The Roadmap Ahead for Big Data in Radiation Oncology

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Conflict of Interest Statement

- TreatSafely – founder and partner
- Radialogica – founder, shareholder, and CTO
- Varian - Licensing, service, grants, honoraria
- Modus - Licensing
- ViewRay – Licensing, service, grants, honoraria
- MedLever - Licensing

The Roadmap Ahead for Big Data in …?

- Oncology
- Radiation Oncology
- Medical Physics

Big data at this meeting (just some of it):

Harnessing Imaging Information to Improve Therapy	Monday - 7/31/2017
Deep Learning and Applications in Medical Imaging	Monday - 7/31/2017
Big Data, Deep Learning, and AI in Imaging	Monday - 7/31/2017
Machine Learning Role in Radiomics and Radiogenomics	Monday - 7/31/2017
Big Data in Radiation Oncology 1 and 2	Tuesday - 8/1/2017
QA For Modern Radiation Therapy	Tuesday - 8/1/2017
Imaging and Machine Learning	Tuesday - 8/1/2017
Big Data, Deep Learning, and AI in Imaging and Radiation Oncology	Tuesday - 8/1/2017

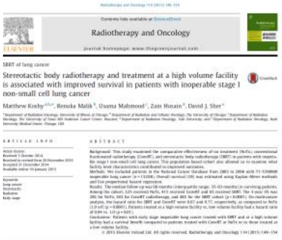
Why Big Data in RT?

- We mainly deliver medicine through numbers\data
- If we improve use of data we are very likely to improve delivery of medicine
- The potential for improvement from Big Data in radiation oncology is larger than in most other medical disciplines

Example: Opportunities for improvement

Can the outcomes in low volume facilities be improved through models created elsewhere?

- Same machines
- Same software
- Similar training
- Same certification
- Can use of data level the playing field?



Radiotherapy and Oncology

journal homepage: www.thegreenjournal.com

SBRT of lung cancer

Stereotactic body radiotherapy and treatment at a high volume facility is associated with improved survival in patients with inoperable stage I non-small cell lung cancer

Matthew Koshy, Renuka Malik, Usama Mahmood, Zain Husain, David J. Sher

As Previously Discussed

2015 Big Data Workshop

August 13-14, 2015
NIH Campus, Bethesda, Maryland

ASTRO, the National Cancer Institute (NCI), and the American Association of Physicists in Medicine (AAPM) are co-sponsoring a two-day workshop for radiation oncology physicians and physicists focused on opportunities for radiation oncology in the era of big data.

The 2015 Big Data Workshop: Exploring Opportunities for Radiation Oncology in the Era of Big Data will provide a platform for leaders in big data projects to interact with their peers in radiation oncology research, quality assessment and clinical care. Presentations will include current big data cancer registries, safety and incident reporting systems and other strategies that will have the greatest impact on radiation oncology research, quality assurance, safety and outcomes analysis/ CRE. Abstract submissions will be solicited for poster presentations.

Outcomes of the Big Data Workshop

- Opportunities
  - Detection
  - Diagnosis\staging
  - Imaging
  - Treatment
  - Safety\quality
  - Outcome response
  - Efficiencies
- Obstacles
  - Access to data

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BIG DATA

A Systems Approach Using Big Data to Improve Safety and Quality in Radiation Oncology

Louis Potters, MD, FACR, FASTRO,[*] Eric Ford, PhD,[†]
Suzanne Evans, MD,[‡] Todd Pawlicki, PhD,[§] and Sasa Mutic, PhD[||]

[*]Department of Radiation Medicine, Northwell Health and Hofstra Northwell School of Medicine, Lake Success, New York; [†]Department of Radiation Oncology, University of Washington, Seattle, Washington; [‡]Department of Therapeutic Radiology, Yale University School of Medicine, New Haven, Connecticut; [§]Department of Radiation Oncology, University of California San Diego, San Diego, California; and [||]Department of Radiation Oncology, Washington University School of Medicine, St. Louis, Missouri

Received Sep 15, 2015, and in revised form Oct 6, 2015. Accepted for publication Oct 12, 2015.

Big Data Use

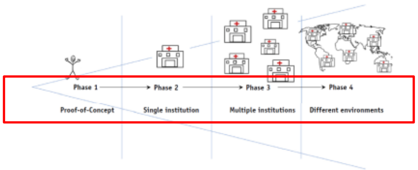


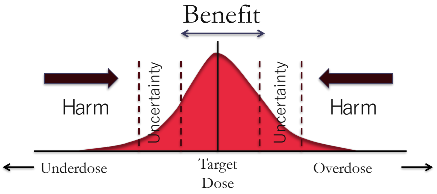
Fig. 1. A paradigm for quality and safety research that requires big data.

Potters et al, Int J Radiation Oncol Biol Phys, Vol. 95, No. 3, pp. 885e889, 2016

Big Data

- Identify improvement opportunities
- Data Collection
- Data Analysis
- Tool creation
- Tool distribution\enablement
- Adoption\Consumption

Example: Knowledge Based Planning

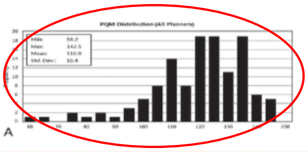


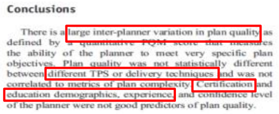
Operating principle: High quality = Reduced Variability

Example: Knowledge Based Planning

Variation in external beam treatment plan quality: An inter-institutional study of planners and planning systems

Benjamin E. Nelms PhD[a,b,*], Greg Robinson CMD[c], Jay Markham CMD[c], Kyle Velasco CMD[c], Steve Boyd CMD[c], Sharath Narayan CMD[c], James Wheeler MD, PhD[d], Mark L. Sobczak MD[e]

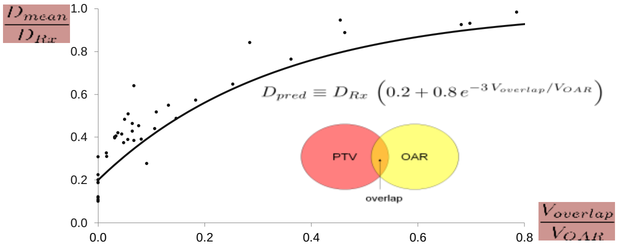



Conclusions

There is a large inter-planner variation in plan quality as defined by a quantitative PQM score that measures the ability of the planner to meet very specific plan objectives. Plan quality was not statistically different between different TPS or delivery techniques and was not correlated to metrics of plan complexity. Certification and education demographics, experience, and confidence level of the planner were not good predictors of plan quality.

Pract Radiat Oncol. 2012 Oct-Dec;2(4):296-305

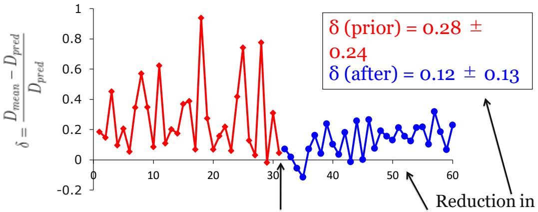
Example: Knowledge Based Planning (Phase 1)



$$D_{pred} \equiv D_{Rx}\left(0.2 + 0.8\,e^{-3\,V_{overlap}/V_{OAR}}\right)$$

K.L. Moore, R.S. Brame, D.A. Low, S. Mutic, Quantitative Metrics for Assessing Plan Quality, Sem. Radiat. Oncol., 22, 62-69, (2012).

Example: Knowledge Based Planning (Phase 1)



δ (prior) = 0.28 ± 0.24
δ (after) = 0.12 ± 0.13

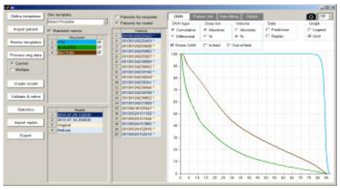
overlap script clinically deployed

Reduction in mean parotid dose and variability

K.L. Moore, R.S. Brame, D.A. Low, S. Mutic, Quantitative Metrics for Assessing Plan Quality, Sem. Radiat. Oncol., 22, 62-69, (2012).

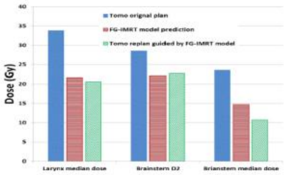
Standalone predictive DVH tool (Phase 2)

- **pDVH DICOM tool**
  - **TPS independent**
  - **Efficient GPU use**
  - **Allows novice users to automatically create and evaluate pDVH models**
  - **Automatically identifies dosimetric outliers and refines pDVH models**



Tan, J. et al., *A Universal Predictive DVH Modeling Toolkit.* Oral presentation, AAPM 2013.

Interinstitution Applicability (Phase 3)



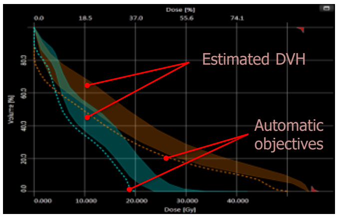
Modeling the dosimetry of organ-at-risk in head and neck IMRT planning: An intertechnique and interinstitutional study
Jun Lian, Lulin Yuan, Yaorong Ge, Bhishamjit S. Chera, David P. Yoo, Sha Chang, FangFang Yin, and Q. Jackie Wu Medical Physics 40, 121704 (2013)

- FG-IMRT model predictions indicated possible reductions in median Tomotherapy doses
  - Larynx – 10.5%
  - Brainstem – 12.8%
  - D2 of Brainstem – 20.4%
- Differences due to interinstitutional planning techniques
- Confirmed by replanning of six cases

Varian's – RapidPlan (Phase 4)

A method for estimating DVHs

- Based on patient geometry
- Previous knowledge contained in a set of existing patient cases
- As of July 2017 – almost 1000 licenses purchased*



*Varian investor report July 27, 2017

Courtesy – Varian Medical Systems

Adoption\Consumption

- Local or global KBP model?
- Time needed to implement models
- Adoption by physicians and dosimetrists
- Model maintenance
- Alternative approaches

Adoption\Consumption

- Systematic change in operating paradigms needed

From:
Collect, Analyze, Develop, Implement, Use, Maintain

To:
(Provide Data), Adopt, Use, Update

Data use challenges, even when data is available

- Proof of principle for big data benefit is currently the main focus
- Availability of data is the typically mentioned obstacle
- We just discussed adoption\consumption
- Acting on data and using it even when available - potentially another problem

IROC (RPC) Paper (2005)

Int. J. Radiation Oncology Biol. Phys., Vol. 63, No. 2, pp. 577–583, 2005
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0360-3016/05/$–see front matter

doi:10.1016/j.ijrobp.2005.05.021

PHYSICS CONTRIBUTION

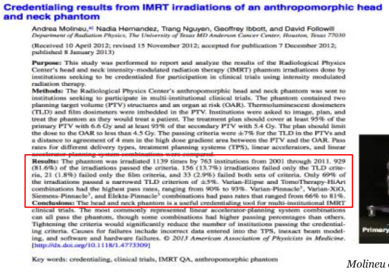
DESIGN AND IMPLEMENTATION OF AN ANTHROPOMORPHIC QUALITY ASSURANCE PHANTOM FOR INTENSITY-MODULATED RADIATION THERAPY FOR THE RADIATION THERAPY ONCOLOGY GROUP

Andrea Molineu, M.S.,* David S. Followill, Ph.D.,* Peter A. Balter, Ph.D.,* William F. Hanson, Ph.D.,* Michael T. Gillin, Ph.D.,* M. Saiful Huq, Ph.D.,† Avraham Eisbruch, M.D.,‡ and Geoffrey S. Ibbott, Ph.D.*

*Department of Radiation Physics, The University of Texas M. D. Anderson Cancer Center, Houston, TX; †Department of Radiation Oncology, University of Pittsburgh Medical Center, Pittsburgh, PA; ‡Department of Radiation Oncology, University of Michigan Medical Center, Ann Arbor, MI

Purpose: To design, construct, and evaluate an anthropomorphic phantom for evaluation of intensity-modulated radiation therapy (IMRT) dose planning and delivery, for protocols developed by the Radiation Therapy Oncology Group (RTOG) and other cooperative groups.
Methods and Materials: The phantom was constructed from a plastic head-shaped shell and water-equivalent plastics. Internal structures mimic planning target volumes and an organ at risk. Thermoluminescent dosimeters (TLDs) and radiochromic film were used to measure the absolute dose and the dose distribution, respectively. The reproducibility of the phantom's dosimeters was verified for IMRT treatments, and the phantom was then imaged, planned, and irradiated by 10 RTOG institutions.
Results: The TLD results from three identical irradiations showed a percent standard deviation of less than 1.6%, and the film-scanning system was reproducible to within 0.35 mm. Data collected from irradiations at 10 institutions showed that the TLD agreed with institutions' doses to within ±5% standard deviation in the planning target volumes and ±13% standard deviation in the organ at risk. Shifts as large as 8 mm between the treatment plan and delivery were detected with the film.
Conclusions: An anthropomorphic phantom using TLD and radiochromic film can verify dose delivery and field placement for IMRT treatments. © 2005 Elsevier Inc.

IROC (RPC) Report (2013)



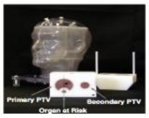
Credentialing results from IMRT irradiations of an anthropomorphic head and neck phantom

Andrea Molineu,[a] Nadia Hernandez, Trang Nguyen, Geoffrey Ibbott, and David Followill
Department of Radiation Physics, The University of Texas MD Anderson Cancer Center, Houston, Texas 77030

(Received 10 April 2012; revised 15 November 2012; accepted for publication 7 December 2012; published 8 January 2013)

Purpose: This study was performed to report and analyze the results of the Radiological Physics Center's head and neck intensity-modulated radiation therapy (IMRT) phantom irradiations done by institutions seeking to be credentialed for participation in clinical trials using intensity modulated radiation therapy.
Methods: The Radiological Physics Center's anthropomorphic head and neck phantom was sent to institutions seeking to participate in multi-institutional clinical trials. The phantom contained two planning target volume (PTV) structures and an organ at risk (OAR). Thermoluminescent dosimeters (TLD) and film dosimeters were imbedded in the PTV. Institutions were asked to image, plan, and treat the phantom as they would treat a patient. The treatment plan should cover at least 95% of the primary PTV with 6.6 Gy and at least 95% of the secondary PTV with 5.4 Gy. The plan should limit the dose to the OAR to less than 4.5 Gy. The passing criteria were ±7% for the TLD in the PTVs and a distance to agreement of 4 mm in the high dose gradient area between the PTV and the OAR. Pass rates for different delivery types, treatment planning systems (TPS), linear accelerators, and linear accelerator-planning system combinations were compared.
Results: The phantom was irradiated 1139 times by 763 institutions from 2001 through 2011. 929 (81.6%) of the irradiations passed the criteria. 156 (13.7%) irradiations failed only the TLD criteria, 21 (1.8%) failed only the film criteria, and 33 (2.9%) failed both sets of criteria. Only 69% of the irradiations passed a narrowed TLD criterion of ±5%. Varian-Elipse and TomoTherapy-HiArt combinations had the highest pass rates, ranging from 90% to 93%. Varian-Pinnacle^3, Varian-XiO, Siemens-Pinnacle^3, and Elekta-Pinnacle^3 combinations had pass rates that ranged from 66% to 81%.
Conclusions: The head and neck phantom is a useful credentialing tool for multi-institutional IMRT clinical trials. The most commonly represented linear accelerator-planning system combinations can all pass the phantom, though some combinations had higher passing percentages than others. Tightening the criteria would significantly reduce the number of institutions passing the credentialing criteria. Causes for failures include incorrect data entered into the TPS, inexact beam modeling, and software and hardware failures. *© 2013 American Association of Physicists in Medicine.* [http://dx.doi.org/10.1118/1.4773309]

Key words: credentialing, clinical trials, IMRT QA, anthropomorphic phantom



Molineu et al, Med. Phys. 40 (2013)

IROC Data (2013)

- Participating Institutions:
  - 20% failed the +/- 7% criteria
  - 30% failed the +/- 5% criteria
- Reasons for Failure
  - Errors in beam data input
  - Inadequate MLC modeling
  - Inadequate beam modeling
- 90-93% pass rates for institutions that had less local user input
  - Tomotherapy –no user input
  - Varian Linac/Eclipse – Presumably golden beam data or the benefit of auto modeling

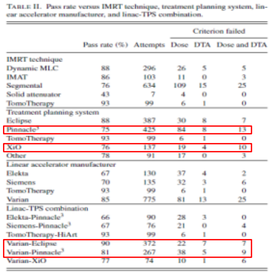
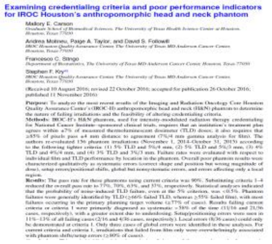


TABLE II. Pass rate versus IMRT technique, treatment planning system, linear accelerator manufacturer, and linac-TPS combination.

	Pass rate (%)	Attempts	Criterion failed		
			Dose	DTA	Dose and DTA
IMRT technique					
Dynamic MLC	88	296	26	5	5
IMAT	86	103	11	0	3
Segmental	76	634	109	15	25
Solid attenuator	43	7	4	0	0
TomoTherapy	93	99	6	1	0
Treatment planning system					
Eclipse	88	387	30	8	7
Pinnacle^3	75	425	84	8	13
TomoTherapy	93	99	6	1	0
XiO	76	137	19	4	10
Other	78	91	17	0	3
Linear accelerator manufacturer					
Elekta	67	130	37	4	2
Siemens	70	135	32	3	6
TomoTherapy	93	99	6	1	0
Varian	85	775	81	13	25
Linac-TPS combination					
Elekta-Pinnacle^3	66	90	28	3	0
Siemens-Pinnacle^3	67	76	21	0	4
TomoTherapy-HiArt	93	99	6	1	0
Varian-Eclipse	90	372	22	7	7
Varian-Pinnacle^3	81	267	38	5	9
Varian-XiO	77	74	10	1	6

IROC (RPC) Report (2016)



Examining credentialing criteria and poor performance indicators for IROC Houston's anthropomorphic head and neck phantom

Mallory E. Carson

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Francesco C. Stingo

Stephen F. Kry[a]

(Received 10 August 2016; revised 22 October 2016; accepted for publication 26 October 2016; published 11 November 2016)

Purpose: To analyze the most recent results of the Imaging and Radiation Oncology Core Houston Quality Assurance Center's (IROC-H) anthropomorphic head and neck (H&N) phantom to determine the nature of failing irradiations and the feasibility of altering credentialing criteria.

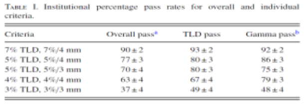

TABLE I. Institutional percentage pass rates for overall and individual criteria.

Criteria	Overall pass[a]	TLD pass	Gamma pass[b]
7% TLD, 7%/4 mm	90 ± 2	93 ± 2	92 ± 2
5% TLD, 5%/4 mm	77 ± 3	80 ± 3	86 ± 3
5% TLD, 5%/3 mm	70 ± 4	80 ± 3	75 ± 3
4% TLD, 4%/4 mm	63 ± 4	67 ± 4	79 ± 3
3% TLD, 3%/3 mm	37 ± 4	49 ± 4	48 ± 4

Conclusions:
- **Failures are the results of systematic dosimetric discrepancies between the TPS and delivered dose.**
- **Half of all failures are due to systematic underdosing.**

Acting on available data

- IROC Houston is the largest QA center in the world
- Their data is likely the biggest TPS\machine performance centric dataset available
- High quality data
- Data showing problems dating back 10+ years
- Actionable solutions still slow to develop

What if Big Data leads to standard data and automatic QA?

Yaddanapudi et al, Med Phys. 2017 Jul;44(7):3393-3406.
Wexler et al, Med Phys. 2017 Apr 17. [Epub ahead of print]

Are we ready to adopt all results of big data?

Roadmap considerations

- Benefits of Big Data already in clinical use
- One of the main areas of current research
  - Many other proofs of principle
  - New applications constantly being developed
- Constant increase in clinical practice likely
- There will likely be a reassortment of our duties
  - Automated treatment planning example
  - **OPPORTUNITIES TO INCREASE MEDICAL PHYSICS VALUE**
- Willingness to provide data but also willingness to consume outcomes of that data

Roadmap considerations

Individual clinics	Research	Industry
Organization for data collection	Development of incentives for data submission	Access to data
Standardization of practices (e.g. TG-263)	Data sharing and access	Provision of flexible solutions
Evolution of clinical practices	Development of new roles for medical physics	Decision support vs. automation
Model implementation (and development) skills	Identification of highest value opportunities	Identification of highest value opportunities
Change adoption	Data based innovation	Pace of development

Thank you!

"Just checking."