Project IX: Big Data Meets Medical Physics Dosimetry

Foundations and Recent Advances

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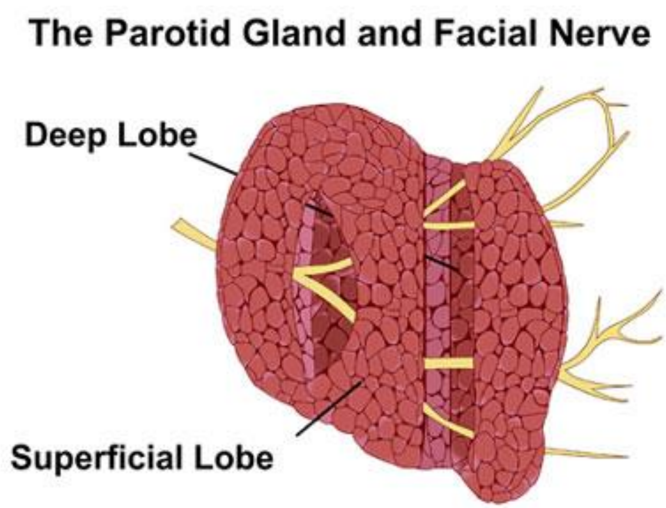
Topic

- Goal – improve radiotherapy risk assessment through data mining.
- Formal term for risk measure is normal tissue complication probability (NTCP)
- Initial focus – xerostomia (dry mouth) due irradiation of the parotid gland.



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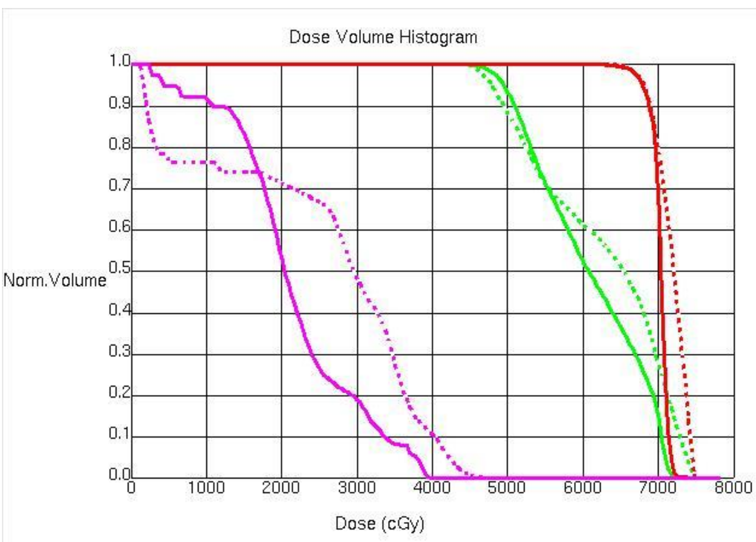
Literature

- Conventional method for computing NTCP, Lyman-Kutcher-Berman (LKB).
- This seminar presents four papers that form the foundation of LKB.
- Seminar includes a more recent paper incorporating PCA.



ROI Statistics

Line Type	ROI	Trial	Min.	Max.	Mean	Std. Dev.	% Ou
green dotted	ptv1	Conformal	3568.6	7567.6	6252.6	896.3	0.
green solid	ptv1	IMRT	3355.2	7366.9	6078.4	743.5	0.
red dotted	ptv2	Conformal	5382.9	7541.1	7174.1	209.3	0.
red solid	ptv2	IMRT	5049.4	7366.9	7016.2	128.2	0.
magenta dotted	s.cord	Conformal	132.1	4687.2	2449.1	1439.0	2.
magenta solid	s.cord	IMRT	236.7	3957.8	1725.1	1138.0	19.

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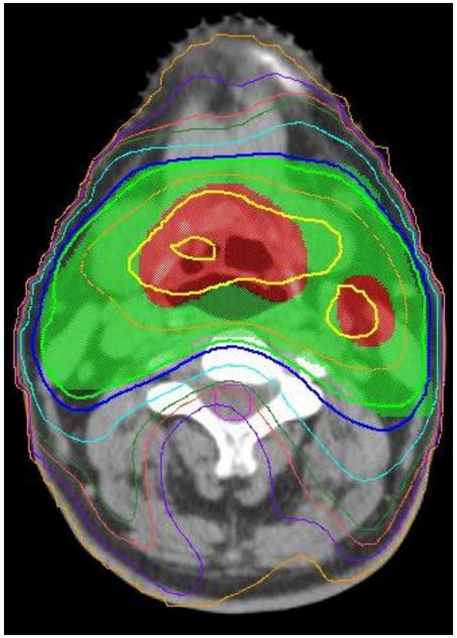
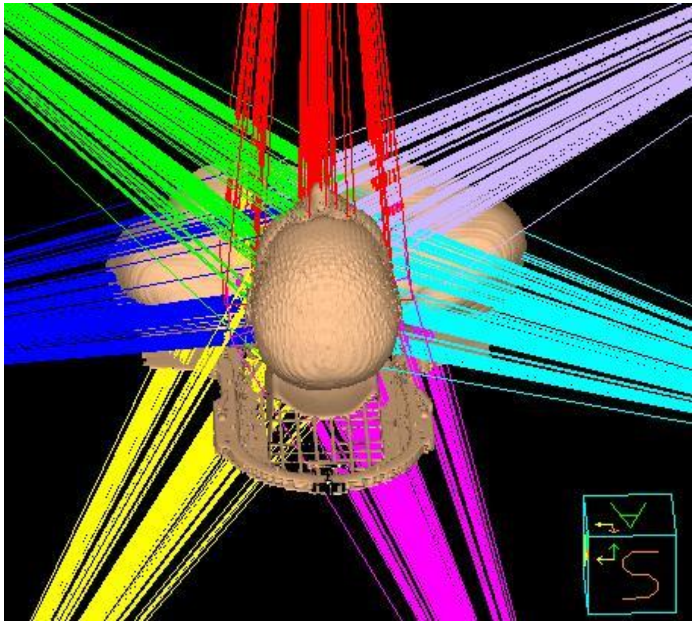
Motivation for LKB

- The adoption of CT led to the emergence of 3D dose planning.
- Previous approach assumed uniform irradiation of the entire organ.
- NTCP assessment used TD_{50} and TD_5 "tolerance doses" (Rubin & Casarett 1972).
- Need to calculate NTCP of non-uniform doses over parts of the volume.





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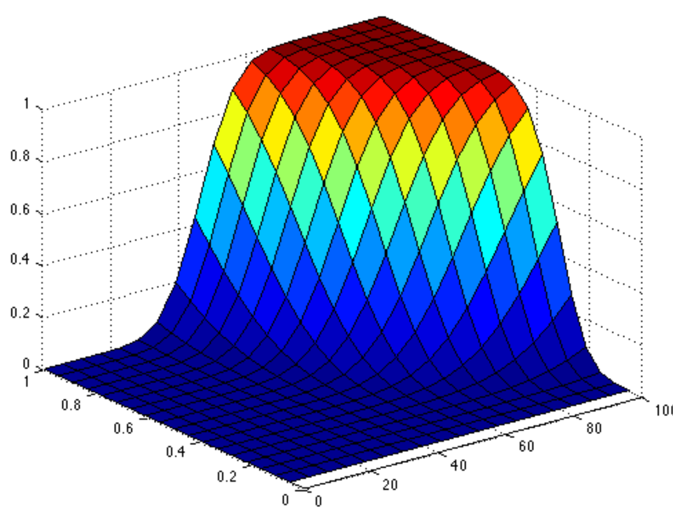
Lyman (1985) – The Model

- Assumes a power equation relationship between whole and partial volume.
- Incorporates previous TD_{50} approach.
- Requires parameterization of *n* and *m*.
- Accounts for partial volume, but still assumes uniform dose.

$$TD_{50}(V) = \frac{TD_{50}(1)}{V^n}$$

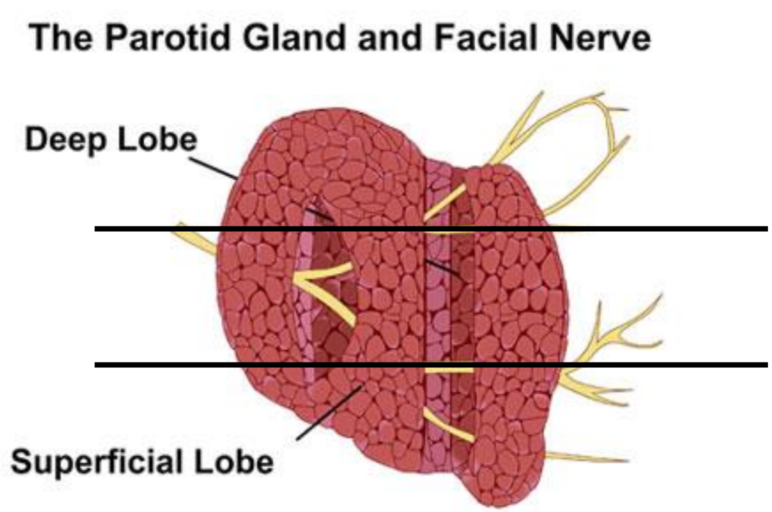
$$t \sim N(0,1), \quad t = \frac{D - TD_{50}}{\sigma(V)},$$

$$\text{where } \sigma(V) = m[TD_{50}(V)]$$



Emami, et al. (1991) – The Data

- Provides TD_{50} and TD_5 values (estimates) for $\frac{1}{3}, \frac{2}{3}$, and whole volumes.
- Values from combination of literature review, hard data, estimates from clinical experience.
- For parotid, assume minimum 50% volume exposure for xerostomia.
- $TD_5 = 3{,}200$, $TD_{50} = 4{,}600$ for $\frac{2}{3}$ and whole volumes; $TD_{100} = 5{,}000$.



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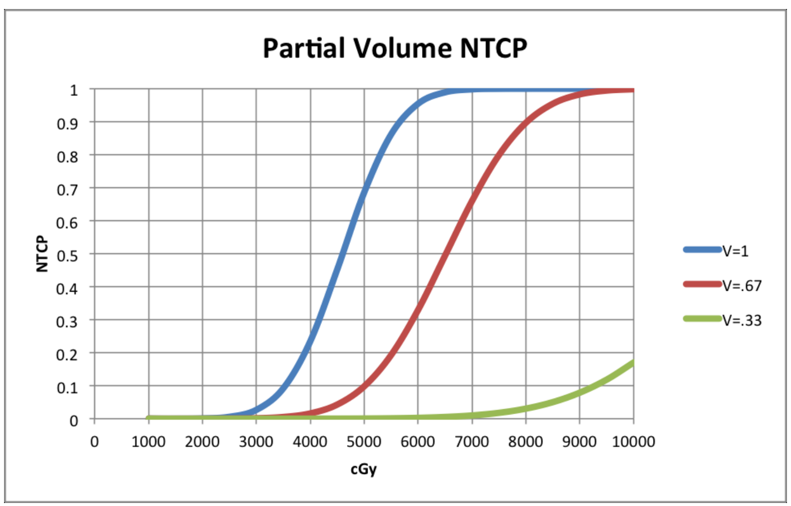
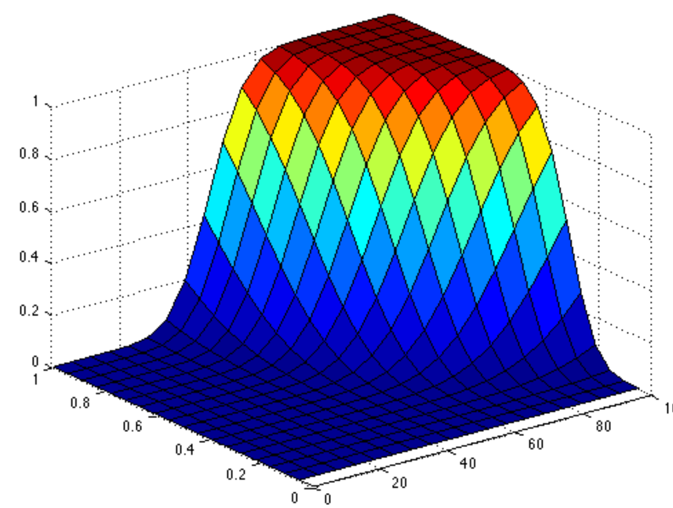
Burman, et al. (1991) – Parameters

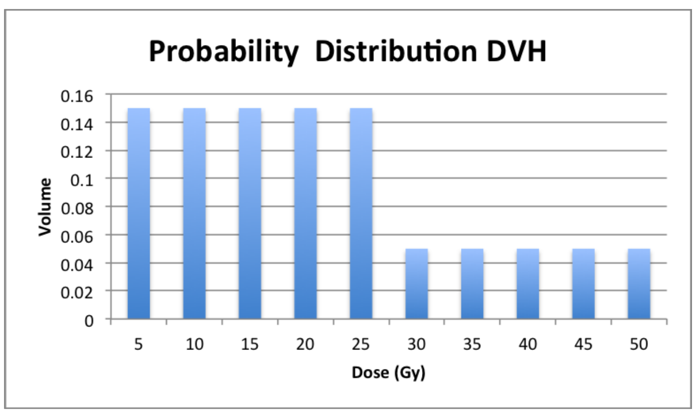
- Uses data from Emani, et. al. to calculate Lyman parameters.
- Values from combination of literature review, hard data, estimates from clinical experience.
- For parotid, assume minimum 50% volume exposure for xerostomia.
- TD_{50} = 4,600, TD_5 = 3,200 for $\frac{2}{3}$ and whole volumes; TD_{100} = 5,000 .

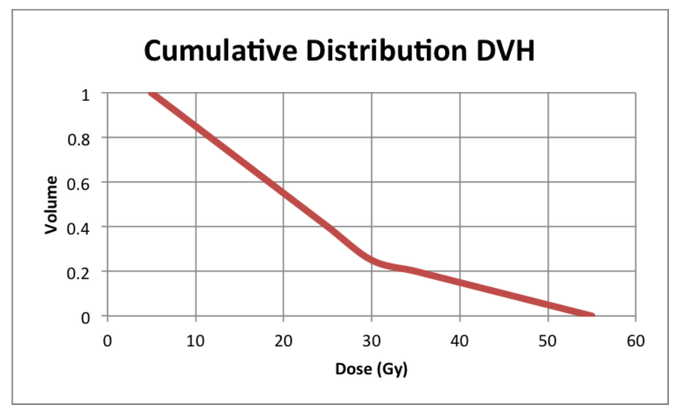




Kutcher & Burman (1989) – DVH

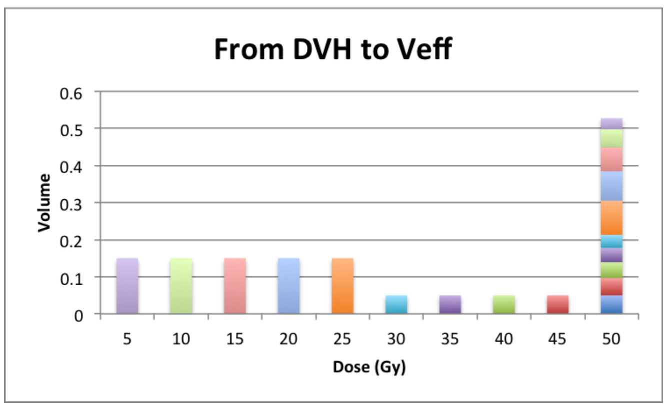
- Replace uniform with dose volume histogram (DVH).
- DVH may represent probability distribution or cumulative distribution.
- DVH removes spatial location.
- Typically visualized as cumulative distribution, "y% of the volume has received at least x dose."

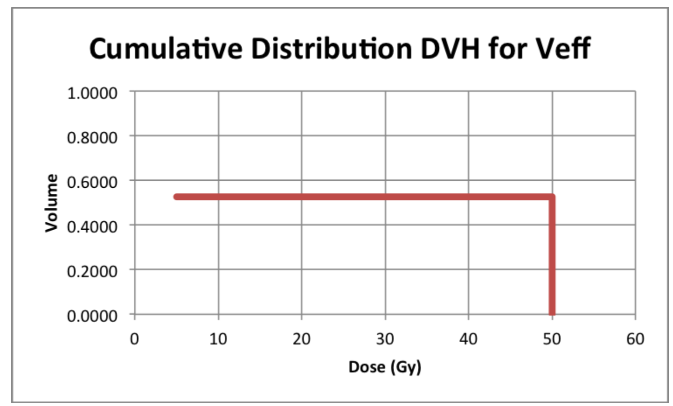




Kutcher & Burman – D_{max}, V_{eff}

- Reduces DVH to a single pair of D_{max}, V_{eff} values.
- Assumes high doses to small volumes are equivalent to smaller doses to larger volumes.
- Equivalence described by power relationship.
- Results in inputs for Lyman equation.





$$\Delta V_{eff} = \Delta V_i \left(\frac{D_i}{D_{max}}\right)^{\frac{1}{n}}$$

$$V_{eff} = \sum_i V_i \left(\frac{D_i}{D_{max}}\right)^{\frac{1}{n}}$$

LKB – Summary

- Pros:
  - Adapts single dose whole volume TD_5 and TD_{50} dose guidelines to NTCP values for non-uniform doses over a partial volume.
  - Makes biological based assumptions.
  - Only three parameters.
- Cons:
  - Does not account for treatment location.
  - Conventional parameterization performed with scarcity of hard data.
  - Using (D_{max}, V_{eff}) removes a great deal of shape data from the DVH.

Dawson et al. (2005) – PCA of DVH

- No need for parameterization.
- For parotid, two PCs described 94% of the variance.
- Three PCs richly capture DVH shape.
- Possible improvement by centering and scaling data.

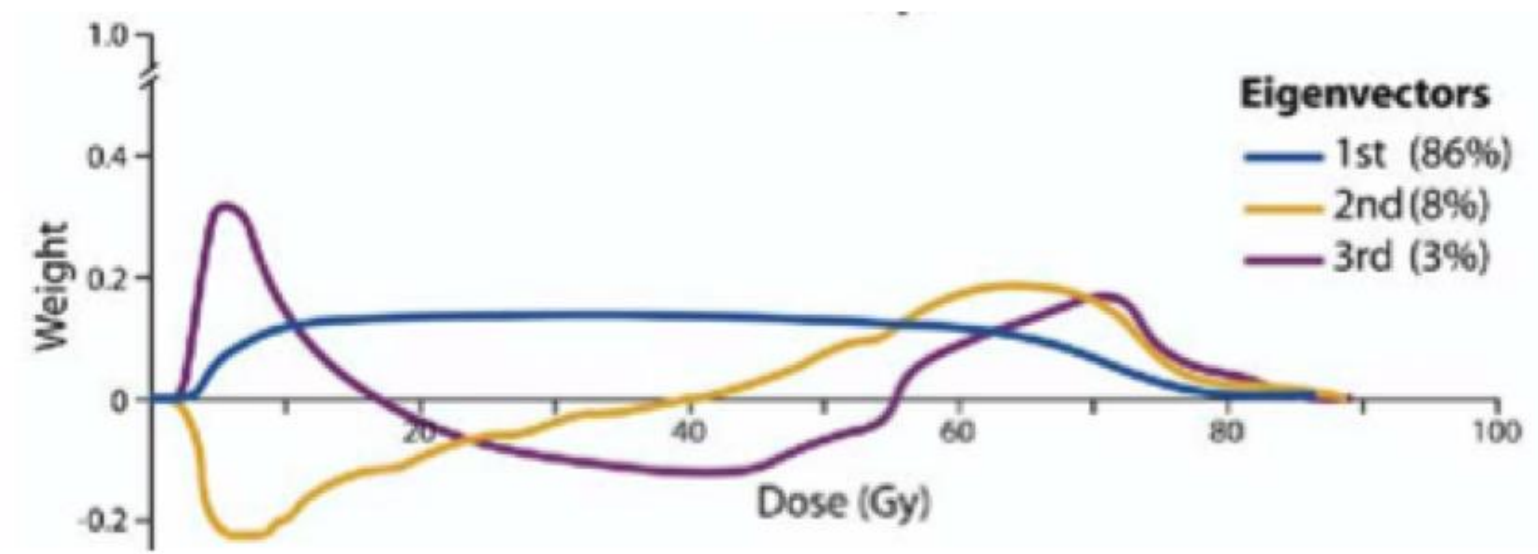
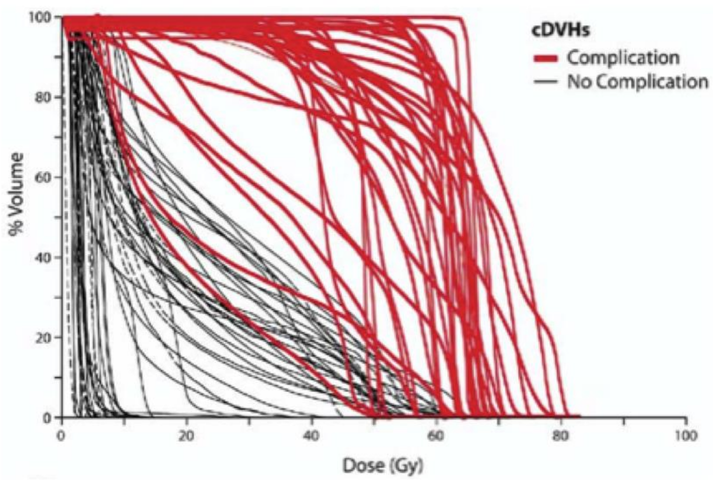
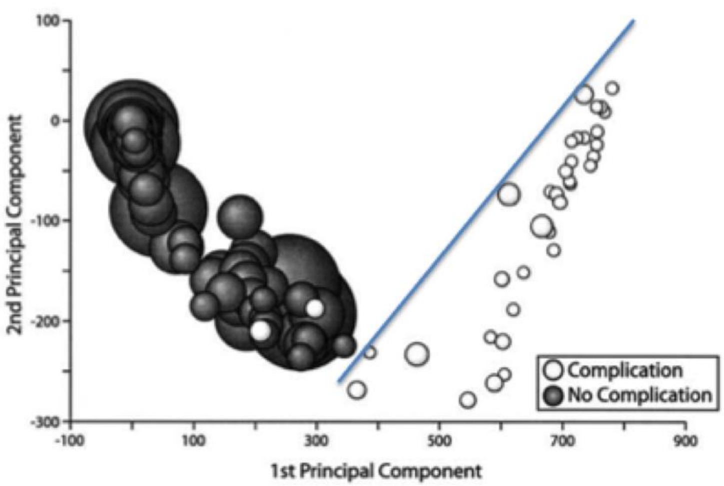


Image from Dawson et. al. (2005)

Dawson et al. (2005) – PCA of DVH

- PCA may provide better classification than D_{max}, V_{eff}.
- Treatment based, not biologically based. PCs may not capture new protocols.

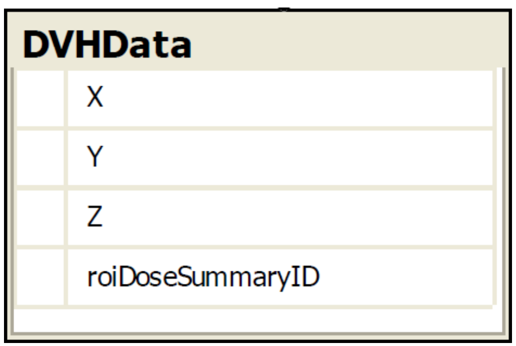


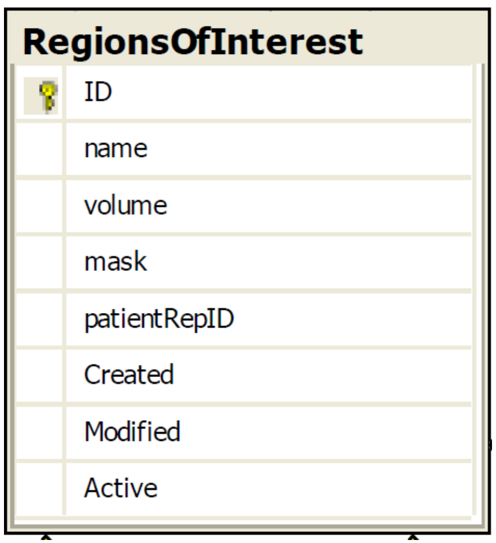


Images from Dawson et. al. (2005), line added.

Application to Project IX

- We wish to include dose location in NTCP calculation.
- Divide our regions of interest into 125 equal sized 3D rectangular volumes.
- Calculate DVHs on the whole ROI and each subregion.
- Reduce DVHs to two PCs for data mining task.





Images courtesy of Dr. Todd McNutt,
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References

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Thank You

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