A Single-isocenter Multi-segment (SiMs) Conformal Arc Technique for Stereotactic Body Radiotherapy

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SiMs Conformal Arc Technique

- Introduction
- SiMs Technique
- Method
- Results
- Conclusion

SiMs Conformal Arc Technique

Introduction

The increasing use of SBRT for tumors in lung, liver and other extra-cranial sites presents a growing challenge for treatment planning and treatment delivery using traditional non-coplanar beam therapy (NCBT) techniques.

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Challenges include:

1. potential patient-machine collisions
   - Conservative- not realizing the max benefit of the allowable geometry
   - Aggressive- creating a non deliverable plan geometry

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Challenges include:

2. involuntary patient motion
   - frequent couch movements and associated acceleration and deceleration of the treatment table
   - increasing the potential with increasing session duration

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Challenges include:

3. long treatment delivery times
   - delivery complexity
   - multiple beam stops
   - room re-entry for field setup

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Challenging factors include:

1. potential patient-machine collisions,
   - conservative, not realizing the max benefit of the allowable geometry
   - aggressive, non deliverable planned geometry
2. involuntary patient motion
   - frequent couch movements and associated acceleration and deceleration of the treatment table
3. long treatment delivery times
   - complexity
   - multiple beam stops and
   - room re-entry for setup

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In response to these challenges, we considered an alternate planning and treatment technique using a single-isocenter multi-segment (SiMs) conformal arc technique.

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In this consideration we determined to make direct comparisons of an alternate technique with respect to:

- dosimetric qualities
- the number of required couch movements
- the delivery times of both techniques

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Our results show the SiMs Arc technique to be a viable and robust method for both treatment planning and treatment delivery for these patients.

The SiMs Arc technique is now used in our department as standard delivery technique for SBRT for tumors in the lung(s)*.

SiMs Conformal Arc Technique

SiMs Technique

- Setup
  - Supine
  - Arms at side
  - Whole body Vac-loc Bag

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SiMs Technique

- Simulation
  - 4D scan acquired using GE Lightspeed 16 slice capable scanner
  - 2.5mm slice thickness
  - 10 phase respiratory cycle constructed

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SiMs Technique

- Treatment Planning
  - Varian Eclipse 8.9
  - AAA based dose calculation
  - Tumor drawn on all phases of the respiratory cycle
  - Planned using AIP CT set for dose calculation and plan evaluation

SiMs Conformal Arc Technique

SiMs technique

1. Identifying an isocenter, usually not in the tumor volume but in the geometric center of patient's axial plane with due consideration of the PTV location and patient immobilization devices, that allows for 360 degree free gantry rotation around the patient

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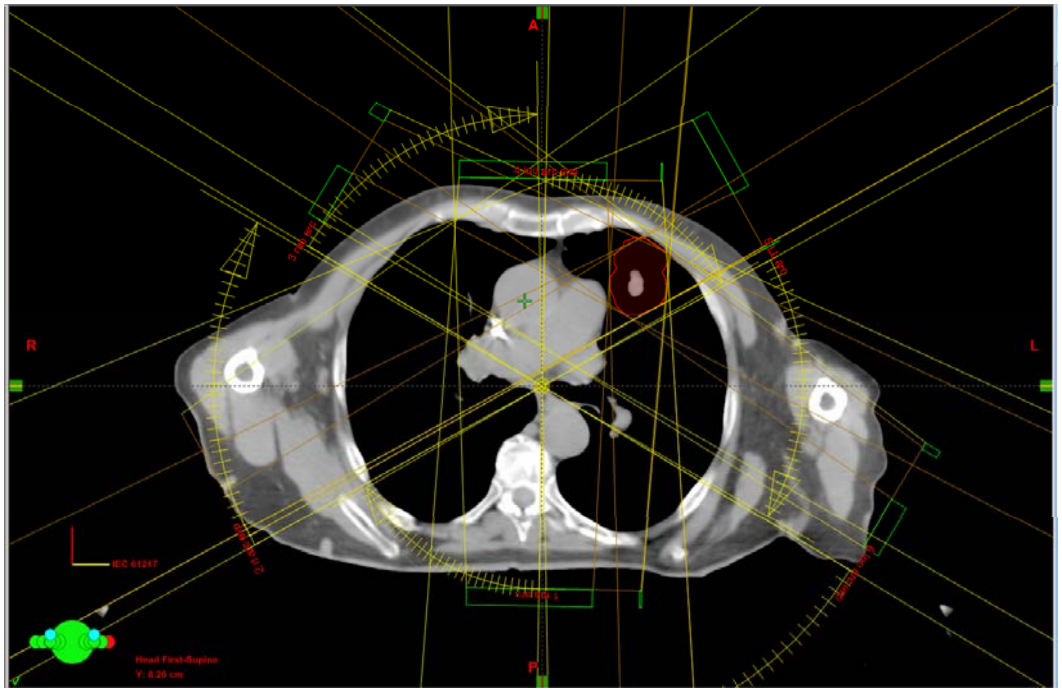
Treatment isocenter:

- Sup/Inf- center of the itv
- Ant/Post- mid distance between couch and most anterior patient surface
- Lt/Rt- patient midline (centered on couch)



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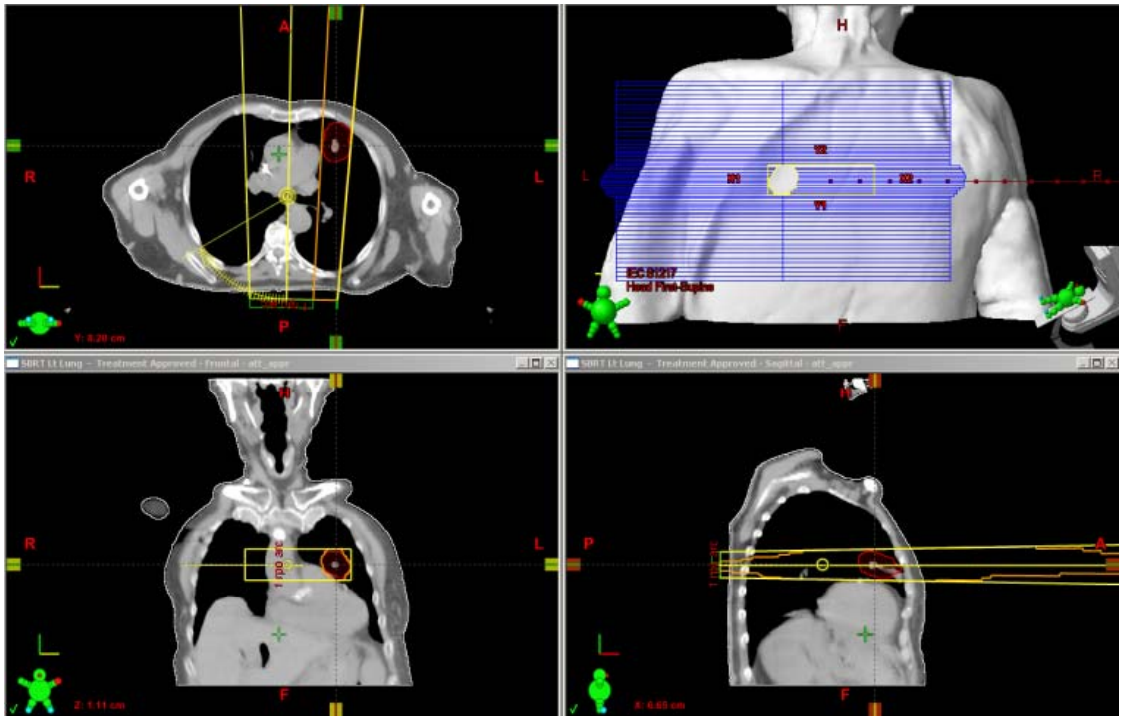
2. Creating six isocentric dynamic conformal arc segments, each spanning approximately 60 degrees



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3. Defining the dynamic MLC apertures of each arc segment based on beam's eye view of PTV in a manner meant to achieve a desired dose fall off in the superior and inferior directions.

- a 7.5mm superior and inferior margin was added to PTV for the contralateral lateral arc relative to the tumor site and subsequently to each alternate arc
- a 2.5mm superior and inferior margin was added for the ipsilateral lateral arc and subsequently to each alternate arc
- The MLC aperture in axial direction were defined by PTV with no additional margins

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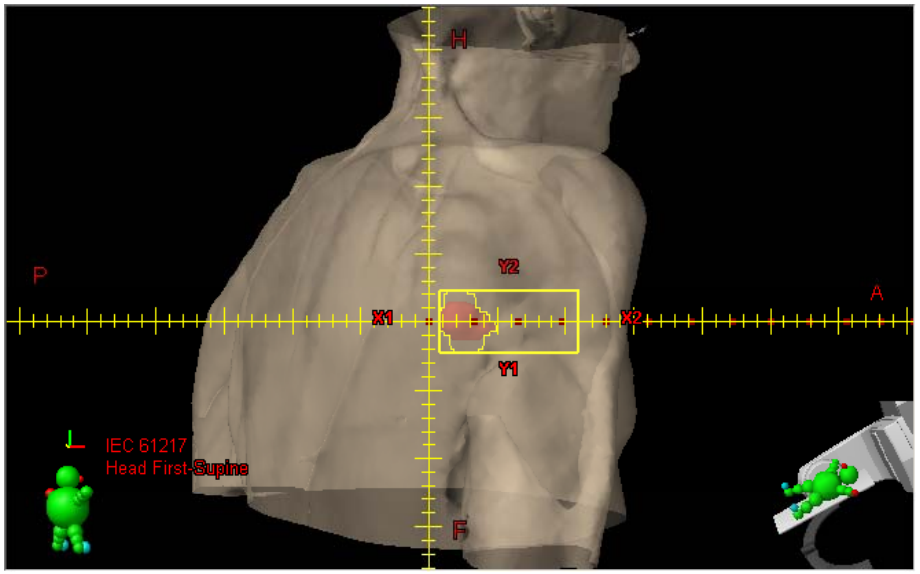

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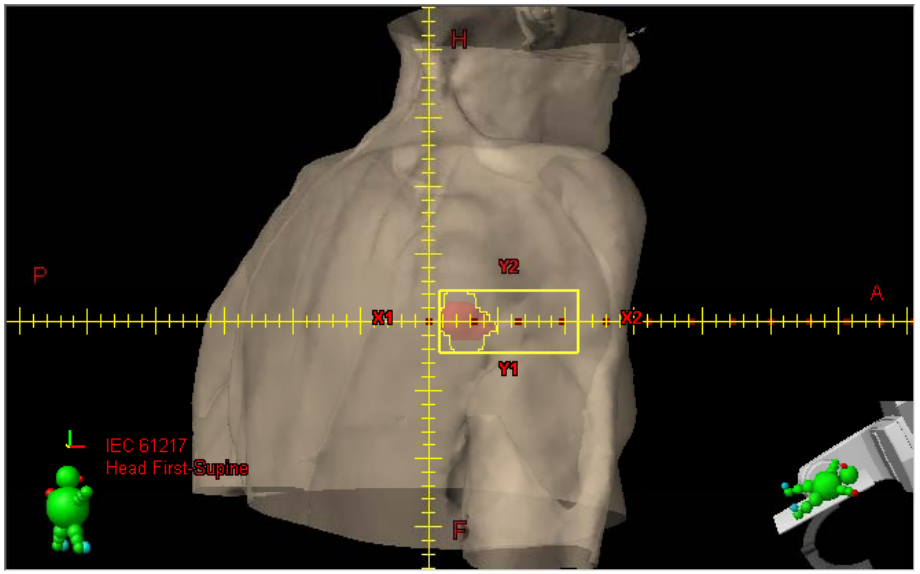

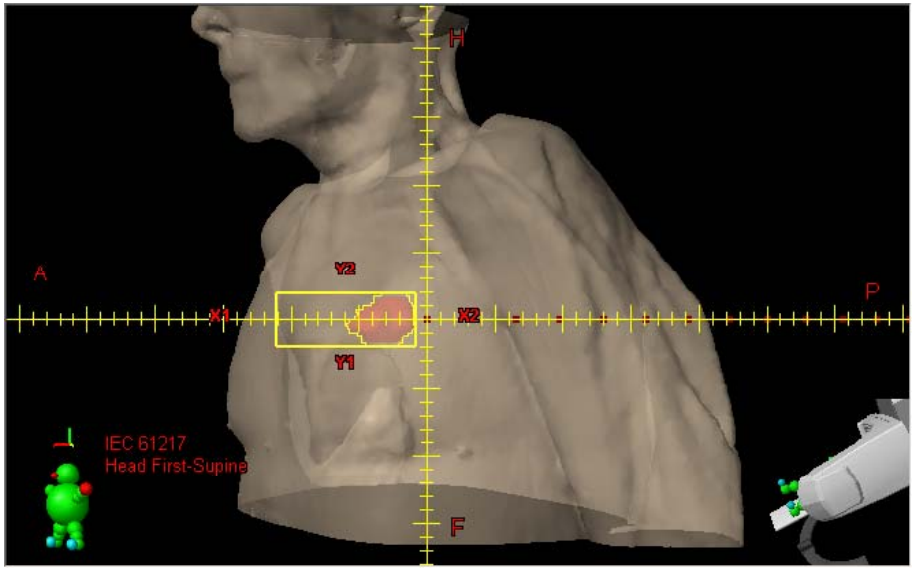

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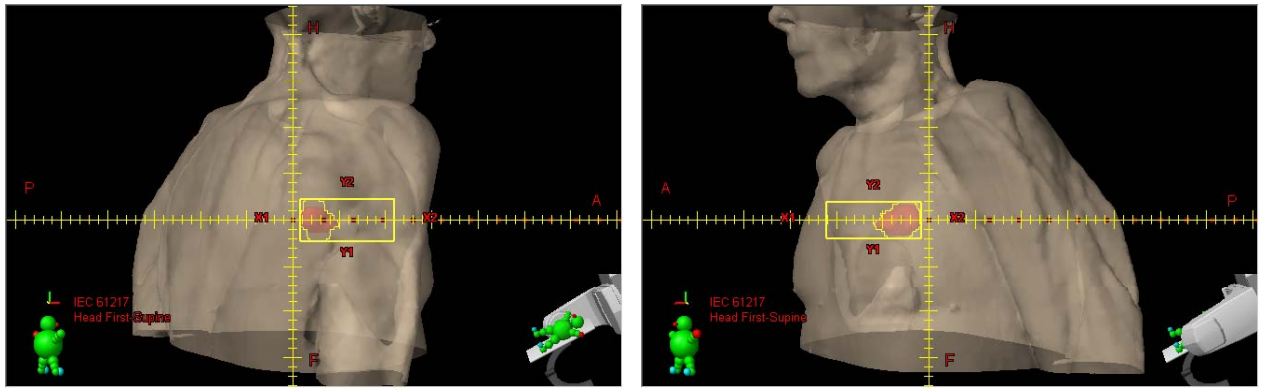

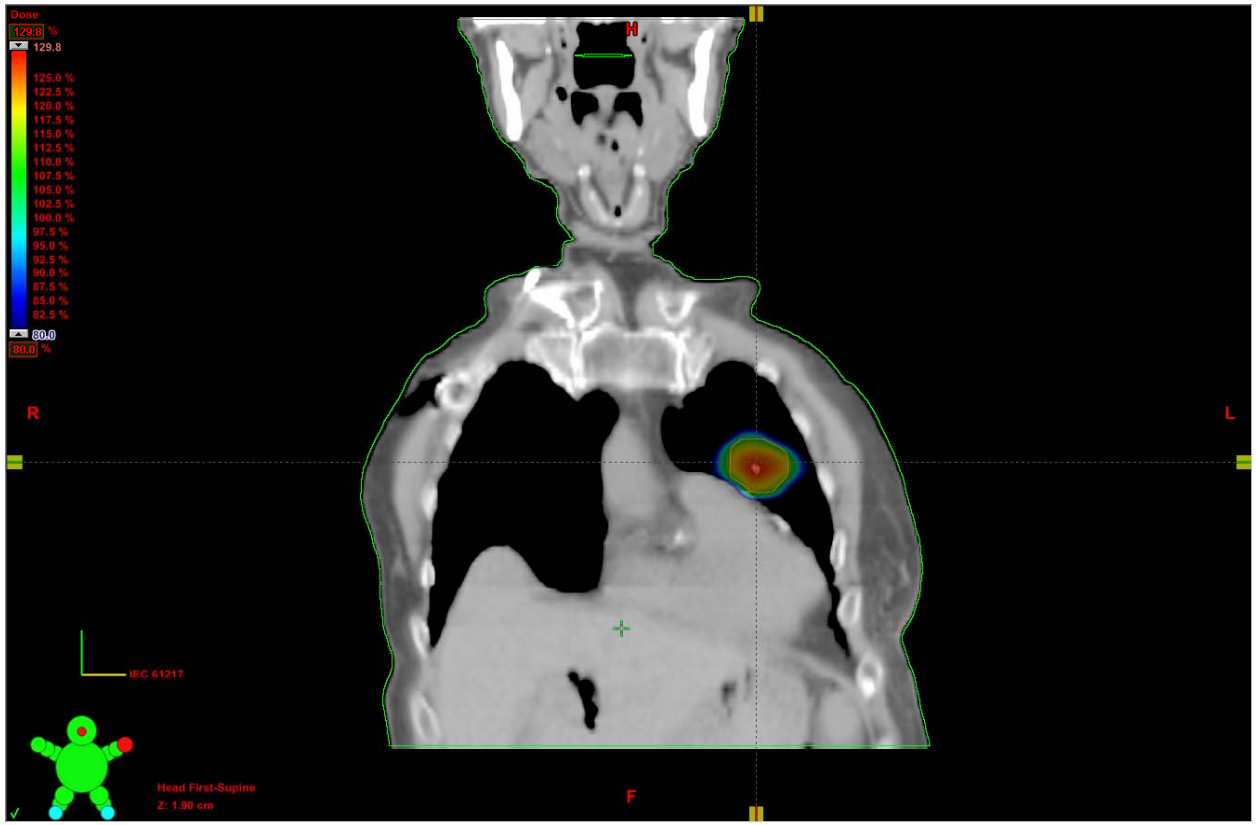


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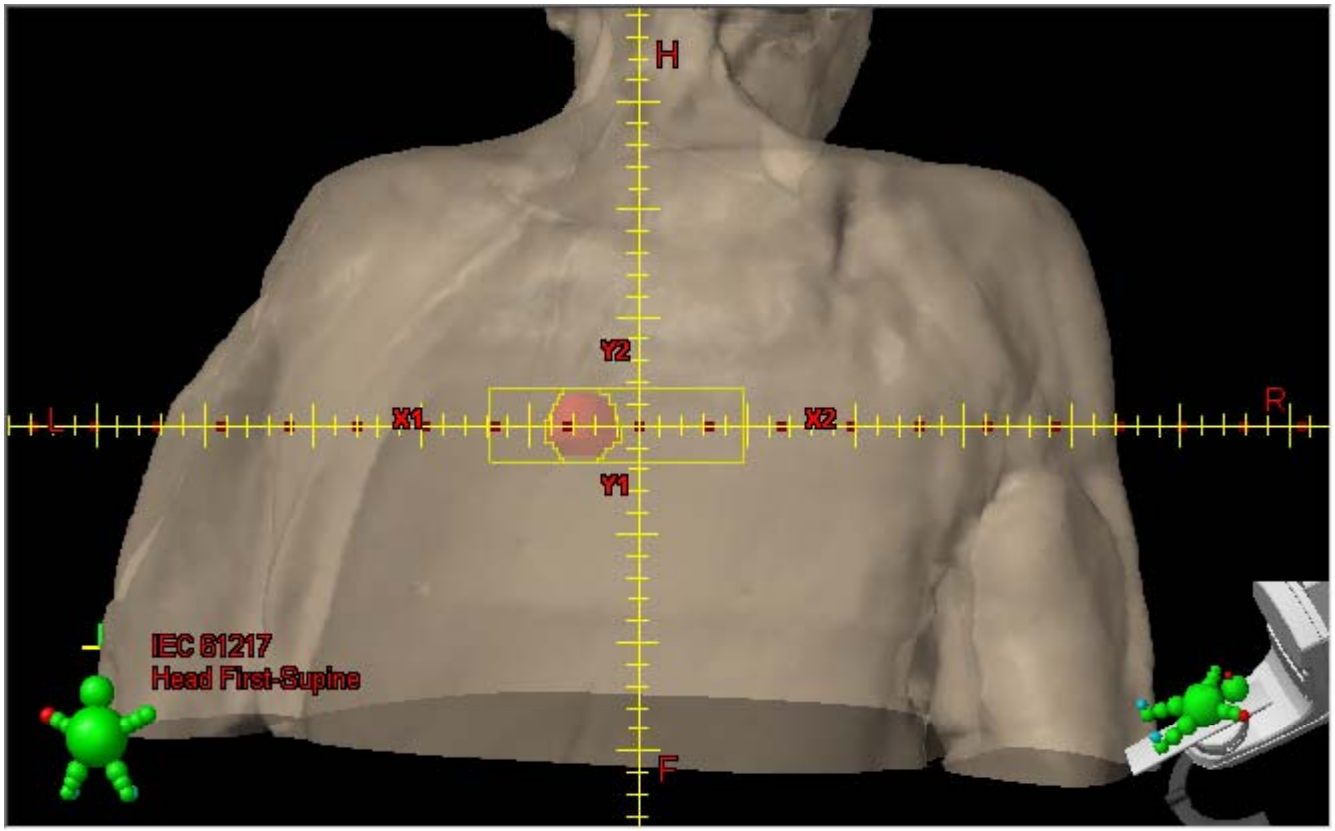
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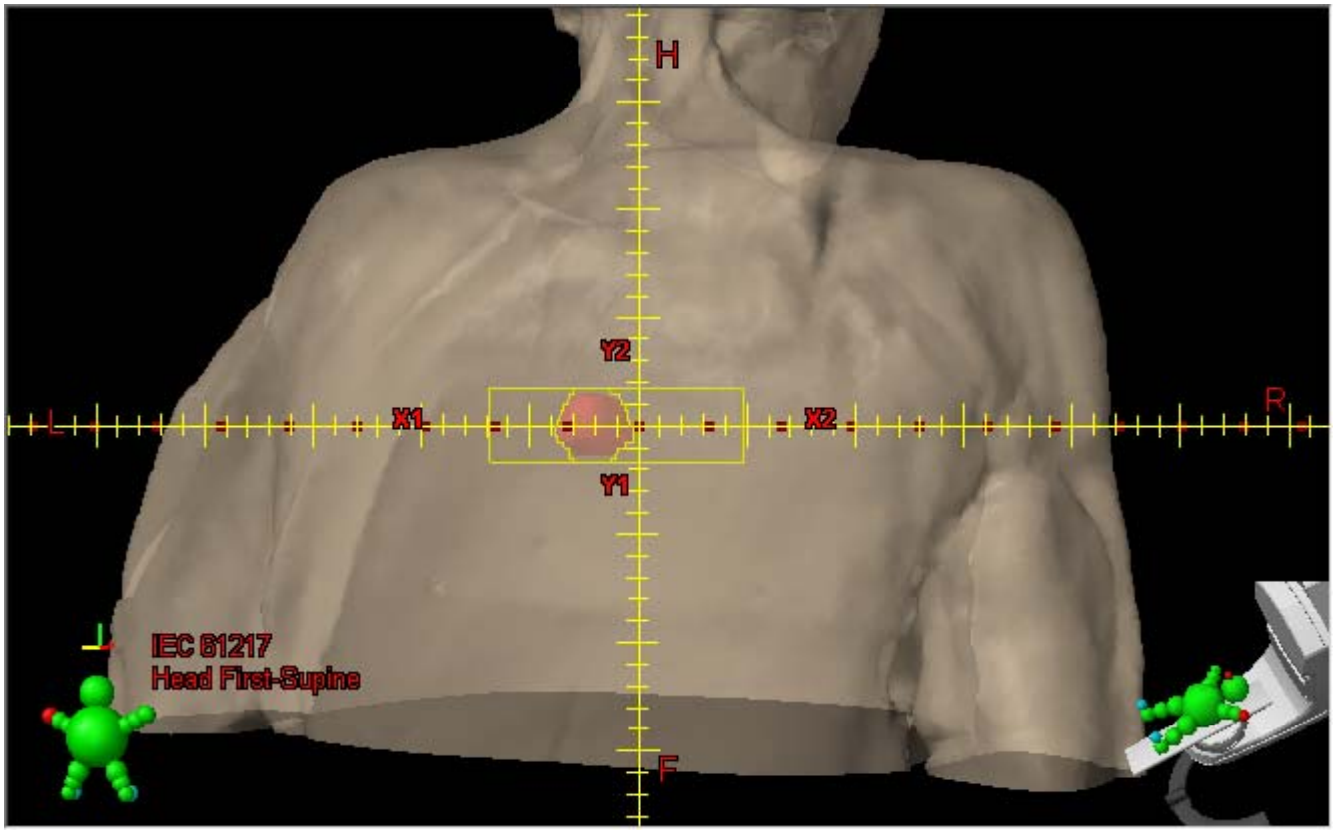
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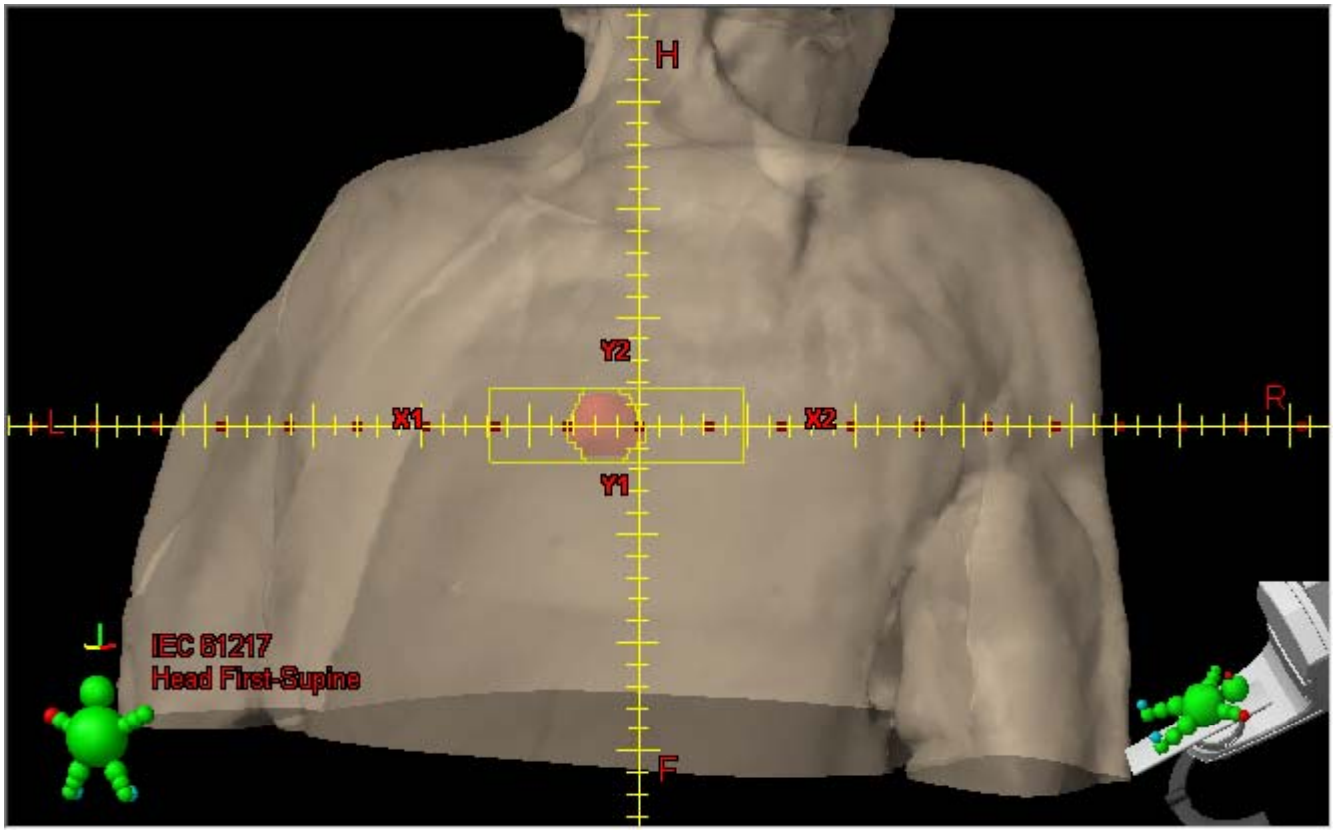
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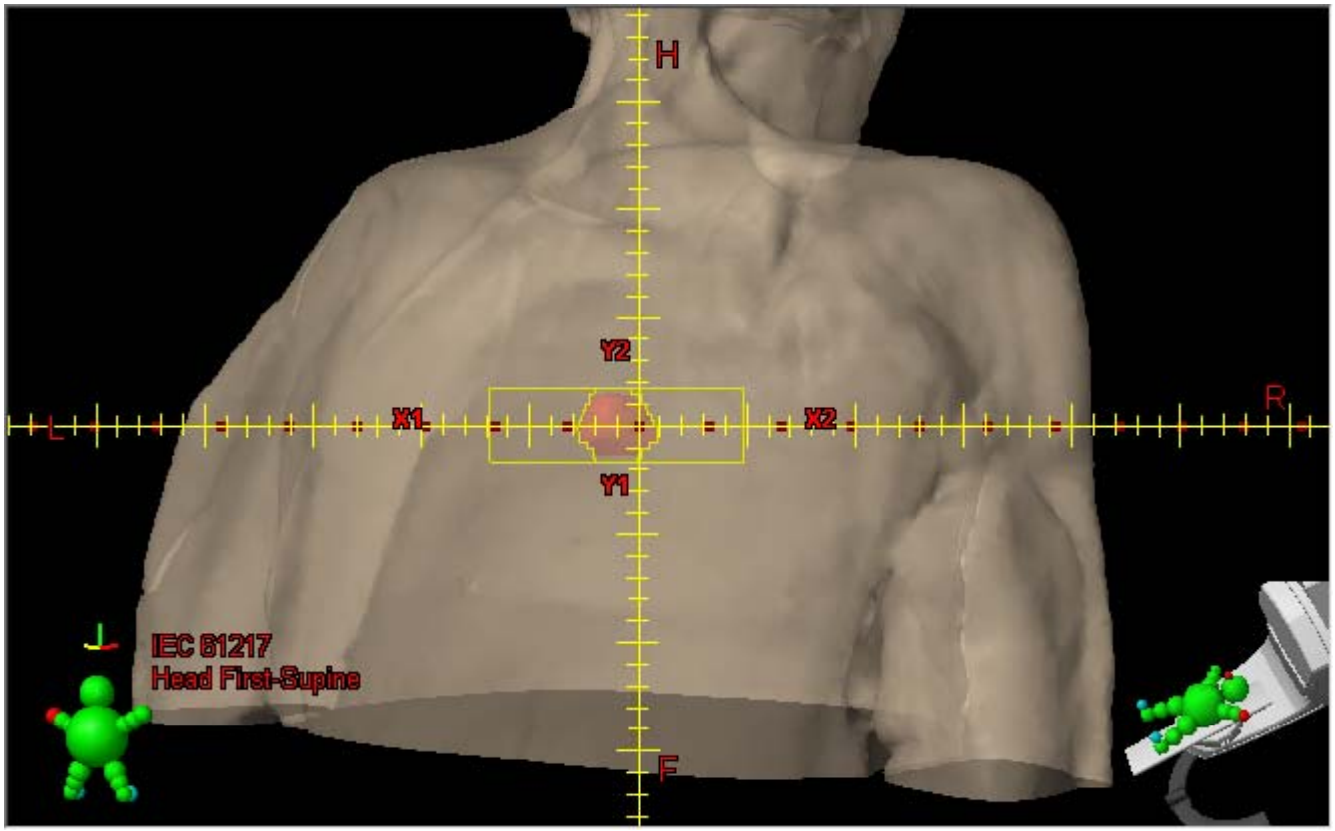
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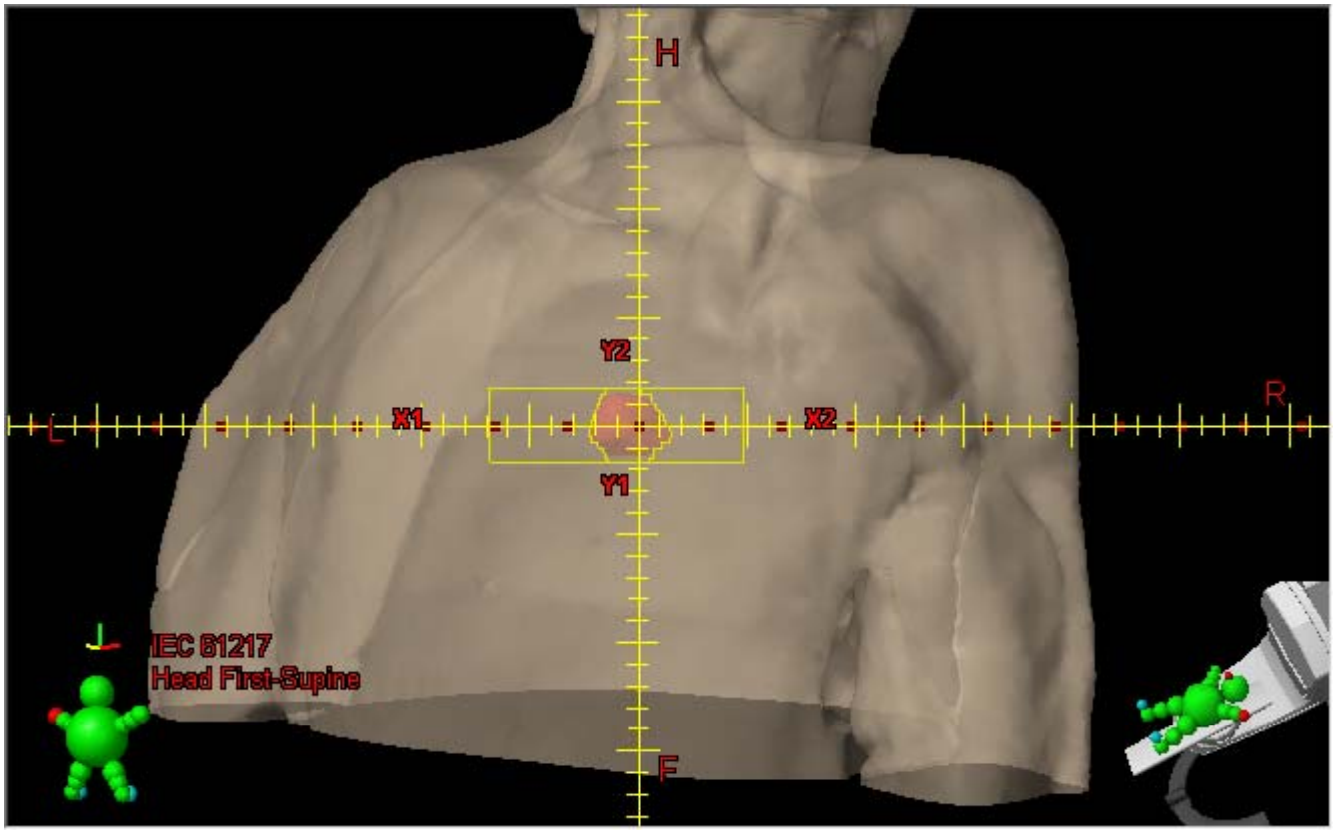
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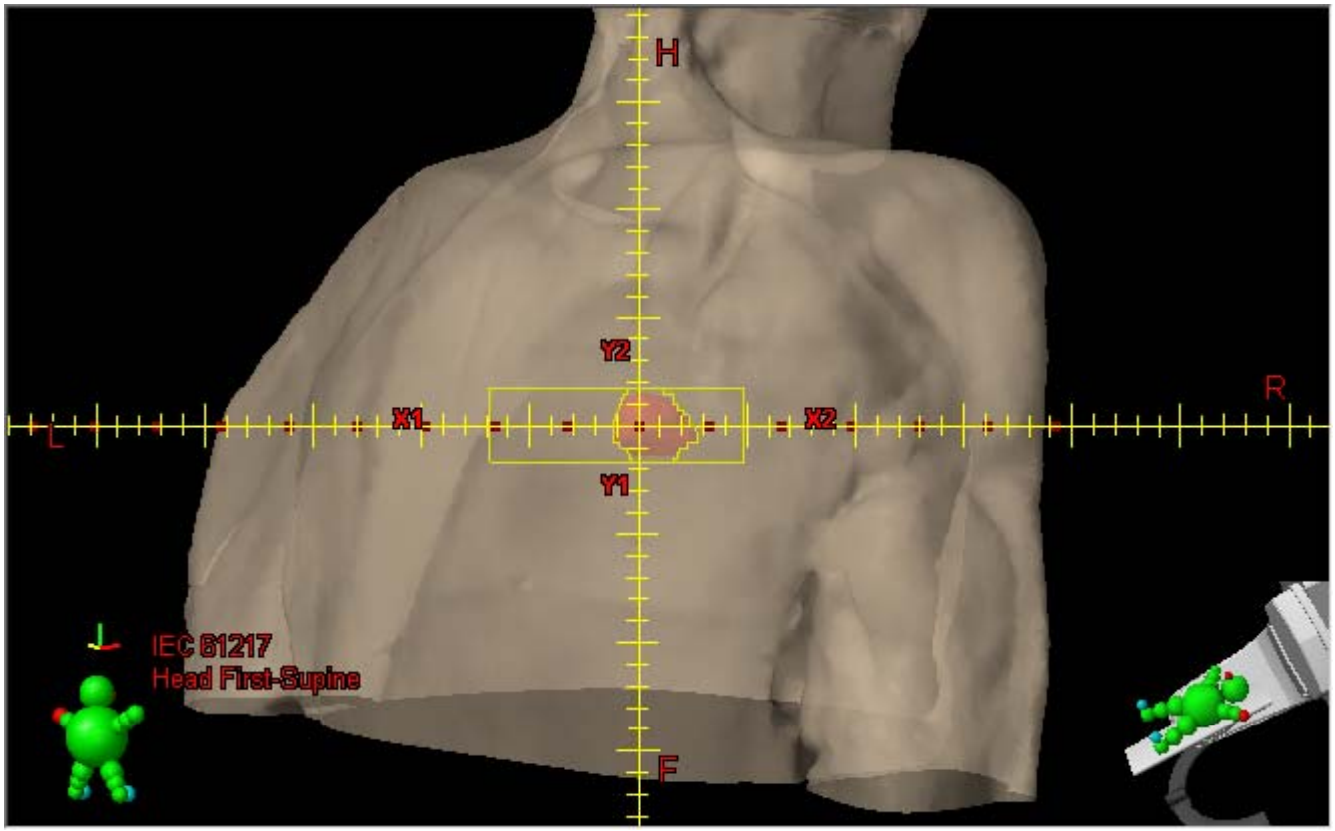
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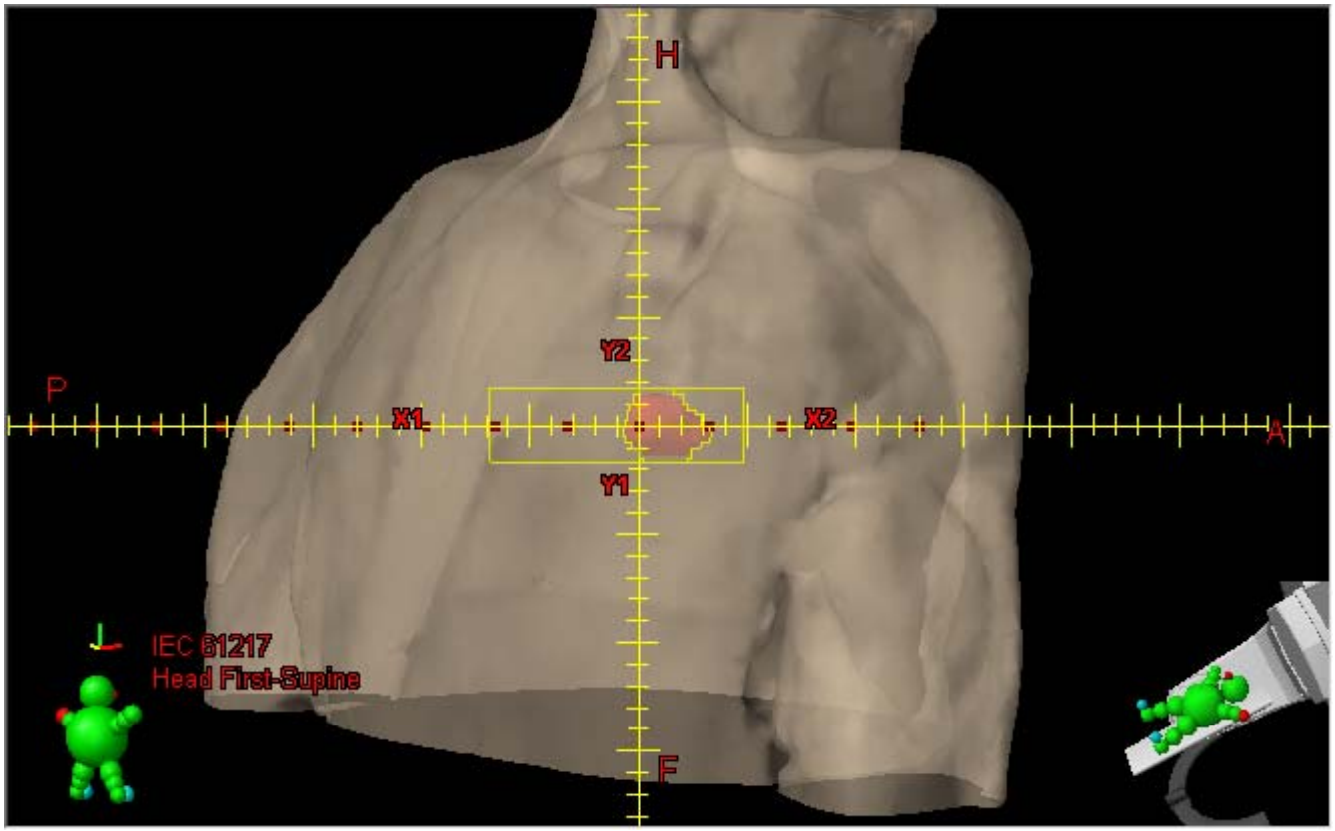
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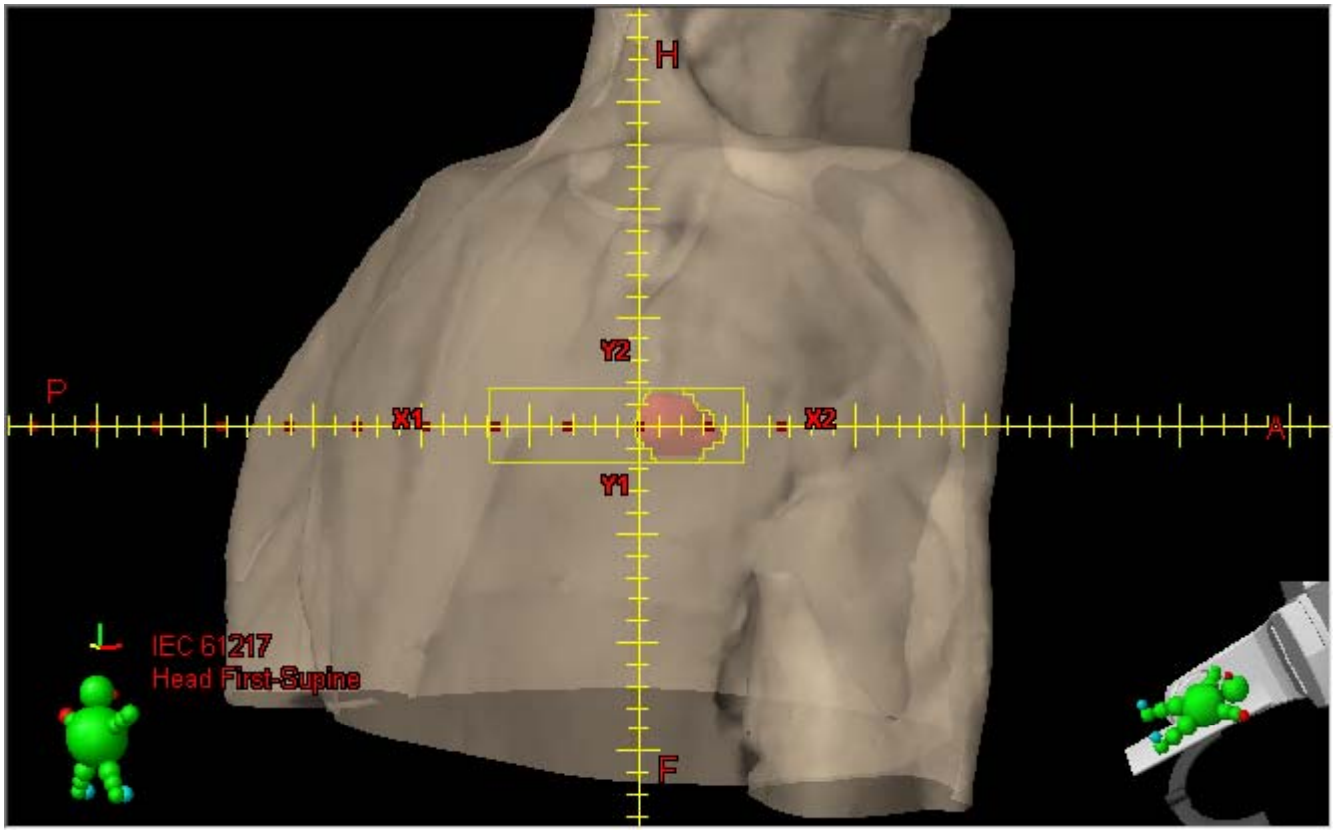
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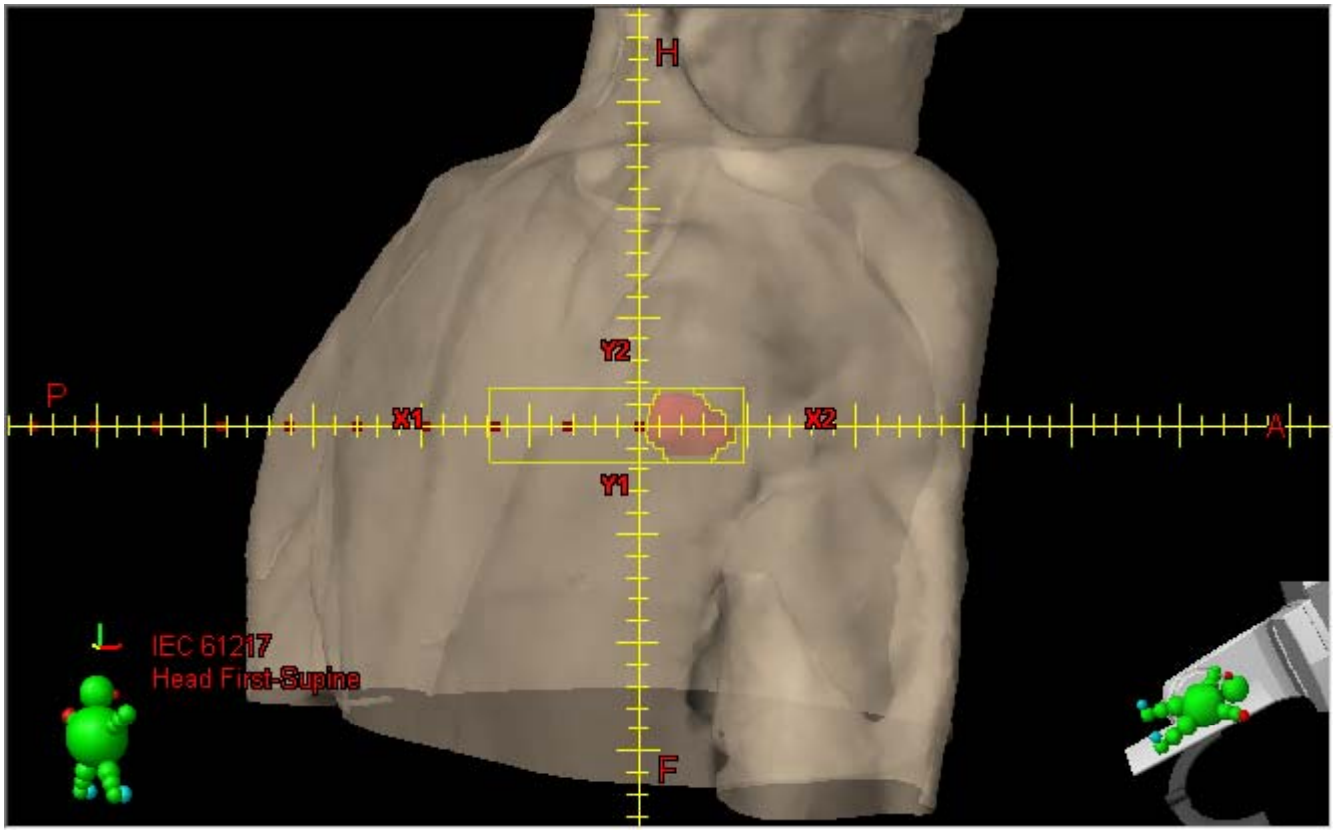
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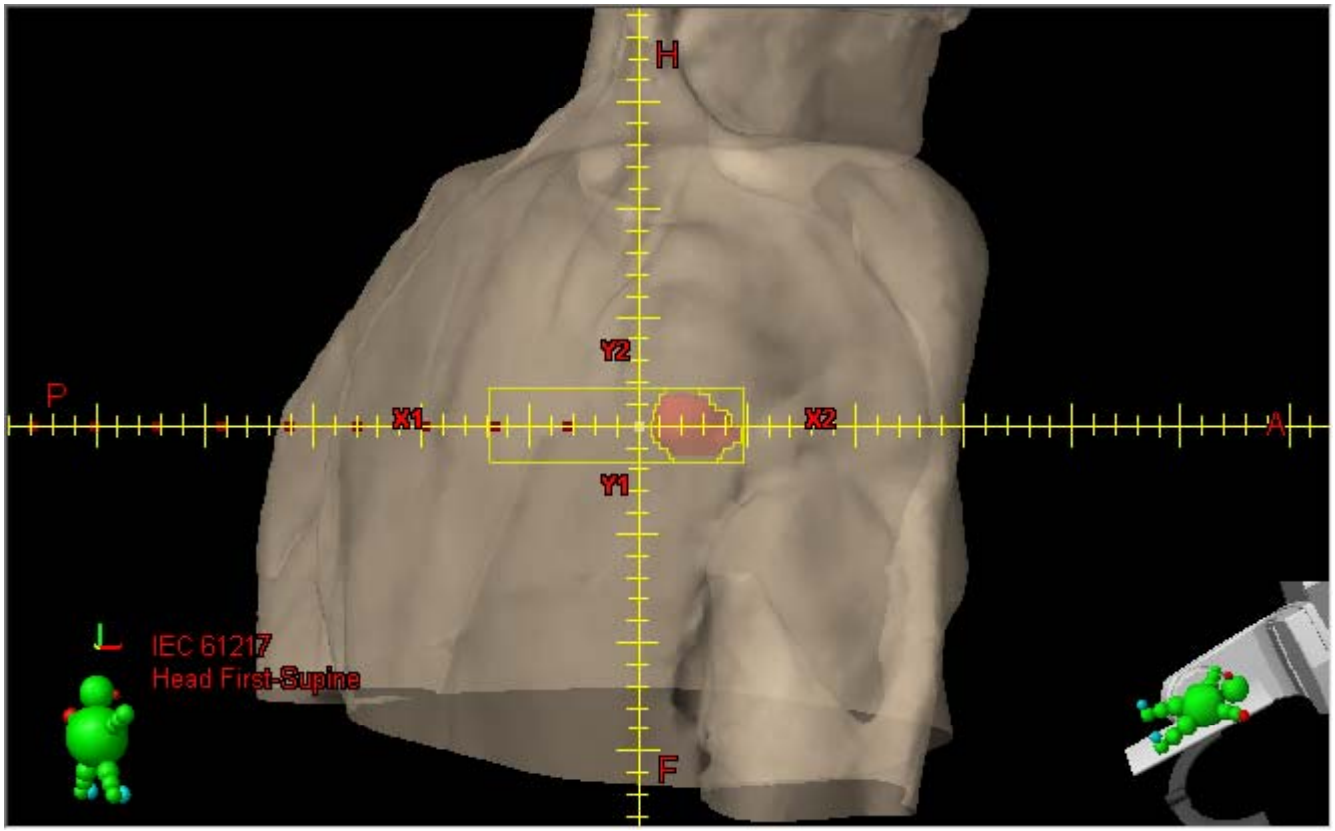
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SiMs Conformal Arc Technique

SiMs technique

4. A) Normalizing the plan so that the PTV was covered adequately and

4. B) Object at Risk (OAR) limits considered

SiMs Conformal Arc Technique

- Normalizing so the PTV was covered adequately
  - The prescribed dose (54 Gy in 3 fractions) shall be prescribed to an isodose surface that covers a minimum of 95% of the PTV
  - The prescription isodose will be from 60-90% of the maximum dose
  - 99% of the PTV will receive at least 90% of the prescription dose
  - No dose ≥ 105% of prescription will be allowed outside of the contoured PTV
  - The conformality index (ratio of the prescription isodose volume to the volume of the PTV) should be less than or equal to 1.3
  - The ratio of the volume of 50% isodose surface to that of the PTV should be less than or equal to 4
  - No dose greater than 30 Gy shall be allowed greater than or equal to 2 cm distance from any edge of the PTV

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- Object at Risk (OAR) limits considered.
  - The volume of lung receiving 20 Gy or higher (V20) shall be less than 10% of the total lung volume (the GTV to be subtracted from the lung volumes)
  - Maximum spinal cord dose to any point will be <= 18 Gy
  - Maximum esophagus dose to any point will be <= 27 Gy
  - Maximum brachial plexus dose to any point will be <= 24 Gy
  - Maximum heart dose to any point will be <= 30 Gy
  - Maximum tracheobronchial dose to any point will be <= 30 Gy
  - Maximum skin dose to any point will be <= 24 Gy

SiMs Conformal Arc Technique

The SiMs Arc technique summary:

1) Identifying an isocenter which allows for 360 degree free gantry rotation around the patient
2) Creating six isocentric dynamic conformal arc segments, each spanning approximately 60 degrees, from 1 to 359 degrees
3) Defining the dynamic MLC apertures of each arc segment based on beam's eye view of PTV with considerations to achieve a desired dose fall off in the superior and inferior directions
4) Normalizing the plan so that the PTV was covered adequately with Object at Risk (OAR) limits considered

SiMs Conformal Arc Technique

Method

All patients, regardless of treatment plan type and delivery technique used for their lung SBRT treatment(s) shared the following:

- Set up and Simulation
  - Whole body Vac-loc bag
  - Arms at side
  - 4D scan acquired using GE Lightspeed 16 slice capable scanner
  - 2.5mm slice thickness
  - 10 phase respiratory cycle created for ITV definition
  - Average intensity projection (AIP) CT constructed for dose calculation and plan evaluation
- Treatment Planning
  - Varian Eclipse 8.9
  - AAA based dose calculation

SiMs Conformal Arc Technique

- Dosimetric analysis was performed using 10 SBRT lung patients treated with the NCBT technique.
  - For each patient, a new plan using the SiMs arc technique was generated
  - The SiMs arc plans were designed using the same dosimetric requirements of our SBRT protocol for lung tumors
  - All plans were required to satisfy the minimum coverage of PTV (V100 ≥ 95%)

SiMs Conformal Arc Technique

- Quantitative comparison of the SiMs arc plan and the clinically approved NCBT were performed using the dosimetric indices of:
  - V100
  - D99
  - V20 for lung
  - Conformality Index (CI) for PTV,
    - CI is defined as the ratio of 100% isodose volume to PTV volume
  - Normal Tissue Irradiation index (NTI).
    - NTI is the ratio of 50% isodose volume to PTV volume.

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When compared to the NCBT techniques, the use of SiMs dynamic conformal arcs were quantitatively similar to the NCBT techniques in terms of both PTV coverage and normal tissue protection.

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Dosimetric comparison of NCBT and Sims Arc techniques for 10 SBRT lung patients

	Pt #	vol 50%	vol Ptv	vol 100%	V100	D99	Lung V20	CI	NTI
NCBT	1	144.8	33.2	37.6	95.0%	94.0%	2.2%	1.1	4.4
Arcs		150.1	33.2	36.1	95.0%	94.6%	2.4%	1.1	4.5
NCBT	2	270.6	69.1	77.7	95.0%	92.0%	5.4%	1.1	3.9
Arcs		285.4	69.1	78.0	95.0%	92.1%	5.9%	1.1	4.1
NCBT	3	88.1	18.6	25.1	95.0%	89.5%	2.3%	1.3	4.7
Arcs		87.1	18.6	21.3	95.0%	90.6%	2.2%	1.1	4.7
NCBT	4	854.6	256.9	308.7	95.0%	90.0%	6.4%	1.2	3.3
Arcs		876.9	256.9	307.4	95.0%	93.7%	7.6%	1.2	3.4
NCBT	5	81.3	16.0	20.4	95.0%	91.5%	1.5%	1.3	5.1
Arcs		76.5	16.0	17.7	95.0%	95.6%	1.5%	1.1	4.8
NCBT	6	71.8	19.0	20.6	95.0%	95.5%	1.7%	1.1	3.8
Arcs		78.5	19.0	20.4	95.0%	94.5%	2.1%	1.1	4.1
NCBT	7	154.6	46.6	48.6	95.0%	94.0%	1.8%	1.0	3.3
Arcs		164.4	46.6	47.3	95.0%	94.2%	2.1%	1.0	3.5
NCBT	8	75.7	21.9	22.7	95.0%	95.0%	2.8%	1.0	3.5
Arcs		78.3	21.9	23.2	95.0%	94.3%	3.0%	1.1	3.6
NCBT	9	303.4	59.4	71.4	95.0%	90.0%	5.4%	1.2	5.1
Arcs		237.9	59.4	63.3	95.0%	92.9%	5.1%	1.1	4.0
NCBT	10	75.0	19.5	20.3	95.0%	96.2%	4.0%	1.0	3.8
Arcs		81.2	19.5	20.3	95.0%	96.2%	4.4%	1.0	4.2
NCBT	Avg	212.0	56.0	65.3	95.0%	92.8%	3.4%	1.1	4.09
Arcs	Avg	211.6	56.0	63.5	95.0%	93.9%	3.6%	1.1	4.09

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Comparison of the DVH's between the SiMs Arc plan and the corresponding NCBT plan for three representative cases highlight the extent of expected differences.

- Higher minimum PTV dose with lower lung dose were considered favorable
  - Side-by-side plan comparison of SiMs Arc (Left panel) and NCBT (Right panel) techniques.
  - The DVH curves were plotted
    - » squares for SiMs Arc plan and
    - » triangles for NCBT plans.
    - » red – PTV
    - » yellow- lungs

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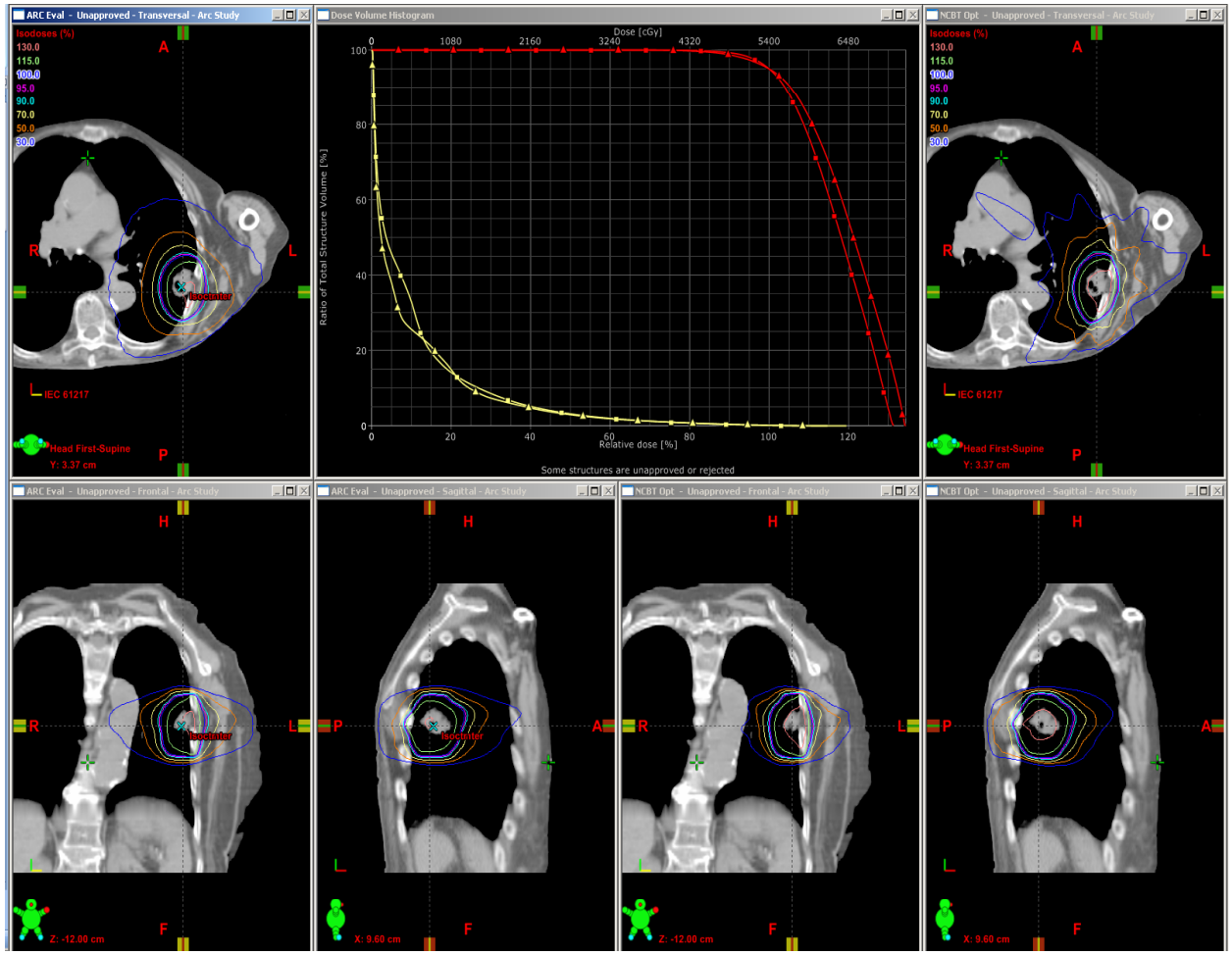
cases for which the NCBT technique was slightly better



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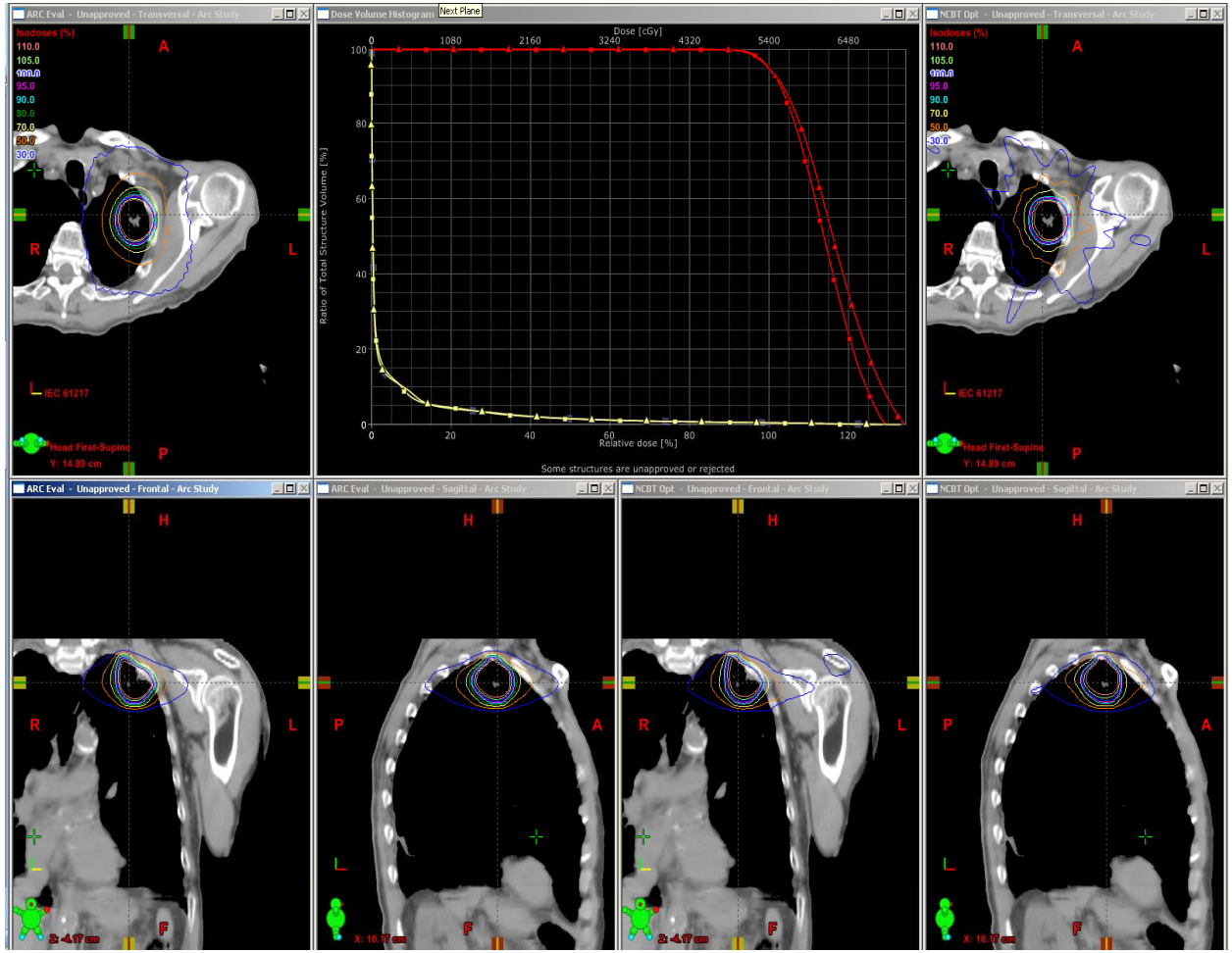
cases for which the SiMs Arc and NCBT techniques were similar



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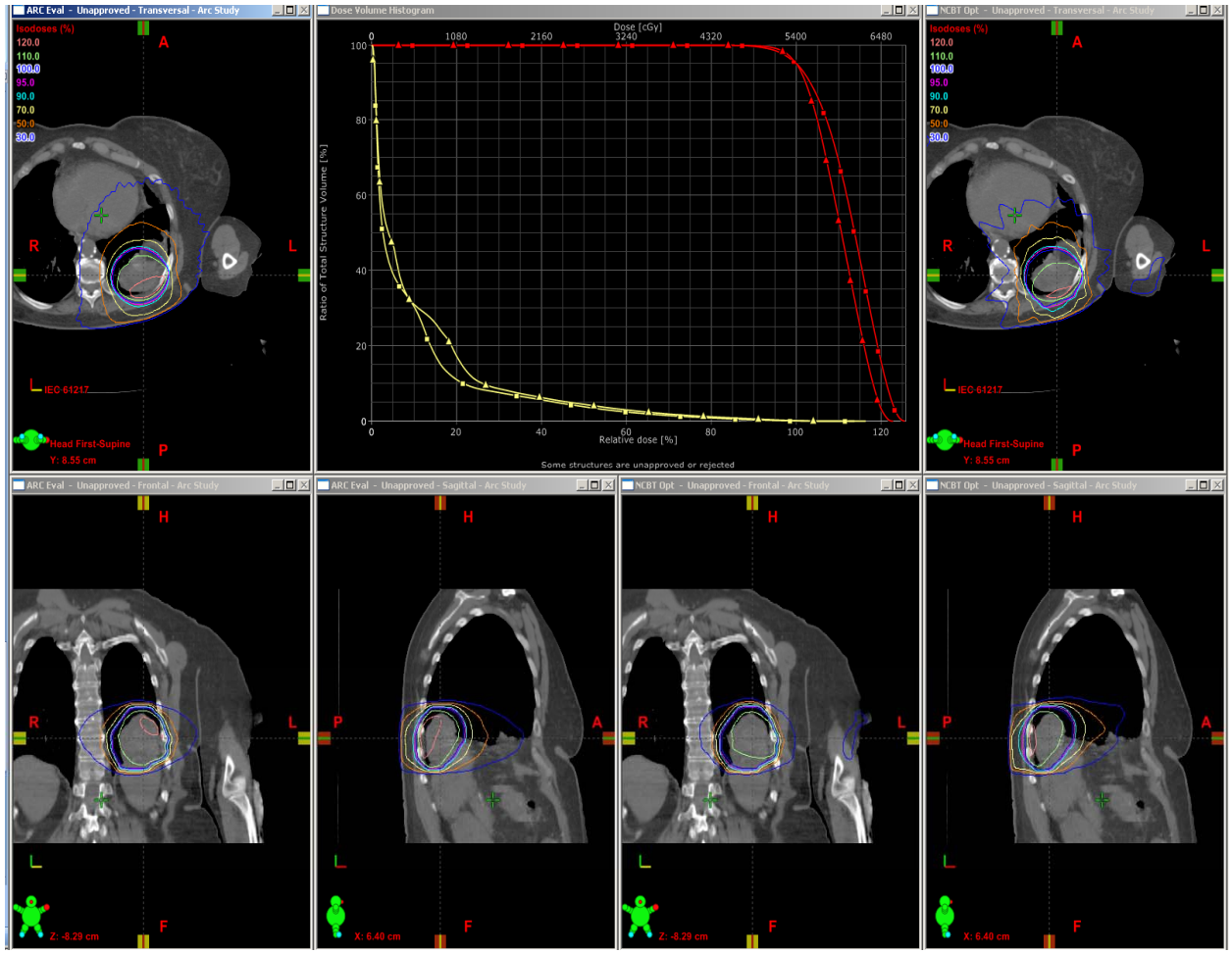

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- The time needed to deliver the SiMs Arc technique and the NCBT technique was analyzed using Varian's ARIA information management system.
  - The delivery time indicates the elapsed time required for each fraction of treatment delivered from time of beam on to final beam off.

To facilitate a meaningful comparison, only those patients treated to a total dose of 54 Gy in 3 fractions were included in the analysis.

Summary of the treatment delivery times for 11 patient treated using the SiMs Arc technique.

Actual Sims Arc delivery times for each fraction (total of 3 fractions of 18 Gy) - Beam on to Beam off

Patient	Delivery Time (s)			
	1	2	3	Avg.
1	470	470	487	476
2	425	438	450	438
3	505	564	552	540
4	523	604	507	545
5	593	532	698	608
6	514	475	467	485
7	514	528	507	516
8	524	537	562	541
9	417	422	411	417
10	440	454	413	436
11	456	442	446	448
AVG	489	497	500	495

Summary of the treatment delivery time (DT) for 22 patient's treated using a NCBT technique

Actual NCBT delivery times for each fraction (total of 3 fractions of 18 Gy) - Beam on to Beam off

Patient	Delivery Time (s)			
	1	2	3	Avg.
1	581	596	621	599
2	891	858	741	830
3	845	876	836	852
4	722	621	651	665
5	712	743	739	731
6	687	643	741	690
7	726	723	630	693
8	750	852	787	796
9	986	1016	1121	1041
10	791	740	686	739
11	754	765	716	745
12	820	741	764	775
13	795	733	782	770
14	680	655	617	651
15	793	842	833	823
16	880	975	907	921
17	1037	755	748	847
18	674	906	928	836
19	812	1007	1130	983
20	776	820	2080	1225
21	1168	705	690	854
22	881	718	719	773
AVG	807	786	839	811

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- We found an average delivery time using the Sims Arc technique to be 495 seconds compared to the average time of 811 seconds using a NCBT technique.
- This results in an average difference of 5.3 minutes or a 39.0% reduction in delivery time using the Sims Arc technique.

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- The number of fields used per plan and the number of non-coplanar fields per plan was also analyzed for 23 SBRT lung patients treated using NCBT techniques. The SiMs Arc technique relies on the use of 6 coplanar fields only.

Patient	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Avg
Plan fields	10	9	11	8	9	11	9	9	11	11	10	12	11	10	8	10	13	9	11	11	10	10	9	10
NC fields	7	8	10	6	8	10	7	8	7	9	7	11	4	9	8	8	5	9	8	9	9	8	9	8

- The use of non-coplanar (NC) fields in the NCBT technique significantly increases treatment times and requires couch movements. The increased treatment time and the frequent couch rotation both contribute to and/or increase the likelihood of dose delivery error associated with patient movement.

SiMs Conformal Arc Technique

Conclusion

- A single-isocenter multi-segment conformal arc technique has been proposed, tested, and successfully applied to SBRT treatments for tumors in lung in our department.
- Our experience demonstrates that this technique has not only improved the efficiency and dosimetric consistency of SBRT treatment planning but also led to more robust treatment delivery.

SiMs Conformal Arc Technique

- Using a SiMs Arc template plan, the time and effort needed to generate an acceptable SBRT plan was greatly reduced compared to 3D NCBT.
  - For the same prescribed dose, the total treatment time was reduced on average by 39% compared to 3D NCBT.
  - The use of SiMs Arc technique eliminated need for inter-beam couch rotation and, hence, involuntary patient movements caused by sudden acceleration and deceleration of the treatment couch as needed in 3D NCBT.

Acknowledgement

- Dosimetrists
  - Monica Kaur
  - Jim Kimmett
  - Huan Liu
  - Jim Picone
  - Jing Jing Ye
- Jay Chen
- David Carlson
- Roy Decker
- Bryan Chang

Thank you