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

James Kavanaugh, MS DABR

Department of Radiation Oncology
Division of Medical Physics

Washington University in St. Louis
School of Medicine

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

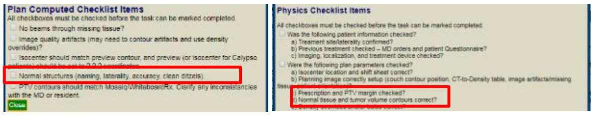

Journal of Thoracic Oncology
Volume 9, Issue 4, April 2014, Pages 527-533
Original Articles
The Impact of Peer Review of Volume Delineation in Stereotactic Body Radiation Therapy Planning for Primary Lung Cancer: A Multicenter Quality Assurance Study
Andrea C. Lo MD, Mitchell Liu MD, CM, FRCPC, Elisa Chan MD, FRCPC, Chad Lund


Brachytherapy
Volume 13, Issue 2, March–April 2014, Pages 210-218
Impact of delineation uncertainties on dose to organs at risk in CT-guided intracavitary brachytherapy
Frances K. Duane, Brian Langan, Charles Gillham, Lorraine Walsh, Guhan Rangaswamy


Practical Radiation Oncology
Volume 5, Issue 2, March–April 2015, Pages e67-e75
Original Report
Contouring variations and the role of atlas in non-small cell lung cancer radiation therapy: Analysis of a multi-institutional preclinical trial planning study
Yunfeng Cui PhD, Wenzhou Chen PhD, Feng-Ming (Spring) Kong MD, PhD, Lindsey A. Olsen

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?

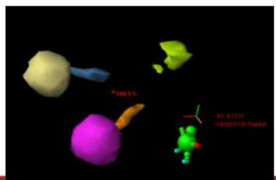
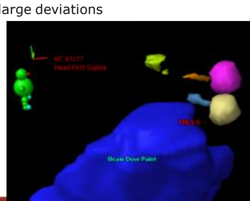

Plan Computed Checklist Items
All checkboxes must be checked before the task can be marked completed.
- No beams through missing tissue?
- Image quality artifacts (may need to contour artifacts and use density overrides)?
- Isocenter should match preview contour, and preview (or isocenter for Calypso ...
- Normal structures (naming, laterality, accuracy, clean ditzels)
- PTV contours should match Mosaiq/WhiteboardRx. Clarify any inconsistancies with the MD or resident.

Close

Physics Checklist Items
All checkboxes must be checked before the task can be marked completed.
- Was the following patient information checked?
  - a) Treament site/laterality confirmed?
  - b) Previous treatment checked – MD orders and patient Questionnaire?
  - c) Imaging, localization, and treatment device checked?
- Were the following plan parameters checked?
  - a) Isocenter location and shift sheet correct?
  - b) Planning image correctly setup (couch contour position, CT-to-Density table, image artifacts/missing tissue ...
  -) Prescription and PTV margin checked?
  -) Normal tissue and tumor volume contours correct?

Contouring Errors vs. Contouring Variations

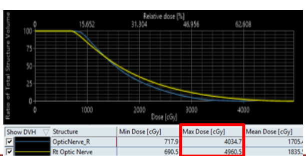
- Contouring Errors: Clinical contours (OARs and PTVs) do not encapsulate underlying anatomic data
  - Example: Optics not connected
  - Subjectively assessed as medium-to-large deviations

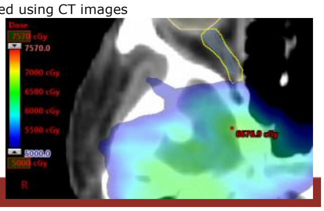
Washington University School of Medicine in St.Louis

Contouring Errors vs. Contouring Variations

- 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



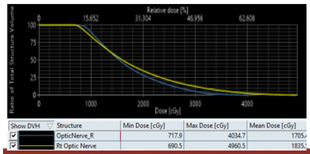
Show DVH	Structure	Min Dose [cGy]	Max Dose [cGy]	Mean Dose [cGy]
☑	OpticNerve_R	717.9	4034.7	1705.4
☑	Rt Optic Nerve	690.5	4960.5	1835.5

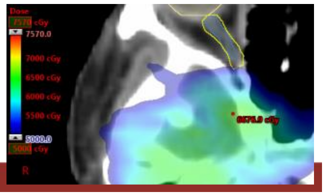


Washington University School of Medicine in St.Louis

Contouring Errors vs. Contouring Variations

- Errors/variations can have significant impact on plan quality
  - Dependent 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





Washington University School of Medicine in St. Louis

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

Washington University School of Medicine in St. Louis

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

Washington University School of Medicine in St. Louis

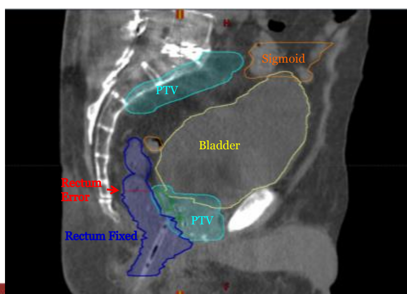
3 Case Studies

- 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

Case 1: Random Error in Rectum Contour

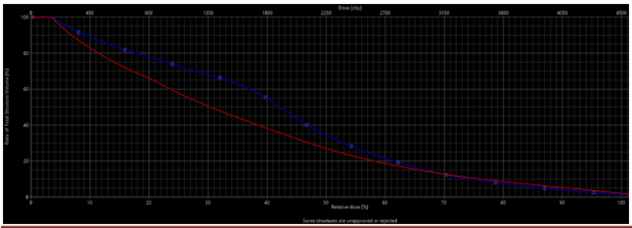
- Prostate and Nodes
  - CTV: Prostate, Seminal Vesicles, Pelvic nodes
  - PTV = CTV + 5mm
  - IMRT + HDR Brachytherapy
  - OARs: Rectum, Bladder, Sigmoid Colon, Bowel
- Rectum contouring error identified during manual QC
  - Standard contouring rules: Contour ends superiorly before rectum connects anteriolry with the sigmoid colon
  - ~5cm of rectum not contoured superiorly
- Classified as a random error
  - Differed from contouring guidelines for single patient
  - Missed by dosimetry and physician
- Impacted plan quality due to poorly optimized plan

Case 1: Random Error in Rectum Contour



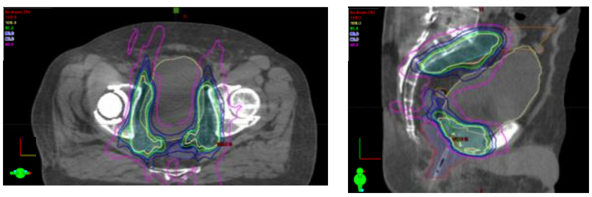
Case 1: Random Error in Rectum Contour

- Reoptimized plan dose on two rectum contours



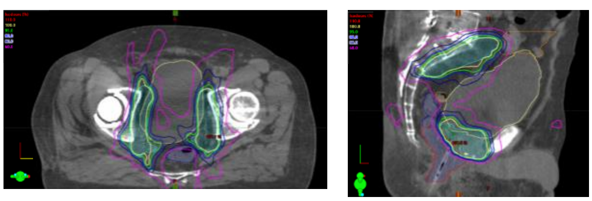
Case 1: Random Error in Rectum Contour

- 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

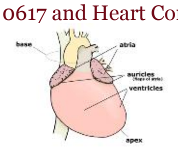
- Final plan re-optimized using corrected rectum contour (Squares)
- Original plan optimized using incorrect rectum contour (Triangles)

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_{20Gy}<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




International Journal of Radiation Oncology*Biology*Physics

Volume 90, Issue 1, Supplement, 1 September 2014, Page S739

Poster Viewing Abstract

Variation of Cardiac Contours Using Different Heart Definitions for NSCLC Patients Enrolled on RTOG 0617

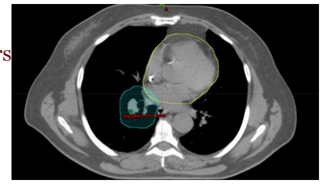
Y. Gong [1], E.M. Gore [2], V. Bar-Ad [1], M. Wheatley [2], F. Kong [3], J. Yu [1], T. Giaddui [1], W. Chen [1], C. Hu [4], R. Paulus [4], Y. Xiao [1], J.D. Bradley [5]

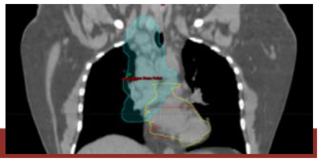
Show more

https://doi.org/10.1016/j.ijrobp.2014.05.2150

Get rights and content

Case 2: Systematic Errors
RTOG 0617 and Heart Contours



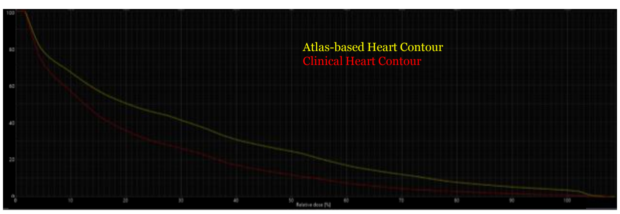


Case 2: Systematic Errors – RTOG 0617 and Heart Contours

- 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)
  - 74Gy 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: 15Gy (RP) vs. 19.5 Gy (Clin)
    - RTOG Heart: 8.2 Gy (RP) vs. 10.4 Gy (Clin)

Patient	Prescription	Revised Heart	RTOG Heart	Difference
L008	60	5.96	1.2	4.76
L078	74	25.23	12.4	12.83
L079	60	24.38	14.9	9.48
L085	60	15.83	5.7	10.13
L091	74	14.04	1.9	12.14
L092	74	23.15	19.9	3.25
L095	60	25.56	20.7	4.86
L097	74	24.15	21.4	2.75
L098	60	21.2	10.7	10.5
L099	60	16.52	2.6	13.92
L101	60	11.26	1.3	9.96
L103	74	15.42	6.8	8.62
L104	74	27.13	19.1	8.03
L105	60	10.84	5.9	4.94
L106	60	23.23	20.7	2.53
L107	60	9.63	4.9	4.73
L108	74	9.72	6.8	2.92
L109	74	24.5	20.1	4.4
L110	60	2.44	1.6	0.84
L112	74	22.42	19.2	3.22
L113	74	4.5	1.2	3.3
L114	60	13.08	8.7	4.38
Average		16.83	10.35	
Std Dev		7.46	7.56	

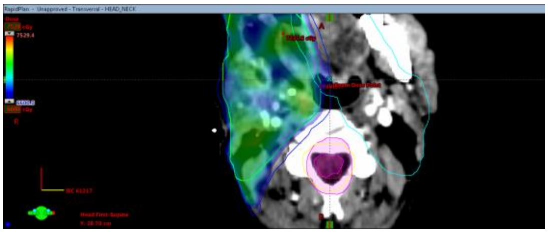
Case 2: Systematic Errors – RTOG 0617 and Heart Contours



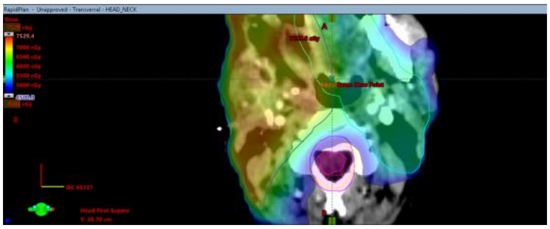
Case 3: Contouring Variations- Spinal Cord

- Bi-lateral head and neck
  - Nasopharyngeal primary tumor
  - Targets: 70Gy primary PTV, 56 Gy nodal PTV
  - OARs: Spinal cord, optics, parotids, 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

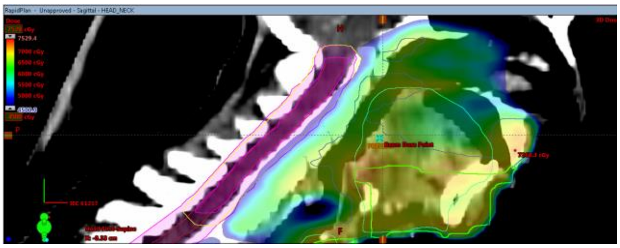
Case 3: Contouring Variations- Spinal Cord



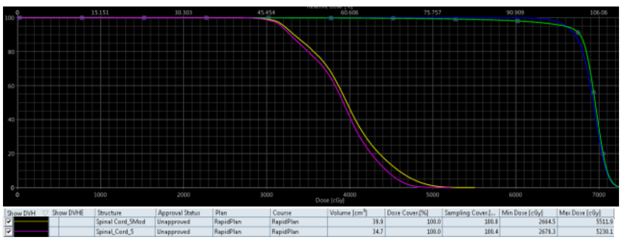
Case 3: Contouring Variations- Spinal Cord



Case 3: Contouring Variations- Spinal Cord



Case 3: Contouring Variations- Spinal Cord



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 consist 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

SITEMAN CANCER CENTER

BARNES JEWISH Hospital BJC HealthCare | Washington University in St. Louis School of Medicine

Washington University School of Medicine in St. Louis

James Kavanaugh
Instructor
Campus Box 8224
4921 Parkview Place
St. Louis, MO 63110
(218) 260-9940

jkavanaugh@wustl.edu

Washington University School of Medicine in St. Louis