Clinical Experience with Knowledge-Based Planning

Lindsey Olsen, M.S.
Washington University in St. Louis

SITEMAN CANCER CENTER
A National Cancer Institute Comprehensive Cancer Center
BARNES-JEWISH Hospital
Washington University in St. Louis School of Medicine
NCCN National Comprehensive Cancer Network
NCI CCC
www.siteman.wustl.edu
800-600-3606

Disclosures

- Speaker Agreement with Varian Medical Systems
- License Agreement with Varian Medical Systems
- Research Agreement with Varian Medical Systems
- Patent filing on a System and Method for Developing Predictive Dose-Volume Relationships for a Radiotherapy Treatment

Learning Objectives

1. KBP background
2. Clinical indication for KBP
3. Importance of KBP model training and validation

Learning Objectives

1. **KBP background**
2. Clinical indication for KBP
3. Importance of KBP model training and validation

Motivation

Motivation

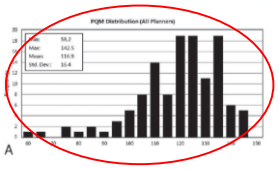
- **IMRT treatment planning relies on user expertise to consistently achieve optimal results**
- **Evaluation of IMRT plans is based on subjective judgment and population based guidelines rather than knowledge from previous radiotherapy treatment data**

Motivation

Practical Radiation Oncology
Volume 2, Issue 4, October–December 2012, Pages 296–305

Variation in external beam treatment plan quality: An inter-institutional study of planners and planning systems

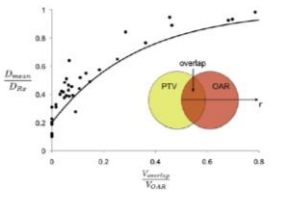
Benjamin E. Nelms PhD[a,b,*], Greg Robinson CMD[c], Jay Markham CMD[c], Kyle Velasco CMD[c], Steve Boyd CMD[c], Sharath Narayan CMD[c], James Wheeler MD, PhD[d], Mark L. Sobczak MD[e]



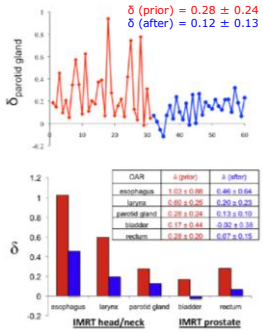
Conclusions

There is a large inter-planner variation in plan quality as defined by a quantitative PQM score that measures the ability of the planner to meet very specific plan objectives. Plan quality was not statistically different between different TPS or delivery techniques and was not correlated to metrics of plan complexity. Certification and education demographics, experience, and confidence level of the planner were not good predictors of plan quality.

Motivation



Moore, K.L. *et al.* Experience-based quality control of clinical intensity-modulated radiotherapy planning, Int J Radiat Oncol Biol Phys. 81(2):545-551 (2011)

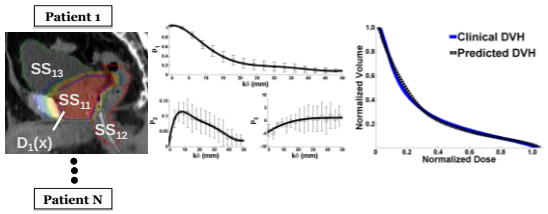


pDVH Process Overview

Step 1
- Identify a set of site similar training patients

Step 2
- Generate pDVH model from training cohort

Step 3
- Utilize pDVH model to obtain DVH prediction for new patient

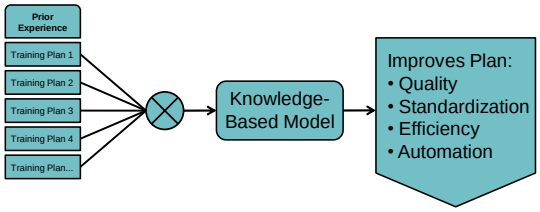


Appenzoller et al, "Predicting DVHs for OARs in IMRT planning " Med Phys 39, 7446 (2012)

In general…

SITEMAN CANCER CENTER

- Significance of Knowledge-Based Planning



Knowledge-based Planning Models

SITEMAN CANCER CENTER

A model-based method for estimating DVHs

- Based on patient geometry and prior knowledge from a set of training plans

Automated planning

- IMRT objectives based on the estimated DVH, prescription dose, and prior planning experience

Treatment plan quality control

- Ability to identify sub-optimal plans

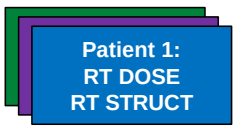
Learning Objectives

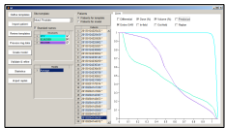
SITEMAN CANCER CENTER

1. KBP background
2. **Clinical indication for KBP**
3. Importance of KBP model training and validation

Outside Clinic Study

- RT datasets for 20 clinically treated prostate IMRT plans from an outside institution transferred to Wash U pDVH DICOM tool





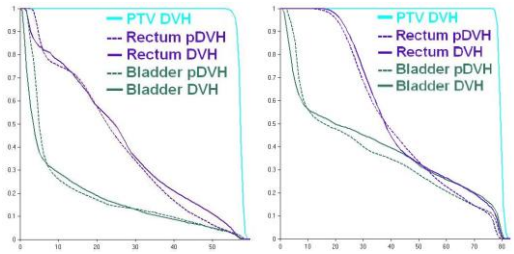
Export DICOM RT files from outside institution TPS

Import files into Wash U pDVH DICOM Tool

Appenzoller L.M., et. al. Predictive DVH models developed at a large institution impact clinically relevant DVH parameters in IMRT plans at an unrelated radiotherapy facility, Oral presentation AAPM 2013.

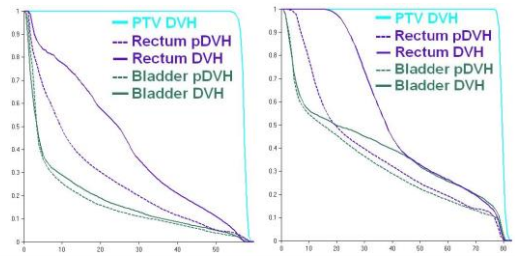
Outside Clinic Study

- Clinic specific pDVH model created using institution's own data
  - Similar plan quality demonstrated for all patients
  - No indication for improvement of clinically treated plans



Outside Clinic Study

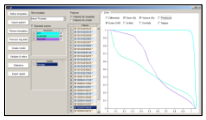
- Comparison against validated Wash U prostate model showed large improvements possible for rectum DVHs and small improvements for bladder DVHs for all patients



Outside Clinic Study

- Five worst patients identified by sum of residuals between clinical DVH and predicted DVH
- Quantify improvements in clinical rectum and bladder DVHs with knowledge of pDVHs by replanning five worst patients

Replan five patients using optimization objectives exported from pDVH tool

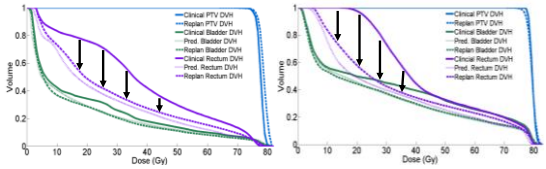


Import replan dose matrix into DICOM tool and compare to original DVHs and pDVHs

Outside Clinic Study

- All five patients replanned showed similar results…

Average Reduction in V65 and V40 for Rectum and Bladder				
Organ	V65(orig)-V65(replan)	dV65	V40(orig)-V40(replan)	dV40
Rectum	4.8%±2.3%	0.9%±1.1%	17.9%±10.3%	0.7%±1.4%
Bladder	3.4%±2.1%	0.4%±0.5%	6.0%±2.8%	0.6%±0.9%



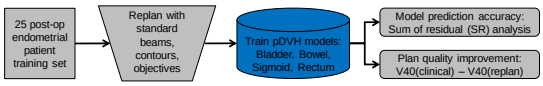
Appenzoller L.M., et. al. Predictive DVH models developed at a large institution impact clinically relevant DVH parameters in IMRT plans at an unrelated radiotherapy facility, Oral presentation AAPM 2013.

Institutional Plan Quality Study

Objective: To assess the impact of DVH prediction (pDVH) models and a standardized planning technique on post-operative endometrial IMRT treatment plan quality.

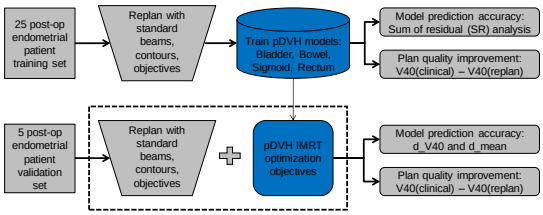
Institutional Plan Quality Study

Objective: To assess the impact of DVH prediction (pDVH)* models and a standardized planning technique on post-operative endometrial IMRT treatment plan quality.



Institutional Plan Quality Study

Objective: To assess the impact of DVH prediction (pDVH)* models and a standardized planning technique on post-operative endometrial IMRT treatment plan quality.



Olsen et al, "Impact of DVH prediction models and a standardized planning technique on post-op endometrial IMRT plan quality." ESTRO 2014.

Results

- The impact of using pDVH models and a standard planning technique is demonstrated by plan quality improvement in the 5 patient validation cohort as seen by a reduction in V40 and mean dose for all OARs compared with the original clinical plan

OAR	25 Patient Training Cohort		
	SR	V40(orig)-V40(replan) (%)	Mean(orig)-Mean(replan) (Gy)
Bladder	0.006 ± 0.045	8.8 ± 7.9	2.5 ± 1.7
Bowel	0.017 ± 0.023	2.7 ± 2.4	2.4 ± 1.6
Rectum	-0.007 ± 0.048	8.3 ± 8.8	3.2 ± 2.4
Sigmoid	-0.012 ± 0.056	12.3 ± 13.9	3.5 ± 2.8

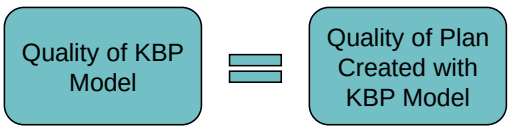
OAR	5 Patient Validation Cohort			
	V40(orig)-V40(replan) (%)	Mean(orig)-Mean(replan) (Gy)	d_V40 (%)	d_mean (Gy)
Bladder	9.8 ± 5.1	2.3 ± 1.5	0.6 ± 5.2	0.5 ± 0.9
Bowel	2.1 ± 2.1	0.5 ± 0.6	1.7 ± 1.4	0.5 ± 1.4
Rectum	9.3 ± 5.9	2.7 ± 3.4	1.8 ± 3.3	0.6 ± 1.1
Sigmoid	9.1 ± 14.8	1.8 ± 2.3	1.3 ± 5.4	0.4 ± 1.5

Learning Objectives

1. KBP background
2. Clinical indication for KBP
3. **Importance of KBP model training and validation**

Model Training and Validation

- Importance of systematic KBP model training and validation process:



Training and Validation Process

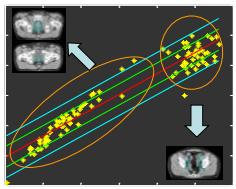
- Patient selection
- Model training evaluation
- Model validation
- Clinical use of model

Training and Validation Process

- Patient selection
- Model training and evaluation
- Model validation
- Clinical use of model

Patient Selection: Geometry

- PTV / OAR Geometry
  - Similar target shape
  - Similar target location
  - Similar relative position of OARs to PTV
- CCMB ex.



Courtesy of J. Alpuche

Patient Selection: Guidelines

- Similar Clinical Objectives
  - Same PTV coverage/OAR sparing criteria
- Similar Clinical Trade-Offs
  - Importance of PTV coverage / OAR sparing
- PTV prescription dose can vary
  - Estimated DVHs will be scaled as a percentage of Rx dose

		Bilateral Neck Treatment	Ipsilateral Neck Treatment
H&N	PTV	95% of PTV > 95% of Rx; Max dose < 110% of Rx	95% of PTV > 95% of Rx; Max dose < 110% of Rx
	Spinal Cord	Max dose 40 Gy	Max dose 40 Gy
	Spinal Cord + Margin	Max dose 52 Gy; < 1% (or 1 cc) exceeds 50 Gy	Max dose 52 Gy; < 1% (or 1 cc) exceeds 50 Gy
	Optic Nerves, Optic Chiasm	Max dose 54 Gy	Max dose 54 Gy
	Brainstem	Max dose 54 Gy; < 1% exceeds 60 Gy	Max dose 54 Gy; < 1% exceeds 60 Gy
	Brain	Max dose 60 Gy; < 1% exceeds 65 Gy	Max dose 60 Gy; < 1% exceeds 65 Gy
	Retina	Max dose 50 Gy; < 5% exceeds 45 Gy	Max dose 50 Gy; < 5% exceeds 45 Gy
	Larynx	As low as possible; mean dose < 45 Gy	As low as possible; mean Dose <25 Gy
	Upper Esophagus	As low as possible; mean dose < 45 Gy	As low as possible; mean dose < 25 Gy
	Parotid	As low as possible; mean dose < 26 Gy	As low as possible; mean dose ≤ 10 Gy (contralateral)
	Pharyngeal Constrictors	As low as possible; V60 < 60 Gy	As low as possible; V60 < 45 Gy
	Submandibular	As low as possible; mean dose < 39 Gy	As low as possible; mean dose < 24 Gy (contralateral)
	Oral Cavity	As low as possible; mean dose < 35 Gy	As low as possible; mean dose < 20 Gy
	Mandible	Max 70 Gy; < 5% exceeds PTV Rx	Max 70 Gy; < 5% exceeds PTV Rx
	Unspecified Tissue	Less than PTV Rx; < 5% exceeds PTV Rx	Less than PTV Rx; < 5% exceeds PTV Rx

Patient Selection: Patient Numbers

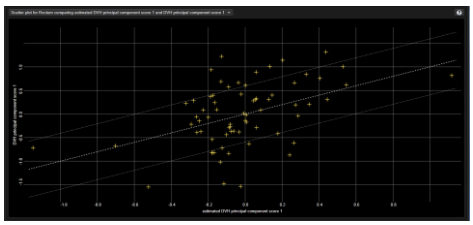
- Number of training patients increases as the model complexity increases.
- Model validation process is used to ensure the number of training patients is sufficient

Patient Selection: Plan Quality

- Training set plan quality
  - Output of KBP model directly correlated to input
  - Statistical noise present in KBP training set can impact model behavior
- QA of training set
  - Clinically approved, safe treatment
  - Consider iterative process in model training to obtain adequate model

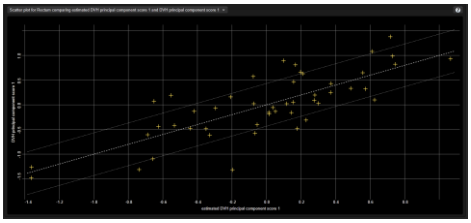
Plan Quality Considerations

- Ex. Prostate and Node model: OAR = Rectum
  - Poor correlation between actual and estimated DVH principal components for model trained with 70 mixed quality treatment plans



Plan Quality Considerations

- Ex. Prostate and Node model: OAR = Rectum
  - Good correlation between actual and estimated DVH principal components for model trained with 48 good quality treatment plans



Training and Validation Process

- Patient selection
- Model training and evaluation
- Model validation
- Clinical use of model

Model Training and Evaluation

- Review the model statistical results
- Review the clinical vs. estimated DVHs
- Review model outliers
  - Geometric and dosimetric

Note: Will discuss model evaluation and validation in context of Varian RapidPlan™. Specific steps will differ depending on algorithm and implementation of KBP software.

Review Model Statistics

- Assess model over-fitting
- Assess predictive ability of the model

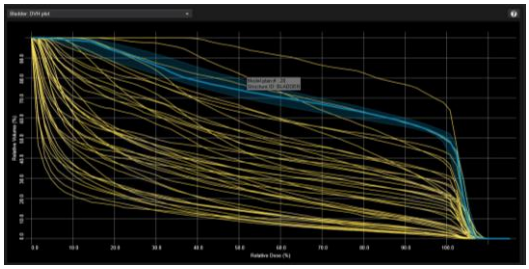
```
Estimation model statistics for structure Rectum:
  Model goodness of fit
    DVH's principal components average fit 0.998977 out of 1.0
    GED's principal components average fit 0.999374 out of 1.0
    Regression model parameters' coefficient of determination 0.772767 out of 1.0
    Regression model's parameters average chi square 1.14286
    Whole estimation model's fit 0.771433 out of 1.0
    Whole estimation model's average MSE 17.4678
  Model goodness of estimation
    Mean squared error between original and estimate 0.00237184
    Statistics outside boundaries:
      Proportion of histogram bins outside boundaries 40.4178
      Mean of absolute deviation of bins outside boundaries -0.00248895
      Mean squared error of bins outside boundaries 0.000618992
      Standard deviation of the error of bins outside boundaries 0.0132559
      Mean of the error of bins outside boundaries 0.0118805

Model was successfully trained with 41 out of 41 plans.

Model training done
```

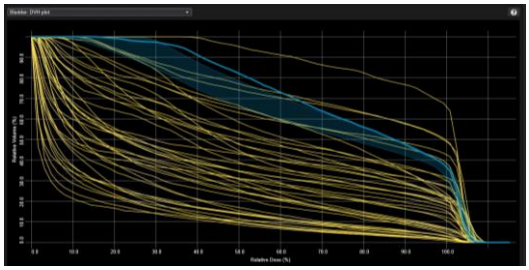

Review Clinical vs. Estimated DVHs

- Model properly identifies variation in training set DVHs



Review Clinical vs. Estimated DVHs

- Clinical DVH > estimate → Outlier
  - Clinically relevant parameter



Identify and Remove Outliers

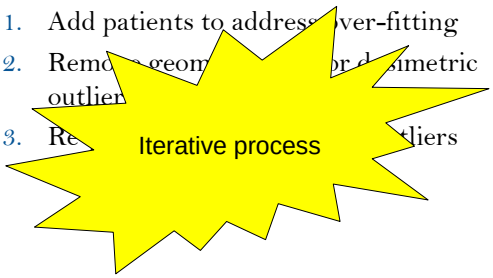
- Dosimetric outlier
  - Clinical DVH substantially differs from estimated DVH based on a clinically significant parameter
- Geometric outlier
  - PTV volume/shape substantially differs from the majority of the training set
  - Structure volume/shape substantially differs from the majority of the training set
  - Positional relationship between structure and PTV substantially differs from the majority of the training set

Steps to Improve Model Quality

1. Add patients to address over-fitting
2. Remove geometric outliers or add similar patients
3. Remove or re-plan dosimetric outliers

Steps to Improve Model Quality

1. Add patients to address over-fitting
2. Remove geometric outliers or add similar patients
3. Remove or re-plan dosimetric outliers



Training and Validation Process

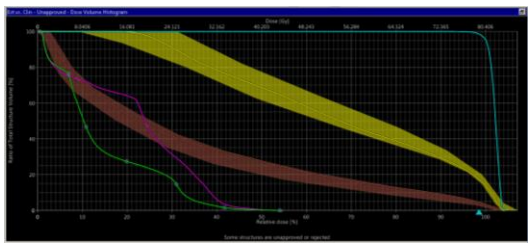
- Patient selection
- Model training and evaluation
- Model validation
- Clinical use of model

Validation Patients

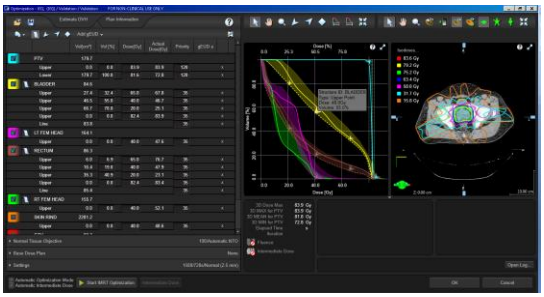
- Independent from patients used to train model
- Represent the range of patient geometries, plan geometries, and plan prescriptions for which the model will be clinically used
- Good plan quality
  - PTV coverage
  - OAR sparing

Clinical vs. Estimated DVHs

- Review that clinically approved plan is within DVH estimation range
- If it is not, it is possible that plan can be improved

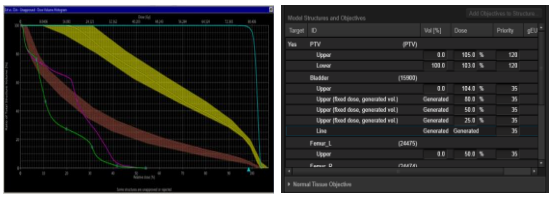


Create Validation Plan w/ Model



Objective Selection

- IMRT objective selection
  - Ensures clinically acceptable plan that achieves model estimate
  - Based on prior clinical experience
  - Priorities and objectives tuned during model validation



Assess Clinical Acceptability

- Review validation plans as per normal institution clinical standards
  - Isodose distribution
  - Clinical guidelines (scorecard)
    - PTV coverage
    - Hotspots
    - Population-based OAR DVH cut-points
  - Plan technical integrity

Training and Validation Process

- Patient selection
- Model training and evaluation
- Model validation
- Clinical use of model

Clinical Use of Model

- Do not venture far from your validation set
- Consider automation/standardized protocols
  - Beam arrangement
  - Contouring guidelines
  - Plan quality reports (scorecards)
- Develop guidelines for clinical use
  - When should I use the model?
  - When should I plan manually?

Final Thoughts

- Proper model training and validation is necessary for the clinical use of knowledge-based planning models
  - Possibility for systematic errors
- KBP is an exciting advancement
  - Potential to improve quality, efficiency, and standardization
  - Does not replace human/clinician judgment

SITEMAN CANCER CENTER

Acknowledgements

- Sasa Mutic, Ph.D.
- Kevin Moore, Ph.D.
- James Kavanaugh, M.S.
- Jun Tan, Ph.D.
- Jorge Alpuche, Ph.D.
- Jackie Wu, Ph.D.
- Beth Bottani, C.M.D.
- Jeff Michalski, M.D.

SITEMAN CANCER CENTER

Questions?

www.siteman.wustl.edu