Managing Change in Radiotherapy

Automated treatment planning and online adaptive radiotherapy

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Conflict of Interest Statement

- Consulting - Varian
- Grants - Varian, ViewRay, Siemens
- Licensing – Varian, ViewRay, Modus, MedLever
- Ownership – Radialogica, TreatSafely

"I did not have a 30 year long career in Radiation Oncology, I had three 10 year long careers."

Retired Radiation Oncologist

Vision for Change - Direction

Vision for Change - Direction

What is the vision (direction) for automated planning and online adaptive radiotherapy?

Hint: It is not automation, nor fast planning!

Is there an insight into the future from the short history of automated planning and online adaptive radiotherapy?

First, let's look at an old article

advance NEWSMAGAZINES
for Imaging & Oncology Administrators

Issue Date: December 01, 2004

Vol. 14 •Issue 12 • Page 59
Radiation Oncology

Radiotherapy faces big changes in the years ahead, with image-guided IMRT taking flight, automated processes replacing patient-specific QA and pressure mounting to reduce rad onc costs.

By Thomas R. Mackie, PhD

Some of Rock's thoughts

Prediction	Today
"Radiotherapy has a future…"	We are still here ☺
"In a decade, CT-guided delivery will likewise become the rule, not the exception."	IGRT is ubiquitous
"…expect image guidance to blur the boundaries between surgery and radiotherapy."	SBRT is ubiquitous
"Brachytherapy will also combine seamlessly with intensity-modulated radiotherapy (IMRT) and radiolabeled tumor-seeking agents."	Modern brachytherapy planning and theranostics
"And like surgery, radiotherapy will adapt during therapy to account for the patient's changing representation."	Online adaptation
"One foundation technology for adaptive radiotherapy is deformable registration to map one 3-D distribution to another. This will be an enabling technology in 4-D imaging to map all time points back to a common time for planning and analysis."	Deformation is ubiquitous

Some of Rock's thoughts

Prediction	Today
"In addition to chemotherapy for treating metastases, multiple courses of radiotherapy to widespread areas of the body—analogous to weeding a garden in addition to using herbicides—will be accomplished by avoiding critical normal tissue using image-guided radiotherapy."	Multiple courses of RT commonly seen
"Ten to 20 years from now, all potentially curative and many palliative patients will have image-guided IMRT."	IGRT+MRT is standard of care
As the speed of delivery and level of integration increases, the superior dose distributions and optimization of numerous beam angles will push IMRT toward intensity-modulated arc therapy paradigms."	VMAT
Protons, IMPT, automation of patient specific QA, automatic machine QA, etc.	Perditions for these individual technologies – all true

Some of Rock's thoughts

Prediction	Today
"The clinical oncology medical physicist will have a role similar to that of clinical radiology colleagues—unwelcome news to most clinical radiation oncology physicists."	Not true (yet)
" But revenue per medical physicist in a therapy department is about 40 times less than in a diagnostic imaging department. As automated patient specific QA procedures increase, pressure to reduce radiation oncology costs will be tremendous."	Not true (yet)
"If our field's technical revolution slows and the revenue falls subsequent to the demise of the baby boomers, the number of practicing clinical radiation oncology physicists will drop. The next generation's medical physicists must be skilled in computer science and medical imaging, which are the driving scientific forces supporting our field."	True and specially important with the proposed Alternative Payment Model

Is there an insight into the future from the short history of automated planning and online adaptive radiotherapy?

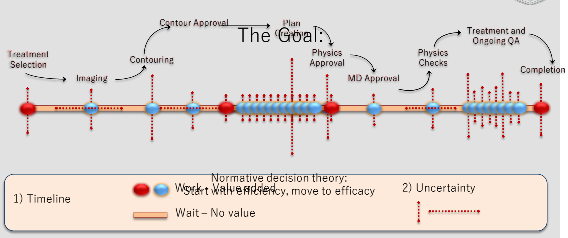
Let's look at some slides from 10 years ago

Adaptive Radiotherapy - Quality

"High-quality" means minimizing process variation and moving the average closer to the optimum value - *Med. Phys., 2007. 34(5): p. 1529-1533.*

Vision - Reducing Variability

The Goal:

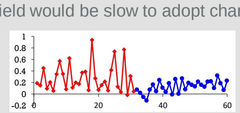


Normative decision theory: Start with efficiency, move to efficacy

Slide circa 2007-09

Back Then

- Could not have predicted the content of today's presentation but understood the high level scope
- Knew that technologically it would be possible
- Knew clinical evidence would be needed for sustainability
- Knew that jobs and roles would change
- Knew that field would be slow to adopt change

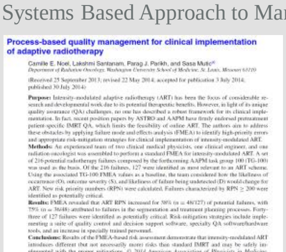


Early evidence for online adaptive radiotherapy

Online Adaptive

- **Online**: Image, Re-contour, Re-optimize, QA, while patient on table
- **Adaptive**: For daily anatomic changes in target and organs at risk (OARs)

Systems Based Approach to Managing ART



Process-based quality management for clinical implementation of adaptive radiotherapy

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Purpose: Intensity-modulated adaptive radiotherapy (ART) has been the focus of considerable research and developmental work due to its potential therapeutic benefits. However, in light of its unique quality assurance (QA) challenges, no one has described a robust framework for its clinical implementation. In fact, recent position papers by ASTRO and AAPM have firmly endorsed pretreatment patient-specific IMRT QA, which limits the feasibility of online ART. The authors aim to address these obstacles by applying failure mode and effects analysis (FMEA) to identify high-priority errors and appropriate risk-mitigation strategies for clinical implementation of intensity-modulated ART.
Methods: An experienced team of two clinical medical physicists, one clinical engineer, and one radiation oncologist was assembled to perform a standard FMEA for intensity-modulated ART. A set of 216 potential radiotherapy failures composed by the forthcoming AAPM task group 100 (TG-100) was used as the basis. Of the 216 failures, 127 were identified as most relevant to an ART scheme. Using the associated TG-100 FMEA values as a baseline, the team considered how the likeliness of occurrence (O), outcome severity (S), and likeliness of failure being undetected (D) would change for ART. New risk priority numbers (RPN) were calculated. Failures characterized by RPN ≥ 200 were identified as potentially critical.
Results: FMEA revealed that ART RPN increased for 38% (n = 48/127) of potential failures, with 75% (n = 36/48) attributed to failures in the segmentation and treatment planning processes. Forty-three of 127 failures were identified as potentially critical. Risk-mitigation strategies include implementing a suite of quality control and decision support software, specialty QA software/hardware tools, and an increase in specially trained personnel.
Conclusions: Results of the FMEA-based risk assessment demonstrate that intensity-modulated ART introduces different (but not necessarily more) risks than standard IMRT and may be safely implemented with the proper mitigations. © 2014 American Association of Physicists in Medicine. [http://dx.doi.org/10.1118/1.4890589]

Noel et al, Med Phys, Vol. 41, No. 8, August 2014

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Physics Contribution

Simulated Online Adaptive Magnetic Resonance–Guided Stereotactic Body Radiation Therapy for the Treatment of Oligometastatic Disease of the Abdomen and Central Thorax: Characterization of Potential Advantages

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Henke *et al.* Int J Radiation Oncol Biol Phys, Vol. 96, No. 5, pp. 1078e1086, 2016

Dose without adaptation

1084 Henke et al. International Journal of Radiation Oncology • Biology • Physics

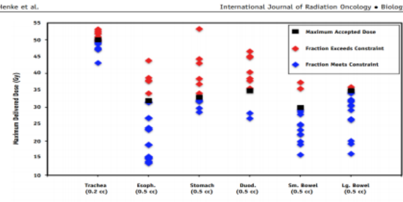


Fig. 3. Maximum point dose delivered to constraint volumes of organs at risk when initial nonadaptive plans were applied to daily anatomy.

Henke *et al.* Int J Radiation Oncol Biol Phys, Vol. 96, No. 5, pp. 1078e1086, 2016

Benefits of adaptation

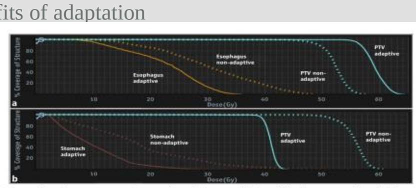


Fig. 4. Dose-volume histograms comparing esophageal (a), stomach (b), and planning target volume (PTV, a and b) dose for initial simulation plans based on simulation anatomy, nonadaptive plans applied to daily anatomy, and daily adaptive plans. In (a), esophageal protection occurred concurrently with PTV dose escalation. In (b), dose de-escalation to the PTV was required to meet hard stomach constraints.

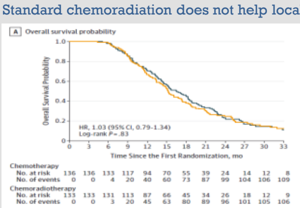
Henke *et al.* Int J Radiation Oncol Biol Phys, Vol. 96, No. 5, pp. 1078e1086, 2016

5 year Anniversary

- 1000s of online adaptive fractions

Clinical Application: Pancreas

Standard chemoradiation does not help locally advanced pancreas cancer

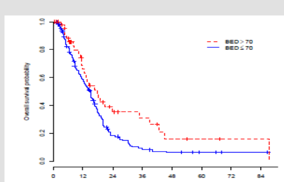


- *"If cancer is the emperor of all maladies, then pancreatic cancer is the ruthless dictator of all cancers"*
  – Deborah Schrag

Hammel et al, JAMA, 2016

Dose escalation may improve survival in LAPC

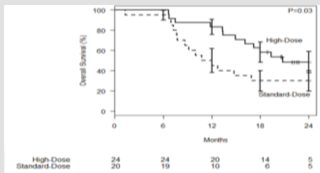
- Tumors **>1 cm** from a GI structure (25% of patients) were considered for hypofractionated dose escalation
- Patients who received radiotherapy with BED >70 Gy had an improved overall survival



Krishnan et al, IJROBP, 2016

LAPC Overall Survival


Using adaptive magnetic resonance image-guided radiation therapy for treatment of inoperable pancreatic cancer



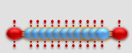
Maximum BED>90 Gy

Maximum BED<90 Gy

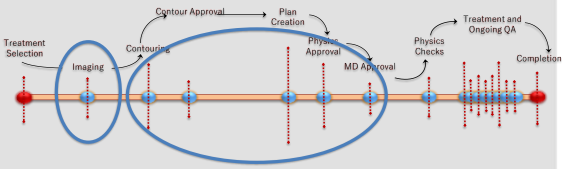
Rudra et al – Cancer Medicine, 2019

What remains to be done?

Vision



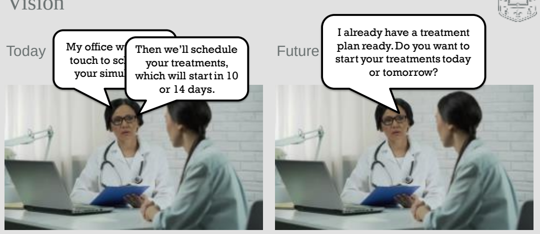
Needed breakthroughs



Vision

Today

Future



Clinical Impact – Why?

- Clear evidence that wait time (diagnosis / surgery to start of RT) impacts control, survival, and quality of life
- 2 week delay: 6% (breast), 14% (post-op HN) relative risk of local recurrence, 3% (breast), 8% (HN) decrease in survival (*Chen, Radiot Oncol 2008*).
- Upstaging (1/3 of patients) from diagnosis to simulation, lung cancer (*Everitt, Cancer 2010*)
- Psychological stress of patients associated with increased wait times (*Paul, Eur J Cancer Care 2012*)

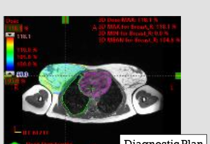
Vision

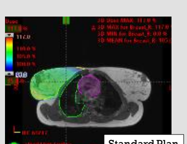
Remove RT simulation (imaging for treatment planning) entirely

Vision

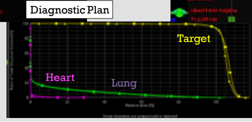
- Diagnostic imaging is sufficient for radiation treatment planning.
  - For example, in some clinics, SRS uses diagnostic MR
- Adaptive radiation therapy allows ‘on table’ modification to daily anatomy
  - Onboard imaging is sufficient for treatment planning
  - Can adjust to pose changes, immobilization, etc.

How do we get there? Option 1



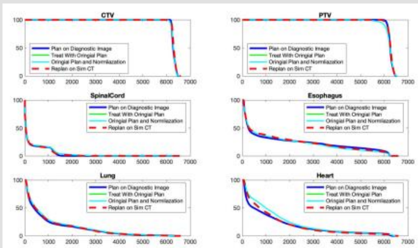


Plan on diagnostic images



Courtesy: T. Zhao

How do we get there? Option 1



Courtesy: T. Zhao

How do we get there? Option 2

Online
Simulation

Halcyon iCBCT

How do we get there? Option 3

- Use curved couches on treatment machines
  - Direct use of diagnostic images
  - More usable FOV
  - Better compatibility with arc delivery
  - Improved clearance
  - Less image artifacts
  - More stable
  - Improved patient comfort

Conclusions

- "If our field's technical revolution slows down …."
- Our roles will change regardless:
  - Online adaptation
  - Continuous patient evaluation
  - Hypofractionation
  - Non-oncologic applications
  - Considerations for the proposed Alternative Payment Model and decoupling between some traditional physics roles and reimbursement
  - ….
- "**You** either have to be **part of the solution**, or **you**'re going to be **part of the problem**."
- Plenty opportunities to be part of the solution

Thank you!

- WashU faculty, staff, trainees
- Outside collaborators
- Alumni
- Industrial partners