machine commissioning all the geometric and dosimetric parameters of the TrueBeam 2.0 system were measured as per the laid down procedures with standard QA methods such as the Winston-Lutz for isocentric accuracy test, ion-chamber measurements for dose output, MLC positioning accuracy with picket fence test, and geometric accuracy of collimator etc. Simultaneously, corresponding parameters were also measured with the MPC for use as baseline values.

### 2.4. Evaluation of reproducibility

The reproducibility of the MPC application for each of the measured parameter over a period of ten months (195 days) was evaluated in terms of standard deviation. It was felt that because of the absolute values of some of the measured parameters, especially the geometric ones were quite small (< 1 mm or < 0.1°), stating the reproducibility in the usual percentage terms may not represent a meaningful interpretation relevant to actual radiotherapy delivery in clinics. Therefore, reproducibility of the MPC data was analyzed and discussed in terms of absolute or relative values as per the clinical relevance of each parameter value.

### 2.5. MPC response to machine output variation

An F65 Farmer-type ion chamber of active volume 0.65 $cm^3$ with Dose-one electrometer and a solid (Perspex) plate phantom (SP33), all from IBA Dosimetry System (Schwarzenbruck, Germany), were used for output measurements. The source to surface distance (SSD) was kept at 100 cm, and the ion chamber was placed at a depth of 10 cm. The output of the machine was set to 1 cGy = 1 MU for each photon energy at its respective $d_{max}$ for a 10 cm × 10cm field size. This output test of the linac system was performed with the 15 MV photon beam. The output was varied in 11 steps of known step size (± 0.5 % of the monitor gain) in the service mode. The first five steps decreased the output from 0 to -2 %; the next five increased it from 0 to + 2 % and the last (11th) step was at the initial value (0 %). The changes in the linac output thus carried out were measured with the ion chamber and the MPC methods.[15-16]

## 3. Results

The QA data measured and analyzed with the MPC was finally displayed as 'pass' or 'fail' for each parameter in a tabular form. The data was depicted in graphical form as well. The display included a warning, in red for fail and in yellow for near to fail, for a test parameter that exceeded the pre-set threshold (tolerance) value. Tables 1 and 2 show the results of the data collected over a period of ten months (195 days) for the geometric and dosimetric parameters, respectively, for a 6 MV photon beam. The trend is also shown graphically in figure 1. It may be noted that for any test involving IsoCal phantom, if the phantom was incorrectly fixed and moved during couch motion on the table-top, it may cause incorrect MPC test result. Thus an erroneously fixed phantom may influence the final measured values, so IsoCal phantom must be affixed firmly enough that it does not move during the test. Figure 2 shows the output changes (%) measured with the ion-chamber and the MPC.

## 4. Discussion

### 4.1. Geometric Checks

As seen in Table 1, the average isocenter size measured with the MPC for the ten month study period is comparable with the independently measured value using Winston-Lutz test carried out with the help of Isolock software tool provided by Varian. It may be mentioned here that the Winston-Lutz test was performed at the time of acceptance testing of the linac system. The MPC value for the isocenter estimated on the same day as the Winston-Lutz test, therefore, served as a benchmark for the following MPC values. The MV and kV isocenter offset values also passed the tests. Gao *et al*. carried out a detailed study of the geometric calibration with IsoCal phantom using OBI and EPID imaging systems (IsoCal test) and compared their results with a simplified Winston-Lutz based test and a Varian cubic phantom based test for Varian linacs. They concluded that the IsoCal is an accurate and consistent method for calibration and periodic quality assurance of MV and kV imaging systems. We designed our own protocol for imager offset correction. As per the protocol if the MPC values were found to be beyond tolerance level set by us (± 0.5 mm), then the IsoCal test was to be used for independent verification of the result. On confirmation of the result with the IsoCal test, offset correction in terms of physical adjustment of the imager was to be effected.

The collimator rotation values, as well as jaw offset values, were well within the tolerance limits except for the Y1 jaw for which the value was in the danger zone. This result was validated with the help of an independent radiochromic film based test and the Y1

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jaw offsets error was accordingly corrected. The maximum offsets of the leaf banks A and B of the MLC were also well within the tolerance values. Similarly, the couch related parameters, including the rotation induced couch shift, were well within the tolerance limits. The absolute and the relative values for gantry angles were found within limits. As for the reproducibility of the geometric parameter values measured over the ten months (195 measurements) study period, the standard deviation in absolute terms is at least one order of magnitude less than 1 mm for the distance parameters and two orders of magnitude less than 1° for the angular parameters. The small spread in the day to day variations depicted in figure 1 (A-D) for ten months is a visual indication of the acceptable reproducibility of the data.

**Table 1:** MPC geometry check report for a 6 MV photon beam

| Parameter | Test procedure | Value ( Mean±SD) | Threshold value | Pass/fail |
|---|---|---|---|---|
| Isocenter | | | | |
| Isocenter size (mm) | MPC | 0.384±0.011 | ± 0.50 | Pass |
| | Winston-Lutz | 0.297 | | |
| Isocenter MV offset (mm) | MPC | 0.286±0.049 | ± 0.50 | Pass |
| Isocenter kV offset (mm) | MPC | 0.185±0.042 | ± 0.50 | Pass |
| Collimator | | | | |
| Collimator rotation offset (°) | MPC | 0.265±0.025 | ± 0.50 | Pass |
| Collimator Jaw X1 (mm) | MPC | -0.008±.027 | ± 1.00 | Pass |
| Collimator Jaw X2 (mm) | MPC | 0.615±0.021 | ± 1.00 | Pass |
| Collimator JawY1 (mm) | MPC | -0.352±0.017 | ± 2.00 | Pass |
| Collimator JawY2 (mm) | MPC | 0.26±0.084 | ± 2.00 | Pass |
| Collimator MLC max offset A (mm) | MPC | -0.231±0.036 | ± 1.00 | Pass |
| Collimator MLC max offset B (mm) | MPC | 0.513±0.020 | ± 1.00 | Pass |
| Collimator MLC mean offset A (mm) | MPC | -0.125±0.036 | ± 1.00 | Pass |
| Collimator MLC mean offset B (mm) | MPC | 0.327±0.019 | ± 1.00 | Pass |
| Couch | | | | |
| Couch lateral (mm) | MPC | 0.014±0.030 | ± 0.70 | Pass |
| Couch longitudinal (mm) | MPC | 0.001±0.023 | ± 0.70 | Pass |
| Couch pitch (°) | MPC | -0.024±0.006 | ± 0.10 | Pass |
| Couch roll (°) | MPC | -0.035±0.007 | ± 0.10 | Pass |
| Couch rotation (°) | MPC | -0.089±0.007 | ± 0.40 | Pass |
| Couch vertical (mm) | MPC | -0.012±0.038 | ± 1.20 | Pass |
| Rotation induced couch shift (mm) | MPC | 0.261±0.041 | ± 0.75 | Pass |
| Gantry | | | | |
| Gantry angle absolute (°) | MPC | -0.106±0.018 | ± 0.30 | Pass |
| Gantry angle relative (°) | MPC | 0.051±0.056 | ± 0.30 | Pass |

SD: Standard Deviation; MPC: Machine Performance Check application

**Table 2:** Beam constancy check results for a 6 MV photon beam

| Parameter | Test procedure | Value Mean± SD | Threshold value | Pass/fail |
|---|---|---|---|---|
| Beam output change (%) | MPC | -0.228±0.449 | ± 2.00 | Pass |
| | Ion-chamber | -0.315±0.514 | | |
| Beam center shift (mm) | MPC | 0.147±0.072 | ± 0.50 | Pass |
| Beam uniformity change (%) | MPC | 0.914±0.360 | ± 2.00 | Pass |

MPC: Machine Parameter Check application; SD: Standard Deviation

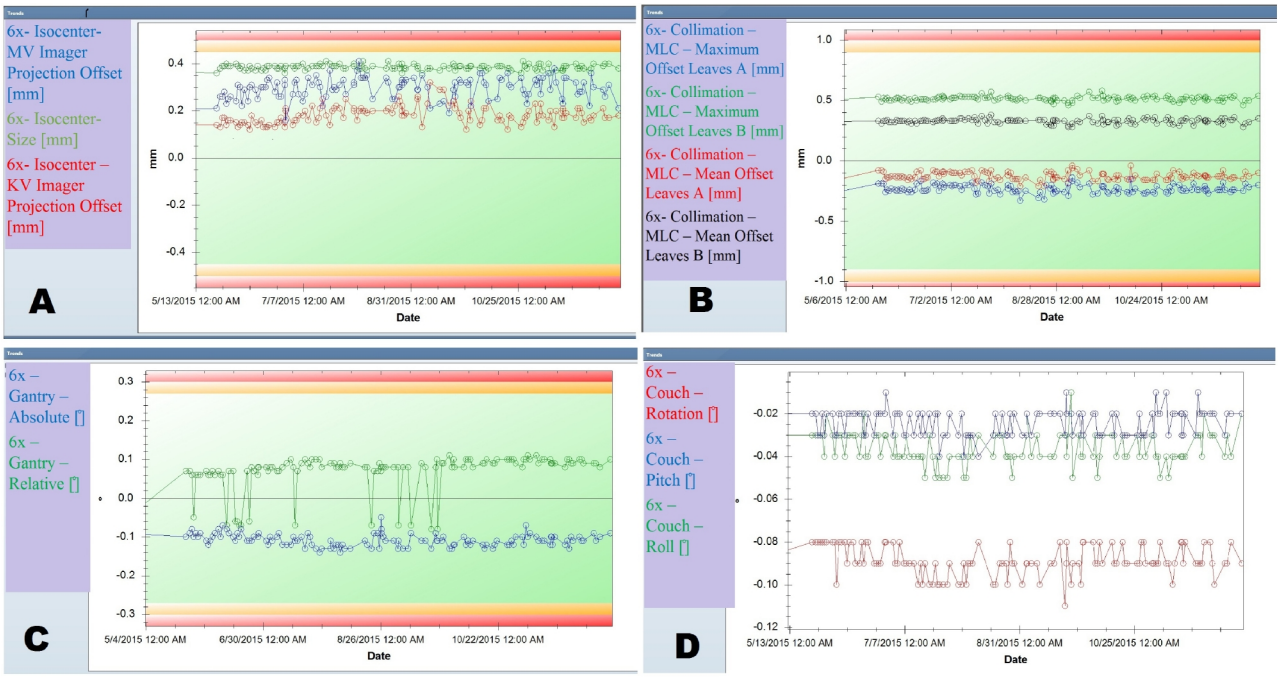



**Figure 1:** Screenshots of the MPC geometry test for ten months data trends: (A) Isocenter size, isocenter MV offset, and isocenter kV offset, (B) Collimation MLC maximum offset and mean offset of leaf banks A and Bank B, (C) Gantry absolute and relative test, (D) Couch rotation, pitch and roll.

### 4.2. Dosimetry Checks

Dosimetry or beam constancy checks were performed for the 6 MV photon beam as this is the most clinically used energy for IMRT, VMAT, and SRS/SRT procedures. The ion chamber measured output values closely match the MPC values as shown in Table 2 (p-value 0.001). The beam center shift and beam uniformity- change data trend for the 195 days showed that both of these parameters had very small values of standard deviation. It was estimated at ± 0.072 mm and ± 0.36% for beam centre shift and beam uniformity change, respectively, confirming the long term stability of MPC response.

### 4.3. Response of MPC with manually changed machine output

The Pearson correlation coefficient between the MPC and ion-chamber measured output change is 0.991 (p-value < 0.001) indicating a strong correlation between them (Figure 2). The data was analyzed with the help of SPSS Statistics for Windows, Version 20.0 (IBM, USA).

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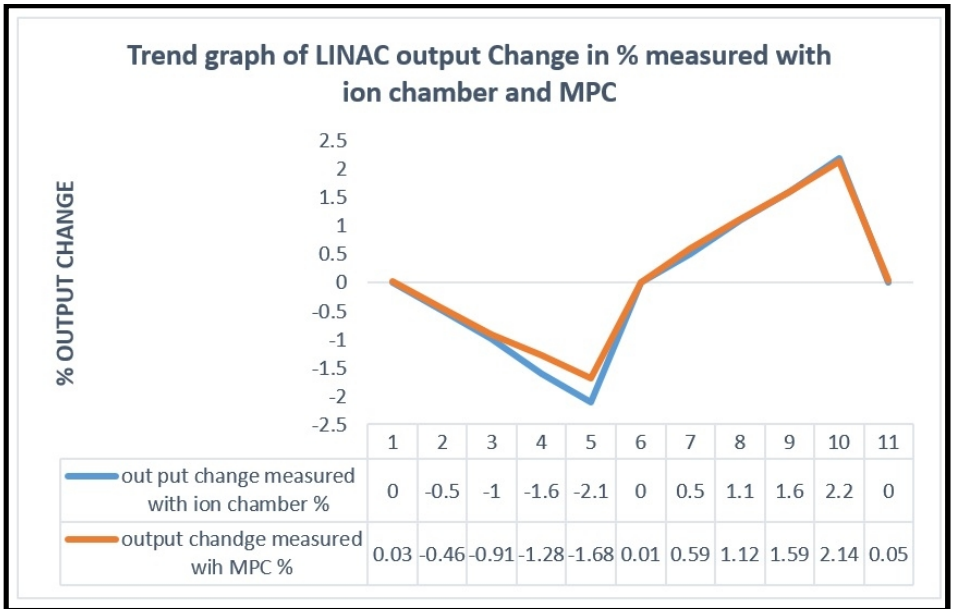



**Figure 2:** Linac output changes measured with an ion chamber and the MPC.

## 5. Conclusion

The study presented here is a preliminary work to test the long-term consistency and efficiency of the MPC application as an automated daily QA application in a clinical environment. From the data analyzed it is evident that the MPC is a stable system for performing the required geometrical and beam consistency checks as per AAPM task group 142 recommendations. It takes about five minutes to carry out the daily QA per photon beam. Integration of the MPC as a quick daily QA application seems eminently feasible.The added advantage is that the measured data can also be stored for a later review, reporting, and analyses. As for validation of the MPC measured values, this preliminary work primarily aimed at assessing the long-term stability of the results obtained and hence validation with independent measurements was limited to a few parameters only. We plan to carry out a comprehensive validation of the MPC in the next phase of our study.

## 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.

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