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A comprehensive EPID-based 3D validation technique for TrueBeam-delivered VMAT plans

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Abstract.

Purpose: To develop and validate a pre-treatment EPI dosimetry method on Varian TrueBeam linacs using continuous imaging, with reconstruction in a 3D cylindrical phantom geometry.
Methods: Delivery of VMAT plans with continuous imaging is currently possible only in Research Mode on TrueBeam linacs, with images acquired in a proprietary format. An earlier technique was adapted to take advantage of technical improvements in EPID delivery, and was tested under various acquisition conditions. The dosimetry of VMAT plans was evaluated at isocentre and within patient volumes that had been transferred to the virtual phantom.
Results: Approximately 60 portal image projections per arc were found to be adequate for 3D reconstruction in phantom volumes of 28cm diameter. Twelve prostate, CNS and Head & Neck deliveries were evaluated in Research mode relative to the corresponding Eclipse (v.10) treatment plans, and to measurements on an ArcCheck device in Treatment mode. Mean dose differences at isocentre were within 2% for the three-way comparison, and in PTV volumes were within 1% (s.d. 1%). However, some discrepancies were observed in ArcCheck results that may be related to the small dimensions of certain VMAT apertures.
Conclusions: EPI dosimetry with 3D dose reconstruction is an accurate, comprehensive and efficient pre-treatment validation technique for VMAT delivery. Although currently limited to a research mode on TrueBeam, it has the potential to be implemented for clinical use.

1. Introduction

Electronic Portal Image Dosimetry (EPID) has become a standard tool for evaluation of intensity-modulated radiation treatments [1]. The EPID has normally been used in integrating mode, which is ideal for acquisition of IMRT fields, as the image data can be used for 2D validation per field as well as 3D volumetric reconstruction of a delivered dose distribution. Integrated acquisition [2] is less useful for Volumetric Modulated Arc Therapy (VMAT), where the gantry rotates during acquisition, because there is no spatial correlation between the so-called "collapsed" 2D portal image and the 3D dose matrix, except for points along the axis of rotation.

3D dose reconstruction for VMAT requires cine (continuous) imaging where each image projection represents the dose averaged over a relatively small gantry angle increment [3]. However, cine mode was developed for imaging applications rather than dosimetry so has proved to be less than ideal. McCurdy and Greer [4] investigated the IAS3 system on Varian Trilogy linacs and reported some

dosimetric nonlinearity. Inaccuracy in the gantry angle recorded for each image acquisition has also been reported but despite this a workable 3D reconstruction model has been proposed [4].

The recent introduction of Varian's TrueBeam accelerator line has complicated and inhibited further attempts at 3D reconstruction because the only cine acquisition mode available in Treatment, ("movie" mode), includes dynamic windowing and signal clipping in order to optimize image contrast, and is therefore quite unsuitable for dosimetry. However, Varian has provided an optional Research (Developer) application on TrueBeam which gives the user direct control of the machine axes and most aspects of the image acquisition, and which can be programmed though the native xml scripting language on which the accelerator platform is built.

In this work we investigated the potential of Research mode for dosimetry-quality cine acquisition, and characterized the dose linearity and gantry angle accuracy, the two elements that had previously been determined as critical. We then adapted a 3D virtual-phantom reconstruction technique that has proven very successful in IMRT QA [6] to make use of these cine images. This technique, known as "3dPD", was used to compare clinical plan reconstructions to both ionization chamber measurements in a cylindrical phantom, and to a widely-accepted measurement technique using an ArcCheck device. In order to perform a full 3D comparison, the ArcCheck measurements were performed using the "3DVH" module rather than simply evaluating the diode signals around the periphery of the device. Twelve plans representing several clinical sites were investigated.

2. Methods and Materials

In Research mode, the creation of the xml code is facilitated by importing a clinical Dicom plan which can then be saved as an xml script. Imaging code was then added with a standard xml editor. All radiation deliveries were performed on Varian TrueBeam linear accelerators at the Vancouver Island Centre in Victoria, using matched 6MV photon beams.

Initially we had expected that acquisition starts and stops would be determined by control points (CPs), as are the motions of the machine axes. However, dosimetry-quality frames are acquired at a fixed rate of approximately 10 f.p.s, and are not synchronized to beam pulses. This proved to be incompatible with CP programming, which is linked to the accumulation of beam pulses, because there is no way to determine CP timing directly. As a result, frames were occasionally dropped, causing as much as a 10% signal loss for a typical 10-frame acquisition. Instead, we discovered that the xml coding allowed the user to access the individual frames accumulated during a single dosimetry acquisition. Ideally it would have been possible to save every N^{th} frame; however, the current version of scripting provides only for the final frame, or all frames, to be saved. Projection images P for small gantry increments were then formed by calculating differences between cumulative frames F

$$P_k = F_{(k+1)N} - F_{kN}$$ *i.e.*, between every N^{th} frame.

Determining the gantry angle recorded in the image header for each frame or each acquisition is critical for accurate 3D reconstruction. Earlier investigations relied on inclinometers to image some identifiable arrangement of wires or ball bearings from which to determine gantry angle. For this study, we took advantage of the xml programming to design VMAT plans where the collimator angle was equal to the gantry angle at each control point. On TrueBeam, the collimator rotates much faster than the gantry, and we had independently determined from analysis of trajectory log files that the collimator angle was accurate to a small fraction of a degree; the collimator orientation, which could easily be measured on each image, was thus a surrogate for the imaged gantry angle.

A third component of 3dPD was the incorporation of backscatter from the portal image support, which had been unnecessary in the original IMRT code. An empirical model developed by Berry *et.al.*[7] was adapted to deal with the irregular apertures and modulation of VMAT delivery, by redefining Berry's "Y1" collimator parameter to be the effective length of any imaged subfield in the gun-target direction.

Clinical validation consisted of 3-way comparisons of 3dPD, ArcCheck and PTW 30010 ionization chamber measurements at isocentre with VMAT plans calculated with the AAA algorithm (Eclipse v10.0, Varian Medical Systems) for 11 prostate, oropharynx and base of tongue cases (One prostate case resulted in two plans). These plans were converted to verification plans on a 26.6 cm diameter phantom. The phantom density was 1.2 for the ArcCheck and ionization chamber cases, and the treatment couch was included. 3dPD phantom density was 1.0 with no couch. Although both 3dPD and ArcCheck's 3DVH can evaluate clinical PTV and OAR volumes, for consistency in this study, dose differences were evaluated within volumes defined by 80% and 40% of the maximum dose. Pass statistics at the 3%/3mm DTA level for both volumes were also recorded but were not discussed, or reported here due to space limitations.

3. Results

Several difficulties were initially encountered with Research mode. As mentioned above, the acquisition mode chosen resulted in the saving of every frame. These images must be saved to a network drive, which can take several minutes for a typical data transfer of more than 1GB, and paralyzes the application for the duration. It was also found that in the current TrueBeam version (1.6), the export fails if a large number of Dicom-formatted images are to be saved. In addition, a bug in the Dicom dosimetry format causes a data overrun, making the image data invalid for more than 7 frames. As a result, a decoder for Varian's proprietary .xim format had to be developed. (These bugs are apparently resolved in a future TrueBeam release)

The gantry angle written to the image header was determined to be within 0.6° of the angle at the mid-point of any acquisition, whether that was a single or multiple (up to 12) frame acquisition. Linearity with MU was determined to be the same as for normal dosimetry acquisition. This was expected of course, as the acquisition was in fact identical to that used for a normal single-integrated image, but with inclusion of the intermediate frames.

The number of projections for 3D reconstruction was fixed at 60, corresponding to between 10 and 15 frames per projection, depending on the instantaneous dose rate and gantry speed. Although a larger number of projections does smooth the dose reconstruction, the dose differences between 3dPD and Eclipse (evaluated with a 3%/3mm DTA tolerance), did not show any change when more than 45 projections were used. The empirical backscatter correction reduced, but did not eliminate, the over-response at the target (inferior) end of the EPID images. A small decrease in agreement was observed on most 3dPD-Eclipse comparisons within 2cm of the inferior extent of the dose distributions.

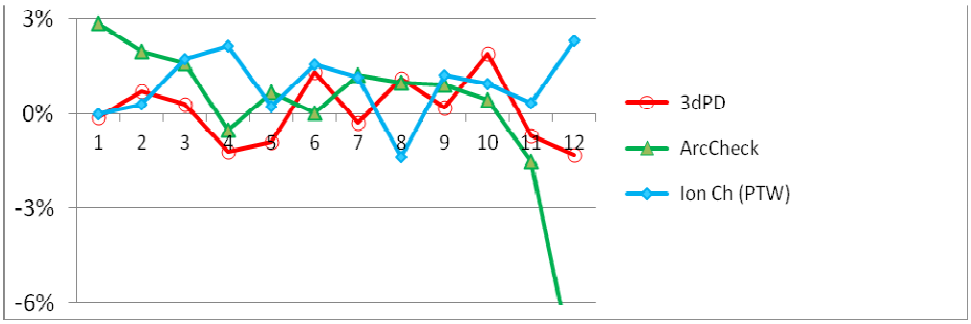

Figure 1. Isocentre dose differences from Eclipse for twelve Head & Neck (1-5) and Prostate (6-12) VMAT plans. In case 12, the ArcCheck difference was -8%

With one exception, all clinical case comparisons were well within expected levels of consistency for all three measurement techniques. The mean dose differences at isocentre were within 1%, with a maximum discrepancy of less than 3% (Figure 1), and both mean high dose (80%) and low dose (40%) ROI volume differences were within 0.5% (Figure 2). However, the results for one plan (case 11) were problematic because the "Global Correction" parameter computed by ArcCheck was -5.4%. According to the vendor's documentation, this correction should be within ±3% for a reliable

interpretation, and for all other cases the correction was within 1%. The correction, when applied to the ROI difference of -3% put the ArcCheck validation out of tolerance. As a result, the case was re-planned as #12, where the Global Correction was 1% but the dose differences were -8% and -7% for the isocentre and ROI respectively. The two plans, 11 and 12, did appear to have more than the average number of small apertures, but were not otherwise judged to be problematic. Results using 3dPD did not show any dose discrepancy.

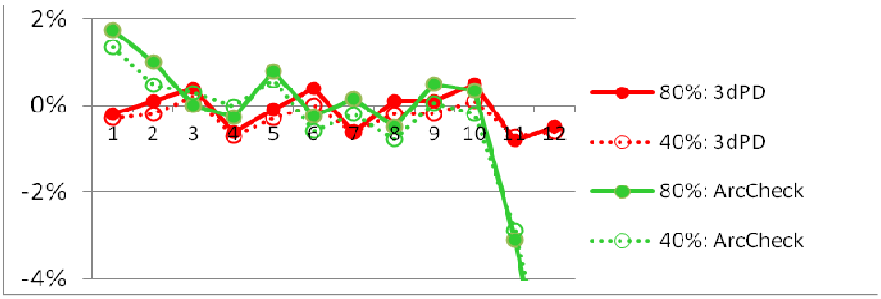

Figure 2 80% and 40% ROI volume dose differences from Eclipse for the same clinical cases. In case 12, the ArcCheck differences were -7% for both ROIs

4. Discussion and Conclusion

Research mode on Varian TrueBeam accelerators has been used to implement a pre-treatment 3D dose reconstruction technique, 3dPD, for efficient VMAT plan validation. The technique employs a user-determined number of image projections, and 60 projections were found to be adequate. The accuracy of gantry angle reconstruction and dosimetric linearity is equal to similar IMRT validation techniques. 3dPD can be used to measure absolute dose at a point with a precision equal to the dosimetric accuracy of the EPID device, and to measure volumetric differences using % dose and DTA metrics within PTV and OAR structures transferred from a CT plan.

A preliminary study has indicated that 3dPD should perform at least as well as a widely-used measurement device, ArcCheck, but requires minimal setup time. One case (consisting of two plans) passed 3dPD validation but failed ArcCheck for reasons that are not clear at this time, but may be related to the spatial resolution of ArcCheck's diode matrix. The 1cm grid is comparable to the dimensions of the small and multiply-connected apertures commonly found in VMAT delivery.

One drawback of the current 3dPD implementation is that it can be used only for *pre*-treatment QA because the necessary images cannot be acquired in normal Treatment mode. In addition, some knowledge of Varian's proprietary .xim image format is required. It is to be hoped that these limitations will be resolved in a future TrueBeam software release.

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