When the World was Flat: The Two-Dimensional Radiation Therapy Era

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Jacob (Jake) Van Dyk

Disclosures
• None ... except I am involved with ...

The Flat Earth Perspective ... Artistic
The Flat Earth Perspective … Scary!

The Past and the Present in RT

<table>
<thead>
<tr>
<th>Phase</th>
<th>Time</th>
<th>Technology</th>
<th>Issues/Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1885-1940s</td>
<td>100-400 kV</td>
<td>Non-uniform dose at depth, skin dose, bone dose</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Brachytherapy</td>
<td>Radon, systems of calculations</td>
</tr>
<tr>
<td>2</td>
<td>1950s</td>
<td>Cobalt-60 4-8 MeV linacs ≥200MeV betatrons</td>
<td>Skin sparing, uniform dose at depth, manual treatment planning</td>
</tr>
<tr>
<td>3</td>
<td>1960s-70s</td>
<td>Multi-energy linacs 3D Systems Simulators</td>
<td>Isocentric machines, more physicists, detailed QA</td>
</tr>
<tr>
<td>4</td>
<td>1970s-80s</td>
<td>CT, 3D-CRT Afterloading</td>
<td>Improved targeting, improved dose computations</td>
</tr>
<tr>
<td>5</td>
<td>1990s-present</td>
<td>IMRT, IGRT, ART, MRT/MRS, PET, SPECT</td>
<td>MLC, on-board imaging, 4D-Us, PET/CT, dose escalation, arc therapy, gating, smaller margins</td>
</tr>
</tbody>
</table>

The Flat Earth Perspective: Radiation Therapy in 1960s & 1970s

- 2-D films for planning
Conventional RT

- Tumor volume and critical structures drawn on orthogonal films
- Simple setups with
  - 2, 3, or 4 fields
  - arcs/rotations
- Treatment planning on external contours
- Broad margins

Patient Data Acquisition

- Various methods used to obtain external contours
  - Solder wire
  - Flexi-curves
  - Contour takers
  - Simulator films

IAEA Atlases, 1965-1972

- Atlas of radiation dose distributions:
  - Vol. 1, Single-field isodose charts. Webster, Tsien, 1965
  - Vol. 2, Multiple field isodose charts. Cohen, Martin, 1966
  - Vol.3, Moving field isodose charts. Tsien, Cunningham, Wright, Jones, Pfalzner, 1967
  - Vol. 4, Brachytherapy isodose charts sealed radium sources. Stovall, Lanzl, Moos, 1972
Manual Isodose Calculations

- 1960s & early 70s
- Isodose shift method
- All patients water-like

<table>
<thead>
<tr>
<th>Photon energy (MV)</th>
<th>k (approximate)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 1</td>
<td>0.8</td>
</tr>
<tr>
<td>60Co – 5</td>
<td>0.7</td>
</tr>
<tr>
<td>5 – 15</td>
<td>0.6</td>
</tr>
<tr>
<td>15 – 30</td>
<td>0.5</td>
</tr>
<tr>
<td>30</td>
<td>0.4</td>
</tr>
</tbody>
</table>

Conformal radiation therapy ~1960s

- Cobalt-60
- Wedge filters
- Wax seats for dose build-up
- Hand drawn isodose curves
- Patients made flat

Patient positioning ~1960s

- Dose delivery system for wedge fields of previous slide
- Plaster cast with wax seats
- Fields interlocked for size and wedge orientation
- Repositioning is precise
Conformal radiation therapy ~1959

- Rotation therapy
  - 2 MV Van der Graaf generator
  - An early "conformation" technique
  - One contour

Conformal Therapy and MLC Proposal by Takahashi, 1965

Not implemented in clinical practice until >30 years later!

1969: Canadian Association of Physicists Annual Meeting

- Jack Cunningham
  - Chairman, Division of Medical and Biological Physics
First Computer for Radiation Therapy - 1967

- Program and data storage on cards with magnetic strips
- Contour entry by a “rho-theta” tracing unit

The “PC”
- Programmed Console
- 12K memory

Programmed Console (PC)
- 12K memory
- 12 bit word
- Note TV camera for enlarging display

Display for treatment planning

- Display of patient’s contour & 3 beams arranged to treat target
- Isodoses shown within the “viewing window”
The Programmed Console (PC)

- Display for treatment planning
- Plotting was also available

Algorithms

- Empirical
  - Measured data only – stored on grid
  - Make corrections for
    - External contours, wedges, inhomogeneities
- Semi-empirical
  - TAR-SAR methods
    - IRREG, CBEAM, MULBEAM, ...
    - EQTAR
- Model-based
  - Convolution/superposition
- Monte Carlo

Matrix Representation

- Doses measured and pre-stored on grid
- For treatment planning, interpolate between points
- Make corrections for contour, wedges, inhomogeneities
Scatter-Air Ratios

J. R. CUNNINGHAM, Ph.D.
Physics Division, Ontario Cancer Institute, Toronto, Canada

Received (revised version) 26 April 1971

Abstract. Scatter-air ratios are empirical quantities derived from tissue-air ratios for use in calculating the dose from scattered radiation at a point in an inhomogeneous phantom. Like tissue-air ratios, for each radiation quality, they depend only on depth and beam cross-section but are independent of the distance from the source. These ratios are determined within uniform and non-uniform radiation beams and the extension to account for tissue heterogeneity is discussed.

CBEAM Uses Cartesian Slabs

Cunningham's CBEAM

Beam intensity modulated in only one direction

Flat or symmetric contour
1-D vs 2-D vs 3-D Comparison

- Sphere
- Cobalt-60

Minus ~ 4%
Minus ~ 8%

The Power of SARs

<table>
<thead>
<tr>
<th>SAR</th>
<th>Scatter at depth from a beam</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sector SAR</td>
<td>Scatter from a pie-shaped 'slab'</td>
</tr>
<tr>
<td>dSAR</td>
<td>Scatter from a 'pencil'</td>
</tr>
<tr>
<td>d²SAR</td>
<td>Scatter from a 'voxel'</td>
</tr>
</tbody>
</table>

Order of Canada! Nov 2005

Original EqTAR Method is considered as “2.5-D”

- For computational speed, adjacent slice data were collapsed to an effective scattering slice

Sontag & Cunningham Radiology 129: 787-94. 1978
Example of Symmetry Assumptions

ICRU 29

- “Target volume” & uniform prescription concepts
  - “2-D era”

Timesharing System, ~1972
2-D RT

- Patient positioning & immobilization
- Patient data for RT planning
- Prescription & simple constraints
- Forward planning
- Manual data transfer
- Setup confirmation
- Dose delivery
- Beam, coolant, vendor set by NHLB

Bar-Arc Technique – 1974

Conventional Bar-Arc

- Bar shielding the critical organ at each gantry angle
  - Pros
    - Concave dose distributions
    - Greatest sparing of organ
  - Cons
    - Organ MUST lie along rotational axis
      - Patients adjusted
        - On a board
        - Feet upward
      - Patients made uniform depth
        - Bolus
    - Rigid high dose distributions
    - Excess volume irradiated

Eugene Wong
Major Technology for 2-D RT

- Simple immobilization
- Simulator
  - Possibly access to CT (starting late 1970s)
- Treatment machine
  - Cobalt-60 or basic linear accelerator
  - Port films

Differences between 2-D RT and 3-D CRT

Different forms of RT
Methods of Producing Missing Tissue Compensators for High Energy Photon Beams

- Make patient flat
  - ... uniform dose ... for uniform H_2O density
  - Layers of lead
  - Semi-automatic compensator cutter (special purpose)
  - Milling styrofoam, low melting point alloy

Mantle Compensator Construction

Mantle Compensator
AECL Theraplan, 1980
• CT-based treatment planning

Summary: “When the World Was Flat”
• 2-D era
  – Anatomy defined by
    • Flexible wires
    • Special contour takers
    • X-rays
  – Dose calculations
    • Predefined atlases
    • Manual isodose summations – single planes
    • Simple beam shapes with wedges or compensators
    • Measurement based or semi-empirical calculations
    • Printed on alpha-numeric line printers or plotters

• Fortunately, we live in a world that has moved forward by several dimensions ...