Automated Treatment Planning Using a Database of Prior Patient Treatment Plans

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Steven Petit PhD, Misha Kazhdan PhD, Russell Taylor PhD

Shape DB work funded by Philips Radiation Oncology Systems

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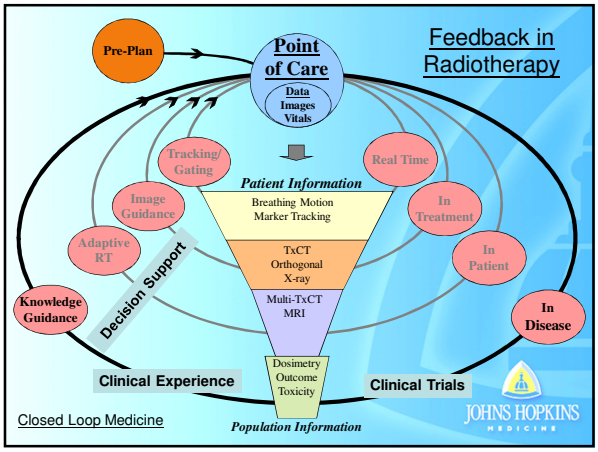
McNutt 2012



Oncospace: An eScience program for the advancement of care in radiation oncology

- Objectives:
  - To develop an analytical database and infrastructure to store clinical information for personalized medicine and future analysis
- **Project 1: Integration of Data Collection with Clinical Workflow**
- **Project 2: Database Design: Security and Distributed Web-Access**
- **Project 3: Tools for Query, Analysis, Navigation and Decision Support**
- **Project 4: Data Mining, Decision Support and Bio-statistic Research,**

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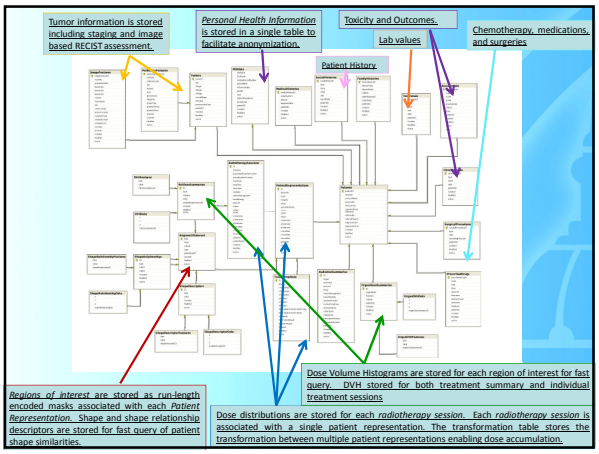
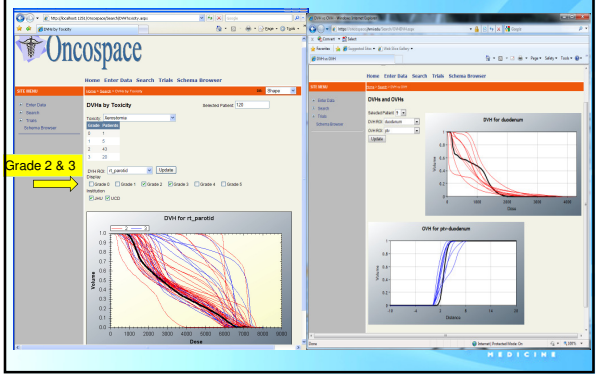
McNutt 2012

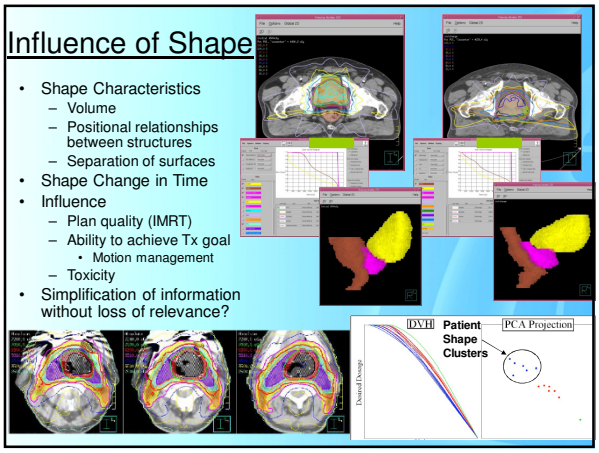


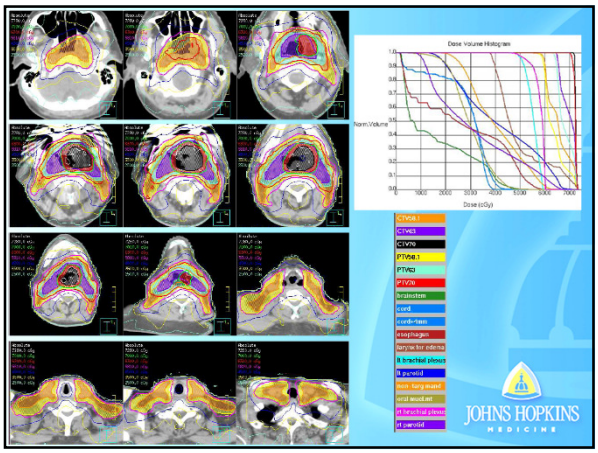
Oncospace Website



Influence of Shape

- Shape Characteristics
  - Volume
  - Positional relationships between structures
  - Separation of surfaces
- Shape Change in Time
- Influence
  - Plan quality (IMRT)
  - Ability to achieve Tx goal
    - Motion management
  - Toxicity
- Simplification of information without loss of relevance?

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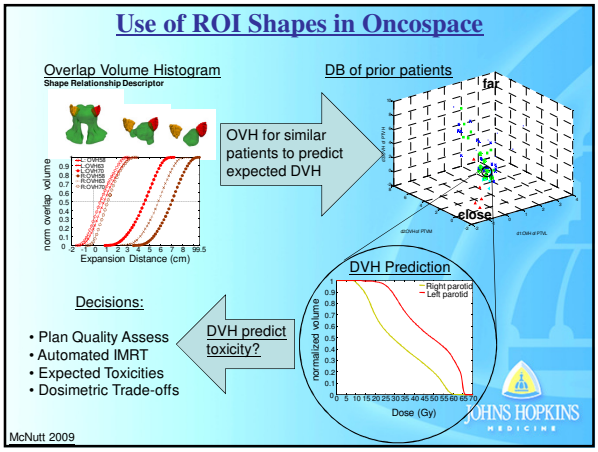
Use of ROI Shapes in Oncospace
Overlap Volume Histogram
Shape Relationship Descriptor
norm overlap volume
Expansion Distance (cm)
OVH for similar patients to predict expected DVH
DB of prior patients
far
close
DVH Prediction
Right parotid
Left parotid
normalized volume
Dose (Gy)
Decisions:
• Plan Quality Assess
• Automated IMRT
• Expected Toxicities
• Dosimetric Trade-offs
DVH predict toxicity?
McNutt 2009
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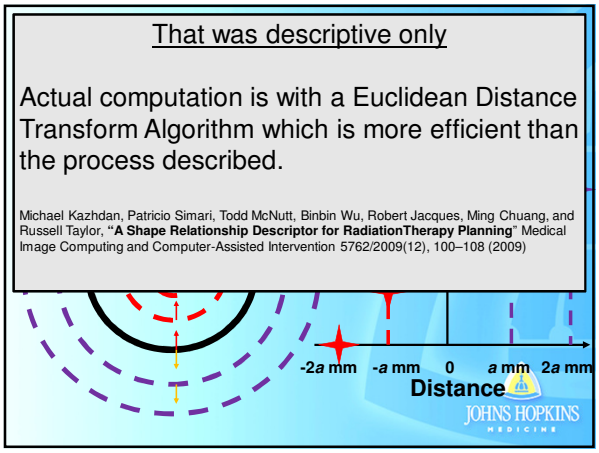
That was descriptive only
Actual computation is with a Euclidean Distance Transform Algorithm which is more efficient than the process described.
Michael Kazhdan, Patricio Simari, Todd McNutt, Binbin Wu, Robert Jacques, Ming Chuang, and Russell Taylor, "A Shape Relationship Descriptor for RadiationTherapy Planning" Medical Image Computing and Computer-Assisted Intervention 5762/2009(12), 100–108 (2009)
-2a mm
-a mm
0
a mm
2a mm
Distance
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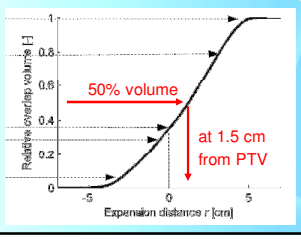
From a point to an organ

Which dose?

- Maximum dose?
- Dose to e.g. 50%
- DVH



Overlap Volume Histogram describes distance from a (sub)volume to the PTV

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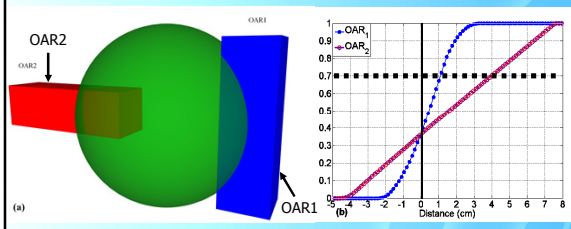
An example of OVH



For parallel organs, OAR2 (red) is more easily spared.
For serial organs, OAR1 (blue) is more easily spared.

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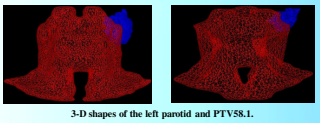
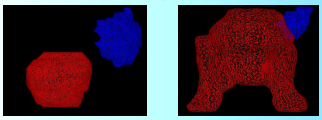
Comparison between 1L and 5L: 1L is an outlier

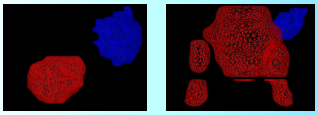
Patient 1 Patient 5



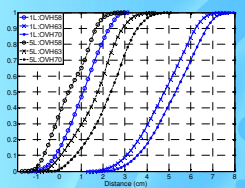
3-D shapes of the left parotid and PTV58.1.



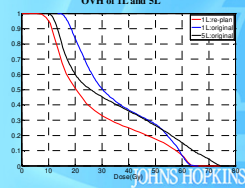
3-D shapes of the left parotid and PTV63.



3-D shapes of the left parotid and PTV70.



OVH of 1L and 5L



DVH of 1L and 5L

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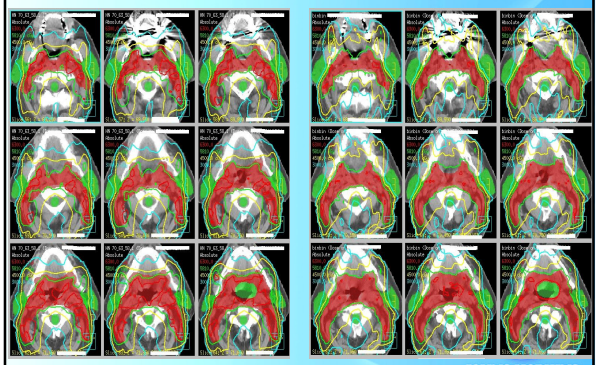
Re-plan results of patient 1



Original plan Re-plan

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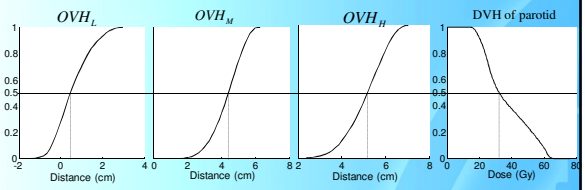
Treatment Plan Quality Control (outlier detection): parotids



Clinical goal: Parotid: V(30Gy)<50% of volume

$$DVH = T[OVH_L, OVH_M, OVH_H]$$

⇓ Dose corresponding 50% of volume:

⇓ Distance corresponding 50% of volume:

$$DGy = T[d_L cm, d_M cm, d_H cm]$$

Detection rule: For covering the same percentage volume of the OAR, the larger the expanded distance is, the easier to spare the OAR.

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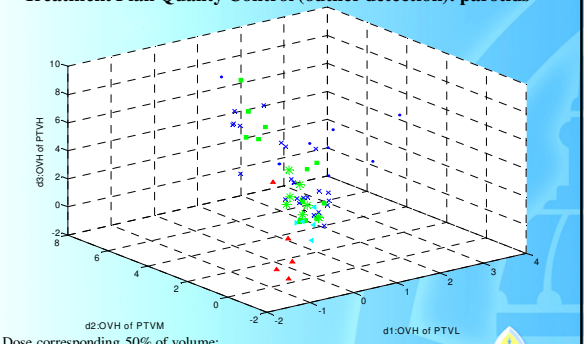
Treatment Plan Quality Control (outlier detection): parotids



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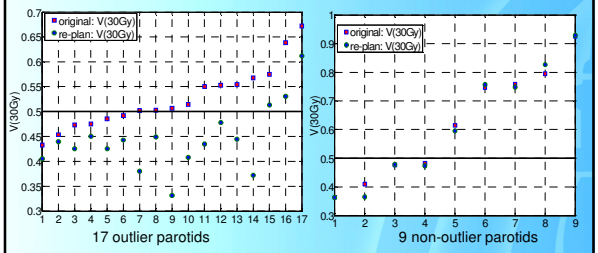
Re-plan results of the 17 outlier patients

Clinical goal (parotid): V(30Gy)<0.5



- 26 re-plan patients, 17 are outliers, 9 non-outlier indicated sby the OVH.
- V(30Gy) of 8 parotids among the 17 outlier parotids are reduced to below 50%!
- Non-outliers were not significantly improved
- All 26 re-plans are reviewed by physician.

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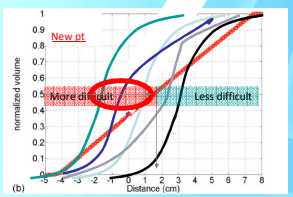
Predict dose minimal dose to e.g. 50% of organ

- Lookup distance PTV to 50% of the organ
- Read OVHs of all prior patients
- Select all patients for which the 50% was closer to the PTV
- Lookup dose at 50% DVH for selected patients
- Select the lowest achieved dose = prediction of what is achievable



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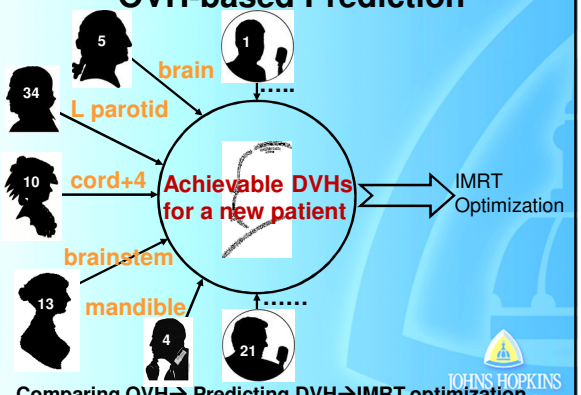
OVH-based Prediction



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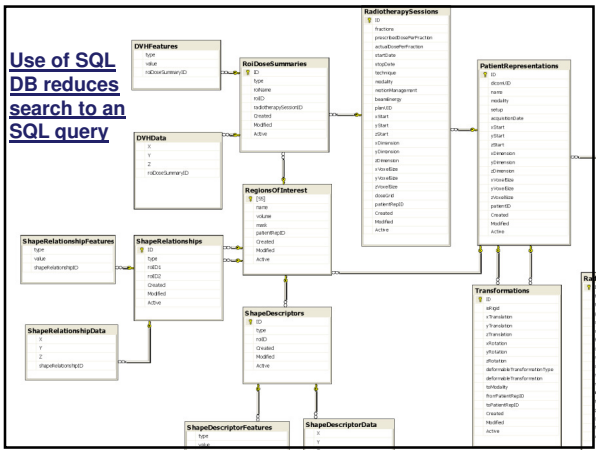
Comparing OVH→ Predicting DVH→IMRT optimization

Use of SQL DB reduces search to an SQL query



H&N Retrospective Planning Demonstration

- **15** random pts from a DB of **91** H&N pts for **OVH-assisted** planning demonstration
  - IMRT-SIB: 58.1 Gy, 63 Gy and 70 Gy
- DVH objectives of 13 OARs queried from the DB as initial planning goals in a **leave-one-out manner**
- Dosimetry of 3 sets of plans were compared:
  - **CP** - Clinical plans
  - **OP1** - OVH-assisted plans after 1 optimization
  - **OP2** - Final OVH-assisted plans

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15 pts: PTV comparisons among CP,OP1 and OP2

	CP	OP1	OP2	Wilcoxon *p* test		
$PTV^{58.1}$	Avg.	Avg.	Avg.	CP vs OP1	CP vs OP2	OP1 vs OP2
V_{100}(%)	94.1	94.3	94.5	0.56	0.23	0.85
V_{98}(%)	97.1	97.9	98	0.3	0.24	0.6
V_{95}(%)	98.9	99	99	0.8	0.71	0.6
D_5-D_{95}(Gy)	16	13.9	13.7	0.2	0.24	0.85
$CI^{58.1}$	1.2	1.2	1.2	0.55	0.76	0.95
PTV^{63}						
V_{100}(%)	98.7	99.1	99	0.08	0.15	0.9
V_{98}(%)	99.2	99.6	99.6	0.12	0.23	0.55
V_{95}(%)	99.7	99.8	99.9	0.34	0.77	0.43
D_5-D_{95}(Gy)	9	8	8.1	0.1	0.28	0.67
CI^{63}	1.3	1.3	1.3	0.6	0.45	0.65
PTV^{70}						
V_{100}(%)	95.1	95.4	95.3	0.5	0.32	0.9
V_{98}(%)	98.6	98.8	99	0.4	0.21	0.9
V_{95}(%)	99.8	99.9	99.9	0.3	0.2	0.93
D_5-D_{95}(Gy)	3.7	3	3.2	0.6	0.97	0.7
CI^{70}	1.2	1.3	1.3	0.6	0.42	0.88

Abbreviations: CP = clinical plan; OP1 = first-around OVH-assisted plan; OP2 = final OVH-assisted plan

PTV coverage and homogeneity were slightly better in both OPs; conformity was similar.

15 pts: OAR Sparing among CP,OP1 and OP2

OAR	End point	CP	OP1	OP2	Wilcoxon *p* value		
		Avg.	Avg.	Avg.	CP vs OP1	CP vs OP2	OP1 vs OP2
cord+4mm	$D_{0.1\,cc}$	45.6	39.5	38.7	**<0.0001**	**<0.0001**	0.7
mandible	$D_{0.1\,cc}$	67.4	67.3	67.8	0.79	1	0.91
brainstem	$D_{0.1\,cc}$	47.7	40.4	40	**<0.005**	**<0.005**	0.85
brain	$D_{1\,cc}$	50.8	50	49.6	0.5	0.38	0.88
ipsi-lateral parotid	V(30 Gy)	65	57	58.5	0.21	0.3	0.8
contra-lateral parotid	V(30 Gy)	52	45	43.3	**<0.0001**	**<0.0001**	0.56
larynx	V(50 Gy)	55.4	53.3	50.1	0.66	0.57	0.91
esophagus	$D_{1\,cc}$	53.9	54.1	54	1	0.9	0.95
ipsi-lateral brachial plexus	$D_{0.1\,cc}$	62.2	62.7	62	0.97	0.93	0.9
contra-lateral brachial plexus	$D_{0.1\,cc}$	58.4	59.44	59.53	0.79	0.84	0.86
oral mucosa	V_{cc}(66.5 Gy)	37.6	39.5	40	0.6	0.74	0.93
ipsi-lateral inner ear	D_{mean}	31	25.7	26	0.32	0.47	1
contra-lateral inner ear	D_{mean}	25	19.5	21	0.2	0.43	1

Abbreviations: CP = clinical plan; OP1 = first-around OVH-assisted plan; OP2 = final OVH-assisted plan

Significantly lower in both OPs: cord4mm (~6 Gy), brainstem (~7.4 Gy) and contra-lateral parotid (~7%)

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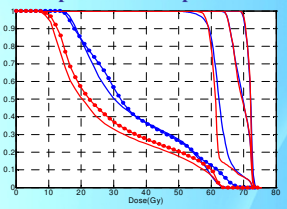
Re-plan results of patient 1

Red: re-plan
Blue: original
Dot: right parotid
No-dot: left parotid



Re-plan results for other OARs

Patient 1	brain (Gy)	Brainstem (Gy)	Cord4mm (Gy)	L inner ear (Gy)
original	61.25	54.58	41.75	57.18
re-plan	56.33	46.48	37.89	43.72
Patient 1	R inner ear (Gy)	mandible (Gy)	larynx for edema	esophagus (Gy)
original	40.57	66.58	61%	63.74
Re-plan	38.38	63.78	59%	61

Brain, brainstem, cord4mm, esophagus and mandible: maximal dose
Inner ear: mean dose
Larynx for edema: V(50Gy)

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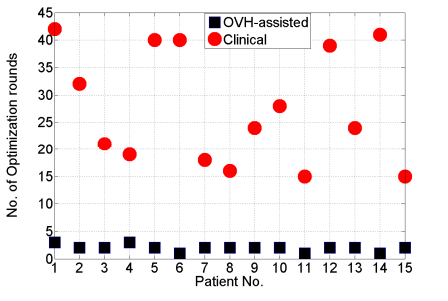
Plan comparison: efficiency (15 plans)



Average number of optimization rounds per OP is 1.9; that number for a CP is 27.6; 3 OPs finished in a single round.

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Prospective clinical trial study

Binbin Wu PhD, Giuseppe Sanguineti MD - IRB Approved

Purpose: Explore the feasibility of the automated OVH planning tool in clinic.

Pt accrual: 40 Pts accrued from 7/10 – 12/10
(26 oropharynx; 9 larynx; 5 nasopharynx)

Protocol: Definitive IMRT to 70 Gy in 35 Fractions to GTV and 63 Gy and 58.1 Gy to high and low risk CTVs.
Three PTVs for each pt: PTV58.1, PTV63 and PTV70

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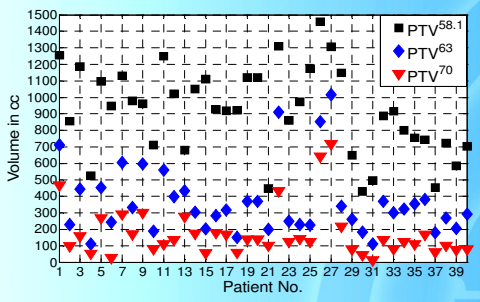
Volume distribution of 40 pts



PTV^{70}: mean (173.4cc); median (130.78 cc); SD (153 cc).
PTV^{63}: mean (363.5 cc); median (309.4 cc); SD (210.6 cc).
$PTV^{58.1}$: mean (914.14 cc); median (922.72cc); SD (253.17cc)

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Study work flow

2 plans generated for each Patient

New patient: contours of the OARs and CTVs

CP- Clinical Plan
manually created by dosimetrists
(unaware of the study).

AP- Automated Plan
plans are automatically generated
by the proposed TPS.

Clinical planning is guided by Dr. Sanguineti and in-house dosimetric guidelines.

1 week of post-approval of CP, both AP and CP are blindly reviewed by Dr. Sanguineti. One of the plans is chosen as the better one.

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Dosimetric Results: CP vs. AP

Primary OARs (optic nerve, chiasm, brainstem, brain, cord and mandible)
- AP: reduced by 1.14 Gy (p=0.004) overall

PTV coverage (V_{95} in %)
- AP: increased by 0.26% (p=0.02) overall

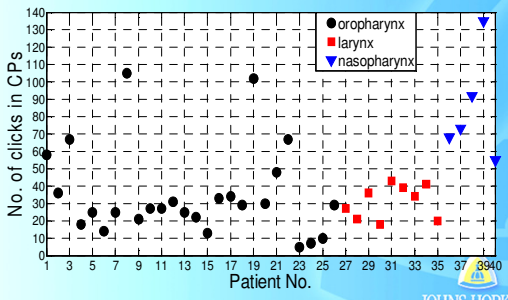
Secondary OARs (parotid, brachial plexus, larynx, inner ear, oral mucosa, esophagus
- AP: reduced by 1.16 Gy (p=0.04) overall

PTV homogeneity and conformity
- AP: significant better homogeneity in PTV^{63} (p=0.002) and PTV^{70} ($p < 0.0001$)
- AP: significant better conformity in $PTV^{58.1}$ (p=0.009).

AP: fully automated plans
CP: clinical plans manually created by dosimetrists in their regular way

Planning efficiency

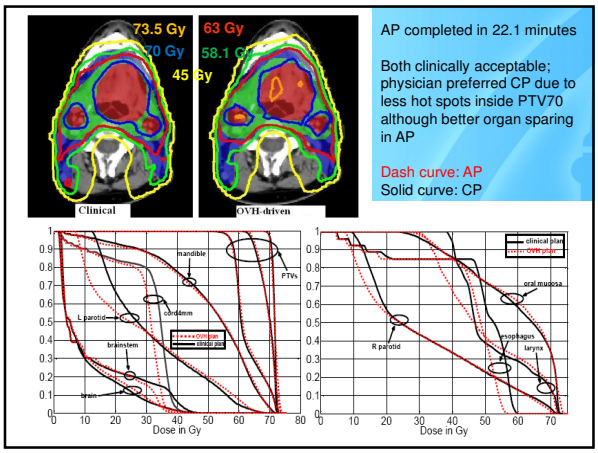
AP: 2 optimization runs per plan (~23 minutes)
CP: ~40 (SD: 29) optimization runs per plan



Physician Preference

Dr. Sanguineti reviewed the isodose distributions and DVH curves without knowing the origins of the plans.

Based on his opinion,
- All APs (40/40) are clinically acceptable and can be used to treat patients
- 27/40 APs are clinically superior to the CPs



AP completed in 22.1 minutes

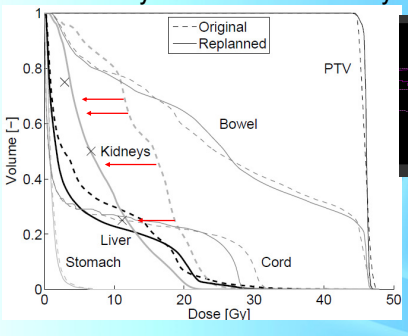
Both clinically acceptable; physician preferred CP due to less hot spots inside PTV70 although better organ sparing in AP

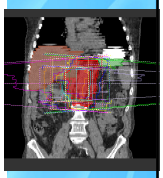
Dash curve: AP
Solid curve: CP

Pancreas example

Steven Petit

Mean kidney dose decrease 6 Gy!





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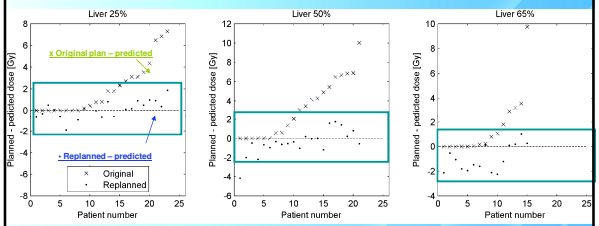
Results: liver



- **25% constraint:** **91% within 1 Gy** **96% within 2 Gy**
- **50% constraint:** **86% within 1 Gy** **100% within 2 Gy**
- **65% constraint:** **93% within 1 Gy** **100% within 2 Gy**

- **After replanning: decrease in mean dose = 10% [0 – 27%]**

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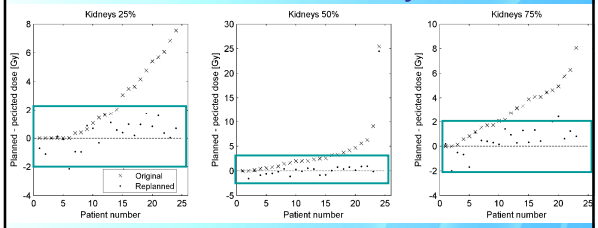
Results: Kidneys



- **25% constraint:** **89% within 1 Gy** **100% within 2 Gy**
- **50% constraint:** **96% within 1 Gy** **96% within 2 Gy**
- **75% constraint:** **65% within 1 Gy** **87% within 2 Gy**

- **After replanning: decrease in mean dose = 17% [0 – 76%]**

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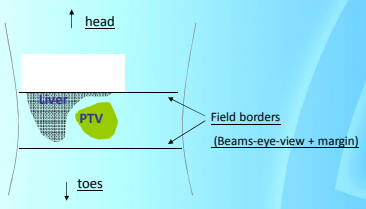
Does this really work? One modification

- Consider part of organ within beams-eye-view of the beams (+ margin)



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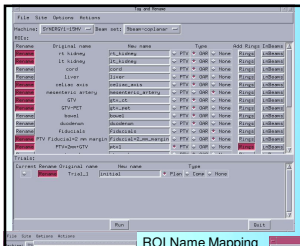


ROI Name Mapping

IMRT Objective Function Query

Green boxes queried from DB
Red if failed

Developed by Joe Moore

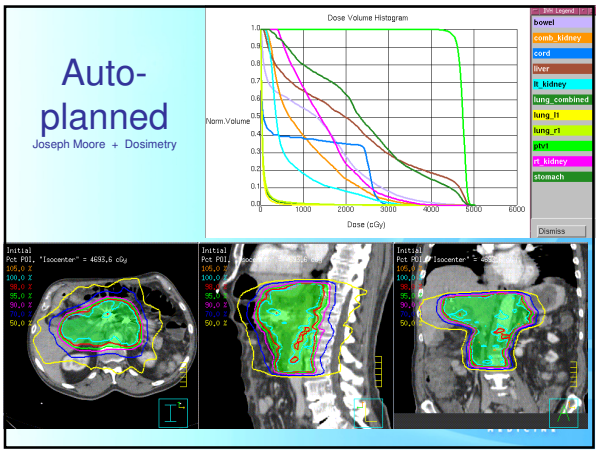
Clinical Release

Joseph Moore

- Tool is easily adapted to any site
- Release for Pancreas first
- Standardization of ROI Names
- Standardization of technique to some extent
- Query DB for predicted dose level for each objective function
- Completed new plans push to DB

Auto-planned

Joseph Moore + Dosimetry



Summary

- **Automated TPS without user intervention**
  - **OVH: retrieve geometrically "similar" pts**
  - **DB of prior plans: control plan quality of future plans**
- **Quality of new plans is independent of experience of planners; consistent with quality of prior plans in DB**
- **Clinical trade-offs made by physician are captured in the database**
- **Easily implemented to other disease sites (pancreas and prostate)**
- **Easily implemented to VMAT modality** (used current DB for VMAT)
- **Easily applied with any commercial TPS**

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