ICRU 83: Clinician’s Perspective

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Hyderabad
• Learning objective
  – Ability to compare salient data points and clinical issues in IMRT Plans using ICRU 83
  – Choose from multiple plans to suit clinical objective
Planning Workflow

- Immobilization
- Image acquisition and registration

<table>
<thead>
<tr>
<th>Contouring</th>
<th>Constraints</th>
<th>Physician’s Responsibility:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planning</td>
<td></td>
<td>To interpret the plan in light of ICRU 83</td>
</tr>
</tbody>
</table>

- Plan evaluation
- Plan implementation
Planning Workflow

- Immobilization
- Image acquisition and registration
- Contouring
- Constraints
- Planning

Plan evaluation
- Plan implementation

To choose the best among multiple plans:
- Target coverage
- OAR sparing
- Hotspot/Coldspot
- DVH analysis
- Isodose coverage
- Indices (CI & HI)
- Clinical relevance
Objective Assessment

• Dose Volume Histogram
  – Cumulative
  – Differential

• Defined Volumes
  – GTV: Gross Tumor Volume
  – CTV: Clinical Target Volume
  – ITV: Internal Target Volume
  – PTV: Planning Target Volume

Discretionary/ Evolving

• Assessment of isodose every slice coverage for clinical relevance
• Multimodality Images
• Biological Volumes
• Effect of variation in dose levels
• TCP/ NTCP

International Commission on Radiation Units & Measurements (ICRU)

- OAR: Organs @ Risk
- PRV: Planning Vol @ Risk
- RVR: Residual Vol @ Risk
RVR: Residual Vol @ Risk Body contour – (CTV + OAR)

TV: Volume apart from PTV receiving clinically significant dose

PTV: Set up errors & organ motion

ITV: Uncertainties of shape, size and position

GTV: Clinically or radiologically assessed tumor (GTV-P / GTV-N)

CTV: Subclinical Extension (CTV-P / CTV-N)

Organ@ Risk (OAR)
Serial: Sp Cord Parallel: Parotid

PRV: Planning Organ @ Risk Volume OAR + Set up Margin
Types of CTV/PTV

- GTV-P_{PET}
- GTV-N_{PET}
- CTV-N
- CTV-P
- CTV 70
- CTV 54
- CTV 60
ICRU through the ages
## ICRU through ages

<table>
<thead>
<tr>
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<tr>
<td>Target Volume</td>
<td>GTV</td>
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<td>GTV</td>
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<tr>
<td></td>
<td>CTV</td>
<td>CTV</td>
<td>CTV</td>
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<tr>
<td></td>
<td>ITV</td>
<td>ITV</td>
<td></td>
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<tr>
<td></td>
<td>PTV</td>
<td>PTV</td>
<td>PTV</td>
</tr>
<tr>
<td>Treatment volume</td>
<td>Treated volume</td>
<td>Treated volume</td>
<td>Treated volume</td>
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<tr>
<td>Irradiated volume</td>
<td>Irradiated volume</td>
<td>Irradiated volume</td>
<td>Irradiated volume</td>
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<tr>
<td>Organ at Risk</td>
<td>Organ at risk</td>
<td>Organ at risk</td>
<td>Organ at risk</td>
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<tr>
<td></td>
<td>PRV</td>
<td>PRV</td>
<td></td>
</tr>
</tbody>
</table>

**Hotspot (more than 100% - 2 sq cm):**
- Hotspot (more than 100% - 15 mm dia)
- Hotspot (more than 100% - 15 mm dia)
- High dose to RVR

**Dose heterogenity (no values):**
- Dose heterogenity (+7 to -5 %)
- Dose heterogenity (+7 to -5 %)
- Not specified
Dose Reporting in 3D (ICRU 50)

- Dose must be reported to the ICRU reference point
  - ICRU reference point is usually isocenter
  - It could be a point in the center of the PTV
  - Uniform dose to PTV (-5 to +7%)

Maximum & minimum dose must be reported in PTV
Whenever possible dose should be reported to PRV
Paradigm Shift with IMRT

IMRT represents a paradigm shift
Non uniform dose (dose painting)
Large dosimetric variations
Isocenter dose is meaningless
Radiobiological consequence of large heterogeneous dose is uncertain (i.e. 180c Gy/day versus 250c Gy/day)
IMRT: Sequential

Phase I: Low Dose: Nodal+ Primary

Summation of Both Plans

Phase II: HighDose: Primary / Boost
IMRT: Simultaneous Integrated Boost

Both Low Dose & High Dose Volumes Treated Simultaneously
Isocenter dose is non-representative.
IMRT: Variability in PTV Dose
IMRT: Variability in OAR Dose

- Rectum
- Bladder
- Rt Femoral Head
- Lt Femoral Head

Graphs showing dose versus volume for different systems and structures.
Variation of doses among 850 patients in 5 Institutions

Median Dose is most consistent
ICRU-83: PTV

• Dose Volume Reporting
  – $D_{50\%}$ (Median Dose)
    • Most representative of prescribed dose
  – $D_{mean}$ is nearly identical to $D_{50\%}$
  – $D_{98\%}$ (Near Minimum Dose)
    • Dose received by 98% of PTV
  – $D_{2\%}$ (Near Maximum Dose)
    • Dose received by 2% of PTV
Comparison of ICRU reference point dose to $D_{98\%}$
Application of ICRU 83 in single dose level plans
DVH of PTV

Ca Oropharynx – PTV Boost
Prescription Dose 70 Gy

Median Dose (D50%) - 70.67 Gy
Near Minimum Dose (D98%) - 68 Gy
Near Maximum Dose (D2%) - 72.3 Gy

(Dmean) 70.59 ~ (D50%) 70.67
Multiple dose level plan:
Nasopharynx with SIB (60Gy & 70Gy in 33Fr)
DVH of PTV

[Diagram showing the DVH of PTV with dose values and relative dose percentages.]
Differential DVH

- 60Gy Peak
- PTV 60
- 70 Gy Peak
- PTV 70
OAR & PRV

• Serial Organs: Spinal Cord, Esophagus
  – $D_{2\%}$ is important
  – Entire organ should be considered if possible
  – Minimum dimension of 15mm to be considered.

• Parallel organs: Parotid, Liver, Lung
  – $D_{\text{mean}}$ is important
  – $D_{\text{mean}}$ and $D_{\text{median}}$ may not be same

• $V_d$ in cases like Lungs ($V_{20}$)
TOLERANCE OF NORMAL TISSUE TO THERAPEUTIC IRRADIATION

B. Emami, M.D., J. Lyman, Ph.D., A. Brown, M.D., L. Cola, M.D., M. Gorten, Ph.D., J. E. Munzenreider, M.D., B. Shank, M.D., L. J. Solin, M.D. and M. Wesson, M.D.

1Memorial Sloan-Kettering Cancer Center, New York, NY 10021; 2Department of Radiation Therapy, University of Pennsylvania School of Medicine and the Fox Chase Cancer Center, Philadelphia, PA 19111; 3Massachusetts General Hospital, Department of Radiation Medicine, Boston, MA 02114; and 4University of California-Lawrence Berkeley Laboratory, Research Medicine and Radiation Biophysics Division, Berkeley, CA 94720.

Table 1. Normal tissue tolerance to therapeutic irradiation

<table>
<thead>
<tr>
<th>Organ</th>
<th>TD 5/5 Volume</th>
<th>TD 50% Volume</th>
<th>Selected endpoint</th>
</tr>
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<tbody>
<tr>
<td>Kidney I</td>
<td>5000</td>
<td>3000*</td>
<td>2300</td>
</tr>
<tr>
<td>Kidney II</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bladder</td>
<td>N/A</td>
<td>8000</td>
<td>6500</td>
</tr>
<tr>
<td>Bone:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Femoral Head I and II</td>
<td>6500</td>
<td>6000</td>
<td>5200</td>
</tr>
<tr>
<td>TM joint mandible</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rib cage</td>
<td>5000</td>
<td></td>
<td>6500</td>
</tr>
<tr>
<td>Skin</td>
<td>7000</td>
<td>6000</td>
<td>5500</td>
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<tr>
<td>Brain</td>
<td>6000</td>
<td>5000</td>
<td>4500</td>
</tr>
<tr>
<td>Brain stem</td>
<td>6000</td>
<td>5500</td>
<td>5000</td>
</tr>
<tr>
<td>Optic nerve I &amp; II</td>
<td>No partial volume</td>
<td>5000</td>
<td></td>
</tr>
<tr>
<td>Chiasma</td>
<td>No partial volume</td>
<td>5000</td>
<td>No partial volume</td>
</tr>
<tr>
<td>Spinal cord</td>
<td>5000</td>
<td>5000</td>
<td></td>
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<tr>
<td>Cauda equina</td>
<td>No volume effect</td>
<td>6000</td>
<td>No volume effect</td>
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<tr>
<td>Brachial plexus</td>
<td>6200</td>
<td>6100</td>
<td>6000</td>
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<tr>
<td>Eye lens I and II</td>
<td>No partial volume</td>
<td>1000</td>
<td></td>
</tr>
<tr>
<td>Eye retina I and II</td>
<td>No partial volume</td>
<td>4500</td>
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<tr>
<td>Ear middle/external</td>
<td>3000</td>
<td>3000</td>
<td>3000*</td>
</tr>
<tr>
<td>Ear middle/external</td>
<td>5500</td>
<td>5500</td>
<td>5500*</td>
</tr>
<tr>
<td>Parotid I and II</td>
<td>3200*</td>
<td>3200*</td>
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<tr>
<td>Larynx</td>
<td>7900*</td>
<td>7900*</td>
<td>7900*</td>
</tr>
<tr>
<td>Larynx</td>
<td>4500</td>
<td>4500</td>
<td>4500*</td>
</tr>
<tr>
<td>Lung I</td>
<td>4500</td>
<td>3000</td>
<td>1750</td>
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<tr>
<td>Lung II</td>
<td>5500</td>
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<tr>
<td>Heart</td>
<td>6000</td>
<td>4500</td>
<td>4000</td>
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<td>Stomach</td>
<td>6000</td>
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<td>5000</td>
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<td>Small intestine</td>
<td>5000</td>
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<td>4000</td>
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<tr>
<td>Colon</td>
<td>5500</td>
<td>4500</td>
<td></td>
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<tr>
<td>Recum</td>
<td>Volume 100 cm³</td>
<td>No volume effect</td>
<td>6000</td>
</tr>
<tr>
<td>Liver</td>
<td>5000</td>
<td>3500</td>
<td>3000</td>
</tr>
</tbody>
</table>

*<.50% of volume doesn't make a significant change.
Organs at Risk: QUANTEC
Quantitative Analysis of Normal Tissue Tolerance in Clinic
<table>
<thead>
<tr>
<th>Organ</th>
<th>Volume segmented</th>
<th>Irradiation type (partial organ unless otherwise stated)</th>
<th>Endpoint</th>
<th>Dose (Gy), or dose/volume parameters</th>
<th>Rate (%)</th>
<th>Notes on dose/volume parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bilateral whole parotid glands</td>
<td>3D-CRT</td>
<td>Long term parotid salivary function reduced to &lt;25% of pre-RT level</td>
<td>Mean dose &lt;39</td>
<td>&lt;50</td>
<td>For combined parotid glands (per Fig. 3 in paper)</td>
<td></td>
</tr>
<tr>
<td>Pharynx</td>
<td>Whole organ</td>
<td>Symptomatic dysphagia and aspiration</td>
<td>Mean dose &lt;50</td>
<td>&lt;20</td>
<td>Based on Section B4 in paper</td>
<td></td>
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<tr>
<td>Larynx</td>
<td>Whole organ</td>
<td>Vocal dysfunction</td>
<td>Dmax &lt;66</td>
<td>&lt;20</td>
<td>With chemotherapy, based on single study (see Section A4.2 in paper)</td>
<td></td>
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<tr>
<td>Larynx</td>
<td>3D-CRT</td>
<td>Aspiration</td>
<td>Mean dose &lt;50</td>
<td>&lt;30</td>
<td>With chemotherapy, based on single study (see Fig. 1 in paper)</td>
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<tr>
<td>Larynx</td>
<td>3D-CRT</td>
<td>Edema</td>
<td>Mean dose &lt;44</td>
<td>&lt;20</td>
<td>Without chemotherapy, based on single study in patients without larynx cancer**</td>
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<tr>
<td>Larynx</td>
<td>3D-CRT</td>
<td>Edema</td>
<td>V50 &lt;27%</td>
<td>&lt;20</td>
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<tr>
<td>Cochlea</td>
<td>Whole organ</td>
<td>3D-CRT</td>
<td>Sensory neural hearing loss</td>
<td>Mean dose ≤45</td>
<td>&lt;30</td>
<td>Mean dose to cochlear, hearing at 4 kHz</td>
</tr>
<tr>
<td>Cochlea</td>
<td>SRS (single fraction)</td>
<td>Sensory neural hearing loss</td>
<td>Prescription dose ≤14</td>
<td>&lt;25</td>
<td>Serviceable hearing</td>
<td></td>
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<tr>
<td>Parotid</td>
<td>Bilateral whole parotid glands</td>
<td>3D-CRT</td>
<td>Long term parotid salivary function reduced to &lt;25% of pre-RT level</td>
<td>Mean dose &lt;25</td>
<td>&lt;20</td>
<td>For combined parotid glands$^5$</td>
</tr>
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<td>Parotid</td>
<td>Unilateral whole parotid gland</td>
<td>3D-CRT</td>
<td>Long term parotid salivary function reduced to &lt;25% of pre-RT level</td>
<td>Mean dose &lt;20</td>
<td>&lt;20</td>
<td>For single parotid gland. At least one parotid gland spared to &lt;20 Gy$^5$</td>
</tr>
<tr>
<td>Organ</td>
<td>Volume segmented</td>
<td>irradiation type (partial organ unless otherwise stated)</td>
<td>endpoint</td>
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</tr>
<tr>
<td>Brain</td>
<td>Whole organ</td>
<td>3D-CRT</td>
<td>Symptomatic necrosis</td>
<td>Dmax &lt; 60</td>
<td>&lt;3</td>
<td>Data at 72 and 90 Gy, extrapolated from BED models</td>
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<tr>
<td>Brain</td>
<td>Whole organ</td>
<td>3D-CRT</td>
<td>Symptomatic necrosis</td>
<td>Dmax ≥ 72</td>
<td>5</td>
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<tr>
<td>Brain</td>
<td>Whole organ</td>
<td>3D-CRT</td>
<td>Symptomatic necrosis</td>
<td>Dmax ≥ 90</td>
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<td>Brain stem</td>
<td>Whole organ</td>
<td>Whole organ</td>
<td>Permanent cranial neuropathy or necrosis</td>
<td>Dmax &lt; 54</td>
<td>&lt;5</td>
<td>Rapid rise when V12 &gt; 5–10 cc</td>
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<tr>
<td>Brain stem</td>
<td>Whole organ</td>
<td>3D-CRT</td>
<td>Permanent cranial neuropathy or necrosis</td>
<td>D1–10 cc ≤ 59</td>
<td>&lt;5</td>
<td>Point dose &lt; 1 cc</td>
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<td>Optic nerve / chiasm</td>
<td>Whole organ</td>
<td>3D-CRT</td>
<td>Optic neuropathy</td>
<td>Dmax ≤ 55</td>
<td>&lt;3</td>
<td>Given the small size, 3D-CRT is often whole organ[1]</td>
</tr>
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<td>Optic nerve / chiasm</td>
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<tr>
<td>Spinal cord</td>
<td>Partial organ</td>
<td>3D-CRT</td>
<td>Myelopathy</td>
<td>Dmax ≤ 50</td>
<td>0.2</td>
<td>Including full cord cross-section</td>
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<tr>
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<td>Partial organ</td>
<td>3D-CRT</td>
<td>Myelopathy</td>
<td>Dmax ≤ 60</td>
<td>6</td>
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<tr>
<td>Spinal cord</td>
<td>Partial organ</td>
<td>3D-CRT</td>
<td>Myelopathy</td>
<td>Dmax ≤ 65</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Spinal cord</td>
<td>Partial organ</td>
<td>SRS (single fraction)</td>
<td>Myelopathy</td>
<td>Dmax ≤ 13</td>
<td>1</td>
<td>3 fractions, partial cord cross-section irradiated</td>
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<tr>
<td>Spinal cord</td>
<td>Partial organ</td>
<td>SRS (hypo fraction)</td>
<td>Myelopathy</td>
<td>Dmax ≤ 20</td>
<td>1</td>
<td>3 fractions, partial cord cross-section irradiated</td>
</tr>
</tbody>
</table>
DVH of OAR (PRV)

Parallel Structure (Parotid)  
Dmean (27Gy)

Serial Structure (Spinal Cord)  
D2% (39 Gy)
Overlapping CTV & OAR

Cropping the PTV or PRV?
Planning constraints and priorities to be adjusted for desirable dose
Planning for overlaps in PTVs or PTV / OAR
Solutions for overlap

1. Assigning a much higher importance weight to PTV-II than to PTV-III at optimization;
2. Relaxing the maximum dose objective for PTV-III;
3. Fragmentation of the PTV-III volume (panel d) and relaxing the maximum dose objective for a subvolume of PTV-III or a combination of 1–3
4. Fragmentation of PTV-III to create a subvolume for relaxing the maximum dose constraint;
5. Unambiguous dose objectives for plan optimization
Checking for dose littering
Solutions for dose littering

1. volume containing a PTV, 4 PRV and the remaining of the imaged volume called UIV: Unspecified Imaged Volume;

2. method described by investigators from Washington University. A soft Dmax (dose maximum) constraint is assigned the whole UIV;

3. method used at Virginia Commonwealth University. No constraints imposed to a narrow TZ (transitional zone) immediately outside PTV but to a shell surrounding the TZ. Inside the remaining UIV, one or more Pseudo-OAR(s) are constructed or draw an RVR.

4. “Matroska” method described by investigators from Ghent University Hospital. Several shell structures inside each other (like Russian matroskas) leave no UIV. Outer shells have more severe dose maximum constraints than inner shells.
Perfectly conformal plan...

- how much of PTV is covered?
- how much is the spill?
- how is the uniformity within PTV?
Coverage Factor

• tells you how much you **miss** on PTV

\[
\text{Coverage Factor} = \frac{\text{volume of PTV covered by RI}}{\text{volume of PTV}} - \frac{\text{volume of overlapping region}}{\text{volume of PTV}}
\]

**Ideal value** $= 1$
Conformity Index (CI)

- ratio of / 
- ratio of / 
- ideally = 1; but expect around 1.3 to 1.5
- presently, inverse of the ratio is followed

Body tells you how much you spill outside PTV
Conformity Index ICRU 50

- Conformity Index (CI) = TV/PTV
- TV = treated volume is the tissue volume that receives at least the dose selected and specified
- CI => optimised close to 1.0
- For small volumes CI up to 2 can be acceptable (SRS)
- For bigger volumes, CI should be closer to 1
Homogeneity Index \((HI)\)

- measure of uniformity within PTV
- expressed as the ratio \(D_2/D_{98}\)
  - \(D_2\) is the maximum dose received by at least \(2\%\) of the PTV
  - \(D_{98}\) is the maximum dose received by at least \(98\%\) of the PTV
Homogeneity Index (RTOG-1993)

\[ HI_{RTOG} = \frac{I_{\text{max}}}{RI} \]

\( I_{\text{max}} \) = maximum isodose in the target, \( RI \) reference isodose

Ideal \( HI \leq 2 \)

Minor violation = 2 to 2.5

Major violation > 2.5 (Clinical discretion needed)

Alternative formula

\[ HI = D_2 - D_{98}/DP \times 100 \]

\( D_2 \) = minimum dose to 2% of the target

\( D_{98} \) = minimum dose to 98% of the target

\( DP \) = prescribed dose
Homogeneity Index ($HI$)

- for a typical 3-D CRT plan, it is around 1.07
- for IMRT it should be $\leq 1.15$
- $D_5 / D_{95}$ has also been used
Conformity & Homogeneity indices

Homogeneity Index

Conformity index

IMRT  VMAT

PAT.1 PAT.2 PAT.3 PAT.4 PAT.5 PAT.6 PAT.7 PAT.8 PAT.9 PAT.10 PAT.11 PAT.12 PAT.13 PAT.14 PAT.15 PAT.16 PAT.17

PAT.1 PAT.2 PAT.3 PAT.4 PAT.5 PAT.6 PAT.7 PAT.8 PAT.9 PAT.10 PAT.11 PAT.12 PAT.13 PAT.14 PAT.15 PAT.16 PAT.17
What the DVH doesn’t tell

Identical DVH
Vault Recurrence
180 x 28 Fr
220 x 28 Fr
What the DVH doesn’t tell

Location of High Dose Area
What the DVH doesn’t tell

Identical DVH

Post OP Larynx + Hypopharnx
What the DVH doesn’t tell

[Image of medical scans with the label "Spillage"]
QA...... Fluence analyses showed most planned cases treatable with ≥ 95% fidelity.
Learning for the day

- Definitions of new volumes as per ICRU 83
- 2D to 3D to IMRT planning
- Evaluation of dose at a relevant point
- Evaluation of dose as a volume
- Accounting for inhomogeneity
- Accounting for overlapping volumes
Learning for the day

- Mathematical and graphical representation of dose across a volume
- No more hot spots & cold spots
- D2, D98 and Dmean are the new standards
- Conformity & Homogeneity indices
- Limitation of DVH
- Ability to choose a proper radiation plan on the basis of these variables
Thank You

"That concludes my prepared remarks. I will now evade your questions."