BASIC PRINCIPLES OF PLAN EVALUATION IN RADIOTHERAPY



Gautam K Sharan

HOD & DNB Coordinator, Radiation Oncology Inlaks & Budhrani Hospital, Pune

Faculty, Radiotherapy MCh, Breast Oncoplasty Orchids Breast Health, Pune University of East Anglia, Norwich, UK

MBBS, RIMS, Ranchi MD, IMS, BHU, Varanasi Maulana Azad Medical College, Delhi Rajiv Gandhi Cancer Institute & Research Center, Delhi APPLIED RADIATION ONCOLOGY

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 Yechieli, MD; Raymond Mak, MD

Mary Dean et al, Applied radiation Oncology, December 2017

Acknowledgement

In Alphabetical Order

Ashutosh Mukherji

Sr. Consultant & Academic Coordinator, Radiation Oncology Yashoda Hospital, Hyderabad

Martyn Booth

Trainee Healthcare Scientist, Radiotherapy University Hospitals Birmingham NHS Foundation Trust

Radhika V Kartha

Medical Physicist Inlaks & Budhrani Hospital, Pune

Vikash Kumar

Sr. consultant, Radiation oncology Asian Institute of Medical Sciences, Faridabad

Identify the correct statement?

- It is a cumulative DVH
- It is an integral DVH
- It does not give idea about Minimum and Maximum dose
- None of the above



Why Should You Listen?

- Essential task for radiation oncologist
- Complex: advancements in techniques
- Multiple components required

The CB-CHOP Approach

Mary Dean et al, Applied radiation Oncology, December 2017



Gautam K Sharan I ICRO, Jaipur, 2018 I Basic Principles of Plan Evaluation in Radiotherapy

Contours

• Review the delineated target volumes

- OARs: accounted for and contoured accurately
 - Delegated to others!
 - Forgot to contour
 - Isodose lines spill into OAR initially thought not at risk
- Accurate expansion: GTV modified without appropriate re-expansion

Contouring: Education & Standardization

- Oncologists should receive and maintain **adequate training**:
 - Workshops, international courses;
 - E.g. ESTRO School of Radiotherapy and Oncology E-Learning FALCON
- Training should include **different** imaging **modalities**:
 - CT, MRI, PET;
 - Relative strengths and weaknesses;
 - Spend time in Nuclear Medicine & Radiology depts
- **Protocols** and **atlases** should be used to standardize contouring.

Contouring: Delineating Volumes

- Access to **appropriate hardware** and **software** is essential for high precision contouring:
 - 3D contouring and volume view is essential;
- Appropriate **quality assurance** should be performed on the hardware and software:
 - Does the display on the treatment planning system match that on the diagnostic systems in terms of orientation, distortion, voxel size etc.
- Standard nomenclature for volumes should be used and standard color-coding is encouraged.

Contouring: Volume Definitions (ICRU 50/62)

- Gross Tumour Volume (GTV) is the gross demonstrable extent of the tumour
- **Clinical Target Volume (CTV)** is an extension of the GTV and includes any microscopic malignant disease
- The delineation of GTV and CTV are based on purely anatomictopographic and biological considerations without regard to technical factors of treatment
- Internal Target Volume (ITV) an expansion of the CTV to account for organ motion

Contouring: Volume Definitions (ICRU 50/62)

- Planning Target Volume (PTV) is a geometrical concept that is an expansion of the ITV to account for any uncertainties in patient positioning, planning systems and treatment delivery
- Organ at Risk (OAR) normal tissue whose radiation sensitivity may impact planning
- Planning OAR Volume (PRV)- is a geometrical expansion of the OAR to account for uncertainties in patient positioning, planning systems and treatment delivery

Contouring: Volume Definitions (ICRU 50/62)

Treated Volume

- It is a volume enclosed by an isodose surface, selected and specified by the radiation oncologist as being appropriate to achieve the purpose of treatment (tumor eradication or palliation)
- It may closely match to the PTV or may be larger than the PTV
- If, however, it is smaller than the PTV, or not wholly enclosing the PTV, then the probability of tumor control is reduced and the treatment plan has to be reevaluated or the aim of the therapy has to be reconsidered

Reasons for Identification of Treated Volume

- 1. The shape and size of the Treated Volume relative to the PTV is an important optimization parameter
- 2. Also, a recurrence within a Treated Volume but outside the PTV may be considered to be a "true", "in-field" recurrence due to inadequate dose and not a "marginal" recurrence due to inadequate volume

Window Levels

- Tissue contrast is heavily dependent on the windowing level and width
- Presets have been optimized

Organ Motion



(0, 5000) (0, 1000) (-750, 1000)

- **4DCT** is an important tool for quantifying organ motion such as breathing:
 - Sets of images are acquired at each stage of the breathing cycle
- There should then be set protocols for delineating using 4DCT

Multimodality Imaging and Image Registration

- Multimodality imaging should be used where appropriate, especially for GTV delineation
- Links with Nuclear Medicine and Radiology departments are recommended to aid with interpretation of multimodality images
- Image fusions can be a source of error and so registration needs to be checked prior to contouring
- Any deformable registration should also be rigorously checked prior and during clinical use
- Flicking between image modalities is an effective way of spotting any motion of features indicating poor registration.

Tools for Assessing Registration

Spy Glass



Split View



Contouring: PTV Margins

- In order to **minimize variation** between clinicians:
 - Published or web-based **atlases** should be used for CTV delineation
 - Defined protocols should be used for deriving the ITV
- Radiation therapists and medical physicists should be involved in determining appropriate protocols for PTV margins
- This should involve **measurement** & analysis of local errors
- Published recipes, such as the Van Herk (2004) formula can be applied:

$$M=2.5\Sigma+0.7\sigma$$

Contouring: OAR Delineation

- Good Planning CT
 - Good Immobilization setup
 - Contrast imaging
 - 3mm slice thickness or smaller
- MRI fusion if required
- Optimal CT window settings [Centre (HU) and width (HU) values] used to delineate the OARs

Contouring: Reviewing Volumes

- The contouring process may involve several clinicians and so it is important that **all OARs** and **targets** have been accounted for and are accurately outlined
- The reviewing process should ideally be performed by a separate oncologist
- Small departments are encouraged to form links with other departments for the purpose of **peer review**
- Documents such as the Peer Review Audit Tool (PRAT)¹ can be useful aids for reviewing and auditing.

¹Royal Australian and New Zealand College of Radiologists (2013)

Contouring: Graphics

- These are used to delineate the different volumes and the other landmarks.
- These are in different colors for an easy and uniform interpretation.
 - GTV Dark Red
 - CTV Light Red
 - ITV Dark Blue
 - PTV Light Blue
 - OAR Dark Green
 - PRV Light Green
 - Landmarks Black



Michael Goitein [1939-2016]

Digitally Reconstructed Radiograph- DRR

- A synthetic radiograph produced by tracing ray-lines from a virtual source position through the CT data to a virtual film plane
- It is analogous to conventional simulation radiographs.



- DRR is used
 - For treatment portal design
 - For verification of treatment portal by comparison with port films or electronic portal images
 - Provides planar reference image for transferring 3D treatment plan to clinical setting

Beam's Eye View - BEV

Observer's viewing point is at the source of radiation looking out along axis of radiation beam

- Demonstrates geometric coverage of target volume by the beam
- Shielding & MLCs are designed on BEV
- Useful in identifying best gantry, collimator, and couch angles to irradiate target & avoid adjacent normal structures by interactively moving patient and treatment beam



Room's Eye View - REV

- The REV display provides a viewing point simulating any arbitrary location within the treatment room.
- The REV helps
 - To better appreciate overall treatment technique
 - Geometry and placement of the isocenter





Beam Arrangements/ Fields

- Simple (single or opposed) to complex arc
- Delivery technique specified by physician
- Beam arrangements discretion of dosimetrist

Beam Arrangements: 3D-CRT

- Choice of beam entrance point is important avoid critical OARs and excessive normal tissue irradiation
- Beam's Eye View (BEV) can indicate whether OARs are appropriately shielded by MLCs and jaws
- Also based on 3D isodose lines overlaid on the CT images



Beam Arrangements: IMRT/ VMAT

- The entrance point for IMRT fields or arc angles for VMAT arcs should be chosen to avoid appropriate OARs;
- Treatment time is also an important consideration and is dependent on the number of fields or arcs:
- Palliative patients may struggle with long treatments;
- Organ motion becomes more significant as treatment time increases.



Rana (2013)



Coverage: Goals of Treatment Planning

- Prescription dose conforms to target volume
- Normal tissues are not excessively irradiated
- PTV receives uniform dose
- Doses to OARs do not exceed tolerance values

Plan Evaluation

- PTV dose coverage, OARs dose sparing, overall maximum dose
- Number of MUs
- Cumulative DVH for each PTV and OAR are compared
- Conformity of the prescription dose to the PTV
 - Conformity index (CI, ICRU-62, 1999)
 - Homogeneity index (HI, ICRU-83, 2010)
- Values of CI and HI approaching 1 and 0 are regarded as favorable indication of plan quality

Plan Evaluation: 3D Planning

- Normalisation and normalised prescription dose
- Global dose maxima
- Dose volume parameters of PTV and OARs
- Plan sum of phase wise plan
- Hot/ Cold spots: their location and value
- Cl and HI
- DVH shape and distribution
- Beam's eye view and DRRs

Optimization

- Physical: based on physical dose coverage
- Biological: based on TCP and NTCP calculation
- A total objective function (SCORE) is then derived from these
- Priorities are defined to tell the algorithm the relative importance of the different planning objectives (PENALTIES)
- The algorithm attempts to maximize the score based on the criteria and penalties

Plan Normalization

- After the dose calculation is over, the dose at some point has to be normalized to 100%
- This point can be anywhere in the grid: User's choice

Check Global Dose Maximum

- Not more than 107% for 3-D CRT, may be up to 115% for IMRT
- Should be within CTV, preferably within GTV

Coverage Evaluation

- Isodose curves
- Orthogonal planes and isodose surfaces
- Dose distribution statistics
- Differential DVH
- Cumulative DVH
Isodose Curves

- Isodose curves are the lines joining the points of equal Percentage Depth Dose (PDD)
- Isodose covering the periphery of the target is compared with the isodose at the isocenter
- If the ratio is within a desired range (95-100%), then the plan may be acceptable provided that critical organ doses are not exceeded
- Ideal approach if the number of transverse slices is small

Orthogonal Planes and Isodose Surfaces

• Larger number of transverse planes (CT scan): axial slice isodose distribution alone is impractical

• Isodose distributions can be generated on orthogonal CT planes, reconstructed from the original axial data.

• Sagittal and coronal plane distributions are available on most TPS

Dose Statistics

- Minimum dose
 - Strong correlation between target minimum dose and clinical outcome
 - High percentage of the dose maximum
- Maximum dose
 - Useful tool for critical structures
 - Typically tolerance dose
- Mean dose
 - Indicator of dose uniformity within the target volume
 - Should be very close to maximum dose

For Target Volumes

- Target volume maximal dose ideally should not be more than 5-7% of the prescribed dose and minimum dose to the target volume should not be less than 5% of prescribed dose
- Inhomogeneity within target volume kept to \pm 10% of the prescribed dose. ICRU 83 report is used for describing IMRT has described D_{98%}, D_{50%}, and D_{2%}. (D_{max}, D_{median} and D_{min})
- D_{max} are checked in the dose color wash in each slice to note its location; whether it is within the PTV

For OARs

- In case of serial OARs, D_{max} is checked as to whether it is limited to within tolerance doses
- In parallel OARs, D_{mean} is seen for analysis. D_{max} is also noted to check for any undue hot spots
- Check plan sum of all phases of the treatment plan to ensure once more that all dose parameters are within prescribed limits



DVH

- 3D treatment plan consists of dose distribution information over a 3D matrix of point over the patient's anatomy
- DVH summarizes the information contained in the 3D dose distribution (in a graphical 2D format)
- Extremely powerful tool for quantitative evaluation of plan
- Direct (or differential) DVH
- Cumulative (or integral) DVH

Generating DVH

- Each volume is divided into a number of voxels (volume elements)
- The dose delivered to each voxel is determined; and
- The number of voxels receiving each dose is tallied



Generating DVH

Dose (D) /%	No. voxels receiving a dose ≥ D	Percentage of total no. voxels
100	0	0.0
90	2	3.8
80	2	3.8
70	4	7.5
60	7	13.2
50	13	24.5
40	23	43.4
30	31	58.5
20	39	73.6
10	44	83.0
0	53	100.0



Target DVH



OARs DVH



Interpreting DVH



Cumulative DVH

- Illustrates the volume of a structure receiving a given dose or greater
- Useful for indicating whether dose-volume constraints are met



Differential DVH

- Illustrates the volume of the a structure receiving a given dose
- Useful for indicating maximum and minimum doses
- Nice tool for assessing PTV dose uniformity



How to Interpret a DVH?



How to Interpret a DVH?

- Whether PTV coverage is adequate?
- Whether OARs are being adequately spared?
- Target volume maximal dose?
- Target volume minimal dose?
- Serial OAR: D_{nearmax}
- Parallel OAR: D_{50%}

Limitations of DVH

- No spatial information
- Location of HOT/ COLD spot
- Whether it occurred in one or several disconnected regions
- Cannot be the sole criterion for evaluation/ disclosing best plan

• Interpretation of the plot can be subjective

Coverage Factor

Tells you how much you miss on PTV



Possible Scenarios



Perfectly Conformal Plan...



- How much of PTV is covered?
- How much is the spill?
- How is the uniformity within PTV?



- As defined in ICRU 50: CI = TV / PTV
- Here the **Treated Volume** (TV) is the volume irradiated by a dose deemed appropriate for the purpose of treatment (typically 95% isodose) or greater
- Ideally, CI = 1. A value greater than 1 implies the TV is too large whilst a value less than 1 implies inadequate coverage



Heterogeneity: Hot & Cold Spots

- Three questions to ask about all hot and cold spots
 - Volume?
 - Magnitude?
 - Location?
- Is there a consensus to *any* of these questions in any tumor site?

Hot Spots

- Volume: In accordance with ICRU 50
 - There should be no hotspots outside the PTV;
 - Hotspots within the PTV should be <107% of the D_{prescription}
- Location: Hotspots should be central within the PTV, preferably within the GTV
- Hotspots at the peripheral of the PTV, especially near OARs, should be avoided
- However, greater doses may be encouraged for certain techniques
 - SABR up to 140%, RCR (2016);
 - APBI up to 120%, RTOG 0413 (2011);

Cold Spots

- Volume: In accordance with ICRU 50, there should be complete coverage of the PTV by the 95% isodose;
- However, this is not always achievable:
 - At the boundary of a lung tumour with air;
 - Due to a compromise with nearby OARs;
- Location:
 - There should be no cold spots at the center of the PTV.

Homogeneity Index (HI)

- Measure of uniformity of absorbed dose distribution within PTV (ICRU 83)
- Expressed as the ratio $(D_{2\%} D_{98\%}) / D_{50\%}$
 - D_{2%} is the dose received by at least 2% of the PTV
 - D_{98%} is the dose received by at least 98% of the PTV
 - D_{50%} is the dose received by at least 50% of the PTV
- An HI of zero indicates that the absorbed-dose distribution is almost homogeneous
- Greater the value of HI, more is the heterogeneity.

Organ(s) at Risk (OAR)

- These are normal tissues whose radiation sensitivity may significantly influence the treatment planning and/or prescribed dose
- They may be divided into 3 classes :
 - Class I : Radiation lesions are fatal or result in severe morbidity
 - Class II : Radiation lesions result in mild to moderate morbidity
 - Class III : Radiation lesions are mild, transient, and reversible

OARs: Biological Classification

- Tissues can be thought of as containing functional subunits (FSUs):
 - E.g. lung alveoli or kidney nephrons
- The FSUs can be arranged in serial or parallel architectures
- In practice, organs will display a mix of serial and parallel characteristics



OARs: Biological Classification

- Serial architecture: tissue function impaired even if a small volume is irradiated above a certain threshold:
 - Maximum dose constraints are important
- **Parallel architecture:** function is impaired if a certain proportion of a tissue receives a dose above a given threshold:
 - Mean or dose-volume constraints are important



OARs: Reviewing Constraints

- **DVH statistics** should be reviewed against recommended constraints:
 - D_v = the dose received by at least V% of the volume
 - V_D = the volume receiving a dose of at least D Gy/%
- The **3D dose distribution** should also be reviewed:
 - The position of isodose contours relative to OARs should be checked, particularly for serial organs

OARs: Choice of Constraints

- The **QUANTEC** data is a useful resource for appropriate constraints;
- **AAPM TG-101** is also useful for hypofractionated regimes;
- BED conversions can be used for alternative fractionations;
- The relative **priority** of constraints is also relevant:
 - Critical thresholds for severe toxicities are likely to take priority



Prescription

- Last step of plan evaluation
- Dosimetrist may have edited the prescription: Recheck
- Treatment details must also be specified
 - Type of radiation (Photon/ electron)
 - Energy
 - Delivery technique (3D-CRT/ IMRT/ VMAT)
 - Schedule
- Specify Image guidance and setup verification imaging

Prescription: Immobilization

- Patient immobilization is important for reproducible patient setup and for preventing patients moving during treatment;
- Appropriate immobilization is both site and technique dependent:
 - Highly conformal treatments with nearby critical organs will require more precise immobilization;
- Patient immobilization will **not** prevent **internal organ motion**.

Prescription: Image Verification

- Image verification involves acquiring patient images immediately prior to treatment and comparing these to reference images (planning CT or DRRs)
- Online verification the verification and reference images are compared immediately prior to treatment and are used to correct set-up if required
- Offline verification the verification and reference images are compared following treatment. Any corrections are applied to following fractions

Prescription: Image Verification

- Image verification can be performed with combinations kV or MV planar or CBCT images
- Planar imaging provides 2D verification which is quick and delivers less dose than CBCT
- CBCT is required for 3D verification
- MV images can be used for portal imaging (imaging with the treatment beam)
- kV images provide better contrast but are more sensitive to metal artifacts
To Recapitulate:



Contours: Review target volumes and OARs Beam Arrangements/ Fields: Appropriate and reasonable Coverage: Evaluate on graphic plan and DVH Heterogeneity/Hotspots: value and location OARs: Review specified constraints, isodose lines, and DVH

Prescription: Total dose, dose per fraction, and image guidance

Conclusions

• CB-CHOP: systematic, step-wise approach

• Develop a consistent approach

• Even a trusted and experienced dosimetrist may commit mistake, stay thorough and objective

• Plan revisions may be requested

Conclusions

- However, remember there is a threshold beyond which further improvements in plan is minimal
- May be detrimental as it will delay initiating the treatment
- Foresee maximum possible requests in the first review
- FINAL RESPONSIBILITY FOR A PLAN'S SUITABILITY LIES WITH THE RADIATION ONCOLOGIST



Cumulative Dose Volume Histogram

Relative dose [%]

DVH	Structure	Coverage [%/%]	Volume	Min Dose	Max Dose	Mean Dose
	BODY	 97.9 / 100.1	16636.5 cm³	0.0 %	117.5 %	7.3 %
	Heart	100.0 / 100.0	422.9 cm ³	0.7 %	36.6 %	3.2 %
	PTV_Eval	100.0 / 100.0	223.5 cm ³	92.3 %	117.3 %	107.9 %
	Thyroid	100.0 / 99.9	8.0 cm ³	0.3 %	0.8 %	0.5 %
	Lung- Lt	100.0 / 100.0	1067.6 cm³	0.3 %	111.5 %	21.3 %
	Lung- Rt	100.0 / 100.0	1269.4 cm ³	0.1%	17.5 %	0.7 %
	Contra Breast	100.0 / 100.0	912.8 cm ³	0.1%	17.6 %	2.4 %
_	UNB	 100.0 / 100.0	586.5 cm³	0.6 %	114.9 %	51.3 %

Thank you



Inlaks & Budhrani Hospital, Pune- 411 001, INDIA



dr.gautamsharan@gmail.com



+91 9326 323109



www.inlaksbudhranihospital.com