University of Nebraska Medical Center

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Adaptive Radiotherapy and the Role of Artificial Intelligence

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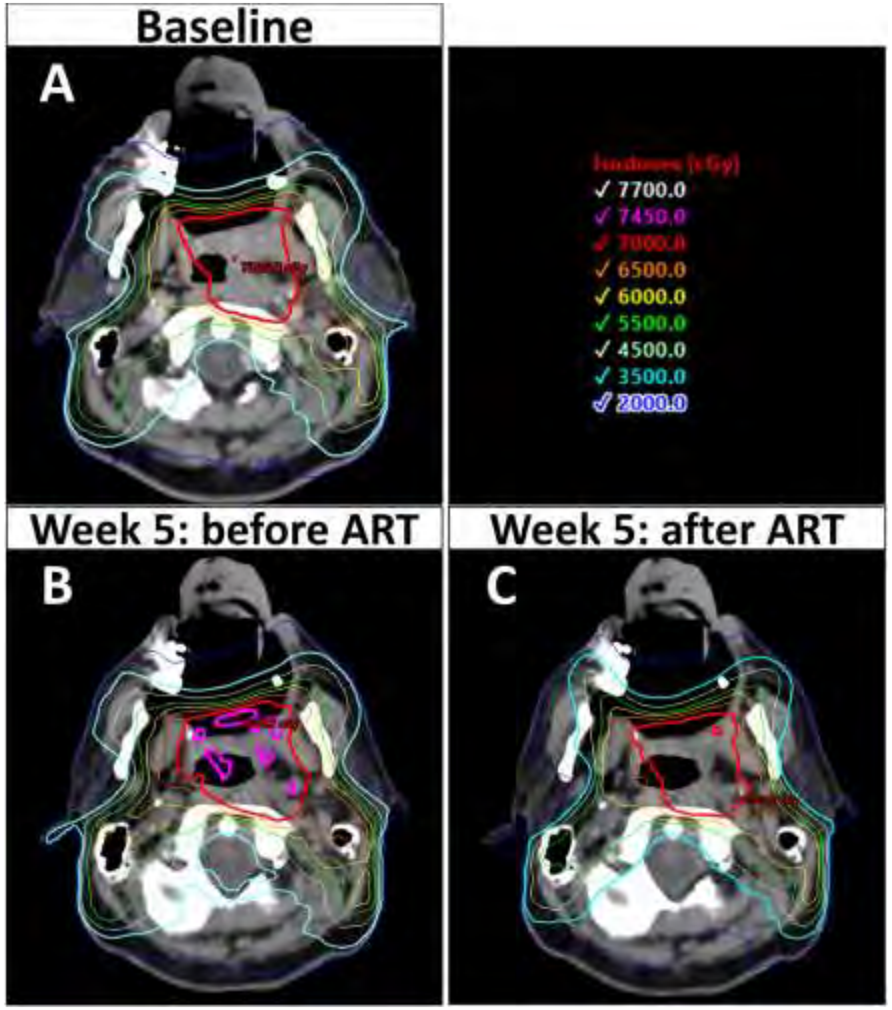
MEDICINE of THE HIGHEST ORDER

UR MEDICINE | WILMOT CANCER INSTITUTE

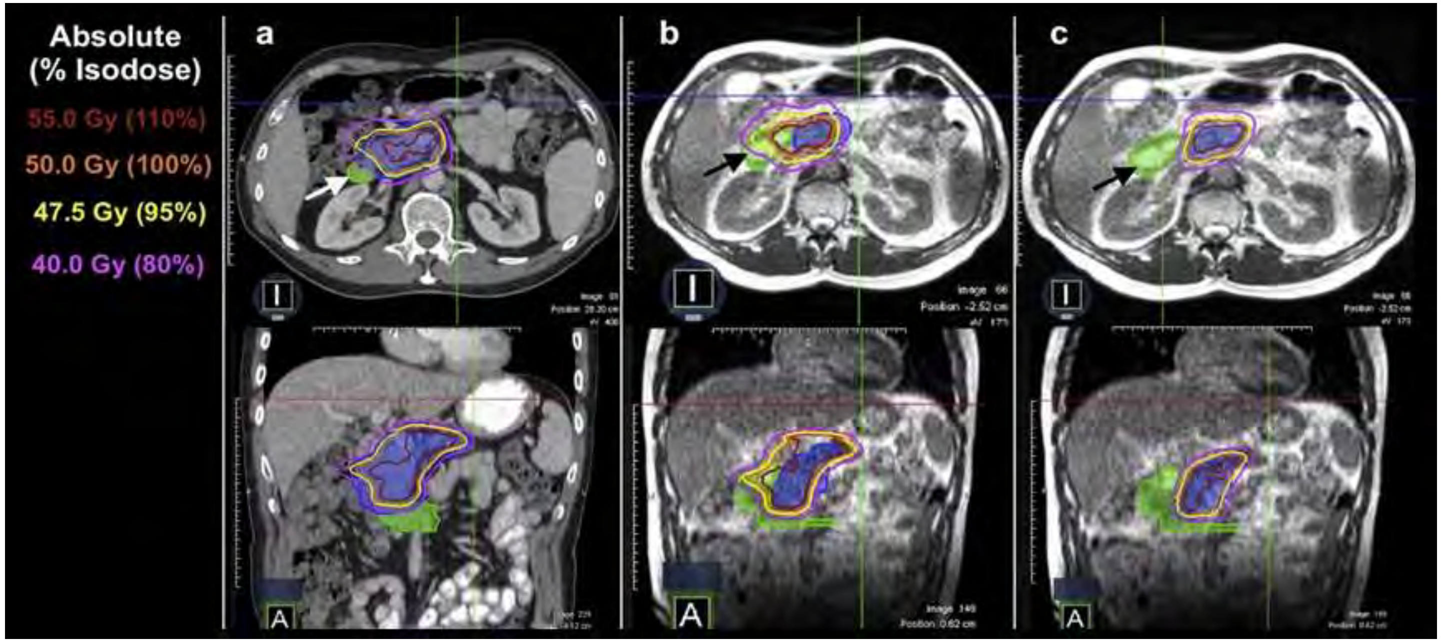
Disclosure

Varian research agreement on ART

Why ART?

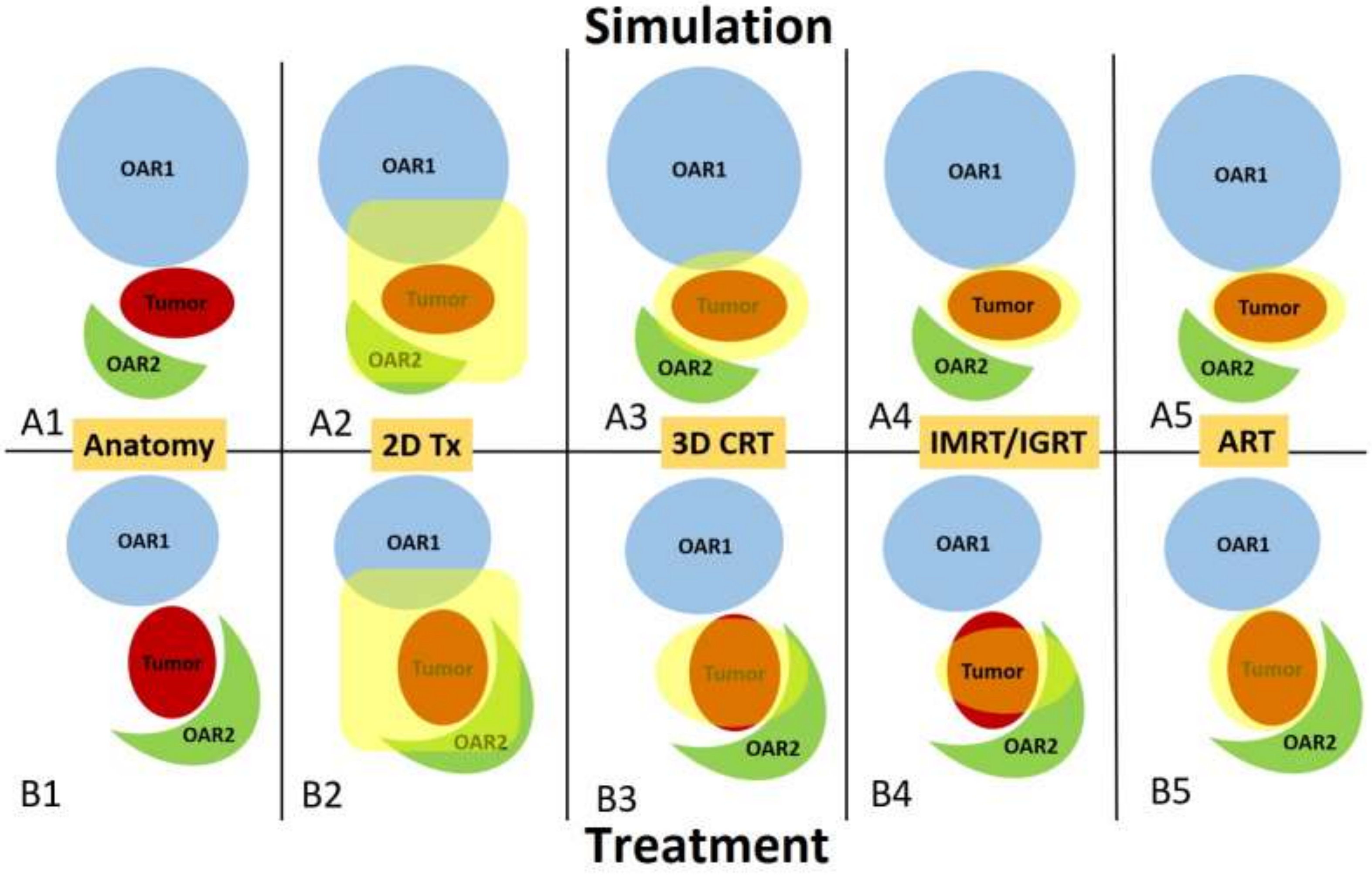


Morgan, H.E., Sher, D.J. Adaptive radiotherapy for head and neck cancer (2020)



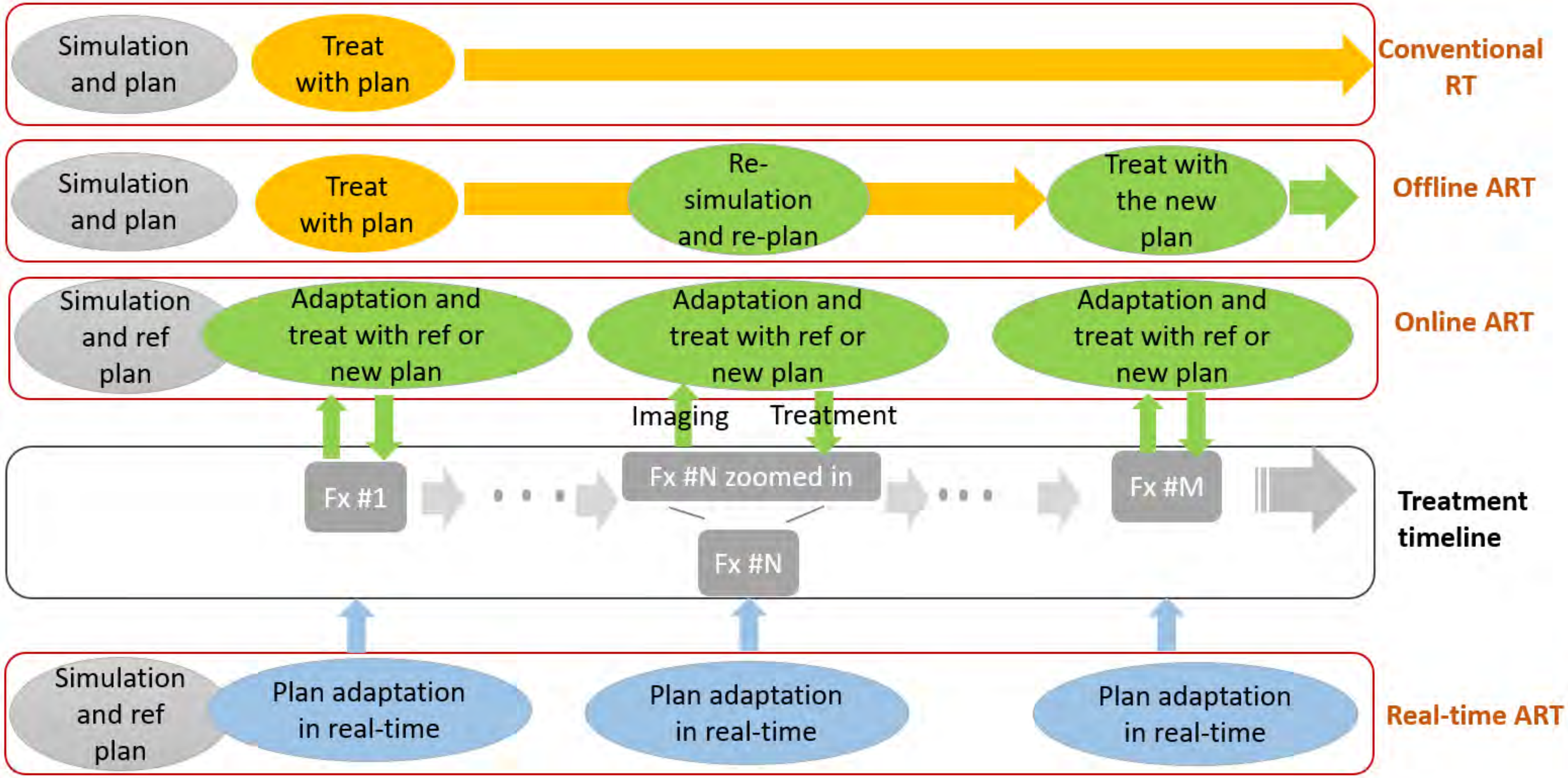
Henke, L., et al. Simulated online adaptive magnetic resonance–guided stereotactic body radiation therapy for the treatment of oligometastatic disease of the abdomen and central thorax: characterization of potential advantages *(2016)*

ART Becomes More Important with Advanced RT

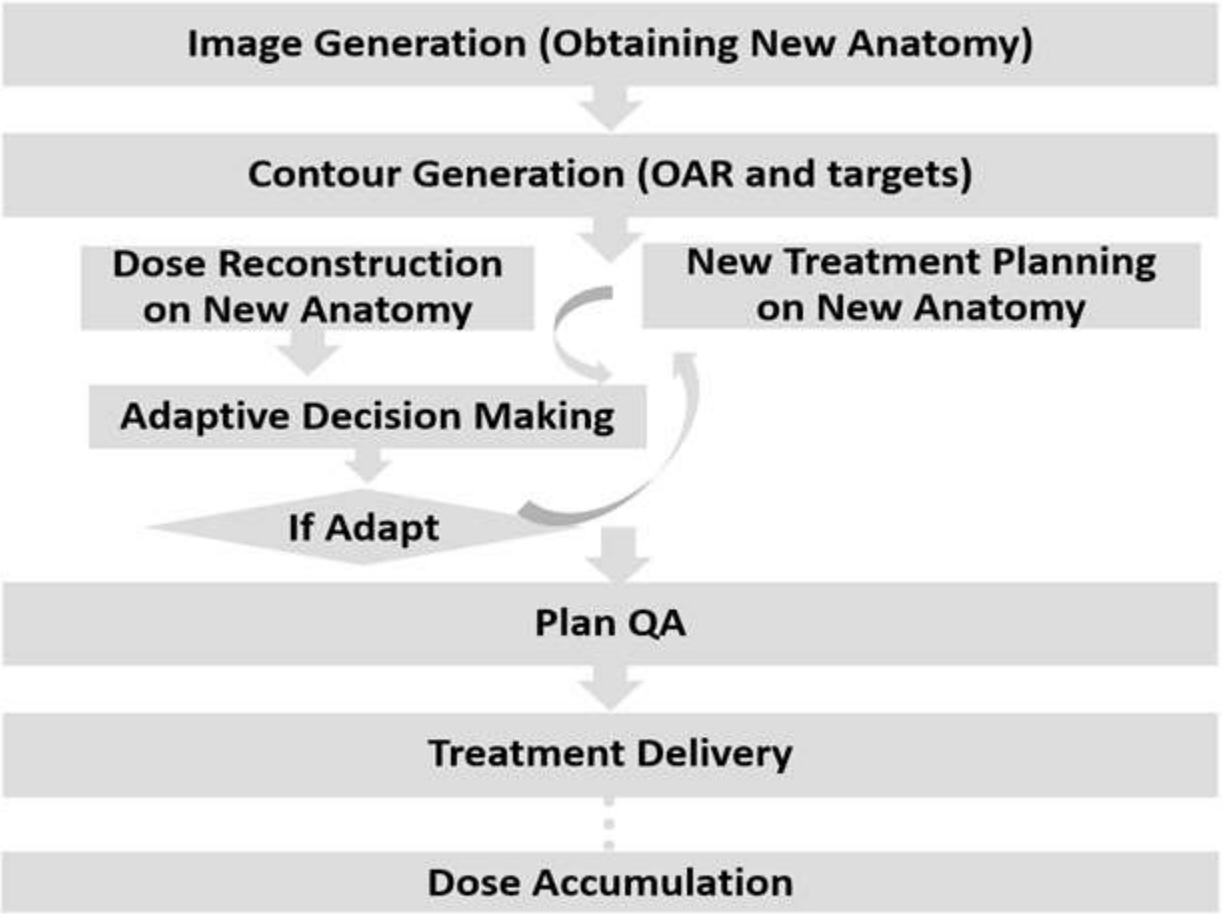


Dona Lemus OM, …, Zheng D. Adaptive Radiotherapy: Next-Generation Radiotherapy. (2024)

Different ART Schedules

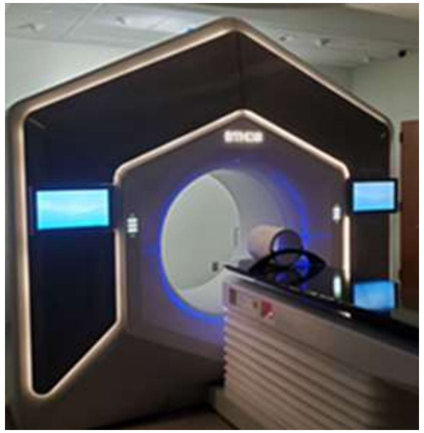


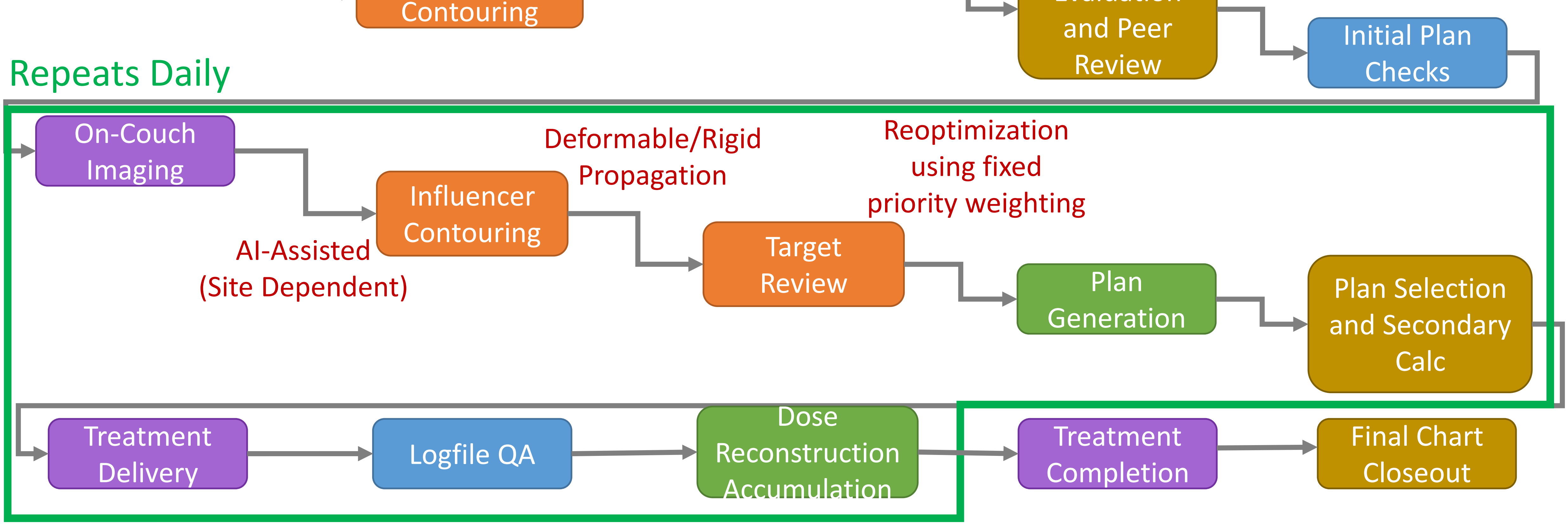
Typical ART Workflow



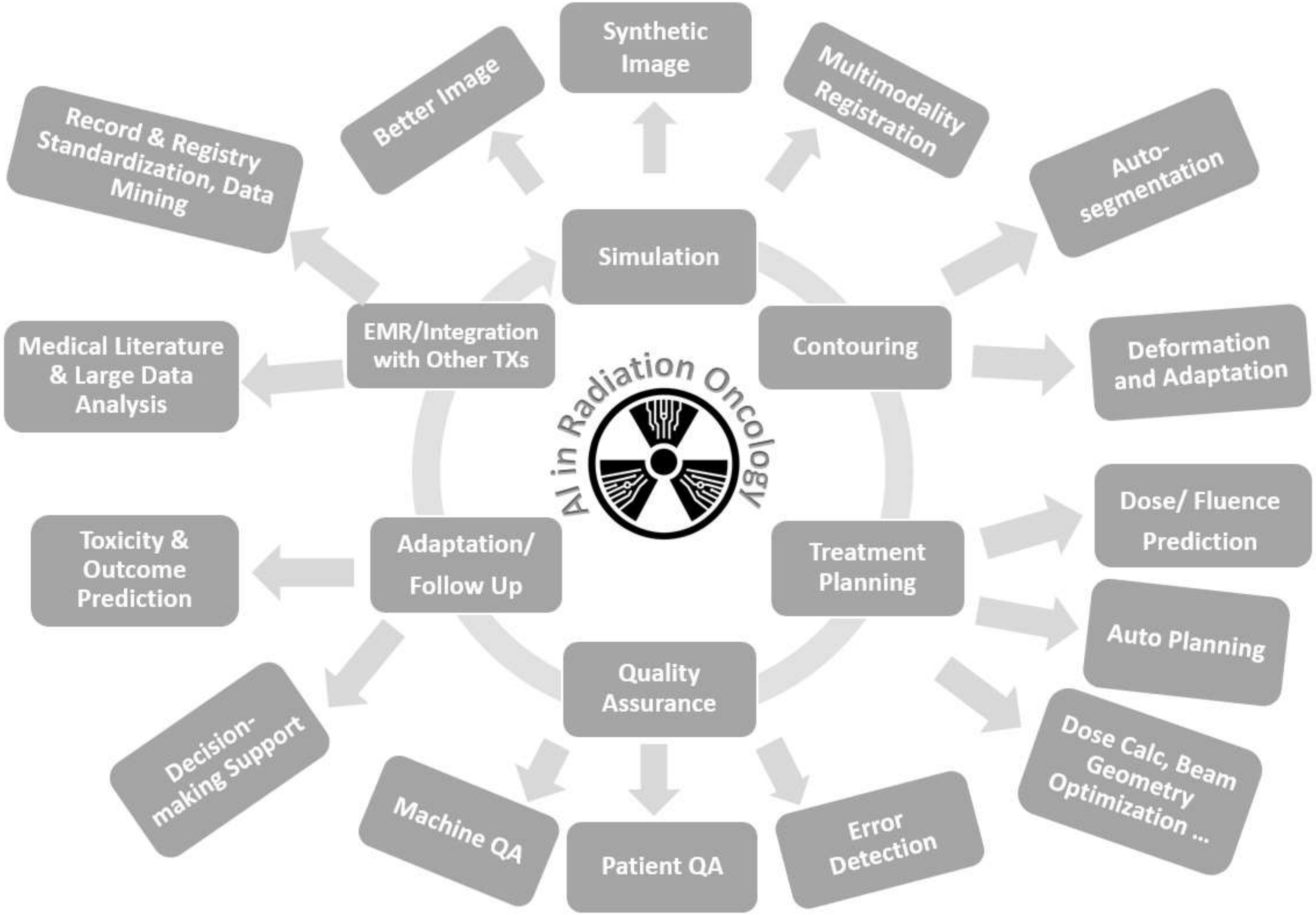
Dona Lemus OM, …, Zheng D. Adaptive Radiotherapy: Next-Generation Radiotherapy. (2024)

Ethos CBCT-ART Workflow



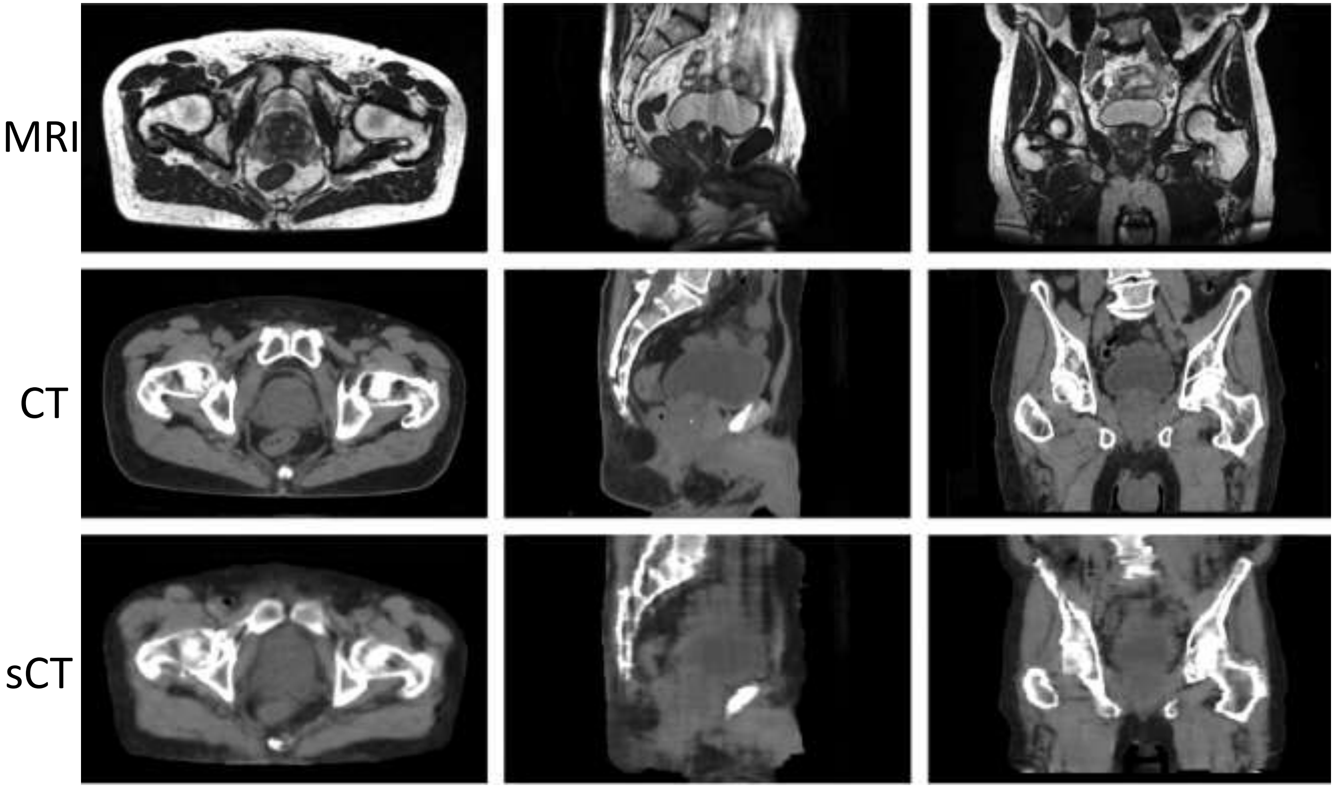


AI in Radiation Oncology

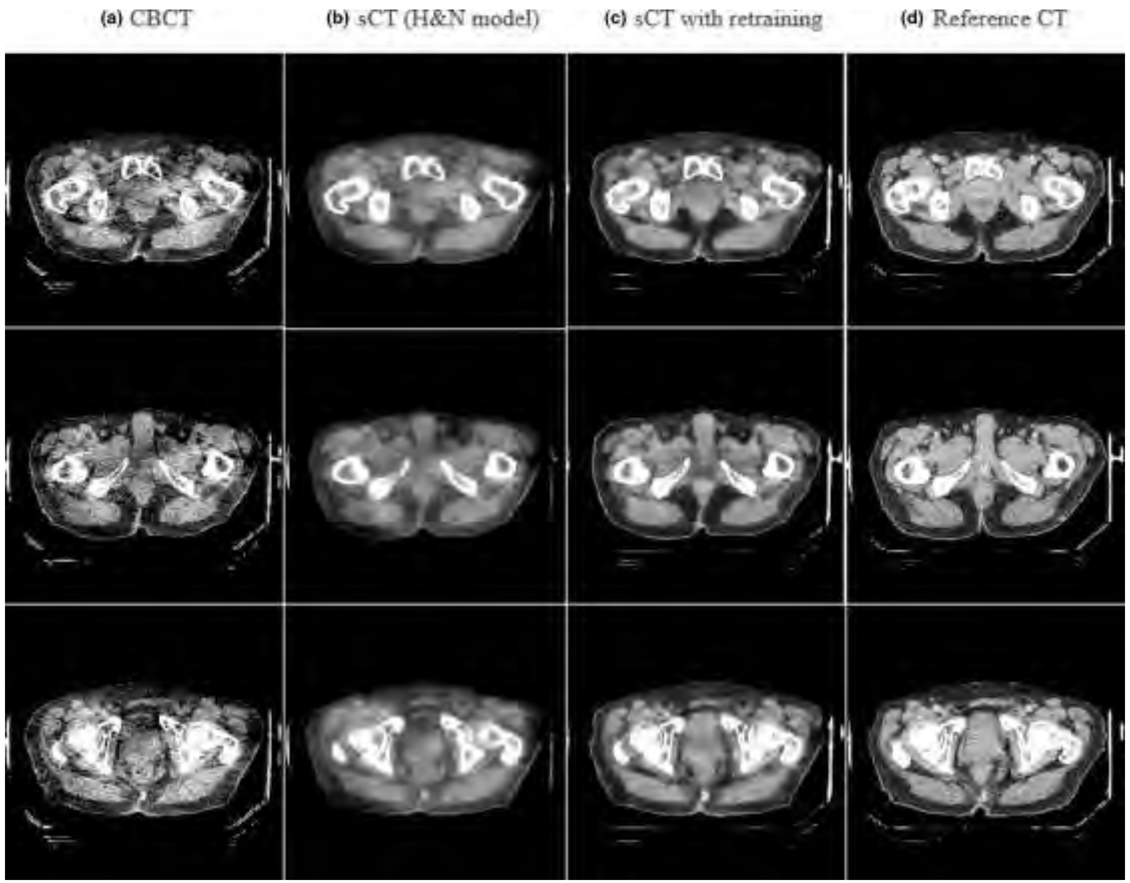


Zheng, D; Ger, R; and Hong, J: Artificial Intelligence in Radiation Therapy (2024)

Synthetic CT Generation with DL

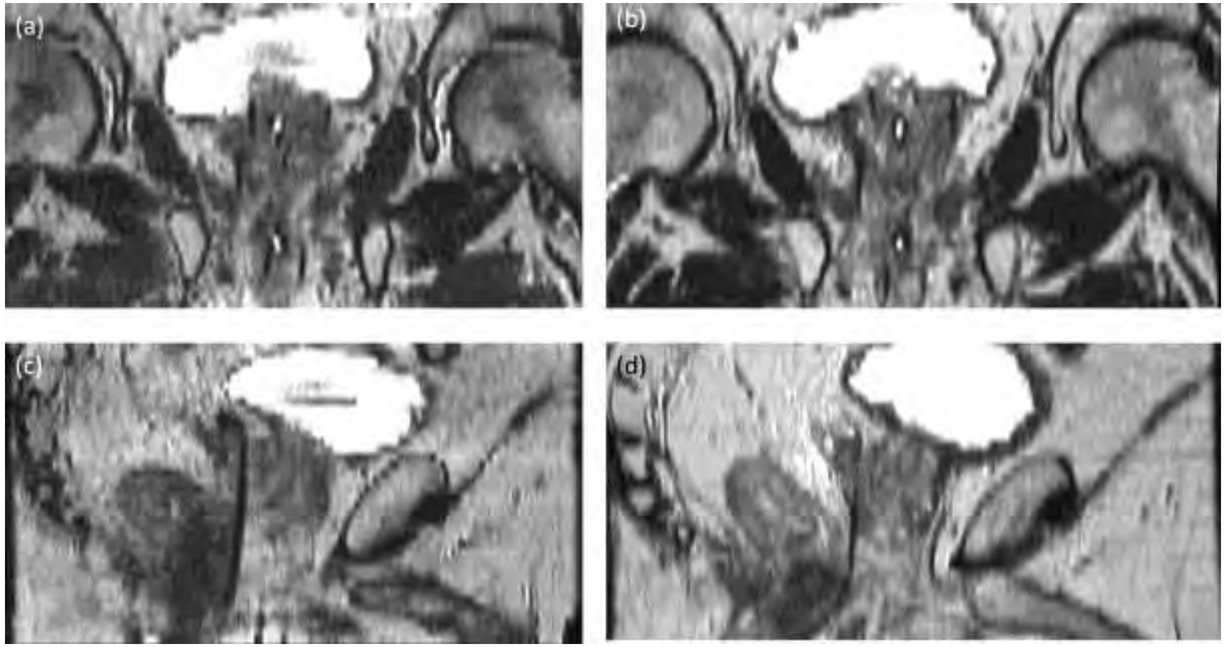


Cusumano, Davide, et al. "A deep learning approach to generate synthetic CT in low field MR-guided adaptive radiotherapy for abdominal and pelvic cases." (2020)



Chen, Liyuan, et al. "Synthetic CT generation from CBCT images via deep learning." (2020)

Other Synthetic Images



sMRI Real MRI

Podgorsak, Alexander R., et al. "Dosimetric and workflow impact of synthetic-MRI use in prostate high-dose-rate brachytherapy." (2023)

Synthetic Image Generation and AI

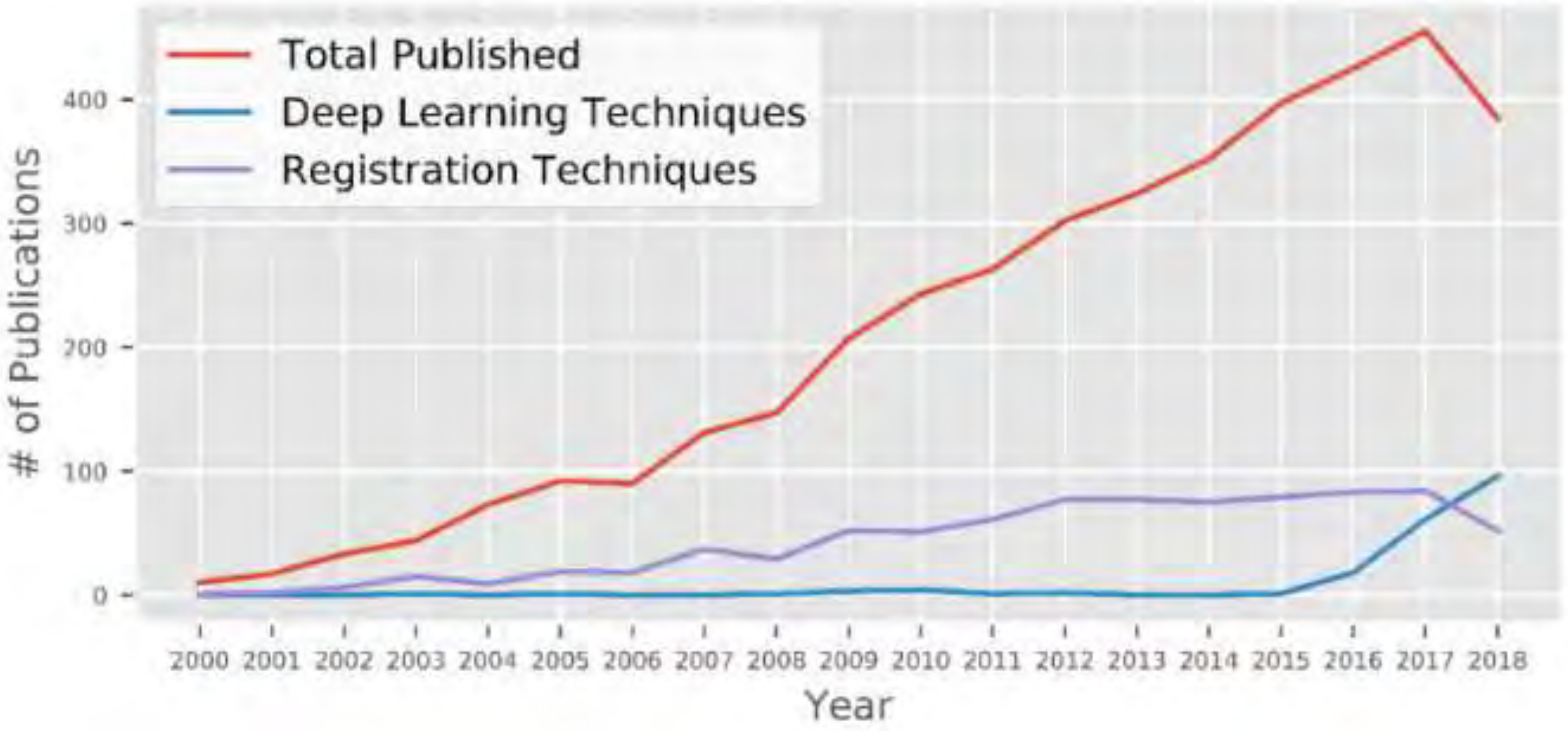
Popular methods:

- Generator-only (CNN, etc):
  - CED, DECNN, FCN, U-Net, ResNet, DenseNet…
- Generative adversarial network (GAN)
  - Cycle-GAN, conditional-GAN, least squares-GAN

Results and challenges:

- Superior performance over bulk-density- or atlas-based methods
- Reference image required for evaluation (intensity, geometry, dose…)
- Errors may propagate over multiple sequential ART steps

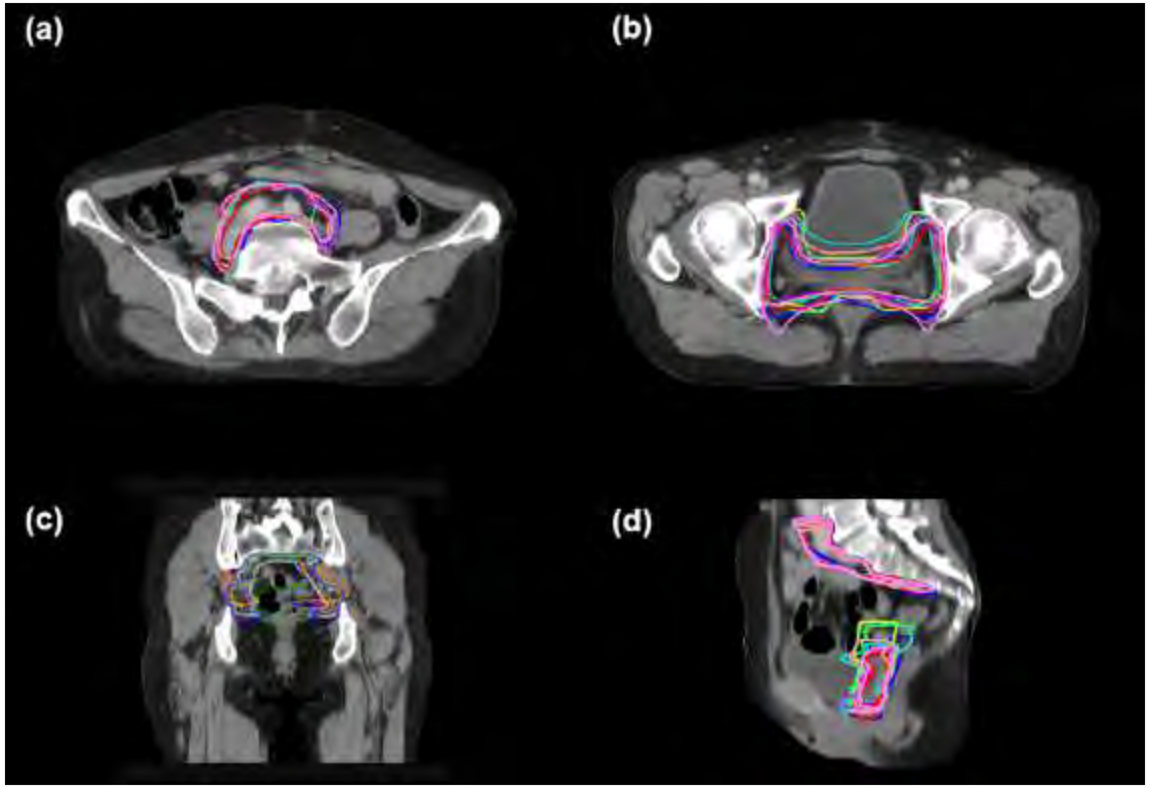
Autosegmentation



Cardenas, Carlos E., et al. "Advances in auto-segmentation." *Seminars in radiation oncology*. 2019.

Autosegmentation

Wong, Jordan, et al. "Comparing deep learning-based auto-segmentation of organs at risk and clinical target volumes to expert inter-observer variability in radiotherapy planning." (2020)



Ma, Chen-Ying, et al. "Deep learning-based auto-segmentation of clinical target volumes for radiotherapy treatment of cervical cancer." (2022)

Popular Methods and Evaluation Metrics

Popular methods:

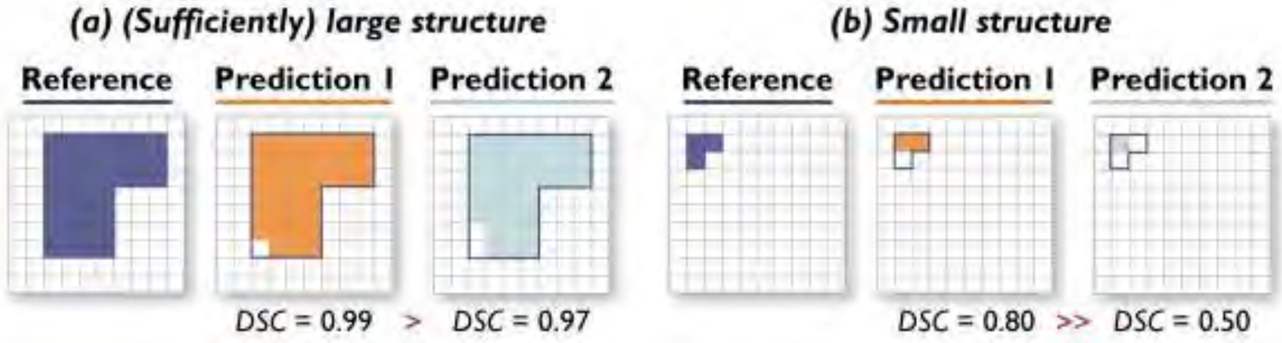
- CNN
  - 2D and 3D U-Net, V-Net, DeepMedic, ResNet…
- GAN

Category[1]	Metric	Symbol
Overlap based	Dice (F1-Measure)	DICE (FMS)
	Jaccard index	JAC
	True positive rate (Sensitivity, Recall)	TPR
	True negative rate (Specificity)	TNR
	False positive rate (=1-Specificty, Fallout)	FPR
	False negative rate (1-Sensitivity)	FNR
	Global Consistency Error	GCE
Volume based	Volumetric Similarity	VS
Pair counting based	Rand Index	RI
	Adjusted Rand Index	ARI
Information theoretic based	Mutual Information	MI
	Variation of Information	VOI
Probabilistic based	Interclass correlation	ICC
	Probabilistic Distance	PBD
	Cohens kappa	KAP
	Area under ROC curve	AUC
Spatial distance based	Hausdorff distance	HD
	Average distance	AVD
	Mahalanobis Distance	MHD

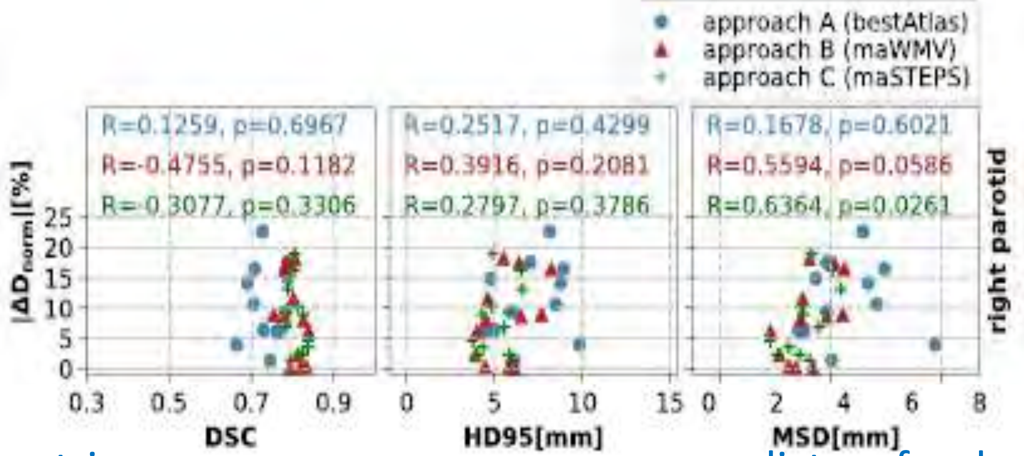
Taha et al. “Metrics for evaluating 3D medical image segmentation: analysis, selection, and tool” 2015

Limitations of DICE

	DSC	IoU	HD	HD95	ASSD	MASD	NSD
Prediction 1	DSC = 0.6	IoU = 0.4	HD = 1.4	HD95 = 1.3	ASSD = 0.9	MASD = 0.9	NSD = 1.0
Prediction 2	DSC = 0.6	IoU = 0.4	HD = 3.6	HD95 = 3.1	ASSD = 1.0	MASD = 1.0	NSD = 0.7
Prediction 3	DSC = 0.6	IoU = 0.4	HD = 3.0	HD95 = 2.0	ASSD = 0.8	MASD = 0.7	NSD = 0.8
Prediction 4	DSC = 0.6	IoU = 0.4	HD = 2.2	HD95 = 2.0	ASSD = 0.8	MASD = 0.7	NSD = 0.8
Prediction 5	DSC = 0.6	IoU = 0.4	HD = 2.0	HD95 = 1.2	ASSD = 0.8	MASD = 0.8	NSD = 0.9



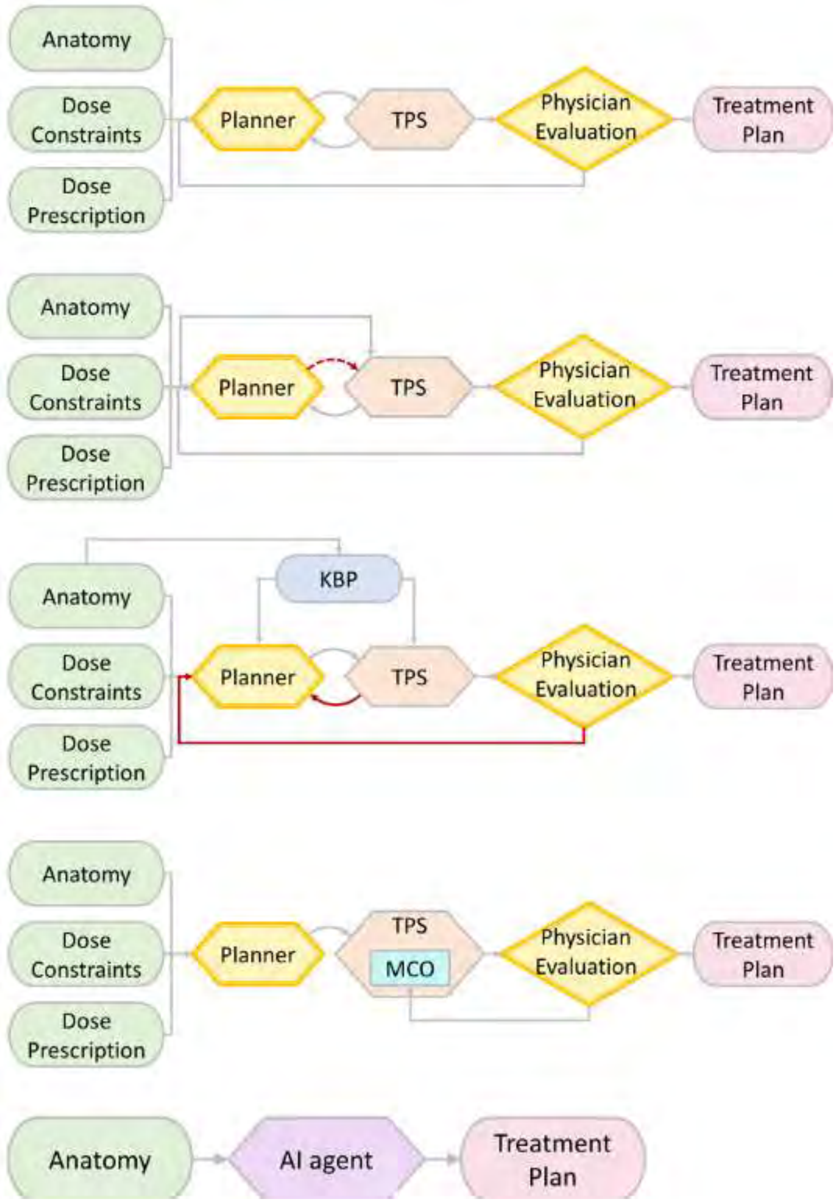
Reinke at al. “Common limitations of performance metrics in biomedical image analysis” 2021



Geometric accuracy measures are poor predictors for dosimetry

Kieselmann at al. “Geometric and dosimetric evaluations of atlas-based segmentation methods of MR images in the head and neck region” 2018

Autoplanning



Manual planning

Automated rule implementation and reasoning (e.g. Pinnacle Auto-Planning)

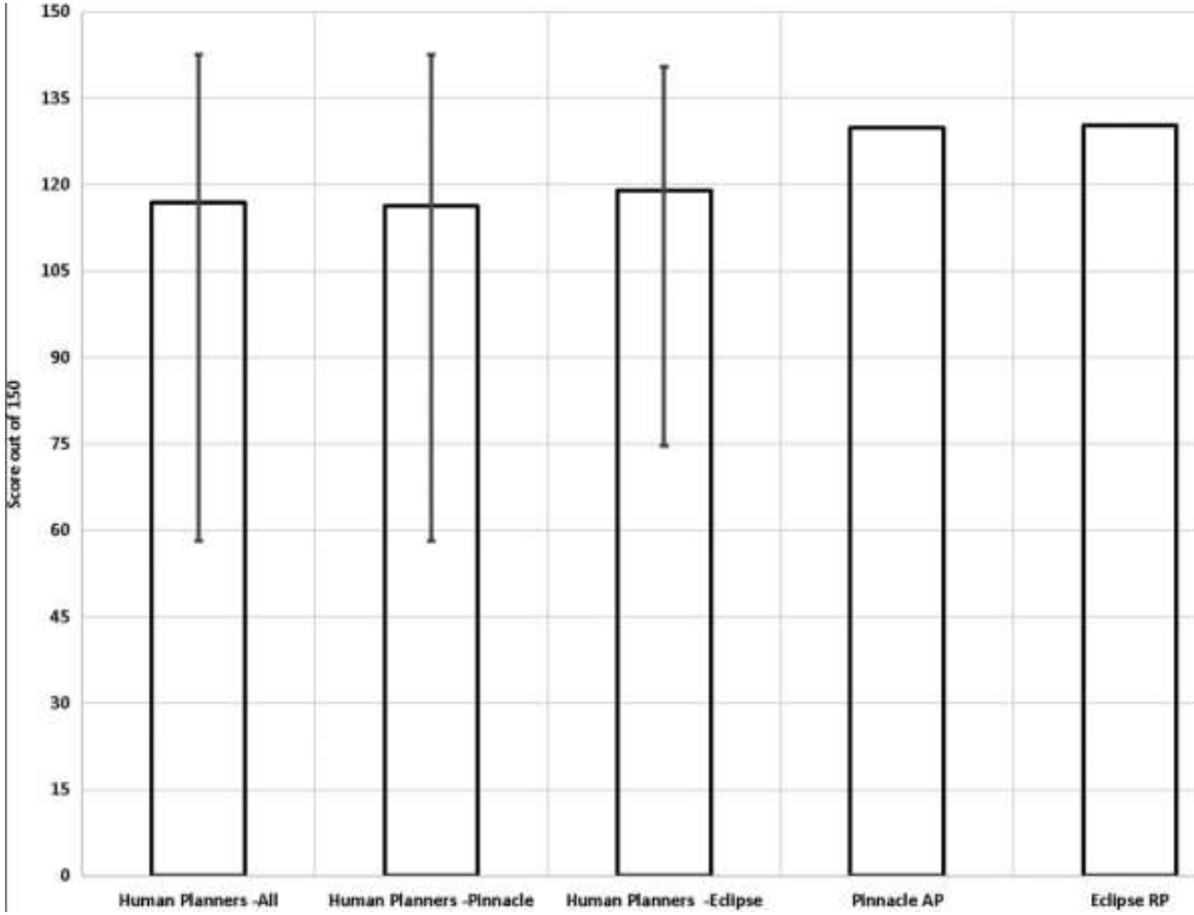
Knowledge-based planning (e.g. Eclipse Rapid-Plan)

Multicriteria optimization (MCO)

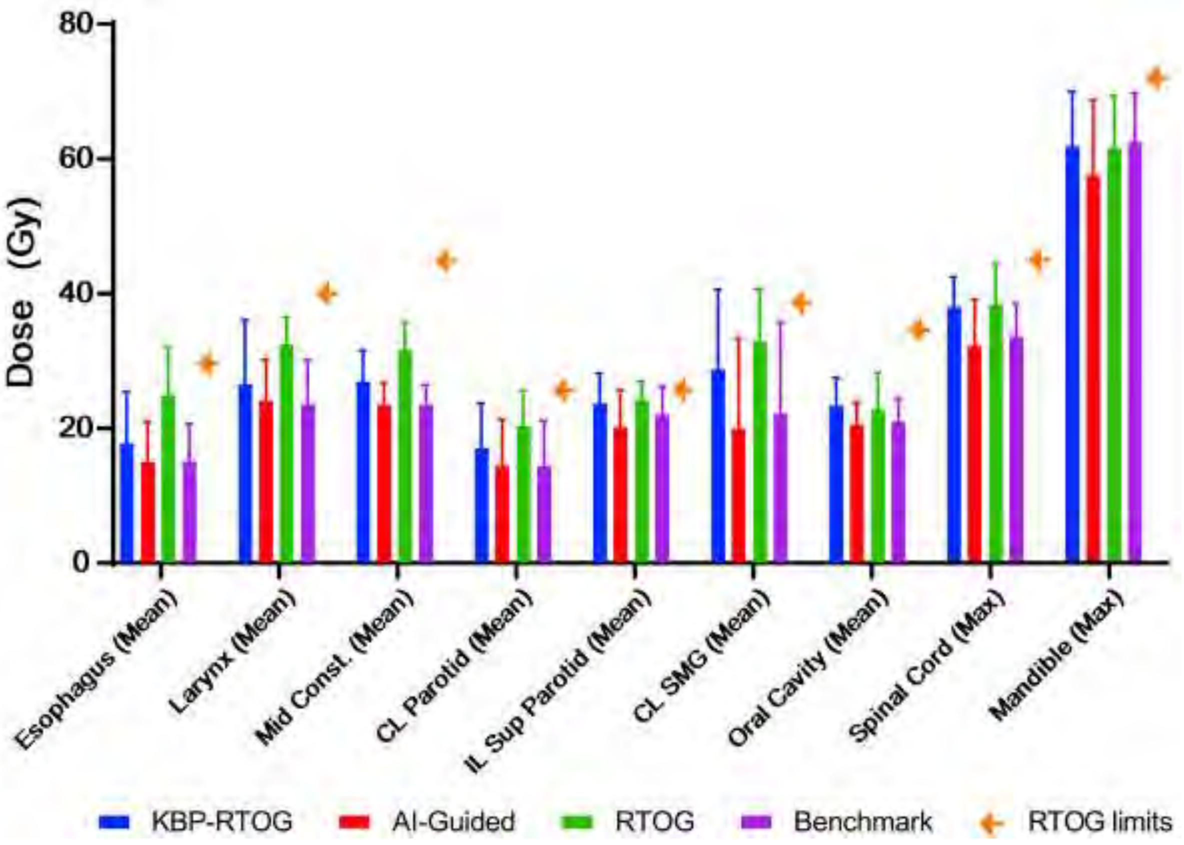
Advanced AI planning

Wang, C…&Zheng, D. "Artificial intelligence in radiotherapy treatment planning: present and future." (2019)

Autoplanning

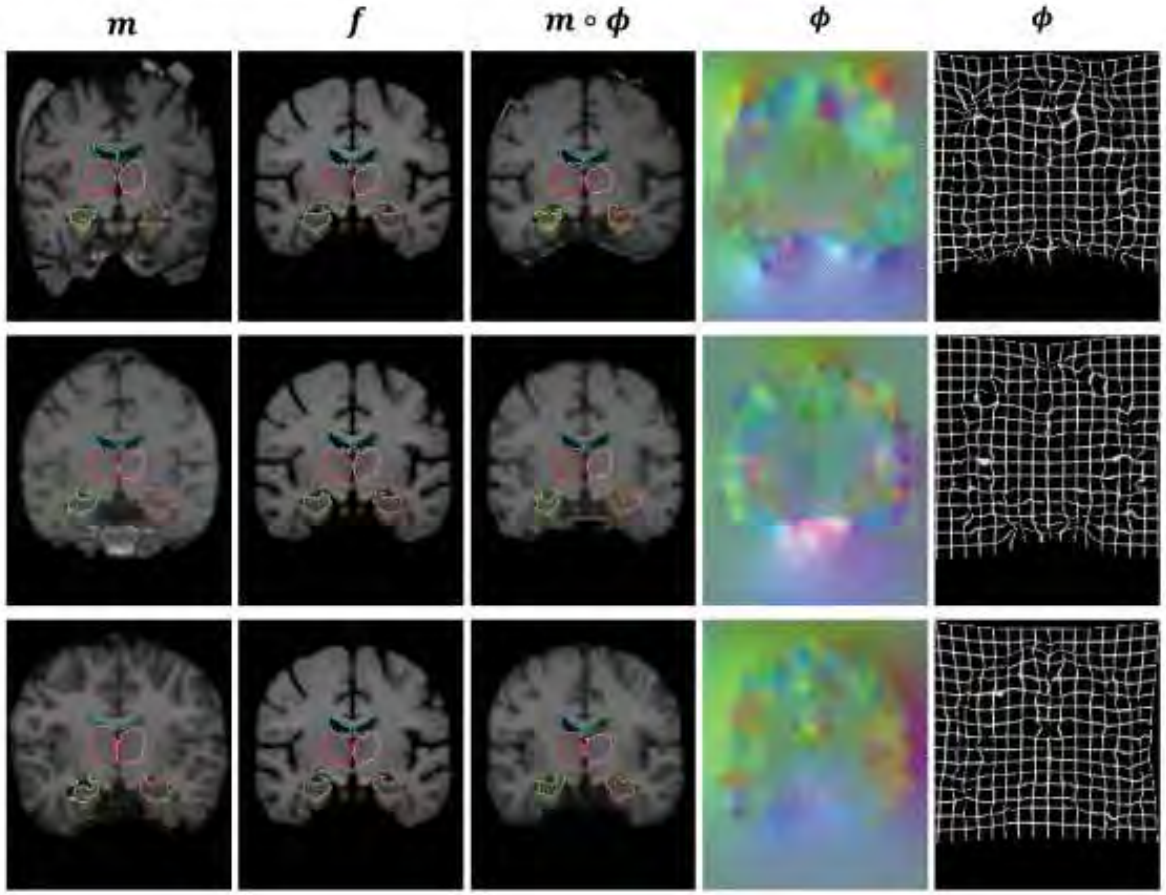


Smith, A…&Zheng, D. "Can the student outperform the master? A plan comparison between pinnacle auto-planning and eclipse knowledge-based RapidPlan following a prostate-bed plan competition." (2019)

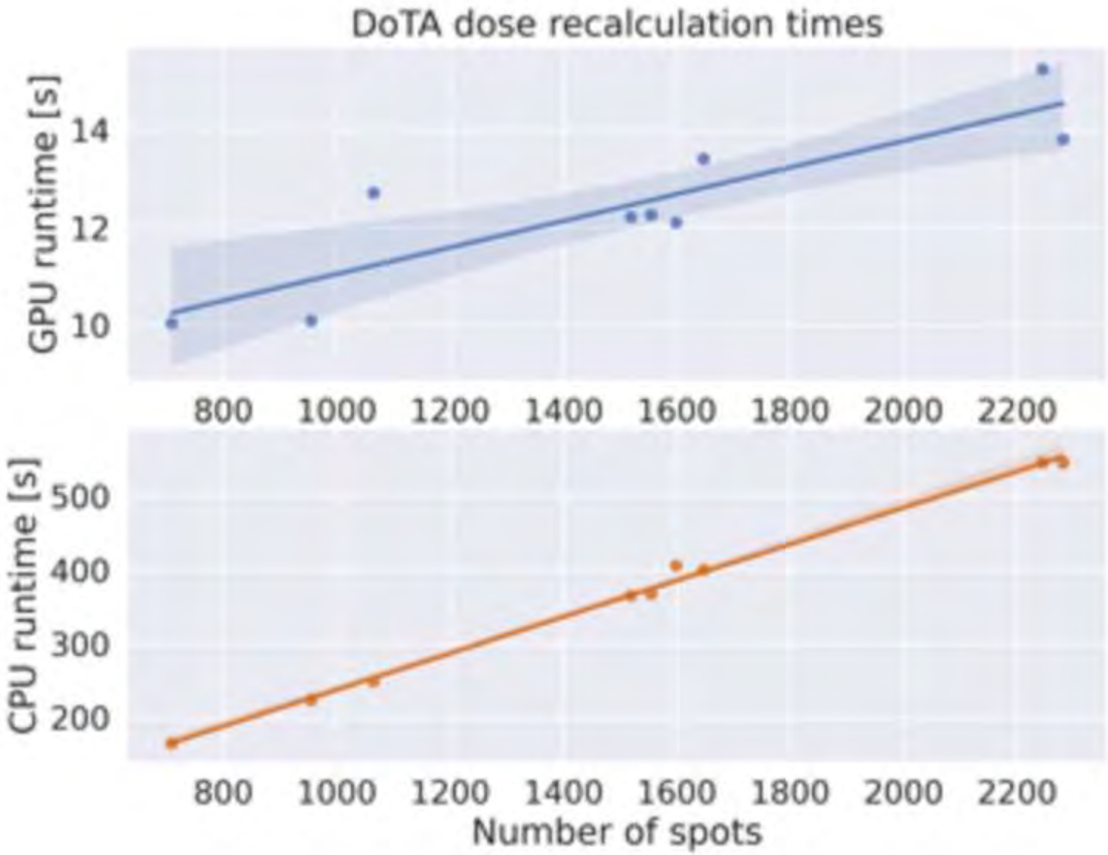


Visak, J, et al. "Evaluating machine learning enhanced intelligent-optimization-engine (IOE) performance for ethos head-and-neck (HN) plan generation." (2023)

Other Applications



Balakrishnan, G. et al. "Voxelmorph: a learning framework for deformable medical image registration." (2019)



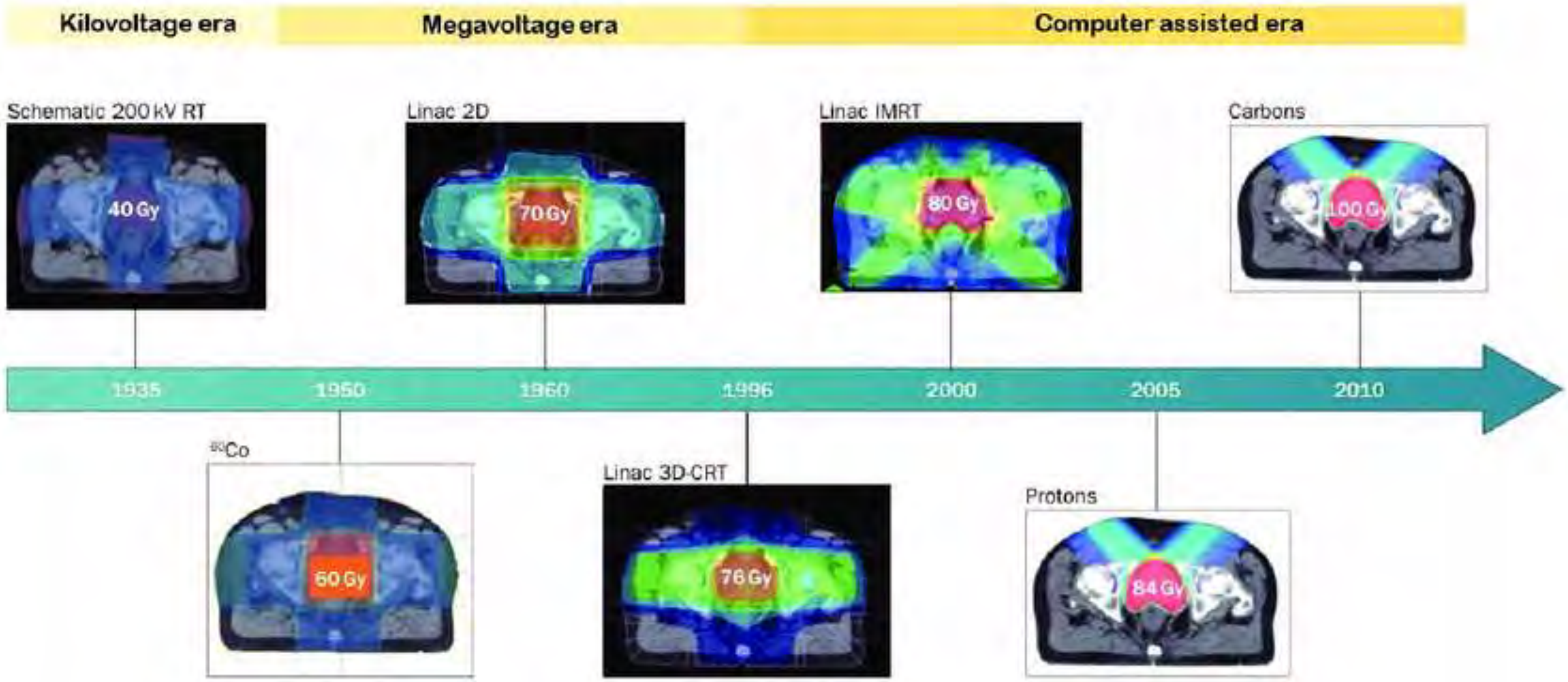
Pastor-Serrano, Oscar, and Zoltán Perkó. "Millisecond speed deep learning based proton dose calculation with Monte Carlo accuracy." (2022)

Other Applications

References	QA Source	Data Source	ML Model	Task
Carlson et al. (2016)	DICOM_RT, Dynalog files	74 VMAT plans	Regression, Random Forest, Cubist	MLC Position Errors Detection
Li and Chan (2017)	Daily QA Device	5-year Daily QA Data	ANN Time-Series, ARIMA Models	Symmetry Prediction
Sun et al. (2018)	Ion Chamber	1,754 Proton Fields	Random Forrest, XGBoost, Cubist	Output for Compact Proton Machine
El Naqa et al. (2019)	EPID	119 Images from 8 Linacs	Support Vector Data Description, Clustering	Gantry Sag, Radiation Field Shift, MLC Offset
Grewal et al. (2020)	Ion Chamber	4,231 Proton Fields	Gaussian Processes, Shallow NN	Output and Patient QA Proton Machine
Osman et al. (2020)	log files	400 machine delivery log files	ANN	MLC Discrepancies during Delivery & Feedback
Chuang et al. (in press)	Trajectory log files	116 IMRT plans, 125 VMAT plans	Boosted Tree Outperformed LR	MLC Discrepancies during Delivery & Feedback
Zhao et al. (in press)	Water Tank Measurement	43 Truebeam PDD, Profiles	Multivariate Regression (Ridge)	Modeling of Beam Data Linac Commissioning

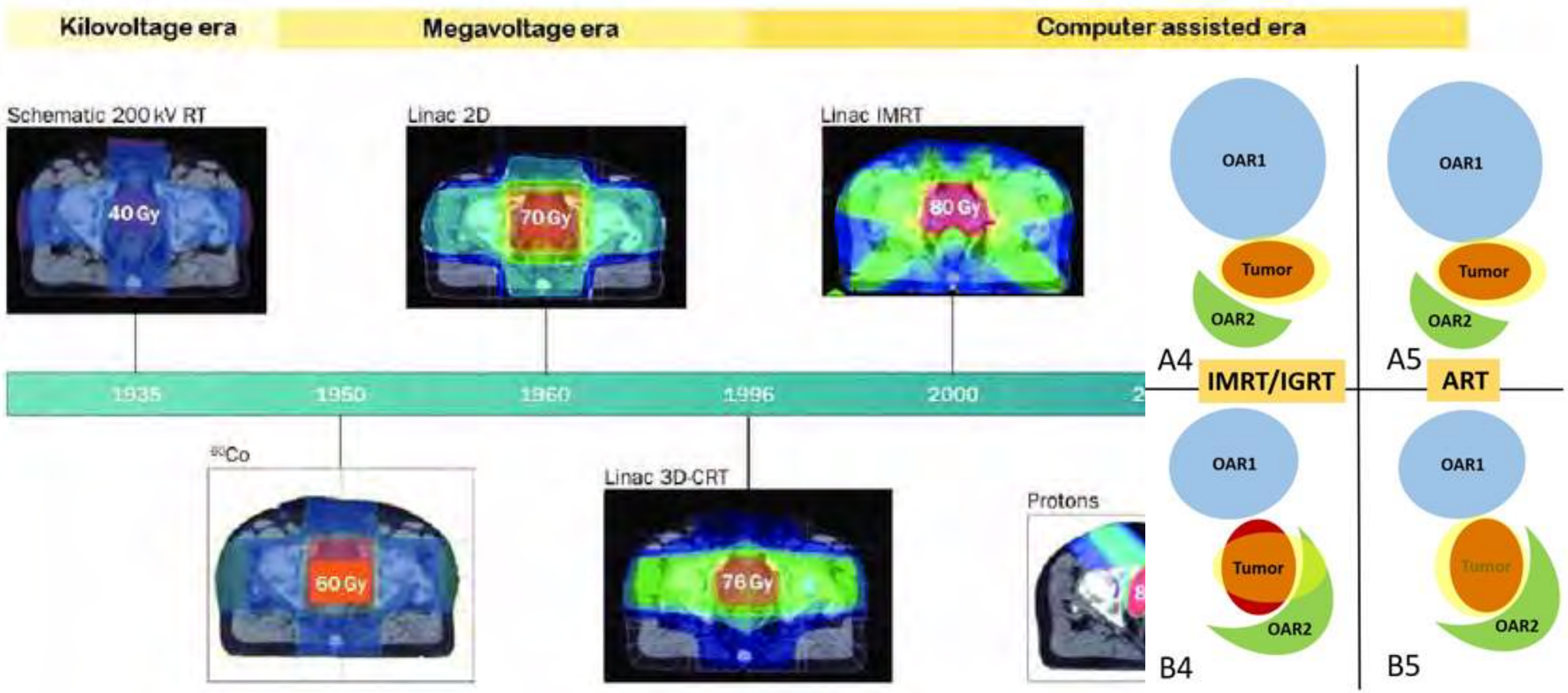
Chan, Maria F., Alon Witztum, and Gilmer Valdes. "Integration of AI and machine learning in radiotherapy QA." (2020)

RT Evolution for Prostate Cancer



Thariat, Juliette, et al. "Past, present, and future of radiotherapy for the benefit of patients." (2013)

RT Evolution for Prostate Cancer



Thariat, Juliette, et al. "Past, present, and future of radiotherapy for the benefit of patients." (2013)

Future Directions

- Reduce on-couch time and physician/physicist time
- Improve accuracy and robustness
- Education and training
- Model diversity – healthcare disparity
- Patient privacy, data security
- Multi-modality, multi-scale, multi-omics integration