Artificial Intelligence for Adaptive Radiotherapy

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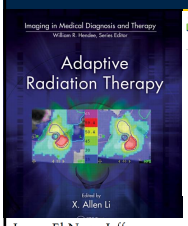
07/18/2019

Acknowledgements



Issam El Naqa, Jeffrey M. Craft, Jung Hun Oh, and Joseph O. Deasy

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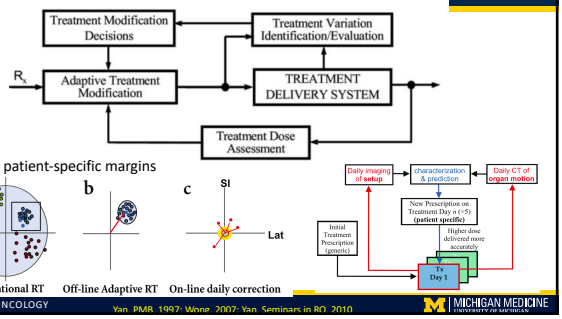
Biomarkers of Early Response for Adaptive Radiation Therapy

NIH National Institutes of Health

Image-guidance vs Adaptive Radiotherapy

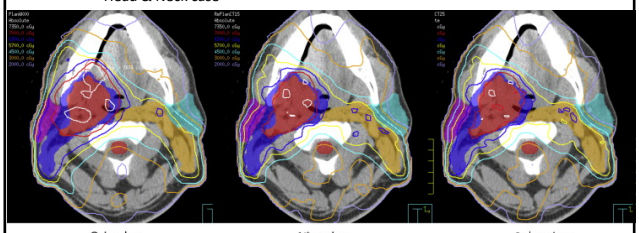
- Image-guidance radiotherapy (IGRT)
  - Goal: Stay a *pre-determined* course
  - Different imaging modalities (CT/PET/MRI) are used to guide planning (target definition) and delivery (localization)
- Adaptive radiotherapy (ART)
  - Goal: Make *changes* in the face of evolving information
  - Repeated measurements of the patient's geometry (imaging) and/or physiology (biomarkers) during the treatment so that a more patient-specific treatment can be delivered.

ART Principles



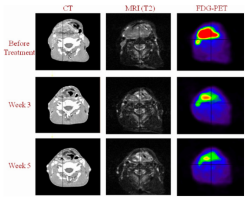
Some ART Examples I

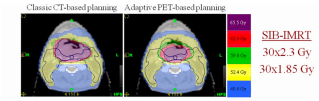
Head & Neck case



Orig.plan 1st replan 2nd replan

Some ART Examples II





SIB-IMRT
30x2.3 Gy
30x1.85 Gy

Planning	V_{10}	V_{50}	V_{80}	V_{90}	V_{95}	V_{100}
Classic CT-based	100%	100%	100%	100%	100%	100%
Adaptive CT-based	99%	100%	100%	85%	80%	66%
Classic PET-based	99%	99%	98%	83%	82%	81%
Adaptive PET-based	99%	100%	98%	73%	67%	58%

Some ART Examples III

ORIGINAL ARTICLES: HEAD AND NECK CANCER

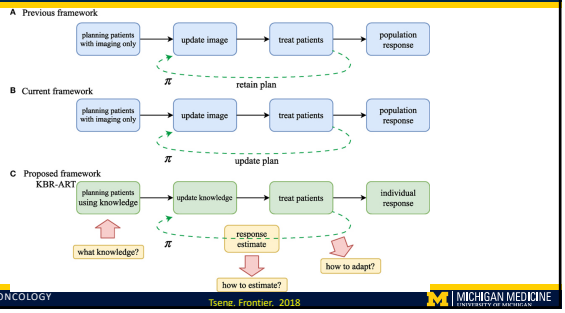
Late mucosal ulcers in dose-escalated adaptive dose-painting treatments for head-and-neck cancer

Luiza Ana Maria Olteanu, Fréderic Duprez, Wilfried De Neve, Dieter Berwouts, Tom Vercauteren, Wouter Bauters, Philippe Deron, Wouter Huvenne, Katrien Bonte, Ingeborg Goethals, Julie Schatteman & Werner De Gersem ...show less

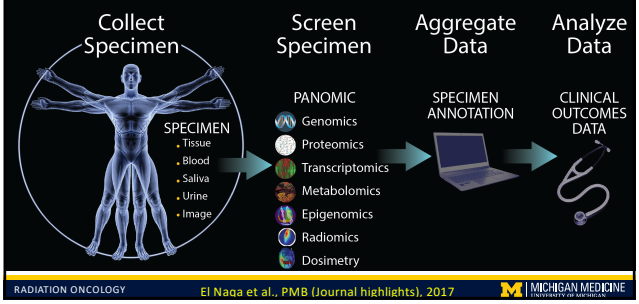
Pages 262-268 | Received 12 Feb 2017, Accepted 01 Aug 2017, Published online: 08 Sep 2017

	Pat number	Fractions 1–10	Fractions 11–20	Fractions 21–30/32	Total dose	NTD2
Patient group I (CTV_{HR})	6	10 × [2.16–3.0]	10 × [2.5–3.5]	12 × 2.16	72.5–90.9	76.9–108.3
Patient group II (GTV)	13	10 × [2.5–3.5]	10 × [2.5–3.5]	12 × 2.16	75.9–95.9	81.8–117.8
Patient group III (GTV)	10	10 × [2.0–3.5]	10 × [2.0–2.5]	10 × [2.0–2.5]	60.0–85.0	60.0–100.5
Patient group IV (GTV)	7	10 × [2.0–3.5]	10 × [2.5–4.0]	10 × 2.16	66.6–96.6	69.8–123.8
	2	10 × [2.0–3.5]	10 × [2.5–3.5]	10 × 2.16	66.6–91.6	69.8–113.3
	1	10 × [2.2–3.1]	10 × [2.2–3.1]	10 × 2.20	66.0–84.0	68.6–98.5

ART Evolution

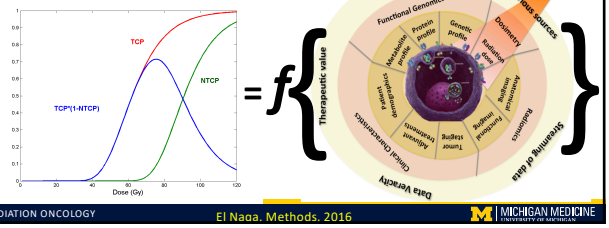


What? - ART in era of -omics

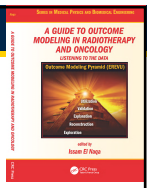


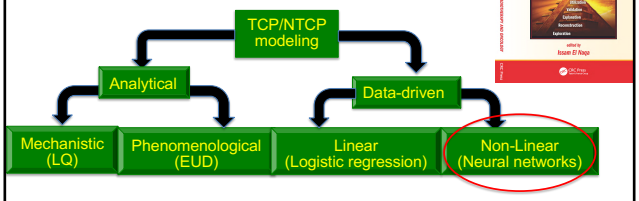
Which? - radiotherapy response estimates

Radiation response is multi-factorial and depend on: radiation dose and patients' physical, clinical, biological and genomic characteristics before and during the course of radiotherapy

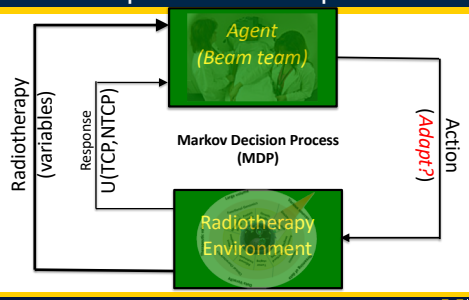


Outcome modeling

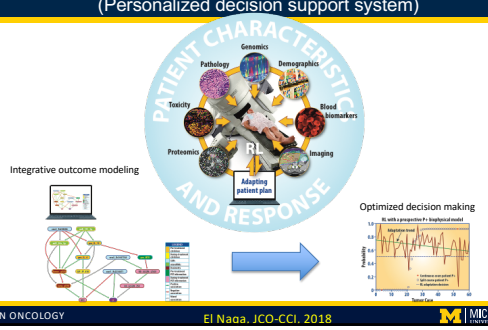




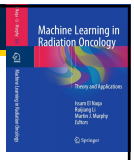
How? - optimize RT adaptation decision?



Precision Radiation Oncology (Personalized decision support system)



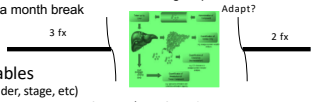
Machine learning for ART



- Supervised learning
  - Source: input ➜ output pairs
  - Learning: Training + testing phases
  - Applications: Classification, regression
- Reinforcement learning
  - Source: input data + agent (critic)
  - Learning: exploration (environment) and exploitation (action)
  - Applications: optimizing decision making

Example: Adaptive Decision Making in Liver Cancer

- Dataset
  - 182 HCC liver SBRT tumors (10 Gyx5) from 120 patients
  - 45 cases on non-adaptive
  - 137 cases on adaptive protocols
    - Adaptation was based on liver function using a split-course of 3+2 fractions with a month break



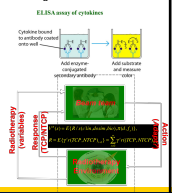
- Candidate variables
  - Clinical (age, gender, stage, etc)
  - Dosimetric (Bio-corrected gEUD of tumor/liver, fx, etc)
  - Plasma biomarkers (cytokines, miRNA)

RL Application to ART

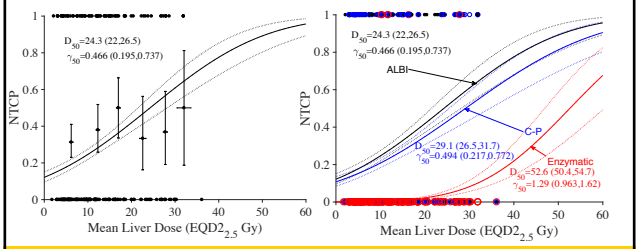
- RT environment
  - Patient's clinical, dosimetric, and biological covariates
- RL objective (reward)
  - Complication-free tumor control (P^+)
    - P^+=TCPx(1-NTCP)
      - TCP as local control
      - NTCP change in ALBI score by 1 point
- Optimization algorithm: Q-Learning
  - Greedy search approach to solve Bellman's principle of optimality with:
    - a simple regression model of state-action mapping

Biological variables (cytokines)

-)Transforming growth factor (TGF-β1
- Eotaxin (CCL11)
- Hormone growth factor (HGF)
- CD40 ligand

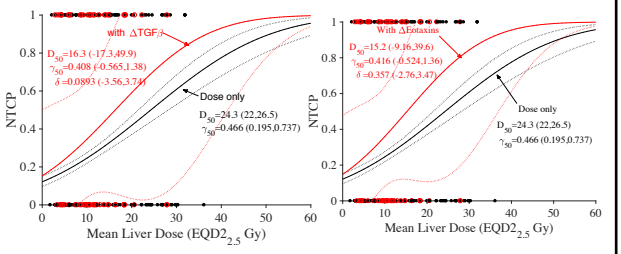


Dosimetric NTCP modeling using LKB



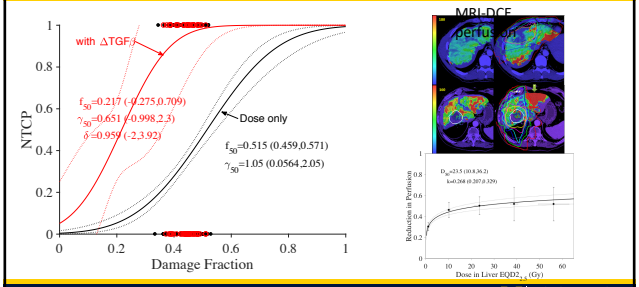
El Naqa et al, IJROBP, 2018

Dose modifying effect of cytokines on LKB-ALBI



El Naqa et al, IJROBP, 2018

Dose modifying effect of cytokines + imaging



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El Naqa et al. IJROBP 2018

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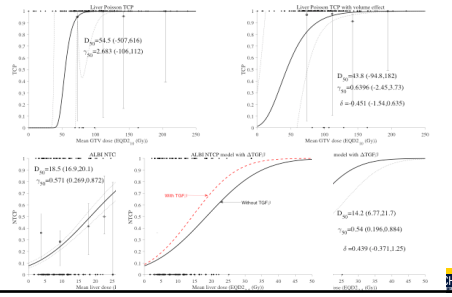
P+ Estimation



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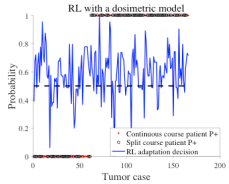
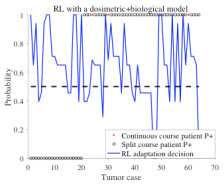
Retrospective RL analysis



- Adaptation recommendation:
  - 71% for split-courses
  - 70% for continuous-courses
- Average adaptation probability:
  - Amplitude=0.59±0.16



- **Adaptation recommendation:**
  - **64% for split-courses**
  - **67% for continuous-courses**
- **Average adaptation probability:**
  - Amplitude=0.64±0.

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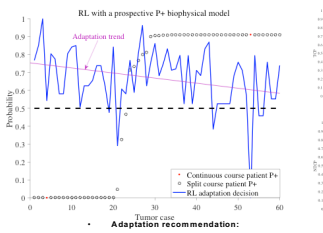
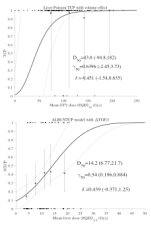
Prospective RL analysis





- **Adaptation recommendation:**
  - **90% for split-courses**
  - **100% for continuous-courses**
- **Average adaptation probability:**

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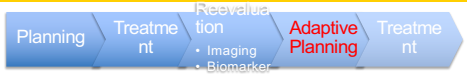
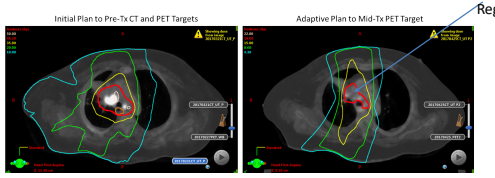
Example II: ART in lung cancer



Boost Region



Kong, JAMA,

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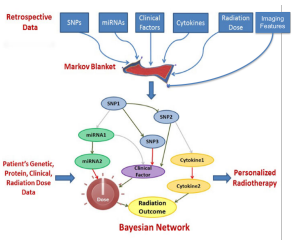
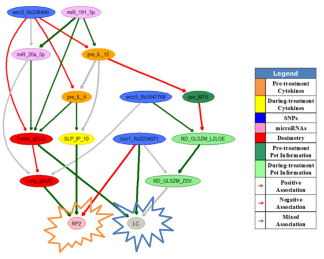
Multi-Objective Generative Models





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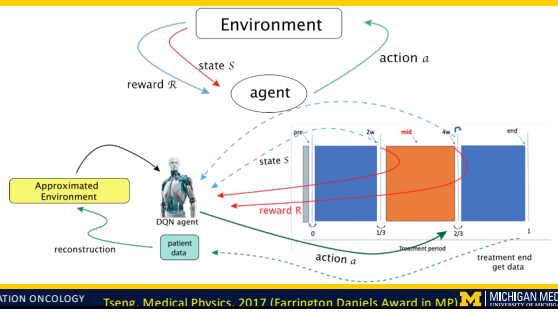
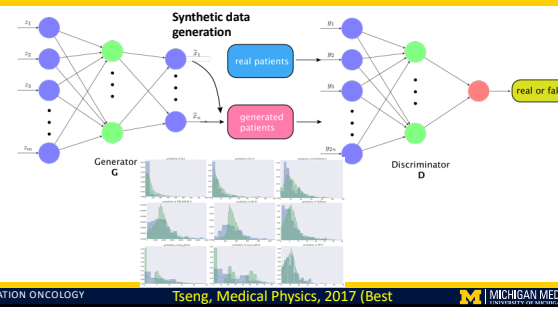
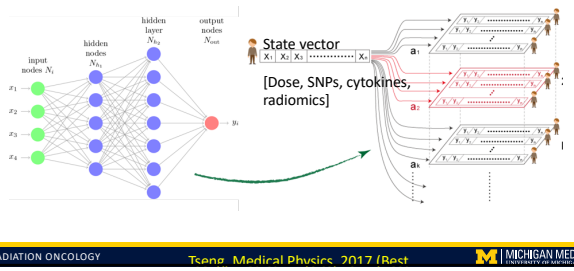
Adaptive Decision Making with Deep Learning I



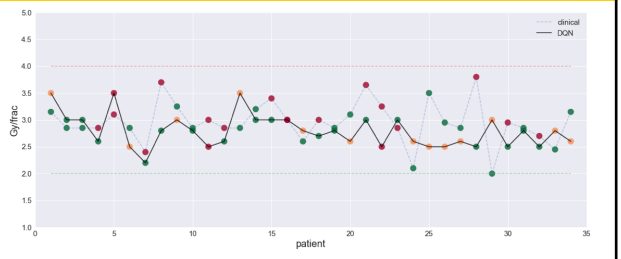
Adaptive Decision Making with Deep Learning II—Need more data?



Adaptive Decision Making with Deep Learning III-Transition probability



Adaptive Decision Making with Deep Learning IV



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Conclusions

- Artificial intelligence/machine learning offers new opportunities to develop better understanding of medical physics/radiation oncology processes and improve their workflow
- AI/ML approaches are uniquely positioned to improve adaptation in radiotherapy from heuristics to data driven realm.
- Adaptive radiotherapy implies improved outcome prediction (e.g., supervised learning) and optimizing decision making (reinforcement learning).
- Larger and multi-institutional datasets are necessary to realize the potential of AI in ART.

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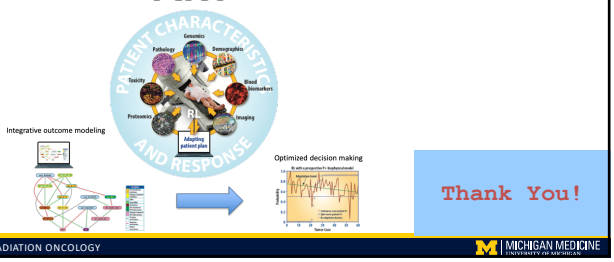
ART



Thank You!

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