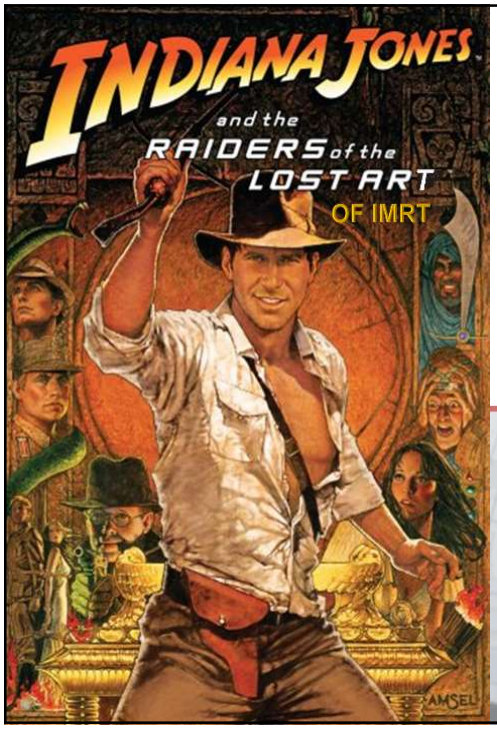

The Lost Art of IMRT

Gavin Graeper, MS
Kristen Krupela, CMD

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Creating a Cancer-free World.
One Person, One Discovery at a Time.

The Ohio State University Comprehensive Cancer Center – Arthur G. James Cancer Hospital and Richard J. Solove Research Institute

Disclosures

- None

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Objectives

- With the recent popularity of volumetric modulated arc therapy (VMAT), the clinical use of traditional intensity modulated radiation therapy (IMRT) may be diminishing

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Objectives

- Goal of this presentation:
  - Steer the dosimetrist's mind from defaulting to VMAT in cases where it may not provide value
  - Attempt to resurrect IMRT planning: THE LOST ART

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RAIDERS of the LOST ART OF IMRT PLANNING

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Outline

- Development of IMRT
- IMRT Optimization – Behind the Curtain
- Case Studies
  - Lung
  - Breast/CW+Nodes
  - Head and Neck
- Clinical Considerations

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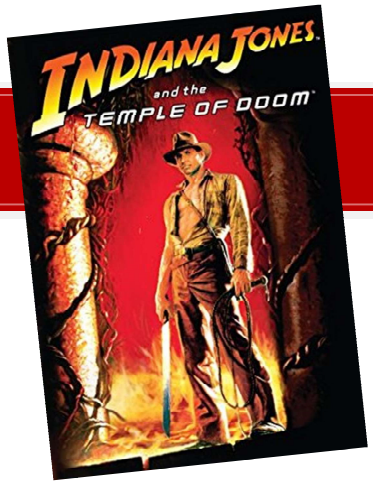

Development of IMRT

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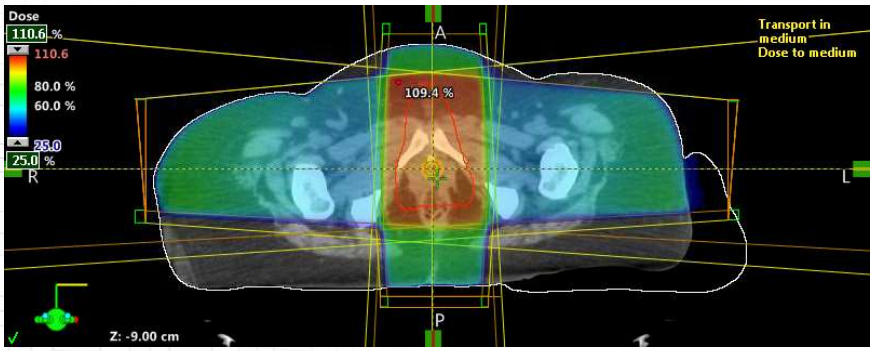
Started from the Bottom…

- Previously, radiation treatments matched height and width of tumor
  - Substantial healthy tissue exposed to full strength of radiation beams



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…Now We're Here

- Advances in imaging technology make it possible to delineate the target
- Accurate target identification allows:
  - Precise radiation treatments
    - High dose directly around tumor
    - Avoiding healthy tissue

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…Now We're Here

- We now have the ability to modulate the intensity or fluence of a radiation beam
  - Each field may have one or many areas of high-intensity radiation and any number of lower-intensity areas within the same field
  - Allows for EVEN greater control of the dose distribution within the target
- By modulating the intensity of radiation within each field, we have limitless possibilities to sculpt radiation dose!

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What is IMRT??

Intensity Modulated Radiation Therapy

- Refers to a technique in which non-uniform fluence is delivered to the patient from any given beam angle to optimize dose distribution
- Non-uniform beam intensities can improve dose distributions by:
  - Compensating for contour irregularities
  - Compensating for tissue inhomogeneities
  - Compensating for highly irregular target volumes
  - Sparing organs at risk located in the vicinity of the target volume

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Development of IMRT

- IMRT was born from the wide adoption of 3DCRT
- It was proven that if the intensity of radiation can be modulated across a radiation field, then this increased freedom would afford a greater ability to shape high dose to better conform to the target than with 3DCRT
  - Lead to emergence of computer optimization techniques – Inverse Planning!

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Development of IMRT

- Concept of inverse planning for IMRT first revealed by Anders Brahme
- Interestingly, the first approaches to calculate intensity maps for IMRT were not based on optimization techniques
  - Instead the underlying integral equations were reveresed
    - spatial dose distribution was prescribed, and the beam intensity distribution that would precisely yield this dose distribution was then calculated
- To find an exact solution to this inverse problem, several assumptions and approximations had to be made, and solutions could only be found for very simple symmetrical cases

Development of IMRT

- 1993 – form of IMRT using rotational fan beams called tomotherapy was proposed
- 1994-1995 – works are published to demonstrate use of MLCs for intensity modulation of fixed gantry in either a dynamic mode or static mode
- 1996 – first clinical implementation of IMRT using dynamic MLC leaf motion at Memorial Sloan Kettering Cancer Center
- 1997 – first IMRT plan is generated using commercially available software from NOMOS Corporation and is delivered at Stanford University
- 2001 – Medicare billing code for IMRT treatment was added to the current procedural terminology (CPT)

Development of IMRT

- 1995 – new form of IMRT (Intensity Modulated Arc Therapy)
- IMAT delivers radiation treatment over a continuous arc
  - Uses cone beams shaped by MLCs to achieve intensity modulation
  - Goal is to eliminate table translations
    - Requires geometric connectivity of aperture from neighboring angles
    - Adds significant complexity to the planning of IMAT treatments
  - Machine dose rate constant during arc rotation
    - Had to increase number of fields, segments, or allow dose rate to fluctuate to achieve desired plan quality

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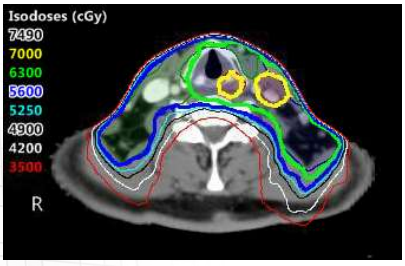
Development of IMRT

Volumetric Modulated Arc Therapy (VMAT)

- Rate of rotation of the gantry and the LINAC dose rate can both be modulated during treatment
  - Even more degrees of freedom!



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Development of IMRT

- Rapid adoption of IMRT was facilitated by additions to the United States Federal funding mechanism for radiation oncology
  - Medicare begin to introduce payment systems that encouraged the introduction of new technology
- Created a financial incentive to purchase treatment planning systems and linear accelerators that included the cutting-edge technology for IMRT
  - Quality of care was improved
  - Health care costs reduced
  - Capital costs recouped
- IMRT rapidly became available in radiotherapy centers

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Aim of IMRT Planning

- Create a custom three-dimensional dose distribution to the target volume
  - High degree of critical organ sparing
  - High degree of dose conformality to target
  - **With great power, comes great responsibility!**
    - Steep Dose gradients
    - Setup reproducibility and contouring accuracy is key
- Take target volumes to higher doses due to superior dose distributions
  - Ability to perform dose escalation

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What do you need for IMRT?

- 3D Anatomic Image Data
  - Mathematically precise geometric information about the patient's anatomy
- Image Segmentation
  - Delineated PTV, CTV, GTV
  - Critical structures (OARs), avoidance structures, optimization structures
- MLCs
  - Non-uniform beam intensities are produced using motion of MLCs during irradiation to spatially modulate the intensity
- Planning Objectives

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Which IMRT Technique to use?

- Sliding window (SW) or dynamic IMRT
  - Radiation beam is modulated by continuously moving MLCs
- Step-and-shoot (SS) or static IMRT,
  - Radiation beam is divided into a set of smaller segments of differing MLC shape
  - Radiation beam is switched off between the segments
- VMAT
  - Gantry and MLCs both in motion
- Forward Planning vs Inverse Planning IMRT?

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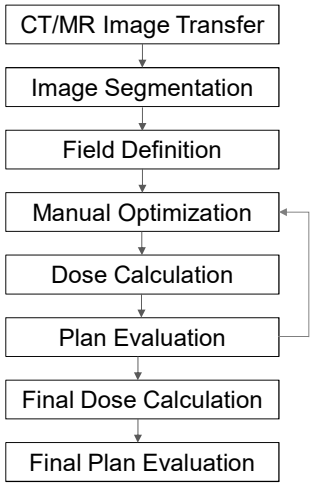
Forward Planning IMRT

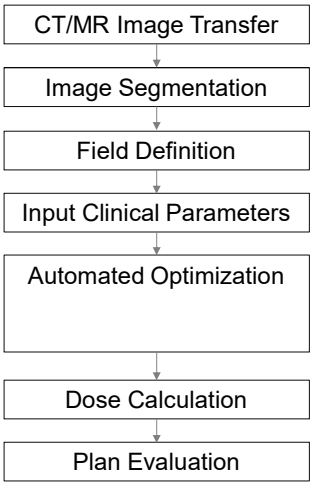
- Clinical implementation of forward planning IMRT is relatively easy, because it is closely related to conventional planning
  - Depends on the geometric relationships between the tumor and nearby sensitive structures
  - Manual definition of the segments leads to intuitive choices of the segment shapes based on the beam's eye view option of the planning system
  - Useful for breast planning

Inverse Planning IMRT

- Inverse planning IMRT is less dependent on the geometric parameters
- Dependent on specification of volumes of tumor targets and sensitive structures, as well as their dose constraints
- Inverse planning is far less related to conventional radiotherapy
  - Segment shapes are not defined manually
  - Number of segments is usually considerably larger

Forward Planning vs Inverse Planning





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Inverse Planning IMRT

- The inverse planning computational methods for calculating the optimum modulated intensity beam distributions fall into two broad categories:
  1. Analytical methods which use a back projection algorithm to arrive at the fluence distribution from the desired dose distribution
  2. Iterative methods which minimize a cost function
     - Quantitatively represents the deviation from the desired goal
     - The further from 0, the less optimal the solution

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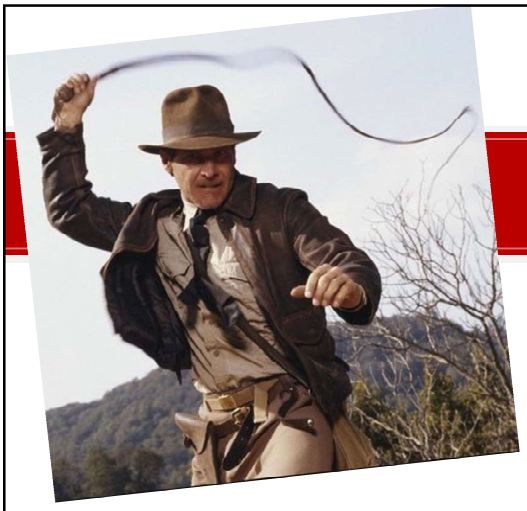

IMRT Optimization: Behind the Curtain

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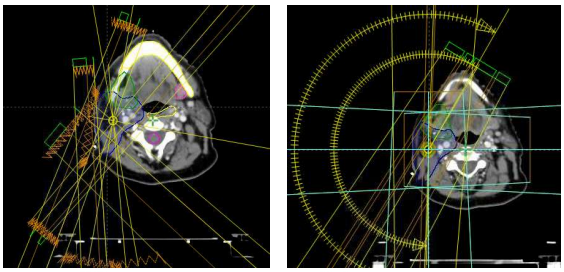
Optimization Differences

- Both IMRT and VMAT use inverse planning to arrive at a final dose distribution
  - Based on user defined optimization objectives
  - Highly contour dependent
- There are several methods to come up with a dose distribution, these can differ between IMRT and VMAT



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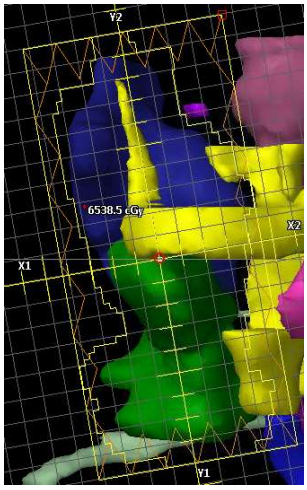
Brief History of Inverse Planning

- Beamlet based optimization
- Break each beam into a series of beamlets
  - Pencil beams



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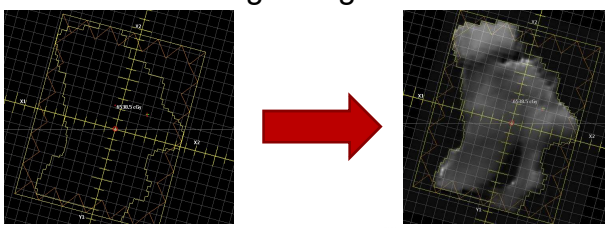
Fluence Optimization

- Based on all of the beamlets from each beam an idealized fluence map is created
- Each beamlet carries a different weight
- The sum of the beamlets provides a basic idea of the dose distribution
  - Crude but fast so optimizer can update relatively quickly
- But how do we assign weights to beamlets?



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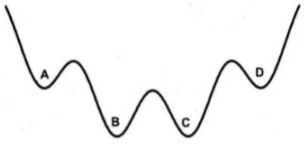
Fluence Optimization

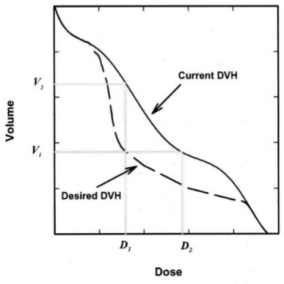
- Start with each beamlet having equal weight, then changing the weight slightly
  - Looks for reduction in error function
  - If this improves the plan then we continue in that direction
  - Keep going until solution has converged
- Process is iterative
  - Stochastic (simulated annealing)
  - Nonstochastic (gradient based)



(a)

$$f(x) = \sum_{j=0}^{3} w_j f_j(d(x)),$$

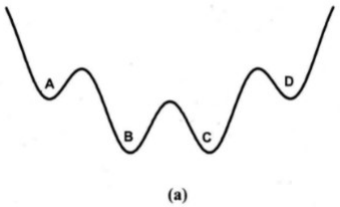
$$f_0(d) = \sum_{i \in S_0} (d_i - b_i)^2,$$



(b)

Fluence Optimization

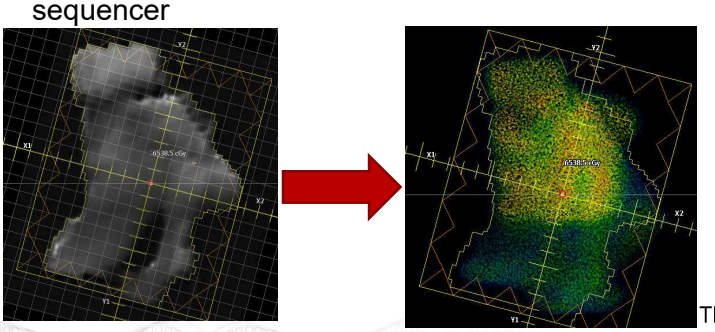
- Gradient based optimization is faster
  - Only goes down the gradient
    - Potential get stuck in local minima
      - Optimizers add functions to help minimize this
- Simulated annealing method is slower but potentially leads to better optimization
  - Optimization steps semi-random
    - Allows escape from local minima



(a)

Converting to Deliverable Dose

- Fluence has been optimized and has reached a global minimum that is as close to our optimization objectives as we can get, then what?
- As of yet in the process there is no MLC sequence
  - The MLC positions are built in retrospectively with a leaf sequencer



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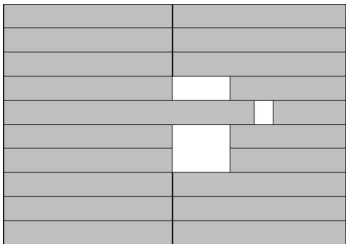
Sequencer Options

- Based on machine MLC limitations
  - Leaf speed
  - Leaf transmission
  - Leaf interdigitation capabilities



- Two options
  - Sliding Window
    - Continuous beam on as MLCs traverse field
  - Step-and-Shoot
    - Fluence pattern is matched based on static MLC segments

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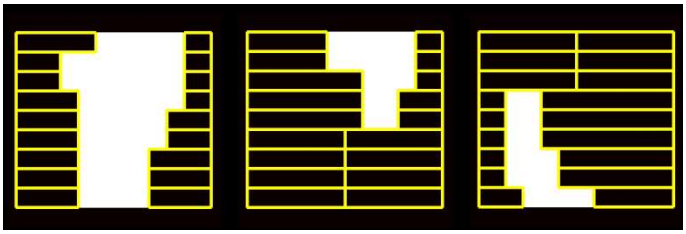
Step-and-Shoot vs Sliding Window

- Delivery time – sliding window
- MU efficiency – step-and-shoot
- Dose distribution – equal

- No clear winner



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Dose Computation

- Once MLC sequencing is complete, dose is computed
- The ideal fluence cannot always be matched perfectly by the machine
- Calculation is done at a finer resolution and with a more advanced algorithm
- There can be large differences between optimized dose distribution and the final calculated distribution
  - Especially in areas with extensive inhomogeneities
    - Pencil beams do not consider lateral scatter well
    - The speed at which optimization occurs comes at the cost of accuracy
    - Knowing this in advance helps us optimize around it
      - Ex. Add margin for lung PTVs largely consisting of air

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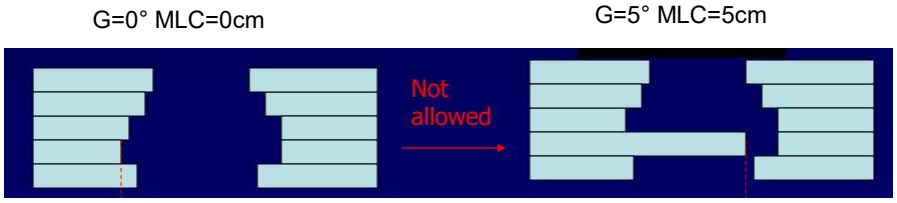
Another Option…

- Direct Aperture Optimization (DAO)
- Reduces the problem down to a one-step process
- MLC delivery constraints are built into the optimization
- MLC sequencing step is removed
  - Final dose distribution more accurate
- Optimizes MLC shapes to come up with dose instead of optimizing fluence and converting to MLC shapes
- VMAT optimizes this way
- No editing of fluence because fluence map is never created

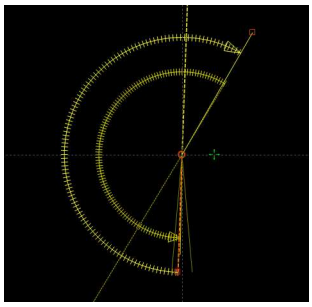
VMAT Optimization

- Uses DAO
- Broken down into various steps to ease the optimization process
- Must consider interconnectedness of leaf sequencing
  - Rapid MLC movements between angles are not allowed
    - If gantry travels at 6°/s and max leaf speed is 2.5 cm/s then leaves can only travel 0.41cm/°



VMAT Optimization

- Arcs are split into control points
  - Each control point corresponds to a gantry position
  - As arc rotates from one control point to the next the MLCs move
  - Forms continuous rotation and delivery
  - MLCs, Jaws, Gantry, and dose rate are all changing continuously



Index	Meterset Weight	X1 [cm]	X2 [cm]	Y1 [cm]	Y2 [cm]	Gantry Rtn [deg]	Dose Rate [MU/min]	Gantry Speed [deg/s]	MU/deg
3	0.0133	+5.0	+4.5	+8.8	+10.3	184.8	462.657	6.000	1.285
4	0.0222	+5.2	+4.2	+8.8	+10.3	186.6	462.657	6.000	1.285
5	0.0310	+5.2	+4.2	+8.8	+10.3	188.5	462.657	6.000	1.285

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VMAT Optimization

- Problem is far too complex with so many “fields” so it is broken down into simpler problems and slowly adds complexity
- Initially arc is broken down into segments evenly sampled over the arc, ex. every 22° for 180° arc
  - Gives rough shape to dose distribution
- Once optimization has converged, twice as many segments are sampled
  - MLC positions at each initial segment have been assigned, so optimization is mostly kept to additional segments, keeping the problem “simple”
- This continues (4 iterations in Eclipse) until all the control points have been segmented and assigned MLC positions

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VMAT Summary

- Biggest constraint is leaf speed
  - Limits the amount of modulation between control points
- No modification of dose distribution
  - DAO does not allow for painting of fluence
- Optimization takes longer
- Main advantages are:
  - Ease of setup
    - 2 arcs instead of 5-12 fields
  - Decreased treatment time
  - Highly conformal dose and even dose falloff

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Clinical Implementation

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Considerations…

- All plans generated using Eclipse Treatment Planning System - Version 13.6
- Plans delivered on Varian TrueBeam
- IMRT refers to fixed field, VMAT refers to arc
- VMAT patients chosen at random, retrospectively planned with IMRT

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IMRT or VMAT?

What should we consider when making the clinical decision between IMRT vs VMAT?

- What should I be avoiding?
  - A careful choice of beam angles can help reduce dose to critical structures
- Is target unilateral?
  - IMRT reduces low dose spill and allows fixed jaws
- How much time do I have to plan?
  - IMRT optimization is quicker
- Can the patient lie on the table?
  - VMAT delivery is quicker
- MU efficiency
  - Potentially lower MUs with VMAT

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Lung

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Lung

- Use of IMRT to treat tumors in regions of the body that experience involuntary intrafraction motion has been worrisome for two reasons:
  - Potential for Geometric Miss
  - Interplay Effects between the motion of the tumor and the motion of the machine (gantry, collimator, and MLC) used to create the modulation pattern
- Both of these concerns can be managed by appropriate imaging and plan design

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Lung - Geometric Miss

- The issue of geometric miss should be addressed by design of appropriate margins on targets and PRVs
- IGRT process
  - Understand the relationship between the imaging surrogate and the actual target
  - Realize this relationship can be influenced by the motion management technique that is chosen
- Motion can also be minimized by gating, abdominal compression, or other approaches

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Lung – Interplay Motion

- The issue of the interplay effect has been extensively studied, and although extremely large dose deviations are theoretically possible, such deviations are generally not found in the MLC sequences of real clinical cases
- Even when the interplay effect does cause dose deviations from day to day, these deviations average out after a few fractions

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Lung – Interplay Motion

- Notably, dosimetrists could potentially create an extremely complicated, overmodulated plan for which the interplay effect can become significant
  - In situations where possible interplay effects are a concern, the dosimetric errors caused by the interplay effect can be reduced by reducing the dose rate
    - Longer treatment times result in more opportunities for the effects to average out
  - To minimize any interplay effects when moving targets are treated with IMRT (or VMAT), treatment planners should avoid overmodulating the treatment plan and use multiple arcs

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Lung

Volumes Created:
- GTV delineated on free breathing scan **or** exhale breath hold (e.g. primary tumor, PET-positive disease, or nodes >1.0 cm short axis)
- ITV constructed from 4D series
- CTV: GTVs plus potential occult disease in ipsilateral hilum (level 10) if no gross involvement
- PTV: expanded a minimum of 10 mm to make PTV unless daily imaging used (in which case it can be reduced to 0.5 cm)
- **Planned boost:** NO

Imaging:
- Tx planning scan: free-breathing
- Additional Series: 4D scan

Prescription Dose:
- PTV total dose: 4500 cGy
- PTV dose/fx: 150 cGy
- Frequency: BID (at least 6 hrs apart)
- Total: 30 fractions over 3 weeks

PTV Planning Dose-volume Objectives:
- Heterogeneity Correction: **ON**
- Energy 6X preferred (consider 10X/18X if needed)
- ≥ 98% of PTV receives ≥ 95 % of the prescribed dose
- ≥ 95% of PTV receives 100 % of the prescribed dose
- ≤ 2% of the PTV receives ≥ 115% of the prescribed dose
- ≤ 5% of the PTV receives ≥ 110% of the prescribed dose

Priority (#1 is highest)	Critical Structure
1	**Spinal Cord** (concurrent chemo): **maximum** point dose 41 Gy **Avoid irradiation of the spinal cord as much as possible (i.e. no more than 1.2 Gy/fraction), and avoid hotspots
2	**Total Lung ([Right + Left] - CTV):** • Mean lung dose = 20 Gy (22 Gy absolute) • No more than 35% is to exceed 20 Gy • No more than 25% is to exceed 30 Gy • No more than 50% is to exceed 10 Gy • No more than 65% is to exceed 5 Gy
3	**Esophagus** *(contoured from cricothyroid to GE junction)*: • Mean esophageal dose = 34 Gy • **Maximum** is <105% of Rx dose
3	**Heart:** • Mean heart dose = 35 Gy (ideally) • No more than 66% is to exceed 35 Gy • No more than 100% is to exceed 30 Gy
1	**Brachial Plexus:** • **maximum** point dose less than 50 Gy (ideally <45 Gy)

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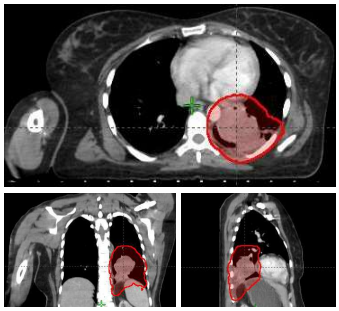
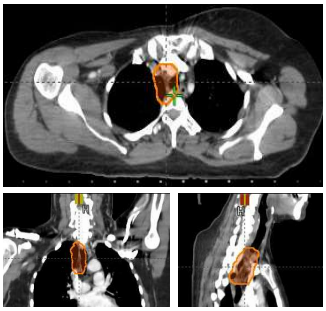
Lung – 2 Targets

- PTV1 – Left Lower Lobe



- PTV2 - Mediastinum



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Lung

2 Arc VMAT	9 Field IMRT (Step-and-Shoot)

▪ Partial Arcs
  ▪ 340-178º
▪ Collimator rotated 10 degrees
  ▪ 10º and 350º
	▪ Use Beam Angle Optimizer with constraints to choose optimal number of beams and beam angles
	▪ Verify clearance, gantry, and collimator angles

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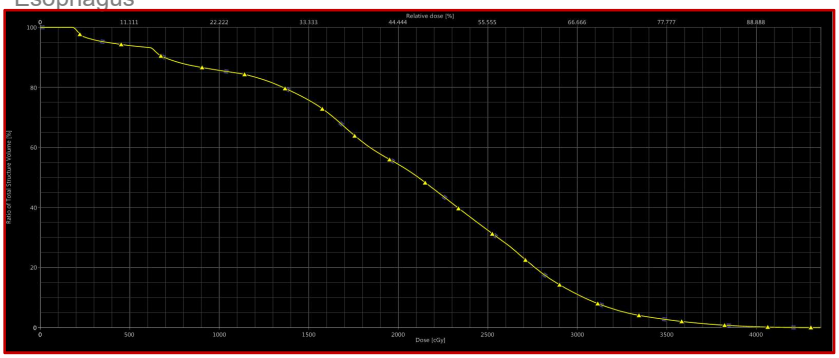
Lung

Triangles = VMAT
Squares = IMRT

Esophagus



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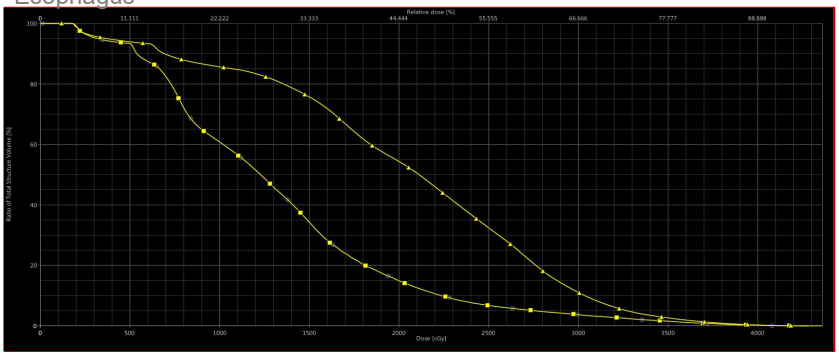
Lung

Triangles = VMAT
Squares = IMRT

Esophagus



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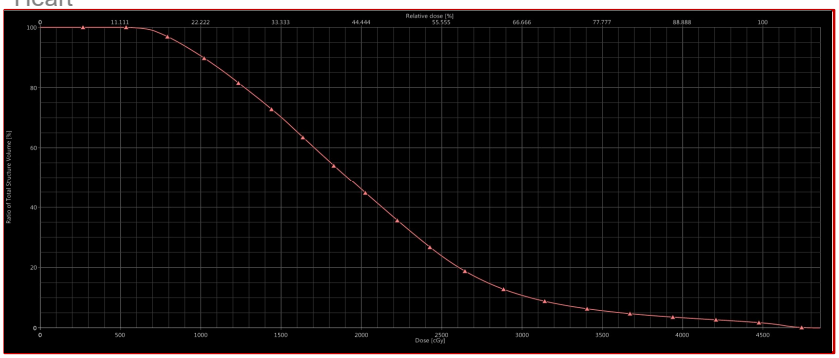
Lung

Triangles = VMAT
Squares = IMRT

Heart



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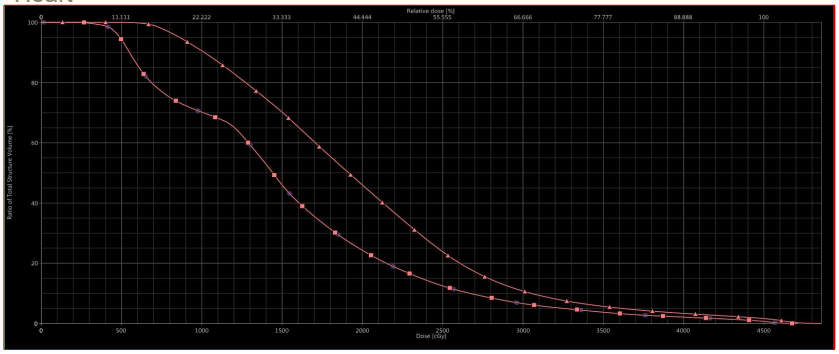
Lung

Triangles = VMAT
Squares = IMRT

Heart



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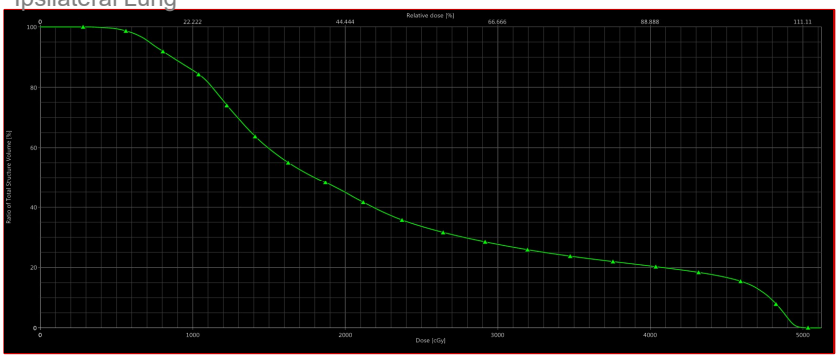
Lung

Triangles = VMAT
Squares = IMRT

Ipsilateral Lung



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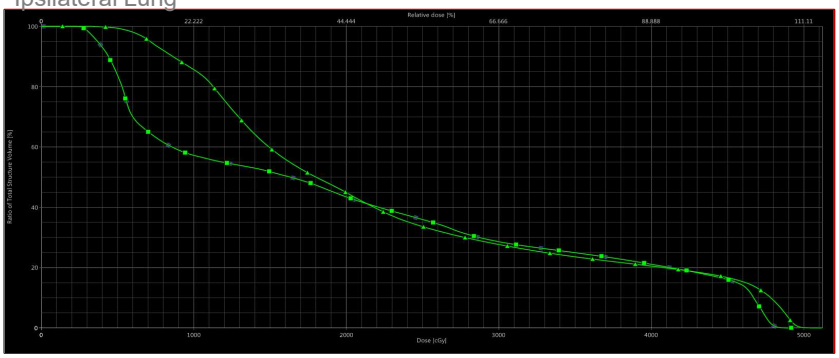
Lung

Triangles = VMAT
Squares = IMRT

Ipsilateral Lung



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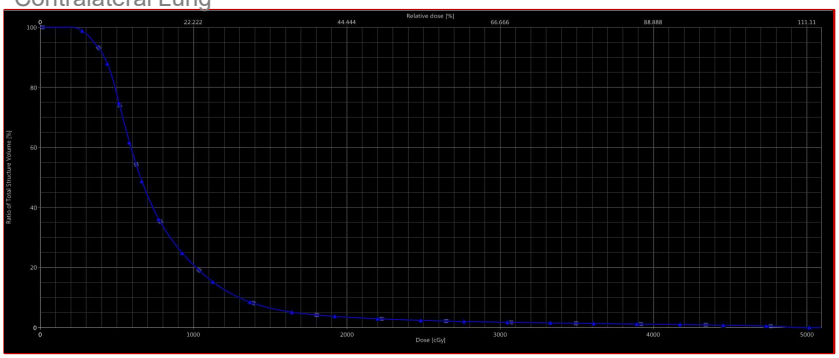
Lung

Triangles = VMAT
Squares = IMRT

Contralateral Lung



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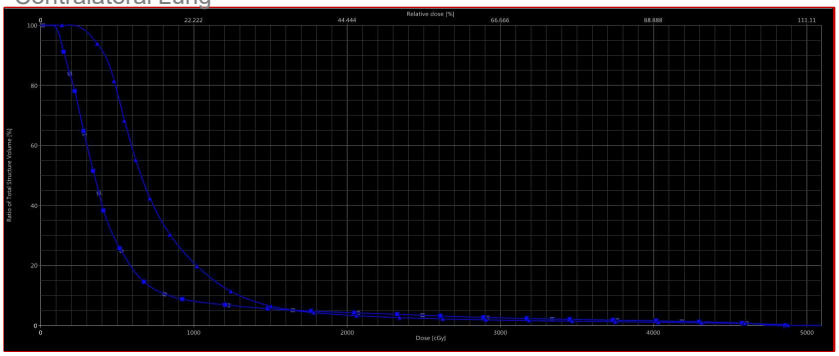
Lung

Triangles = VMAT
Squares = IMRT

Contralateral Lung



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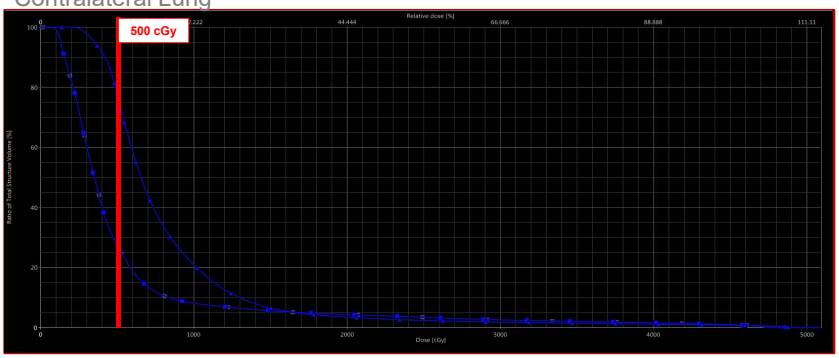
Lung

Triangles = VMAT
Squares = IMRT

Contralateral Lung



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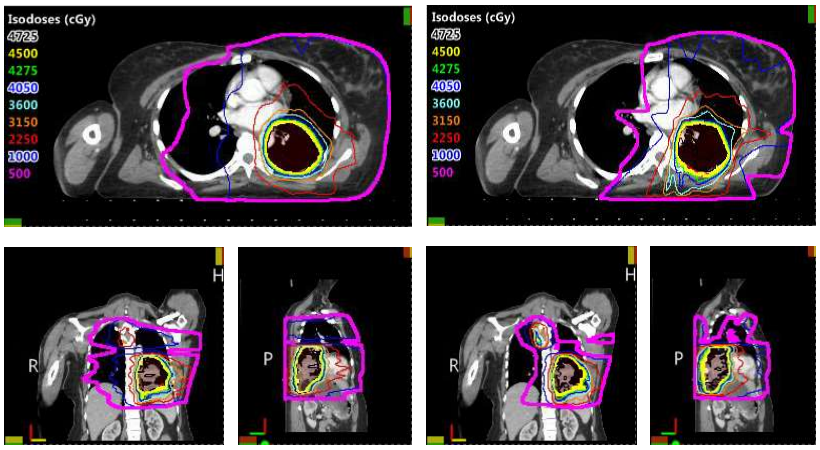
Lung



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Lung

Mean

	VMAT	IMRT
Esophagus	2025 cGy	1318 cGy
Heart	2009 cGy	1546 cGy
Ipsilateral Lung	2315 cGy	2053 cGy
Contralateral Lung	819 cGy	535 cGy

Lung Metrics

	VMAT	IMRT
V_{5Gy}	86%	47%
V_{20Gy}	16%	16%

Conformality Index

	VMAT	IMRT
PTV Total	0.98	1.03

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Lung

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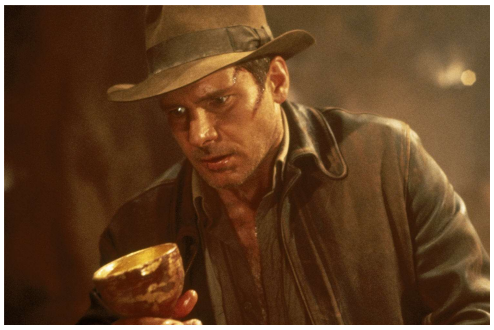

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Stereotactic Lung

- Significant dose and field overlap on skin surface can be a nasty combination
- High-risk for skin toxicity:
  - Patients with large body habitus
  - Posterior tumor locations with limited distance between lesion and skin
  - Beams traverse through immobilization devices
    - Bolus effect
- Use non-coplanar beams and avoid overlap on skin
  - Overlap beams near target

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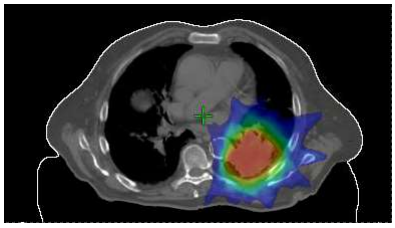
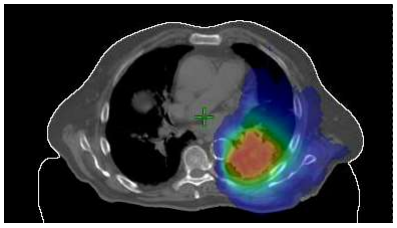
Stereotactic Lung

IMRT



VMAT



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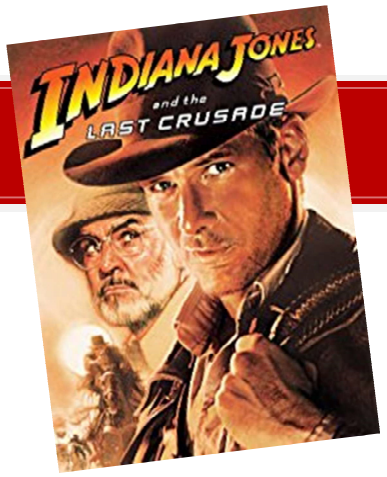

Breast/CW + Nodes

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Breast/CW+Nodes

- IMRT is best reserved for specific cases where more conventional techniques such as forward-planning are unable to meet dose constraints
  - Should not be used routinely
  - Especially in cases where only the breast is being treated

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Breast/CW+Nodes

Forward Planning	Inverse Planning IMRT
▪ Advantages: ▪ Less low dose spread outside of field ▪ Disadvantages: ▪ Hot and cold spots with field matching ▪ Leads to under dosing/overdosing at junctions	▪ Advantages: ▪ Offers greater control of high dose ▪ No need for field matching ▪ Disadvantages: ▪ Multiple beam geometry results in higher doses to both superficial and deep tissues outside the target volume, such as the lung and contralateral breast ▪ Need to account for flash

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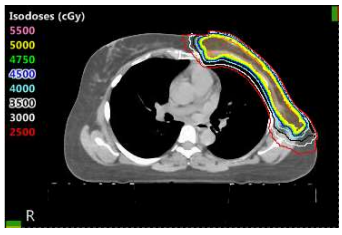
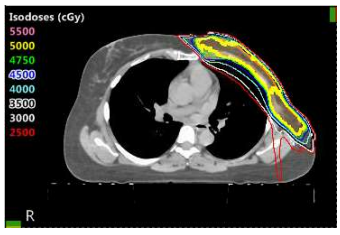
Breast/CW+Nodes

VMAT – 3 Partial Arcs



IMRT – 9 Field (Sliding Window)



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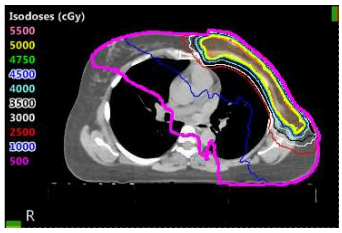
Breast/CW+Nodes

VMAT – 3 Partial Arcs



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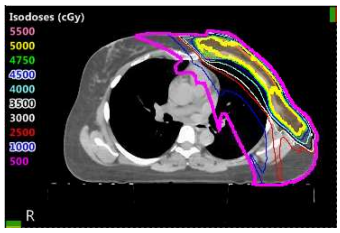

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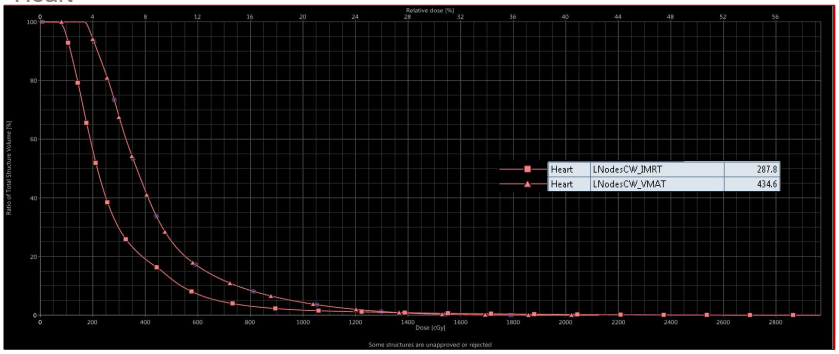
Breast/CW+Nodes

Triangles = VMAT
Squares = IMRT

Heart



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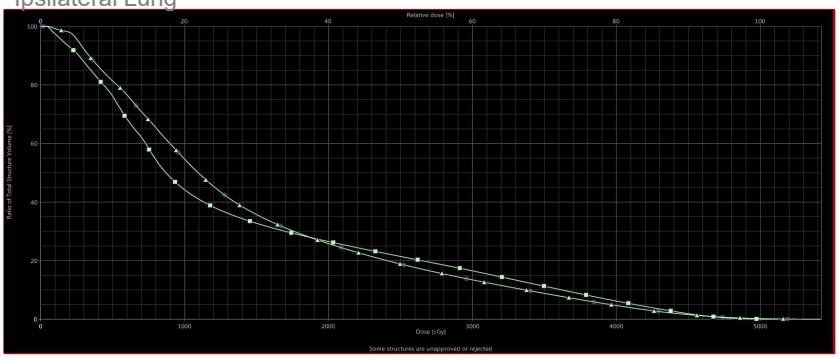
Breast/CW+Nodes

Triangles = VMAT
Squares = IMRT

Ipsilateral Lung



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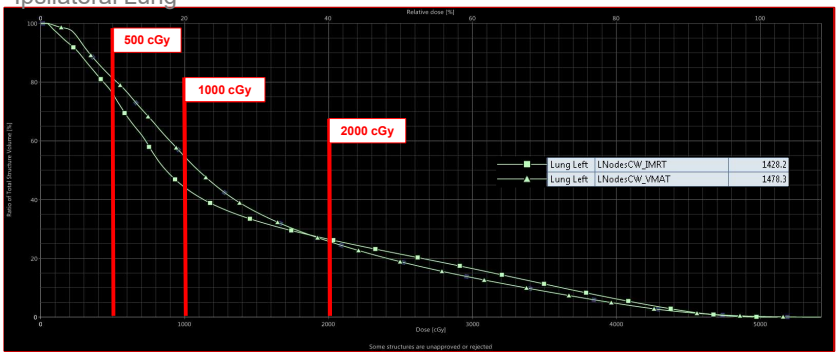
Breast/CW+Nodes

Triangles = VMAT
Squares = IMRT

Ipsilateral Lung



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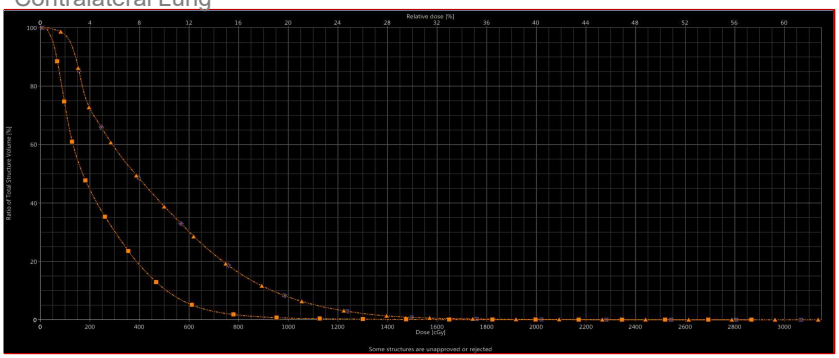
Breast/CW+Nodes

Triangles = VMAT
Squares = IMRT

Contralateral Lung



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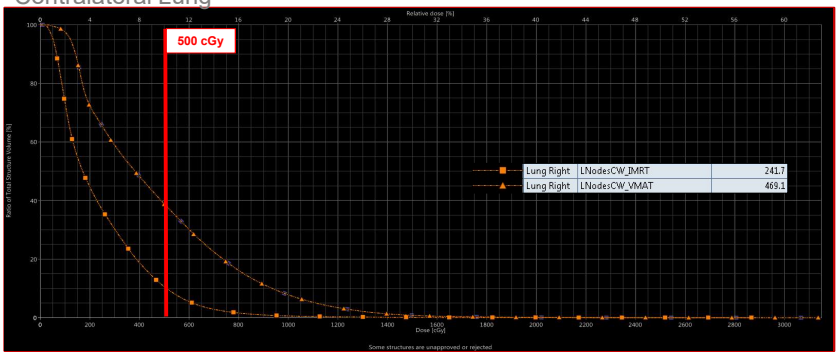
Breast/CW+Nodes

Triangles = VMAT
Squares = IMRT

Contralateral Lung



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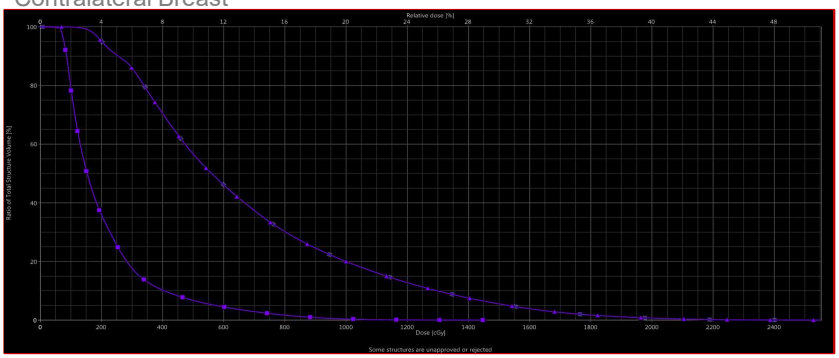
Breast/CW+Nodes

Triangles = VMAT
Squares = IMRT

Contralateral Breast



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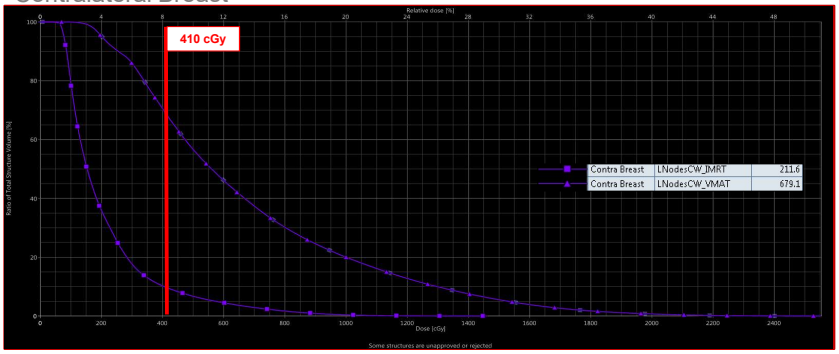
Breast/CW+Nodes

Triangles = VMAT
Squares = IMRT

Contralateral Breast



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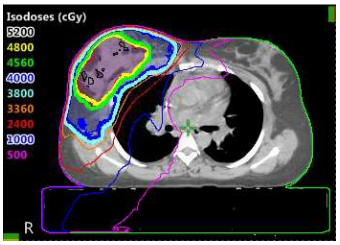
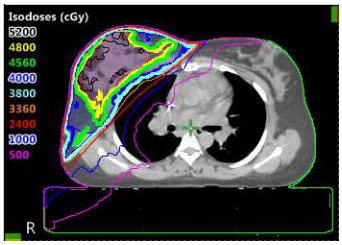
Breast/CW+Nodes – SIB technique

- VMAT – 3 Partial Arcs



- IMRT – 8 Field (Step-and-Shoot)



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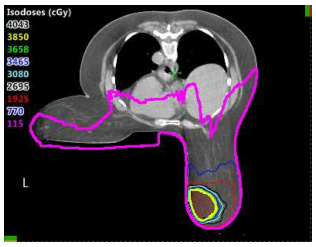
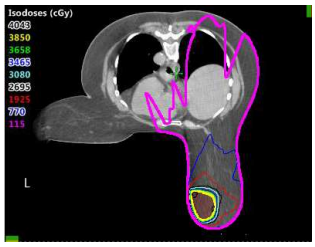
APBI – OSU 13282

- VMAT – 2 Partial Arcs



- IMRT – 9 Field (Sliding Window)



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Head and Neck

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Head and Neck

- VMAT
  - Produces highly conformal dose distributions
  - Extensive clinical use with HN (default technique)
  - May not be advantageous in all cases

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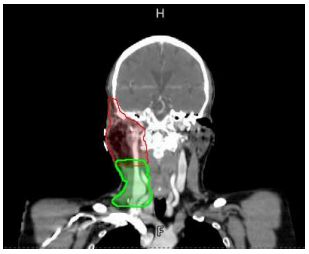
Head and Neck

- Unilateral HN
  - Malignant neoplasm of parotid gland
  - 54/60Gy in 30 fractions SIB
  - VMAT vs IMRT



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Head and Neck

Priority (#1 is highest)	Structure	Treatment Planning Goals	Treatment Planning Limit (if target is close to structure, higher doses may be accepted)
1	Spinal Cord	Max dose ≤ 45 Gy	Max dose ≤45 Gy
1	Spinal Cord + 5mm	Max dose ≤ 50 Gy	Max < 52 Gy
2	Brainstem	Max dose ≤ 50 Gy	Max dose ≤ 52 Gy
2	Brainstem + 3mm	Max dose ≤ 52 Gy	Max dose ≤ 54 Gy
3	Brachial Plexus	No more than 5% >60 Gy	No more than 5% >70 Gy
		Max dose ≤66 Gy	Max dose ≤72 Gy
4	Globes	Max dose ≤ 40 Gy	Max dose ≤ 45 Gy
		No more than 5% > 35 Gy	
4	Optic Nerves	Max dose ≤ 45 Gy	Max dose ≤ 50 Gy
4	Optic Chiasm	Max dose ≤ 45 Gy	Max dose <50 Gy
4	**Brain Avoidance**	**Max ≤ 54 Gy**	**Max ≤ 60 Gy, Minimize hot spots**
5	PTVint	95% of PTV receives the prescription dose	
		maximum dose 110% of the prescription dose	maximum dose 115% of the prescription dose
		100% of PTV receives 95% of prescription dose	99% of PTV receives 93% of prescription dose
6	Parotid gland contralateral to primary tumor site	Mean dose <20Gy, minimize dose	Mean dose <26 Gy
7	OARpharynx	Mean dose <45 Gy, V50 < 33%; V60 <15%; Constraint only for OAR pharynx minus PTVhigh, no hot spots, minimize dose	Mean dose <60 Gy, V65 <30%;
8	Larynx	Mean dose <30 Gy	Mean dose <40 Gy
9	Esophagus	Mean dose <30 Gy, no hot spots in the esophagus, minimize dose	Mean dose <35 Gy, no hot spots in the esophagus
10	Lips	Mean dose <20 Gy, minimize dose	Mean dose <25 Gy
11	Oral Cavity	Mean dose <30 Gy, avoid hot spots >60 Gy, minimize dose	Mean dose <40 Gy, avoid hot spots >60 Gy
13	Mandible	V60 <20%, Max 66 Gy to mandible, minimize dose	V60 <20%, Max 66 Gy to mandible minus PTV; minimize hot spots in the mandible
14	Cochlea	Mean dose <20 Gy, max dose <25 Gy, minimize dose	Mean dose <30 Gy, max dose <40 Gy
14	Inner ear	Mean dose <20 Gy, max dose <25 Gy, minimize dose	Mean dose <30 Gy; max dose <40 Gy
15	Submandibular gland left	Gland minus PTV mean <39 Gy	None
16	PTVlow	see #5	see #5

- Techniques:
  - 2 VMAT arcs
    - 182-230º
  - 7 Field IMRT
    - Sliding Window

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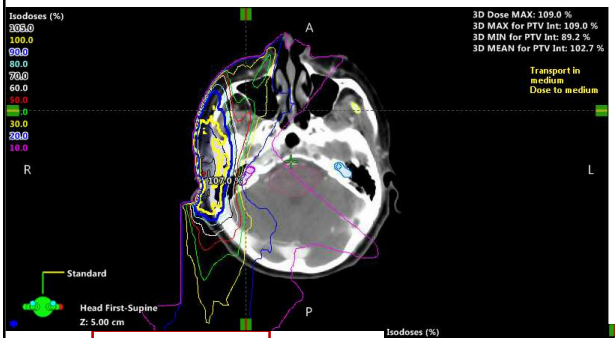
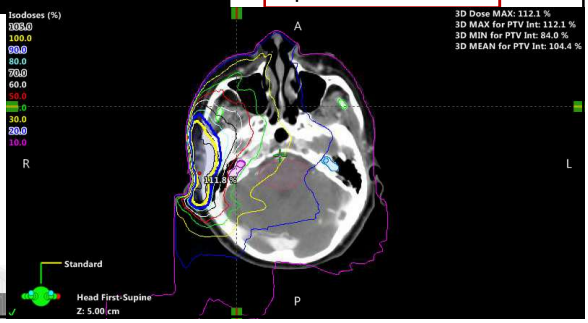
Head and Neck



7 field IMRT

2 partial VMAT arcs



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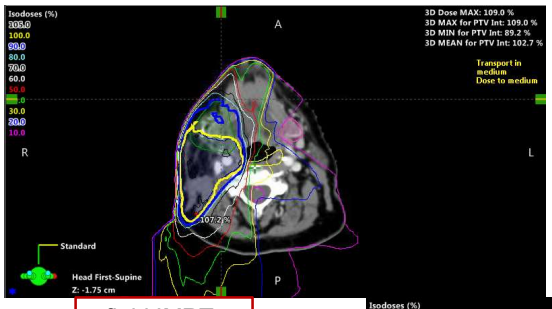
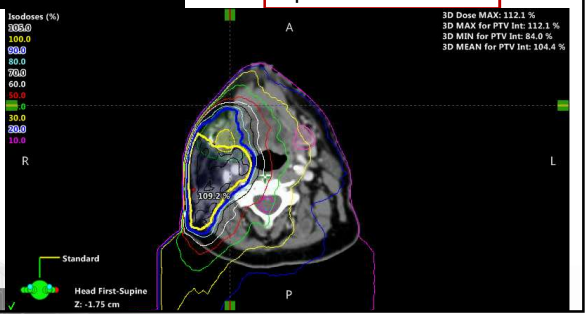
Head and Neck



7 field IMRT

2 partial VMAT arcs



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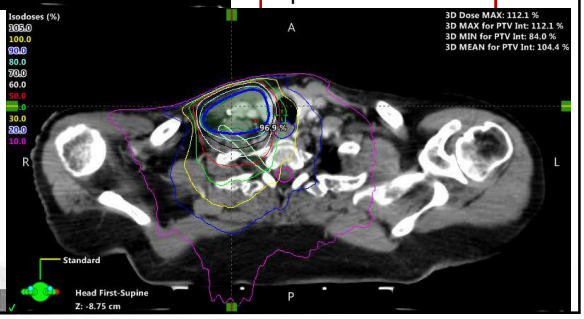
Head and Neck

7 field IMRT

2 partial VMAT arcs



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Head and Neck

- Observations:
  - Coverage is similar
  - By careful choice of fields we can better control the low dose to contralateral side
  - Falloff with IMRT can be a little more streaky
    - Is it worth it for better OAR sparing?
      - This is what we have to ask ourselves for every plan

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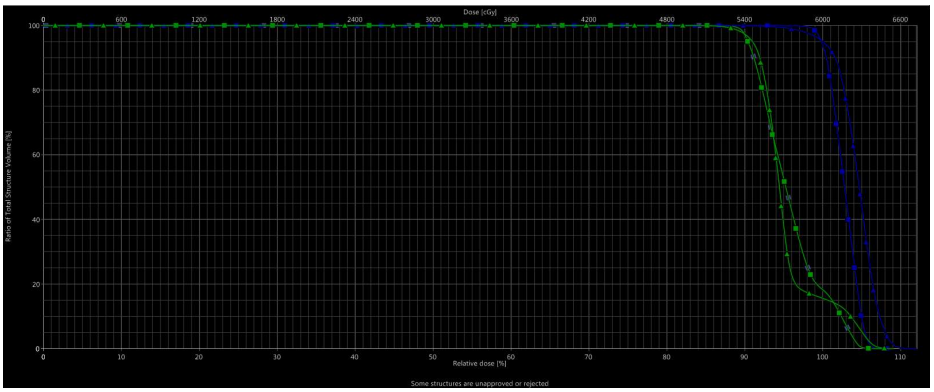
HN DVH Analysis - PTV



Triangles = VMAT
Squares = IMRT

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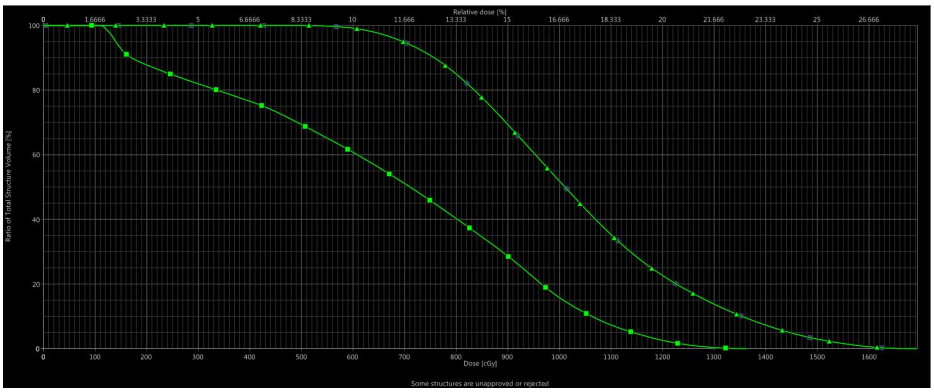
HN DVH Analysis – Lt Parotid



Triangles = VMAT
Squares = IMRT

- Rt Parotid Primary Cancer

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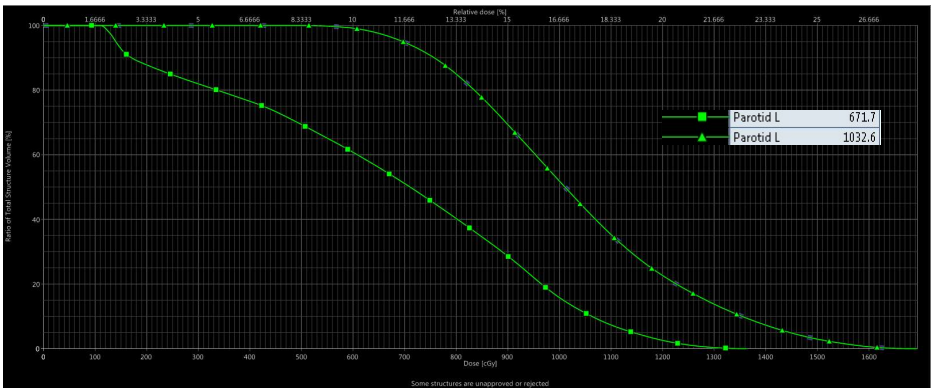
HN DVH Analysis – Lt Parotid



Triangles = VMAT
Squares = IMRT

- Rt Parotid Primary Cancer

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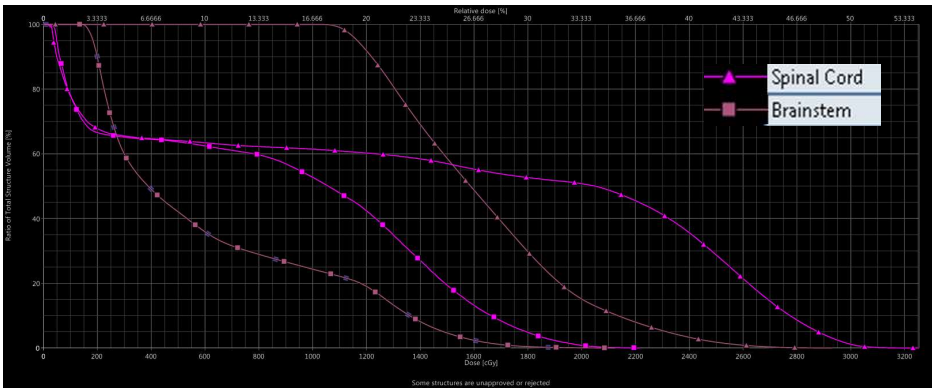
HN DVH Analysis – Spine and Brainstem



Triangles = VMAT
Squares = IMRT

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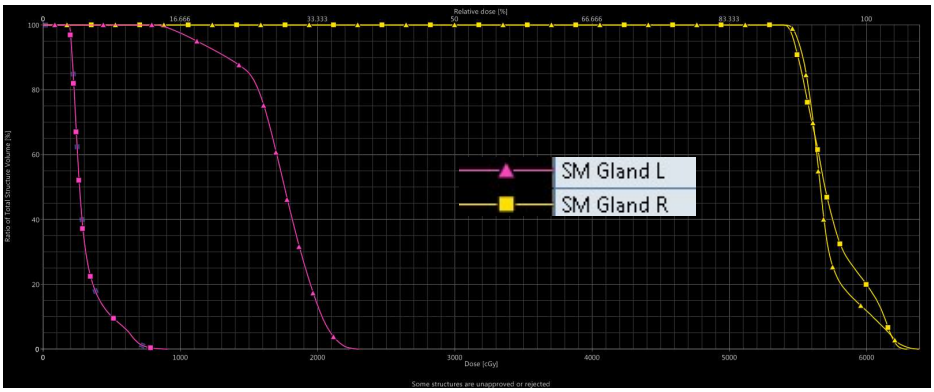
HN DVH Analysis – Submandibular Glands



Triangles = VMAT
Squares = IMRT

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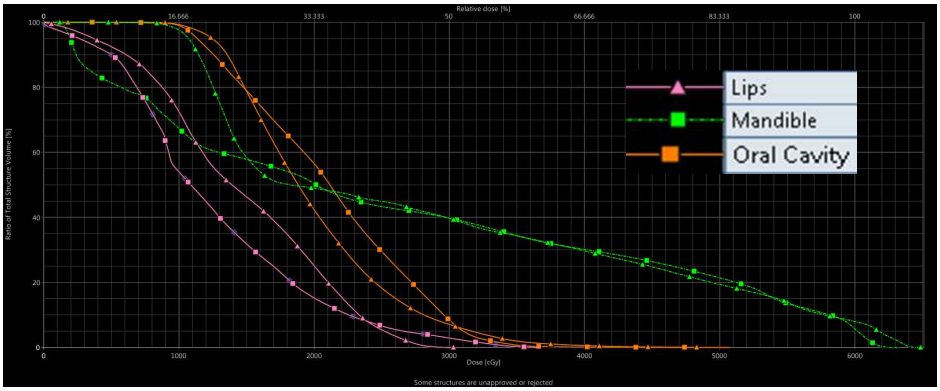
HN DVH Analysis – Lips, Oral Cavity, Mandible



Triangles = VMAT
Squares = IMRT

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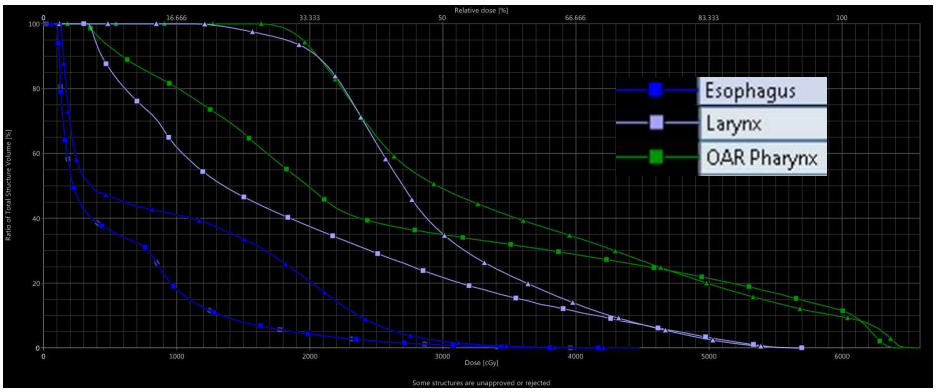
HN DVH Analysis – Larynx, Pharynx, Esophagus



Triangles = VMAT
Squares = IMRT

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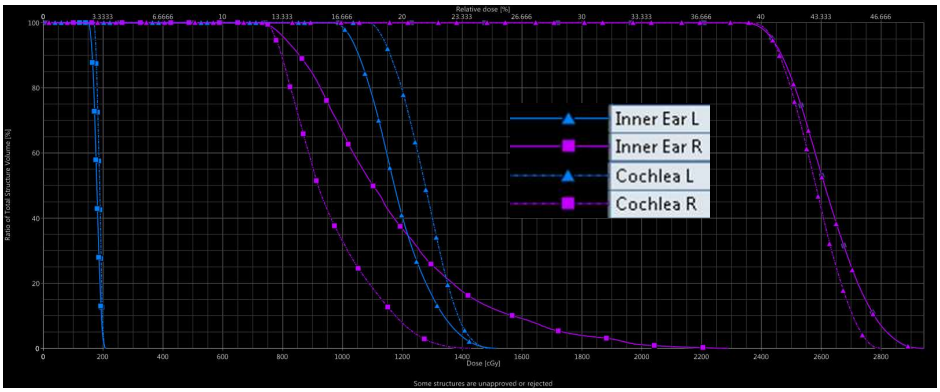
HN DVH Analysis – Inner Ear and Cochlea



Triangles = VMAT
Squares = IMRT

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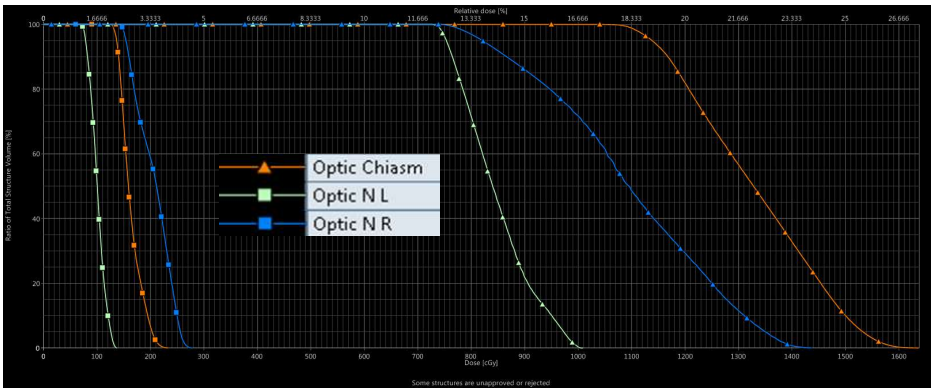
HN DVH analysis – Chiasm and Optic Nerves



Triangles = VMAT
Squares = IMRT

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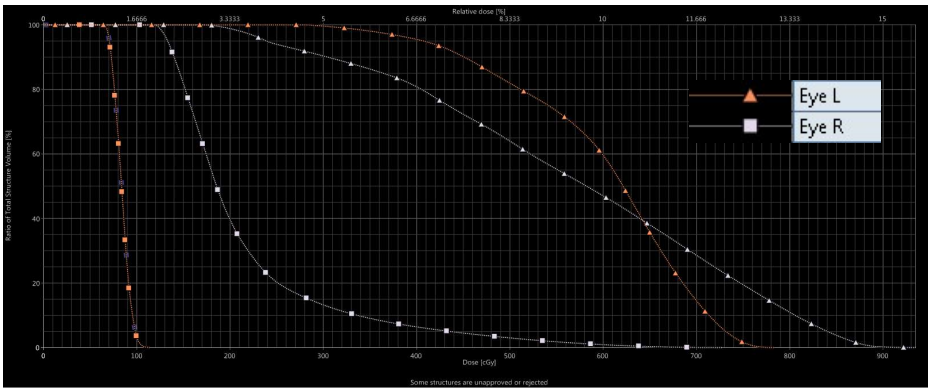
HN DVH Analysis - Eyes



Triangles = VMAT
Squares = IMRT

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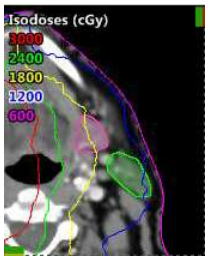
Head and Neck

- IMRT can be highly beneficial in unilateral HN planning
- It mostly involves careful upfront work with beam angles and optimization structures
  - After that sit back and let the optimizer do the work for you!

Happy Parotid and Submandibular



Sad Parotid and Submandibular

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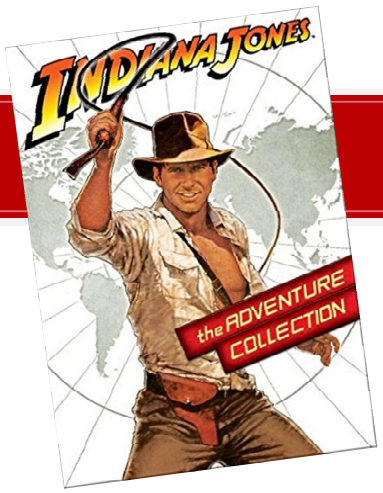

Clinical Considerations

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Treatment Errors

- Error rates with IMRT have been reported lower than with 3D/conventional
  - Does not involve the use of accessories
    - e.g., blocks, electron cones
    - Incorrect use is one of the main source of errors in RT
  - Patients who require urgent treatment tend to be treated with techniques other than IMRT
  - Extensive patient specific QA that is carried out for IMRT patients is also important in reducing error rates

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Treatment Errors

- Most common errors with IMRT were found to be related to incorrect data entry (to the record-and-verify system)
  - Improvements in technology should reduce the probability of such errors
- Treatment errors can also occur because of the different data needed to commission treatment planning systems for IMRT
  - Very small fields are possible in IMRT - If measured incorrectly (e.g., by using too large a detector), this can result in incorrect treatments
  - Similarly, the radiation characteristics of MLCs (e.g., transmission) make a larger contribution to IMRT treatments than for conventional treatments, so incorrect entry of these parameters into the treatment planning system can result in incorrect dose calculations

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Unanticipated Clinical Consequences

- IMRT dose distributions can be quite complex and are unusual in comparison with dose distributions from the pre-IMRT era.
  - Large volumes of normal tissue may be exposed to low doses
- An example of such consequences was described by Allen and colleagues - found that IMRT for mesothelioma led to an unexpectedly high rate of fatal pneumonitis
  - This case highlighted the need for extreme care when applying DVH constraints to new clinical treatment techniques

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Unanticipated Clinical Consequences

Fatal pneumonitis associated with intensity-modulated radiation therapy for mesothelioma

Aaron M. Allen M.D. *, Maria Czerminska M.S. *, Pasi A. Jänne M.D., Ph.D. †, David J. Sugarbaker M.D. ‡, Raphael Bueno M.D. ‡, Jay R. Harris M.D. *, Laurence Court Ph.D. *, Elizabeth H. Baldini M.D., M.P.H. *

Conclusions: Intensity-modulated RT treatment for mesothelioma after EPP and adjuvant chemotherapy resulted in a high rate of fatal pneumonitis when standard dose parameters were used. We therefore recommend caution in the utilization of this technique. Our data suggest that with IMRT, metrics such as V5 and MLD should be considered in addition to V20 to determine tolerance levels in future patients.

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Out-of-Field Dose and Secondary Malignancies

- Patients may be at increased risk of developing secondary malignancies caused by radiation outside of the treatment volume
  - Sources of out-of-field dose:
    - Photon leakage (proportional to MUs)
    - Radiation scattered from the collimators (also related to MUs)
    - Radiation scattered within the patient (proportional to target dose)

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Out-of-Field Dose and Secondary Malignancies

- Higher MUs required for IMRT mean that the risk of secondary malignancy is unavoidably higher
  - This risk can be minimized to some extent by the choice of IMRT approach (e.g., dynamic IMRT delivery vs. step-and shoot) and energy

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Conclusions

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Conclusion

- Don't let the beauty of VMAT plans fool you
- Don't store away your IMRT techniques
- Don't let the THE LOST ART OF IMRT disappear!

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References

- The Evolution of Treatment Planning Techniques
  https://link.springer.com/content/pdf/10.1007%2F978-4-431-55486-8.pdf
- David Shepard's talk, "IMRT Optimization Algorithms"
  - On AAPM website
- Nishimura's textbook "Intensity-Modulated Radiation Therapy, Clinical Evidence and Techniques"
- Eclipse algorithms reference guide
- "Volumetric Modulated Arc Therapy, IMRT in a single gantry arc," Karl Otto, 2007.
- Khan and Gerbi's textbook "Treatment Planning in Radiation Oncology"
- Khan's textbook "The Physics of Radiation Therapy"

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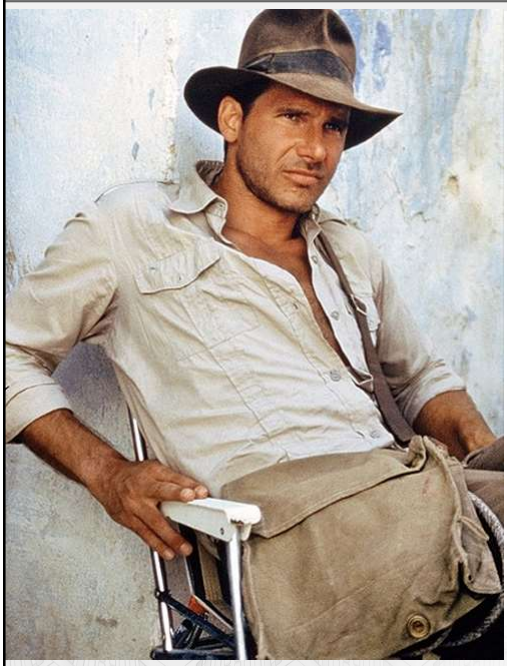

THANK YOU FOR YOUR ATTENTION!

Questions??

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