Validation of Machine Performance Check (MPC) Beam Output Change on Two TrueBeam Linac Systems

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Abstract

Daily quality assurance (QA) is an essential requirement of modern radiotherapy. Validation of the performed QA tests is equally fundamental. Daily Machine Performance Check (MPC) tests were conducted on two newly acquired VARIAN linacs, TrueBeam STX (TB STX) and TrueBeam (TB) for the commissioned photon energies. This MPC data was compared with independent absolute dose measurements performed on the linacs. The aim of the study was to assess the beam output change on two TrueBeam linacs, and compare the outcomes against MPC integrated tool. A weekly percentage dose output variation was measured using a secondary dosimetric system (SS) consisting of RW3 solid water phantoms, farmer type ionization chamber and PTW’s Unidose electrometer over twelve (12) months for flattened photon energies on TB STX and six (6) months for flattening filter free (FFF) on TB STX, flattened and FFF photon energies on TB. The acquired MPC and SS data were compared using student’s t-test tool for paired samples with a significant threshold level α of 0.05. The mean difference and standard deviation of the beam output change measured with MPC and SS was computed, and graphs plotted. The observed average standard deviation between output variations measured with the SS and MPC tool were less than ±1% and the mean output change within ±2%. There was a good agreement between the output variation measured with the SS and MPC tool. The department decided to trust in the daily MPC tests supported by the weekly secondary dosimetric measurement system to assess linacs performance in comparison to MPC tool.

Keywords: Machine Performance Check (MPC); Beam Output Change; Flattening Filter Free (FFF); Electronic Portal Imaging Device (EPID); Secondary Dosimetric System (SS).

Introduction

Daily quality assurance (QA) is an essential requirement of modern radiotherapy [1]. Validation of the performed QA tests is equally fundamental. Machine Performance Check (MPC) is an integrated QA self-check tool provided by VARIAN [2]. It is used to verify if the critical functions of TrueBeam systems are operating within specifications [2, 4, 8]. Beam constancy and geometry tests are performed daily before routine treatment starts, using the isocenter calibration (IsoCal) phantom that is firmly mounted to the couch top using a dedicated MPC phantom holder. MPC uses the Electronic Portal Imaging Device (EPID) to evaluate beam constancy. The study by Barnes and Greer [3] evaluated MPC beam output change with an ionization chamber (IC). A drift in MPC output was observed hence performance of a periodical acquisition of baseline, and a regular inter-comparison of MPC output with an IC was recommended. During MPC beam constancy checks, the IsoCal phantom is retracted and the EPID set to 150cm source-detector distance [4]. A study by Binny et al. [5] recommended each MPC parameter to be individually analyzed using specific process control methods to derive tolerances specific to...
the machine to improve error detection capabilities and treatment efficiency. Clivio et al. [4] evaluated MPC with standard QA tests for 10 consecutive days and recommended carrying out acquisitions and evaluations over a longer period to better understand the stability and full reliability of the dosimetric checks. Beam constancy checks cannot be considered as true dosimetric QA controls, but only relative to the baseline MV images [3]. MPC is not a machine QA tool and should not replace routine QA [2, 4], therefore independent evaluation was performed on MPC beam output change in the department for over 6 months.

In this study, MPC beam output change results recorded daily using an IsoCal phantom (Figure 1) on two newly acquired TrueBeam linacs were used. TrueBeam STX (TB STX) with photon energies 6, 10, 15 MV, 6 FFF and 10 FFF, and TrueBeam (TB) with 6 MV, 10 MV, 6 FFF and 10 FFF photon energies commissioned in August 2018 and February 2019 respectively. Both linacs were equipped with an amorphous silicon aSi1200 electronic portal imaging device (EPID) used by MPC tool for output verification. A reference state of the linac is marked as the baseline, on which other subsequent acquisitions are compared [4]. Using an uncorrected jaw-collimated symmetric (18 x 18 cm²) beam image at zero (0°) gantry position, a ratio image is calculated between the baseline and the respective image of the checking beam for a given energy [2, 4].

The acquired MPC data was compared and validated with absolute dose measurements obtaining the percentage dose deviation between the dose measured at a point and the calibration dose value. With the exception of 6 FFF on TB STX used for stereotactic treatments, FFF photon energies were not in clinical use in the department. The aim of the study was to assess the measured linac output on two TrueBeam linacs, and compare the outcomes against the results from MPC tool.

### Materials and Methods

Validation was performed weekly on TB STX and TB by verifying the percentage variation between the dose measured at a point under reference conditions and the calibration dose value. This QA test was performed with a secondary dosimetry system (SS) consisting of a Farmer type IC (NE 2581/1177), PTW’s Unidose electrometer and 15 RW3 solid water phantom slabs, 1 cm each. The SS was cross-calibrated using the procedure described in TRS 398 protocol [6]. The exposure parameters for the linac output measurements are shown in Table 1.

Fifteen (15) cm water equivalent RW3 solid phantom slabs were placed on the linac couch, with the setup shown in Figure 2. With a 10 x10 cm² field size, three (3) measurements of the collected charge acquired on the electrometer were recorded for each energy, average charge reading (M) and standard deviation computed.
For all the commissioned photon energies, the absorbed dose to water at a point of measurement, \( D_w \) (equation 1) was calculated and corrected for temperature and pressure \( (K_{TP}) \) following TRS398 protocol [6]; and using the appropriate chamber cross-calibration factor \( N_Q \) in cGy/nC, for the quality of the beam.

\[
D_w = \text{Ave. } M \times K_{TP} \times N_Q
\]  

The absorbed dose to water at the buildup position was obtained based on the corresponding Tissue maximum Ratio (TMR) for the respective photon energy using equation 2.

\[
D_{w,\text{buildup}} = \frac{D_w}{\text{TMR}}
\]  

The percentage dose deviation between the dose measured at a point under reference conditions and the calibration dose value was calculated using equation 3, and compared with the MPC beam output change for that specific day. The percentage (%) dose deviation had a tolerance of ± 2%.

\[
\text{Percentage dose deviation} = \frac{D_{w,\text{buildup}} - \text{Calibration dose}}{\text{Calibration dose}} \times 100
\]  

The beam output change was validated weekly using the percentage dose output variation measured with the SS over twelve (12) months on TB STX for flattened beams, and six (6) months for FFF on TB STX and for all photon energies commissioned on TB. The mean difference in the beam output change measured with MPC and SS was computed (Table 3), and a null hypothesis that the mean beam output change obtained with MPC and SS were equally postulated. The acquired beam output change with MPC and SS were compared using student’s t-test tool for paired samples with a significant threshold level \( \alpha \), of 0.05 (Table 4). The standard deviation of the two systems was computed and graphs plotted as in Figures 3-6, and supplementary Figures 7-11.

### Results

The results of the mean beam output change obtained with MPC and SS in Table 2, were expressed using ± 1 standard deviation. The mean beam output change acquired with both systems for all energies was within the tolerance of ± 2%.

Figure 3 demonstrates a known behavior of drift in beam output change with time for new linacs [7]. As the beam output change reached the tolerance level (±2%), a measurement with the primary dosimetric system was performed just before calibration of the linacs. The high values of beam output change obtained beyond ±2% could have resulted from uncertainties in the secondary dosimetric measurement system and/or random errors.
Table 3. Mean difference in Beam Output change on TB STX and TB

<table>
<thead>
<tr>
<th>Linac</th>
<th>6 MV</th>
<th>10 MV</th>
<th>15 MV</th>
<th>6 FFF</th>
<th>10 FFF</th>
</tr>
</thead>
<tbody>
<tr>
<td>TB STX</td>
<td>0.25% ± 0.37%</td>
<td>0.06% ± 0.34%</td>
<td>-0.03% ± 0.34%</td>
<td>-0.14% ± 0.42%</td>
<td>0.65% ± 0.52%</td>
</tr>
<tr>
<td>TB</td>
<td>-0.11% ± 0.42%</td>
<td>-0.15% ± 0.33%</td>
<td>N/A</td>
<td>-0.28% ± -0.11%</td>
<td>-0.25% ± 0.31%</td>
</tr>
</tbody>
</table>

Table 4. Student’s t-test analysis for Beam Output change on TB STX and TB

<table>
<thead>
<tr>
<th>Energy</th>
<th>P-value TB STX</th>
<th>P-value TB</th>
</tr>
</thead>
<tbody>
<tr>
<td>6MV</td>
<td>3.18E-06</td>
<td>0.278</td>
</tr>
<tr>
<td>10MV</td>
<td>0.207</td>
<td>0.101</td>
</tr>
<tr>
<td>15MV</td>
<td>0.580</td>
<td>N/A</td>
</tr>
<tr>
<td>6FFF</td>
<td>0.138</td>
<td>0.003</td>
</tr>
<tr>
<td>10FFF</td>
<td>1.35E-05</td>
<td>0.007</td>
</tr>
</tbody>
</table>

Figure 3. Trend of Beam Output Change for 6 MV on TB STX.
**Figure 4. Trend of Beam Output Change for 6 FFF on TB STX.**

**Figure 5. Trend of Beam Output Change for 6 MV on TB.**
Figure 6. Trend of Beam Output Change for 6FFF MV on TB.

Figure 7. Trend of Beam Output Change for 10 MV on TB STX.
Figure 8. Trend of Beam Output Change for 15 MV on TB STX.

Figure 9. Trend of Beam Output Change for 10FFF on TB STX.
Figure 10. Trend of Beam Output Change for 10 MV on TB.

Figure 11. Trend of Beam Output Change for 10FFF on TB.
MPC baselines obtained after calibration of the linac output were used as reference. The baseline data acquired on August 02, 2018 and June 21, 2019 on TB STX and TB respectively were used. TB had two baselines (January 22, 2019 and June 21, 2019), however up to June 2019, the comparison between the beam output change from MPC and the correspondent measured value with the SS was not in good agreement as shown in Figures 5-6. This could have resulted from uncertainties in acquiring the baseline data. For this study therefore, data analyzed on TB was that acquired after the second baseline on June 25, 2019. The linacs were calibrated each time the MPC’s beam output change and/or the linac output obtained with the ionization chamber with respect to the calibration value approached ± 2%.

**Discussion**

Results of Table 4 indicate no statistically significant difference in the beam output change for photon energies 10 MV, 15 MV, 6 FFF on TB STX and 6 MV and 10 MV on TB. The MPC’s beam output change and the percentage dose deviation measured with SS were in agreement. Photon energies 6 MV, 10 FFF on TB STX and 6 FFF and 10 FFF on TB had a P-value less than 0.05 implying a statistically significant difference. It was however observed that a 0.25%±0.37% difference attained on TB STX with 6 MV was not so clinically relevant. FFF beams were not in clinical use, hence the variation in beam output change measured with MPC and SS could not be conclusively established.

In a multi-institutional study [5], MPC output change for 6 MV was checked on 6 different machines, had a percentage relative difference between MPC and IC consistent with this study. The average % variation for 6MV ranged from -0.271 to 0.779 with a SD 0.292 to 0.739 comparable with this current study [7], it was deemed necessary to perform beam output measurements using an ionization chamber fortnightly on TB STX and weekly on TB in the department given the different behavior exhibited by the two EPID systems. A periodic calibration procedure for EPID maintenance was performed and we observed that this had no impact on MPC response. At the time of installation, TB STX platform had version 2.5 and this was updated to version 2.7 four months later. For the TB, a new platform released (TB 2.7 version) with new monitor chamber design was acquired at installation, so several differences were present. After the first commissioning done on the TB, the monitor chambers were changed due to a fault and all the energies commissioned again.

**Conclusions**

The independent beam output change tests conducted were in agreement with MPC tool. Departments should however maintain an ongoing QA program to assess the efficiency of the TrueBeam systems in comparison to MPC tool. Our final decision in the department was to trust in the MPC daily checks supported by the weekly secondary dosimetric measurement system for both linacs and for all the energies.

**Abbreviations**


**Author Contributions**

All authors contributed equally to this study and gave their final approval.

**Competing Interests**

The authors have declared that no competing interest exists.

**References**


[7] Teaching material from Varian course on TrueBeam platform Physics and administration course (May 2018) held at University Hospital of Zurich.


