IMRT, IGRT, SBRT

By
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PROF & HOD,
DEPT OF RADIATION ONCOLOGY,
A.H. REGIONAL CANCER CENTRE,
CUTTACK
High-cost Technology in Radiation Oncology: A value judgment

**Benefit**

Complexity & Cost

<table>
<thead>
<tr>
<th>KV: Kilovoltage X-rays</th>
<th>MV: Megavoltage X-rays</th>
</tr>
</thead>
<tbody>
<tr>
<td>3D-CRT: 3D-Conformal Radiotherapy</td>
<td></td>
</tr>
<tr>
<td>SiMAT: Simplified Intensity Modulated Arc Therapy</td>
<td></td>
</tr>
<tr>
<td>IMAT: Intensity Modulated Arc Therapy (X-rays)</td>
<td></td>
</tr>
<tr>
<td>IMRT: Intensity Modulated Radiotherapy (X-rays)</td>
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<tr>
<td>IGRT: Image Guided Radiotherapy (Tomo etc.)</td>
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<tr>
<td>Hi-LET: High LET radiation (Charged particles)</td>
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<tr>
<td>IMRT+Hi-LET: Combination</td>
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</tbody>
</table>
CONVENTIONAL RADIATION

Conventional RT Beam
Uniform Beam Intensity
squares / rectangles
THERAPEUTIC RATIO
CURE CANCER WITHOUT INCURRING SIDE EFFECT

TUMOR CONTROL PROBABILITY > 1
NORMAL TISSUE TOXICITY
TCP, NTCP

TCP and NTCP curves are sigmoid in shape. The purpose of treatment is to move the TCP curve to the left and the NTCP curve to the right. The therapeutic index (= therapeutic window increases if the region the between two curves becomes large, and the expected benefit from treatment increases.
CONFORMAL RADIATION

Conventional open field

3 D CRT with MLC

Uniform Beam Intensity
CTV Delineation

- **Low Risk CTV**: Consists volume at risk of potential microscopic disease spread at the time of diagnosis. Typically treated to a dose of 50 - 55 Gy.

- **Intermediate Risk CTV**: Major risk of local recurrence in areas that correspond to significant macroscopic extent of disease. which corresponds to a dose of at least 60 Gy.

- **High Risk CTV**: Gross Disease. Dose to be delivered as high as possible (> = 70 Gy) and appropriate to eradicate all residual macroscopic tumour.
ME = 42-45 Gy
MX = 50 Gy

MX = 5-10 Gy
MX = 50 Gy

ME = 34 Gy
MX = 54 Gy

MX = 24 Gy
MX = 70 Gy
Fluence refers to the number of "particles" incident on an unit area (m$^{-2}$).
What exactly is IMRT?

A type of precision radiotherapy where beam intensity modulated to achieve a highly conformal dose distribution in the target volume.
COMMON RADIATION MODALITIES

- CONVENTIONAL RADIOTHERAPY
- GEOMETRIC FIELD SHAPING: 3DCRT
- GEOMETRIC FIELD SHAPING+MODULATION OF THE INTENSITY OF THE FLUENCE: IMRT
- GEOMETRIC FIELD SHAPING+MODULATION OF THE INTENSITY OF THE FLUENCE+IMAGE GUIDANCE: IGRT
IMRT FACTS

- Better normal tissue sparing
- Dose escalation
- Better conformality
- Modulates radiation intensity.
STEPS IN IMRT

1. Patient positioning and Immobilization
2. Volumetric Data acquisition
3. Image Transfer to the TPS
4. Treatment QA
5. Treatment Delivery
6. Dose distribution Analysis
7. Forward Planning
8. Inverse Planning
9. 3D Model generation
10. Target Volume Delineation
PT
POSITIONING, IMMOBILIZATION
IMAGE ACQUISITION

KNOW THE EXTENT
RADIATION PLANNING
IGRT
RESPONSE EVALUATION
CT SIMULATOR

- WIDE BORE (75-85cm)
- FLAT COUCH
- LASER SYSTEM (internal as well as external laser)
- WORK STATION
IMAGE ACQUISITION

- MOSTLY BY CT SIMULATION
- PT IS IN TREATMENT POSITION
- USE IMMOBILIZATION.
- PUT FIDUCIAL AT PRESUMED ISOCENTRE (needed for coordinate Transformation for image registration)
- GENERATE TOPOGRAM: - For patient allignment, area to be scanned.
- FOV is selected to permit visualization of the external contour
- IMAGE ACQUIZITION: - 3 TO 5 MM CUTS.
- IMAGE & DATA TRANSFER TO TPS
TREATMENT PLANNING SYSTEM

- IMAGE REGISTRATION
- IMAGE SEGMENTATION
- VIRTUAL SIMULATION
- DOSE CALCULATION
- PLAN EVALUATION
- DATA STORAGE
- DATA TRANSFER TO CONSOLE
- TREATMENT CERIFICATION
WHY IMAGE REGISTRATION

- TO DEFINE THE TARGET VOLUME
- FUSION: BETTER ASSESS THE ANATOMY AS WELL AS PHYSIOLOGY
- ORGAN MOTION STUDY
- 3D CT+ ORGAN MOTION = 4D CT
- ANALYSIS OF DOSE DISTRIBUTION
IMAGE SEGMENTATION

An image segmentation is the partition of an image into a set of regions whose union is the entire image.
### TARGET VOLUME

#### VOLUME/MARGIN

- **Gross Tumor Volume (GTV)**
- **Subclinical disease**
- **Clinical Target Volume (CTV)**
- **Internal Margin (2) (IM)**

#### REFERENCE POINT AND COORDINATE SYSTEM (1)

- **C\(_i\)** for imaging procedures
- **C\(_p\)** internal reference point
- **C\(_R\)** external reference point

- **Internal Target Volume (ITV)**
  
  \(= \text{CTV} + \text{IM}\)

- **Setup Margin (3) (SM)**

- **Planning Target Volume (4) (PTV)**
  
  \(= \text{CTV} + \text{combined IM and SM}\)

- **Organ At Risk (5) (OAR)**

- **Planning Organ at Risk Volume (PRV)**

- **PTV and PRV for treatment planning purpose (6)**
Organ at Risk (ICRU 62)

- Normal critical structures whose radiation sensitivity may **significantly** influence treatment planning and/or prescribed dose.
- Each organ is made up of a functional subunit (FSU)
DRR

- DRR is the artificial version of an X-ray image. Computed from CT data.
- Two-dimensional image simulating normal X-ray/fluoroscopic image.
- Use to design treatment portal.
- Verification of treatment portal.
BEAMS EYE VIEW, ROOM EYE VIEW

VIEW THE GEOMETRIC COVERAGE OF TARGET VOLUME
IDENTIFY MOST SUITABLE GANTRY COLLIMATOR, COUCH ANGLE DESIGN OF SHIELDING, MLC

UNDERSTAND THE OVERALL TREATMENT GEOMETRY
Planning

**Forward Planning**
From field definition to dose distribution

- T/t parameters
- Dose calculation
- Dose distribution
- Dose delivery with uniform radiation intensity

**Inverse Planning**
From dose distribution to field definition

- Dose delivery with nonuniform radiation intensity
- Leaf sequence generation
- Optimization
- T/t goals (objective function)
FORWARD Vs INVERSE PLANNING

Conventional Treatment Planning
Forward Planning

IMRT Treatment Planning
Inverse Planning
OPTIMISZATION

Refers to the technique of finding the best physical and technically possible treatment plan to fulfill the specified physical and clinical criteria

- **Physical Optimization Criteria:**
  - Based on physical dose coverage

- **Biological Optimization Criteria:**
  - Based on TCP and NTCP calculation

A total objective function *(score)* is then derived from these criteria
PLAN EVALUATION
TOOLS USED TO EVALUATE THE PLAN

- 2D DISPLAY
- ISODOSE LINES
- COLOUR WASH
- DOSE DISTRIBUTION STATISTICS
- DVH
- CUMULATIVE DVH
- DIFFERENTIAL DVH
DVH

- **Differential DVH**
  - Represents exact volume of tissue receiving that particular dose.
  - Histogram of frequency with which each dose occurs.

- **Cumulative DVH:**
  - Plot of entire volume of anatomical structure specified dose or higher dose.
  - More useful and commonly used.
DVH 78 Gy
(Prostate only)

Dose Volume Histogram

- V95 ≥ 95%
- V95 = 96%
- Mean dose = 78 Gy
- V70 < 50%
- V72 < 25%
- V55 < 5%
- Vmax (1.8 cc) < 76 Gy
- Vmax (1.8 cc) < 80 Gy

- Rectal wall
- Bladder wall
- PTV prostate
- PTV SV
- Femoral heads
- Healthy tissue
PLAN EVALUATION

CI is employed when the PTV is completely enclosed by the Treated volume.

Quotient of treated volume and PTV.

Absorbed dose distribution

Homogenous dose distribution throughout the PTV is desirable.

Inhomogeneity should be within + 7 % and - 5 % of the prescription dose

Maximum dose (Dmax):

Maximum dose to the PTV and to the tissues outside the PTV and to OAR should be identified.

A volume is considered significant only if its minimum diameter exceeds 15mm

Hot spots:

Volume outside the PTV receiving dose higher than 100% of the specified PTV dose. A volume is considered significant only if its minimum diameter exceeds 15mm
PLAN IMPLEMENTATION

- BEAM PARAMETERS
- MLC PARAMETERS
- DRR GENERATION
- TRANSFER DATA
PLAN VERIFICATION
IMRT DELIVERY TECHNIQUE

- Physical compensator & conformal blocks
- MLC based system
  - segmented MLC (SMLC) – step & shoot
  - dynamic MLC (DMLC) – sliding window
- IMAT – Intensity modulated arc therapy
- Tomotherapy
- IMRT with robotic arm
Revolution Continues

IMRT

Image Guided IMRT

Varian Trilogy
IGRT

INTER AND INTRA FRACTION ORGAN MOTION

**PERIODIC PHYSICAL MOMENT**

BREATHING, CARDIAC MOTION

**RANDOM PHYSIOLOGICAL MOVEMENT**

SWALLOWING, COUGH

PT SET UP ERROR

PATIENT MOTION

WEIGHT LOSS

TIGHT MARGIN

GEOGRAPHICAL MISS
Image Guided Radiotherapy (IGRT)

Organ Motion

- **Interfraction**
  - motion occurs between fractions and primarily is related to *changes in patient localization*

- **Intrafraction**
  - motion occurs during fractions and *primarily is related to respiration*

<table>
<thead>
<tr>
<th>Table 1 Anatomic “Motions” and the Timescale at Which They Occur</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Day to day</strong></td>
</tr>
<tr>
<td>Skin motion</td>
</tr>
<tr>
<td>Nonpredictable</td>
</tr>
<tr>
<td>Respiration</td>
</tr>
<tr>
<td>Predictable</td>
</tr>
</tbody>
</table>

Van Herk M. Semin Radiat Oncol 2007; 17: 258-267
Tumor Motion During Respiration

- All tumor motion is complex

Cross-sectional View of Patient’s Chest

Some motion is mostly Anterior / Posterior

Some motion is mostly Superior / Inferior

All tumor motion is Complex
IGRT

- Planar X ray based
  - EPID
  - Cyber knife
- Volumetric
  - CT on rails
  - Tomotherapy
  - MV cone beam CT
  - KV cone beam CT
- Video based
  - Real Time video guided IMRT
- Ultrasound based
  - BAT

TIGHT MARGIN
GEOGRAPHICAL MISS

INTER & INTRA FRACTION ORGAN MOTION
PT SETUP ERROR
Electronic portal imaging (EPID)

Verification of patient setup

Uses 6 MV beam to acquire image.

Take one AP and one LAT field for setup verification

The position error is determined using a daily treatment radiographic image and a reference radiographic image digital reconstructed radiographic (DRR) image created in treatment planning.
2D KV imaging: on-board imagers

- Two arms with kV x-ray tube, flat-panel imager
- Plain radiographs/fluoroscopic
- kV contrast is superior to MV imaging
- Orthogonal portal images – can be acquired without gantry rotation for AP and Lat online patient setup or KV/KV image pair
In-room kV 2D x-ray imaging:

- Diagnostic x-ray tube on the axis of source rotation, but at an angle of 30° to 45° from the MV source.
- Dual x-ray sources and fluoroscopic image intensifiers mounted in the floor and ceiling.
- These systems use surrogate markers for actual tissue anatomy.
**kV CT: In-room conventional CT or CT-on-Rails**

- CT scanner is mounted at the end of the linac couch and a 180-degree couch rotation, with the patient on couch, is then required before treatment.

**Tomotherapy: Helical MVCT**
kV-CB CT On-board imager

- Radiography, fluoroscopy, and CBCT
- Large flat-panel imager
- kV x-ray tube mounted on a retractable arm at 90 degrees to the treatment beam line
- Cone-beam CT reconstruction acquiring multiple kV radiographs as the gantry rotates through at least 180 degrees
Fiducial Tracking

Gold seeds
5.0 mm x 0.9-1.2 mm
IGRT: with fiducials or CBCT
Respiratory Tracking System
Techniques to treat mobile tumors

Static Tumor
Techniques to treat mobile tumors

Moving Tumor
No margin
Techniques to treat mobile tumors

Moving Tumor with margin
Techniques to treat mobile tumors

Moving Tumor Gating
Accounting for Intrafraction Motion

- Respiratory gating techniques
- Active breathing control (ABC)
- Dynamic tumor tracking/4D radiotherapy
- Abdominal compression?
RESPIRATORY GATING
Techniques to treat mobile tumors

Moving Tumor Gating
Respiration Gating with RPM

- RPM is an external gating system.
- System consists of an infra-red camera that is mounted to the foot of the CT.
- Markers block containing 2 reflectors.
- The marker block was placed on the patient’s skin in the abdominal region.
- Surrogate signal = abdominal surface motion correlation to tumor motion.
- The x-ray on signal from the CT scanner was recorded synchronously with the respiration signal.
Techniques to treat mobile tumors

Moving Tumor
Breath Hold
ACTIVE BREATHING COORDINATOR (ABC)

- Temporarily immobilizes patient’s breathing
- The inspiration and expiration paths of airflow are closed at a predetermined flow direction
Techniques to treat mobile tumors

Moving Tumor Tracking with DMLC
4D Radiotherapy Delivery

Linac Controller → MLC Workstation

Treatment parameters → 4DC → MLC Controller

Tracking Signal

MCV setup for 4D Radiotherapy
Principle of 4D scanning
Techniques to treat mobile tumors

Moving Tumor Tracking with CyberKnife
Synchrony™ Respiratory Tracking System

- Synchrony camera
- Synchrony tracking markers
- Fiber optic sensing technology
- Tracks patient’s respiratory motion
HEAD AND NECK CANCER
Rationale of IMRT in H & N Cancer

- Anatomically complex H&N region - 
  an ideal option - IMRT.

- Lack of organ motion in the H&N region
  - an ideal region for IMRT.

- Allows for dose escalation
  - concomitant boost – ideal for H&N
## Impact of PET-CT in H & N Cancer

<table>
<thead>
<tr>
<th>Author</th>
<th>Patients using PET</th>
<th>Change of GTV</th>
<th>Increase in GTV</th>
<th>Decrease in GTV</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rahn, 1998</td>
<td>22(prim)</td>
<td>41%</td>
<td>41%</td>
<td>0%</td>
<td>No image fusion</td>
</tr>
<tr>
<td></td>
<td>12(recur)</td>
<td>58%</td>
<td>58%</td>
<td>0%</td>
<td></td>
</tr>
<tr>
<td>Nishioka, 2002</td>
<td>21 fusion</td>
<td>71%</td>
<td>0%</td>
<td>71%</td>
<td>PET/CT/MRI</td>
</tr>
<tr>
<td>Ciernik, 2003</td>
<td>12</td>
<td>50%</td>
<td>17%</td>
<td>33%</td>
<td>Integrated PET-CT</td>
</tr>
<tr>
<td>Daisne, 2004</td>
<td>29</td>
<td>93%</td>
<td>18%</td>
<td>75%</td>
<td>CT-PET image fusion</td>
</tr>
<tr>
<td>Paulino, 2005</td>
<td>40</td>
<td>100%</td>
<td>-</td>
<td>-</td>
<td>PET/CT/MRI and surgical specimen</td>
</tr>
</tbody>
</table>
Changes in Anatomy during course of Rx

Planning CT

Three Weeks into RT

Barker et al. *IJROBP* 59:960, 2004 & Lei Dong et al. (MDACC)
Anatomical modifications during radiotherapy

<table>
<thead>
<tr>
<th>Author</th>
<th>No. of Patients</th>
<th>Per-Treatment Imaging</th>
<th>Image Registration</th>
<th>Volume Analysis</th>
<th>Shape and Positional Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barker et al (2004)</td>
<td>14</td>
<td>In-room CT-on-rail 3 times/wk; no iv contrast</td>
<td>Rigid</td>
<td>Reduction of:</td>
<td>• GTV: COM displacement: 3.3 mm (asymmetric shrinkage)</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• PGs: 0.6%/treatment day</td>
<td>• PG: COM shift medially by 3.1 mm</td>
</tr>
<tr>
<td>Geets et al (2007)</td>
<td>10</td>
<td>CT scan at mean doses of 14, 25, 35, and 45 Gy; iv contrast</td>
<td>Rigid</td>
<td>After a mean dose of 45 Gy:</td>
<td>NA</td>
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<td></td>
<td>• GTV: mean decrease of 65.5%</td>
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<td></td>
<td>• High dose CT: mean decrease of 50.9%</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>• High dose PTV: mean decrease of 47.9%</td>
<td></td>
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<tr>
<td>Han et al (2008)</td>
<td>5</td>
<td>Daily helical MVCT</td>
<td>Rigid</td>
<td>At the end of treatment: PGs had decreased from 20.5 to 13.2 cm³, i.e., an average decrease of 0.21 cm³/treatment day or 1.1%/treatment day</td>
<td>NA</td>
</tr>
<tr>
<td>Vasquez Osorio et al (2008)</td>
<td>10</td>
<td>CT scan at 46 Gy; iv contrast</td>
<td>Deformable</td>
<td>Reduction after 46 Gy:</td>
<td>After 46 Gy:</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• GTV: 25 15%</td>
<td>• Lateral and inferior regions of homolateral PG</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>• Homolateral PG: 17 7%</td>
<td>• Homolateral SMG: 20 10%</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>• Heterolateral PG: 5 4%</td>
<td>• Heterolateral SMG: 11 7%</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>• GTV: no change</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>• Right PG: 15.6%</td>
<td>• Left PG: 21.5%</td>
</tr>
<tr>
<td>Robar et al (2007)</td>
<td>15</td>
<td>Weekly CT scans; no iv contrast</td>
<td>Rigid</td>
<td>Reduction of supercical regions of both PGs: 4.9%/wk</td>
<td>Supercical regions show medial translation of: left PGs: medial shift of 0.91 0.9 mm/wk right PGs: medial shift of 0.78 0.13 mm/wk</td>
</tr>
<tr>
<td>Castadot et al (2008)</td>
<td>10</td>
<td>CT scan at mean doses of 14, 25, 35, and 45 Gy; iv contrast</td>
<td>Deformable</td>
<td>Reduction of</td>
<td>After 5 treatment ws:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• GTV : 3.2%/treatment day</td>
<td>• Homolateral PG: medial shift of 3.4 mm</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>• GTV : 2.1%/treatment day</td>
<td>• GTV : lateral shift of 1.3 mm</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Homolateral PG: 0.9%/treatment day</td>
<td>• GTV : medial shift of 0.9 mm</td>
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<td></td>
<td>• Heterolateral PG: 1.0%/treatment day</td>
<td>• Low dose homolateral CT: 0.5%/treatment day</td>
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<td></td>
<td>• Low dose homolateral CT: 1.8 mm No shift for the heterolateral PG and heterolateral low dose CT:</td>
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<td></td>
<td>• Low dose heterolateral CT: 0.4%/treatment day</td>
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</tbody>
</table>

CT: computerized tomography; GTV, gross tumor volume; CTV, clinical target volume; PTV, planning target volume; PG, parotid gland; COM, condylar region; SMG, submandibular gland; wk, week.
Dosimetric effect of Anatomical modifications during radiation therapy

<table>
<thead>
<tr>
<th>Author</th>
<th>No. of Patients</th>
<th>Per-Treatment Imaging</th>
<th>Image Registration</th>
<th>Results</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>O'Daniel et al (2007)</td>
<td>11</td>
<td>In-room CT-on-rail scans twice/wk; no iv contrast</td>
<td>Deformable</td>
<td>Cumulative PG dose greater than planned; median dose increase: 1 Gy</td>
<td>If no image-guidance for daily setup error correction, cumulative PG dose greater than planned; median dose increase: 3 Gy for homolateral PG and 1 Gy for heterolateral PG</td>
</tr>
<tr>
<td>Hansen et al (2006)</td>
<td>13</td>
<td>CT scan after a mean dose of 38 Gy</td>
<td>Rigid</td>
<td>High dose PTV D_{95}, D_{95}, V_{85%} decreased by 12.1, 12.2 Gy, and 7%, respectively</td>
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<tr>
<td></td>
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<td></td>
<td></td>
<td>Low dose PTV D_{95}, D_{95}, V_{85%} decreased by 12.6, 11.3 Gy, and 8.2%, respectively</td>
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<td></td>
<td>Right PG V_{95%} increased by 10.9%</td>
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<td></td>
<td></td>
<td>Mandible V_{95%} increased by 7.2%</td>
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<td></td>
<td>Left PG D_{mean} increased by 2.6 ± 4.3%, V_{95%} increased by 3.5 ± 1.7%</td>
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<td>Right PG D_{mean} increased by 0.2 ± 4.7%</td>
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<td></td>
<td></td>
<td></td>
<td>NA</td>
<td></td>
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<tr>
<td>Rober et al (2007)</td>
<td>15</td>
<td>Weekly CT scan; no iv contrast</td>
<td>NA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Han et al (2008)</td>
<td>5</td>
<td>Daily helical MVCT</td>
<td>Rigid</td>
<td>PG D_{mean} increased from 0.83 to 1.42 Gy with an average increase rate of 0.17 Gy/treatment day corresponding to an average increase of 2.2%/treatment day</td>
<td></td>
</tr>
<tr>
<td>Lee et al (2008)</td>
<td>10</td>
<td>Daily helical MVCT</td>
<td>Deformable</td>
<td>PG, daily D_{mean} differed from the planned dose by an average of 15%</td>
<td></td>
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<tr>
<td></td>
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<td>PG cumulative D_{mean}: planned: 29.7 Gy actual: 32.7 Gy (110% of planned dose)</td>
<td></td>
</tr>
<tr>
<td>Castaño et al (2009)</td>
<td>10</td>
<td>CT scan at mean doses of 14, 25, 35, and 45 Gy; iv contrast</td>
<td>Deformable</td>
<td>PGs D_{mean}: planned: 17.9 Gy, actual 18.7 Gy</td>
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<td>SMGs D_{mean}: planned 51.9 Gy, actual: 52.7 Gy</td>
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<td>OCP D_{mean}: planned 26.0 Gy, actual 26.7 Gy</td>
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<td>SC D_{2}: planned 40.1 Gy, actual: 41.0 Gy</td>
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<td></td>
<td>Skin V_{95%}: planned 17.2 Gy, actual: 18.3 Gy</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>No difference in PTV or CTV coverage</td>
<td></td>
</tr>
</tbody>
</table>

OC, oral cavity; SC, spinal cord; D_{x}, dose to x% of the volume; D_{mean}, maximum dose; D_{tumor}, dose to 1 cc.; D_{mean}, mean dose; D_{median}, dose to 50% of the volume; V_{x}, volume receiving a dose of x Gy or x% of the prescribed dose.
<table>
<thead>
<tr>
<th>Study</th>
<th>No. of Patients</th>
<th>Primary Site</th>
<th>RT</th>
<th>Follow-Up (months)</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Definitive</td>
<td>Postoperative</td>
<td>Median</td>
</tr>
<tr>
<td>Chao et al</td>
<td>126</td>
<td>Various</td>
<td>52</td>
<td>74</td>
<td>26</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lee et al</td>
<td>67</td>
<td>NPX</td>
<td>67</td>
<td>0</td>
<td>31</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chao et al</td>
<td>74</td>
<td>OPX</td>
<td>31</td>
<td>43</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eisbruch et al</td>
<td>133</td>
<td>Various, non-NPX</td>
<td>60</td>
<td>73</td>
<td>32</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kam et al</td>
<td>63</td>
<td>NPX</td>
<td>63</td>
<td>0</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kwong et al</td>
<td>33</td>
<td>NPX</td>
<td>33</td>
<td>0</td>
<td>29</td>
</tr>
</tbody>
</table>

Abbreviations: IMRT, intensity-modulated radiotherapy; RT, radiotherapy; NPX, nasopharynx; OPX, oropharynx.

*Patients treated from 1994 to 2002; three-dimensional conformal radiotherapy was used before 1996, and IMRT thereafter.
# IMRT Vs. Conventional RT in Head & Neck Cancer

## Lee NY, 2006

**Comparative Trial**

<table>
<thead>
<tr>
<th>Patients</th>
<th>Disease Control</th>
<th>Toxicity</th>
<th>Survival</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CVRT</td>
<td>IMRT</td>
<td>Died of toxicity</td>
</tr>
<tr>
<td>112</td>
<td>71</td>
<td>41</td>
<td>3</td>
</tr>
</tbody>
</table>

**85%**

**95%**

**- None**

**- 4%**

**76%**

**82%**
XEROSTOMIA

Phase III trial

Kam et al, JCO-2007
HN CANCER

Mean Xerostomia score per tumor group

- Others
- Larynx
- Oropharynx
- Total group

[Graph showing xerostomia scores for different tumor groups and a comparison between control and IMRT.]

Do you have trouble speaking due to dry mouth? (p < 0.001)

[Graph showing the frequency of dry mouth experiences for IMRT and control groups.]

Van Rij et al. (Radiation Oncology 2008)
Patient position and parotid dose
**Tomo vs IMRT (sequential)**

*Fiorino et al, Radiother.Oncol. 2006*

- 5 H&N pts
  - IMRT SS (5 fields, 10 levels) vs Tomo-a (same constraints used for IMRT) vs Tomo-b (stressed parotids and mandible sparing)

  - **Better PTV coverage and homogeneity with Tomo:**
    - V95%: 90% (IMRT) – 96-97% (Tomo):

    | Dmax: 60.3Gy (IMRT) – 57.4 Gy (Tomo-a) – 58.7 Gy (Tomo-b) |
    | Spinal cord Dmax reduction: Dmax: 31.6 Gy (IMRT) – 26.5 Gy (Tomo-a) – 24.6 Gy (Tomo-b) (non stressed in the optimisation) |
    | Reduction of Parotid mean dose: 26.1 Gy (IMRT) – 25.1 Gy (Tomo-a) – 20.8 (Tomo-b) |
    | Mandible dose reduction: 34.9 Gy (IMRT) – 34 Gy (Tomo-a) – 30.7 Gy (Tomo-b) |
IMRT:- WHAT HAS BEEN LEARNT

- IMRT IS FEASIBLE
- IMRT HAS GOOD LOCOREGIONAL CONTROL but NO SURVIVAL ADV
- IMRT ALLOWS PRESERVATION OF SALIVA, ESPECIALLY WITH MEAN DOSE $\leq 25$ Gy
CARCINOMA PROSTATE
<table>
<thead>
<tr>
<th>Risk group</th>
<th>Stage</th>
<th>Gleason score</th>
<th>PSA (ng/ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low risk</td>
<td>T1-2a</td>
<td>2-6, and</td>
<td>&lt;10</td>
</tr>
<tr>
<td>Intermediate risk</td>
<td>T2b-2c, or</td>
<td>7, or</td>
<td>10-20</td>
</tr>
<tr>
<td>High risk</td>
<td>T3a, or</td>
<td>8-10</td>
<td>&gt;20</td>
</tr>
<tr>
<td>Locally advanced</td>
<td>T3b-T4</td>
<td>any</td>
<td>Any</td>
</tr>
<tr>
<td>metastatic</td>
<td>N1 and/or M1</td>
<td>any</td>
<td>any</td>
</tr>
</tbody>
</table>
Pathological diagnosis of adenocarcinoma of prostate

Risk group classification

<table>
<thead>
<tr>
<th>Clinical stage</th>
<th>PSA</th>
<th>Gleason</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Low risk</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stage T1-2a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GS 2-6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PSA &lt;10 ng/ml</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Treatment option</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Active surveillance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brachytherapy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High dose EBRT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radical prostatectomy</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Intermediate risk (Favourable)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage 2b-2c,N0,M0</td>
</tr>
<tr>
<td>PSA 10-20</td>
</tr>
<tr>
<td>GS 7</td>
</tr>
<tr>
<td>Treatment option</td>
</tr>
<tr>
<td>High dose EBRT</td>
</tr>
<tr>
<td>Radical prostatectomy</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Intermediate risk (Unfavourable)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage 2b-2c,N0,M0</td>
</tr>
<tr>
<td>PSA 10-20</td>
</tr>
<tr>
<td>GS 7</td>
</tr>
<tr>
<td>Treatment option</td>
</tr>
<tr>
<td>1) High dose EBRT</td>
</tr>
<tr>
<td>2) EBRT with brachy boost</td>
</tr>
<tr>
<td>3) Radical prostatectomy</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>High risk (Favourable)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage 3a,N0,M0</td>
</tr>
<tr>
<td>GS 8-10, or PSA 10-20</td>
</tr>
<tr>
<td>Treatment option</td>
</tr>
<tr>
<td>1) High dose EBRT</td>
</tr>
<tr>
<td>2) EBRT with brachy boost</td>
</tr>
<tr>
<td>3) Radical prostatectomy</td>
</tr>
</tbody>
</table>

May be defined as ≥ 50% positive biopsy cores, >50% core length involvement, annual PSA velocity >2 ng/ml/year
Treatment volume

- **Prostate alone**
  - T1c-T2a, Gleason score <6, PSA <10 ng/ml

- **Prostate + SV**
  - If seminal vesicle involvement >15%
    - = PSA + (GS - 6) ×10

- **Whole pelvis**
  - Pelvis LN risk >15% (pertins table / Roach’s formula)
  - Patient with suspicious pelvic LN
**Benefit of pelvis irradiation?**
*(randomized studies)*

<table>
<thead>
<tr>
<th>Study</th>
<th>Follow-up</th>
<th>Biochemical control</th>
<th>Toxicity</th>
</tr>
</thead>
<tbody>
<tr>
<td>RTOG 94-13</td>
<td>6 years</td>
<td>No difference</td>
<td>Grade 3: &lt; 3%</td>
</tr>
<tr>
<td><em>(IJROBP 2007)</em></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GETUG 01</td>
<td>3.3 years</td>
<td>No difference</td>
<td>Grade 2-4 rectal and bladder toxicities not different</td>
</tr>
<tr>
<td><em>(JCO 2007)</em></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

...RT of the pelvic lymph nodes = still debated
CA PROSTATE

Prostate cancer (M0)
LN + risk > 15%
(Modified Roach formula)

Young pts (< 65 y.) + few co morbidity factors
EXTENSIVE pelvic LN dissection
N +
Pelvis irradiation
(46 Gy; 2 Gy/fr)
N -

Older pts (> 70 y.) or co-morbidity factors
No lymphadenectomy

Prostate (and SV) only
WHY DOSE ESCALATION

- With dose 70Gy of conv. EBRT alone T2c-T4, 30-50% of patient develop local recurrence within 10yrs & majority will develop distant mets.
- Standard dose of RT doesn’t have the capacity to completely eradicate the prostate disease in majority.
- Thus dose escalation is needed.
## CA PROSTATE

### Randomized studies showing the benefit of dose escalation

![Diagram showing dose escalation with standard dose (67-70 Gy) and high dose (76-80 Gy).]

### Table

<table>
<thead>
<tr>
<th>Study</th>
<th>Local control (negative biopsy)</th>
<th>Freedom from biochemical failure</th>
<th>Freedom from clinical failure</th>
<th>Specific survival</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shipley 1995</td>
<td><strong>Gl 8:</strong> 19% vs 64%</td>
<td>No PSA available</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Pollack, Kuban 2000, 2002, 2008</td>
<td>72% vs 65% NS</td>
<td>PSA≤10: NS</td>
<td>7% vs 15% (p=0.01)</td>
<td>P&lt;0.05</td>
</tr>
<tr>
<td>Zietman 2005</td>
<td><strong>48%</strong> vs <strong>67%</strong> <em>(p&lt;0.001)</em></td>
<td>61% vs 80% <em>(p&lt;0.001)</em></td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Dutch 2008</td>
<td>NS</td>
<td>45% vs 56% <em>(p&lt;0.001)</em></td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>GETUG 06 2010</td>
<td>NS</td>
<td>PSA&gt;15: p=0.03</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>
HIGH DOSE RADIATION DELIVERED BY INTENSITY MODULATED CONFORMAL RADIOThERAPY IMPROVES THE OUTCOME OF LOCALIZED PROSTATE CANCER

Up to 86.4 Gy !!!

Zelefsky, J Urol 2001
IMRT decreases GI toxicity compared to 3DCRT
(non randomized study)
• 127 patients - 3D CRT - total dose of 78 Gy

• **Rectal distension** = average cross-sectional rectal area (CSA; defined as the rectal volume divided by length) and measuring three rectal diameters on the planning CT.

Rectal distension decreased the probability of biochemical control, local control, and rectal toxicity in patients without daily IGRT.

Therefore, an empty rectum is warranted at the time of simulation.

Emphasize the need of empty rectum for IGRT to improve LC.

Benefit of IMRT in high dose prostate cancer radiotherapy (Rennes, France)

**Dosimetric benefit of IMRT**

- **80 Gy in the prostate**
  - IMRT: 77 pts
  - 3DCRT: not mentioned

- **(no pelvis)**
  - IMRT: 80 pts
  - 3DCRT: not mentioned

IMRT decreased significantly the dose in:
- the rectal wall (V10 to V70) and NTCP/2
- the bladder wall (V4 to V70)

[Graphs showing dose distribution for Rectum and Bladder comparing IMRT and 3DCRT]
TOXICITIES

- Conventional EBRT: Grade 2/ higher rectal/ bladder morbidity; needs medication in 60%.
- The risk of complication increases when RT dose exceeds 70Gy.
- Rectal complication depends on % of rectum treated to 70Gy/ higher dose.
- Rectal complication increases with increased dose of radiation.
- IMRT reduces the incidence of acute & late rectal effect compared to 3DCRT but not acute & late urinary complication.
- At present time IMRT doesn’t appear to significantly reduce the urinary symptoms compared to 3DCRT.
- With EBRT + Brachytherapy, the complication rates are high.
CA CERVIX

IMRT in gynaecological tumor

DOSIMETRIC benefit of IMRT?

IMRT reduces the dose to the:
- small bowel
- rectum
- bladder
- bone marrow
- kidney

Minimal TOXICITY

Decreasing the dose in the OARs

Maximal LOCAL CONTROL

Increasing the dose in the tumor
DOSIMETRIC STUDY: standard 3DCRT versus IMRT

IMRT spares the bladder

<table>
<thead>
<tr>
<th>Dose (Gy)</th>
<th>Conventional</th>
<th>IMRT</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>100 ± 0</td>
<td>100 ± 0</td>
<td>1.0</td>
</tr>
<tr>
<td>20</td>
<td>100 ± 0</td>
<td>99.9 ± 0.3</td>
<td>0.32</td>
</tr>
<tr>
<td>30</td>
<td>100 ± 0</td>
<td>96.8 ± 2.3</td>
<td>0.08</td>
</tr>
<tr>
<td>40</td>
<td>99.5 ± 0.4</td>
<td>86.1 ± 7.2</td>
<td>0.0008</td>
</tr>
<tr>
<td>50</td>
<td>99.5 ± 1.3</td>
<td>76.0 ± 11.7</td>
<td>0.0009</td>
</tr>
</tbody>
</table>

average volume of bladder irradiated at the prescription dose reduced by 23% (p<0.001)

DOSIMETRIC STUDY: standard 3DCRT versus IMRT

IMRT spares the small bowel

IMRT spares the bone marrow

DOSIMETRIC STUDY: standard 3DCRT versus IMRT

IMRT spares the rectum

<table>
<thead>
<tr>
<th>Dose (Gy)</th>
<th>Conventional</th>
<th>IMRT</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>100 ± 0</td>
<td>100 ± 0</td>
<td>1.0</td>
</tr>
<tr>
<td>20</td>
<td>100 ± 0</td>
<td>99.9 ± 0.2</td>
<td>0.14</td>
</tr>
<tr>
<td>30</td>
<td>99.9 ± 0.2</td>
<td>94.5 ± 4.2</td>
<td>0.001</td>
</tr>
<tr>
<td>40</td>
<td>94.0 ± 2.4</td>
<td>78.5 ± 8.7</td>
<td>0.0002</td>
</tr>
<tr>
<td>50</td>
<td>83.3 ± 5.3</td>
<td>54.3 ± 13.8</td>
<td>0.0002</td>
</tr>
</tbody>
</table>

average volume of rectum irradiated at the prescription dose reduced by 23% (p<0.001)

Locally advanced cervical cancer

Provides high local control and survival

IMRT for gynecological cancer

Non-randomized study: 135 pts IMRT vs 317 pts 3D technique

<table>
<thead>
<tr>
<th>Recurrence</th>
<th>IMRT</th>
<th>Non-IMRT</th>
<th>Total</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
<td>39 (28.9%)</td>
<td>139 (43.8%)</td>
<td>178</td>
<td>0.036</td>
</tr>
</tbody>
</table>

Kidd, IROBP 2010
Clinical benefit of IMRT in pancreas

46 pts with pancreatic cancer:
IMRT (50.4 Gy) + concurrent chemo (5-FU ± capecitabine)

→ acute GI toxicity compared with those from RTOG 97-04 (3DCRT without IMRT)

<table>
<thead>
<tr>
<th>Toxicity</th>
<th>3-D conformal</th>
<th>IMRT</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n (%)</td>
<td>n (%)</td>
<td></td>
</tr>
<tr>
<td>Nausea/vomiting</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grade 0–2</td>
<td>402 (89)</td>
<td>46 (100)</td>
<td>0.016</td>
</tr>
<tr>
<td>Grade 3–4</td>
<td>49 (11)</td>
<td>0 (0)</td>
<td></td>
</tr>
<tr>
<td>Diarrhea</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grade 0–2</td>
<td>373 (83)</td>
<td>44 (96)</td>
<td>0.02</td>
</tr>
<tr>
<td>Grade 3–4</td>
<td>78 (17)</td>
<td>2 (4)</td>
<td></td>
</tr>
<tr>
<td>Anorexia</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grade 0–2</td>
<td>442 (98)</td>
<td>44 (96)</td>
<td>&gt; 0.05</td>
</tr>
<tr>
<td>Grade 3–4</td>
<td>9 (2)</td>
<td>2 (4)</td>
<td></td>
</tr>
</tbody>
</table>

Yovino, IJROBP 2011
A randomized controlled trial of 300 patients comparing IMRT with standard wedged tangential fields at the Institute of Cancer Research and Royal Marsden Hospital.

WITH IMRT:
Dose inhomogeniety only in 4% of patients treated with IMRT Vs 70% of patients treated with standard techniques
- 25% reduction in the dose to the heart
- 42% reduction in the mean dose to the contralateral breast
- 30% reduction in the ipsilateral lung volume
LATE COMPLICATION
Scope of IMRT in Whole Breast RT

- Reducing dose inhomogeneity across the treatment volume
- Increasing Conformity of the dose
- Internal mammary node irradiation
- Simultaneous Integrated Boost to tumor cavity
- Possibly reduce morbidity
IMRT/IGRT in pelvis/abdomen: conclusions

<table>
<thead>
<tr>
<th></th>
<th>IMRT</th>
<th>IGRT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Experience</td>
<td>Dosimetric benefit</td>
</tr>
<tr>
<td>Prostate</td>
<td>« in place »</td>
<td>++++++++</td>
</tr>
<tr>
<td>+ pelvic LN</td>
<td>+++++</td>
<td>-bowel</td>
</tr>
<tr>
<td>post-op</td>
<td>+++</td>
<td>- local control</td>
</tr>
<tr>
<td>Gynecol</td>
<td></td>
<td></td>
</tr>
<tr>
<td>cervix</td>
<td>++</td>
<td>- rectum -bladder -bowel -kidney -bone -ParaclLN</td>
</tr>
<tr>
<td>endometrium</td>
<td>++</td>
<td></td>
</tr>
<tr>
<td>Digestive</td>
<td></td>
<td></td>
</tr>
<tr>
<td>anal canal</td>
<td>++</td>
<td>- rectum -bladder -bowel -kidney -bone -perineum</td>
</tr>
<tr>
<td>rectum</td>
<td>++</td>
<td></td>
</tr>
<tr>
<td>pancreas</td>
<td>+</td>
<td>- rectum -bladder -bowel -kidney</td>
</tr>
<tr>
<td>CYBERKNIFE-INDICATIONS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Intracranial lesions:</strong> single fraction, or fractionated</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Head and neck:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Nasopharynx &amp; base of skull, primary or recurrent</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Other sites, as boost following conventional RT, or recurrent</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Spine:</strong> where surgery indicated but not feasible, and conventional RT less effective or not possible</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Lung:</strong> where surgery indicated but not feasible</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Liver:</strong> where surgery indicated but not feasible</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Pancreas:</strong> unresectable but localized tumors</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Kidney:</strong> where surgery indicated but not feasible</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Previously irradiated tumors:</strong> retreatment w/ conventional RT not possible, for severe symptoms, Karnofsky $\geq 40$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Clinical Applications

- Benign conditions
  - Acoustic neuroma/Vestibular schwannoma, AVM
  - Meningioma
  - Pituitary adenoma, Craniopharyngioma
  - Glomus jugulare tumors
  - Trigeminal neuralgia
INDICATIONS OF TOMOTHERAPY

**Magnafield radiotherapy – Large Field IMRT**
- Total Marrow Irradiation (TMI) & Total Lymphoid Irradiation (TLI)
- Whole Abdominopelvic Radiotherapy (WAR)
- Craniospinal Irradiation (CSI)
- Mantle, Mini-Mantle, Extended Mantle field
- Inverted-Y, Spade field

**Simultaneous targeting of multiple lesions**
- Synchronous double primaries
- Multiple metastases closely or far apart
- Primary plus metastatic lesions

**Conformal avoidance**
- Whole Brain sparing scalp radiotherapy
- Scalp sparing Whole brain radiation therapy (WBRT)
- Hippocampal & neural stem cell sparing WBRT
- Cardiac sparing mediastinal radiotherapy
Indications of SBRT

- **Lung**
  - Stage I (T1–2 N0 M0) NSCLC
  - Lung mets

- **Liver**
  - Hepatocellular carcinoma
  - Liver mets

- **Spine**
  - Spinal mets (primary trt, postop, re-irradiation)
  - Benign spinal tumors

- **Promising early results**
  - Prostate cancer
  - Renal cell carcinoma
  - Pancreatic cancer
Immobilization—Blue Bag

Medical Intelligence BodyFIX
# SBRT Dose

## Most Commonly Reported SBRT Prescriptions for Spine Tumors (n=170)

<table>
<thead>
<tr>
<th>Fractions (%)</th>
<th>Common Dose/Fraction, Gy (%)</th>
<th>Median Dose/Fraction, Gy (range)</th>
<th>Median IDL, % (range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (57%)</td>
<td>18 (40%), 16 (34%)</td>
<td>18 (7-24)</td>
<td>85 (70-100)</td>
</tr>
<tr>
<td>3 (22%)</td>
<td>8 (51%), 7 (14%)</td>
<td>8 (6-12)</td>
<td>80 (75-95)</td>
</tr>
<tr>
<td>5 (18%)</td>
<td>6 (60%), 7 (10%)</td>
<td>6 (4-12)</td>
<td>100 (90-100)</td>
</tr>
</tbody>
</table>

## Most Commonly Reported SBRT Prescriptions for Lung (n=262)

<table>
<thead>
<tr>
<th>Fractions (%)</th>
<th>Common Dose/Fraction, Gy (%)</th>
<th>Median Dose/Fraction, Gy (range)</th>
<th>Median IDL, % (range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 (47%)</td>
<td>20 (46%), 18 (45%)</td>
<td>18 (10-20)</td>
<td>80 (70-100)</td>
</tr>
<tr>
<td>4 (21%)</td>
<td>12 (78%), 12.5 (11%)</td>
<td>12 (10-16)</td>
<td>85 (80-100)</td>
</tr>
<tr>
<td>5 (30%)</td>
<td>10 (51%), 12 (34%)</td>
<td>10 (3-20)</td>
<td>90 (75-100)</td>
</tr>
</tbody>
</table>

## Most Commonly Reported SBRT Prescriptions for Liver (n=142)

<table>
<thead>
<tr>
<th>Fractions (%)</th>
<th>Common Dose/Fraction, Gy (%)</th>
<th>Median Dose/Fraction, Gy (range)</th>
<th>Median IDL, % (range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 (48%)</td>
<td>15 (40%), 20 (25%)</td>
<td>15 (8-20)</td>
<td>80 (70-100)</td>
</tr>
<tr>
<td>4 (9%)</td>
<td>12 (77%), 10 (8%)</td>
<td>12 (8-12)</td>
<td>80 (80-95)</td>
</tr>
<tr>
<td>5 (38%)</td>
<td>10 (38%), 12 (19%)</td>
<td>10 (5-12)</td>
<td>90 (70-100)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Study</th>
<th>Trial type</th>
<th>Disease stage</th>
<th>Number of patients</th>
<th>Radiation dose</th>
<th>Follow-up period (months)</th>
<th>Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>McGarry et al. (2005)</td>
<td>Prospective (phase I)</td>
<td>Medically inoperable stage I</td>
<td>47</td>
<td>24–72 Gy in 3 fractions at 80%</td>
<td>27.4 for T1, 19.1 for T2</td>
<td>LC: 78.7%</td>
</tr>
<tr>
<td>Fakiris et al. (2009)</td>
<td>Prospective (phase II)</td>
<td>Medically inoperable stage I</td>
<td>70</td>
<td>T1 tumors: 60Gy in 3 fractions at 80% T2 tumors: 66Gy in 3 fractions at 80%</td>
<td>50.2</td>
<td>LC: 88.1% at 3 years OS: 42.7% at 3 years CSS: 81.7% at 3 years</td>
</tr>
<tr>
<td>Nagata et al. (2005)</td>
<td>Prospective (phase I–II)</td>
<td>IA and IB</td>
<td>45</td>
<td>48Gy in 4 fractions at isocenter</td>
<td>30 for T1 tumors, 22 for T2 tumors</td>
<td>LC: 98% (crude) OS: 92% and 83% at 1 and 3 years, respectively DFS: 80% and 72% at 1 and 3 years, respectively</td>
</tr>
<tr>
<td>Baumann et al. (2009)</td>
<td>Prospective (phase II)</td>
<td>Medically inoperable stage I</td>
<td>57</td>
<td>45Gy in 3 fractions at 67%</td>
<td>35</td>
<td>LC: 92% at 3 years OS: 86%, 65% and 60% at 1, 2 and 3 years, respectively CSS: 93%, 88% and 88% at 1, 2 and 3 years, respectively PFS: 52% at 3 years</td>
</tr>
</tbody>
</table>

### SBRT for Lung Metastases

<table>
<thead>
<tr>
<th>Study</th>
<th>Trial type</th>
<th>Number of patients</th>
<th>Number of targets</th>
<th>Radiation dose</th>
<th>Median follow-up (months)</th>
<th>Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uematsu et al. (1998)&lt;sup&gt;3&lt;/sup&gt;</td>
<td>Retrospective</td>
<td>22</td>
<td>43</td>
<td>30–75 Gy in 5–15 fractions prescribed to 80%</td>
<td>9</td>
<td>LC: 98% (crude) No or minimal adverse effects</td>
</tr>
<tr>
<td>Hara et al. (2002)&lt;sup&gt;49&lt;/sup&gt;</td>
<td>Retrospective</td>
<td>14</td>
<td>18</td>
<td>20–30 Gy in one fraction prescribed to periphery of PTV</td>
<td>12</td>
<td>LC: 78% at 13 months. No grade 3 or higher toxic effects</td>
</tr>
<tr>
<td>Lee et al. (2003)&lt;sup&gt;50&lt;/sup&gt;</td>
<td>Retrospective</td>
<td>19</td>
<td>25</td>
<td>30–40 Gy in 3–4 fractions (10 Gy per dose) prescribed to periphery of PTV</td>
<td>18</td>
<td>LC: 88% at 2 years OS: 88% at 2 years No symptomatic or late serious complications</td>
</tr>
<tr>
<td>Hof et al. (2007)&lt;sup&gt;51&lt;/sup&gt;</td>
<td>Retrospective</td>
<td>61</td>
<td>71</td>
<td>12–30 Gy in one fraction prescribed to isocenter</td>
<td>14</td>
<td>LPF: 88.6%, 73.7% and 63.1% at 1, 2 and 3 years, respectively OS: 78.1%, 65.1% and 47.8% at 1, 2 and 3 years, respectively No clinically significant toxic effects</td>
</tr>
<tr>
<td>Okunieff et al. (2006)&lt;sup&gt;52&lt;/sup&gt;</td>
<td>Retrospective</td>
<td>42</td>
<td>125</td>
<td>50 Gy in 10 fractions (5 Gy per dose) prescribed to 80%</td>
<td>18.7</td>
<td>LC: 94% (crude), 91% at 3 years PFS: 25% and 16% at 1 and 2 years, respectively Grade 3 toxic effects: 4%</td>
</tr>
</tbody>
</table>

# SBRT for Liver Metastases

<table>
<thead>
<tr>
<th>Study</th>
<th>Type</th>
<th>Number of patients</th>
<th>Number of targets</th>
<th>Radiation dose</th>
<th>Median follow-up (months)</th>
<th>Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Katz <em>et al.</em></td>
<td>Retrospective</td>
<td>69</td>
<td>174</td>
<td>30–55 Gy in fractions of 2–6 Gy prescribed to 80%</td>
<td>14.5</td>
<td>LC: 76% and 57% at 10 and 20 months, respectively OS: 46% and 24% at 6 and 12 months, respectively Grade 3 or higher toxic effects: 0%</td>
</tr>
<tr>
<td>Wulf <em>et al.</em></td>
<td>Retrospective</td>
<td>23</td>
<td>23</td>
<td>30 Gy in 3 fractions of 10 Gy prescribed to 65%</td>
<td>9.0</td>
<td>LC: 76% and 61% at 1 and 2 years, respectively OS: 71% and 43% after 1 and 2 years, respectively Grade 3–5 toxic effects (acute): 0%</td>
</tr>
<tr>
<td>Gurnvén <em>et al.</em></td>
<td>Retrospective</td>
<td>7</td>
<td>9</td>
<td>20–40 Gy in 2–4 fractions, 30–45 Gy in 2–3 fractions, or 40 Gy in 2 fractions prescribed to 65%</td>
<td>117.0</td>
<td>LC: 100% (crude) OS: 100% (crude)</td>
</tr>
<tr>
<td>Herfarth <em>et al.</em></td>
<td>Prospective (phase I–II)</td>
<td>33</td>
<td>56</td>
<td>14–26 Gy in 1 fraction prescribed to 80%</td>
<td>5.7.0</td>
<td>LC: 78% (crude); 75%, 71% and 67% at 6, 12 and 18 months, respectively † OS: 72% at 1 year † RILD: 0%</td>
</tr>
</tbody>
</table>

Biologically Guided Radiotherapy: Theragnostics

- "Theragnostic": use of molecular imaging to prescribe the distribution of radiation doses in 4 dimensions
  - Tumor burden / clonogenic density
  - Hypoxia
  - Proliferation
  - Receptor expression (EGFR) etc

(targeted)
TAKE HOME MESSAGE

- GEOMETRIC FIELD SHAPING: 3DCRT
- GEOMETRIC FIELD SHAPING + MODULATION OF THE FLUENCE: IMRT
- GEOMETRIC FIELD SHAPING + MODULATION OF THE FLUENCE + IMAGE GUIDANCE: IGRT

HEAD AND NECK:
- HIGH RISK CTV $\rightarrow$ $> 70$ Gy.
- INT. RISK CTV $\rightarrow$ 63 Gy.
- LOW RISK $\rightarrow$ 50-55 Gy.

- POSITION AS COMFORTABLE AS POSSIBLE.
- **TARGET VOLUME:**
  - GTV + subclinical disease = CTV.
  - CTV + IM + SM = PTV.
  - OAR = serial, parallel, serial in parallel, combination of serial and parallel.

- **BEAMS EYE VIEW** → looking from the source.
- **CONVENTIONAL AND 3D CRT** → forward planning.
- **IMRT** → inverse planning.
- **DIFFERENTIAL DVH** → exact volume of tissue received that particular dose.
- CUMULATIVE DVH → entire volume received specified dose.
- Inhomogenity should be within + 7% to − 5%.
- Motion may be Interfractional/ Intrafractional.
- IGRT → planning -> EPID, Cyberknife.
  volumetric -> CT on rail, Tomo, MVCT, CVCT.
- 3D CT + Respiratory gating → 4 D.
- PAROTID dose less in chinup position.
- IMRT IN H& N→ less xerostomia, better speaking.
- PROSTATE → Biochemical control no difference in prostate Vs pelvis + prostate Radiation.
  4 year PFS improved but more toxicity.
  Dose escalation → Better freedom from biochemical failure and better PSA relapse free survival.
- Ca Cervix → Less toxicity, better overall survival.
- Ca Pancreas → Less toxicity.
- SBRT indicated in:
  T1, T2 NSCLC
  Lungs metastasis
  Hepatocellular carcinoma.
  Spinal RT.
THANK YOU