Comparison of Leaf Sequencing Techniques: Dynamic vs. Multiple Static Segments

H. Gőrkem Kuterdem[1], Paul S. Cho[1,2], Robert J Marks II[1], Mark H Phillips[2] and Homayoon Parsaei [2]
[1]Department of Electrical Engineering, University of Washington, Seattle, WA 98195-2500, USA and [2]Department of Radiation Oncology, University of Washington, Seattle, WA 98195-6043, USA

Introduction

Static and dynamic multileaf collimation have been so far identified as two fundementally different methods of intensity modulation in radiotherapy. In multiple static collimation, the desired fluence is deposited using two steps: In the first step, the leaves (and the backup diaphragms if available) are moved to create the desired field, but no radiation is delivered in this step. In the second step, the beam is turned on, but no leaf motion occurs. This process is repeated for each static field until the desired fluence deposition has been obtained. This type of delivery has been chiefly used for the delivery of plans with constant fluence levels over several contiguous bixels.

In dynamic multileaf collimation, the beam is turned on in the beginning of the delivery, and is turned off once the desired fluence profile is obtained, the leaves and the diaphragms being in motion during the delivery. This method has the obvious advantage of increased speed of delivery, in addition to the ability to create smoother gradients along directions of leaf travel. This method, by its very nature, lends itself to be used for the delivery of fluence profiles with rapid changes of intensity, and when the intensity levels do not remain constant over successive bixels or when the bixel sizes are small with respect to the MLC gap constraints. Convery and Webb [1] have also used this method to deliver fields with constant fluence levels.

At the University of Washington, software has been developed that can translate either kind of fluence profile, namely, smoothly varying or discrete. At the current iteration of the software, both types of profiles can be directly translated, or can be preprocessed with such tools as intensity level quantization, spatial subsampling with averaging, spatial oversampling with interpolation and then translated. The translations were designed to minimize tongue-and-groove underdosages [2] and honor the minimum gap constraints of the Elekta MLC (Elekta Oncology Systems, Crawley, UK).

The purpose of this work is to compare the above mentioned techniques of delivery in terms of such factors as efficiency of delivery, total expected time for delivery, total number of segments, tongue-and-groove underdosage, and RMS error (as calculated in delivery simulation).

Materials and Methods

The following software was developed to handle the different translation needs for the Elekta SL20 MLC for different fluence profiles. Both the dynamic and the static collimation translators have been designed with the MLC constraints (such as minimum gap requirements, leaf velocities, allowable dose rates etc.) in mind, while trying to reduce the delivery error, decrease the total delivery time and facilitate verification.

Dynamic Multileaf Collimation

Translation of fluence to MLC time-position sequence is performed through the use of *XYLate-D* program which has been developed in house [3]. The fluence profile is input to the software, which then sets the velocities of the left and right bank leaves in accordance with the slope of the fluence profile at a given point [4] and then synchronizes the leaves to minimize tongue-and-groove underdosages [2] and minimum gap constraint violations [3][5]. Furthermore, the backup diaphragms are extensively used to overcome the limitations imposed by the minimum gap constraints.

This method requires preprocessing to be able to cope with prescriptions which have coarse bixel widths comparable to the minimum gap requirements of the MLC. These profiles are characterized with isolated points of large gradients and large regions of zero gradient, which make it difficult to set the leaf velocities efficiently. This problem is overcome with the usage of a preprocessor which spatially interpolates the given profile.

Static Multileaf Collimation

Another software named *XYLate-S* was developed in house to provide the static multileaf collimation translation services. The software first separates the fluence profile along each track into its components. The algorithm then assembles the components into control points to be sequenced, avoiding assembling components which would violate the minimum gap constraints into the same control point. The control point that outlines the fluence profile is scheduled first, to allow for portal imaging and verification of the dose. The remaining control points are then optimized such that the total leaf travel is minimized. Tongue-and-groove underdosages are minimized through the original control point assembly process, it is not possible to completely eliminate tongue-and-groove artifacts in static delivery using only the MLC leaves[6].

There are two other optional features of *XYLate-S*: Intensity level quantization and spatial subsampling with averaging. At the user's discretion, the fluence profile that was input to the translator can be quantized to any desired

number of levels, which decreases the number of segments at the expense of increased delivery error. The quantization method chosen is a uniform quantization scheme, with the maximum intensity of the given profile and the zero intensity level being two of the chosen levels, with the remaining levels chosen in equally spaced intervals between these two extreme values.

Spatial subsampling can be used to merge the bixels of the fluence profile, to make the profile easier to translate, especially if the subsampling level is such that the resulting bixel width that is larger than the minimum gap requirements of the MLC. The subsampling level is user specified and accomplished by merging the bixels and assigning the average of the intensity levels of the merged bixels as the intensity level of the newly created bixel.

Delivery Simulation

In-air fluence due to primary radiation passing through the MLC opening was calculated by the *vdel* program. For dynamic sequencing the program accounts for the motion of the leaves and diaphragms to accurately simulate the accumulation of photon fluence. The program compares the simulated in-air profile with the prescription and computes RMS errors, maximum underdosage, maximum overdosage, delivery efficiency, and RMS tongue-and-groove underdosage. Delivery efficiency is given by

$$E_{ff} = \frac{\text{Max peak MU}}{\text{Total MU required for delivery}} \qquad (1)$$

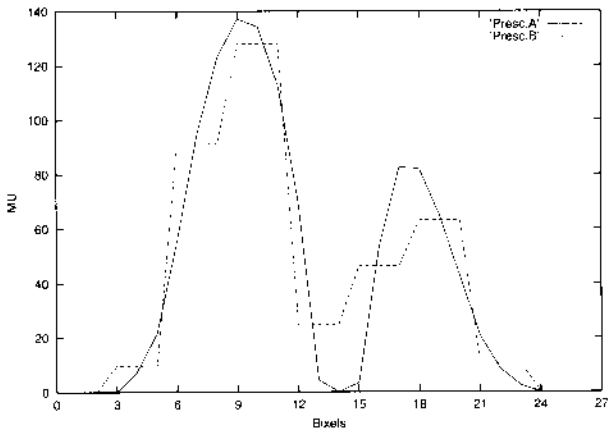

Figure 1: Third track of the test prescriptions

Results and discussion

To compare the merits of various translation strategies, two test prescriptions consisting of 6 MLC tracks were used. Test prescription A has a bixel width of 0.33 cm which is less than the current minimum gap requirement of the Elekta MLC (1.0 cm). The maximum fluence value was 144 MU. Test prescription B has a bixel width of 1 cm, with a maximum fluence value of 136 MU. Figure 1 shows the third track of these test prescriptions. Test prescription A was translated both dynamically and statically (Translation 1 and 2, respectively). Test prescription B was then translated dynamically, with and without interpolation, and statically (Translations 3, 4, and 5, respectively). The parameters of each translation are listed in Table 1.

The machine-related translation parameters were dose rate of 400 MU/min, 1 cm/s maximum leaf and diaphragm velocities, and 1 cm minimum gap requirement. X diaphragm (the one that moves perpendicular to the MLC) pauses were allowed for the dynamic mode. An average beam pause duration of 7 seconds was assumed in estimation of total delivery time.

The results of performance comparison are presented in Tables 2 and 3. Comparison of dynamic and static translation of a profile with fine bixel resolution (Translation 1 and 2) indicates that the dynamic translation scheme achieves low RMS errors with few beam pauses and moderate efficiency, while the multiple static segments can achieve even lower RMS errors if efficiency could be sacrificed. However, the total MU and delivery time required are prohibitively high, thus rendering the static method virtually impractical in this case.

As expected, the dynamic translation algorithm used cannot efficiently cope with prescriptions with large bixel widths without interpolation (Translation 4). In this case, the distance between the bixels is too large for the algorithm to set the leaf velocities with the required precision. When coupled with oversampling, however, the dynamic translation can achieve a high level of performance as seen in the statistics for Translation 3. It is important to note that the static collimation scheme outperforms the dynamic collimation in this case, by presenting a much lower RMS error value without significant efficiency penalties. However, in comparing Translations 3 and 5, we note that while the two translations have the same total beam-on time, the total time required for Translation 5 is almost six times that of Translation 3 due to the number of pauses required to create the static fields. It is expected that, in the next iteration of the MLC control hardware and software, the time for the MLC to recover from a beam pause will be less than one second, in which case the static collimation should also be comparable to the dynamic collimation in terms of total delivery time.

No significant tongue-and-groove underdosages were observed for any of the translations, except for a small residual underdosage in the static translations.

Conclusions

While, in general, the multiple static collimation method yielded lower RMS errors for a given prescription, the gain in error reduction over the dynamic sequencing may not be clinically significant. If this is true, then clearly the dy-

namic delivery would be the more efficient method of the two. On the other hand, for coarsely quantized modulation the multiple static scheme may be just as efficient, especially if the duration of beam on/off cycle is made near instantaneous.

Acknowledgement

This work was supported in part by a grant from the Whitaker Foundation.

References

[1] Convery D J and Webb S 1998 Generation of discrete beam intensity modulation by dynamic multileaf collimation under minimum leaf seperation constraints *Phys. Med. Biol.* **39** 231–251

[2] van Santvoort J P C and Heijmen B J M 1996 Dynamic multileaf collimation without 'tongue-and-groove' underdosage effects *Phys. Med. Biol.* **41** 2091–2105

[3] Kuterdem H, Cho P and Marks II R 1999 Dynamic multileaf-diaphragm sequencing with adjacency gap constraints *Med. Phys.* **26** 1136

[4] Boyer A L and Strait J P 1997 Delivery of intensity-modulated treatments with dynamic multileaf collimator in *Proceedings of the XIIth ICCR* 13–15

[5] Budgell G J, Sykes J R and Wilkinson J M 1998 Rectangular edge synchronization for intensity modulated radiation radiation therapy with dynamic multileaf collimation *Phys. Med. Biol.* **43** 2769–2784

[6] Xia P and Verhey L J 1998 Multileaf leaf sequencing algorithm for intensity modulated beams with multiple static segments *Med. Phys.* **25** 1424–1434

Trans.	Presc.	Input bixel width (cm)	Trans. bixel width (cm)	Trans. type
1	A	0.33	0.33	Dynamic
2	A	0.33	0.33	Static
3	B	1.00	0.10	Dynamic
4	B	1.00	1.00	Dynamic
5	B	1.00	1.00	Static

Table 1: Translation parameters

Trans. #	# of ctrl. pts	RMS Error (MU)	TG (MU) underdosage	Eff.
1	100	2.16	0.0	0.38
2	246	0.94	0.3	0.05
3	159	2.51	0.0	0.44
4	48	20.38	0.0	0.44
5	92	0.18	0.4	0.45

Table 2: Translation results

Trans. #	# of pauses	Tot. MU	Beam-on time (sec)	Time to deliv (sec)
1	5	378	57	92
2	123	2976	446	1061
3	3	306	46	67
4	0	306	46	46
5	46	304	46	368

Table 3: Translation results (cont.)