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Technical Note

Beam output checks of a commercial high-field magnetic resonance-guided radiotherapy machine with its on-board megavoltage imager

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A R T I C L E I N F O

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A B S T R A C T

Beam output checks of a commercial high-field magnetic resonance-guided radiotherapy machine can be performed with its on-board megavoltage imager (MVI). This is a fast and efficient method, but only recommended for daily checks. The aim of our study was to show its suitability for weekly checks by investigating its long-term agreement with the golden standard: ionization chamber measurements in a water tank. For one year, the output deviations obtained with both methods were compared. The difference was 0.1 ± 0.3 (1SD) percentage point. This indicated an excellent agreement, and translated into a tolerance level of ± 2 %.

1. Introduction

As part of the quality assurance (QA) program of a commercial high-field magnetic resonance-guided radiotherapy (MRgRT) machine, periodic beam output checks are required. These can be performed with its on-board megavoltage imager (MVI), a daily QA device, and with an ionization chamber in either water equivalent plastic or in a water tank [1]. The first method, using the amorphous silicon (a-Si) MVI, is the most efficient and the fastest as it does not require any additional equipment and no set-up. Unfortunately, this method is not recommended for weekly checks.

Our aim was to show the suitability of the MVI for weekly output checks by investigating its long-term agreement with the golden standard: ionization chamber measurements in a water tank. To the best of our knowledge, such a study has not been published before for the specific type of MRgRT machine.

2. Materials and methods

For one year – from July 1, 2021 to June 30, 2022 – output measurements were performed with both the MVI and an ionization chamber in a water tank. All output measurements were performed in the 7 MV FFF beam ($TPR_{20,10} = 0.705$) of our clinical Unity (Elekta, Stockholm, Sweden); a commercial high-field MRgRT machine [2–7].

Output measurements in water were performed weekly in an MP1 MR Manual Water Phantom (PTW, Freiburg, Germany) with an PTW30013 Farmer waterproof ionization chamber placed anti-parallel to the magnetic field in the isocenter at a depth of 10 cm (SSD = 133.5 cm and SDD = SAD = 143.5 cm). The ionization chamber was irradiated with 200 MU using a 10 cm × 10 cm field at a gantry angle of 0 degrees. This should result in a dose of 2 Gy, since the machine has been calibrated to give 1 Gy per 100 MU under these conditions.

MVI output measurements were performed daily. The a-Si MVI (Perkin Elmer, Santa Clara, CA) was irradiated with 100 MU using an 18 cm × 8 cm field at a gantry angle of 0 degrees. Image acquisition was performed with the MVIC v2.0.0.B109 software (Elekta, Stockholm Sweden). From the acquired frames, MVIC creates an averaged frame with re-normalized 16-bit pixel values, which is stored as an image. A pixel factor that contains information about the total number of frames and the re-normalization value [8,9] is reported and allows for the determination of the integrated pixel value (i.e. the total response).

The output measured by the MVI (O_{MVI}) was calculated with a PYTHON script from the ratio of the actual integrated pixel value and the integrated pixel value obtained during the cross calibration against an output measurement in water. Based on Eq. 3 in [8]:

$$O_{MVI} = \left(\frac{65535 - PV}{PF} \middle/ \frac{65535 - PV_{w,x}}{PF_{w,x}} \right) \times O_{w,x} \qquad (1)$$

In this equation, PV is the mean pixel value in a square ROI of 101 × 101 pixels around the beam axis (≈ 2.2 cm × 2.2 cm at the level of the isocenter), and PF is the pixel factor. $PV_{w,x}$ and $PF_{w,x}$ are the PV and PF obtained during a cross calibration against an output measurement in

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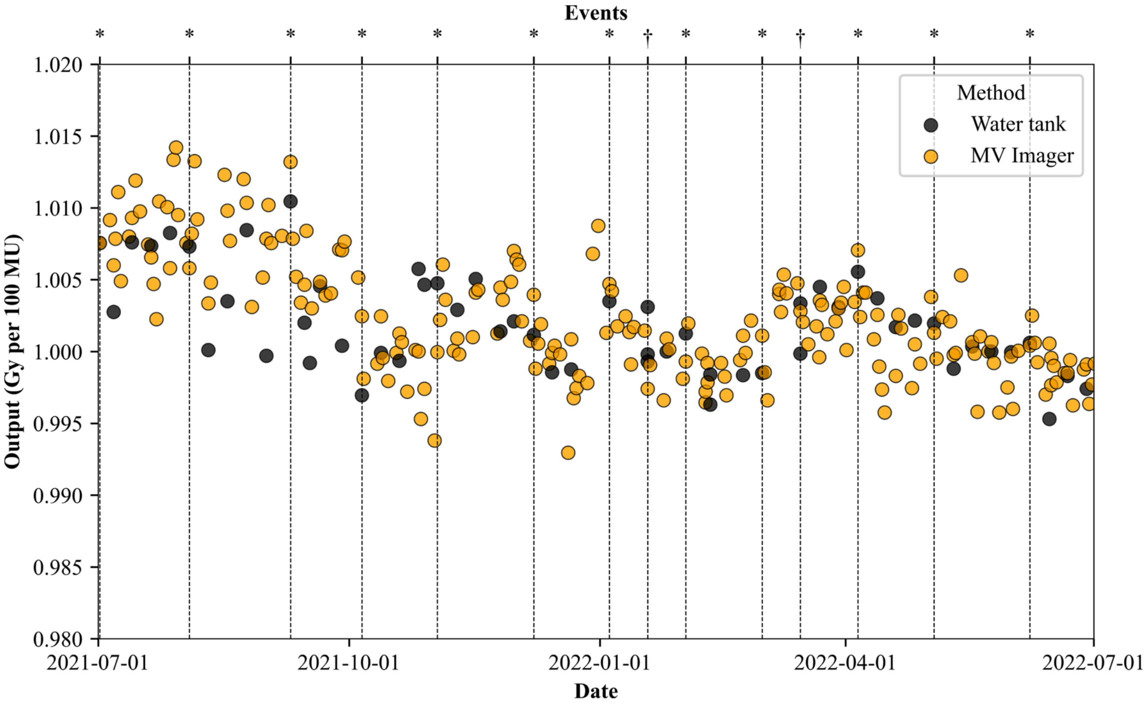

Fig. 1. Overview of output measurements with an ionization chamber in a water tank (black) and with the on-board megavoltage imager (yellow) for a period of a year. On the upper horizontal axis, notable events are indicated (* = cross calibration, † = output adjustments).

water ($O_{w,x}$), respectively. Cross calibrations were performed each month. The value of 65,535 (=2^{16} –1) was necessary to ‘reverse’ the 16-bit pixel values, since PV decreases when the absorbed dose increases.

On days when both methods were used, the output deviation obtained with the MVI was compared to the output deviation obtained with an ionization chamber in a water tank. To prevent bias by introducing perfect agreements of 0.0 percentage points (pp) on the cross calibrations days, the MVI output measurements on these days were made using the previous cross calibration. Thus, new cross calibrations did not become effective until the next MVI output measurement.

To define the tolerance level for MVI output measurements, first a Shapiro-Wilk test [10] was performed on the output deviation differences to verify that they followed a normal distribution. Subsequently, a Gaussian fit was applied. Then, the sum of the tolerance level for the water measurements (i.e. ± 1 %) and 2SD of the Gaussian fit was calculated. Finally, the tolerance level for routine MVI output measurements was defined as the result of this sum rounded up to the nearest whole percent.

3. Results

In total, 55 output measurements were performed in water and 208 with the MVI. All measured output deviations in water were within ± 1.0 %, except one: on September 9, it was slightly larger. The outputs measured with the MVI followed the same trend as the outputs measured in water, but their spread was larger: 206 of the 208 output deviations were in the range of −0.5 to 1.5 %. Fig. 1 shows the results of all output measurements in this study. The upper horizontal axis indicates when cross calibrations and output adjustments were performed. During the year, no image calibrations (i.e. dead pixel map, offset and/or gain calibrations) of the MVI were performed.

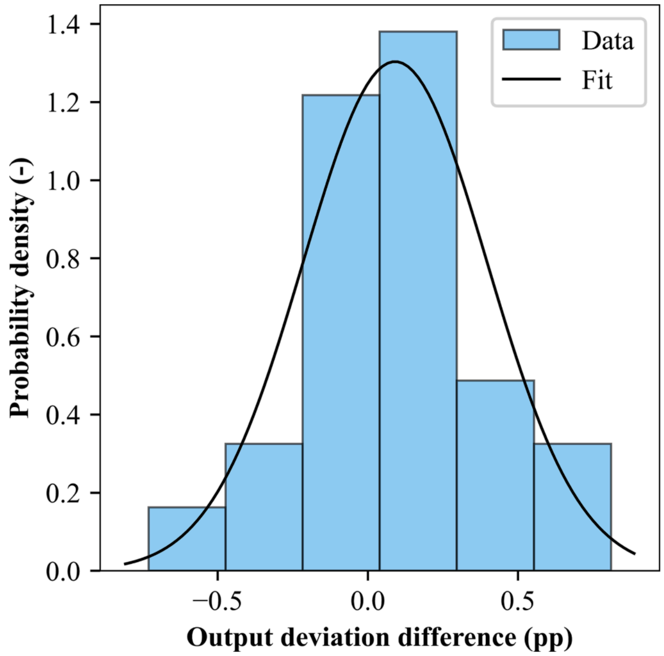

Fig. 2. Distribution of output deviation differences (output deviation obtained with the on-board megavoltage imager minus output deviation obtained with an ionization chamber in a water tank) in percentage points (pp). The black line shows a Gaussian fit (μ = 0.1 pp, σ = 0.3 pp) to the measured data (48 samples).

The output was adjusted on two separate occasions. On January 18, the dose rate had decreased to approximately 400 MU·min^{-1}. The manufacturer’s advice was to re-calibrate the output even though the deviation was only 0.3 %, as the same built-in procedure that takes care of adjusting the monitor chamber sensitivities also takes care of adjusting the dose rate to the nominal value of 425 MU·min^{-1}. On March 15, another adjustment of 0.3 % was made after the magnetron had been replaced.

On 48 days, both types of output measurements were performed and the output deviation differences (MVI output deviation minus output deviation in water) were calculated. The mean difference was 0.1 pp (range: −0.7 – 0.8 pp). The Shapiro-Wilk test did not show any evidence of non-normality (W = 0.98, p-value = 0.77). Therefore, we fitted a

Gaussian curve to the output deviation differences. The parameters of this fit were μ = 0.1 pp and σ = 0.3 pp, which translated into a tolerance level of ± 2 % for MVI output measurements. Fig. 2. shows the differences as a histogram and the Gaussian fit.

4. Discussion

For one year, we compared daily MVI output measurements to weekly output measurements with an ionization chamber in a water tank to investigate their long-term agreement and to define a suitable tolerance level for MVI output measurements.

A study similar to ours was performed by Budgell et al. [11] for a different type of linac. They found that the difference between a-Si EPID and ion chamber measurements followed a normal distribution with σ = 0.64 %. This is somewhat larger than the σ of the Gaussian fit to our output deviation differences.

Berresford et al. [12] compared the variation of daily MVI output measurements to weekly output measurements with a Farmer chamber at a gantry angle of 90 degrees. They found a slightly larger variation for the MVI (1SD = 0.6 %) than for the Farmer chamber (1SD = 0.4 %). Although it is not clear whether they measured with the Farmer chamber in water equivalent plastic or in a water tank, this is consistent with our findings (see Fig. 1). Our results also show a slightly larger spread for measurements with the MVI compared to those with the Farmer chamber.

Chen et al. [13] have implemented an MVI output measurement as part of their daily end-to-end quality assurance for their Unity system. They reported an output variation of < 2.0 % based on daily MVI measurements over a period of approximately 6 months, whereas Fig. 8. in their work shows a variation of ± 1.5 %. The latter is consistent with our findings, since 206 of 208 output deviations were in the range of −0.5 to 1.5 %. Note that the method of Chen et al. can be used to check whether the daily output is within ± 3.0 % of the nominal output, but cannot be used to perform routine output measurements. They converted the PF of the daily images into dose with a directly proportional relationship, whereas this is actually inversely proportional (see Eq. (1)). However, in the small dose range in which they were interested, this only introduces a small error. Furthermore, the pixel value (PV) was not taken into account, which constitutes the potential risk of interpreting a change in the re-normalization value of the acquired images as an output change.

Subashi et al. [14] reported on monthly output measurements with a Farmer chamber in water equivalent plastic at a gantry angle of 90 degrees for the period of a year. Fig. 9. in their work shows a variation of −0.7 to 1.7 %, which is consistent with our findings. They also performed daily MVI output measurements at a gantry angle of 0 degrees for a period of 40 days. These varied ± 1.0 %. This spread of 2.0 % is consistent with the spread of −0.5 to 1.5 % that we found.

The Elekta MR-Linac Consortium [1], recommends tolerance levels of ± 2 % and ± 1 % for weekly and annual output measurements with an ionization chamber in a water tank, respectively. In our clinic, we apply the annual tolerance level, since this can easily be met (see Fig. 1). Moreover, the output proved to be very stable, which is in agreement with the work of Winter et al. [15]. Over a period of a year, only two adjustments were necessary. These had nothing to do with output deviations that were too large, but were due to a decreased dose rate and a new magnetron. Also, the observed variation in MVI output measurements is consistent with findings in recent publications.

We found an excellent agreement between MVI output measurements and those with an ionization chamber in a water tank (see Fig. 2) and defined a tolerance level of ± 2 %. This tolerance level is more strict than the ± 3 % recommended by the consortium for daily checks of the output constancy. Since Fig. 1 shows a small shift in output around October 5, 2021 and we could not find any identifiable source, an additional analysis of the output deviation differences from this date forward was performed. This analysis confirmed the original analysis.

In conclusion, the suitability of the MVI for weekly output checks has been shown. A tolerance level of ± 2 % is achievable if a monthly cross calibration is performed.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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