Dosimetric impact of contouring errors and variability in Intensity Modulated Radiation Therapy (IMRT)

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Outline

• Importance of contour quality control
• Classification of contouring errors
• 3 Case Studies
  • Random Error: Prostate treatment
  • Systematic Error: Lung (RTOG 0617)
  • Variation: Head and Neck

Contour quality control

• Why should contour quality/accuracy be evaluated?
  • Decision support on plan quality
  • Standardization across the field
  • Impacts clinical study results/analysis
• Contour variability/errors one of the largest sources of dosimetric uncertainty in radiation therapy

Contour quality control

- How to incorporate into a clinical workflow?
  - Buy-in from all members of RO team
  - Exists as a required step in planning workflow
  - May require extensive training of all involved staff
  - Standard agreed upon contouring methodology

- How to assess deviations from standard practices?

Contouring Errors vs. Contouring Variations

- Contouring Errors: Clinical contours (OARs and PTVs) do not encapsulate underlying anatomic data
  - Example: Optics not connected
  - Subjectively assessed as medium-to-large deviations

- Contouring Variations: Clinical contours (OARs and PTVs) have minor deviations
  - Frequently associated with some ambiguity in the imaging
  - May arise from inter-observer differences
  - Example: Optic nerve/chiasm defined using CT images
Contouring Errors vs. Contouring Variations

- Errors/variations can have significant impact on plan quality
  - Depending on a large number of patient and plan specific variables
  - Dosimetric impact needs to be understood and assessed for any deviations
  - Impact of error/variation assessed on a case-by-case basis

Factors impacting dosimetric uncertainty

- Proximity to target/high dose gradients
  - Impacts PTV coverage/OAR sparing
  - Impacts mean/max dose objectives
  - Largest dosimetric impact
- Type of dosimetric objective
  - Max dose objective:
    - Higher impact for errors/variations occurring close proximity to target
    - Small changes in contour can have a large impact
    - Prioritize accuracy evaluation for targets close to PTV, inspecting for fine details
  - Volume-based DVH objectives (Dmean, V_{xxGy}):
    - Sensitive to errors
    - Relatively insensitive to variations
- Volume of normal tissue
  - Small volumes sensitive to variations and errors (Optics)
  - Medium/Large volume less sensitive to small variations/errors

Systematic vs. Random Contouring Errors

- Systematic Contour Errors
  - Physician, Practice, or entire RT field consistently produces contours deviating from underlying anatomy
  - Issue 1: Outcomes (survival/complications) may not correlate to dosimetric data
  - Issue 2: Results from clinical studies may produce incorrect conclusions
  - Issue 3: Field-wide clinical guidelines may not correlate to practice specific dosimetric results
  - May have significant impact on a large number of patients
  - Contours created following standard guidelines

- Random Contouring Errors
  - Contours produced for an individual patient deviate from underlying anatomy
  - Impacts plan quality evaluation and optimization
3 Case Studies

- Prostate (Random contouring error)
  - Rectum contouring error
  - Impacted optimization and plan evaluation

- Lung (Systematic contouring error)
  - Heart contouring error across RTOG 0617 clinical trial
  - Impacted clinical trial evaluation and possible outcome analysis

- Head and Neck (Contouring variation)
  - Spinal cord contouring variation
  - Impact dosimetric evaluation of plan quality

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Case 1: Random Error in Rectum Contour

- Prostate and Nodes
  - CTV: Prostate, Seminal Vesicles, Pelvic nodes
  - PTV = CTV + 5mm
  - IMRT + HDR Brachytherapy
  - OARs: Rectum, Bladder, Sigmoid Colon, Bowel

- Rectum contouring error identified during manual QC
  - Standard contouring rules: Contour ends superiorly before rectum connects anterolily with the sigmoid colon
  - ~5cm of rectum not contoured superiorly

- Classified as a random error
  - Different from contouring guidelines for single patient
  - Missed by dosimetry and physician

- Impacted plan quality due to poorly optimized plan

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![Image of Case 1: Random Error in Rectum Contour]
Case 1: Random Error in Rectum Contour

- Reoptimized plan dose on two rectum contours

Case 1: Random Error in Rectum Contour

- Original plan optimized using incorrect rectum contour

Case 1: Random Error in Rectum Contour

- Final plan re-optimized using corrected rectum contour
Case 1: Random Error in Rectum Contour

- Final plan re-optimized using corrected rectum contour (Squares)
- Original plan optimized using incorrect rectum contour (Triangles)

Case 2: Systematic Errors – RTOG 0617 and Heart Contours

- RTOG 0617: Standard dose vs. high-dose radiotherapy for patients with stage IIIA or IIIB NSCLC
  - Compare overall survival of patients receiving standard dose (60Gy/30fx) vs high-dose (74Gy/37fx) with concurrent chemotherapy
  - Prioritized Lung-CTV ($V_{20}< 37\%$), Spinal Cord (Dmax < 50Gy), and PTV coverage
  - Low priority for heart dose objectives

- Overall survival worse for high-dose arm
  - Standard-dose median OS: 28.7 months
  - High-dose median OS: 20.3 months
  - More treatment related deaths in high-dose arm (8 vs 3).

- Higher heart dose may have impacted overall survival

Case 2: Systematic Errors – RTOG 0617 and Heart Contours

- RTOG Heart Contouring Guidelines
  - The heart should be contoured from its base to apex
  - Beginning at the CT slice where the ascending aorta originates

- Standardized heart contour atlas created in response to RTOG 0617
  - Ventricles
  - Atria
  - Pulmonary Artery
  - Pericardium
  - Coronary Space

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Case 2: Systematic Errors
RTOG 0617 and Heart Contours

- Planning study to compare RTOG 0617 clinical plans to RapidPlan autoplan
  - PTV coverage normalized with Rx to cover 95% PTV
  - 22 patients
  - Utilization of RapidPlan to remove subjective planning
- Comparison of dose to RTOG heart vs. revised heart (Dmean)
  - 74 Gy Arm:
    - Revised Heart: 19 Gy (RP) vs. 26.6 Gy (Clin)
    - RTOG Heart: 12.9 Gy (RP) vs. 14.5 Gy (Clin)
  - 60 Gy Arm
    - Revised Heart: 15 Gy (RP) vs. 19.5 Gy (Clin)
    - RTOG Heart: 8.2 Gy (RP) vs. 10.4 Gy (Clin)

Average: 16.83
Std Dev: 7.46
Case 3: Contouring Variations - Spinal Cord

- Bi-lateral head and neck
- Nasopharyngeal primary tumor
- Targets: 70Gy primary PTV, 56Gy nodal PTV
- OARs: Spinal cord, optic, parotid, oral cavity, submandibular nodes

- Spinal cord contouring variation identified during QC physics precheck
  - Institutional contouring rules: Spinal cord delineated as cylindrical column of uniform width
  - User creates Cord + 5mm structure to optimize on
  - Cord + 5mm < 50Gy, Cord <45Gy
  - Resident contoured visible cord from CT scan, expanded on structure to create cord + 5mm

- Classified as a variation
  - Differed from contouring guidelines for single patient
  - Variation is caused by imaging ambiguity and institutional standards

- Impacted plan quality evaluation due to high dose to Cord + 5mm
How to limit contouring variability?

- Manual/automated contour QC implemented during planning process
  - Peer review (physicians, physicists, dosimetrists)
  - Standardized contouring guidelines implemented across a practice
  - Implement contouring atlas to assist in contour creation

- Utilize auto-segmentation tools
  - Reduces variability by minimizing subjectivity created by human involvement
  - Creates consistent contours, may require manual modifications

- Incorporate multi-modality pre-imaging studies
  - Minimizes ambiguity for soft tissue structures created on CT scan
Summary

- Contour QC is a critical component of an IMRT planning workflow
  - Auto-contouring, peer review, and contouring atlases can minimize errors/variations
  - All members (physics, dosimetry, physician) of the treatment planning team should be involved in a contour QA process

- Errors/variations in contours can significantly impact plan quality
  - Dependent on proximity to target, magnitude of errors, and type of planning objective
  - Must be evaluated on a case-by-case basis