International Journal of Cancer Therapy and Oncology
www.ijcto.org

The advantages of collimator optimization for intensity modulated radiation therapy

Brian E Doozan[1], Farrah Mohamed[2], Erika Nourishirazi[3], Silvia Pella[4], Theodora Leventouri[5]

[1]*Department of Radiation Oncology, South Florida Radiation Oncology, Wellington, Florida, United States*
[2]*Department of Physics, Washington University, St. Louis, Missouri, United States*
[3]*University of Miami Miller School of Medicine, Miami, Florida, United States*
[4]*Department of Radiation Oncology, South Florida Radiation Oncology, Wellington, Florida, United States*
[5]*Department of Physics, Medical Physics Program, Florida Atlantic University, Boca Raton, Florida, United States*

Received September 09, 2016; Revised April 3, 2017; Accepted July 15, 2017; Published Online August 28, 2017

Technical Report

Abstract

Purpose: The goal of this study was to improve dosimetry for pelvic, head and neck and other cancers with aspherical planning target volumes (PTV) using collimator optimization for intensity modulated radiation therapy (IMRT). **Methods:** A retroactive study on the effects of collimator optimization of 20 patients was done by comparing collimator angles from optimized plans in *Eclipse* version 11.0. Keeping all other parameters equal, plans were created with four collimator techniques: CA_0, all fields have collimators set to 0°, CA_E, using the Eclipse collimator optimization, CA_A, minimizing the area of the jaws around the PTV, and CA_X, minimizing the x-jaw gap. The minimum area and the minimum x-jaw angles were found by evaluating each field beam's eye view of the PTV with *ImageJ* and finding the desired parameters with a custom script. The evaluation of the plans included the monitor units (MU), the maximum dose of the plan, the maximum dose to organs at risk (OAR), the conformity index (CI) and the number of split fields. **Results**: Compared to the CA_0 plans, the monitor units decreased on average by 6% for the CA_X with a p-value of 0.01 from an ANOVA test. The average maximum dose stayed within 1.1% between all four methods with the lowest being CA_X. The maximum dose to the most at risk organ was best spared by the CA_A, which decreased by 0.62% from the CA_0. Minimizing the x-jaws significantly reduced the number of split field from 61 to 37. **Conclusion:** In every field tested the CA_X optimization produced as good or superior results than the other three techniques. For aspherical PTVs, CA_X on average reduced the number of split fields, the maximum dose, minimized the dose to the surrounding OAR, and reduced the MU all while achieving the same control of the PTV.

Keywords: Dosimetry, Collimator optimization, Radiation planning, IMRT, Monitor units, Split fields

1. Introduction

About half of all cancer patients undergo radiation at some point in their treatment.[1] Depending on the type of cancer and severity, roughly half of the patients that receive radiation are inversely planned using intensity modulated radiation therapy (IMRT). In the case of pelvic, lung and head and neck cancers, the usage of IMRT becomes more frequent.[2, 3] Most of these are planned with a single collimator angle using a sliding window or step-and-shoot technique for delivery.[4]

Radiation therapy alone or in combination with chemotherapy or surgery offers numerous advantages over solely chemotherapeutic or surgical treatment of cancers. Radiation can provide local and targeted treatment of tumor, therefore decreasing the systemic adverse effects caused by chemotherapy.[5] Furthermore, radiation therapy for prostate cancer reduces complications seen after prostectomy, including erectile dysfunction and urinary incontinence.[6] For non-small cell lung cancer, chemoradiation has been shown to give

Corresponding author: Brian E. Doozan; Department of Radiation Oncology, South Florida Radiation Oncology, Wellington, Florida, United States.

***Cite this article as**: Doozan B. The Advantages of Collimator Optimization for Intensity Modulated Radiation Therapy. Int J Cancer Ther Oncol. 2017; 5(1):517. **DOI:** 10.14319/ijcto.51.7*

ISSN 2330-4049

statistically significant benefits in terms of survival rates than chemotherapy alone, and allows for treatment in areas of the lung deemed inoperable.[7]

Cancer therapy has been revolutionized with the introduction of IMRT and multileaf collimators (MLC).[8-13] With the use of IMRT, planning can be made accurately to conform to the shape of a tumor, helping to treat patients suffering from cancers while minimizing the dose to surrounding tissue. MLCs are used to shape beams delivered in IMRT, allowing for an optimal dose to reach the tumor while minimizing the dose to surrounding areas and organs. The use of IMRT is already used with large rates of success in sparing normal tissue and the majority of those are all planned with a single collimator angle.[14] There could be several reasons why many dosimetrists avoid using multiple collimator angles including reducing the length of treatment delivery, unsure of what angles to use or simply because they see little or no benefit in the rotation. However, there is evidence that collimator rotation can provide positive effects on a plan and help to reduce the monitor units (MU), eliminate or minimize the number of split fields and lower overlapping interleaf leakage.

The goal of this study is to elucidate on conflicting reports about collimator optimization with IMRT. Publications from Chapek *et al.* showed differences in IMRT collimator rotations with pelvic cases, while other articles have stated that the fluence was largely independent from collimator angles.[15, 16] Using the presented techniques in collimator optimization to minimize different the x-jaw gap or the area of the jaws can influence the quality of a plan.

2. Methods and Materials

2.1. Programs and TPS

All of the treatments in the present study had been planned using *Eclipse* version 11.0. Patients in the study had been treated within the last two years. The treatment plans used were all done by trained dosimetrists. The treatment plans in the study were then replanned with the four collimator optimizations using the same dose constraints and normalization parameters as the original plan.

For the CA_A and CA_X cases, the values were determined through a script that was created by the authors in *ImageJ*. An image of the PTV was taken for each field with the beam's eye view in *Eclipse*. A script was written to analyze using a minimum bounding box at intervals of one degree of rotation. The values of the box were found for the set of possible collimator angles and the minimum parameters for the x-jaw gap and area of the jaws were recorded for CA_X and CA_A, respectively.

2.2. Patient selection

Twenty patient cases that consisted of pelvic (10), lung (5) and head and neck (5) cancers were studied. The criteria for a selected case were that they had already been treated with an IMRT plan and that the PTV was greater than 100 cc and aspherical. Breast patients were avoided because collimator rotation is routinely implemented for such plans. Small lesions were dismissed due to the small number leaves that would intersect the radiation field. Spherical PTVs pose the problem that can lead to a non-unique solution. Patients selected had been treated on Varian IX, TrueBeam and Trilogy accelerators that use 120 leaves for dose modulation. All plans were originally created by experienced dosimetrists and replanned with the original constraints. To keep the plans fair, no fluence editing was done after the optimization and plans were normalized to the same value.

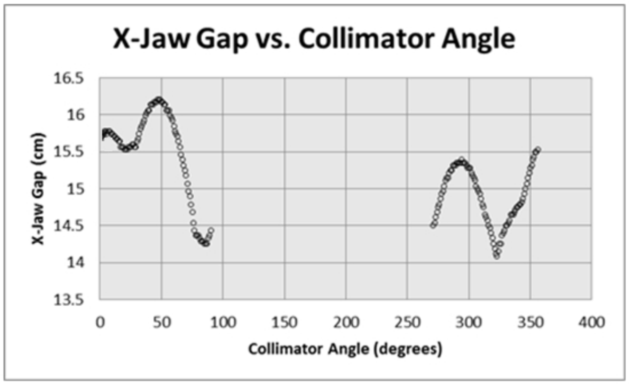

Figure 1: A plot of the x-jaw gap vs collimator angle for a pelvic field that could split. The program was run to find the minimum value. The angles between 91-270 degrees were unused to avoid redundancy as well as angle limitations for the collimator.

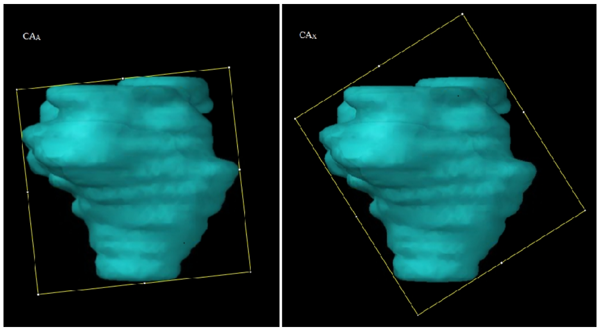

Figure 2: The box surrounding the PTV in ImageJ for the minimum area and the minimum x-jaw distance gives the angles for CA_A and CA_X.

2.3. Method of study

Each patient case was first evaluated for the criteria that it was planned and approved for treatment using IMRT. Screen captures of the PTV were taken through the beam's eye view for each of the fields. The images were run through the custom script in *ImageJ* and the results of the CA_A and CA_X were calculated. The optimization process to find the minimum x-jaw gap is graphed in Figure 1. The fields analyze angles between 0 and 90 degrees and 271-359 degrees. This allows accommodating all possible results without the redundancy angles. Figure 2 shows the jaw positions for the CA_A and CA_X for a test field after the minimization process.

For the CA_E plan, each field was set to optimize the collimator angle using the *Eclipse* algorithm to calculate the ideal angle. The four plans were then set to run in *Eclipse* being generated as a new plan through the IMRT optimization. The program was allowed to run to completion and each plan was normalized to give equivalent planning target volume (PTV) coverage as the original plan without editing the fluence. The differences between each test were evaluated with an analysis of variance (ANOVA) statistical evaluation comparing each method for the six metrics.

2.4. Plan Evaluation

There were six metrics for which the plans were evaluated: the total number of monitor units, the maximum dose in the plan, the maximum dose to the two most relevant organs at risk, the number of split fields and the conformality index (CI), which was defined using equation (1)

$$CI = \frac{V_{100\%}}{V_{PTV}}. \qquad (1)$$

The total MU measured for each plan is based on a single fraction of 180 cGy. For evaluation purposes the differences from the plans are based on the normalized CA_0 plan. This will render any effects of higher prescriptions to hold the same weight for comparisons. A typical fraction prescription dose for the plans was 180 cGy but ranged as high as 1000 cGy for lung stereotactic cases. The maximum dose to the plan is checked so that it is inside of the PTV. For pelvic cases, the organs at risk (OARs) consisted of the bladder and the rectum. For lung cases, the OAR varied between the heart, esophagus, spinal cord and contralateral lung. In the head and neck patients, the OAR reviewed included the parotids, larynx, esophagus, brainstem and mandible. The two highest OAR were taken as OAR_1 and OAR_2 and normalized between plans for comparison to the CA_0 plan. Split fields were generated automatically with the *Eclipse* optimization when the x-jaw gap exceeded 14.5 cm. Figure 3 shows the setup from the four optimizations. The CA_A has the PTV covered by the jaws due to the field splitting. The subfield matched the line of the jaw to provide the additional coverage of the PTV.

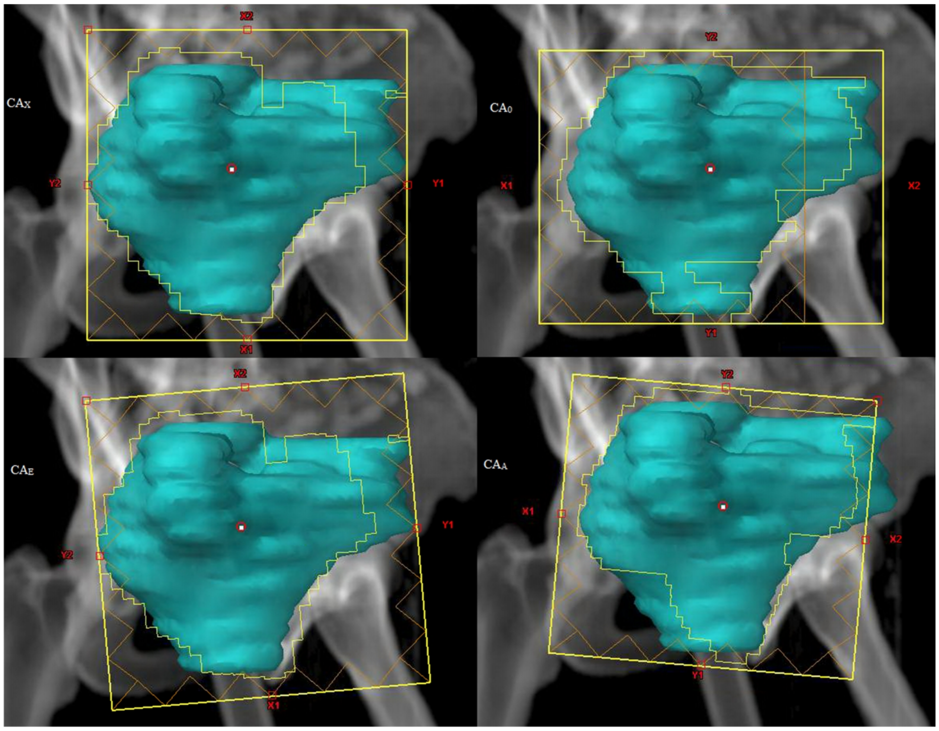

Figure 3: The four configurations for collimator angles are shown for a pelvic case. The field for CA_A has the jaws covering the edge of the PTV. A subfield moved the jaws to cover the additional PTV.

Table 1: A comparison of the six metrics for each modality of collimator optimization.

	CA_0	CA_E	CA_A	CA_X
Avg MU	1376	1350	1385	1293
Avg Plan Max Dose	110.09%	110.26%	110.31%	109.83%
Avg Max to OAR_1	103.47%	103.49%	102.42%	102.94%
Avg Max to OAR_2	101.48%	102.20%	101.13%	101.22%
Avg CI	1.039	1.045	1.037	1.040
Total Split Fields	61	63	60	37

Table 2: A one way ANOVA results for each metric. The statistically significant p-values are highlighted and show a reduced MU in CA_X compared to CA_0 and CA_A as well as a decrease in split fields with CA_X against all other methods.

	CA_0 vs CA_E	CA_0 vs CA_A	CA_0 vs CA_X	CA_E vs CA_X	CA_E vs CA_A	CA_A vs CA_X
Monitor Units (MU)	0.20	0.67	0.01	0.31	0.27	0.05
Maximum Dose	0.32	0.49	0.56	0.92	0.42	0.37
Max to OAR_1	0.99	0.79	0.89	0.89	0.78	0.89
Max to OAR_2	0.87	0.94	0.96	0.81	0.81	0.79
Conformality Index	0.88	0.97	0.97	0.91	0.84	0.94
Split Fields	0.26	1.00	0.02	0.01	0.84	0.02

3. Results

The results of the study are summarized in Table 1. Most of the parameters showed insignificant changes between the four different techniques. The only optimization that had statistical significance came from the plans run with CA_X, which showed changes in the MU and the split fields. The results of the ANOVA tests are summarized in Table 2. There was a decrease in MU by 6% on average from the CA_0 method and the lowest of the four tested arrangements. A decrease in MU is desirable as it leads to less radiation time and therefore lower doses of leaked radiation through the gantry head.

The maximum dose on average to the 20 patients was with the CA_X optimization, followed by the CA_E. No method offered a statistically significant advantage on average, although variations in individual plans are worth noting. A lower value of the maximum dose after optimization can help to improve the overall coverage of the PTV by allowing more flexibility in the normalization process. Another advantage to the lowered maximum dose in planning occurs when there is an abutting serial organ, where the dose constraint is often measured by looking at the maximum dose, such as the spinal cord.

The dose at the OAR_1 became the lowest by minimizing the area of the jaws that is exposed to the treatment field. The primary OAR in this case was that which was closest to the PTV. For the CA_A method, covering the most area with the jaws reduced the maximum dose to the OAR_1 by 1.4% from the CA_0 plans. The second lowest was from the CA_X method, which lowered it by about 1.0%, although the difference was not enough in either case to quantify as statistically significant. The OAR_2, which was determined in the plans as the second most vulnerable organ per patient, was also lowered by the two methods, though CA_X did slightly better by decreasing the maximum dose by 1.0% and CA_A by 0.6% from the CA_0 plans.

The confomality index was almost identical for all four methods on average at a value of 1.04. All plans were normalized to the same value per patient. Little difference and nothing statistically significant were found for any individual plans for each of the four methods, indicating similar $V_{100\%}$ volumes regardless of the method exercised. A value of 1.00 is desirable, indicating that the volume of the 100% is the same as the PTV. Although the information that can be derived from the confomality index is limited, it does suggest that similar tumor control is delivered independently from collimator angle.

Split fields were greatly reduced by using the CA_X approach. In the 20 plans tested, there were nine that produced split fields. Since a field will split when the MLC moves more than 14.5 cm due to the limited range of the MLC leaves, rotating the jaws to minimize this was shown to lower the incidence. The number of split fields reduced from 61 with CA_0 to 36 with CA_X. It is worth noting that CA_E increased slightly to 63. At times, the CA_E worked well in reducing the split fields while others it picked angles that caused a split. Similarly, CA_A, which had 60, looks for the first minimization as it is known that a 90º rotation will give an identical area.

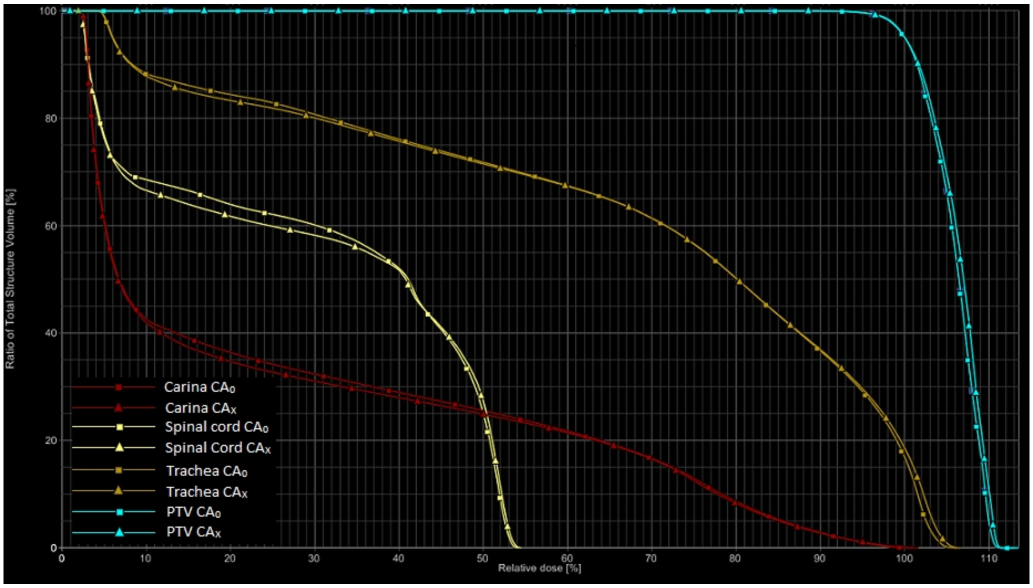

Figure 4: A dose-volume histogram (DVH) of the CA0 and CA¬X plans for a head and neck case. The CAX reduced the dose for the spinal cord, trachea and carina in large volumes of each OAR.

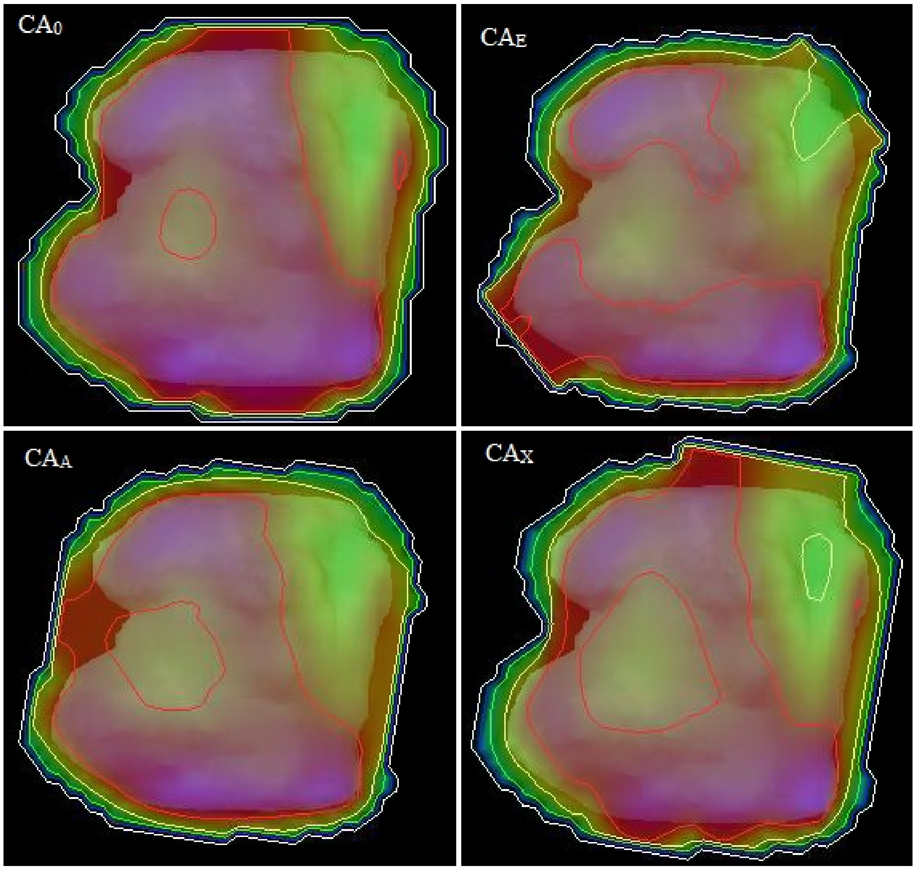

Figure 5: Fluence models of the four configurations for field. The fluence determines the leaf motion. Higher gradients can lead to more modulation, which can increase the MU and deviations from the planned and delivered treatment.

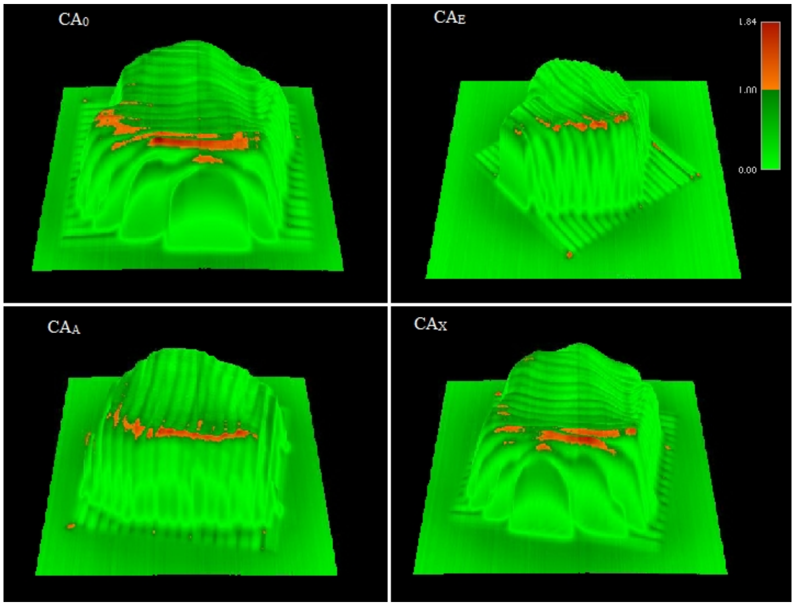

Figure 6: A delivered portal dosimetry with four planned collimator methods for a single field. The red areas indicate higher deviations from the planned and delivered.

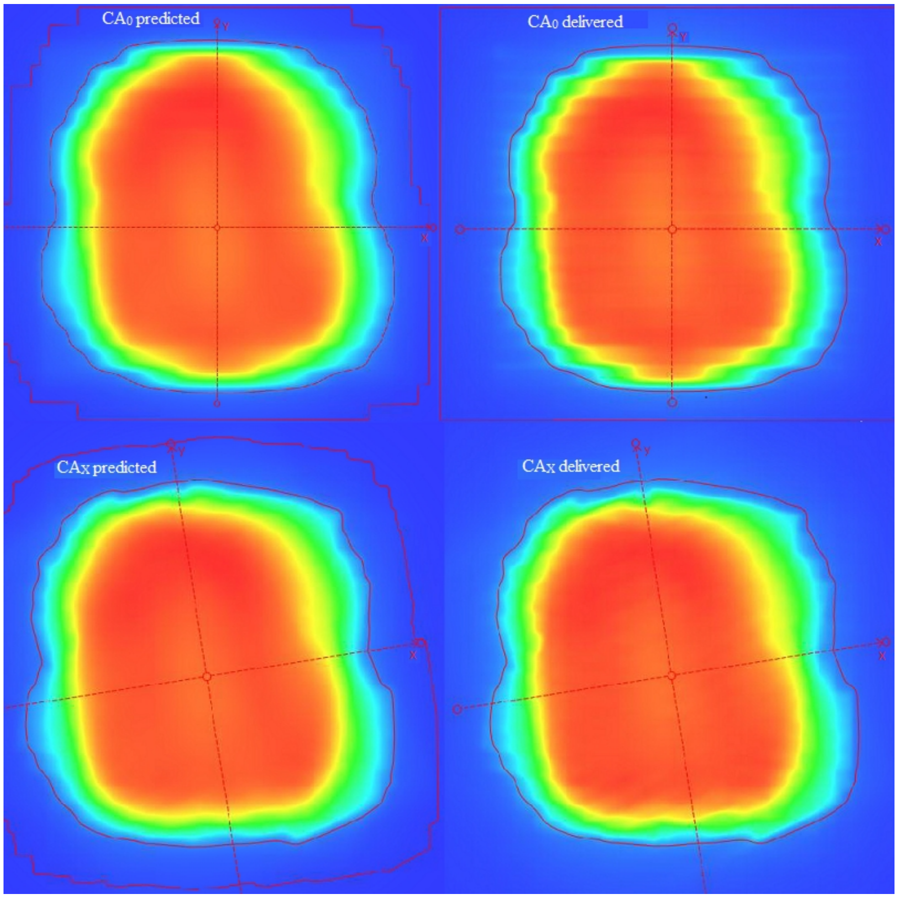

Figure 7: The portal dosimetry calculation for a treatment sum with nine fields between the CA0 and CAX. The interleaf leakage effects add to give a noticeable difference in the CA0 plan, while rotating the collimator between fields gives a more desirable distribution.

4. Discussion and Conclusion

It has been shown that for large (> 100 cc) tumors in the pelvic, head and neck and lung lesions that collimator rotation can statistically impact a plan. By using a CA_X approach, a planner can decrease the MU and minimize the number of split fields for a plan. This helps reduce the amount of time a patient is being exposed to leakage from the machine and better care for secondary risks. While decreased MU leads to lower radiation time, rotation of the collimator can add time that a patient is on the table. To avoid adding treatment time, rotation of the collimator should be less than the gantry angle differences between fields, since the collimator rotates slower than then gantry angular speed.

While the maximum dose is an important factor in evaluating the risk for an organ, a comprehensive look at the volume constraints for OAR is necessary for determining the safety of a plan. The DVH for a lung case between the CA_X and CA_0 is seen in Figure 4 for the spinal cord, trachea, carina and PTV. The largest differences between the methods were observed in the higher volumes of the organs.

While plans may look good on a computer, the actual results can vary. Figure 5 shows the fluence of a test field for a pelvic case. High gradient fluence can be increasingly difficult to model and accurately deliver. Figure 6 shows the same field delivered on an electronic portal imaging device (EPID) and analyzed with portal dosimetry. The red shows differences between the planned dose with that of the delivered for the four methods. Another benefit to collimator rotation between fields is shown in Figure 7, which shows the interleaf leakage that adds up in the CA_0 plan. By rotating the collimator between fields, the interleaf leakage is smoothed out, which can be seen in the delivered plan with CA_X.

While determining the angle to minimize the x-jaw gap is often easy to guess based on the geometry, there were cases that the solution was not so obvious. Many cases involved pelvic and head and neck cases that had a PTV measure close the 14.5 cm threshold for splitting. A small deviation from the lowest angle with such a PTV can cause an unnecessary field split. There is more benefit in preventing this than just the time for a patient to be treated. The match lines are prone to errors that are proportional to the slope of the penumbra from the sub-fields. If a patient is slightly out of alignment, an under or over exposure is the result.

Conflict of Interest

The authors declare that they have no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

References

1. Comprehensive Cancer Information. National Cancer Institute. Retrieved on August 1, 2016.
2. Maceira Rozas Mdel C, Rey Liste T, García Caeiro AL, *et al*. Recommendations for treatment with IMRT for prostate and head-neck cancer. Axencia de Avaliación de Tecnoloxías Sanitarias de Galicia. Clin Transl Oncol. 2006;8(4):262-5.
3. Carlson RH. Large, prospective study shows less toxicity with IMRT in locally advanced NSCLC. Oncol Times. 2015;37(24):6.
4. Badusha MA, Mcgarry CK. Practical collimator optimization in the management of prostate IMRT planning: A feasibility study. J Radiother Pract. 2011;11(02):107-15.
5. Shapiro CL, Recht A. Side effects of adjuvant treatment of breast cancer. N Engl J Med. 2001;344(26):1997-2008.
6. Glatstein E, Morrow M. Five-year outcomes after prostatectomy or radiotherapy for prostate cancer: The prostate cancer outcomes study. Yearbook of Oncology. 2006(2006): 146-9.
7. Provencio M, Isla D, Sánchez A, *et al*. Inoperable stage III non-small cell lung cancer: Current treatment and role of vinorelbine. J Thorac Dis. 2011;3(3):197-204.
8. Peñagarícano JA, Ratanatharathorn V, Papanikolaou N, *et al*. Intensity-modulated radiation therapy reduces the dose to normal tissue in T2N0M0squamous cell carcinoma of the glottic larynx. Med Dosim. 2004;29(4): 254-7.
9. Bucci MK, Bevan A, Roach M 3rd. Advances in radiation therapy: conventional to 3D, to IMRT, to 4D, and beyond. CA Cancer J Clin. 2005;55(2) :117-34.
10. Agarwal J, Rathod S, Murthy V, *et al.* Improved quality of Life (QOL) outcomes in patients with head-and-neck squamous cell carcinoma (HNSCC) treated with Intensity Modulated Radiation Therapy (IMRT) compared to 3-dimensional Conformal Radiation Therapy (3D-CRT): Evidence from a prospective randomized study. Int J Radiat Oncol Biol Phys. 2012;84(3).
11. Young CD, Speight JL, Akazawa PF, *et al*. Improved conformal coverage of the prostate with an IMRT potency-sparing technique. Int J Radiat Oncol Biol Phys. 2000;48(3):351.
12. Vergeer, MR, Doornaert PA, Rietveld DH, *et al*. Significant reduction of radiation-induced xerostomia in head and neck cancer with Intensity Modulated Radiotherapy (IMRT) compared to conventional 3D-Conformal

Radiotherapy (3D-CRT). Int J Radiat Oncol Biol Phys. 2007;69(3).

13. Luxton G, Hancock SL, Boyer AL. Dosimetry and radiobiologic model comparison of IMRT and 3D conformal radiotherapy in treatment of carcinoma of the prostate. Int J Radiat Oncol Biol Phys. 2004;59(1):267-84.
14. Gunderson, Leonard L, Joel E. Tepper. Clinical Radiation Oncology. Philadelphia, PA: Elsevier Churchill Livingstone. 2007;293-4.
15. Kataria T, Rawat S, Sinha SN, *et al*. Intensity modulated radiotherapy in abdominal malignancies: our experience in reducing the dose to normal structures as compared to the gross tumor. J Cancer Res Ther. 2006;2(4): 161-5.
16. Chapek J, Tobler M, Toy BJ, *et al*. Optimization of collimator parameters to reduce rectal dose in intensity-modulated prostate treatment planning. Med Dosim. 2005;30(4):205-12.