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Increasing Efficiency and Quality in External Beam Treatment Planning Through Automation and Scripting

07/15/2019
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MO-AB-204-4: Scripting Applications in the Clinic, That is an Easy Button

Disclosures

- Sean Berry holds research grants from Varian Medical Systems for work unrelated to this talk
- The Plan Check Tool is the result of a collaboration between University of Michigan, MSKCC, and Varian Medical Systems.
- There is a licensing agreement between MSKCC and Varian Medical Systems for the breast compensator program.

Objectives

- To describe our experience in using an applications programming interface (API) to develop tools for scripting/automation in the external beam radiotherapy planning (EBRT) process.

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Plan Check Tool

MSKCC
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Marc Kessler, PhD
Jean Moran, PhD

Varian Medical Systems
Wayne Keranen
Seppo Tuomaala

PCT: Background

- Radiotherapy pre-treatment physics chart checks have been shown to be a highly effective method of catching errors before they propagate to patient treatment[1]
- Issues with manual checks:
  - Lapses in human attention/knowledge can limit effectiveness and lead to uneven error detection rates between personnel
  - Time consuming: ~9 FTE physicist positions devoted solely to this job function campus wide

[1]Ford EC, et al. Quality control quantification (qcq): A tool to measure the value of quality control checks in radiation oncology. *International journal of radiation oncology, biology, physics* 2012;84:e263-269.

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PCT: Introduction

- ESAPI based automated plan checking tool written in C#
- Result of collaboration between UMich\MSKCC\Varian
- Used clinically >15,000-20,000x at each institution
  - Released 2/2015 at UM, 4/2016 at MSKCC
- Used on all campuses of MSKCC, UMich Main Campus, and UMich affiliate sites
- Eclipse versions v11 – v15

K Younge, S Berry, et al. "SU-H300-GePD-F4-1: A Model for Collaborative Software Development: Integration in Treatment Plan checks." *Medical Physics* v45, no 6 (2018): E158.

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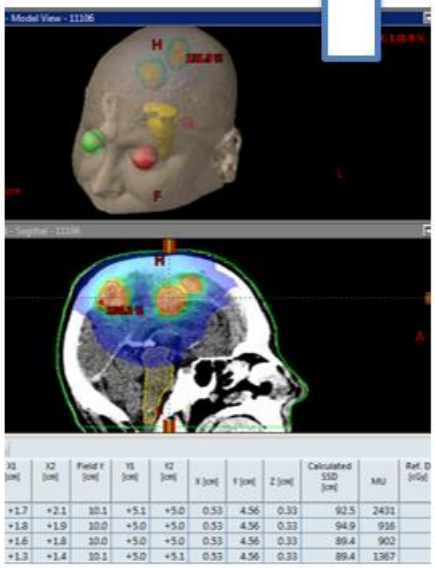
PCT: Overview

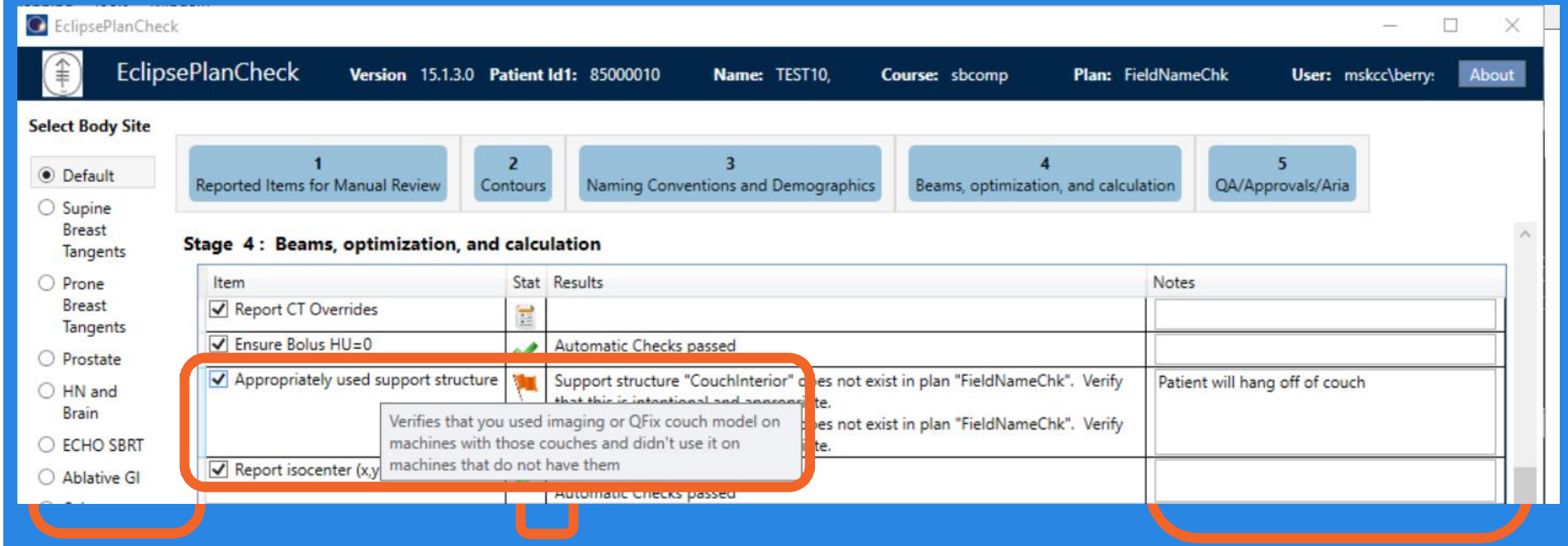
1.) Extracts info directly from treatment planning system

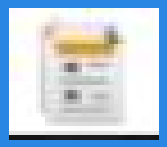


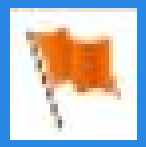
2.) Compares extracted data vs. expected values

3.) Makes judgment

Plan Check Tool: GUI







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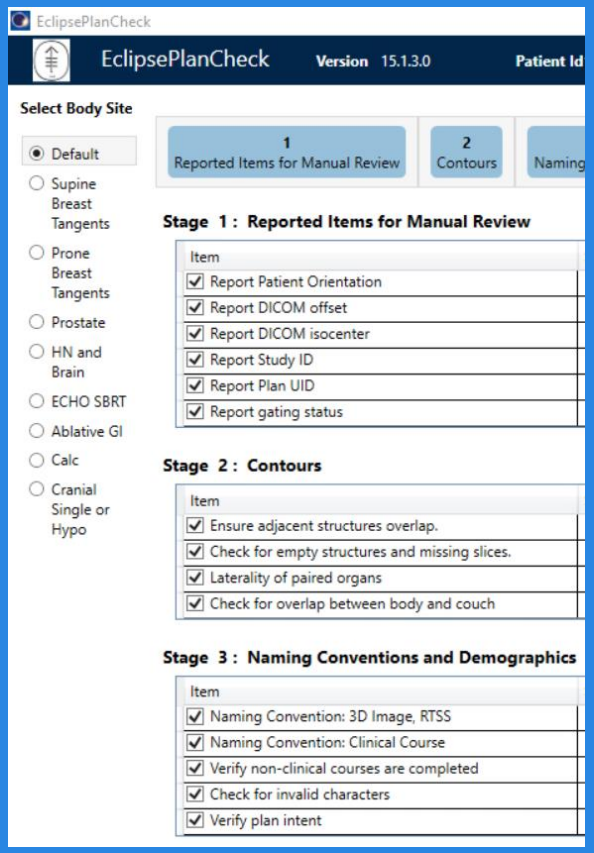
Plan Check Tool: GUI

Å53 checkers:



Stage 4 : Beams, optimization, and calculation

Item
Report CT Overrides
Ensure Bolus HU=0
Appropriately used support structure
Report isocenter (x,y,z)
Report isocenter shift from user origin
Machine Released For SBRT
Beam Clearance Checker
180E Used When Appropriate
Verify Primary Collimator not exposed
Verify no overlap at matchline
Couch collisions in small room
FFF beams used when appropriate.
Plan naming and normalization
Reasonable Fluence Checker
Appropriate number control points
Correct LMC algorithm
LostMU x MaxMU for IMRT
Report VMAT duty cycle
Check VMAT jaw position relative to MLC
Verify calculation model and options
CT Slice Thickness
Global max hot spot is inside PTV
Dose calculation model is OK for target size
Alert unusual warnings
Bolus linked to fields

Stage 5 : QA/Approvals/Aria

Item
Confirm plan status * Verify appropriate review approval * Verify appropriate plan approval * Show plan current status
Check prescribed percentage
Verify appropriate dose rate.
Verify DRR ID matches Field ID
Verify DRR overlays
Report field tolerance tables
Verify default couch position.
Verify consecutive setup fields are orthogonal
Verify setup fields are valid
Verify imager position on setup fields
CBCT will load on linac
Check Reference Points
Check QA plans * QA plans must live in an appropriately named course * QA plans must point back to appropriate clinical plan * EPID QA plan's name must end with "PD". * EPID QA plans must have the correct Imager Vrt. * EPID QA plans must exist for VMAT/ArcDynamic/IMF * Mapcheck QA plan's name must end with "MAP". * Mapcheck QA plans must have all beams with 0s gar * QA plans must have tolerance table and treatment ti * QA plans must have correct status. * Verify breakpoint dose in plans with PD or MAP verif

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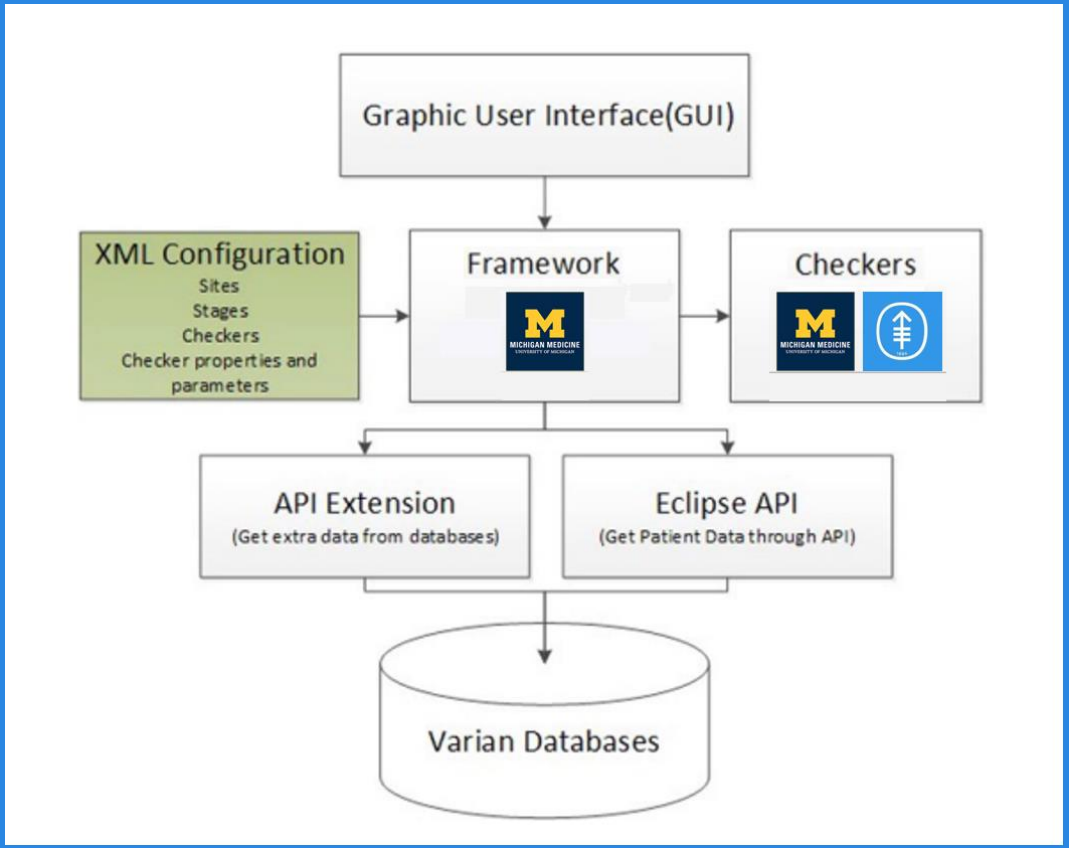
Plan Check Tool: Architecture



Modified from:
Covington, et al. "Improving treatment plan evaluation with automation." *JACMP* v17, no 6 (2016): 16-31.

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Plan Check Tool: Architecture

ÅXML Configuration file:

```
<Site name="Default">
  <Stages>
<Stage name="PrePlan" description="Naming Conventions and Demographics">
  <Checkers>
    <Checker name="DatasetNameConsistencyChecker" description="Naming Convention: 3D Image, RTSS" longdescription="Checks whether the naming convention modality_site_date is being followed.
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        <Parameter name="StructureSetIDPattern" value="^(CT|MR|PT|4DCT)_([A-Z]|[a-z]|[0-9]|\ |\-|_|&amp;){1,}_([1-9]|0[1-9]|1[012])([1-9]|0[1-9]|[12][0-9]|3[01])([0-9][0-9])$"/>
        <Parameter name="ImageIDPattern" value="^(CT|MR|PT|4DCT)_([A-Z]|[a-z]|[0-9]|\ |\-|_|&amp;){1,}_([1-9]|0[1-9]|1[012])([1-9]|0[1-9]|[12][0-9]|3[01])([0-9][0-9])$"/>
        <Parameter name="SeriesIDPattern" value="^"/>
      </Parameters>
    </Checker>
    </Checkers>
  </Stage>
  </Stages>
</Site>
```

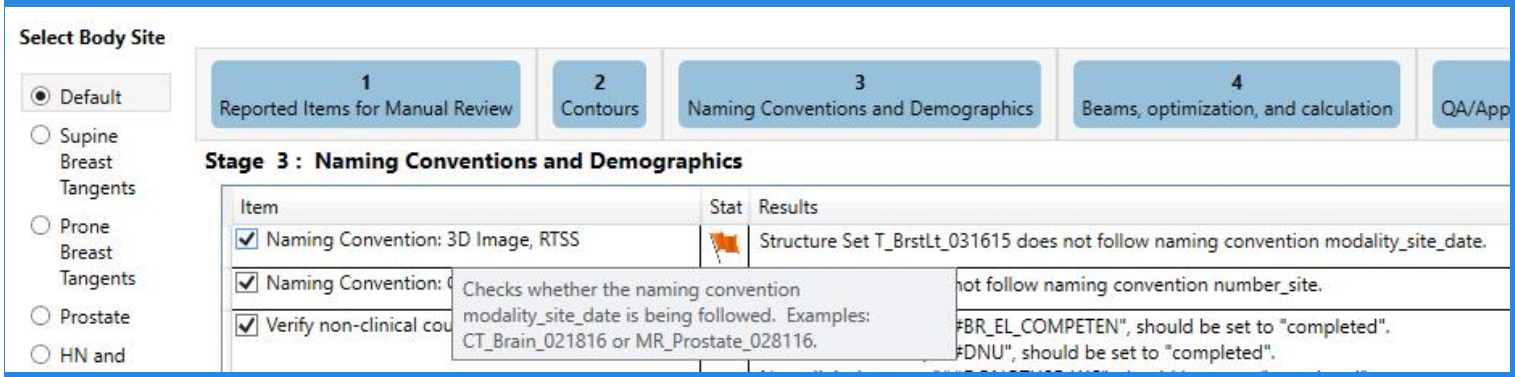

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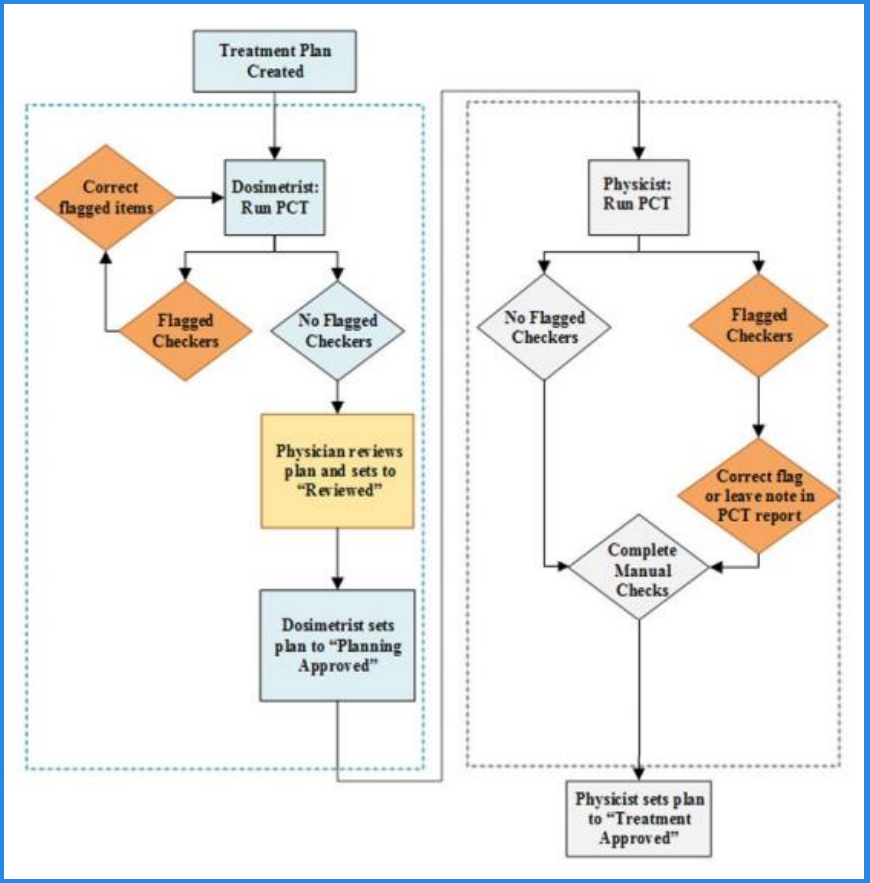
Plan Check Tool: Clinical Use @MSKCC



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Covington, et al. "Improving treatment plan evaluation with automation." *JACMP* v17, no 6 (2016): 16-31.

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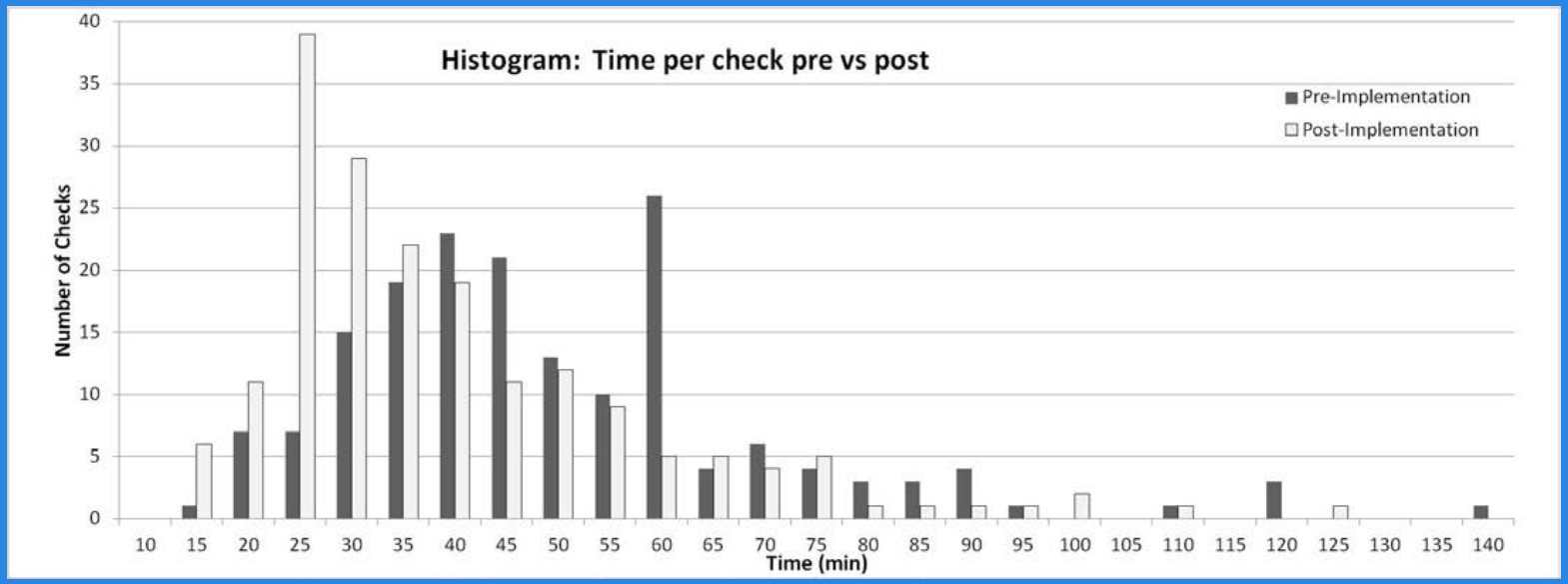
Plan Check Tool: Clinical Use @MSKCC

- Observation: 20% decrease in time per check after implementation:



# Checks Pre-Implementation	Time Average (min)	Time Median (min)	# Checks Post-Implementation	Time Average (min)	Time Median (min)	Difference in Average	Difference in Median	Welch's t-test p-value
187	49.4	45	186	39.3	35	0.80	0.78	< 0.001

Berry, et al. Efficiency and Safety Increases after Implementation of a Multi-Institutional Automated Plan Check Tool. *Under Review, Practical Radiation Oncology*

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Plan Check Tool: Clinical Use @MSKCC

- **Observation: Proportion of issues recorded by human plan checker related to checks automated by PCT statistically significantly decreased:**

Category	# Pre-Implementation	% Pre-Implementation	# Post-Implementation	% Post-Implementation
Un-related to checks performed by PCT:				
Missing/Incorrect: contours, Booleans	21	10.5%	7	5.5%
Missing/Incorrect: documentation, billing, database logs	64	32.0%	49	38.6%
Prescription problems	17	8.5%	20	15.7%
Plan quality: DVH, isodose lines unsatisfactory, beam arrangement, missing flash	13	6.5%	5	3.9%
Aria details: treatment time, imaging templates, session scheduling, carepaths, breakpoint	11	5.5%	9	7.1%
DRR quality, window/level	5	2.5%	2	1.6%
Treatment field technical parameters (names, MLC, intensities, jaws, etc.)	7	3.5%	11	8.7%
Setup field technical parameters (angles, names, etc.)	6	3.0%	2	1.6%
Miscellaneous	6	3.0%	9	7.1%
Total:	**150**	**75.00%**	**114**	**89.76%**
Related to checks performed by PCT:				
Completion status of non-clinical courses	17	8.5%	3	2.4%
DRR overlays	5	2.5%	1	0.8%
Treatment field technical parameters: bolus, couch coordinates	2	1.0%	0	0.0%
Setup field technical parameters: imager position	2	1.0%	1	0.8%
Reference Points: missing or incorrect contributions	5	2.5%	2	1.6%
Incorrect grid size	3	1.5%	0	0.0%
Course/plan not follow naming conventions	10	5.0%	5	3.9%
Incorrect tolerance tables	6	3.0%	1	0.8%
Total:	**50**	**25.00%**	**13**	**10.24%**
Grand Total:	**200**	**100.00%**	**127**	**100.00%**
Number of plan checks:	**187**		**186**	

Berry, et al. Efficiency and Safety Increases after Implementation of a Multi-Institutional Automated Plan Check Tool. *Under Review, Practical Radiation Oncology*

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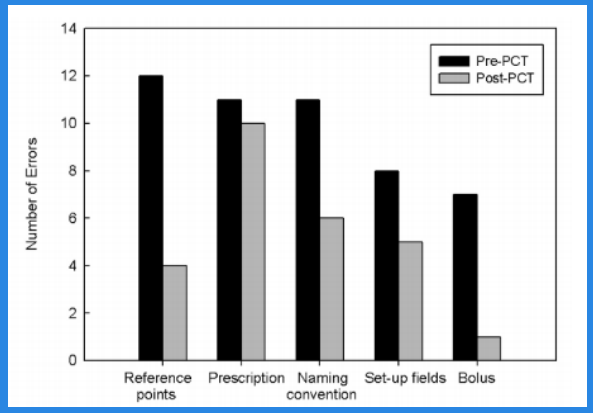
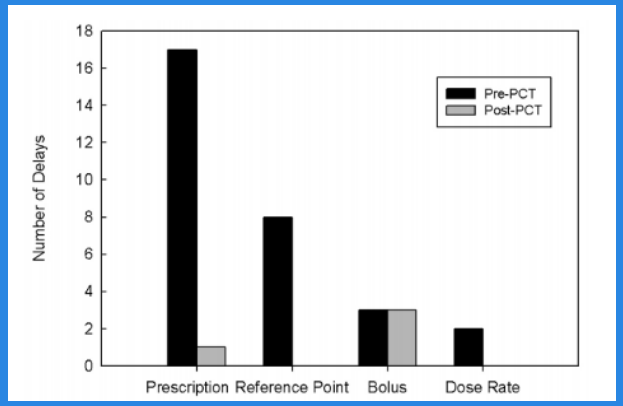
Plan Check Tool: Clinical Use @UMich

- **Observation: Although similar # of errors pre/post-PCT overall those related to automated checks decreased.**
- **Treatment machine delays related to planning errors decreased by 60%.**





Covington, et al. "Improving treatment plan evaluation with automation." *JACMP* v17, no 6 (2016): 16-31.

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Plan Check Tool: Clinical Use @UMich

- **Observation: Estimated ~200 hours saved per year in plan checking time + add't 288 hours saved by replacing subsequent checks with review of PCT output**

Activity	*Number of Plans*	*Time Saved per Plan (min)*	*Total Time Saved (min)*
Plan check	2830	4.25	12028
IMRT/VMAT Plan check	1240	4.25	5270
First weekly chart check	2830	4.25	12028
	Total time savings		29326 (488.8 hrs)

Covington, et al. "Improving treatment plan evaluation with automation." *JACMP* v17, no 6 (2016): 16-31.

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Plan Check Tool: Conclusions

- Very successful inter-institutional collaboration
- Flexible software that fits the needs of two large institutions and affiliate sites
- Improved detection of errors
- Time saved

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DVH Summary

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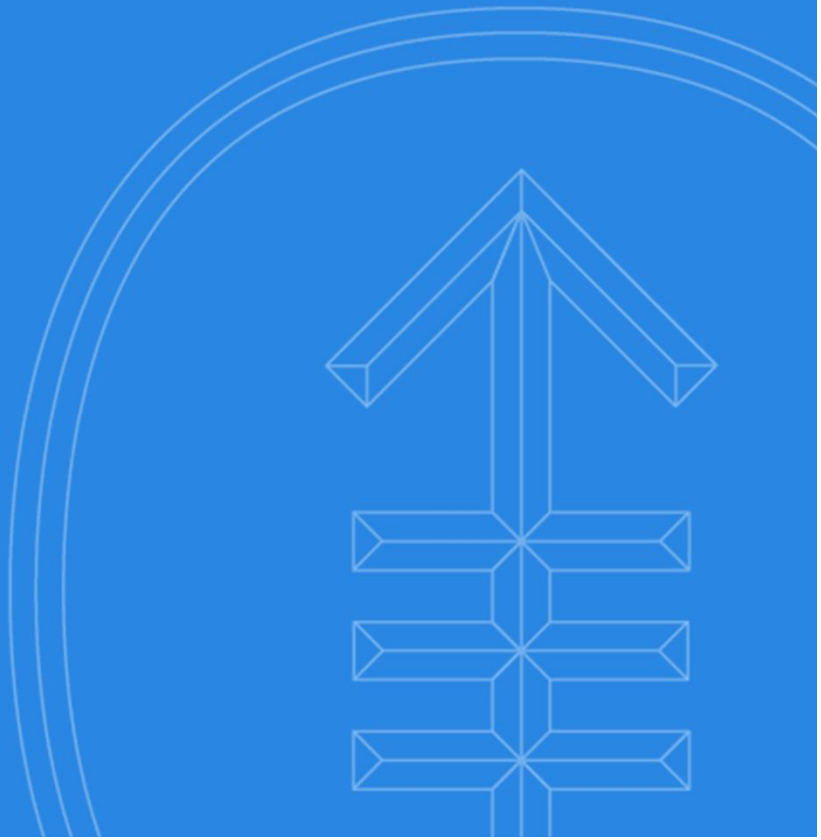
Jim Mechalakos, PhD
Perry Zhang, PhD
Gig Mageras, PhD



DVH Summary: Background

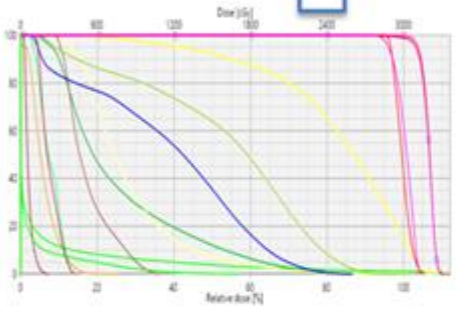
- MSKCC has extensive, specific, and particular constraints for a large range of anatomical sites and prescription paradigms.
  - Max, min, mean, $D_{x\%}$, D_{xcc}, $V_{x\%}$, V_{xcGy}, NTCP, Gradient Index,
- Issues with manual checks:
  - Slow, error-prone, has to be repeated by each observer
- Issues with solutions within Eclipse:
  - Limited functionality

DVH Summary: Introduction

- ESAPI based automated DVH Summary tool written in C#
- Used on all campuses of MSKCC and extended to a hospital with an affiliation with MSKCC
- Eclipse versions v11 – v15

DVH Summary: Overview

1.) Extracts info directly from treatment planning system



2.) Compares extracted data vs. anatomical site specific constraints

3.) Makes judgment

- Meets criteria
- Exceeds guideline, within limit
- Exceeds limit

Prostate 8100cGy

Target Criteria		
PTV	$V_{95\%} \geq 90\%$	
	$D_{max} \leq 110\%$	
PTVCD	$V_{95\%} \geq 90\%$	
	$D_{max} \leq 110\%$	
PTV Mean Dose ≥ 102% (Ideal) or 101% (acceptable)		
Normal Tissue Criteria		
Structures	**Todal Dose* or Volume ≤**	**To:**
Rectal Wall	30% of *total volume*	$V_{75.6Gy}$
	53% of *total volume*	V_{47Gy}
	103%	Max Point Dose
RECTOE**	103%	Max Point Dose
Bladder Wall	53% of *total volume*	V_{47Gy}
	107%	Max Point Dose
Femoral Heads	68Gy	Max Point Dose
Large Bowel	60Gy	Max Point Dose
Small Bowel	50Gy	D_{500}
	53Gy	Max Point Dose

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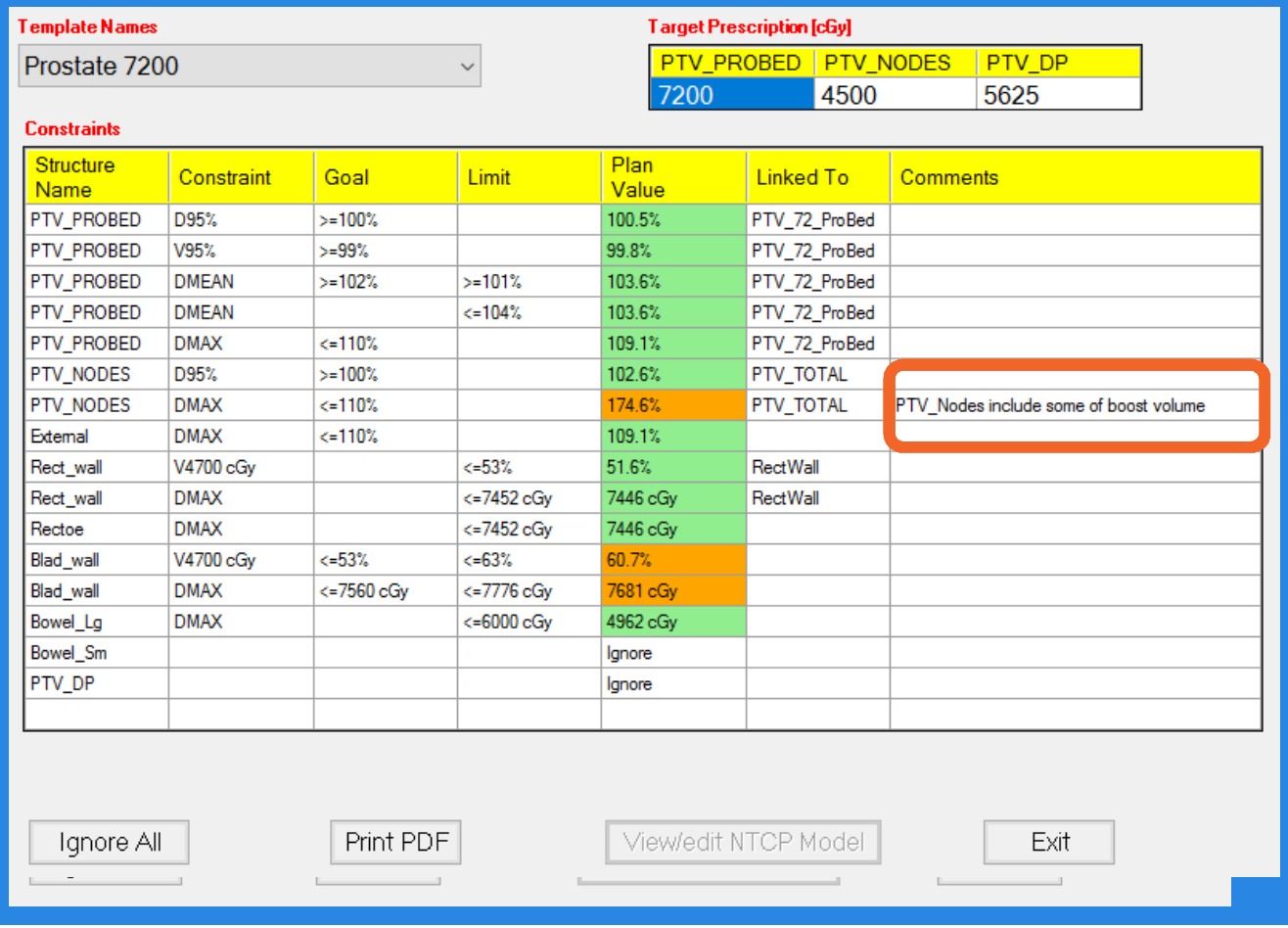
DVH Summary: GUI



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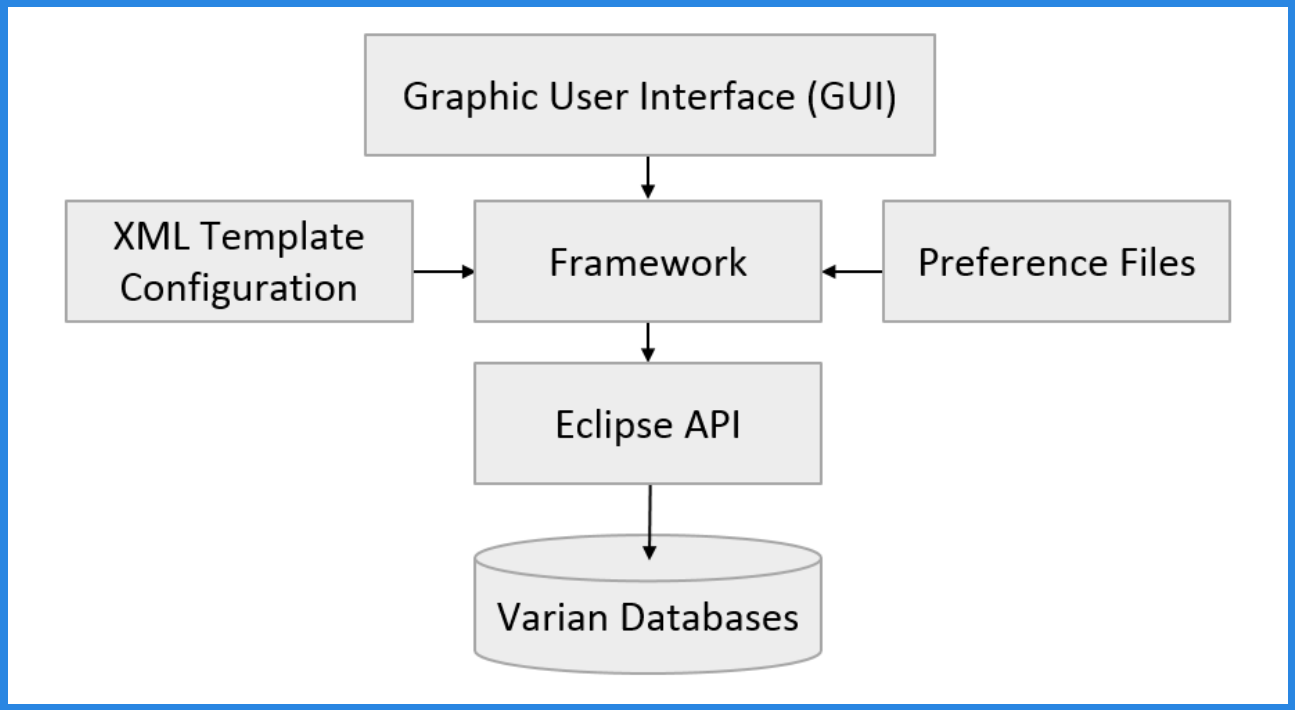
DVH Summary: Architecture



Modified from:
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DVH Summary: Architecture

ÅXML template configuration file:

Template Names

Prostate 7200

Target Prescription [cGy]

PTV_PROBED	PTV_NODES	PTV_DP
7200	4500	5625

Constraints

Structure Name	Constraint	Goal	Limit	Plan Value	Linked To	Comments
PTV_PROBED	D95%	>=100%		100.5%	PTV_72_ProBed	
PTV_PROBED	V95%	>=99%		99.8%	PTV_72_ProBed	
PTV_PROBED	DMEAN	>=102%	>=101%	103.6%	PTV_72_ProBed	
PTV_PROBED	DMEAN		<=104%	103.6%	PTV_72_ProBed	
PTV_PROBED	DMAX	<=110%		109.1%	PTV_72_ProBed	
PTV_NODES	D95%	>=100%		102.6%	PTV_TOTAL	
PTV_NODES	DMAX	<=110%		174.6%	PTV_TOTAL	PTV_Nodes include some of boost volume
External	DMAX	<=110%		109.1%		
Rect_wall	V4700 cGy		<=53%	51.6%	RectWall	
Rect_wall	DMAX		<=7452 cGy	7446 cGy	RectWall	
Rectoe	DMAX		<=7452 cGy	7446 cGy		
Blad_wall	V4700 cGy	<=53%	<=63%	60.7%		
Blad_wall	DMAX	<=7560 cGy	<=7776 cGy	7681 cGy		
Bowel_Lg	DMAX		<=6000 cGy	4962 cGy		
Bowel_Sm				Ignore		
PTV_DP				Ignore		

Ignore All | Print PDF | View/edit NTCP Model | Exit

```
<Filename name = "Prostate 7200.xml">
    <TemplateName>Prostate 7200</TemplateName>
    <TemplateStructure name = "PTV_PROBED" TargetPrescription="7200">
    <StructureType>TARGET</StructureType>
        <Constraint name = "D95%">
            <IndexType>D</IndexType>
            <IndexArgument>95</IndexArgument>
            <IndexArgumentUnits>%</IndexArgumentUnits>
            <IndexUnits>%</IndexUnits>
            <IndexRelation>Greater Than</IndexRelation>
            <NumberOfIndexGoals>1</NumberOfIndexGoals>
            <IndexGoal_1>100</IndexGoal_1>
            <IndexLimit>""</IndexLimit>
        </Constraint>
    </TemplateStructure>
    <TemplateStructure name = "Blad_wall" TargetPrescription="">
    <StructureType>NORMAL</StructureType>
        <Constraint name = "V4700cGy">
            <IndexType>V</IndexType>
            <IndexArgument>4700</IndexArgument>
            <IndexArgumentUnits>cGy</IndexArgumentUnits>
            <IndexUnits>%</IndexUnits>
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            <NumberOfIndexGoals>1</NumberOfIndexGoals>
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            <IndexArgument>MAX</IndexArgument>
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            <IndexLimit>7776</IndexLimit>
        </Constraint>
    </TemplateStructure>
</Filename>
```

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DVH Summary: Clinical Use @MSKCC

- Planners view via scripting interface during planning process
- Planners include in plan pdf for upload to dynamic documents
- Plan checker runs via scripting interface and verifies matches copy in plan pdf
- Copy of plan pdf used during chart rounds for rapid review

PDF created 5/15/2019 5:30 PM

Patient Name: [redacted]
Campus: Westchester
MRN: [redacted]
Course: 1_PRSTNODES
Plan: Plan Sum1
Approval Status: UnApproved

Template Name:
Prostate 7200

Target Prescription[cGy]

PTV_PROBED	PTV_NODES	PTV_DP
7200	4500	5625

Constraints

Structure Name	Constraint	Goal	Limit	Plan Value	Linked To	Comments
PTV_PROBED	D95%	>=100%		100.5%	PTV_72_ProBed	
PTV_PROBED	V95%	>=99%		99.8%	PTV_72_ProBed	
PTV_PROBED	DMEAN	>=102%	>=101%	103.6%	PTV_72_ProBed	
PTV_PROBED	DMEAN		<=104%	103.6%	PTV_72_ProBed	
PTV_PROBED	DMAX	<=110%		109.1%	PTV_72_ProBed	
PTV_NODES	D95%	>=100%		102.6%	PTV_TOTAL	
PTV_NODES	DMAX	<=110%		174.6%	PTV_TOTAL	PTV_Nodes include some of boost volume
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Blad_wall	DMAX	<=7560 cGy	<=7776 cGy	7681 cGy		
Bowel_Lg	DMAX		<=6000 cGy	4962 cGy		
Bowel_Sm				Ignore		
PTV_DP				Ignore		

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DVH Summary: Conclusions

- Successful instance of enhancing functionality existing in the TPS via scripting.
- Flexible software that fits the needs of one large institution and one affiliate site.
- Flexible software, templates easily updated as constraints are modified.
- More efficient review of planned values vs constraints during planning, plan checking, and chart rounds processes.

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ECHO

MSKCC
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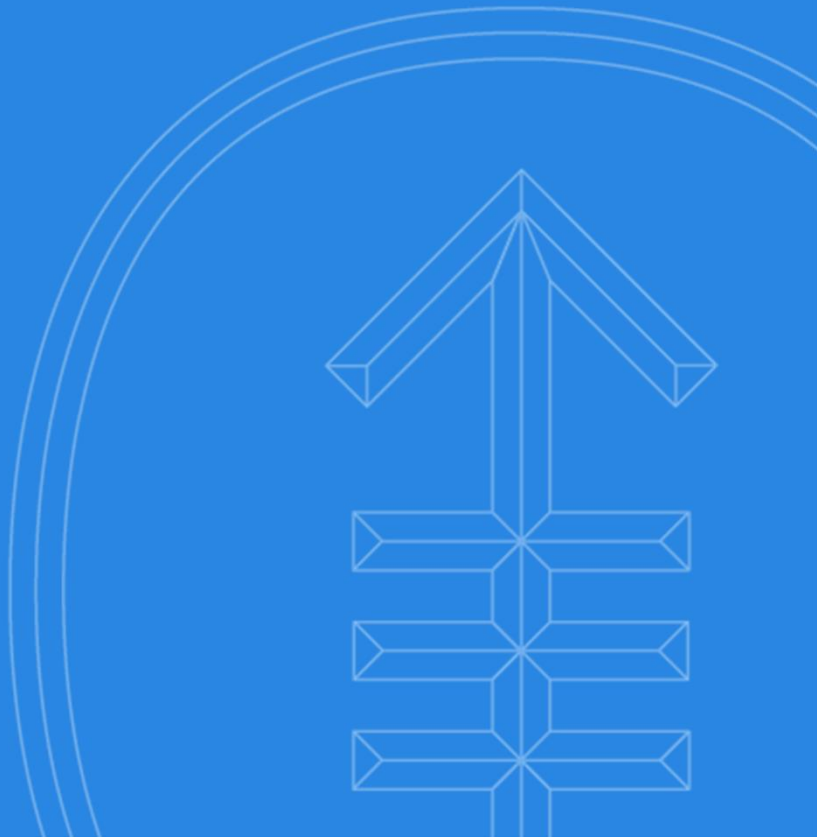
Ying Zhou, MS
Jung Hun Oh, PhD
Jie Yang, PhD
Jim Mechalakos, PhD
Margie Hunt, MS
Gig Mageras, PhD
Joe Deasy, PhD



ECHO: Background

- Radiotherapy planning is a complex, time-consuming, and labor-intensive task
- Interobserver variability in RT plan quality exists[1]
- Constrained hierarchical optimization is a classic optimization technique, but not available in commercial TPS[2,3]
- ECHO is a demonstration of how a home-grown optimization technique can become part of the clinical workflow using API scripting.[4]

[1]Berry, et al. "Interobserver variability in radiation therapy plan output: results of a single-institution study." *PRO*, 2016;6:442-449

[2]Deasy, et al. "Prioritized treatment planning for radiotherapy optimization", *Proc. World Congress on Medical Physics and Biomedical Engineering* (Chicago, 2000) CD-ROM (2000).

[3]Deasy, et al. "The IMRT optimization problem statement", *Proc. From the NCI-NSF Sponsored Workshop on Operations Research Applications in Radiation Therapy (OART)* (Washington, DC, 2002) (2002).

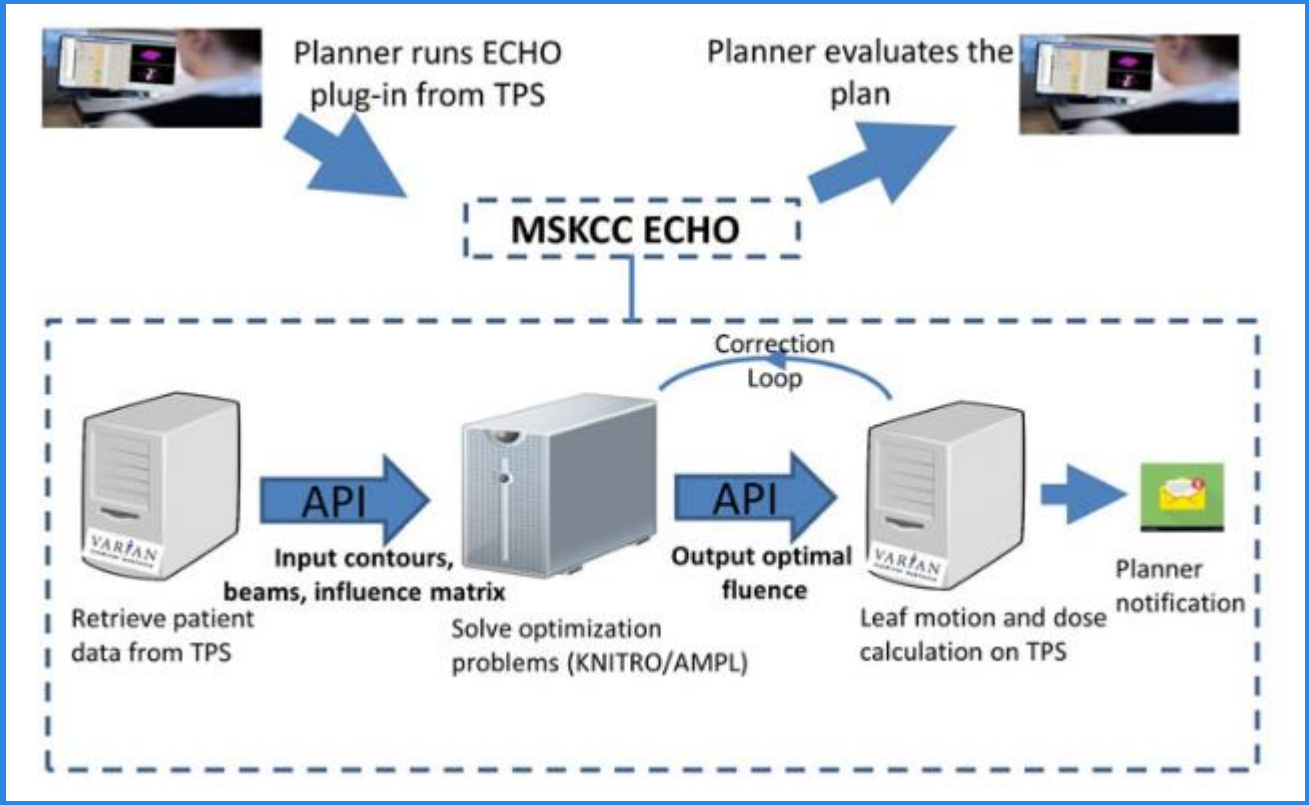
[4]Zarepisheh, et al., "Automated intensity modulated treatment planning: the expedited constrained hierarchical optimization (ECHO) system", Med Phys (doi: 10.1002/mp.13572)

ECHO: Introduction

- ESAPI based automated constrained hierarchical optimization tool written in C#
- Used on all campuses of MSKCC
- Used clinically on ~1500 SBRT paraspinal patients between 4/2017 and 5/2019.
- Eclipse versions v13 – v15.

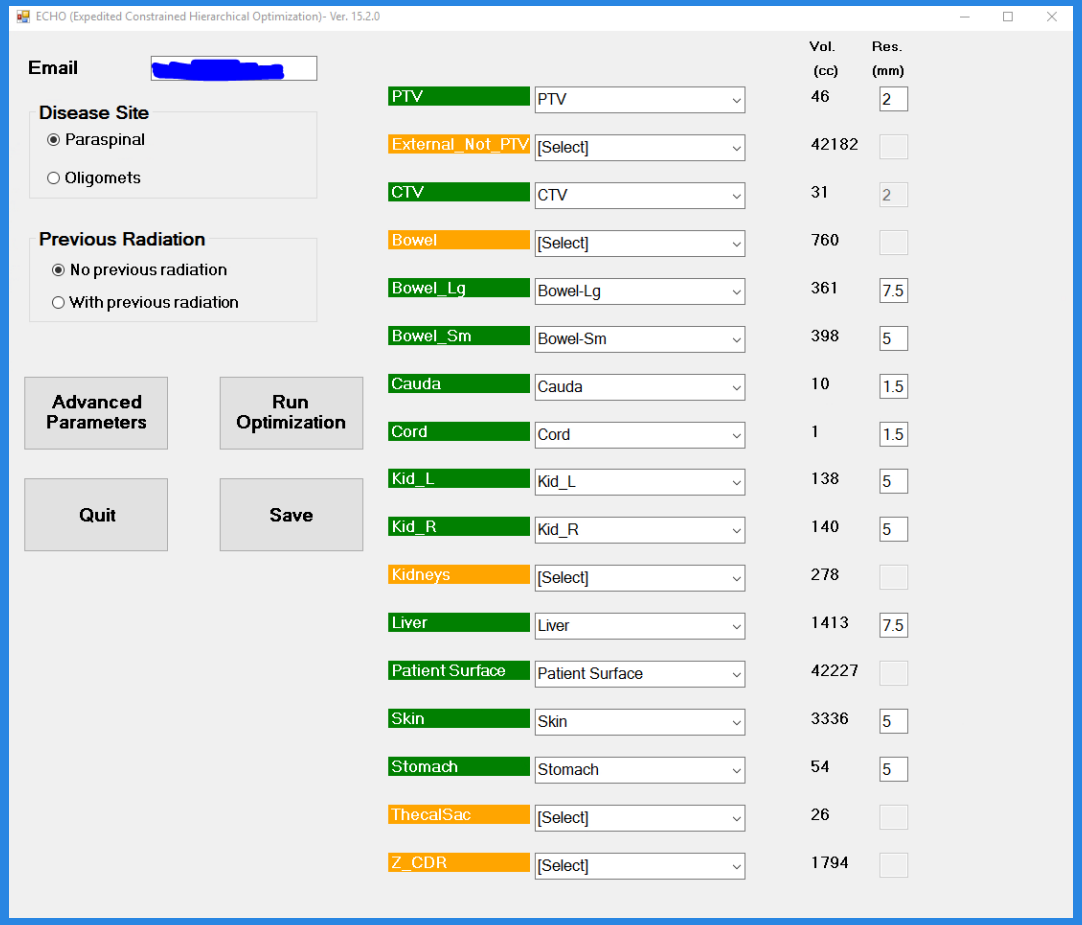
Zarepisheh, et al., "Automated intensity modulated treatment planning: the expedited constrained hierarchical optimization (ECHO) system", Med Phys (doi: 10.1002/mp.13572)

ECHO: Overview



Zarepisheh, et al. "Automated intensity modulated treatment planning: the expedited constrained hierarchical optimization (ECHO) system." *Med Phys, in press*, 2019 (doi: 10.1002/mp.13572)

ECHO: GUI



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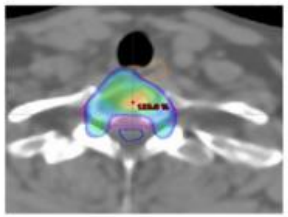
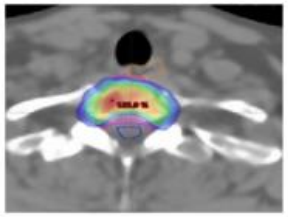
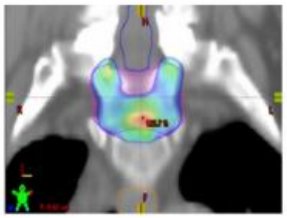
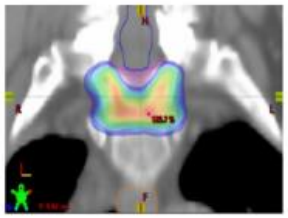
ECHO: Clinical Use @MSKCC



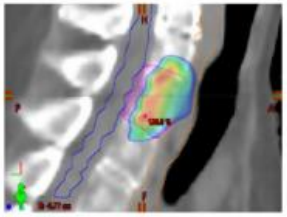


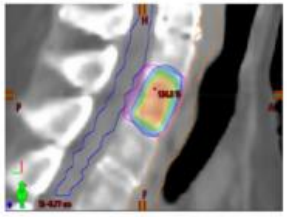
(a) Transverse view dose distribution (left is manual, right is ECHO)



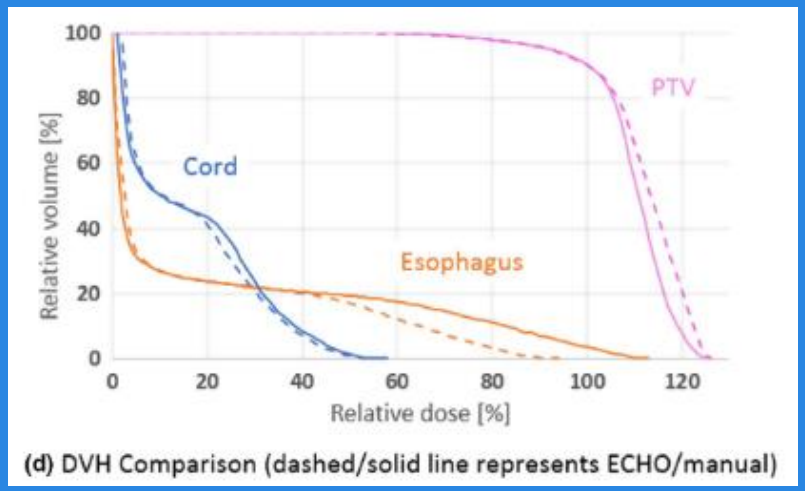


(b) Coronal view dose distribution (left is manual, right is ECHO)





(c) Sagittal view dose distribution (left is manual, right is ECHO)



(d) DVH Comparison (dashed/solid line represents ECHO/manual)

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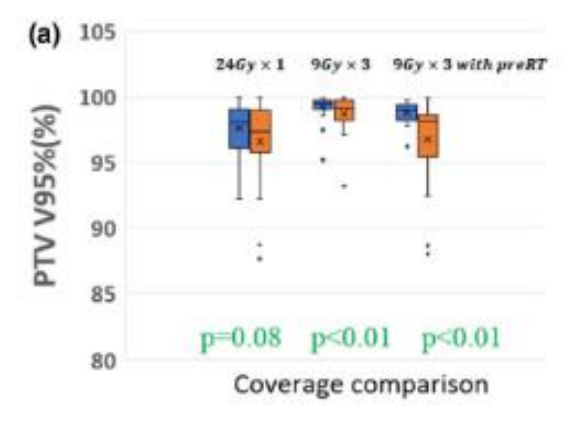
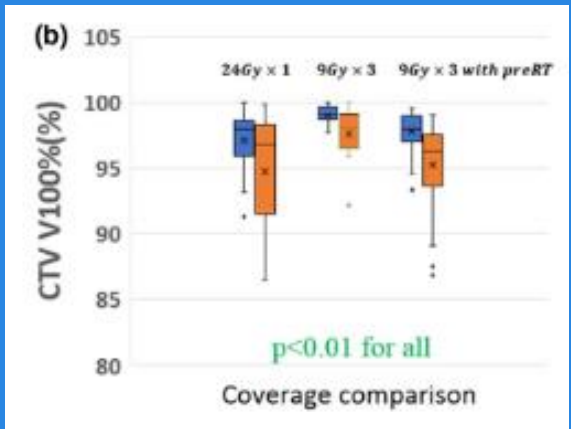
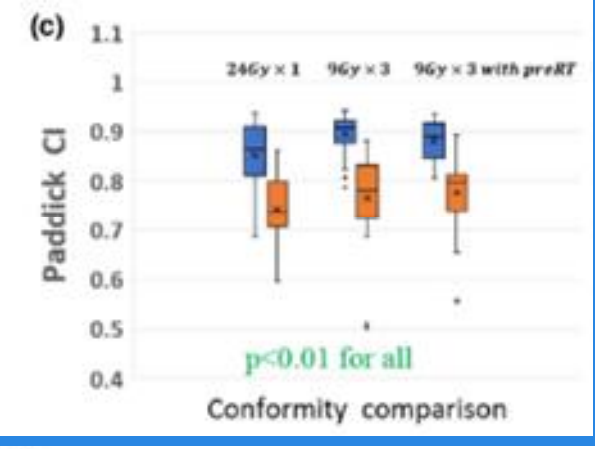
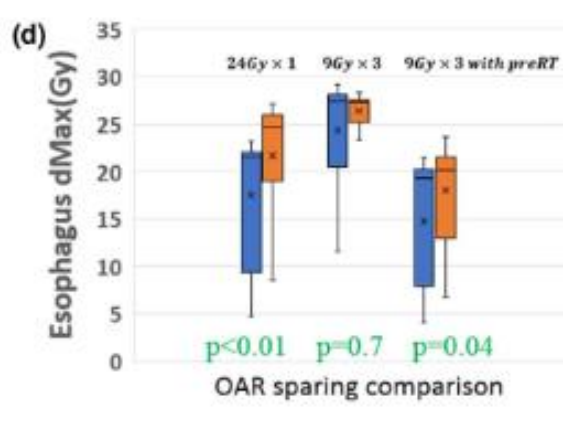
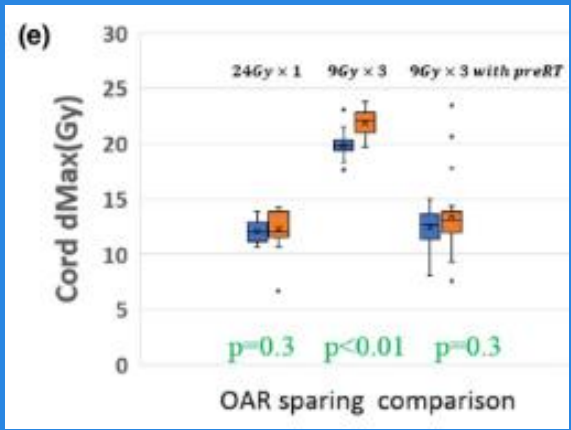
ECHO: Clinical Use @MSKCC

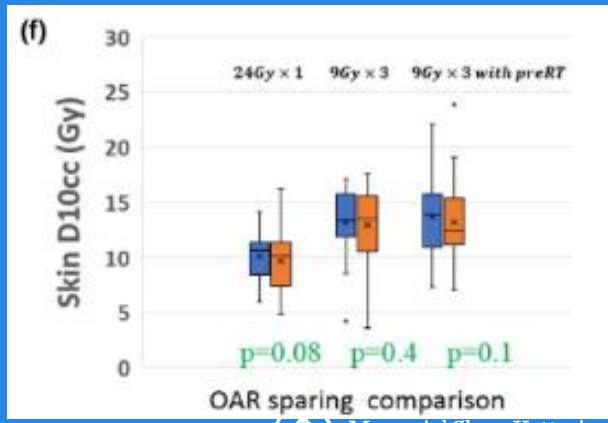












Zarepisheh, et al. "Automated intensity modulated treatment planning: the expedited constrained hierarchical optimization (ECHO) system." *Med Phys, in press*, 2019 (doi: 10.1002/mp.13572)

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ECHO: Conclusions

- Successful instance of “enhancing” a FDA approved, commercial, TPS with API functionality and advanced algorithms.
- Increases plan efficiency *and* plan quality

Zarepisheh, et al., “Automated intensity modulated treatment planning: the expedited constrained hierarchical optimization (ECHO) system”, Med Phys (doi: 10.1002/mp.13572)

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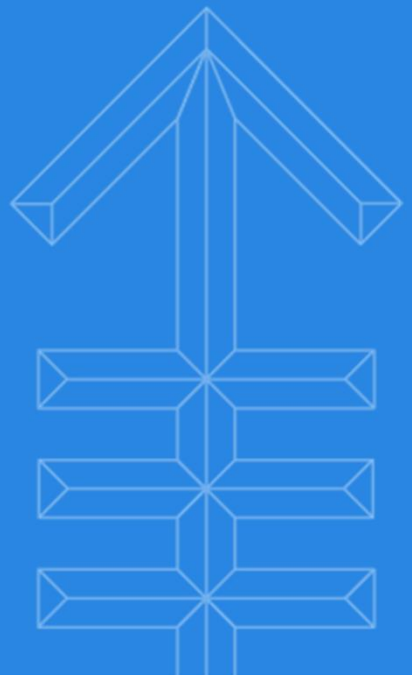
Other Scripts

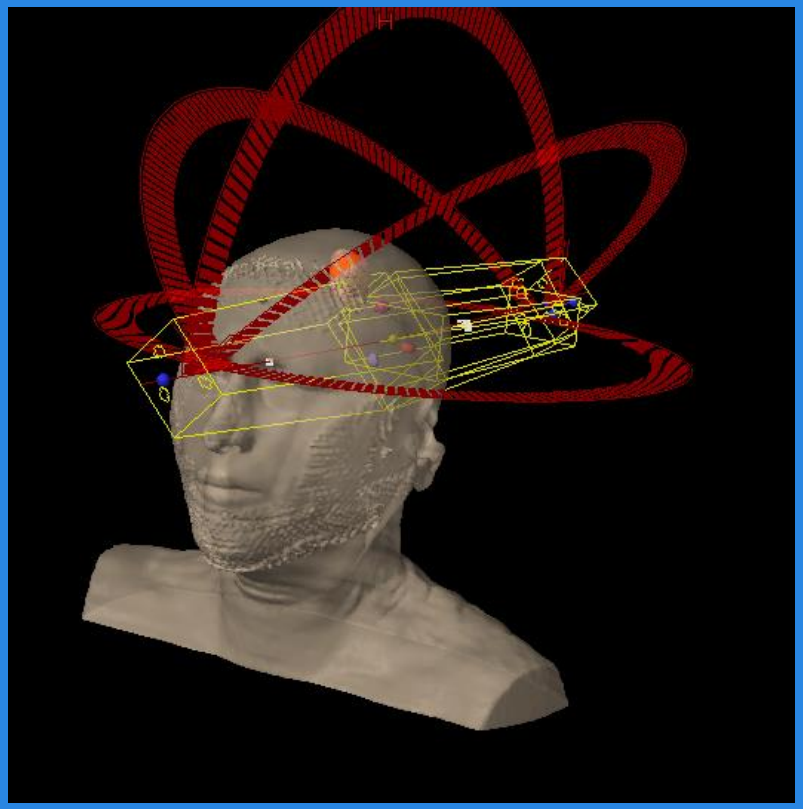
MSK GO
Li Cheng Kuo, MS
Pengpeng Zhang, PhD
Hai Pham, MS
Åse Ballangrud-Popovic, PhD

Breast VSim
Linda Hong, PhD
Jianping Xiong, MS
Gig Mageras, PhD

Compensator Design
Chen Chui, PhD
Linda Hong, PhD
Beryl McCormick, MD
Margie Hunt, MS
Gig Mageras, PhD
Jie Yang, PhD



MSK GO: Further Information



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Therapy SNAP Oral

Implementation and Validation of An In-House Geometry Optimization Software for SRS VMAT Planning of Multiple Cranial Metastases

L Kuo*, P Zhang , H Pham , A Ballangrud , Memorial Sloan Kettering Cancer Center, New York, NY

(Sunday, 7/14/2019) 1:00 PM - 2:00 PM
Room: Stars at Night Ballroom 1

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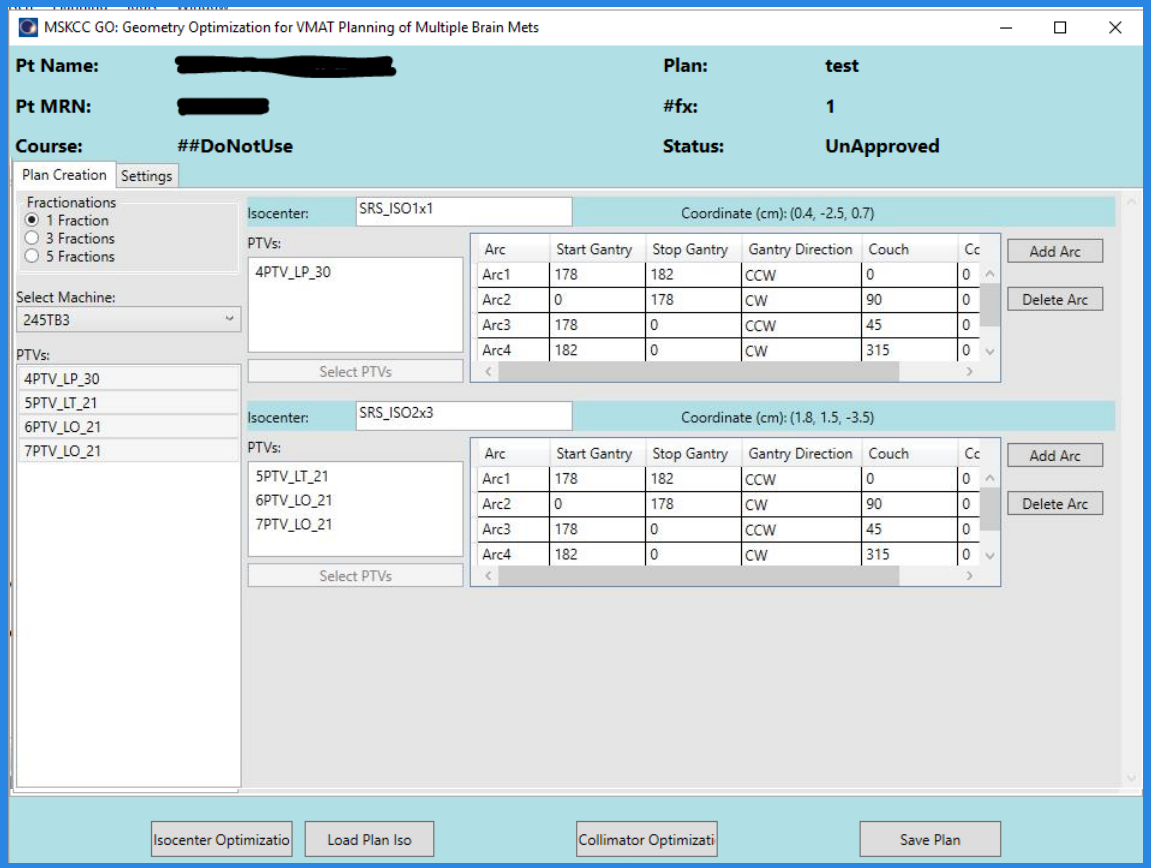
MSK GO: GUI



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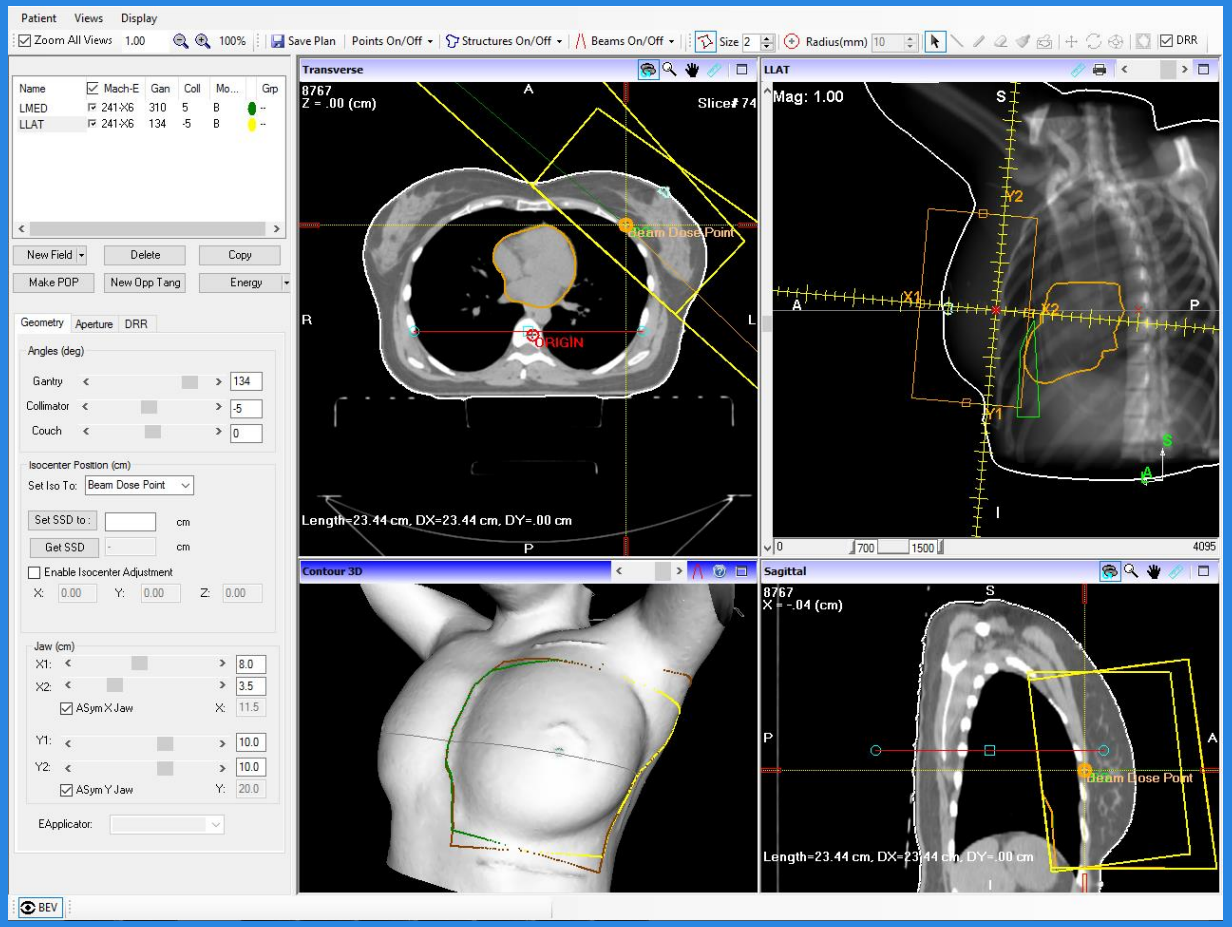
Breast VSim



- Built to solve problem that can't see BEV and field edges on surface at same time in Eclipse.

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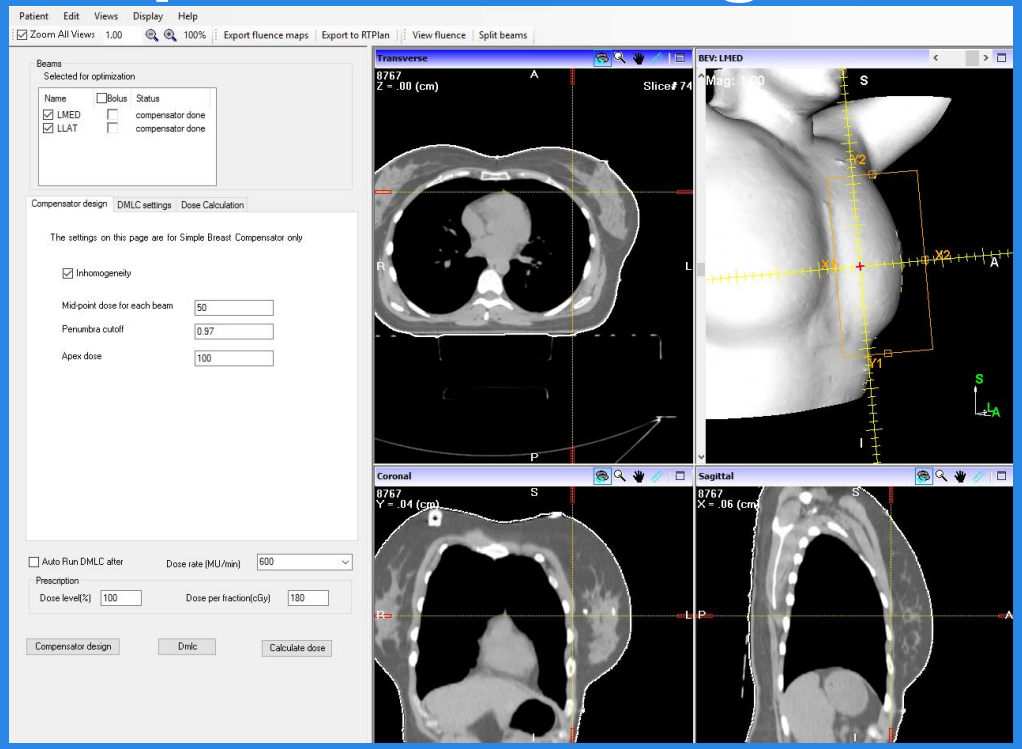
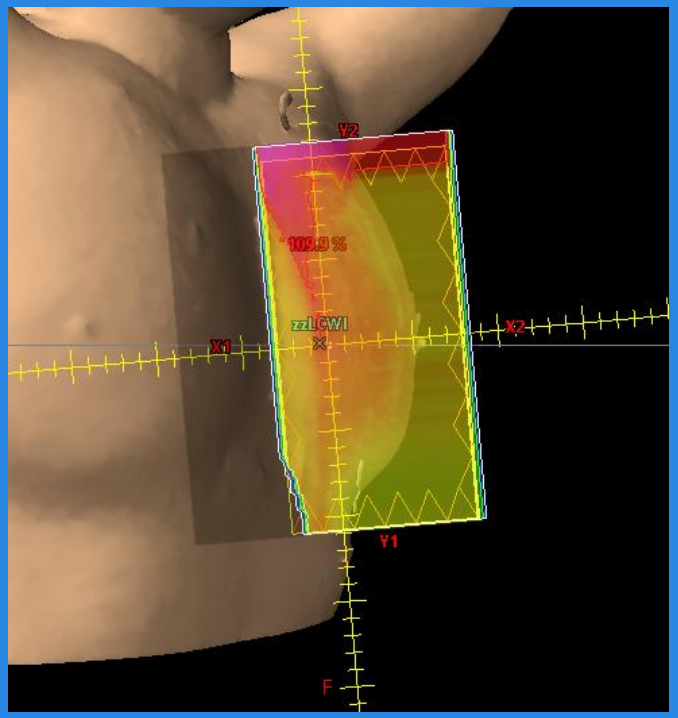
Compensator Design





Chui CS, Hong L, McCormick B. Intensity-modulated radiotherapy technique for three-field breast treatment. Int. J. Radiat. Oncol. Biol. Phys., 62(4), 1217-1223 (2005).

Chui CS, Hong L, Hunt M and McCormick B. A simplified intensity modulated radiation therapy technique for the breast. Med. Phys. 29, 522-529 (2002).

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Conclusions

- **Scripting can be a powerful way to:**
  - **Improve upon vendor functionality**
  - **Increase safety and efficiency in your clinic**
  - **Free yourself of the algorithmic limitations of the vendor's software**
    - **Improved optimization**
    - **Improved segmentation**
    - **Improved workflows**
- **@MSK scripts are written by software engineers/developers but also by clinical physicists.**