Audience Survey

Which IMRT delivery device(s) has treated patients in your clinic?

- DMLC IMRT
- SMLC IMRT
- Compensator-based IMRT
- Serial tomotherapy
- Helical tomotherapy
- Robotic linac
- Proton IMRT
DMLC IMRT Overview

- Introduction
- Leaf sequencing
- DMLC vs. SMLC
- Quality assurance
- Dynamic splitting
- Clinical implementation (lung)
- Respiratory motion
- Summary
Definition: DMLC-IMRT

A method used to deliver intensity-modulated beams using an MLC, with the leaves in motion during radiation delivery. The sliding window technique is a form of DMLC-IMRT in which the window formed by each opposing pair of leaves traverses across the tumor volume while the beam is on.

IMRTCGW 2001 Intensity-modulated radiotherapy: current status and issues of interest, *Int J Radiat Oncol Biol Phys* 51 880-914
Science is a dynamic undertaking directed to lowering the degree of the empiricism involved in solving problems

The ‘MLC’ in DMLC-IMRT

Would ideally have

- Negligible leakage
- Small dosimetric penumbra
- Good patient clearance
- Fine leaf widths
- High maximum leaf speed and fast leaf acceleration
- Excellent mechanical accuracy, precision and stability
The ‘D’ in DMLC-IMRT

- Leaf positions change with MU (not time)

- Inputs
  - Leaf positions at control points
  - MUs at control points

- Each leaf is controlled by a separate motor

- The leaf positions are indicated by encoders attached to the motors
The ‘D’ in DMLC-IMRT

- Independent feedback mechanism verifies correct leaf positioning during DMLC delivery
- Control software monitors leaf positions and compares them to their prescribed positions
- The beam is interrupted momentarily if any leaf position is outside tolerance
Leaf Design

- Tongue-and-groove/Stepped edge design
- Different radiological pathlengths and hence leakage variation

Kim et al. 2001 Med Phys 28 2497-506
Leaf Tip Design

- Single focused (round tips)
  - Mechanically easier
- Double focused
  - Smaller dosimetric effect
- Source size & MLC-patient distance larger components of penumbral width
Beam Hardening

- MLC transmitted fluence is hardened
- MLC scatter is also present
- Challenges existing dose calculation algorithms

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Kim et al 2001 Med Phys 28 2497-506
Who has DMLC?

- BrainLab
- Varian
- Elekta
- MRC
- Siemens
- 3D Line
- Radionics/Tyco
The nearer a conception comes towards finality, the nearer does the dynamic relation, out of which this concept has arisen, draw to a close. To know is to lose.

Creating intensity patterns through leaf motion

Intensity vs. Position
Creating intensity patterns through leaf motion
Creating intensity patterns through leaf motion
Leaf Sequencing

Convergence Criteria:
- $\text{MSE}(k) < \varepsilon$
- $\text{MSE}(k) - \text{MSE}(k-1) < \delta$
- $\|E(k)\| \geq \|E(k-1)\| \rightarrow \text{Take } \Gamma(k-1) \text{ and } \Phi_\delta(k-1) \text{ as the final results}$

Initial Conditions:
- $\Phi(0) = \Phi_0$
Fluence-to-trajectory

- $\Phi(k)$
- Find Total MU
- Generate Leaf Trajectories
- Leaf Position Synchronization
- Trim MUs
- $I(k)$

Trajectory-to-fluence

- $I(k)$
- Generate Intensity
- Add Leaf Scatter
- Add Head Scatter and Finite Source Size
- $\Phi_d(k)$
‘Deliverable’ Optimization

Siebers et al 2002, Med Phys 29 952-9

Traditional optimization flow

Deliverable optimization flow

1. Initial Intensity $I_i$
2. Compute Dose $D_o$
3. Evaluate Plan Objective
4. Converged?
5. Adjust Intensity
6. Optimized Intensity $I_o$
7. Create Leaf Sequence
8. Create Deliverable Intensity $I_D$
9. Create Deliverable

$D_D = D_o$

$(I_D = I_o)$
DMLC vs. SMLC

Imagination is always the fabric of social life and the dynamic of history.

Audience Survey

“\textit{I would choose DMLC IMRT over SMLC IMRT}”
Conversion from continuous to discrete intensity profiles
Courtesy Dr. Chen Chui

DMLC IMRT

SMLC IMRT
Pro SMLC-IMRT

Xia P and Verhey L J 2001 Med Dosim 26 169-77

- Easy to understand (a simple extension of current 3D-CRT practice)
- No requirement to control individual leaf speeds and thus simplifying the MLC control system
- An interrupted treatment is easy to resume
- It is easy to verify an intensity pattern for each field
- Fewer MUs are required in comparison with DMLC
Pro DMLC-IMRT

Xia P and Verhey L J 2001 Med Dosim 26 169-77

☑ Shorter treatment time for complex intensity modulated beam

☑ Reduction of dosimetric errors introduced by SMLC due to the discretization of a continuous intensity profile
Comparison of DMLC and SMLC Methods

DMLC:
• Accurate delivery of the desired intensity profiles

SMLC:
• User more comfortable - resembles multi-segment conventional treatment
• Shorter beam-on-time (MU) compared to DMLC
• Longer delivery time (min.) compared to DMLC (depending on planning software and machine/MLC characteristics)
• Loss of spatial & intensity resolution

Courtesy Dr. Chen Chui
Mathematician’s Perspective

- DMLC has more degrees of freedom, hence an equal or better solution will always be found
Other errors in radiotherapy are much larger.

Both techniques have been successfully clinically applied.

Both techniques are evolving and improving.

Economics will be the winner.

Which implementation can treat the greatest number of patients in the smallest amount of time with the minimal overheads in terms of planning and QA time.
Audience Survey

“\text{I would choose DMLC IMRT over SMLC IMRT}”
Instead of being a static one-time event, bonding is a process, a dynamic and continuous one.

Patient specific QA procedure

- Re-compute approved plan with Monte Carlo
- Perform quantitative film dosimetry
Pre-Treatment MC Check

--- Monte Carlo
--- Superposition

Fractional Volume vs Dose (cGy) for different structures:
- Cord
- CTV
- Lt Parotid
- Brain Stem
- PTV
Film Dosimetry
EPID DMLC Dosimetry: Pre-Treatment Meas. vs. Calc.
EPID DMLC Dosimetry: Treatment Meas. vs. Calc.
Real-time DMLC IMRT QA?
Monthly QA Procedure

- Output for 5 mm sliding window
- Output for interrupted and resumed treatment
- Absolute leaf positions
- Output with 90° gantry angle
Leaf positions using film
For more QA, come back tomorrow
Magic is the envelopment and coercion of the objective world by the ego; it is a dynamic subjectivism.

DMLC IMRT best when used for entire treatment, not just boost
However, current FS limited to 14.5 cm
∴ need to split fields
To avoid hot and cold spots best to have smooth intensity changes at boundary
Figure 1. Dynamic splitting of intensity distributions of an IMRT field. (a) Original intensity for one leaf pair. (b) The split intensities of component fields 1 and 2. The field boundaries are $x_1$ and $x_2$, the midpoint is $x_0$, and $2d$ is the dynamic feathering width.

Wu et al 2000 Phys Med Biol 45 1731-40
Dynamic Splitting

Wu et al 2000
*Phys Med Biol* 45 1731-40
Dynamic Splitting

Wu et al 2000
Phys Med Biol 45 1731-40
And once an editor wrote me, “Your poems are dynamic, colorful, exciting, but too strong for a woman.”

Daisy Aldan (b. 1923), U.S. poet and publisher. As quoted in The Little Magazine in America, ch. [17], by Elliott Anderson and Mary Kinzie (1978).
Tumor sites treated with DMLC IMRT at VCU

Brain
Head & Neck
Breast
Lung
Sarcoma
Prostate
Cervix
Determine Beam Angles
Dose Volume Histogram

- - - - Monte Carlo
      ___ Superposition

PTV<sub>Nodes</sub> PTV<sub>GTV</sub>

Heart

Lungs

Cord
Even if I died in the service of the nation, I would be proud of it. Every drop of my blood ... will contribute to the growth of this nation and to make it strong and dynamic.

Respiratory motion causes errors during the imaging, planning and delivery of radiotherapy.

Respiratory gating is compatible with both SMLC and DMLC-IMRT.

Breath hold is compatible with both SMLC and DMLC-IMRT.

4D radiotherapy requires couch or DMLC.

Tumor deformation requires DMLC.
IMRT Delivery: Interplay between anatomy and MLC leaf motion leads to motion artifacts

![Diagram showing IMRT delivery with MLC and CTV](image)
4D radiotherapy delivery

Linac Controller -> 4DC -> MLC Controller

MLC Workstation

Treatment parameters

Tracking Signal
4D PTVs
BEVs

3D BEV

4D BEV
MLC leaf motion

3D IMRT

4D IMRT
Tracking motion perpendicular and parallel to the MLC
IMRT isodose results
IMRT dose profile results

- Control
- 3D IMRT
- Control
- 4D IMRT
By Iowa standards, Des Moines is a mecca of cosmopolitanism, a dynamic hub of wealth and education, where people wear three-piece suits and dark socks, often simultaneously.

DMLC-IMRT Summary

- DMLC is an effective and clinically proven method to deliver IMRT
Audience Survey

Which IMRT delivery device(s) will be most prevalent in 10 years?

- DMLC IMRT
- SMLC IMRT
- Compensator-based IMRT
- Serial tomotherapy
- Helical tomotherapy
- Robotic linac
- Proton/particle IMRT
- Other
We can become a dynamic equilibrium, a harmony of many different elements, in which the whole will be greater than all its parts and greater than any society the world has seen before. It can still happen.

Future ...

- The combination of IMRT and both functional tumor image information and functional normal tissue image information takes planning complexity beyond the comfortable realm of humans.

- The combination of gene therapy (particularly radiation-inducible replication competent viruses) and IMRT will potentially substantially improve the therapeutic ratio.
Future ...

- Automated tissue segmentation will reduce the most laborious aspect of IMRT and reduce the large inter- and intra-observer variations.
- Class solutions will reduce the current trial-and-error approach to optimization.
- Automated EPID-based IMRT QA will substantially reduce current QA time.
Future …

- Optimization will include deliverable constraints obviating the time and errors introduced by a separate leaf sequence conversion process.
- Increased resolution and degrees of freedom during optimization (including couch, gantry, collimator, energy, modality …) will result in significantly improved plans.
- Delivery time will be reduced by more intelligent leaf sequencing.
Future …

- Planning time will be close to real time
- Real time planning and delivery adaptation will be tied to image guidance
- 4D radiotherapy will become the standard
- Monte Carlo dose calculation will become the standard
Thank you to...

- Devon Murphy (reviewing)
- Dr Art Boyer (content)
- Dr Jeffrey Siebers (ideas, data, reviewing)
- Drs Sastry Vedam and Vijay Kini (movies)
- NCI R01 grant #93626 (funding)
- Nader Salehi (3D Line)
- Carsten Raupach (BrainLab)
- Rajinder Dhada (Elekta)
- Jörg Stein (MRC)
- Zach Leber (Radionics/Tyco)
- Michelle Svatos (Siemens)
- Cal Huntzinger (Varian)