

VMAT Breast and CW: A Full Planning Workflow

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MEDICAL DOSIMETRY
WHERE THE REAL MAGIC HAPPENS

AAMD 51st ANNUAL MEETING
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ORLANDO FLORIDA, ORLANDO, FL

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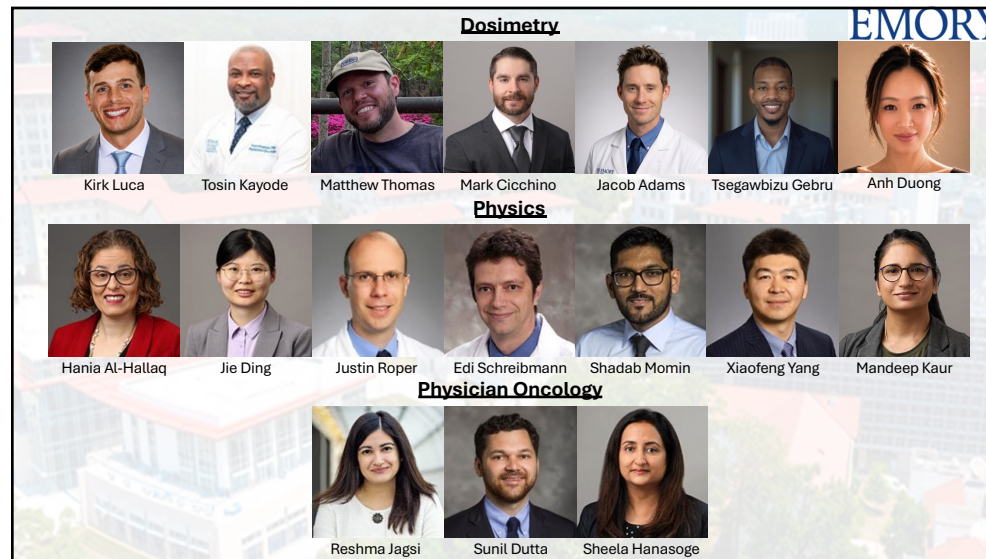
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Disclosures


- None

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Learning Objectives

- Understand the tradeoffs associated with VMAT
- Design strategic VMAT beam geometry based on patient specific anatomy
- Implement an effective optimization strategy

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Presentation Outline



<p>Overview</p> <ul style="list-style-type: none">AnatomyOrgans-at-riskAdvantages of 3DCRTDifficult anatomyTransitioning to VMATPlanning goals	<p>Beam Geometry</p> <ul style="list-style-type: none">Field sizeIsocenterCollimatorArc lengthCollision check	<p>Optimization</p> <ul style="list-style-type: none">EnergyStructuresFlashOptimization settingsTradeoffsPlan evaluation	<p>Research</p> <ul style="list-style-type: none">Dosimetry-led researchResults
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Overview

- Anatomy
- Organs-at-risk
- Advantages of 3DCRT
- Difficult anatomy
- Transitioning to VMAT
- Planning goals

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Comprehensive Breast/CW Review

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Patients

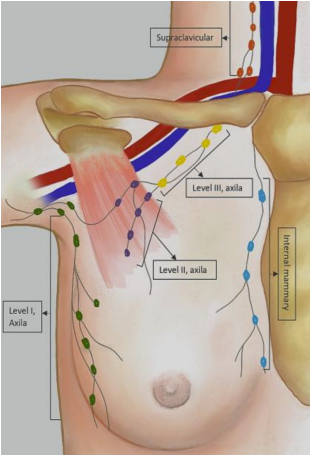
- Node-positive or high-risk breast cancer

Targets

- Breast/CW
- Internal mammary lymph nodes
- Supraclavicular lymph nodes
- Level I lymph node
- Level II lymph node
- Level III lymph node

Fractionation

- Conventional fractionation
 - 50-50.4 Gy in 25-28 fx
- Moderate fractionation
 - 40-42.56 Gy in 15-16 fx



DOI: 10.26044/feer2024/C-22402

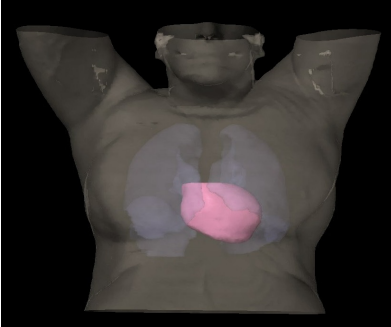
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Organs-At-Risk (OAR)

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Heart & Lungs

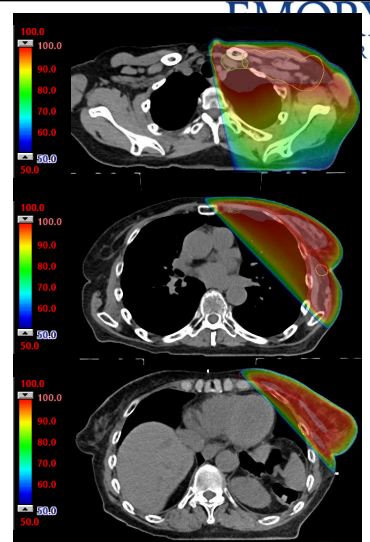
- Major coronary event risk rises ~7.4% per Gy mean heart dose, with no clear safe threshold
DOI: 10.1056/NEJMoa1209825
- Higher heart dose increases later cardiac event risk
DOI: 10.1056/NEJMoa1209825
- Modern breast RT data suggest higher cardiac dose may worsen cardiac function and future cardiovascular risk
DOI: 10.1016/j.jacc.2025.01.012
- Higher lung V20Gy is a key predictor of radiation pneumonitis and is commonly limited to ≤30-35%
DOI: 10.1016/j.ijrobp.2009.06.091



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Advantages of 3DCRT

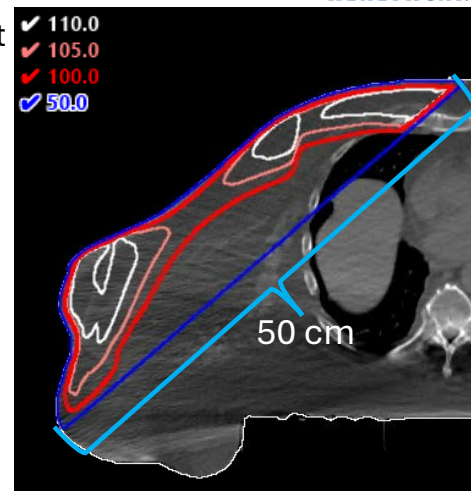
- Simple, effective technique used for decades
- Minimal dose outside of the treatment fields
- Low contralateral exposure (breast and lung)
- Robust to variations in setup and respiratory motion



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Anatomy Determines Planning Techniques

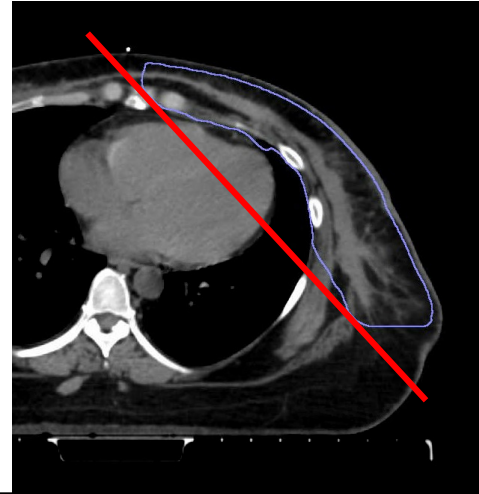
- The tissue lateral effect says that dose uniformity degrades as separation increases
- The effect is less pronounced with higher energy photons, though still present
- **Clinical impact:** increased heterogeneity may contribute to fibrosis, breast firmness, and poorer cosmesis



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Anatomy Determines Planning Techniques

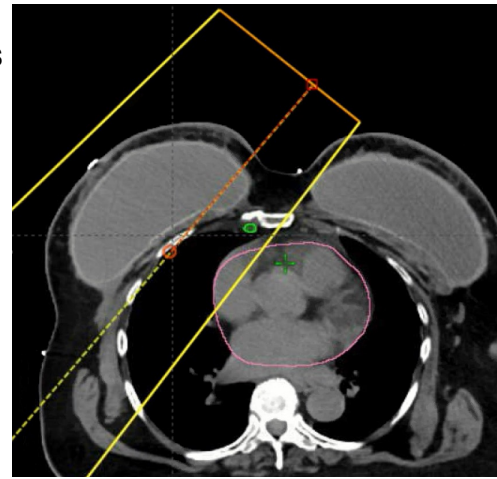
- Heart dose is a major consideration for left-sided plans
- DIBH inflates the lungs to create greater separation between the heart and chest wall
- **Clinical impact:** higher heart dose may increase long-term cardiac risk



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Anatomy Determines Planning Techniques

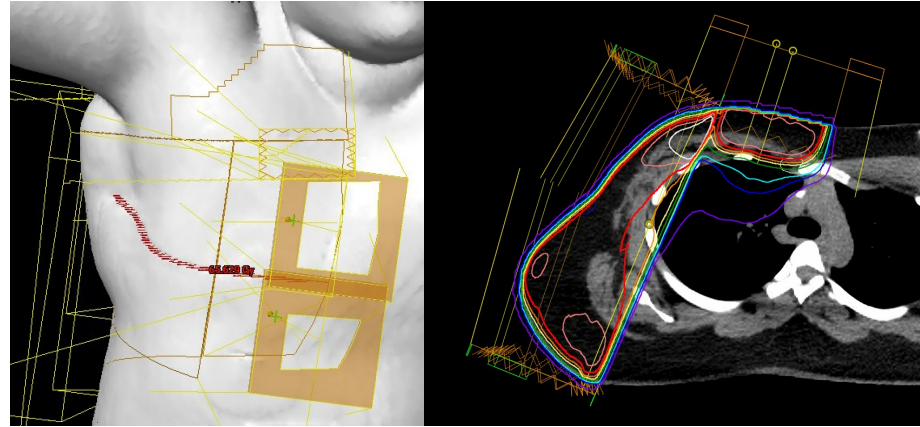
- IMN coverage may be achieved with deep tangents
- However, dose increases to heart, ipsilateral lung, and contralateral breast
- **Clinical impact:** higher heart and lung dose may increase long-term cardiac and pulmonary toxicity risk



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Anatomy Determines Planning Techniques

- Mixed photons & electrons are an alternative to deep tangents



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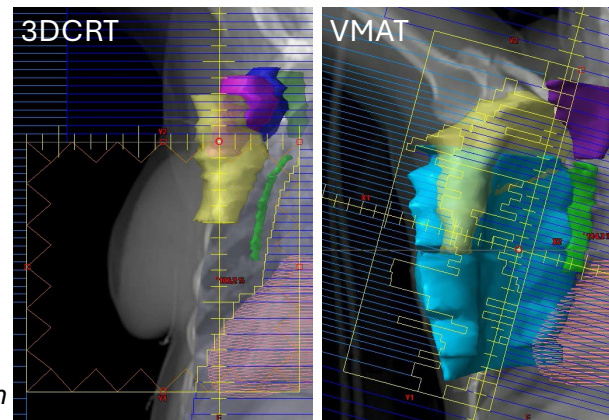
From 3D to VMAT

3DCRT

- Fixed beam angles
- Uniform beam intensity
 - Limited modulation

VMAT

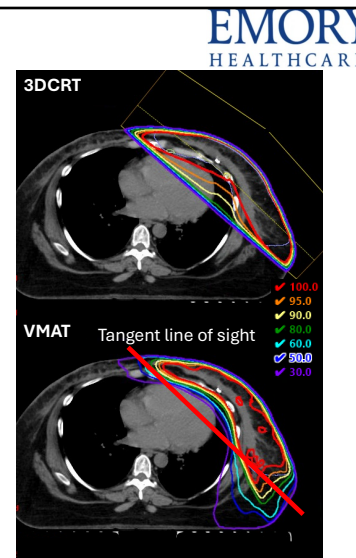
- Continuous arc
 - Many beam angles
- Dynamic MLC motion
 - High modulation
- Variable dose rate
- Variable gantry speed
- *Variable collimator rotation*
- *Variable couch rotation*



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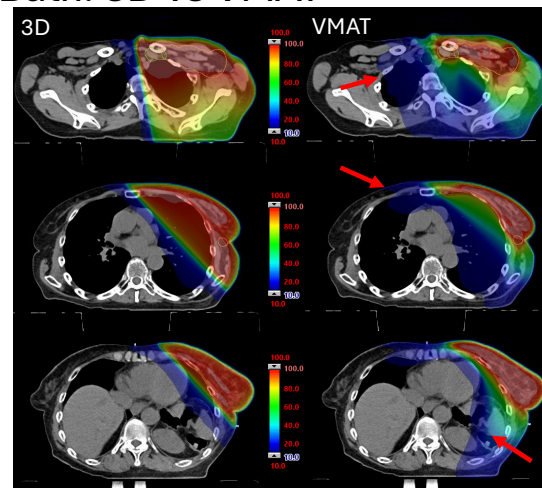
3D vs VMAT: Case Selection

- Consider tradeoffs
 - Low dose wash
 - Robustness
 - Excessive modulation
- In select cases, VMAT reduces heart/lung dose and improves high dose conformity



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Low Dose Bath: 3D vs VMAT

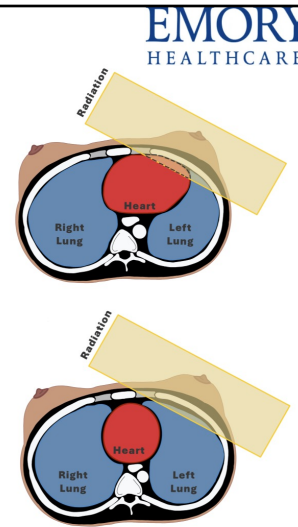


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ASTRO Guidelines

ASTRO WBI 2018 / ASTRO PMRT 2025

- Patient positioning
 - Account for reproducibility of breast tissue
 - Minimize skin folds
 - **IMRT/VMAT when 3DCRT cannot meet treatment goals**
- DIBH
 - Strongly recommended
 - Use active motion management (ex. SGRT, chest wall device, spirometry)
- IGRT
 - Daily use for patients at risk for less reproducible positioning
 - For IMRT/VMAT, strongly recommend daily IGRT and 3D assessment (CBCT, SGRT)



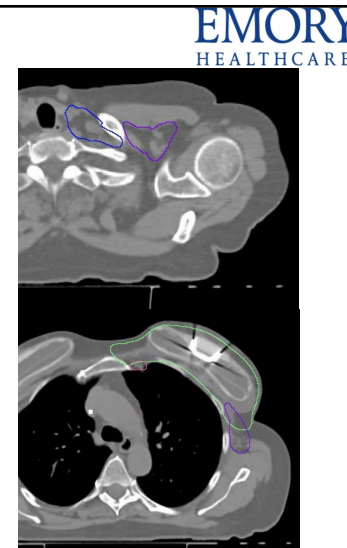
Slide content provided by Hania Al-Hallaq

DOI: 10.1016/j.prro.2018.01.012
DOI: 10.1016/j.prro.2025.05.001

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PTVs Are Important

- PTV margins recommended
- CTV + 5 mm
 - **Breast/CW PTV**
 - Exclude heart, do not cross midline
 - **IMN PTV** is not expanded anterior/posterior
 - Exclude sternum, lung, heart, breast/CW
 - **SCV PTV** is not expanded medially
 - Exclude thyroid, trachea, esophagus, lung, vertebral body and skin
 - **Axillary PTV**
 - Exclude lung



Alliance A011202

https://irachouston.mdanderson.org/trc/credentialing/NODAL_CONTOURING_ATLAS.pdf

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PMRT: An ASTRO/ ASCO/SSO Clinical Practice Guideline

Structure	Goal	5000-5040 cGy in 25-28 fx	4000-4256 cGy in 15-16 fx
Ipsilateral chest wall ^{50,85}	Ideal	D95 ≥95% PTV	D95 ≥95% PTV
	Acceptable	D90 ≥90% PTV	D90 ≥90% PTV
	Ideal	D0.1 cc ≤110%	D0.1 cc ≤107% [†]
	Acceptable	D0.1 cc ≤115% Rx	D0.1 cc 115% Rx
Axilla ^{50,85}	Ideal	D95 ≥95% PTV	D95 ≥95% PTV
	Acceptable	D90 ≥90% PTV	D90 ≥90% PTV
	Ideal	D0.1 cc 110% Rx	D0.1 cc 107% Rx [†]
	Acceptable	D0.1 cc ≤115% Rx	D0.1cc 115% Rx
Supraclavicular fossa ^{50,85}	Ideal	D95 ≥95% PTV	D95 ≥95% PTV
	Acceptable	D90 ≥90% PTV	D90 ≥90% PTV
	Ideal	D0.1 cc 115% Rx	D0.1 cc 112% Rx [†]
	Acceptable	D0.1 cc ≤120% Rx	D0.1 cc 115% Rx
Internal mammary nodes ^{50,85}	Ideal	D95 ≥90% PTV	D95 ≥90% PTV
	Acceptable	D90 ≥80% PTV	D90 ≥80% PTV

DOI: 10.1200/JCO.25-01747

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PMRT: An ASTRO/ASCO/SSO Clinical Practice Guideline

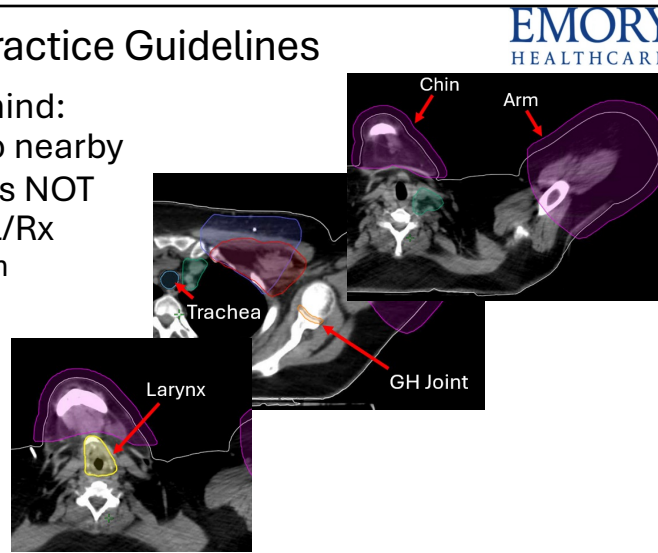
Structure	Goal	5000-5040 cGy in 25-28 fx	4000-4256 cGy in 15-16 fx
Ipsilateral lung ^{80,85}		V5 Gy ≤75%	V4 Gy ≤65% [‡]
	Ideal	V10 Gy ≤65%	V8 Gy ≤55% [‡]
	Acceptable	V20 Gy ≤35% [‡]	V17 Gy ≤35% [‡]
Contralateral lung ⁸⁵	Ideal	V5 Gy ≤10%	V4 Gy ≤10% [‡]
	Acceptable	V5 Gy ≤15%	V4 Gy ≤15% [‡]
Heart ⁸⁵	Ideal (left sided)	Dmean ≤3 Gy	Dmean ≤2.4 Gy [‡]
	Acceptable (left sided)	Dmean ≤5 Gy	Dmean ≤4 Gy [‡]
	Ideal (right sided)	Dmean <2 Gy	Dmean <1.6 Gy [‡]
	Acceptable (right sided)	Dmean ≤3 Gy	Dmean ≤2.4 Gy [‡]
Contralateral breast/chest wall ^{10,85}	Ideal	V3 Gy ≤10%	V3 Gy ≤10%
	Acceptable	V5 Gy ≤10%	V5 Gy ≤10%
Additional considerations			
Brachial plexus ⁹⁰	Suggested	D0.1 cc ≤105% Rx	D0.1 cc ≤105% Rx
Esophagus	Suggested	V10 Gy <30% / V20 Gy <15% ¹²⁸	V8 Gy <30% / V17 Gy <15% ¹²⁷
Left ventricle ²⁹	Suggested	V2 Gy <36%	V1.6 Gy <36% [‡]
Spinal cord [‡]	Suggested	D0.1 cc 45 Gy	D0.1 cc 38.54 Gy
Thyroid ^{10,131}	Suggested	Dmean <21 Gy	Dmean <21 Gy
Humeral head	Suggested	Dmean <20 Gy	Dmean <17 Gy
Stomach (left sided)	Suggested	Dmean <3 Gy	Dmean <2.4 Gy
Liver (right sided)	Suggested	Dmean <7 Gy	Dmean <5.6 Gy

DOI: 10.1200/JCO.25-01747

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Goals Beyond Practice Guidelines

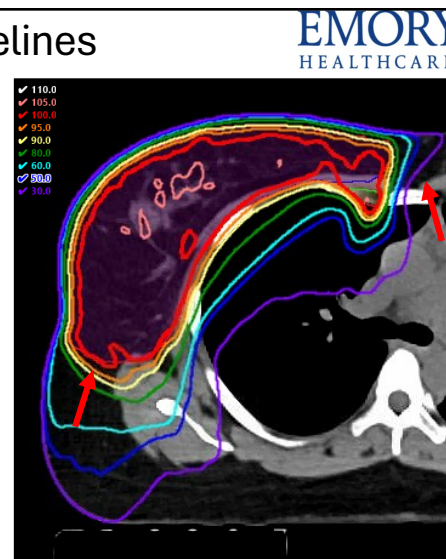
- Keep ALARA in mind: minimize dose to nearby critical structures NOT listed in protocol/Rx
 - Ipsilateral arm
 - Chin
 - GH Joint
 - Trachea
 - Larynx



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Goals Beyond Practice Guidelines

- Control intermediate-to-high dose spill
- Limit contralateral dose/low dose bath
- Improve robustness by adding flash and avoiding entry through the arms, chin, and contralateral breast



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Beam Geometry

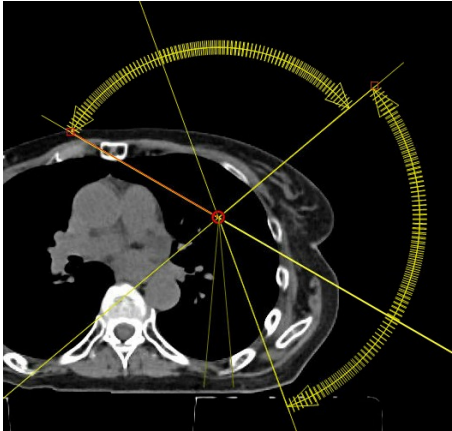
Field size
Isocenter
Collimator
Arc length
Collision check

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Beam Geometry

- High-quality beam geometry is often overlooked
 - In many cases, poor beam geometry cannot be “out-planned” in optimization
- Beam geometry settings
 - Field Size
 - Isocenter
 - Collimator
 - Arc Length

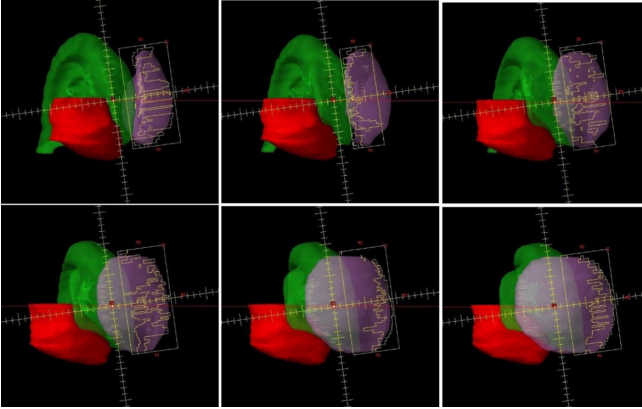


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Beam Geometry: Field Size

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- Jaw-offset technique: deep field border truncated
- To reduce dose to sensitive OARs...
 - Minimize time in field during arc delivery
- Reduces heart and ipsilateral lung dose



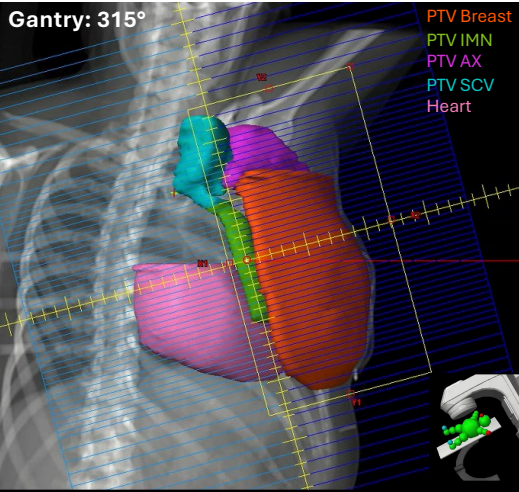
DOI: 10.1002/acm2.14365

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Beam Geometry: Field Size

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- **Aperture-restricted** beam geometry
 - Deep field border ~1.0-2.5 cm



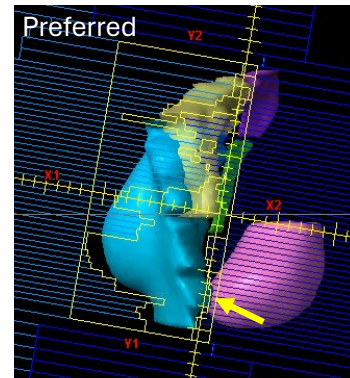
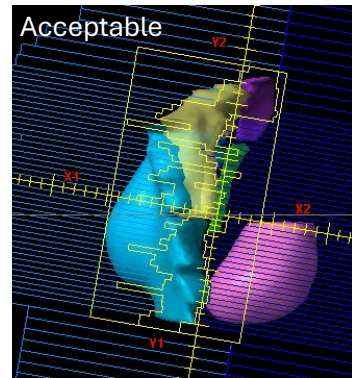
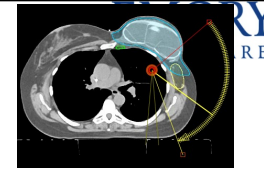
Gantry: 315°

PTV Breast
PTV IMN
PTV AX
PTV SCV
Heart

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Beam Geometry: Field Size

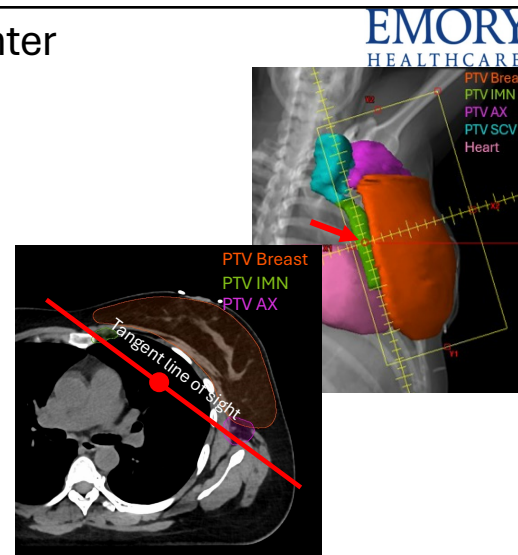
- Aperture-restricted beam geometry improves heart and ipsilateral lung sparing



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Beam Geometry: Isocenter

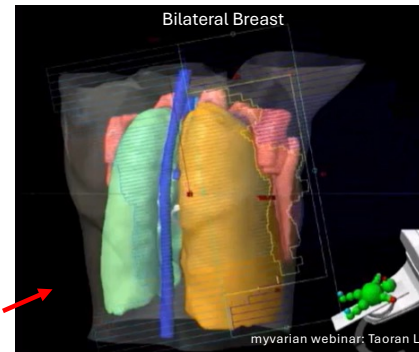
- Place the isocenter at the midpoint of the superior-inferior extent of target(s)
 - Usually near superior aspect of the heart
- Draw deep field border along tangent line of sight
 - Place isocenter along this line



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Beam Geometry: Collimator

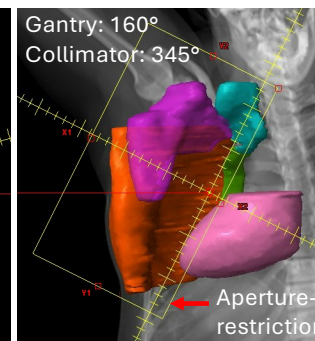
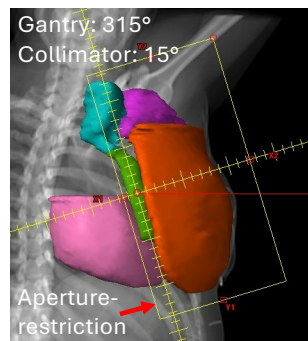
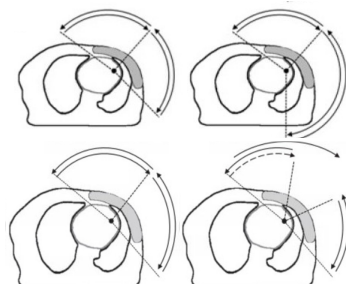
- Collimator rotated so that MLC travel across the target's short axis
- Traditional VMAT
 - Fixed collimator during arc delivery
- RapidArc Dynamic (Eclipse V18)
 - VMAT-style arc delivery, modulated beam ports, and a dynamic collimator



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Beam Geometry: Fixed Collimator Workaround

- Split arcs allow collimator rotation to follow the CW



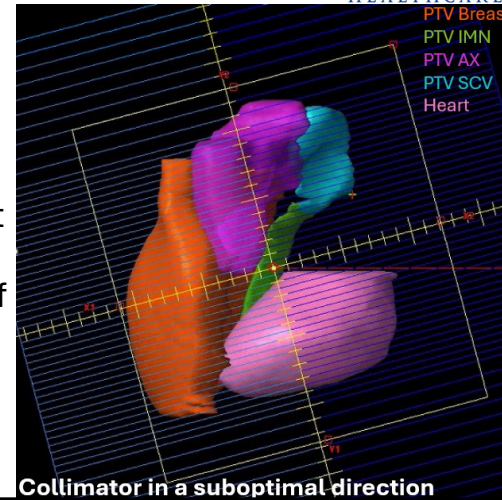
DOI: 10.1016/j.ejmp.2016.10.012

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Beam Geometry: Split Arc Technique

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- At **50°–60°**, the beam becomes more **en face** to the breast/CW, making heart blocking less favorable and reducing the effectiveness of the collimator angle

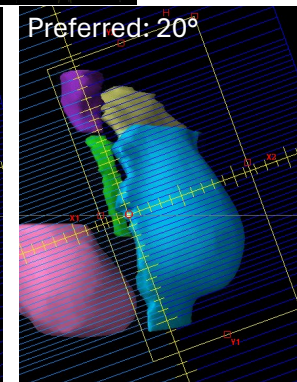
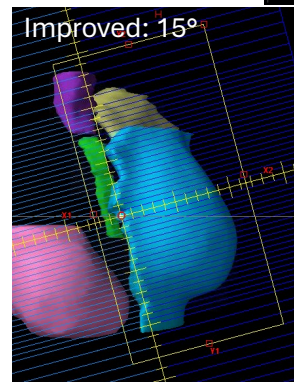
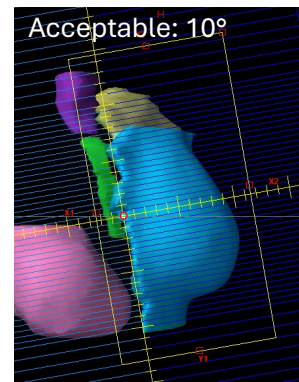
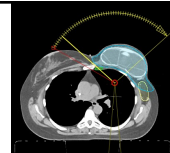


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Beam Geometry: Collimator

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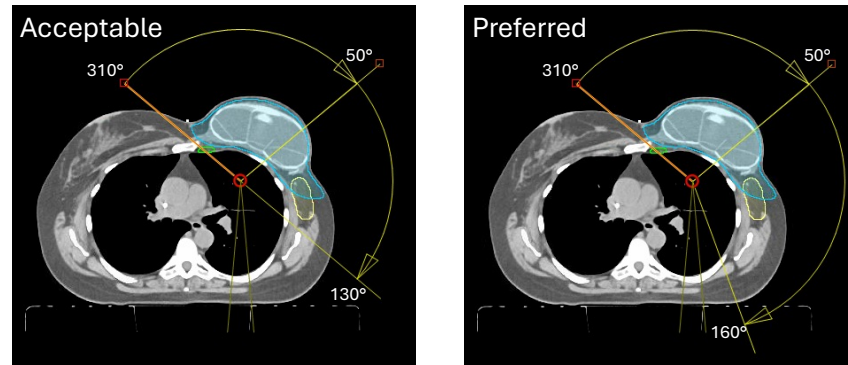
- Use a “tangent control point” to visualize the optimal collimator angle



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Beam Geometry: Arc Length

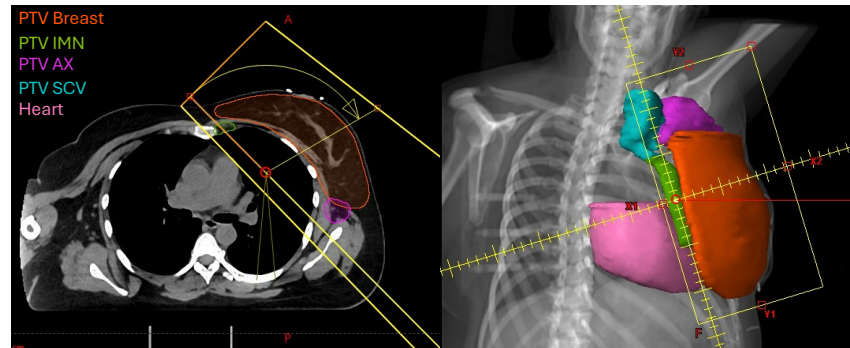
- Extending arcs slightly beyond traditional tangent angles can improve lung sparing



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Beam Geometry: Arc 1

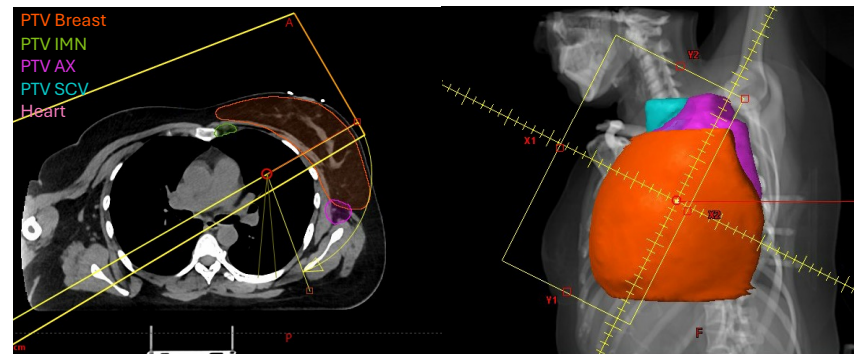
- Gantry: 315° CW 60°
- Collimator: 20°



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Beam Geometry: Arc 2

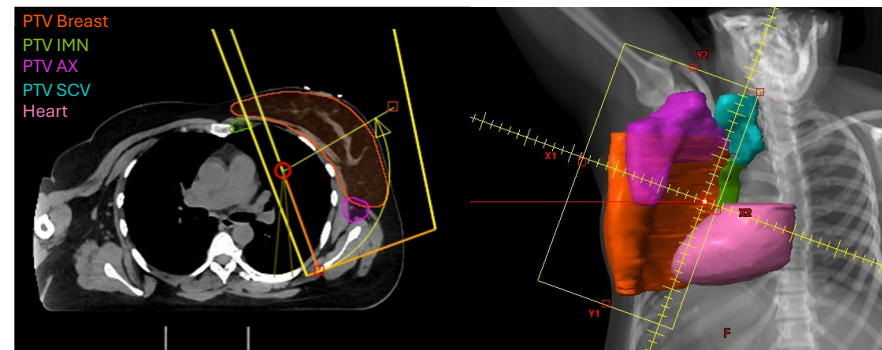
- Gantry: 60° CW 160°
- Collimator: 335°



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Beam Geometry: Arc 3

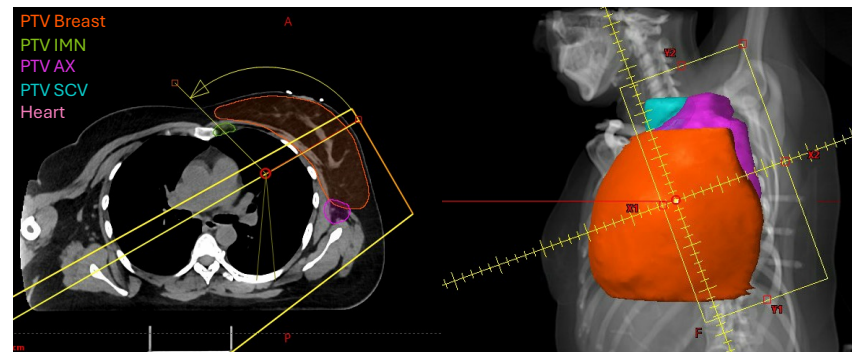
- Gantry: 160° CCW 60°
- Collimator: 340°



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Beam Geometry: Arc 4

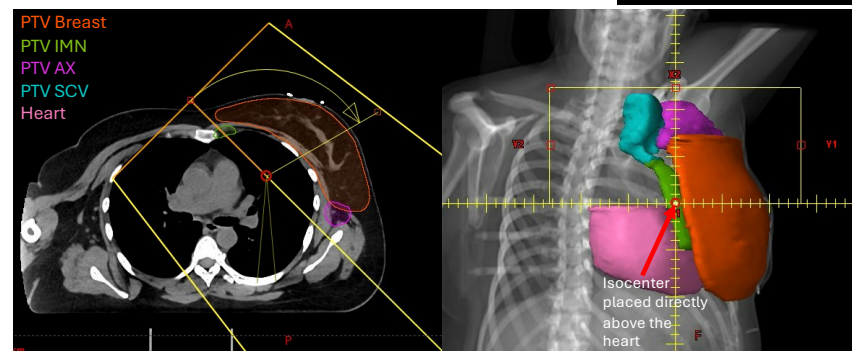
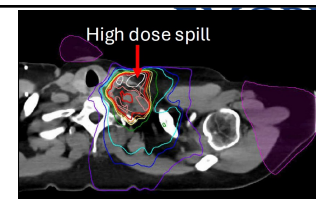
- Gantry: 60° CCW 315°
- Collimator: 15°



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Beam Geometry: Arc 5

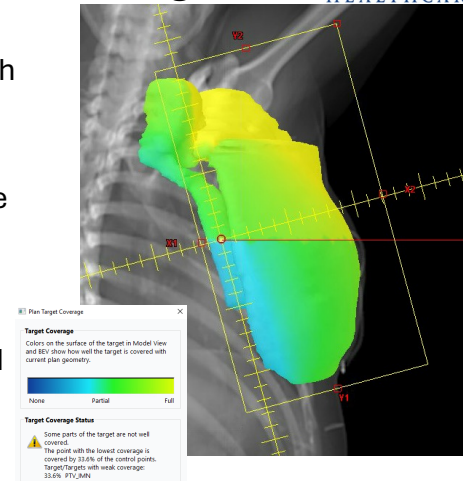
- Gantry: 315° CW 60°
- Collimator: 90°
- Improves conformity in supraclavicular region



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Beam Geometry: Plan Target Coverage

- Plan Target Coverage: Displays how well the target is covered with the current plan's geometry
- Point with lowest coverage can be as low ~25% using aperture-restricted geometry
- Adjust collimator angles and field sizes to help improve target coverage if needed



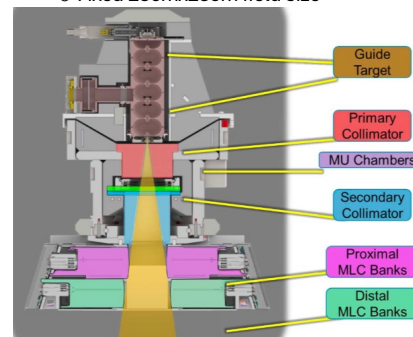
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Beam Geometry: Halcyon & Elekta

How can aperture-restriction be applied on machines without X jaws?

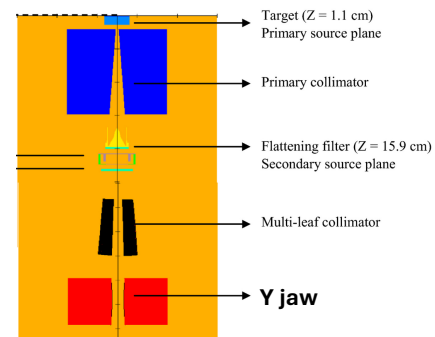
Varian Halcyon

- No jaws
 - Fixed 28cmx28cm field size



Elekta Versa HD

- No X jaw



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Beam Geometry: Halcyon & Elekta

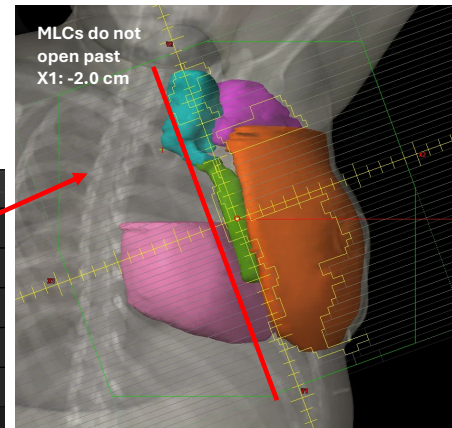
- “Limit leaves” is a deliverability constraint that puts a hard cap on how far the MLC leaves travel
- Fixed leaf travel limit along the X1/X2 direction

Halcyon Planning Tip:

- If target size > 26 cm, two isocenters are required
- Long treatment fields with multi-isocenter support
 - Max longitudinal separation of 8 cm

ID	Gantry Rotation [deg]	Limit Leaves
01-CW	310.0-60.0 CW	X1 -2.0 cm X2 cm
02-CW	60.0-170.0 CW	X1 cm X2 2.0 cm
03-CCW	170.0-60.0 CCW	X1 cm X2 2.0 cm
04-CCW	60.0-310.0 CCW	X1 -2.0 cm X2 cm
05-CW	310.0-60.0 CW	X1 0.0 cm X2 cm

Jaw Tracking



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Beam Geometry: Field Templates

Left Breast/Chest Wall

Arc #	Gantry	Collimator
1	330° CCW 60°	15°
2	60° CCW 160°	345°
3	160° CW 60°	350°
4	60° CW 330°	10°
5	330° CCW 60°	90°

Right Breast/Chest Wall

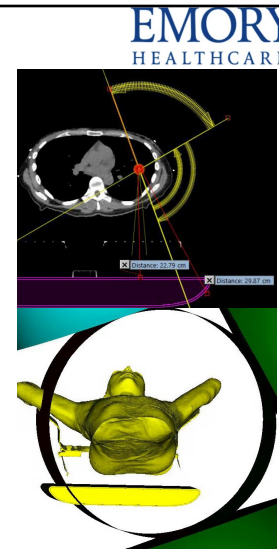
Arc #	Gantry	Collimator
1	30° CCW 300°	345°
2	300° CCW 200°	15°
3	200° CW 300°	10°
4	300° CW 30°	350°
5	30° CCW 300°	90°

- Deep field border for Arc 1-4 is set to ~1.5cm (aperture-restricted)
- Arc 5 is HBB inferiorly to help improve superior conformity
- Adjust beam geometry based on patient anatomy

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Beam Geometry: Collision Check

- Advanced beam geometry is meaningless if there is a collision
- Multiple ways to determine safe angles
 - Dry run with patient
 - Virtual dry run
- Perform collision check before planning to select the best safe beam angles



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Optimization

Energy
Structures
Flash
Optimization settings
Tradeoffs
Plan evaluation

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Optimization: Energy Selection

- 6X
 - Good standard option

 - 6FFF
 - Good alternative
 - May reduce contralateral low dose
 - More MUs, but shorter beam-on-time due to higher dose rate
- DOI:10.4103/jmp.jmp_146_21
- Higher energy VMAT beams can increase lung dose and are generally avoided
- DOI:10.1097/MD.0000000000003295

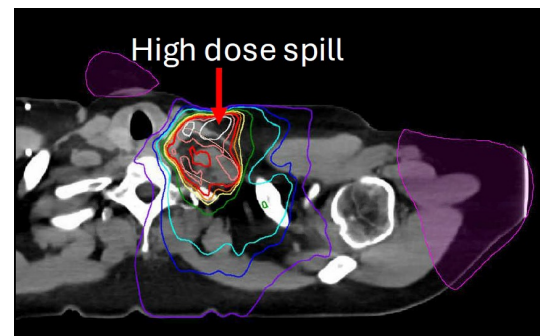
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Optimization: Helper Structures

- Avoid entry (add a margin):
 - Chin
 - Contralateral breast
 - Ipsilateral arm

- High dose ring
 - Clean up high dose spill, especially in SCV region

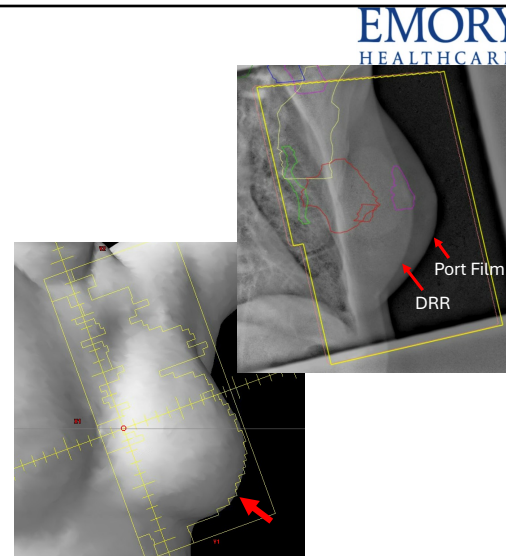
- PTV_FLASH



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Optimization: Flash

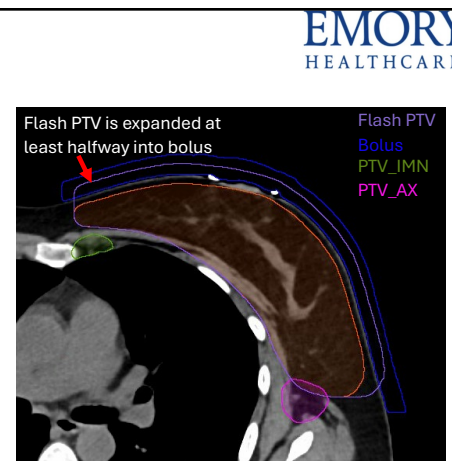
- VMAT plans: MLC leaves conforms tightly to a target
- **Should flash be added?**
 - Day-to-day variability
 - Accounts for breathing and CW motion
 - Helps increase superficial dose
 - Improves plan robustness



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Optimization: Flash

- Place 1.0 cm virtual bolus over PTV_Breast/CW (-500 HU)
DOI: 10.1016/j.ejmp.2019.05.010
- Link bolus to each field
- Create flash PTV
 - Expand PTV_Breast/CW anterior & lateral
 - Assign low-moderate optimization priority to encourage MLC opening beyond patients' surface



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Optimization: Manual NTO

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$$\text{NTO}(x) = f_0^{-k(x-x_0)} + f_\infty (1 - e^{-k(x-x_0)})$$

- **Distance (x)** from target surface (mm)
- **Distance from target border (x₀)** – where NTO gradient starts
- **Start dose (f₀)** – Inner ring dose level*
- **End dose (f_∞)** – Outer ring dose level*
- **Fall-off (k)** – Gradient (mm⁻¹)
 - Higher value = steeper gradient

*Dose is scaled to the lowest upper objective or 105% of the lowest lower objective
 ** **NTO Priority** may be higher than PTV weights

Manual NTO Settings	
Normal Tissue Objective	Manual
Priority	100
Distance from Target Border	0.10 cm
Start Dose	100.0 %
End Dose	60.0 %
Fall-off	0.15

Dose [%] vs Distance [cm] graph showing a smooth decay curve from 100% at 0.0 cm to approximately 60% at 2.0 cm.

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Optimization: Convergence Mode

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- Convergence mode (On, Extended) can improve plan quality
 - Modifies the maximum number of iterations and the criteria for the cost function convergence

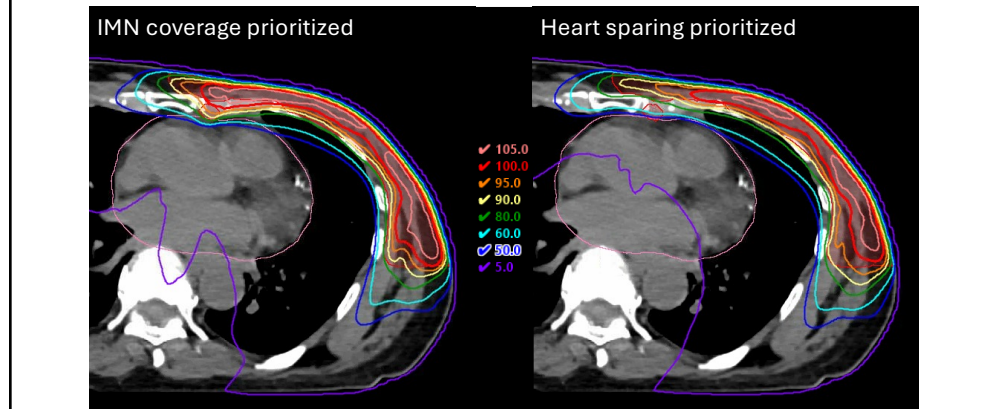
Convergence mode: Off
Optimization time: 5 min

Convergence mode: Extended
Optimization time: 50 min

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Optimization: Understanding Tradeoffs

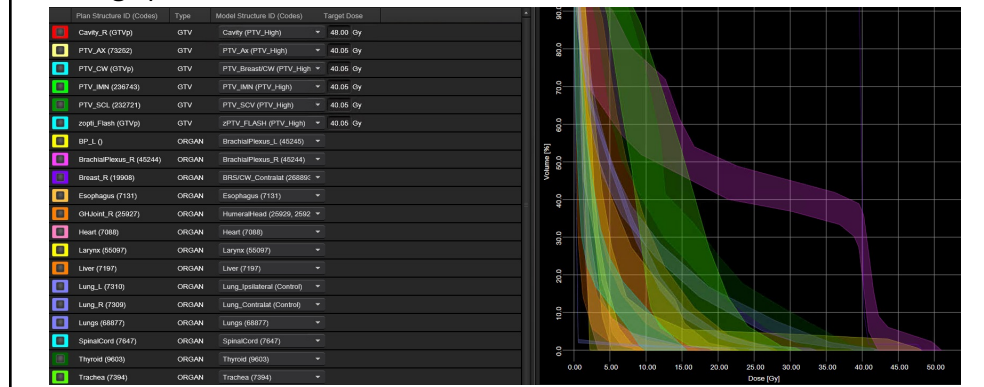
- Coverage of IMN and heart/contralateral breast constraints often compete
- Establish priorities when dosimetric compromises are needed



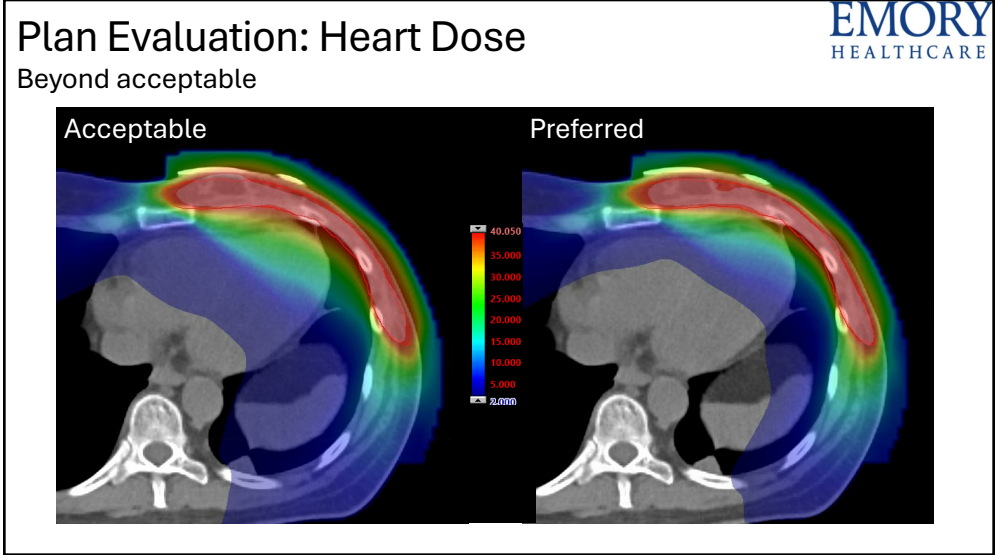
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Optimization: RapidPlan

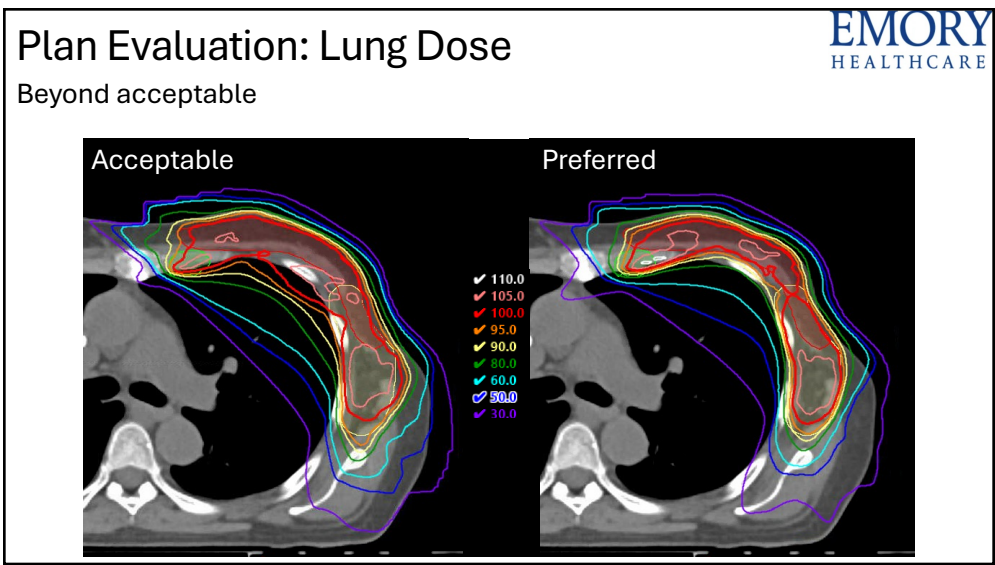
- KBP helps streamline planning by generating patient-specific objectives from prior high-quality plans, reducing trial-and-error during optimization



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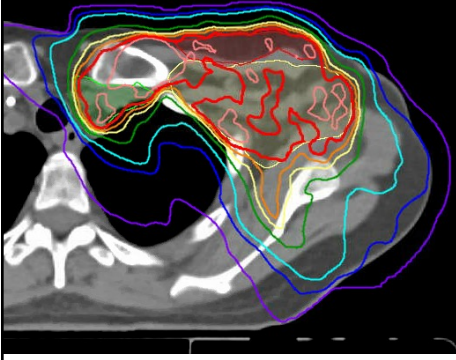
Plan Evaluation: Conformity

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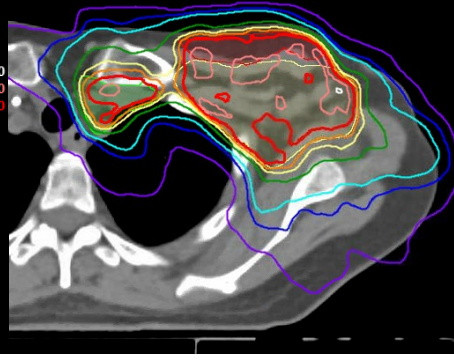
Beyond acceptable

- High-to-low isodose levels should be evaluated for conformity and compactness

Acceptable



Preferred

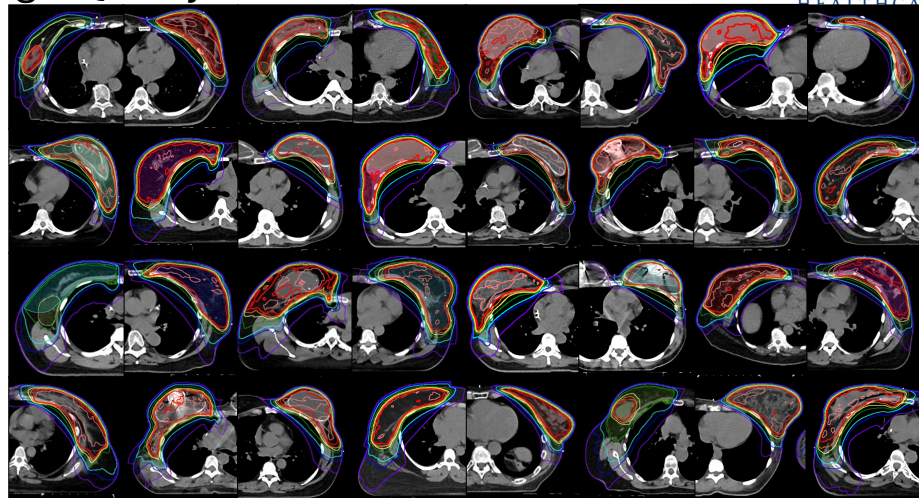


- ✓ 110.0
- ✓ 105.0
- ✓ 100.0
- ✓ 95.0
- ✓ 90.0
- ✓ 80.0
- ✓ 50.0
- ✓ 30.0

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High-Quality Treatment Plans

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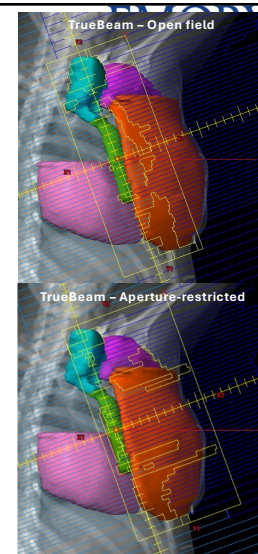
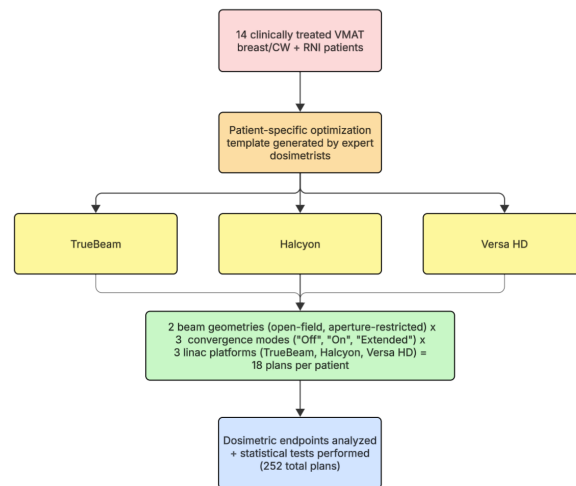
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Research

Dosimetry-led research
Results

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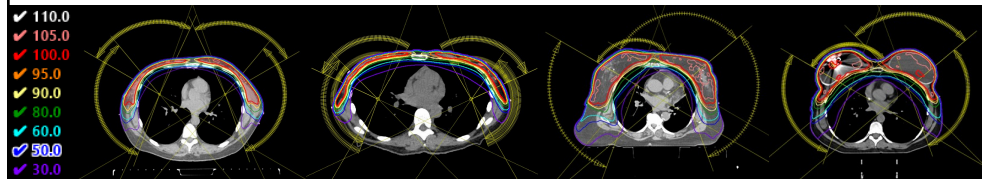
Research: Methods



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Bilateral Patients

- Beam geometry and optimization strategies can be applied to bilateral patients
- Use two isocenters?
 - Separate isocenters with a right-to-left shift only
 - Optimize as a single plan, then split into right and left plans after optimization
- One isocenter
 - Less moving parts...



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Take Home Message

- Consider VMAT when it provides a dosimetric benefit
- Strategic beam geometry is the foundation of a high-quality plan whether 3D or VMAT
- Be intentional with optimization settings

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Thank you for your attention

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