Practical IMRT Planning Issues

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Context

CE Clinical IMRT Sessions
• MO-B: Practical Planning Issues
• TU-B: Clinical Pitfalls & Limitations
• WE-B: IMRT System QA
• TH-B: Patient-based QA for IMRT

IMRT Panels
• MO-D: Promises & Problems
• WE-E: QA – What is Enough?

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IMRT Requirements
• Key technologies:
  • Imaging and Segmentation
  • Delivery
  • Optimization
  • Strongly interdependent
  • Training
  • Systematic technical procedures and quality assurance.

Key Technologies: Delivery
• Limited number of Beams, with fixed gantry/couch positions
• Physical filters (compensators)
• Step-and-Shoot MLC
• Dynamic MLC
• Arc/Rotational techniques:
• MIMiC
• Tomotherapy
• Intensity Modulated Arc Therapy (IMAT)
• Direct machine parameter optimization

Key Technologies: Optimization
• Parameters to be manipulated:
  • Pencil Beams (“beamlets”), or predefined apertures (“Segments”)
  • Beamlet-based is most common.
  • Group beamlets into deliverable MLC shapes.
  • (MLC, “converter”, “sequencer”, “translator”).
• Goals objectives and constraints:
  • Physical (dose, dose-volume).
  • Biological
  • Physical machine parameters (e.g., gantry angles, max field size, min. leaf gap)
  • Formal evaluation (optimization)
Why IMRT?

- Precisely shape target dose, or avoid normal tissue:
  - Reduce complications.
  - Dose escalation to improve local control.
- Capacity to respond therapeutically to new information emerging from molecular biology and medical imaging.

When to use IMRT?

- Rapidly expanding applications:
  - GU, GI, GYN: Pelvic node irradiation, Dose escalation
  - Head & Neck: RTOG H0022, RTOG H0225
  - Missing tissue and dose compensation (e.g., breast)
  - Preferably under protocol (e.g., RT OG)
  - Previously treated patients
- Use caution:
  - Moving targets (e.g., breathing, bladder filling, bowel gas)
  - Tissue density variations (i.e., heterogeneity)
  - Simultaneous integrated boost (i.e., different fractionation)
  - Achieve dose uniformity where possible

IMRT: A Clinical Perspective

- Unique power to create and manipulate dose gradients
- Detailed quantitative treatment objectives
- Collimator movement during treatment
- Increased number of treatment monitor units
- Need to control and determine treatment margins through objective measurement of set-up uncertainties internal organ motion.
- All aspects of the radiotherapy process should be re-examined under more stringent requirements for accuracy and precision.

IMRT: A Technical Perspective

Thanks to Dr. James Purdy
IMRT: A Technical Perspective

- IMRT is an extension of "3D Conformal" practices.
- Existing recommendations for RTP QA are applicable.
- IMRT technologies are integrated; i.e., quality of IMRT/RTP plans depends on "up- and downstream" technologies:
  - Imaging, segmentation, R&V, accelerator, and PROCESS

IMRT and the Radiotherapy Process

Setup & Immobilization
- Volume Segmentation
- Evaluate & Verify Plan
- IMRT Technologies
- Treatment Delivery

Technical Procedures & QA

- Key to success
- Clear (Documented)
- Concise
- Meaningful
- Maintainable
- Review and Revise
- Avoid Moving Targets!

Imaging for IMRT

- Volumetric CT planning
- Complimentary Imaging (e.g., MR)
- Image (and contour) import/export
- Target definition: The Weakest Link?

Immobilization

- Minimize/control positioning uncertainties.
- Margins for uncontrolled uncertainty:
  - Internal organ movement
  - Tissue deformation
  - Breathing, cardiac motion
- Develop consistent "rituals" for use.
- Assess effectiveness, comfort.
- Reassess as treatment progresses.
- Be aware of weight loss, medications.
- Be aware of dosimetric impact, e.g., potential loss of skin sparing.
- Level of effort match clinical goal and resources

Patient Set-up (Isocentre)

- Optimize placement:
  - Cover edge of target volume(s)
  - Efficient set-up and delivery
  - Patient set-up issues
  - Dosimetry
  - QA
- ½ a leaf width might make a difference
- Follow ICRU50/62 dose reporting, e.g.:
  - Centre of the target volume, or of all targets
  - Prescribe to a POI located within the PTV
**Contours and IMRT**

- IMRT is driven by volumetric segmentation.
- Greater need to assure diligent care and accuracy of the segmented structures.
- Segmentation guidelines outlined by TG 53
- The interaction of segmentation with the processes of IMRT depends on
  - staff awareness,
  - adequate time
  - Resources for adherence to clinical protocols

**Target Volumes**

- ICRU 50 & 62
- GTV - Gross Tumour Volume
- CTV - Clinical Target Volume
- PTV - Planning Target Volume
  - Accounts for internal organ motion and patient setup variations.
  - Margins should also be applied to organs at risk (OARs) -> PRVs
  - The PTV must be large enough to ensure the CTV receives the prescribed dose.
  - The larger the PTV, the more normal tissue irradiated.
  - Need to reconcile PTV/PRV overlap

**General Tissue Segmentation**

- Explicitly delineate targets requiring dose, and every organ at risk (objectives, and evaluation)
- Generally more volumes than 3D planning.
- Margins:
  - Adequate evidence for designing PTV?
  - Consider margins around critical structures to partially account for organ motion, patient movement and setup uncertainties (cord + 0.5 cm)
  - Avoid volumes extending outside the patient.
  - If target includes buildup region, consider bolus.

**Beam Selection**

- Often, equally-spaced, unopposed, coplanar beams
- Use geometry to advantage; ie, angle beams to:
  - miss critical structures,
  - treatment table (couch bars)
  - immobilization devices
- Minimize number of beams, to reduce planning, setup, and delivery time.
- An acceptable IMRT plan can usually be generated using 5 to 9 beams
- Depends on the complexity of the target shape and its proximity to critical structures.

Small variations in the dose distributions and DVHs for 5, 7, and 9-beam plans. More beams may result in a more conformal target dose.

- Orient MLC leaves to maximize the protection of a critical structure.
- Optimal collimator angle may vary from control point to control point.

- Higher energies reduce peripheral dose.
- Less impact when more beams are used.
- Some institutions use 6 MV for all IMRT plans.
- Some use the same energies as for 3D plans.
- IMRT tends to increase total MUs delivered.

- Consider the impact of neutron generation on shielding requirements for higher energy beams.
- Second cancer risk.

- Dose-volume goals, or constraints (weighted)
- Describe qualities of dose distribution, in terms of the acceptable dose to PTV and organs at risk.
  - Commonly:
    - Minimum and/or maximum dose
    - Minimum and/or maximum dose per volume of tissue
    - Uniform dose
  - Other possibilities:
    - Equivalent uniform dose (EUD)
    - Biological Objectives

- Defining Treatment Objectives
  - Objectives, or Constraints?
  - Start with the target.
  - Target objectives often weighted higher than critical structure objectives.
  - “Manage” min. dose objective to a target extending into the buildup region or outside external contour.
  - Introduce normal tissue objectives.
  - Try “soft” objectives, e.g. low weights, then adjust.

- IMRT Objectives
  - Concurrent boost
    - Base of tongue example:
      - PTV (GTV+margin) 63 Gy in 35 fx (1.80 Gy/fx)
      - Contralateral nodes (CTV) 50.4 Gy in 35 fx (1.44 Gy/fx)
    - Prostate example:
      - PTV (prostate+margin) 72.0 Gy in 40 fx (1.80 Gy/fx)
      - SVs (CTV+margin) 45.0 Gy in 40 fx (1.13 Gy/fx)
    - H&N example:
      - Neck nodes (CTV) 50.4 Gy in 28 fx (1.80 Gy/fx)
      - PTV (GTV+margin) 45.0 Gy in 28 fx (2.36 Gy/fx)

- Differential Target Objectives
  - Ensure prescription clearly states Gy/fx for each target.
  - Beware of uncertain radiobiological end points.
**Critical Structure Objectives**

- Often different and more comprehensive than stated prescription goals.
- Often an iterative process.
- Avoid unrealistic or conflicting objectives... (KISS)
- DVH from 3D-CRT experience as reference.
- Use explicit objectives for overlapping ROIs.
- Set normal tissue objectives aggressively to reduce dose down as much as possible.
- Add secondary low-weight objectives to some or all critical structures.
- Use surrounding tissue or dose-shaping ROIs.
- Consult the literature.

**Overlapping Structures**

- Create three separate, non-intersecting ROIs by taking union of overlapping structures.
- Resolve competing dose-volume objectives by specifying different doses to the three structures.

**Dose-Shaping Structures**

- PTV "ring":
  - Max Dose = Min PTV dose (95-97% isodose).
  - Improves Conformally.
- Normal Tissue
  - Reduce peripheral hot spots.
  - Equates dose contributions.
  - Avoidance of Regions.
  - Analogous to isodose lines.

**Dose-Shaping Structures**

- Target (green) and dose-limiting regions (tan) with 0.5 cm margin from skin surface.

**Critical Contour Review**

- Initial PTV
- Smoothed
- Comparison
Minimize Intensity "Artifacts"

- Intensity pattern affected by shape and density differences in and near the PTV
- Eliminate "artifacts" in PTV that result in excessive localized intensities
- Smooth PTV
  - Review and edit manually
  - Expand/Contract
- Heterogeneity
  - Remove contrast (Δdensity=1)
  - Avoid isocenter placement near air cavity
  - Proximity of PTV to external contour
  - Suppress air cavities for optimization; final dose with heterogeneity on

Heterogeneity Issue

Density ON (optimization)  Density OFF (final dose)

Fluence Map Optimization (Ideal)

- Convert fluence map into field shapes and Monitor Units
- Interplay between accuracy and efficiency
- Avoided by direct machine parameter or aperture optimization

Leaf Motion Calculator

- Intensity Profile
- Intensity Grouping
- Recomputed from Beam Segments
- Includes MLC constraints

Delivery

- Step-and-shoot, and dynamic MLC
- Overall delivery time affected by
  - Number of beams & segments
  - Total MU and dose rate
  - Time components
    - Beam On time (~1-2 min @500 MU/min)
    - Interbeam deadtime (2-3 min @30s/bm)
    - Intersegment deadtime (<<1s-7s/seg)
    - 200 seg x 3s/seg = 6 min of deadtime!

Complexity and Deliverability

- For more efficient S&S delivery
  - Reduce intersegment deadtime (hardware), or
  - Reduce intensity map complexity (software)
- Reduce complexity
  - Use fewer iterations -> less modulation,
  - Smooth intensity before segmenting,
  - Increase minimum MU/segment, or
  - Reduce impact of discretization "artifacts" during optimization
No Smoothness Constraint

- Number of step&shoot fields > 120 for tolerance level = 7%
- Number of step&shoot fields < 50 for tolerance level = 5%

Radiation Protection and IMRT

- Primary barrier and secondary barrier due to patient scatter:
  - dependent on the target dose
  - no difference between conventional treatment and IMRT.
- Secondary barrier (head leakage, neutron shielding):
  - dependent on the beam-on time
  - Generally, IMRT greater than conventional treatment.

- Secondary Cancer Risk is potentially greater:
  - for more details, see:
    - Followill et al. IJROBP.38:667-672, 1997
    - Hall EJ, Wuu CS. IJROBP 56:83-88 2003

Final plan evaluation

- Review the DVHs, all structures.
- Review ROI statistics (min, mean, max dose)
- Adjust your prescription isodose, if necessary.
- Review the isodose distribution:
  - in multiple planes
  - 3D dose clouds
  - Un-segmented tissues
- Check the maximum dose for the plan.
- Several different dose distributions may satisfy the same set of dose-based objectives
- Run several competing plans scenarios if needed.

Plan Export for QA and TxDelivery

- Treatment time/complexity managed via automated treatment delivery.
- Configuration of RTP, R&V and linac are essential
- Incorrect configuration can lead to:
  - Collimator reversal
  - Transposed collimator jaws
  - Rejected prescriptions, or undeliverable segments
  - Round-off errors in “cumulative meters at weighting”
  - Apparently unrelated errors (incorrect energy)
  - Plan transmission timeouts and failures
  - Plan transmission with incorrect number of segments
  - Mismatch between linac/beam modifiers
- Review DICOM-RT, vendor conformance statements

Basic Commissioning Requirements

- Small fields (1 to 5 cm):
  - Output Factors
  - Assess and re-measure dose profiles, depth dose
  - Consult radio-surgery literature and TG Reports
- Verify machine parameters:
  - MLC
  - Jaw transmission
- Refine beam modeling for small fields
- Update and verify CT to density tables
IMRT Can Include Small Fields

- Accuracy of dose model at small field sizes is a consideration
- Convolution-superposition or Monte Carlo desirable

Small Field Dosimetry

- IMRT = Σ small fields
- Dose = function( penumbra + leakage + head scatter )
- Need accurate treatment head model to get this right

Verify all MLC parameters

- MLC parameters will affect dosimetric quality of plan:
  - MLC Transmission
  - MLC replaces jaws?
  - MLC position and thickness
  - MLC interdigitiation
- MLC parameters will affect physical ability to deliver plan:
  - Maximum tip differences
  - Minimum leaf gap

Light and X-Ray Field Edges


Curved Leaf Face Correction

Commissioning and QA

- ISO Precis:
  - "Everything required to make everything right".
- Components:
  - General validation
  - Procedure validation
  - Routine checks (Monitor for change/deviations)
- Confidence comes from evidence.
- Errors often come from unforeseen events.

RTP Commissioning & QA

- Accept hardware and software.
- Measure and enter basic dosimetric data, machine geometry, other operational parameters.
- Tune algorithm for best performance in anticipated clinical situations.
- Verify dose algorithms and associated configuration parameters.
- Configure import interfaces for imaging systems.
- Verify image quality and geometry after data transfer.
- Configure export interfaces to treatment machines.
- Learn how to interact with the system and apply it to clinical cases.

What is IMRT?

- It's complicated.
- A integrated system of technologies:
  - Patient setup and immobilization
  - CT-Sim with complementary imaging
  - Volume Segmentation
  - Computer-aided treatment planning
  - Linac and MLC
  - Verification Imaging
- It is not a treatment modality or technique!

The Evolution of IMRT

- The history of the arts and sciences could be written in terms of the continuing process by which new technologies create new environments for old technologies.
- You have to perceive the consequences of the new environment on the old environment before you know what the new environment is.

Mars Hall Mac Luhan

IMRT Planning System QA

- Geometry
  - Image and Structure Import
  - Multilayer reconstructions
  - Beam and DRR geometry, display, and export
- Image Segmentation
  - 3D-display
  - Automatic tools - auto-contouring auto-margin, etc.
  - Dose volume histograms (DVH)
- Dose Calculation Algorithms
- Plan Evaluation Tools
Summary

- IMRT is a technical evolution, not a treatment modality per se.
- Consider all aspects of the radiotherapy process.
- Commission planning system, "learn how to drive", and validate each treatment planning procedure.
- It is difficult to "decouple" all components of IMRT planning software.
- The dependence of IMRT on images and segmentation requires adherence to clinical protocols
- Participate in multi-institutional protocols