Plan evaluation in high technique radiotherapy

DR KANHU CHARAN PATRO
MD, DNB (RADIATION ONCOLOGY), MBA, FAROI (USA), PDCR, CEPC
HOD, RADIATION ONCOLOGY
Mahatma Gandhi Cancer Hospital And Research Institute, Visakhapatnam
drkcpatro@gmail.com  M-9160470564
Different plans
Basics – isocentric vs nonisocentric
Basics – 2d verification vs 3d verification

Figure 6: On-board imaging used for IGRT- On-board Cone Beam CT images are registered onto planning CT scan to calculate shifts which are then applied onto the patient’s couch to achieve perfect targeting.
Basics – hexapod couch
Basics – FFF vs no FFF
Basics – Immobilization
Basics of plan evaluation – review your contour
Basics – Notes to physics
Basics of plan evaluation – Defining the dose

Dose Volume Reporting

1. **D50% (Median Dose)**
   1. Most representative of prescribed dose

2. **Dmean** is nearly identical to D50%

3. **D98% (Near Minimum Dose)**
   1. Dose received by 98% of PTV

4. **D2% (Near Maximum Dose)**
   5. Dose received by 2% of PTV
Basics of plan evaluation – Defining the dose

Ca Oropharynx – PTV Boost
Prescription Dose 70 Gy

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

(Dmean) 70.59 ~ (D50%) 70.67
Basics – Michael Goitein

Fig. 1 Michael Goitein in 2007 delivering an invited lecture in the Massachusetts General Hospital Ether Dome. Reprinted from [1] with permission from Elsevier

Fig. 2 A team of three senior physicists evaluating a complex treatment plan: Michael Goitein at the center with his colleagues. On the right side of the figure are an operation terminal (lower side) of the VAX computer and a computer-driven image display device (upper side) (probably in the early 1980s). Reprinted from [1] with permission from Elsevier
Basics of plan evaluation – DVH
Basics of plan evaluation – DVH pitfalls

1. Insensitive to hot spot and cold spot
2. Shape of DVH alone can be misleading
3. DVH can only be calculated using VOI
4. DVH throws away spatial information
5. DVH is the most direct and informative representation of a treatment plan available
6. 3D dose distribution are large and cumbersome to analyse quantitatively
7. User interactivity is essential to extract the most information from dose distribution.
Basics of plan evaluation – BASIC DVH

Calculation and interpretation
The cumulative dose volume ‘histogram’

- Differential DVH
- Bin-by-bin integration
- Cumulative DVH
1. Volumes receiving at least a given dose value are plotted.
2. The cumulative DVH integrates the direct histogram, so it always begins at 100% (100% of the organ receives at least 0 dose)
3. It ends at maximum dose
Basics of plan evaluation – Analyzing DVH
1. The generic form of any histogram, displaying the volume of the organ that receives dose within each bin (1% or 0.5 to 1 Gy is a typical dose bin width.
2. It is useful for display of the dose to target volumes, because one can easily visualise the minimum dose, the maximum dose, and the most representative of the dose to the entire target volume.
Basics – plan evaluation
Basics – ICRU

ICRU
Prescribing, Recording, and Reporting Photon-Beam

ICRU REPORT 29 (1978)
• Dose Specification for Reporting External Beam Therapy with Photons and Electrons

ICRU REPORT 50 (1993)
• Prescribing, Recording, and Reporting Photon Beam Therapy

ICRU REPORT 62 (1999)
• A Supplement to Report 50
  • conventional external photon-beam irradiation techniques, including 3D-CRT

ICRU REPORT 83 (2010)
ICRU 50/62/83

- **Gross tumor volume (GTV):** Tumor visible
- **Clinical target volume (CTV):** GTV and microscopic tumor
Basics – OAR

PTV: Planning Target Volume
\( PTV = CTV + IM : \text{internal Margin} + SM : \text{set-up margin} \)

CTV: Clinical Target Volume

GTV: Gross Target Volume

PRV: Planning Organ at Risk Volume
\( PRV = OAR + IM : \text{internal Margin} + SM : \text{set-up margin} \)

OAR: Organ At Risk
Basics – mlc and cone
CB-CHOP: A simple acronym for evaluating a radiation treatment plan

Mary Dean, MD; Rachel Jimenez, MD; Eric Mellon, MD, PhD; Emma Fields, MD; Raphael Yecheili, MD; Raymond Mak, MD

- **Contours**: Review target volumes and OARS
- **Beam Arrangements/Fields**: Appropriate and reasonable
- **Coverage**: Evaluate on graphic plan and DVH
- **Heterogeneity/Hot Spots**: Value and location
- **Organs at Risk**: Review specified constraints, corresponding isodose lines on plan, and DVH
- **Prescription**: Total dose, dose per fraction, and image guidance

*FIGURE 1. Flowchart diagram summarizing the CB-CHOP acronym and components of plan quality.*

Mary Dean/Applied Radiation Oncology/2017
# Basics – Coverage Index

<table>
<thead>
<tr>
<th>PTV/CTV/GTV</th>
<th>$D_2/D_{98}$</th>
<th>95-107</th>
</tr>
</thead>
</table>

Patro K C/Journal of Current Oncology/2022(UNDER REVIEW)
Basics – OAR INDEX

Max dose in series organ

Mean dose in parallel organ

Volumetric analysis
Basics – Delivery index

Complexity of plan

MU
Basics – Delivery index

Complexity of plan

Complexity of Delivery

MU
# PTV coverage index

<table>
<thead>
<tr>
<th>SL NO</th>
<th>PARAMETER</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>D\text{\textsubscript{MAX}}</td>
<td>36.43Gy</td>
</tr>
<tr>
<td>2</td>
<td>D\text{\textsubscript{95%}}</td>
<td>31.01Gy</td>
</tr>
<tr>
<td>3</td>
<td>D\text{\textsubscript{100%}}</td>
<td>28.23Gy</td>
</tr>
<tr>
<td>4</td>
<td>V\text{\textsubscript{95%}}</td>
<td>99.99%</td>
</tr>
<tr>
<td>5</td>
<td>V\text{\textsubscript{30 Gy}[V\text{\textsubscript{100%}}]}</td>
<td>99.56%</td>
</tr>
<tr>
<td>6</td>
<td>V\text{\textsubscript{110%}}</td>
<td>44.45%</td>
</tr>
<tr>
<td>7</td>
<td>V\text{\textsubscript{120%}}</td>
<td>0.03%</td>
</tr>
<tr>
<td>8</td>
<td>V\text{\textsubscript{130%}}</td>
<td>0%</td>
</tr>
</tbody>
</table>

1. Prescription Isodose level is usually not 100\% PD covering 100\% PTV
2. Often 95\% PD covering 95\% PTV or higher
3. Or 100\% PD covering 95\% PTV or higher.

Michael Torrens, J Neurosurg (Suppl 2)/2014
RTOG conformity index

- **FORMULA**
  - VOLUME OF PRESCRIPTION ISODOSE/PTV VOLUME

- 43.798/37.491 = 1.17
- DESIRABLE = 1

The conformity index was first proposed in 1993 by the Radiation Therapy Oncology Group (RTOG) and described in Report 62 of the International Commission on Radiation Units and Measurements (ICRU). It is presented as a relation between the volume of the reference dose ($V_{RI}$) and the target volume (TV).

$$Conformity\ index_{RTOG} = \frac{V_{RI}}{TV}$$

According to the RTOG guidelines, ranges of conformity index values have been defined to determine the quality of conformation. If the conformity index is situated between 1 and 2, the treatment is considered to comply with the treatment.
Paddick conformity index

• FORMULA
  
  \[
  \frac{\text{PTV VOLUME} \times \text{VOLUME OF PRESCRIPTION ISODOSE}}{\text{(VOLUME OF PRESCRIPTION ISODOSE IN AREA OF INTEREST)}^2}
  \]

  \[
  = \frac{39.764 \times 39.764}{37.494 \times 43.798} = 0.96
  \]

  • IDEAL = > 0.85. AND <1

---

This inadequacy has led to the development of the Paddick Conformity Index (PCI).\textsuperscript{48} This value is the coverage multiplied by the Selectivity Index:

\[
\text{TV}_{\text{PIV}}^2 / (\text{TV} \times \text{PIV})
\]

A perfect plan has a score of 1, whereas less perfect plans have a score of < 1. An ideal value for PCI conformity could be > 0.85.

Michael Torrens, /J Neurosurg (Suppl 2)/2014
**HOMOGENITY index**

- **FORMULA**
  - MAXIMUM DOSE/PRESCRIPTION DOSE
- 36.43Gy/30Gy = 1.21
- DESIRABLE = 1.1 - 1.3

It is an objective tool to analyse the uniformity of dose distribution in the target volume.

Homeogeneity Index (HI) = \( D_{2\%} - \frac{D_{98\%}}{D_{50\%}} \)

Ideal HI: 1.1 - 1.3
Dose fall off

- Dose fall off observation is very much needed in this evaluation under headings
- Gradient index
- Difference between various isodose lines
- e.g. between 80% and 60% - ideal - <2mm
- Between 80% and 40% - ideal - <8mm
- For that reason we have to calculate equivalent radius
Equivalent radius

- To evaluate dose gradient we have to find out difference between radius of various isodose line
- But none is iso spherical
- We have to find out equivalent radius from formula
- First find out the specified isodose volume
- Then calculate the radius
- \( V = \frac{4}{3} \pi r^3 \)
- \( r = \left( \frac{3V}{4\pi} \right)^{1/3} \)
### Equivalent radius

\[ r = \left( \frac{3V}{4\pi} \right)^{1/3} \]

<table>
<thead>
<tr>
<th>SL NO</th>
<th>PARAMETER</th>
<th>VOLUME</th>
<th>RADIUS</th>
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<tbody>
<tr>
<td>1</td>
<td>100% ISODOSE</td>
<td>43.79CC</td>
<td>2.19mm</td>
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<tr>
<td>2</td>
<td>80% ISODOSE</td>
<td>64.45CC</td>
<td>2.49mm</td>
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<tr>
<td>3</td>
<td>60% ISODOSE</td>
<td>101.19CC</td>
<td>2.89mm</td>
</tr>
<tr>
<td>4</td>
<td>50% ISODOSE</td>
<td>130.84CC</td>
<td>3.15mm</td>
</tr>
<tr>
<td>5</td>
<td>40% ISODOSE</td>
<td>177.96CC</td>
<td>3.49mm</td>
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</table>
Gradient index

- **FORMULA**
  - Difference of equivalent radius of prescription isodose and equivalent radius of 50% isodose
  - $2.19\text{mm} - 3.15\text{mm} = 0.96\text{mm}$
  - It should be between 0.3 to 0.9
Distance between various isodose lines

• BETWEEN 80% AND 60%- IDEAL-<2mm
  • HERE- 0.4mm
• BETWEEN 80% AND 40%- IDEAL- <8mm
  • HERE- 1mm

EORTC-22952-26001
### ISODOSE LINES

<table>
<thead>
<tr>
<th>COLOUR</th>
<th>ISODOSE LINE</th>
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<tbody>
<tr>
<td>Dark green</td>
<td>100%</td>
</tr>
<tr>
<td>Light green</td>
<td>80%</td>
</tr>
<tr>
<td>Sky green</td>
<td>60%</td>
</tr>
<tr>
<td>Pink</td>
<td>50%</td>
</tr>
<tr>
<td>Blue</td>
<td>40%</td>
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</table>
## OAR coverage

<table>
<thead>
<tr>
<th>SL NO</th>
<th>ORGAN</th>
<th>DESIRABLE</th>
<th>ACHIEVED</th>
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<tbody>
<tr>
<td>1</td>
<td>RT. EYE</td>
<td>MAX &lt;22.5Gy</td>
<td>1.97Gy</td>
</tr>
<tr>
<td>2</td>
<td>LT. EYE</td>
<td>MAX &lt;22.5Gy</td>
<td>4.4Gy</td>
</tr>
<tr>
<td>3</td>
<td>RT. OPTIC NERVE</td>
<td>MAX &lt;22.5Gy</td>
<td>2.3Gy</td>
</tr>
<tr>
<td>4</td>
<td>LT. OPTIC NERVE</td>
<td>MAX &lt;22.5Gy</td>
<td>5.5Gy</td>
</tr>
<tr>
<td>5</td>
<td>OPTIC CHIASM</td>
<td>MAX &lt;22.5Gy</td>
<td>7.5Gy</td>
</tr>
<tr>
<td>8</td>
<td>BRAIN STEM</td>
<td>MAX 23-31Gy</td>
<td>10.01Gy</td>
</tr>
<tr>
<td>9</td>
<td>RT. COCHLEA</td>
<td>MEAN &lt;25Gy</td>
<td>&lt;1Gy</td>
</tr>
<tr>
<td>10</td>
<td>LT. COCHLEA</td>
<td>MEAN &lt;25Gy</td>
<td>&lt;1Gy</td>
</tr>
</tbody>
</table>
Conformity Index of Contours 1 and 2

\[ \text{CI} = \frac{\text{Intersection}}{\text{Union}} \]
Basics of plan evaluation – Voxel And Pixel

- A **voxel** represents a value on a regular grid in three-dimensional space.

- Voxel is a combination of "volume" and "pixel" where **pixel** is a combination of "picture" and "element"
Accept under dosage in one of the Subvolumes
1. For plan optimization, additional dose may be dumped in RVR.

2. High absorbed dose in RVR
Basics of plan evaluation – FLASH vs BOLUS
Basics of plan evaluation – dose displaying

1. **Isodose Contours**: Set of closed contours linking voxels of equal dose
2. **Color Wash**: The coding of CT and Dose in the same voxel through the modulation of both intensity (CT) and color (Dose)
3. **Isodose Surfaces**: The Shaded surface (pseudo 3D) representation of the particular dose level and selected VOI
Figure 1. A comparison between a three-dimensional conformal radiotherapy (3DCRT) plan and a volumetric modulated arc therapy (VMAT) plan for a head and neck tumour. Notice the larger volume of the posterior fossa receiving a low dose bath in the VMAT plan. (a) 3DCRT; (b) VMAT.
Basics of plan evaluation – Beam arrangements

**BEAM ARRANGEMENT**

- **No. of fields/arc**
- **Treatment time**
- **Patient movement and internal organ motion**

**RapidArc**
Single arc IMRT: 496 MU

**Conventional**
7-field IMRT: 1685 MU
Patient positioning: A neutral head position with the patient supine is easily reproducible. Noncoplanar beams can be used to avoid entry and exit dose to organs at risk (OAR).
## Basics of plan evaluation – standardizing names

### Standardizing Normal Tissue Contouring for Radiation Therapy Treatment Planning: An ASTRO Consensus Paper

Jean L. Wright, MD, a Sue S. Yom, MD, PhD, MAS, b Musaddiq J. Awan, MD, c Samantha Dawes, CMD, d Benjamin Fischer-Valuck, MD, e Randi Kudner, MA, f Raymond Mailhot Vega, MD, MPH, g George Rodrigues, MD, PhD

- a. Johns Hopkins University, Baltimore, MD
- b. University of California, San Francisco, CA
- c. University Hospitals of Cleveland and Case Western Reserve University, Cleveland, OH
- d. American Society for Radiation Oncology, Arlington, VA
- e. Washington University School of Medicine, St. Louis, MO
- f. Perlmutter Cancer Center Department of Radiation Oncology, New York University, New York, NY
- g. London Health Sciences Centre, London, ON, Canada

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<table>
<thead>
<tr>
<th>Treated Organ</th>
<th>Recommended</th>
<th>Consider</th>
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<tbody>
<tr>
<td><strong>Face, Parotid</strong></td>
<td>Brainstem</td>
<td>Bone_Mandible</td>
</tr>
<tr>
<td></td>
<td>Eye_L/R</td>
<td>Cavity_Oral</td>
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<tr>
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<td>Lens_L/R</td>
<td>Cochlea</td>
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<td>Lips</td>
<td>Glnd_Lacrimal_L/R</td>
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<td>Parotid_L/R</td>
<td>Glnd_Submand_L/R</td>
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<td>SpinalCord</td>
<td>Joint_TM_L/R</td>
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<td>Lobe_Temporal_L/R</td>
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<td><strong>Orbit</strong></td>
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<td>Parotid_L/R</td>
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Basics of plan evaluation – check list
TRAIN YOUR BRAIN TO DECREASE THE DOSES TO DARS STRUCTURES BUT NOT AT THE COST OF PTV
RESTRAIN YOURSELF FROM GIVING STRICT CONSTRAIN OTHERWISE TUMOR WILL SUSTAIN.
Thanks

kanhu