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# Sensitivity of collapsed arc QA method for delivery errors in Volumetric Modulated Arc Therapy (VMAT)

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## Abstract

In this paper the sensitivity of an Electronic Portal Imaging Device (EPID) to detecting introduced Volumetric Arc Therapy (VMAT) treatment errors was studied using the Collapsed Arc method. Two clinical Head and Neck (H& N) and Prostate treatment plans had gantry dependent dose and MLC errors introduced to the plans. These plans were then delivered to an Elekta Synergy Linear Accelerator EPID and compared to the original treatment planning system Collapsed Arc dose matrix. With the Collapsed Arc technique the EPID was able to detect MLC errors down to 2mm and dose errors of down to 3% depending on the treatment plan complexity and gamma tolerance used.

## Keywords

modulated, volumetric, therapy, vmat, collapsed, errors, sensitivity, delivery, method, qa, arc

## Disciplines

Engineering | Science and Technology Studies

## Publication Details

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# Sensitivity of collapsed arc QA method for delivery errors in Volumetric Modulated Arc Therapy (VMAT)

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**Abstract**. In this paper the sensitivity of an Electronic Portal Imaging Device (EPID) to detecting introduced Volumetric Arc Therapy (VMAT) treatment errors was studied using the Collapsed Arc method. Two clinical Head and Neck (H&N) and Prostate treatment plans had gantry dependent dose and MLC errors introduced to the plans. These plans were then delivered to an Elekta Synergy Linear Accelerator EPID and compared to the original treatment planning system Collapsed Arc dose matrix. With the Collapsed Arc technique the EPID was able to detect MLC errors down to 2mm and dose errors of down to 3% depending on the treatment plan complexity and gamma tolerance used.

## 1. Introduction

Modern radiotherapy techniques are increasingly complex in both planning and treatment delivery, with the Volumetric Modulated Arc Therapy (VMAT) technique following this trend [1-3]. The high complexity demands rigorous commissioning and also pre-treatment plan-specific dose verification using 3D dose measurements [4, 5]. All such radiotherapy techniques are dependent on strict machine tolerances to ensure consistent and accurate dose delivery [6, 7]. Errors due to both MLC [8] and dose differences [9] have been investigated and also different combinations of tools and commercial QA devices have been compared to varying extents [10, 11] for use in rotational therapies.

The collapsed arc technique involves the calculation of the dose matrix resulting from a VMAT arc in a plane perpendicular to the beam at isocentre. The algorithm used has been outlined elsewhere [12]. The technique allows the measurement of the VMAT arc using gantry mounted devices, or detectors which are always perpendicular to the treatment beam, but is not able to detect delivery errors from gantry angle position. Conventional linear accelerators have an EPID permanently attached with the imaging plate directly perpendicular to the treatment beam and so are well suited to capture fluence measurements in the treatment plane. Many different groups have utilized the EPID for QA purposes of different modality treatment plans, as well as the possibility of *in vivo* dosimetry [13-16]. In this study we investigate the sensitivity of the collapsed arc technique to detect deliberately-introduced errors to VMAT treatment plans measured using the EPID.

## 2. Material and Methods

### *2.1. VMAT Planning and Delivery*

VMAT plans were generated using the Pinnacle, v 9.6, Treatment Planning System (TPS) for a 6 MV photon beam model for an Elekta Synergy (Elekta Ltd, Crawley, UK) linear accelerator (linac). Four clinical VMAT treatment plans were considered here – two prostate plans and two Head and Neck (H & N) plans. Each plan was collapsed to a single plane to produce a dose matrix. The linac was equipped with a MLCi head and Integrity v1.1, linac control software. The standard EPID panel for this linac was used for these measurements.

### *2.2. Studied delivery errors:*

Gantry dependent MLC and dose error scenarios with varying levels of dosimetric impact [17] were considered. All errors were introduced to the treatment delivery file using an in-house computer program written in the Python language.

MLC error: MLC positional errors as a function of control point (CP) gantry angle were introduced to the VMAT arc. The error values were generated as a sine (SIN) function of gantry angle, with amplitudes of 1 to 7mm introduced to both X1 and X2 MLC banks (figure 1a).

Dose Error: CP weight errors as a function of gantry angle were introduced to all CPs of the arc. The error values were generated as a modulus of the sine (SIN) function of the CP gantry angle with amplitude ranging from 1% to 15% (figure 1b). The overall MU of the arc was kept constant.

All plans with introduced errors and the original error-free plan were measured using the EPID.

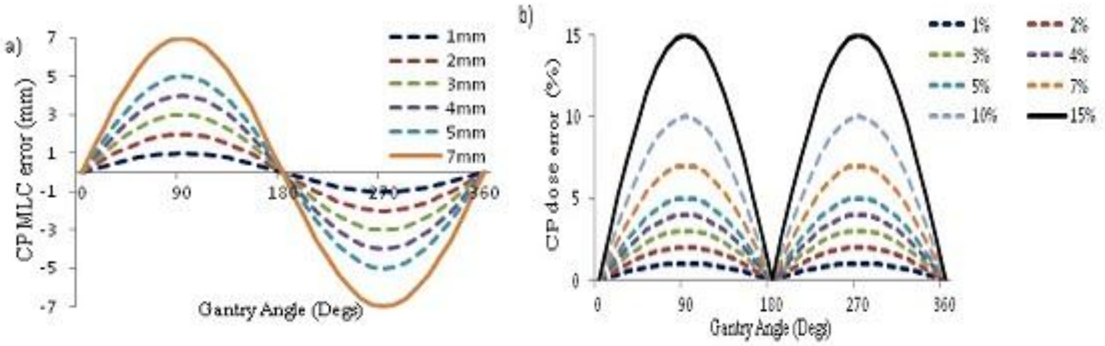

**Figure 1.** a) Magnitude of gantry angle dependent a. MLC error and b) weight error introduced to individual control points of studied VMAT arcs.

### *2.3. Treatment plan analysis:*

The measured dose matrices were compared with the Pinnacle calculated error free dose matrices using gamma (γ) analysis [18] in OmniPro I'mRT (v1.6) software with a γ tolerance of 1. The γ analysis was performed with a tolerance of 2 % dose difference and 2 mm Distance-to-Agreement (DTA) (2%/2mm) and also 3%/3mm. Dose points receiving less than 10% of the maximum dose in the dose matrix were not considered in the analysis. The measured EPID images were converted into dose matrices using existing methodology and computer code outlined elsewhere [19].

## 3. Results

Both MLC and dose errors were detectable using the EPID. The magnitude of error detected varied depending on the complexity of the plan and the gamma tolerance criteria used.

### *3.1. MLC Errors*

The gamma pass rates decreased as the magnitude of MLC error increased for both treatment sites. Considering a gamma pass rate above 90%, for the H&N plans a minimum 3mm MLC error was detected by the EPID with the tighter 2%/2mm gamma tolerance for HN1 and a minimum 4mm MLC error detected for HN2. For a 3%/3mm tolerance the MLC errors were not detected until beyond 5mm (HN1) or 7mm (HN2). For the prostate plans the MLC errors were detected by the EPID beyond 2mm for PRO1 using the 2%/2mm gamma tolerance, and beyond 3mm for PRO2. For a 3%/3mm tolerance the MLC errors were not detected until beyond 5mm (PRO1) or 7mm (PRO2).

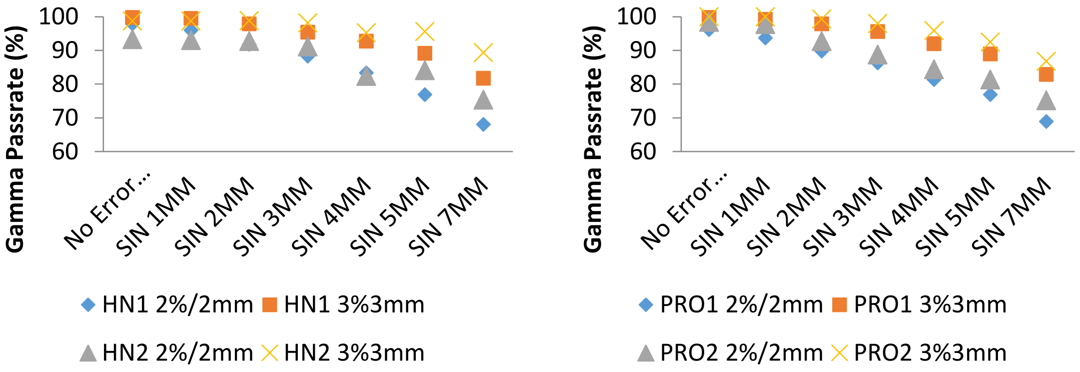

**Figure 2.** Results for plans with MLC errors introduced using a sine (SIN) function (figure 1)

### 3.2. *Dose Errors*

The gamma pass rates decreased as the magnitude of dose error was increased for both treatment sites. For the H&N plans the dose errors were detected by the EPID beyond 3%. For the prostate plans the dose errors were not detected by the EPID even at a 15% dose error, with the gamma pass rate above 90% even using the tighter gamma tolerance. For the H&N plans the dose error was detected at a 3% dose error for HN1 and at the 4% dose error for HN2 using the 2%/2mm gamma tolerance. Using the 3%/3mm gamma tolerance, the dose error was detected at 10% for HN1 and 15% for HN2. Only a limited subset of dose errors was able to be measured for HN1, leading to the possibility that the dose error may have been detectable between 4% and 10%.

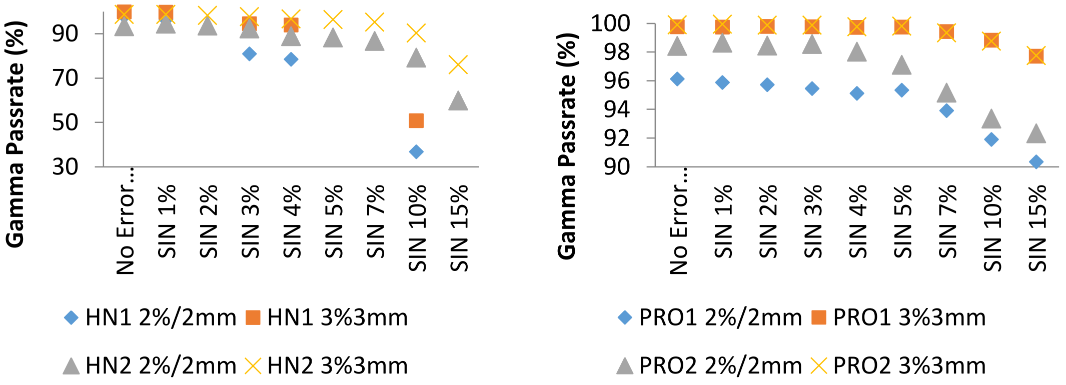

**Figure 3.** Results for plans with dose errors introduced using a sine (SIN) function (figure 1).

## 4. Discussion

The different complexity involved in treatment plans for the prostate and H&N resulted in different sensitivities to both MLC and dose errors dependent on gantry angle. The sensitivity in detecting MLC errors is dependent on the spatial resolution of the EPID. The ability of the EPID to resolve changes in fluence due to changes in MLC appears to be adequate for both prostate and H&N cases, with the gamma pass rates dropping with increased magnitude of errors in both cases. For detecting dose errors, the EPID is unable to quantify large dose differences for prostate plans, with gamma pass rates still above 90% even for introduced dose errors of up to 15%. The ability to resolve dose error is reduced due to collapsing the arc into a single dose matrix, which may potentially cancel out some of the introduced dose errors, depending on where the sinusoidal distribution is offset in relation to gantry angle. However the EPID was able to detect some dose errors for the much more complex H&N plans, though this was only when using the tighter gamma tolerance, suggesting that a tighter tolerance than 3%/3mm should be used to detect potential dose errors. For the simpler prostate plans, increasing the expected minimum gamma pass rate may enable detection of potential dose errors.

The Collapsed Arc technique enables 2D detectors to be used in conjunction with arc therapy. The algorithm outlined in [12] has been verified against a 3D dosimeter and a gantry mounted 2D array, with acceptable pass rates for 3%/3mm gamma tolerance. The main disadvantage of this Collapsed Arc single plane dose matrix is that it is unable to provide any information regarding possible gantry delivery errors, as the measurement plane is always perpendicular to the beam. Future work incorporating a gantry inclinometer feedback into the measurement may provide some ability to detect these potential errors. The method is suitable for pre-treatment patient QA of a radiotherapy system that has been verified by appropriate commissioning procedures and that is supported by an appropriate equipment QA program.

## 5. Conclusion

Using the collapsed arc technique, the EPID was able to detect the majority of MLC and dose errors of different magnitudes introduced to H&N and prostate plans, with sensitivity to errors depending on plan complexity. A gamma tolerance of 2%/2mm is more appropriate than 3%/3mm for use with the technique in detecting errors. The sensitivity of a clinical EPID is reasonable for pre treatment patient QA of VMAT plans at detecting potential delivery errors in MLC position and dose for complex plans. For simpler plans the expected minimum gamma pass rate may need to be increased to detect potential dose errors.

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