IMRT and Inverse Planning:
From the Art
to the State-of-the-Art

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Evolution of the art of radiation therapy
courtesy of John Schreiner, Kingston, Ontario, CA

IMRT forerunners:
Synchronous shielding, Proimos 1961
IMRT forerunners:
Conformation therapy, Takahashi 1965

Problem with synchronous shielding

Rawlinson & Cunningham Radiology 102, 1972

see also: "synchronous shielding" by B. Proimos

Problem with synchronous shielding
This calls for intensity modulation!

Rawlinson & Cunningham Radiology 102, 1972

uniform intensity, no wedge (arccos)
linear wedge

The idea of inverse planning was born

\[ f(p) = \begin{cases} D_0 \frac{|p|}{2\pi r_0^2} & \text{if } |p| \geq r_0 \\ 0 & \text{otherwise} \end{cases} \]

Birth of IMRT: 1982


Solution of an integral equation encountered in rotation therapy

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Received 30 March 1981, in final form 4 December 1981

Abstract. An integral equation relating the desired absorbed dose profile of a photon beam to the scattered dose distribution of a tangential field in ion chamber therapy has been set up and solved for the case of a cylindrical phantom with the axis of rotation coinciding with the axis of symmetry of the phantom. In the first approximation the results obtained are also valid when the axis of rotation is not coincide with the axis of symmetry of the phantom. The required dose distribution can be determined using a new type of non-linear wedge-shaped phantom, which can easily be designed using the known general analytic solution to the integral equation.
Intensity modulation for the “donut” case

Birth of IMRT: 1982

Lax, Brahme
Radiology 145
1982

The line gives the calculated dose profile for a rotation irradiation. The crosses are the result of radiographic measurements in a spherical phantom.

Key idea: Applicable to arbitrary cases with concave targets

Brahme et al, 1988
IMRT = I aM aRT

idea of dose painting

© Henning Willers, MGH

IMRT “palette”
1. “Inverse” treatment planning

“Conventional” Planning

Inverse Planning

© W. Schlegel, A. Marr

IMRT “palette”
2. Delivery with MLC

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Clinical translation of the IMRT idea early 1990's

Art and Thomas @ AAPM Austin, 2014

Clinical translation of the IMRT idea early 1990's, MD Anderson CC

Art Boyer
Thomas Bortfeld
Darren Kahler
Tim Waldron
...

Art and Thomas @ AAPM Austin, 2014

IMRT proof of concept in 1993
**proof of concept (1993)**

- 6 films in different slices showing concave dose distributions
- Overlay on anatomy

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**IMRT proof of concept in 1993**

Prostate phantom dose distribution in 3D

*Delivery time: 3 hours*

Therapeutic Dose
Target

(c) A. Boyer, 1993

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**Translation into clinical use: 1995**

MSKCC, New York

Radhe Mohan
Clifton Ling
Zvi Fuks
Sam Hellman
et al.

81 Gy isodose: bends around rectum

Treatment time: 10-12 min

Ling et al., IJROBP 35(4): 721-730, 1996
IMRT delivery technology 1990s

**Cone Beam**
- Multiple Static Fields
- Step & Shoot MLC
- Dynamic MLC 1995>

**Fan Beam**
- Multiple Rotations
- Nomos Mimic (Mark Carol) 1994>

Cone beam IMRT vs. fan-beam IMRT 1990s

MLC based IMRT (Varian, Elekta, Siemens)

IMRT delivery technology today

**Cone Beam**
- Multiple Static Fields
- Step & Shoot MLC
- Dynamic MLC 1995>

**Fan Beam**
- Arc Treatment
- IMAT VMAT/RapidArc 2007>
- Spiral Treatment
- Tomotherapy (Rock Mackie) 2002>
- Multiple Rotations
- Nomos Mimic (Mark Carol) 1994>
IMRT: A success story of **INNOVATION** in Medical Physics

- Millions of patients treated
- Clear dosimetric advantage established
- Clinical benefit demonstrated through (few) randomized clinical trials

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**What comes next?**

- Make IMRT simpler, faster, less of an Art
  - Multi-Criteria optimization
  - Automation
- Make IMRT truly optimal
  - What do we really want to accomplish: use biologically/clinically motivated objectives
- IMRT for particles - IMPT
- Smarter ways to deal with uncertainties
  - Robust optimization
- Optimize dynamics of multi-modality therapy over the treatment course

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courtesy of John Schreiner, Kingston, Ontario, CA
If intensity modulated therapy does improve patient outcome, it is clear that the systems of the future will be different from those used today. Manufacturers may elect to make the sort of modifications suggested by Bortfeld and the co-authors or support a dedicated machine such as described by Mackie et al. (12). More likely, a system would evolve that is not linked to what is familiar to us all at this time. We believe that the clinical experience we gain today with this type of technology will enable radiation therapy community to obtain the most practical system.

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- Conflict of interest
  No conflict of interest with any of the material presented here.

- Disclaimer
  While trying to be as objective as possible, there will be some personal bias.

IMRT “palette”
1. “Inverse” treatment planning

- Deconvolution approach:
  Lind/Brahme, Holmes/Mackie, et al.

- Optimization approach
  - Simulated Annealing:
    Webb, Mohan/Mageras, et al.
  - Gradient Descent:
    Censor, Bortfeld, et al.
IMRT optimization algorithms

• First developed by Physicists (they can do everything)
• Further developed by optimization experts (Operations Research)

• Who came up with the IMRT = Intensity-Modulated Radiation Therapy acronym, and when?

• IMRT is a misnomer. We do not modulated the intensity – but the fluence.