Plan Evaluation in Head & Neck Brachytherapy

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Why & How?

- Multidisciplinary – Physician (RO & Surg) & Physicist
- H&N- lip, tongue, floor of mouth, palate, buccal mucosa, etc.
- Tx- Interstitial or Mould
- Radiograph based planning may raise ethical issues
- CT - accurately tailors the treatment plan
Implantation Rules

- As per size – Single/double plane or volume implant
- Thickness of 10 mm – Single plane
- Thickness 10 to 25 mm – Double plane
- > 25 mm multiple planes
- Surface mould - 5mm
ICRU 58

- **PTV = CTV** (max. dimension in three orthogonal directions)
- Treated volume = Volume of ref isodose encompassing CTV
- Central Plane – In centre, where source are straight, parallel & perpendicular to source lines
- **MCD** - mean central dose is the mean of the minimum doses between sources (**Basal Dose**) 
- **MTD** - minimum dose at the periphery of CTV (**Ref Dose**)
GEC-ESTRO/ACROP recommendations

GEC-ESTRO ACROP recommendations for head & neck brachytherapy in squamous cell carcinomas: 1st update – Improvement by cross sectional imaging based treatment planning and stepping source technology

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ABSTRACT

The Head and Neck Working Group of the GEC-ESTRO (Groupe Européen de Curiethérapie – European Society for Therapeutic Radiology and Oncology) published in 2009 the consensus recommendations for low-dose rate, pulsed-dose rate and high-dose rate brachytherapy in head & neck cancers. The use of brachytherapy in combination with external beam radiotherapy and/or surgery was also covered as well as the use of brachytherapy in previously irradiated patients. Given the developments in the field, these recommendations needed to be updated to reflect up-to-date knowledge.

The present update does not repeat basic knowledge which was published in the first recommendation but covers in a general part developments in (1) dose and fractionation, (2) aspects of treatment selection
GEC-ESTRO Recommendation

- Around CTV no additional margin
- Paris system & prior CT for no. of catheters/plane
- Adequate CTV coverage with implanted catheters
- Optimal spacing between tubes is ≤15 mm
- Prescription dose is the min. dose received by the CTV or a CTV surrogate (i.e. $D_{90} > 100$, $V_{100} > 90\%$).
- Hyper-dose sleeves thinnest possible
- Dose to skin, bone, nerves, vessels – Min./avoided
- Spacers between OAR and implant is encouraged
Planning Process

- Labeling - Numbering of catheters for identification
- CT based - thin slices of 1 to 2 mm
- Markers (thin Cu wires) at the edges of the tumour
- Images - free of artifacts
- Radiopaque marker or air in catheters for contrast.
- Catheter reconstruction as per labeling
- Plan evaluation - slice-by-slice visualization
- DVH
Catheter Reconstruction
Source Position Simulator

- Determine the length of catheter
- Clearance of the catheter paths
- Kinks can be detected
- Any resistance to passage of source
  - Resistance can be anticipated during catheter reconstruction also.
- Measured length can be compared against the length of the catheter in TPS.
Planning & Dose Calculation

- Active source positions inside the PTV
- manually or automatically
- Paris system – BD in central plane is important
- BD points are placed manually or automatically
- Normalizing to mean central dose
- Dose is prescribed to the 85% of MCD
- Optimization for CTV coverage and homogeneity
- optimization is not a substitute of good implant
Optimization

- Forward optimization
- Dwell positions & dwell time manipulation manually
  - Manual dwell weights/times optimization
  - Geometrical optimization
  - Optimization on dose points
  - Graphical optimization
- Inverse optimization - optimized plan when all clinical objectives are met
  - Inverse Planning by Simulated Annealing (IPSA)
  - Hybrid Inverse Planning Optimization (HIPO)
IPSA - HIPO

IPSA

- Stochastic algorithms and slow
- Dwell times vary from 0.00 to maximum
- Produce heterogeneous dose distributions
- DTDC - large values - degradation of DVH metrics

HIPO

- Hybrid deterministic & stochastic dose–volume-based
- Allows to lock catheters to keep their dwell times fixed & do optimization of the remaining catheters
- Reduces selective hot spots and more uniform dwell time distribution, DTGR

Dwell Time Gradient Restriction

[Diagrams showing relative dwell time for different DTGR values]
Plan Evaluation

- Classical BT – Limited PE, 2D, related to catheters/applicators, reference points
- These methods are still used
- Additional tools are now available
- Visual inspection is still relevant but subjective
  - Hot or cold spot with in the CTV
- Objective assessment with quantitative parameters is required.
**Coverage Index**

- Fraction of CTV receiving dose ≥ reference dose.
  - Estimate of CTV getting 100% dose

\[ \text{CI} = \frac{\text{CTV}_{\text{reference}}}{V_{\text{CTV}}} \]

- Ideal value of CI = 1 (should be ≥ 0.9)
  - \( \text{CTV}_{\text{reference}} \) (cc) = 10, 12, and \( V_{\text{CTV}} \) (CC) = 12

<table>
<thead>
<tr>
<th>Coverage Index</th>
<th>Value</th>
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<tbody>
<tr>
<td>10/12</td>
<td>0.83</td>
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<tr>
<td>12/12</td>
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</tr>
<tr>
<td>12/12</td>
<td>1</td>
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<td>12/12</td>
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</tbody>
</table>
Physics Contribution

A CONFORMAL INDEX (COIN) TO EVALUATE IMPLANT QUALITY AND DOSE SPECIFICATION IN BRACHYTHERAPY

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Steps in planning process to determine COIN

Conformity Index (COIN)

- How well the reference dose encompasses the CTV and excludes healthy tissue
  - Quantitative evaluation of conformity (Baltas D et al 1998)
  - COIN does not depend on a definition of homogeneity

- $\text{COIN} = \text{CI} \times \frac{\text{CTV}_{\text{reference}}}{\text{V}_{\text{reference}}}$

- Ideal value = 1.
  - $\text{CTV}_{\text{reference}} (\text{cc}) = 10, 12, $ and $\text{V}_{\text{ref}} (\text{CC}) = 14, 15, 20$

0.83*10/14 = 0.60  1*12/14=0.86  1*12/15=0.8  1* 12/20=0.60
External Volume Index (EI)

- Indicator of dose gradient beyond CTV
- Ratio of normal tissue volume outside CTV (receiving ≥ ref dose) to Volume of CTV
- Ideal value of EI = 0.0

\[ EI = \frac{NTV_{\text{ref}}}{V_{\text{CTV}}} \quad (NTV_{\text{ref}} = V_{\text{ref}} - CTV_{\text{ref}}) \]

\[
\frac{14 - 12}{12} = 0.17 \\
\frac{15 - 12}{12} = 0.25 \\
\frac{20 - 12}{12} = 0.67
\]
Dose Homogeneity Index

- Dose inhomogeneity is a reality & can’t be removed.
- The ratio of CTV receiving 1-1.5 times of ref. dose to the CTV receiving ref dose.
- Ideal value = 1

$$DHI = \frac{CTVD_{\text{reference}} - CTV1.5D_{\text{reference}}}{CTVD_{\text{reference}}}$$

- $(12-5)/12 = 0.58$
- $(12-6)/12 = 0.5$
- $(12-8)/12 = 0.3$
Overdose Volume Index (ODI)

- Ratio of CTV (receiving $\geq 2$ times of ref dose) to the CTV receiving $\geq$ ref dose
- Indicator of dose gradient beyond CTV
- Ideal value of ODI = 0.0
- $\text{ODI} = \frac{\text{CTV2D}_{\text{ref}}}{\text{CTVD}_{\text{ref}}}$

3/12 = 0.25  4/12 = 0.33  5/12 = 0.42
Dose Nonuniformity Ratio

- Ratio of the CTV receiving ref dose to CTV getting 1.5 times of reference dose
- DNR = $\frac{CTV_{1.5D_{\text{reference}}}}{CTV_{D_{\text{reference}}}}$
- Ideal DNR = 0

5/12 = 0.42  
6/12 = 0.50  
8/12 = 0.67
## Analysis

<table>
<thead>
<tr>
<th>Volumes (CC)</th>
<th>Plan-1</th>
<th>Plan-2</th>
<th>Plan-3</th>
<th>Plan-4</th>
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</thead>
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<tr>
<td>V_{CTV}</td>
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<td>V_{ref}</td>
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<td>6</td>
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<td>CTV_{2Dref}</td>
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<td>DNR</td>
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<tr>
<td>A</td>
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<td>C</td>
<td>D</td>
<td>E</td>
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<tr>
<td></td>
<td>INPUT (cc)</td>
<td>INPUT (%)</td>
<td>OUTPUT</td>
<td>acceptance level</td>
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<td>CTV\textsubscript{100}</td>
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<td>Dose Non-uniformity Ratio (DNR)</td>
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<td>Over Dose Volume Index (ODI)</td>
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<td>8</td>
<td>NTV\textsubscript{100}</td>
<td>5.43</td>
<td>External Volume Index (EI)</td>
<td>0.54</td>
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</tbody>
</table>

**Abbreviations**

- CTV\textsubscript{100} volume of CTV receiving 100% of prescription dose
- CTV\textsubscript{150} is the volume of CTV receiving 150% of prescription dose
- CTV\textsubscript{200} is the volume of CTV receiving 200% of prescription dose
- CTV\textsubscript{300} is the volume of CTV receiving 300% of prescription dose
- VCTV is the volume of CTV
- IV\textsubscript{100} is the volume covered by 100% of isodose surface
- NTV\textsubscript{100} is the volume of normal tissue (excluding target) receiving 100% dose

**PQI = CI + COIN + DHI**

Useful for comparing plans using different optimization method for same case, if its
3, consider as ideal plan
Conclusion

- Plan evaluation is tricky
- Quantitative outcome depends upon contouiring
- Plan indices help in choosing good plan
- Good research tool
- Correlation between indices and clinical outcome is useful
Thank you