Quality assurance and workflow considerations for adaptive radiotherapy

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2020 Improving Health QUALITY. Increasing Global IMPACT
JULY 12–16 VIRTUAL EASTERN TIME [GMT-4]
JOINT AAPM | COMP MEETING

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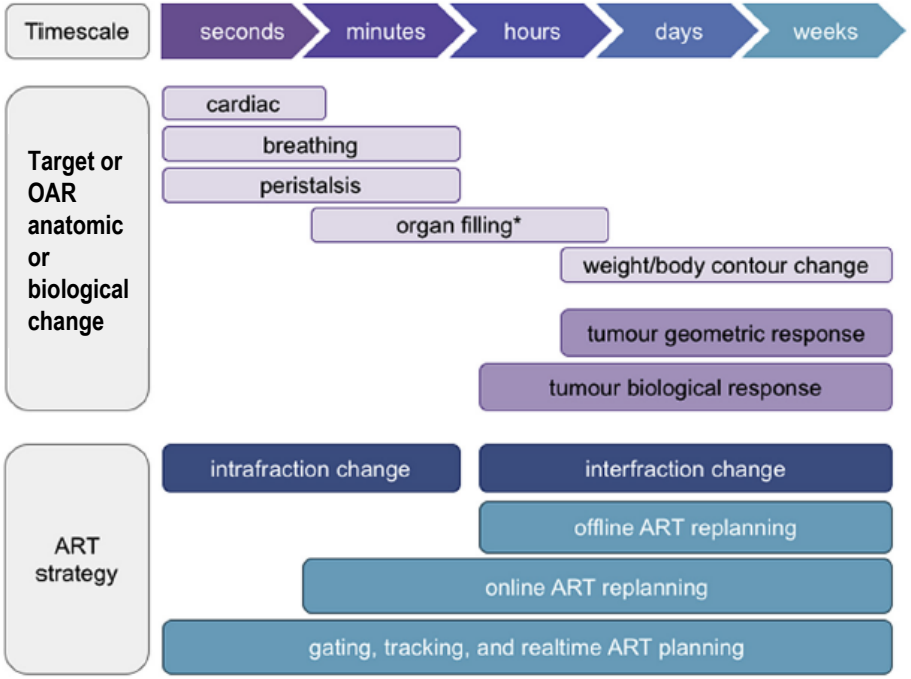
Adaptive Radiotherapy (ART)

- A close-loop process involving systematic monitoring of treatment variations (anatomic or biological) and altering treatment plan to account for:
  - Systematic or progressive changes (offline ART)
  - Stochastic changes (online ART)



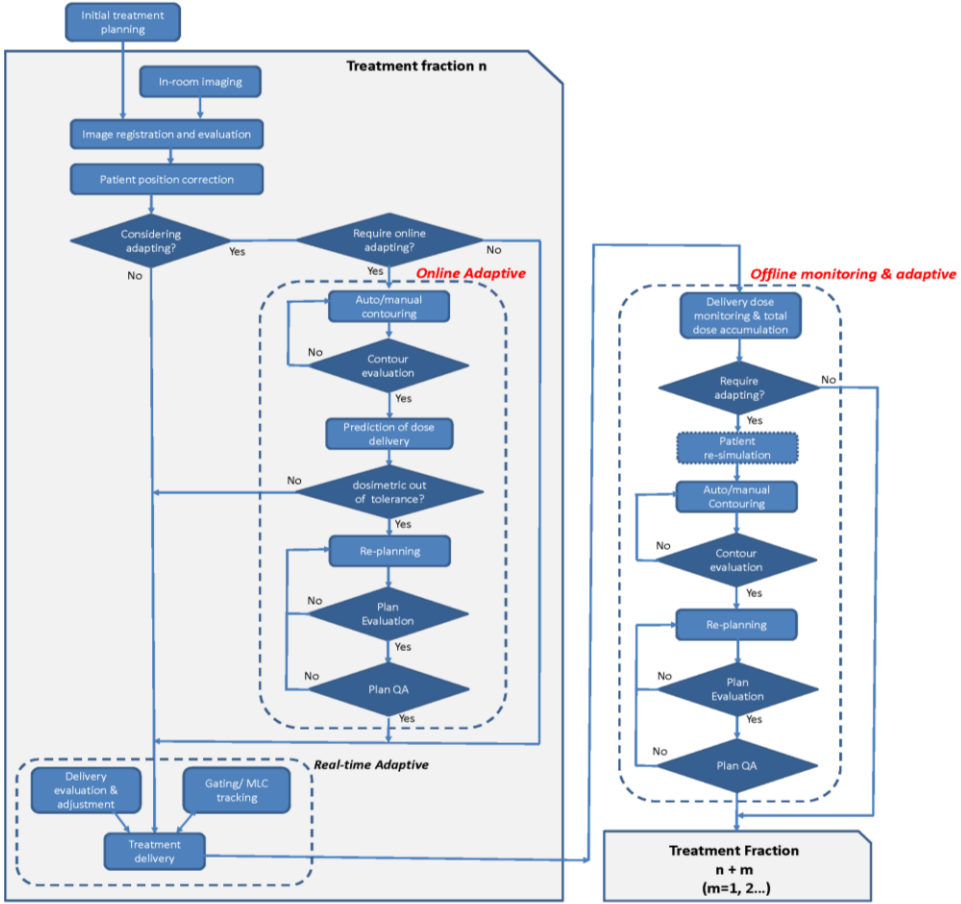
* Organs subject to filling and deformation including bladder, rectum, cervix, and stomach etc

A Hunt *et al*. Clinical Oncology 30 (2018)

Offline and online ART

- Complex workflow and decision-making
- Compressed time frame
- Key components:
  - Imaging for monitoring
  - Assessment
  - Re-planning and evaluation
  - Quality Assurance (QA)

Green et al. Semin Radiat Oncol 29, 2019



Courtesy of NRG ART workgroup

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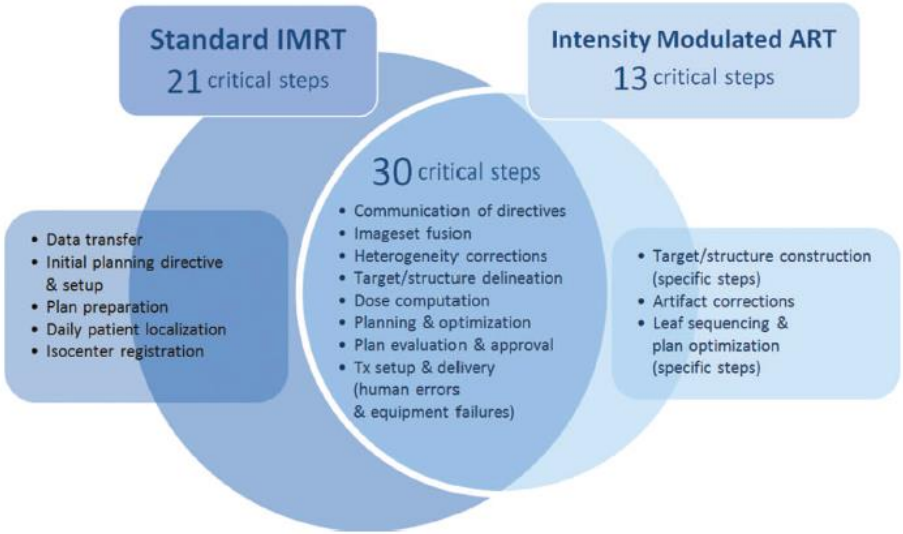
Offline ART - Risk and failure mode



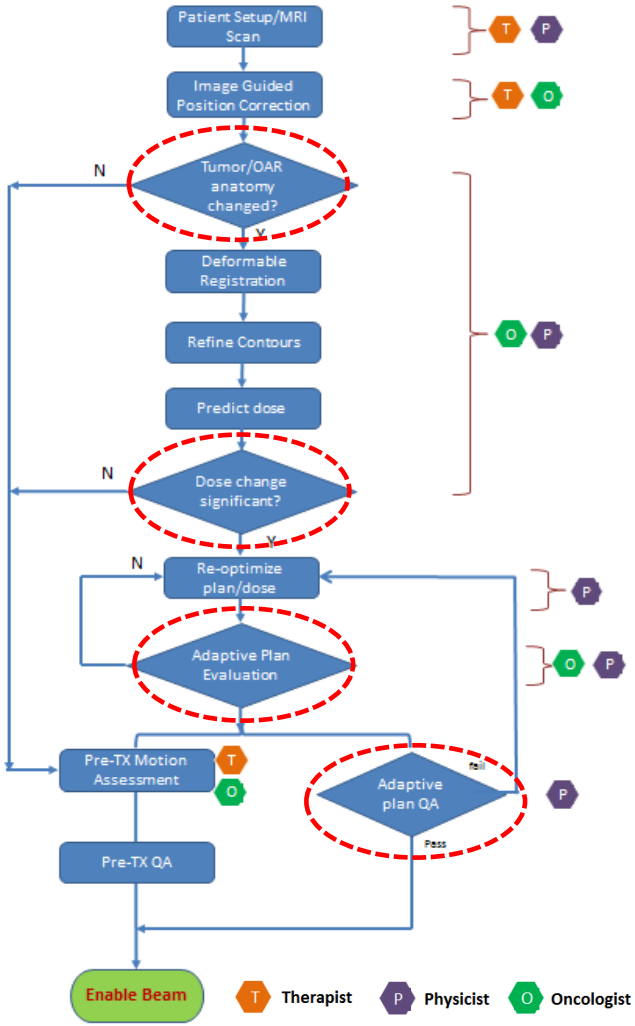
- Failure mode and effects analysis (FMEA) indicated:
  - ART risk priority numbers (PRN) increased by 38%
  - 75% attributed to **segmentation** and **planning** processes
  - 13 unique critical failures for offline ART
  - Largely due to increased time constraints, user inattention and inadequate training

Process-based quality management is essential for ART

Noel et al. Medical Physics, 41(8), 2014

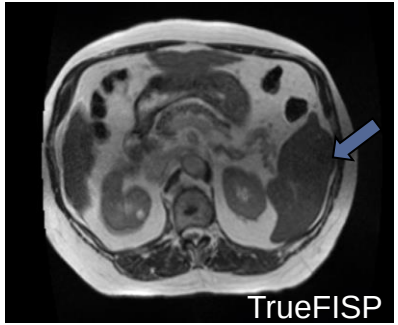
Online MR guided ART

- Complex workflow involving several critical clinical decisions
- Multidisciplinary teamwork similar to surgical operation
- Requires high quality on-board imaging guidance and automated planning tools
- Time and efficiency management
- Safety and QA



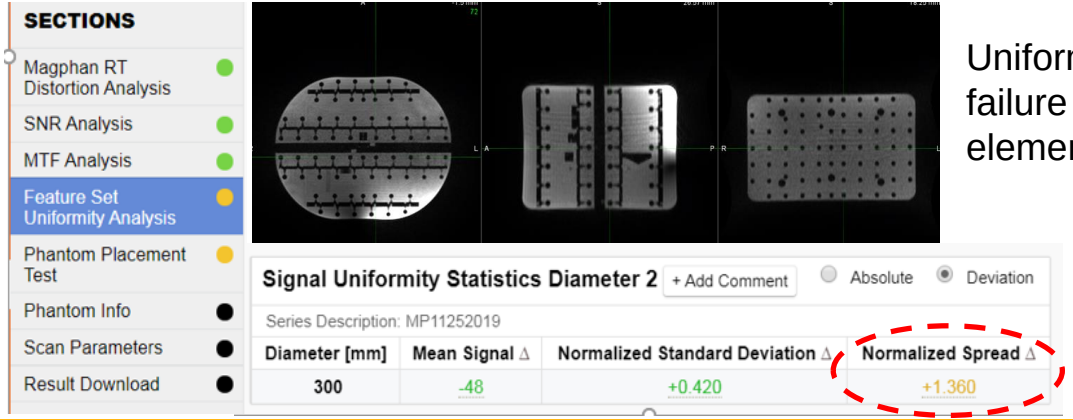
Monitoring and Assessment - Imaging

- Image quality directly impacts assessment and decision-making
- Optimal image sequence for soft tissue contrast
- Image artifacts (motion, metal…)



Daily MR QA tests

- Traditional ACR phantom based QA tests are too time-consuming to be performed on a daily basis
- Automated phantom image analysis can expedite the process for daily QA

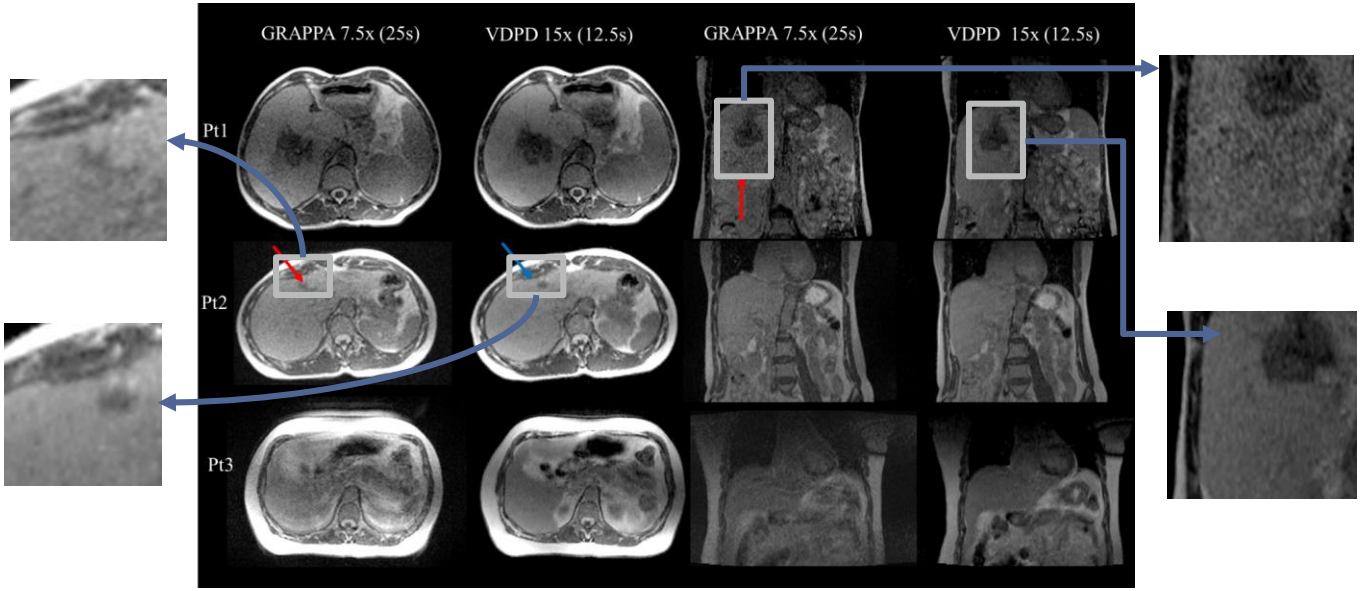


Uniformity test detected failure in one of the MR coil elements

Courtesy of Dr. Yingli Yang, UCLA

Accelerated 3D Balanced SSFP imaging

- Variable-density Poisson-Disk (VDPD) technique with 15x under-sampling (12.5s)

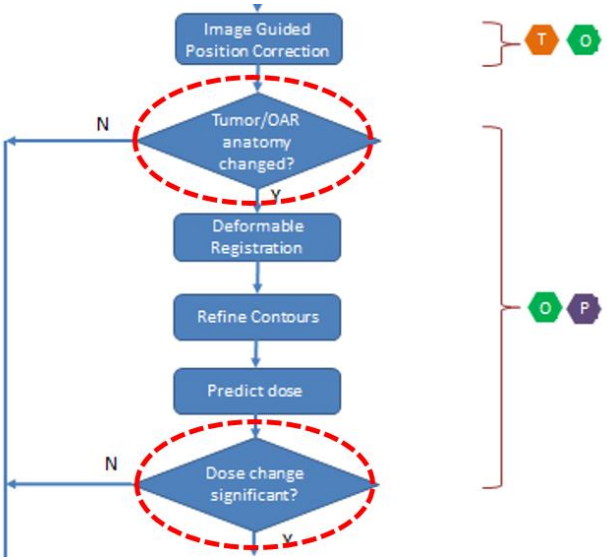


Courtesy of Dr. Yingli Yang, UCLA

Assessment - Decision making

- To adapt or not:
  - Visual evaluation can be subjective
  - Uncertainties in direct deformable registration of dose and structures
- Dose prediction with manually refined contours is accurate, but time-consuming

ON-LINE \ OFF-LINE	25 YES	10 NO
14 YES	13	1
21 NO	12	9

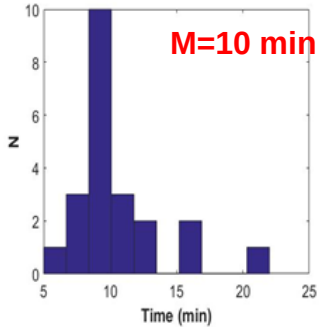


Retrospective dosimetric analysis indicated that more fractions need adaptive than online visual assessment

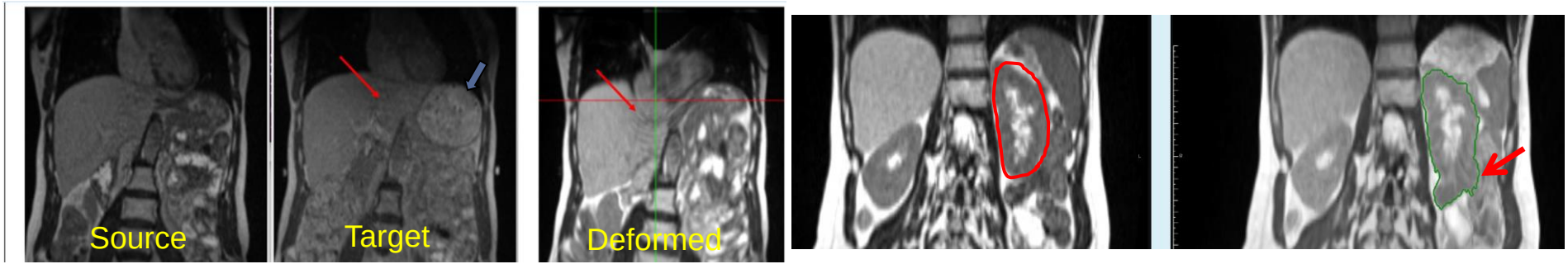
Tyran M *et al*. Radiother Oncol. 129.2 (2018)

Quality and Efficiency of Contouring

- Relies on quality of deformable image registration
- Usually requires labor-intensive manual correction
- Advanced auto-segmentation approaches (statistical shape, deep-learning, biomechanical models…)
- QA tools for checking contour integrity (empty, incomplete, size/shape change, etc.)



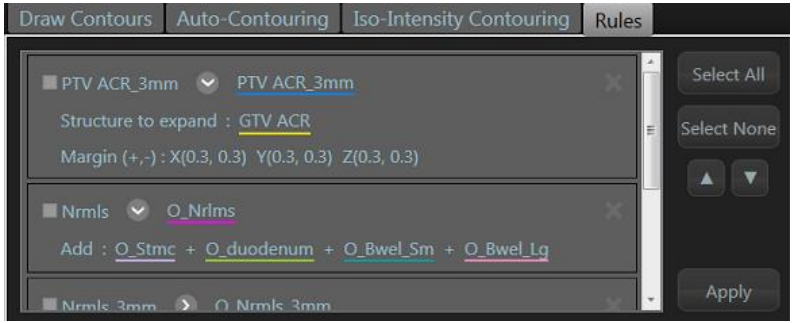
Time for adaptive re-contour

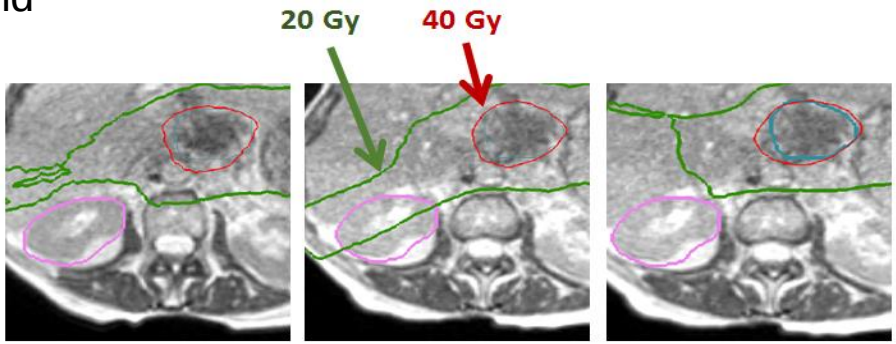


Lamb J, Cao M, Kishan A, et al. Cureus 9(8), 2017

Re-planning / optimization

- Speed and efficiency
  - Forward adaption (beam weighting, aperture shape, MUs)
  - Using initial plan parameters for optimization
  - Automated tools: structure expansion and Boolean, dosimetric evaluation etc.
- Plan quality:
  - Robust planning
  - Beam angle optimization
  - Knowledge based planning



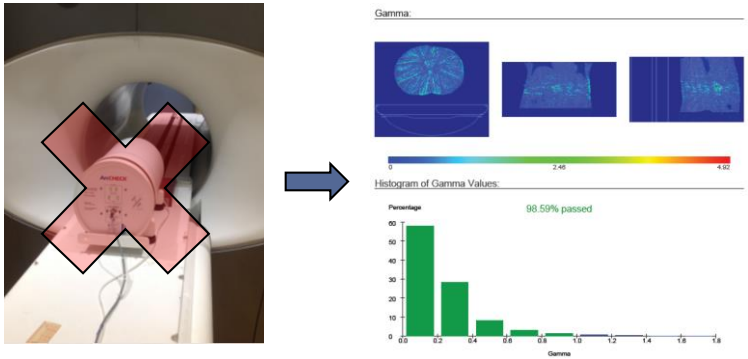


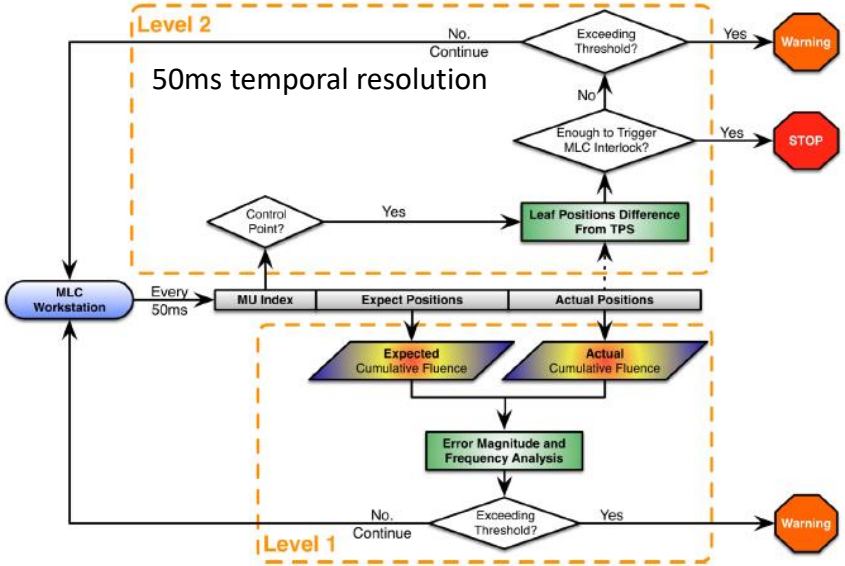
Original plan | 1st adaptive plan | 2nd adaptive plan

Lamb J, Cao M, Kishan A, et al. Cureus 9(8), 2017

Patient specific QA

- Traditional measurement based QA is not feasible for online ART
- Alternative methods:
  - Independent dose calculation
  - Retrospective post-treatment measurement or delivery log analysis
  - “Simulated” treatment delivery without beam-on
  - Real-time monitoring (EPID, real-time tracking of machine delivery…)





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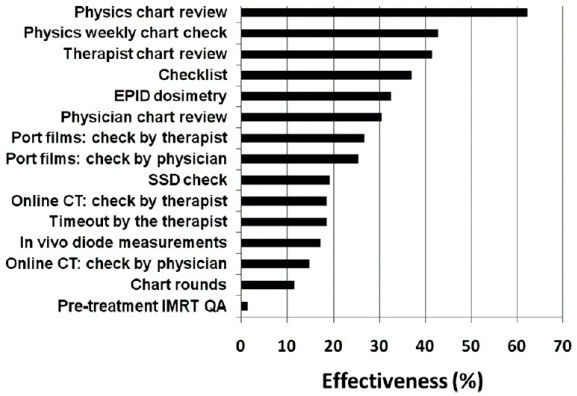
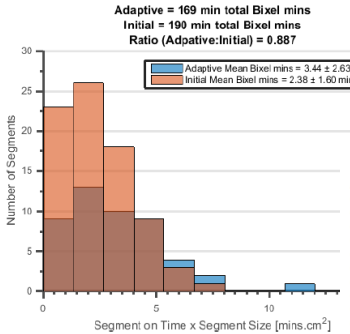
Li *et al*, Medical Physics, 42,1, 2015

Physics plan and chart review

- Most effective QC procedure, but actual sensitivity varies depending on the design of checks and workload stress
- Risk analysis (FEMA) and incident learning system can be used to develop the checklist
- Automated plan check tools to improve efficiency



Ford et al. IJROB, 84, 2012

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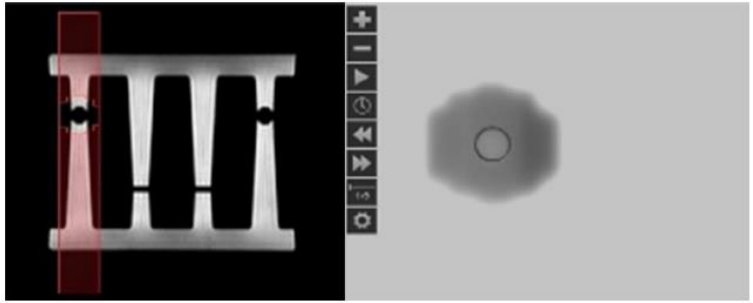
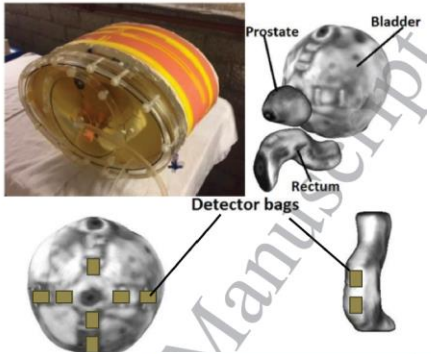
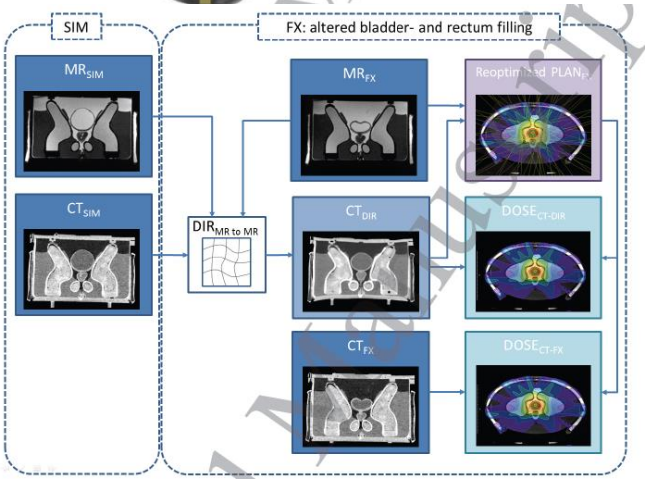
GatingTarget         = 4.25 (4.18) cc [1.02]
O_Stomach            = 216.53 (726.59) cc [0.30]
O_Hrt                = 535.37 (450.33) cc [1.19]
O_Livr               = 1267.22 (1374.42) cc [0.92]
G_per_pancreatic     = 9.64 (11.18) cc [0.86]
O_spleen             = 81.43 (123.70) cc [0.66]
O_Kdny_Rt            = 148.54 (148.59) cc [1.00]
O_Kdny_Lt            = 205.70 (179.91) cc [1.14]
O_Bwel               = 271.40 (1845.24) cc [0.15]
O_Panc               = 3.01 (19.44) cc [0.15]
O_Cord               = 56.29 (73.70) cc [0.76]
P_peri_panreatic_40  = 26.14 (30.58) cc [0.85]
O_Esgs               = 7.08 (12.23) cc [0.58]
AVOID                = 2.52 (2.85) cc [0.88]
```

End-to-end test

- A simple and effective method to validate the entire workflow
- Require phantoms capable of simulating anatomical change (displacement or deformation)
- Periodic (daily) E2E to test functionality and connectivity of all the major components of ART







Chen et al. JACMP, 21, 2020

Hoffmans et al 2020 Phys. Med. Biol

Communication and documentation

- Complex workflow and decision-making require well documented directives and communication
- A “hand-off” procedure with clear documentation to ensure consistency in decision-making

Radiation Oncology Department
Online Adaptive Treatment Log
Resident Physician: [redacted], M.D.
Attending Physician: [redacted] MD

Fraction			1	2	3	4	5
Treated with:							
Base plan (no dose prediction)			☐	☐	☐	☐	☐
Base plan (with dose prediction)			☐	☐	☒	☒	☐
Adapted plan			☒	☒	☐	☐	☒
Base plan for next fraction			i1Panc	i1Panc	i1Panc_Fx2_Adpt	i1Panc_Fx2_Adpt	i1Panc_Fx2_Adpt
Delivery calendar updated			☒	☒	☐	☒	☒
Adaptive documents uploaded to ARIA			☒	☒	☐	☒	☒
MD			AR	JH	AUK	AR	JH
Planner			AM	MC	YLY	AM	AM
Physicist			SQ	MC	YLY	JL	YLY
RTT			NV/FS	JTT/HA	NV/FS	FS/NV	HA/FS
Planning Structures	Structure	Constraint	Dosimetric parameters achieved:				
GTV							
PTV	PTV_crop	V50>94%	93%	95.99	93.26	91%	95
OAR 1	O_Stmc	V33<0.5	0.36	0.04	0.56	0.16	0.2
OAR 2	O_Duodenum	V33<0.5	0.25	0.14	0.01	0.05	0.19
OAR 3	O_Bwel_Sm	V33<0.5	0.73	0	0.02	0.49	0.2

Radiation Oncology Department
Online Adaptive Treatment Planning Instructions

Resident Physician: [redacted]
Attending Physician: [redacted]

Planning Structures:		Re-optimize if the following constraint(s) were not met:
GTV:	G_Panc_40	V40<95%
PTV:		
OAR1:	O_Duodenal_loop	V35<0.5cc
OAR2:	O_Stmc	V35<0.5cc
OAR3:		
OAR4:		

Physician free text notes (please specify prioritization of constraints and any other knowledge transfer to Doc of the Day):

This is a 72 y.o. female with locally advanced pancreatic cancer s/p multiple cycles of chemotherapy. She is referred for consideration of SBRT. Imaging shoes a hypoenhancing pancreatic neck mass involving the mesenteric root with encasement of the superior mesenteric/celiac arteries and the splenic, left gastric and common hepatic arteries, which remain patent. Marked narrowing of the portal vein with chronic thrombosis of the splenic vein, and involvement of the IVC and aorta by approximately 180 degrees.

Structure Boolean Instructions:

Structure	Operator	Margin (mm)	Structure 2		Resultant structure
G_Panc_40	Expand	70	N/A	=	Exp_7cm
G_Panc_40	Expand	40	N/A	=	Ring_4cm
Exp_7cm	Subtract	N/A	Ring_4cm	=	Ring_4cm
O_Kdny_Rt	Add	N/A	O_Kdny_Lt	=	O_Kdnys_Bilat
	Select			=	
	Select			=	

Optimization target volume: G_Panc_40

Comments:

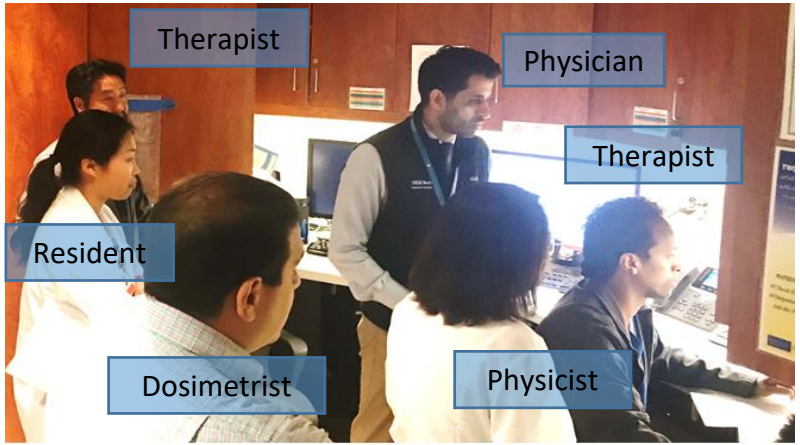
Process management and improvement

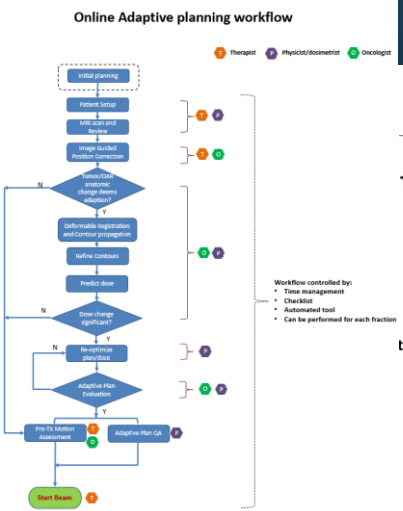
- Compressing many days of work in a much shorter setting
- Require robust process-based quality management
- Areas for improvement
  - Improve image acquisition speed and quality
  - Contouring accuracy and efficiency
  - Fast and robust re-planning and effective QA
  - Staff training, coordination and communication

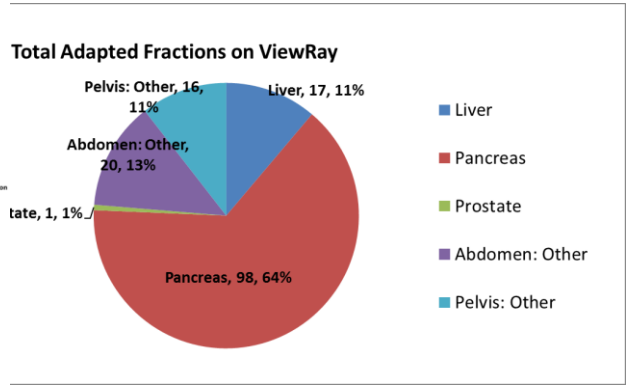
Automation to maximize efficiency, quality and safety

Minimizing errors through application of risk analysis

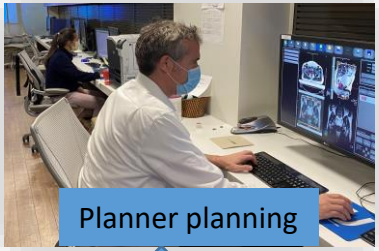
ART - an evolving process

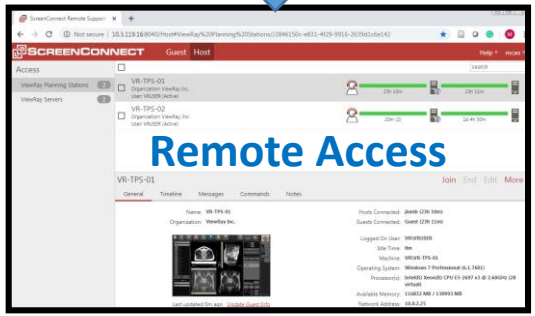






ART - an adapting process





Summary

- ART holds great promise for personalized patient care, but involves complex workflows in compressed timeframe.
- Robust and comprehensive process-based quality management is necessary:
  - Automation to maximize efficiency, quality and safety
  - Well-documented procedure and well-integrated team work with sufficient training
  - Prospective quality management (process map, FMEA analysis, fault tree..)

Thank you!

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