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Clinical validation of intensity modulated arc therapy (IMAT) by means of polymer gel dosimetry

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1. Introduction

Intensity Modulated Arc Therapy (IMAT) [1,2] allows homogeneous irradiation of a target volume lying concavely around an organ at risk (OAR) with a relatively large inner radius, and is characterized by a rotating gantry and traveling leaves during irradiation. At the Ghent University Hospital, IMAT has been implemented for two applications, being whole abdominopelvic radiotherapy (WAPRT) [2] and rectal cancer. Many uncertainties were introduced due to the implementation of this new technique. As clinicians, we had the following concerns:

1. Are the clinical constraints, eventually obtained in the treatment plan, also respected in the measured dose distribution?
2. What is the general dose computation error for IMAT planning? Is it larger than the computation error for conventional planning?
3. What is the accuracy of IMAT delivery by the linear accelerator (linac)?

As both gantry and leaves are constantly moving during treatment, tracking their position during delivery is hard to perform. We decided to measure the integrated dose of a clinical IMAT plan, in order to obtain an estimate of the final dosimetric accuracy of the treatment. Polymer gel dosimetry is unique in its ability to perform three-dimensional absolute dosimetry. We report on the use of polymer gel dosimetry for the validation of IMAT for rectal cancer.

2. Materials and methods

An anthropomorphic Barex (Cifra, Chateau Thierry, France) phantom was vacuum molded around the pelvic region of Rando (Alderson Research Laboratories, Stamford, USA). The gel-filled phantom was scanned by computed tomography (CT), and the anatomical structures (PTV, OARs) of a clinical rectal cancer case were transposed to this CT set after matching of the skin contours. An IMAT plan and a 3D conformal plan (3DCRT) were made. More details about our IMAT planning procedure are given elsewhere [2]. The IMAT planning was optimized and calculated on base of an 8° gantry angle discretization. The final control points (CPs) are prescribed to the linac, which interpolates the leaf positions between these CPs. Both plans (IMAT and 3DCRT) were calculated using the collapsed cone convolution/superposition algorithm from Pinnacle (Philips Medical Systems, Best, The Netherlands). Technical details about the polymer gel dosimetry (or accurate references to it), and the validation of polymer gel dosimetry for use in large phantoms can be found in reference [3]. Three polymer gel dosimetry measurements were performed, using the same phantom, and giving 7.5 Gy as a median dose to the PTV. The IMAT treatment was measured twice, once in dynamic arc mode.
(IMAT\textsubscript{d}, this is how IMAT is clinically executed), and once in static mode (IMAT, this is with IMRT beams every 8°, and reflects the way the IMAT plan is calculated). For each experiment, gel-filled test tubes from the same batch were irradiated to doses between 0 and 10 Gy for calibration purposes. The total irradiated phantom was measured in the MR scanner, together with the calibration test tubes. The measured dose distributions were then transferred to the planning system. An accurate position of both dose distributions in the planning system was acquired by contouring the gel on both the planning CT and the MRI, after which the centers of volumes of both structures were matched. Possible rotation errors were minimized by using (laser) line positioning on both the CT and the MRI scanner. Dose volume histograms (DVHs) for the PTV and for the small bowel were reconstructed and compared. Low’s $\gamma$-index [4] was calculated in 3D (dose difference criterion = 5%, distance to agreement 5 mm).

3. Results

DVHs are shown in figure 1. The relative differences in the median PTV dose between the calculated and the measured dose did not exceed 1.1%. The minimal dose ($D_1$) in the PTV was overestimated by 2.5% by the calculations, when compared to the measured dose (in both the static and the dynamic delivery). The largest relative difference in maximal PTV dose ($D_{99}$) was seen in the IMAT\textsubscript{d} experiment with a measured $D_{99}$ being 4% higher than the calculated one. The clinical constraints, which were imposed on the IMAT plans, were also met in the measured dose distribution. Measured dose to the small bowel was not higher than calculated, and thus confirmed that the small bowel is spared by IMAT. A $\gamma$-index > 1 was seen in 1.6%, 1.1% and 0.0% of the PTV volume in the IMAT\textsubscript{s}, the IMAT\textsubscript{d} and the 3DCRT experiment, respectively. The largest difference was seen for the bladder, where a relative difference in mean dose of 10% was found between calculated and measured dose in the IMAT\textsubscript{d} experiment. 12% of the partial volume of the bladder had a $\gamma$-index > 1 in the IMAT\textsubscript{d} measurement (for the 3DCRT, this was 0%).

![Figure 1. Dose Volume Histograms (DVHs), comparing the measured dose (full lines) with the calculated dose (dashed lines) for the dynamic IMAT delivery (a), the static IMAT delivery (b) and the 3DCRT treatment (c). DVHs are given for the PTV, small bowel and bladder. The bold dots represent the clinical planning constraints for the PTV.](https://example.com/figure1)

Dose contribution to the bladder in the IMAT plan is mainly by scatter and transmission, so calculation errors in scatter and transmission have a high impact on calculated bladder dose. The measured dose distribution showed a clinically satisfying correlation with the calculated dose distribution, as can be seen in figure 2. The ripples in the low dose regions are a consequence of the angular discretization of the calculations (figure 2a), and can also be seen in the dose distribution of IMAT\textsubscript{d}, (figure 2c). They disappear when the IMAT plan is executed with a dynamic gantry (IMAT\textsubscript{d}), as shown in figure 2b. Figure 3 shows the dose distributions as measured in the IMAT\textsubscript{d} experiment, showing the concave isodoses, created in order to spare small bowel.
Figure 2. Dose distribution of the IMAT plan, in a transverse plane, as calculated (a), and measured by polymer gel dosimetry in a dynamic (b) and static (c) delivery. Isodose lines are in Gy. The PTV is indicated in red.

Figure 3. Dose distributions in a coronal (a) and sagittal (b) plane, as measured with polymer gel dosimetry in the IMAT_d experiment. The PTV is indicated in red. The caudal part of the PTV was not within the phantom. Isodose lines are in Gy.

4. Discussion

Polymer gel dosimetry was used to validate IMAT for clinical use. It showed that:

1. The clinical planning constraints, specifying minimal and maximal PTV dose, were met both in the planning and in the IMAT execution.
2. The dose calculation for IMAT is as accurate as for a 3DCRT plan, and the calculated median PTV dose is within 1% of the measured one. The error due to interpolation during the execution is visible in the low dose regions, but does not affect the dose in the PTV and the small bowel.
3. The gel-measured dose distribution is in good correlation with the calculated plan, so we may assume that the delivery on the linac (leaf motion, gantry position, dose rate control…) is accurate.

As polymer gel dosimetry is a real 3D integrating absolute dosimeter (see figure 3), it is possible to answer some clinically relevant questions with a well-conceived experiment. The major difficulties we experienced in applying gel dosimetry were the production of the anthropomorphic phantom, the time consuming production of the gel, the limited volume of gel that could be produced in one batch (10 liter) and the availability of the MRI scanner.
A search on Medline (using “gel” and “dosimetry” in all fields, done 27 March 2004) yielded 163 publications. Of these, 113 papers dealt with gel dosimetry. There were 9 (8%) reviews/comments, 70 (62%) reports on technical development of gel dosimetry and 34 (30%) papers were discussing (possible) applications of gel dosimetry. In the latter group, only 14 (12%) of the papers reported on the use of gel dosimetry for clinical dosimetry, five of which dealt with brachytherapeutic sources. Although research in optimization of gel composition and measurement methods is – of course – very important, the author believes more effort should be done for making established polymer gel dosimetry methods available for clinical use.

5. Conclusion

Polymer gel dosimetry was used to verify the clinical use of IMAT. There was a satisfactory correlation between calculated and measured dose, thus validating the planning procedure, the calculation algorithm and the delivery. Although still elaborate and costly, polymer gel dosimetry has some unique features (3D absolute dosimetry) for verification of complex irradiation techniques.

References