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Intensity-modulated radiotherapy with a multileaf collimator

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In intensity-modulated radiation therapy (IMRT), a small number of spatially-modulated beam ports is used to deliver a uniformly high dose to the target region, while simultaneously producing a better sparing of normal tissues than is possible with conventional, non-modulated beam delivery. When intensity-modulation is carried out with a multileaf collimator rather than with physical compensators, any required intensity pattern can be produced with a minimal planning effort on the part of the physicist or dosimetrist, and with reduced manipulation on the part of the therapists. The paper describes the recent implementation of multileaf collimator-based intensity-modulated radiation therapy at McGill University in Montreal.

Key words: radiotherapy-methods; radiotherapy planning, computer-assisted; radiotherapy dosage; multileaf collimator,

Introduction

Intensity modulated radiation therapy (IMRT)[1-3], carried out with multileaf collimators (MLC)[4-6] in combination with 3D planning systems which have the capability for inverse planning[7-9], represents the current forefront in radiotherapy. Since MLCs can be retrofitted to existing linear accelerators and controlled with readily available manufacturer hardware and software components, it is neither difficult nor excessively expensive to make the transition from conventional to intensity-modulated radiation therapy.

In our department, the MLC-IMRT treatment procedure is typically separated into the following six distinct steps: (a) definition of beam geometry for a prospective patient; (b) calculation of intensity-modulation matrices for each radiation field; (c) determination of MLC leaf sequencing for each field; (d) calculation and evaluation of the dose distribution; (e) verification of the beam delivery sequence with respect to machine outputs and the MLC sequence; and (f) patient treatment.

In this paper we describe each of the six steps involved in the MLC-IMRT process, and, as an example, present a typical head and neck treatment with the technique.

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Materials and methods

Patient simulation and treatment planning

In preparation for treatment planning, the patient is scanned on a dedicated radiotherapy CT-simulator (Picker-5000; Cleveland, OH). The complete set of axial CT images covering the tumour volume and neighbouring structures is transferred to a virtual simulation and image processing workstation (Picker VoxelQ/AcQSim; Cleveland, OH) for the localization and delineation of critical organs and target structures. The beam geometry (treatment isocenter, field sizes, gantry angles, special shielding, etc.) is determined using anatomical landmarks visible on digitally reconstructed radiographs (DRRs) and beam's- eye-views (BEVs) of the previously delineated target and critical organ data.

The axial CT slices together with the beam geometry are then transferred via a computer network to our treatment planning system (CadPlan, version 3.12; Varian, Palo Alto, CA) for calculation of the appropriate isodose distributions. For all our IMRT treatments to date we have used beam configurations common to standard techniques (e.g., three fields for head and neck, four-field box technique for prostate, etc.) in order to facilitate the transition from conventional, non-modulated therapy to MLC-IMRT.

Calculation of the intensity modulation matrix

Once the beam parameters have been established, we instruct the CadPlan system to create intensity-modulation matrices for each field of the treatment plan. Currently, these intensity matrices serve to compensate for irregularities in the patient's contour; however, in the future a complete inverse-planning package will provide the appropriate intensity modulation matrices to optimise the preplanned sparing of critical structures and dose homogeneity within the target volume.

Calculation of the leaf sequence

A leaf sequence algorithm[10,11] translates an intensity-modulation matrix into a set of MLC leaf configurations delivered at the treatment machine. The leaf sequence algorithm that we use has been developed in-house; however, most modern commercial treatment planning systems now have the ability to write leaf sequences. Our algorithm is designed to write the step-and-shoot type leaf sequences, implying that the leaves move to a given configuration, a prescribed number of monitor units is delivered for this configuration, the leaves then move to the next configuration, followed by the delivery of the prescribed number of monitor units, and so on.

The algorithm for the calculation of the leaf sequence proceeds as follows. At 1 cm intervals throughout the intensity-modulation matrix, profiles of the intensity along the direction of leaf motion are extracted. These profiles represent the intensity to be delivered under each of the 26 leaf pairs of the MLC. Each 2D intensity profile is then partitioned, or "sliced", into a number of regularly spaced intensity levels. The positional coordinates of the intercepts of a given intensity level with the intensity profile form a set of positions at which that particular MLC leaf pair must be placed during beam-on to deliver the given intensity level. This process is repeated for all intensity levels and then for all leaf pairs. Once completed, the resultant set of leaf pair positions is sorted to establish a sequence of segments that can be delivered efficiently. A percentage monitor unit setting (or "dose index") is calculated for each segment from the knowledge of the particular dosimetric characteristics of the linear accelerator. The leaf sequence is then transferred to the Varian MLC Dynamic Beam Delivery (DBD) Toolbox workstation, which controls the 52-leaf MLC of our linear accelerator (Clinac-2300 C/D; Varian, Palo Alto, CA).

Generation and verification of isodose distribution

In order to ensure accurate treatment planning, we reintroduce the MLC segments, determined by the leaf sequence program, into the CadPlan system in the form of separate blocked fields which are weighted according to the calculated "dose index" and calculate a new dose distribution. If there are no errors in the leaf sequence calculation, the dose distribution calculated from the "dose-index" weighted fields will agree closely with the dose distribution calculated with the original intensity matrices, leading to the conclusion that the proposed MLC sequence is adequate for the treatment. The actual treatment is carried out only after full agreement between the two calculated dose distributions is found and the beam delivery verified.

Verification of beam delivery

Prior to patient treatment the leaf sequence for each field is subjected to two dosimetric tests. The first test is a film measurement of the planar dose distribution resulting from the delivered leaf sequence for each individual field consisting of multiple subfields. This measurement confirms the proper orientation of all fields and allows us to verify that the beam intensity delivered to selected points is consistent with the intensity matrix.

The second test is a central axis measurement of the cumulative dose resulting from the leaf sequence for all fields. This test is carried out with a calibrated ionization chamber at the treatment isocenter depth in a tissue equivalent phantom.

Patient treatment

The actual patient treatment is similar to conventional type treatments. The main difference is that, instead of placing a physical compensator in the beam path for each field, the therapist first loads a leaf sequence file into the MLC control computer and then programs in the total monitor unit setting pertaining to that leaf sequence. The Varian DBD ToolBox software apportions the appropriate percentage of monitor units according to the "dose-index" to each segment of the leaf sequence.

The MLC segments are delivered at the nominal operating dose-rate of the linac (~400 MU/minute). During the time that the MLC leaves are changing position, however, the dose-rate drops to zero allowing the leaf movement under "beam off" conditions before returning to the nominal dose-rate for the delivery of the next MLC segment. Typically, the delivery of an MLC intensity-modulated leaf sequence requires 20%-50% more beam time than would the same treatment produced with physical compensators. However, this loss of beam time is amply made up by the radiation therapists not having to enter the treatment room to change the compensators, blocks, or wedges for each individual field used in the treatment plan.

Results and discussion

The first treatment with MLC-IMRT at the McGill University Hospital Centre was carried out in April 1998 and within six months 15 patients were treated with the technique. We now give an example of a typical MLC-IMRT treatment. The patient was treated for a base of tongue carcinoma with a dose of 44 Gy using an isocentric set-up consisting of two half-blocked lateral parallel-opposed 6 MV photon beams with a collimator setting of 11x10 cm^2. An additional 16 Gy boost (sparing the spinal cord) was delivered with the same beam geometry. The lower neck region was treated with a single anterior half-blocked field to 50 Gy prescribed at a depth of 3 cm. Intensity-modulation was desirable for the lateral fields to compensate for the uneven surface of the neck region, which under standard conditions would have

required the construction of custom-built compensators. Before calculating the intensity matrices for each field, the BEV and DRR modes were used to position shielding for the protection of the base of skull as well as the eyes and nose.

Figure 1 shows the digitally-reconstructed radiograph (DRR) generated for the patient from a series of axial CT slices and used for field placement and delineation as well as for comparison with portal images in the verification of patient positioning prior to dose delivery.

Dose distributions for the initial portion of the IMRT treatment are shown in Figure 2; part (A) for the midseparation sagittal plane, part (B) for an axial slice through the target volume as indicated by the dashed line in part (A). The distributions were calculated with the CadPlan 3D treatment planning system and are normalized to 100% at the dose maximum in the target volume. The total dose of 44 Gy, delivered in 22 fractions, was prescribed to the 96% isodose surface which covers the target volume. The dose uniformity in the treated volume is considerably better than that achievable without the use of intensity-modulated beams.

Figure 3 displays the four irregular subfields which were used to produce the intensity-modulation for the right lateral beam for the treatment of Figure 2. The irregular fields were produced and the dose was delivered with a multileaf collimator and a step-and-shoot method using the dynamic MLC option on our linear accelerator. For the right lateral field the basic irregular subfield shown in part (A) delivered the 85% of the total dose, while the other three subfields shown in parts (B), (C), and (D) each delivered 5% of the total dose.

The patients treated with the IMRT technique have an unusually mild skin reaction compared to reactions normally observed in patients treated with standard techniques. We believe that the lack of wedges, blocking trays, and compensators, all of which may increase the skin dose, is to be credited for the reduction in skin reaction.

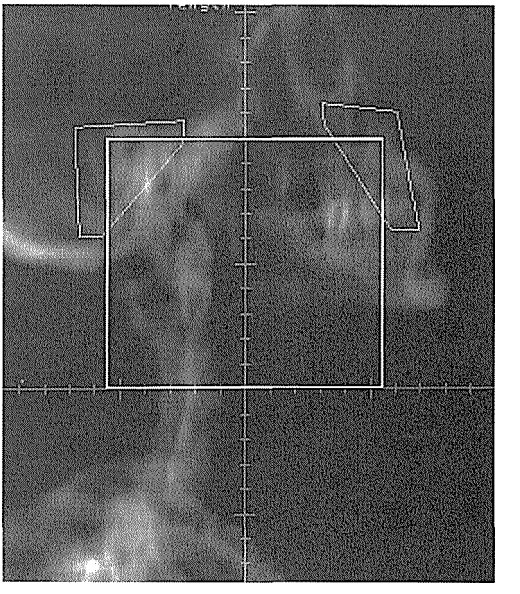

Figure 1. A digitally reconstructed radiograph (DRR) for a typical patient treated with intensity-modulated beams at McGill University.

Summary

Intensity-modulated radiation beams produced with a multileaf collimator are rapidly becoming an essential component of modern radiation therapy. With a wise purchase of equipment, the investment in time and money required for the successful implementation of intensity-modulated radiotherapy into the clinic can be maintained at a reasonable level and yield a substantially improved patient treatment when compared to standard techniques.

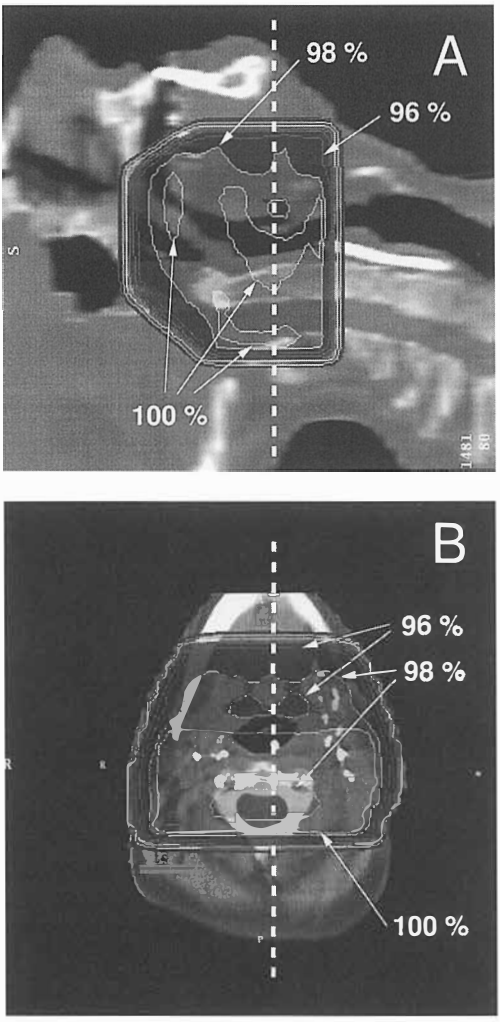

Figure 2. Dose distributions for a typical patient treated for a base of tongue carcinoma with intensity-modulated 6 MV beams. Part (A) is for the midseparation sagittal plane, part (B) for an axial plane defined with the dashed line in part (A). The distributions are normalized to 100% at the dose maximum in the target volume.

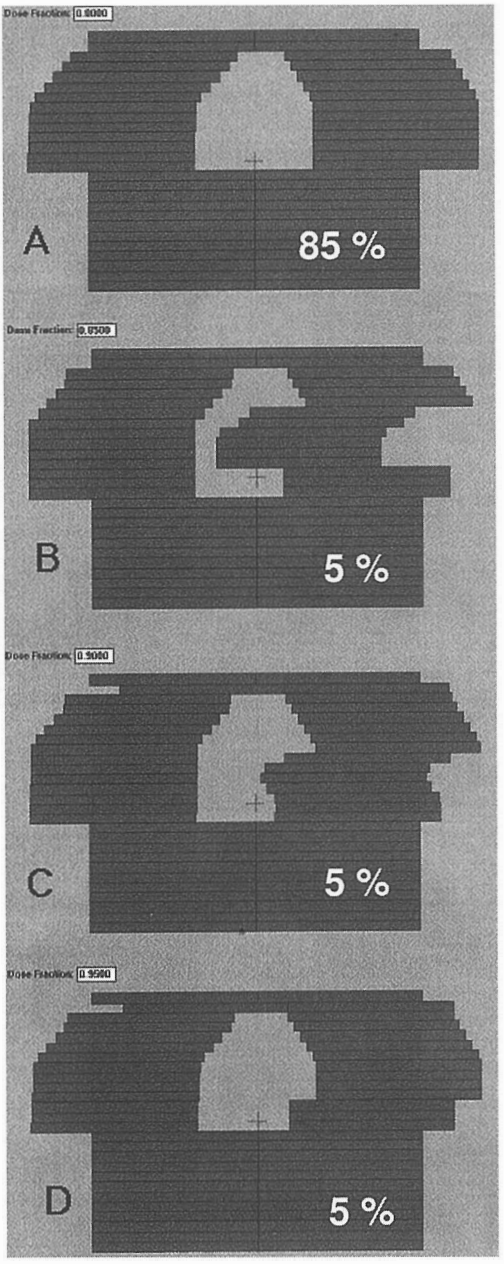

Figure 3. The four irregular subfields which were used to deliver the intensity-modulated right lateral beam for the dose distribution of Figure 2. The basic irregular subfield of part (A) delivers 85% of the total dose, the other subfields deliver 5% each.

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