The advantages of collimator optimization for intensity modulated radiation therapy

Brian E Doozan¹, Farrah Mohamed², Erika Nourishirazi³, Silvia Pella⁴, Theodora Leventouri⁵

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

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: CA₀, all fields have collimators set to 0°, CAₑ, using the Eclipse collimator optimization, CAₐ, minimizing the area of the jaws around the PTV, and CAₓ, 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 CA₀ plans, the monitor units decreased on average by 6% for the CAₓ 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 CAₓ. The maximum dose to the most at risk organ was best spared by the CAₐ, which decreased by 0.62% from the CA₀. Minimizing the x-jaws significantly reduced the number of split field from 61 to 37. Conclusion: In every field tested the CAₓ optimization produced as good or superior results than the other three techniques. For aspherical PTVs, CAₓ 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 to 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...
statistically significant benefits in terms of survival rates than chemotherapy alone, and allows for treatment in areas of the lung deemed inoperable.\textsuperscript{7}

Cancer therapy has been revolutionized with the introduction of IMRT and multileaf collimators (MLC).\textsuperscript{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.\textsuperscript{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.\textsuperscript{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\textsubscript{A} and CA\textsubscript{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\textsubscript{X} and CA\textsubscript{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.](image1)

![Figure 2: The box surrounding the PTV in ImageJ for the minimum area and the minimum x-jaw distance gives the angles for CA\textsubscript{A} and CA\textsubscript{X}.](image2)
of the CA\textsubscript{A} and CA\textsubscript{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\textsubscript{A} and CA\textsubscript{X} for a test field after the minimization process.

For the CA\textsubscript{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)

\[ CI = \frac{V_{\text{HEP}}}{V_{\text{PTV}}} . \]

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\textsubscript{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\textsubscript{1} and OAR\textsubscript{2} and normalized between plans for comparison to the CA\textsubscript{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\textsubscript{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](image_url)
Table 1: A comparison of the six metrics for each modality of collimator optimization.

<table>
<thead>
<tr>
<th></th>
<th>CA₀</th>
<th>CAₑ</th>
<th>CAₐ</th>
<th>CAₓ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg MU</td>
<td>1376</td>
<td>1350</td>
<td>1385</td>
<td>1293</td>
</tr>
<tr>
<td>Avg Plan Max Dose</td>
<td>110.09%</td>
<td>110.26%</td>
<td>110.31%</td>
<td>109.83%</td>
</tr>
<tr>
<td>Avg Max to OAR₁</td>
<td>103.47%</td>
<td>103.49%</td>
<td>102.42%</td>
<td>102.94%</td>
</tr>
<tr>
<td>Avg Max to OAR₂</td>
<td>101.48%</td>
<td>102.20%</td>
<td>101.13%</td>
<td>101.22%</td>
</tr>
<tr>
<td>Avg CI</td>
<td>1.039</td>
<td>1.045</td>
<td>1.037</td>
<td>1.040</td>
</tr>
<tr>
<td>Total Split Fields</td>
<td>61</td>
<td>63</td>
<td>60</td>
<td>37</td>
</tr>
</tbody>
</table>

Table 2: A one way ANOVA results for each metric. The statistically significant p-values are highlighted and show a reduced MU in CAₓ compared to CA₀ and CAₐ as well as a decrease in split fields with CAₓ against all other methods.

<table>
<thead>
<tr>
<th></th>
<th>CA₀ vs CAₑ</th>
<th>CA₀ vs CAₐ</th>
<th>CAₑ vs CAₐ</th>
<th>CAₑ vs CAₓ</th>
<th>CAₐ vs CAₓ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monitor Units (MU)</td>
<td>0.20</td>
<td>0.67</td>
<td>0.01</td>
<td>0.31</td>
<td>0.27</td>
</tr>
<tr>
<td>Maximum Dose</td>
<td>0.32</td>
<td>0.49</td>
<td>0.56</td>
<td>0.92</td>
<td>0.42</td>
</tr>
<tr>
<td>Max to OAR₁</td>
<td>0.99</td>
<td>0.79</td>
<td>0.89</td>
<td>0.89</td>
<td>0.78</td>
</tr>
<tr>
<td>Max to OAR₂</td>
<td>0.87</td>
<td>0.94</td>
<td>0.96</td>
<td>0.81</td>
<td>0.81</td>
</tr>
<tr>
<td>Conformality Index</td>
<td>0.88</td>
<td>0.97</td>
<td>0.97</td>
<td>0.91</td>
<td>0.84</td>
</tr>
<tr>
<td>Split Fields</td>
<td>0.26</td>
<td>1.00</td>
<td>0.02</td>
<td>0.01</td>
<td>0.84</td>
</tr>
</tbody>
</table>

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 CAₓ, 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 CA₀ 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 CAₓ optimization, followed by the CAₑ. 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 OAR₁ 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 CAₐ method, covering the most area with the jaws reduced the maximum dose to the OAR₁ by 1.4% from the CA₀ plans. The second lowest was from the CAₓ method, which lowered it by about 1.0%, although the difference was not enough in either case to quantify as statistically significant. The OAR₂, which was determined in the plans as the second most vulnerable organ per patient, was also lowered by the two methods, though CAₓ did slightly better by decreasing the maximum dose by 1.0% and CAₐ by 0.6% from the CA₀ plans.

The conformality 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 V₁₀₀% 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 conformality index is limited, it does suggest that similar tumor control is delivered independently from collimator angle.

Split fields were greatly reduced by using the CAₓ 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 CA₀ to 36 with CAₓ. It is worth noting that CAₑ increased slightly to 63. At times, the CAₑ worked well in reducing the split fields while others it picked angles that caused a split. Similarly, CAₐ, 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 CAₓ 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 CAx 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 CAx and CA0 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 CA0 plan. By rotating the collimator between fields, the interleaf leakage is smoothed out, which can be seen in the delivered plan with CAx.

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.

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