Positioning Features in Current Immobilization Systems

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Disclosures

- None.

Learning Objectives

- Special considerations for SBRT / SRS immobilization
- Understand positioning features of immobilization systems
  - Identify pros / cons of available immobilization systems
- Identify practices to improve your home institution's immobilization procedures.

Outline

- Goals and overall themes of immobilization
- Intracranial
  - Invasive
  - Non-invasive
- Extracranial
  - Lung + liver
  - Motion management techniques
  - Spine

Treatment Uncertainties

- Sources of Geometric Uncertainty:
  - Mechanical
  - Target Localization
  - ***Patient Positioning***

Goals of Immobilization

- ***The main goal of immobilization is to help reduce patient positioning uncertainties***
  – Accurately reproduce patient positioning from simulation to treatment
  – ***Inter-***fraction: Improve treatment-to-treatment alignment
  – ***Intra-***fraction: Minimize movement during treatment

Special considerations in SRS / SBRT immobilization

- Highly conformal dose distributions in close proximity to critical structures
- High dose / fraction
- Small number of fractions
  - Setup errors become more "systematic" in nature, not blurred out like random errors.
- Longer treatment times (30 – 90 mins)
  - More chance of intra-fraction motion

Proper immobilization and

well-integrated patient setup procedures

are crucial to help ensure

SABR treatments are

delivered safely and accurately

Common Themes

- Patient-specific considerations & comfort
  - Performance status, anxiety, etc. Will the patient be able to tolerate the immobilization system for as long as we need them to?
- Patient training & feedback
  - Does the patient understand the goals of immobilization and its importance? Is the patient given the chance to provide feedback?
- Staff training, involvement and feedback
  - Do the staff have an adequate understanding of how to and how not to use the device? Is there a mechanism for feedback between treatment and simulation?
- *A stable, comfortable patient and a well integrated procedure for immobilization and pre-treatment imaging can improve workflow efficiency.*

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- Goals and overall themes of immobilization
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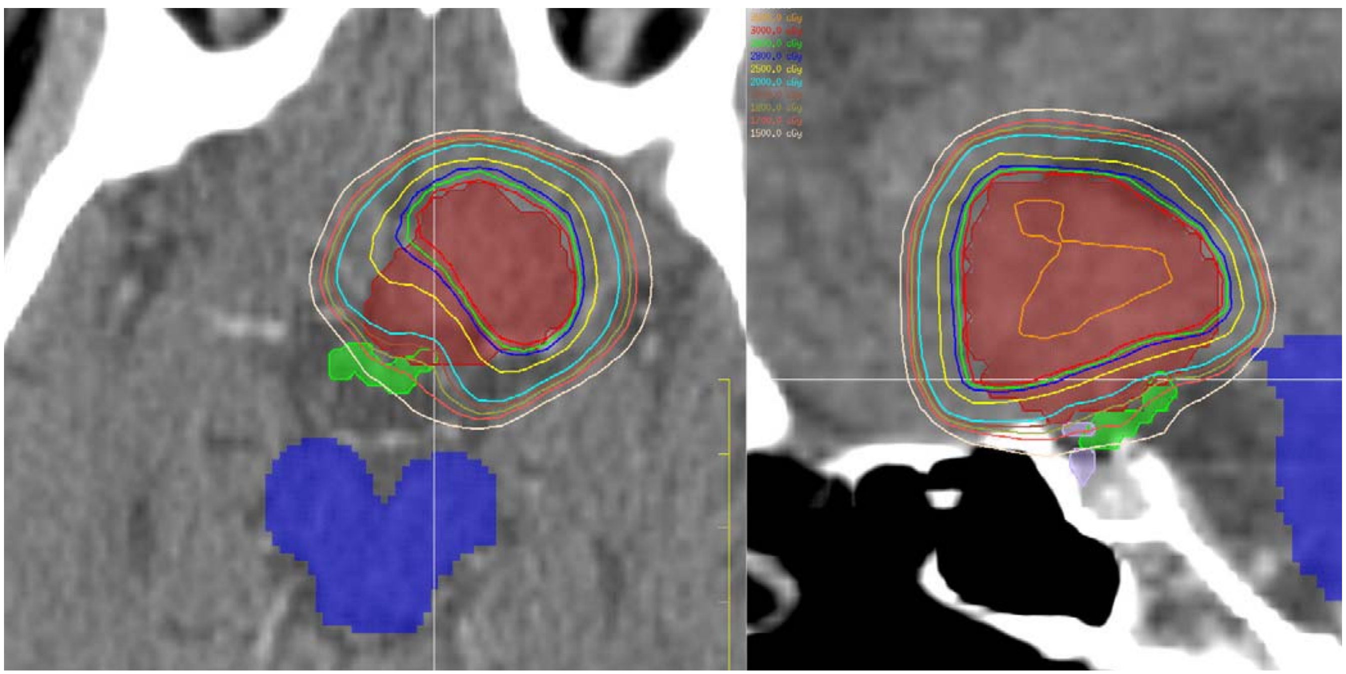
Intra-cranial Immobilization

- High dose, close proximity to critical structures
  - Typically 1 – 5 fractions
- Non-invasive vs invasive immobilization

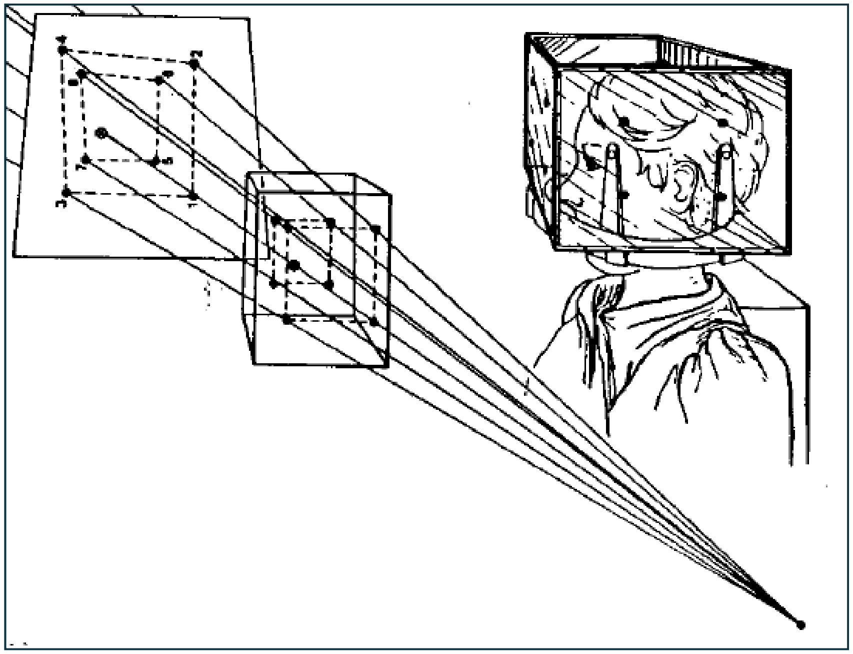


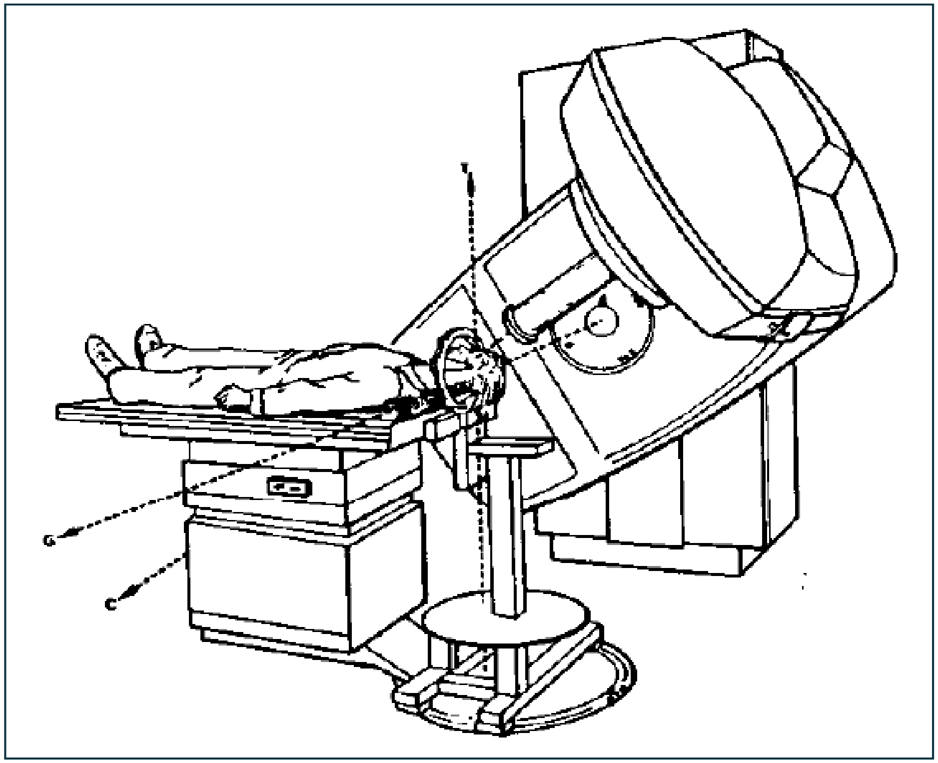
Invasive fixation

- Screws attached to skull
- Ring in lower portion of head to avoid interference with treatment beams
- Some examples…
  - BrainLab non-relocatable head frame
  - Leksell coordinate frame G (Gamma Knife)
  - Best Nomos Talon system (relocatable)

Images courtesy of Elekta and Dr. Martin Murphy

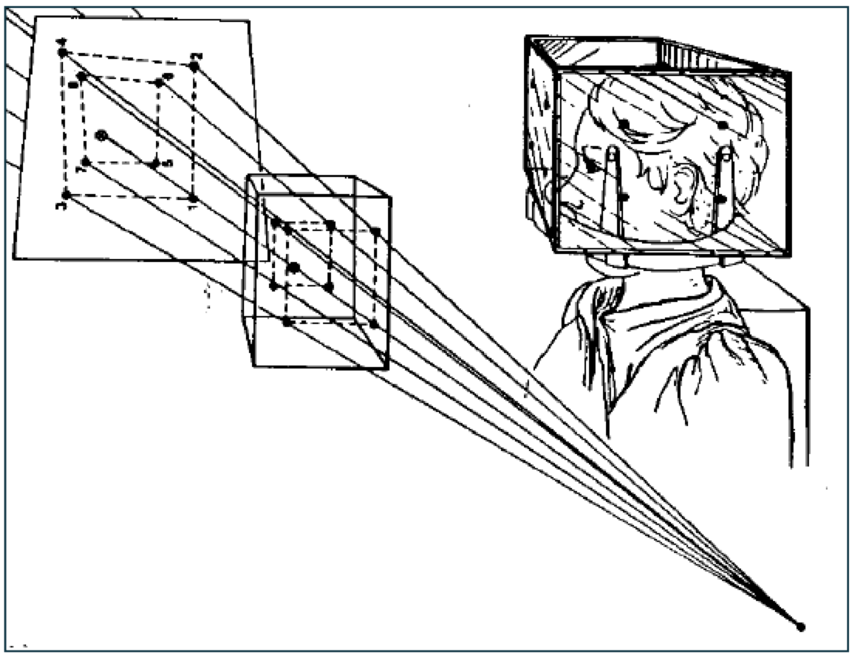
- Mechanical association between frame and isocenter





AAPM TG-42 (1995)

- Mechanical association between frame and isocenter



Head frame in place in a Gamma Knife collimator helmet
Image from Google Images

Invasive head frames

- Best accuracy (≤ 1 mm)
  - Gamma Knife[1] & Linac based[2]
- Typically limited to only single day, scan, plan, treat workflows

- Could be better for claustrophobic patients (than non-invasive thermoplastic masks to come)

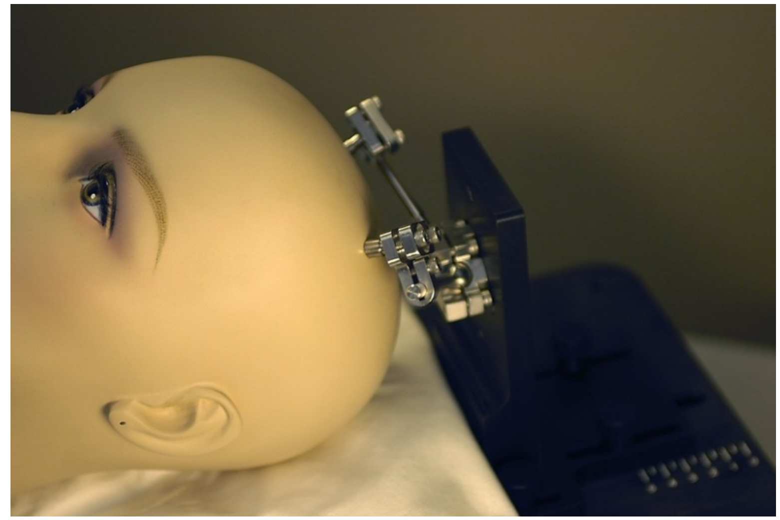
[1]B. Heck, et al. “Accuracy and stability of positioning in radiosurgery: long-term results of the Gamma Knife system,” Med Phys **34** (4), 1487-95 (2007)

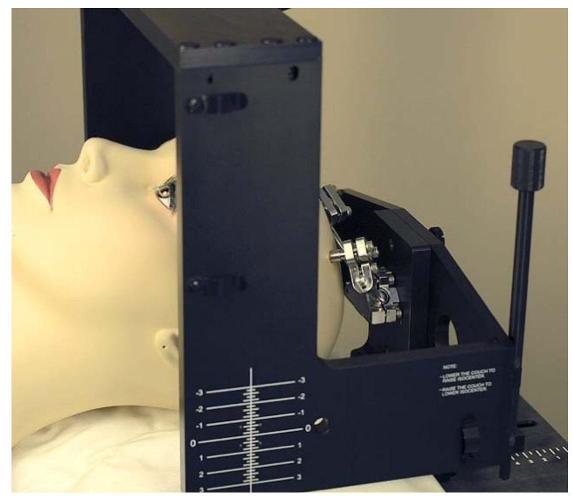
[2]L. X. Hong, et al. “Clinical experiences with onboard imager KV images for linear accelerator-based stereotactic radiosurgery and radiotherapy setup,” Int J Radiat Oncol Biol Phys **73** (2), 556-61 (2009).

Talon System
(Best Nomos)

- Invasive, relocatable system
- Two screws inserted in skull at vertex

- Mean isocenter deviation (over 6 weeks) ~ 1.38 ± 0.48 mm





Images courtesy of Best Nomos

B. J. Salter, *et al.*, “The TALON removable head frame system for stereotactic radiosurgery/radiotherapy: measurement of the repositioning accuracy,” Int J Radiat Oncol Biol Phys **51** (2), 555-62 (2001).

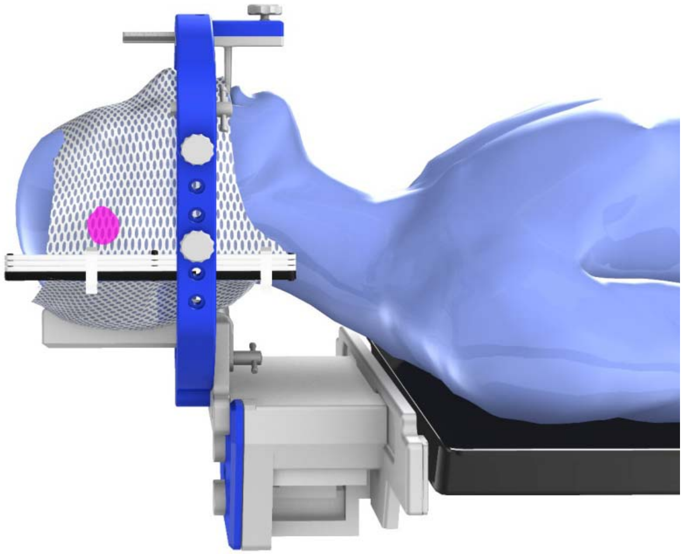
Non-invasive systems

- Movement away from rigid fixation to patient's skull.
- Non-invasive techniques increase reliance on pre-tx image guided setup
- Examples:
  - BrainLab 3 piece mask
  - Elekta eXtend

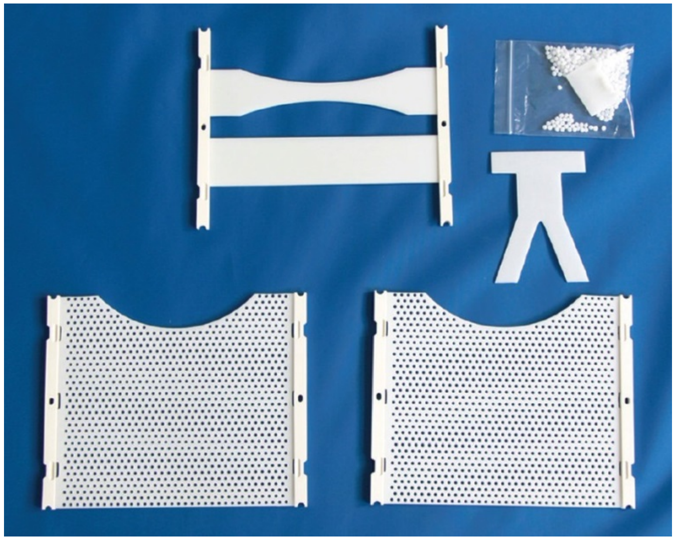
BrainLab mask

- Non-invasive, relocatable device
- Thermoplastic material

- May not good for claustrophobic patients
- Potential for mask shrinkage

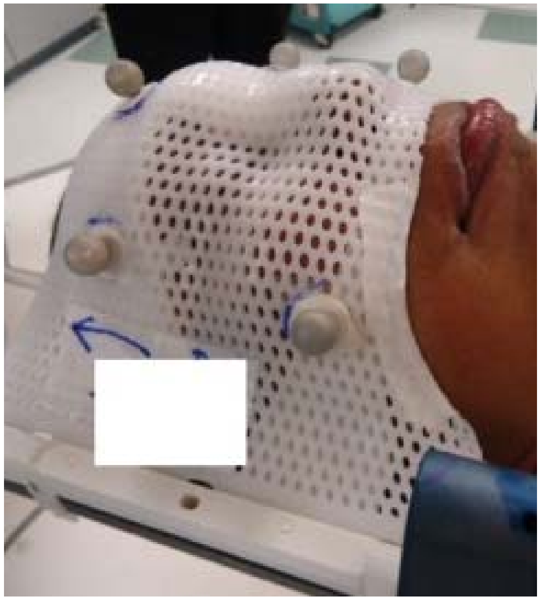


Images courtesy of BrainLab



Patient positioning

- Infrared markers used to pre-position the patient.
- Oblique x-rays used for bony cranial alignment
- IR markers used to confirm couch motion from x-ray derived shifts



Images courtesy of BrainLab and VCU

Minor mask modifications

- Can cut small portions of mask to reduce “hotspots” on patient skin.
- Don’t cut solid thermoplastic support pieces

Elekta eXtend

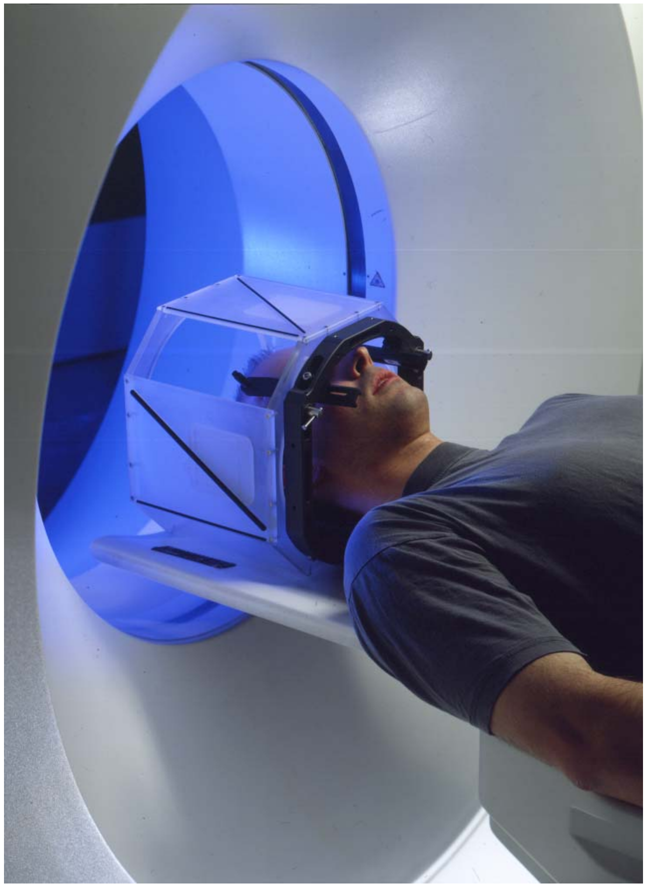
- Non-invasive, relocatable device for fractionated SRS
- Mouth piece with active suction to hard palate
- Repositioning check tool required to verify patient setup

Images courtesy of Elekta

Target localization considerations

- **Frame-based**:
  - Localizer box or fixed geometry (GammaKnife) to create stereotactic coordinate system
  - CT modalities will artifact if high-Z metal present in device (head frames)

- **Frameless:**
  - Localizer box
  - Or in-room image guidance (ExacTrac, OBI, CBCT, etc.)



Non-invasive accuracy

- Non-invasive immobilization generally considered to be slightly inferior than invasive-frame based systems.
  - More potential for intra-fraction patient motion
    - Kumar 2005 (GTC relocatable frame)
      - total 3D displacement: 1.8 mm ± 0.8 mm
    - Hong 2009 (BrainLab 3-piece mask)
      - ~ 10% rate of > 3 mm pre-tx shift on OBI images
    - Ruschin 2010 (Elekta Extend)
      - Linac with CBCT: mean 3d setup error = 0.8 mm
      - Gamma Knife: mean 3d setup error = 1.3
- Pre-treatment image guided verification are crucial when using non-invasive systems

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- Goals and overall themes of immobilization
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- **Extracranial**
  - Lung + liver
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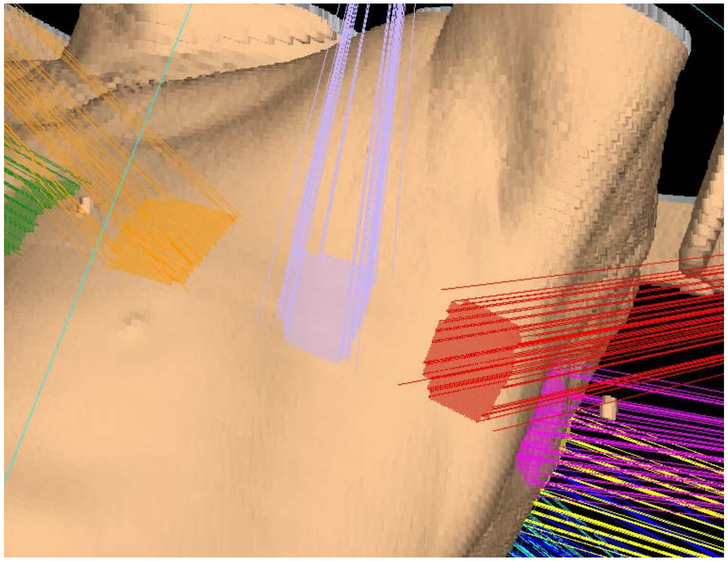
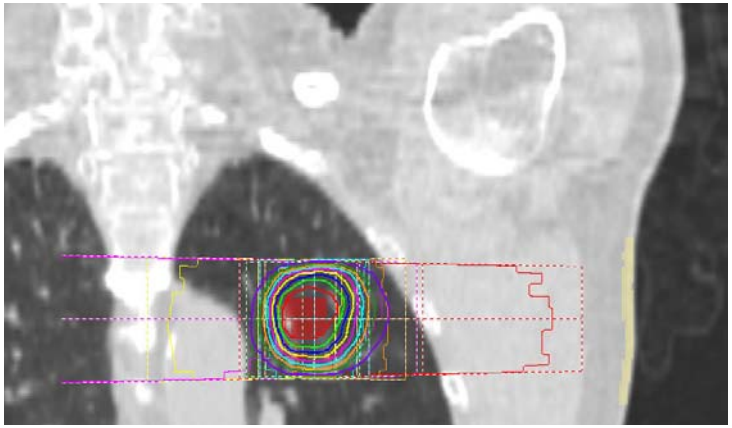
Extra-cranial

- Similar basic rationale as intra-cranial
  - High dose + close proximity to critical structures
- With the added consideration of physiologic motion
  - Breathing, swallowing, bowel gas
  - Target definition and margins
  - Pre-treatment imaging difficulties
    - Image blurring
    - Worse correlation between external surrogates or bony anatomy to tumor location





Images courtesy of VCU

Thorax SBRT

- Patient comfort important:
  - E.g. shoulders to avoid patient dropping arms in middle of treatment.
- Talk to the patient in sim; take care of issues early

Images courtesy of VCU

Basic Immobilization (body conformal bags)

- Vacuum-lock bags or Alpha Cradles
- Can make leveling marks on patient and device for reproducible setup

Images courtesy of AlphaCradle

Motion Management

- Major immobilization challenge for lung and liver treatments is management of breathing motion

- 4d motion-compensation planning techniques:
  - Next session with Dr. Wijesooriya

- Immobilization question:
- *Can we limit or regulate the motion?*

Body SBRT Frames

- Index-able components
- Compression plate / compression belt

Images courtesy of Bionix and Civco

Abdominal Compression

- Compression of abdomen to limit breathing excursion
  - forced shallow breathing

- Roughly reduce tumor motion from ~ 10 – 15 mm (free-breathing) to ~ 7 – 8 mm (compression)[1,2]

[1] J. H. Heinzerling, et al., "Four-dimensional computed tomography scan analysis of tumor and organ motion at varying levels of abdominal compression during stereotactic treatment of lung and liver," Int J Radiat Oncol Biol Phys **70** (5), 1571-8 (2008).

[2] Y. Negoro, et al., "The effectiveness of an immobilization device in conformal radiotherapy for lung tumor: reduction of respiratory tumor movement and evaluation of the daily setup accuracy," Int J Radiat Oncol Biol Phys **50** (4), 889-98 (2001).

Images courtesy of Bionix and Civco

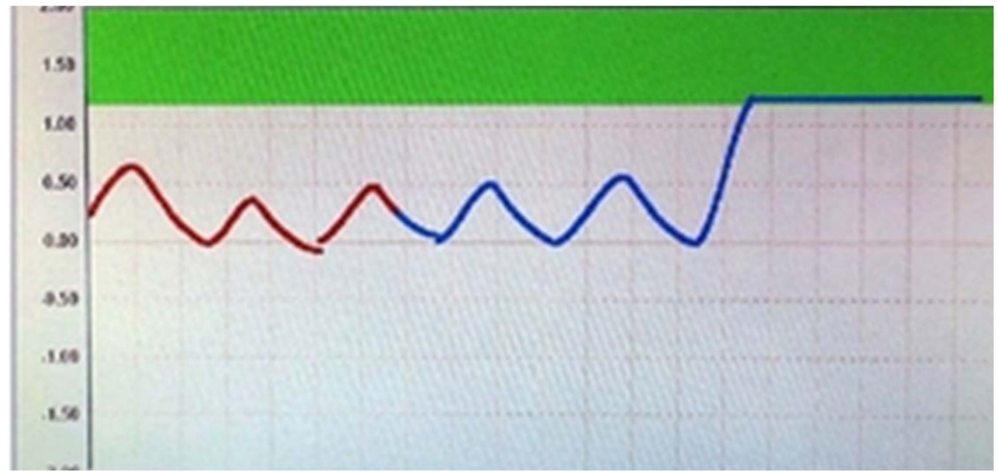
Elekta BodyFix

- Vac-lock bag
- "Saran-wrap" with active evacuation

- Mean intra-fraction tumor positioning
  - Shah 2012
    - 2.7 $\pm$ 2.6 mm
  - Han 2010
    - 2.3 mm

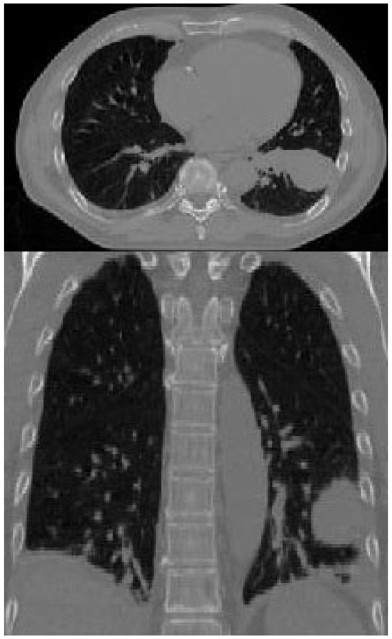
Images courtesy of Elekta

Active Breath-hold

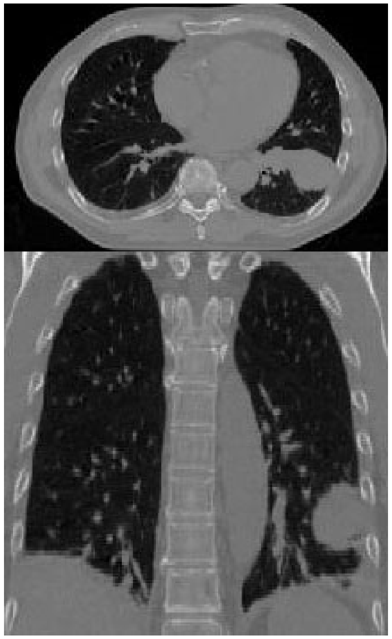


Images courtesy of Geoff Hugo

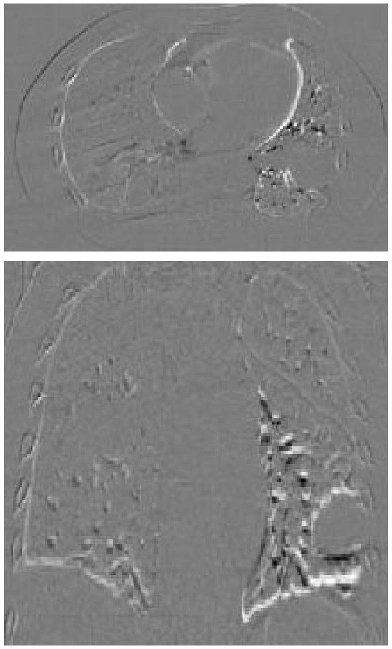
- Adjust the active breath hold process to maximize compliance
  - Short, normal inspiration breath hold
  - Or deep inspiration breath hold
  - Gate the accelerator with the ABC device



Week 1 (Scan 1)



Week 1 (Scan 3)



Images courtesy of Geoff Hugo

Intra-fraction reproducibility

2 – 3 breath-hold images during each session

Week 1

Week 7

Inter-fraction reproducibility
3 - 7 imaging sessions over course of treatment

Images courtesy of Geoff Hugo

ABC Breath-hold Reproducibility

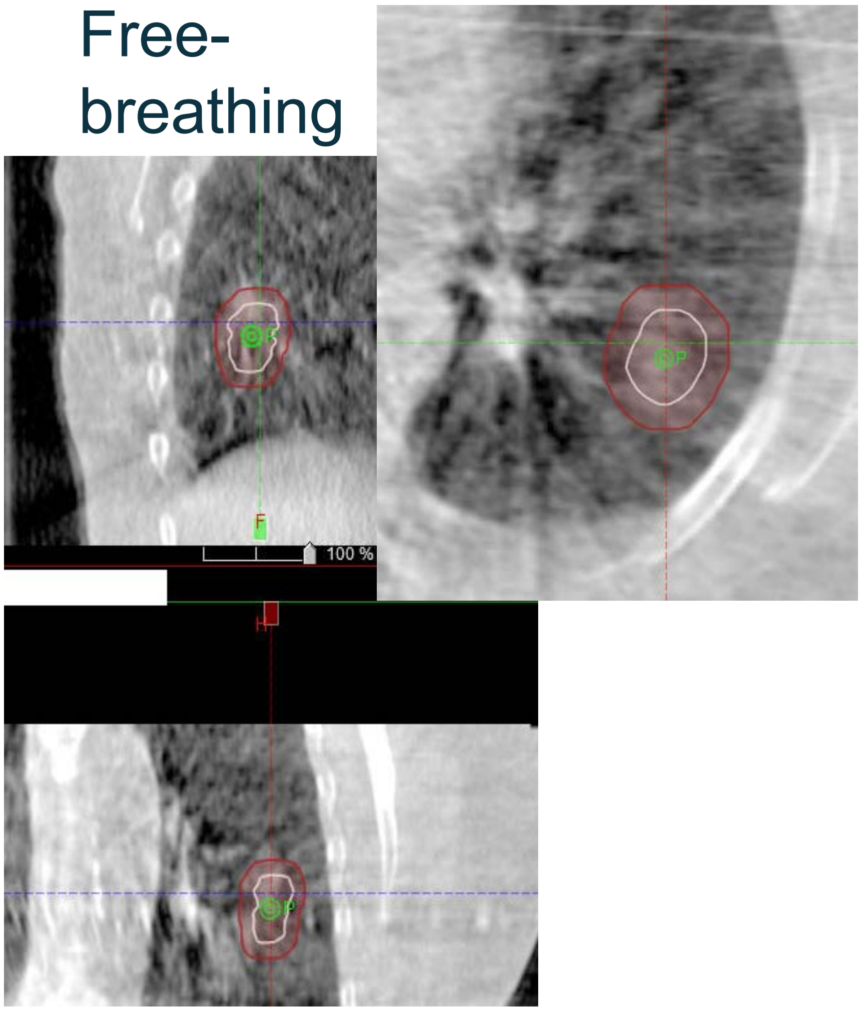
- Assess tumor centroid variation
- Repeat ABC scans
  - *Intra-fraction*
  - 2 – 3 breath-hold images during each session
  - *Inter-fraction*
  - 3 - 7 imaging sessions over course of treatment

Study	Intra-fraction	Inter-fraction
Summary	**~ 1 – 2 mm**	**~ 5 – 8 mm**
Kashani 2006	0.4 ± 2.2 mm	1.4 ± 5.2 mm
Glide-hurst 2010	1.8 ± 1.2 mm	8.5 ± 5.9 mm
Weiss 2012	0.9 ± 2.2 mm	6.8 ± 4.8 mm

[1]E. Weiss, et al. "Tumor, lymph node, and lymph node-to-tumor displacements over a radiotherapy series: analysis of interfraction and intrafraction variations using active breathing control (ABC) in lung cancer," Int J Radiat Oncol Biol Phys **82** (4), e639-45 (2012).
[2] C. K. Glide-Hurst, et al. "Anatomic and pathologic variability during radiotherapy for a hybrid active breath-hold gating technique," Int J Radiat Oncol Biol Phys **77** (3), 910-7 (2010).
[3]R. Kashani, et al. "Short-term and long-term reproducibility of lung tumor position using active breathing control (ABC)," Int J Radiat Oncol Biol Phys **65** (5), 1553-9 (2006).

ABC – Improve localization

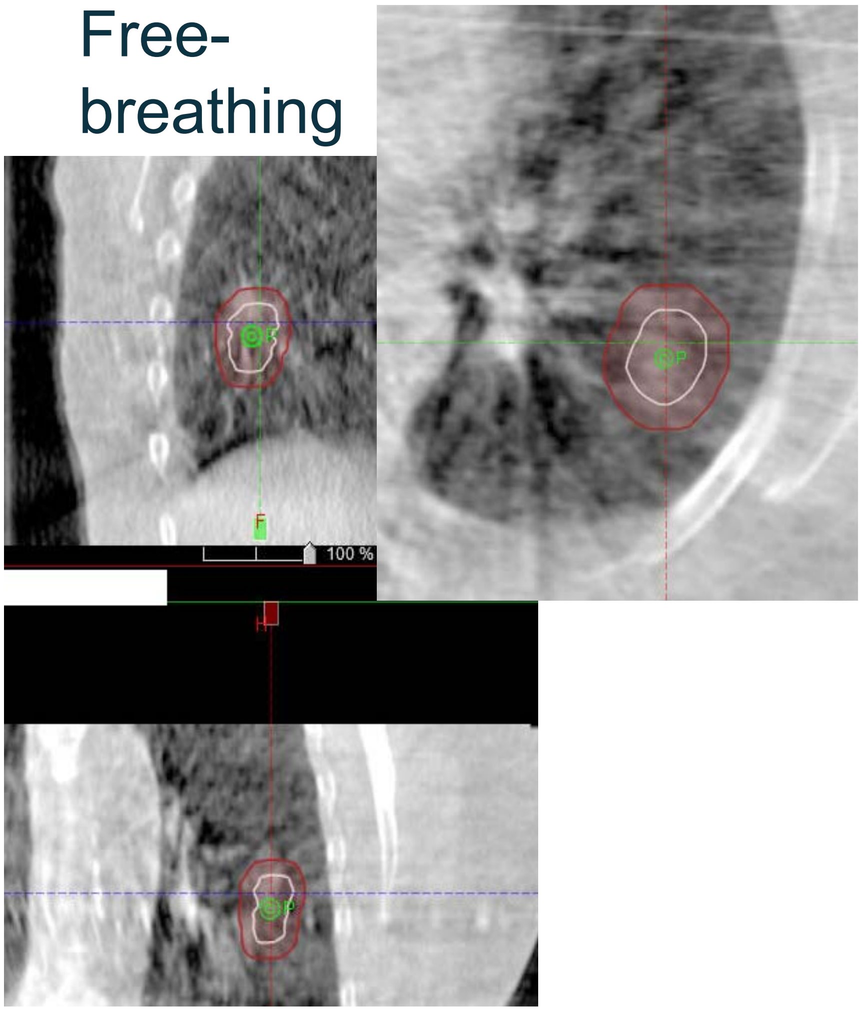
Free-breathing



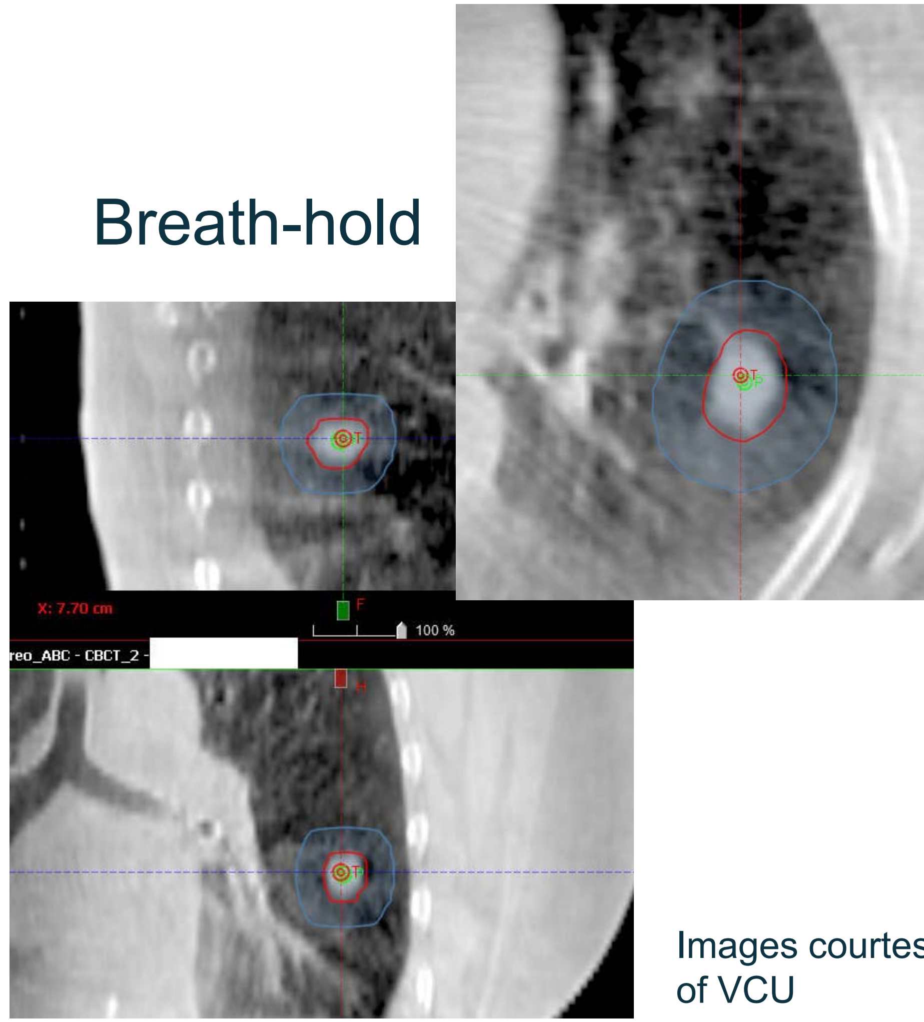
Images courtesy of VCU

ABC – Improve localization

Free-breathing



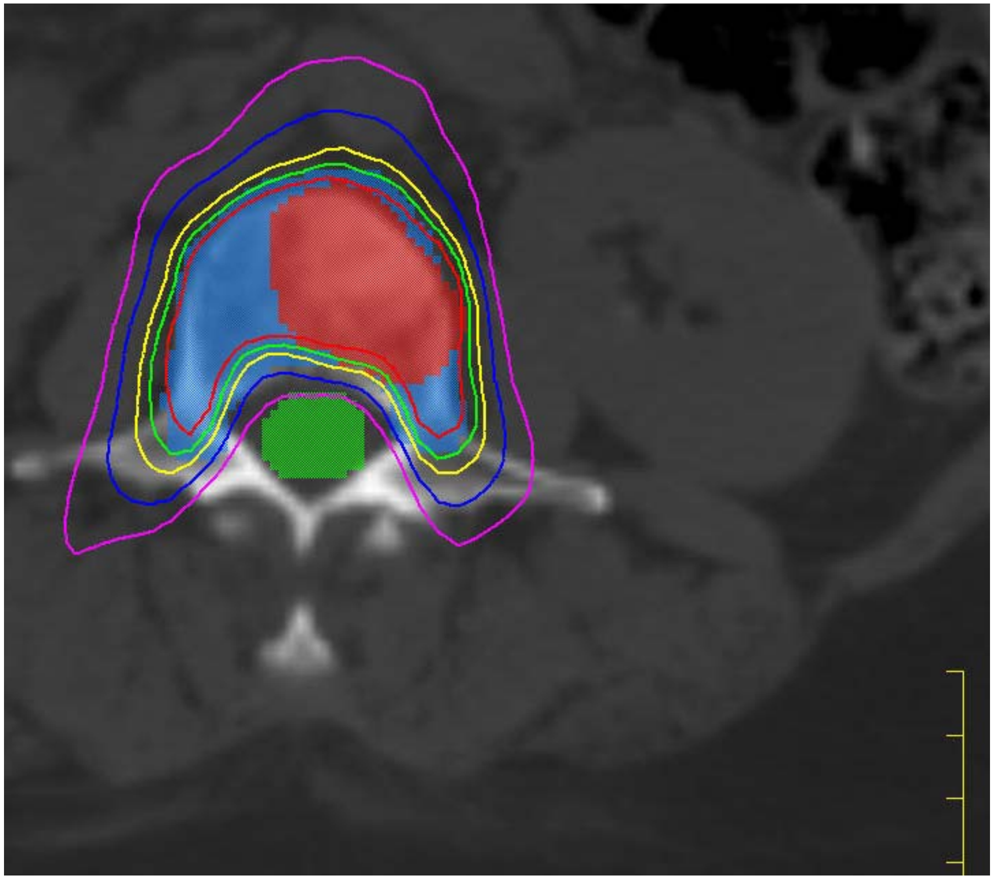
Breath-hold



Images courtesy of VCU

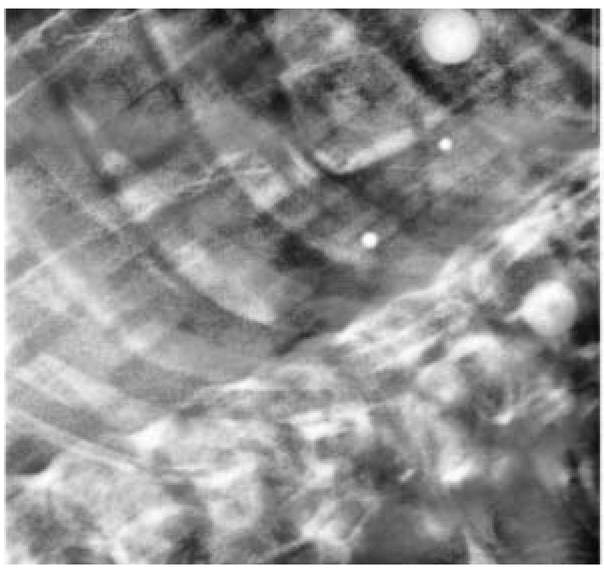
Spine

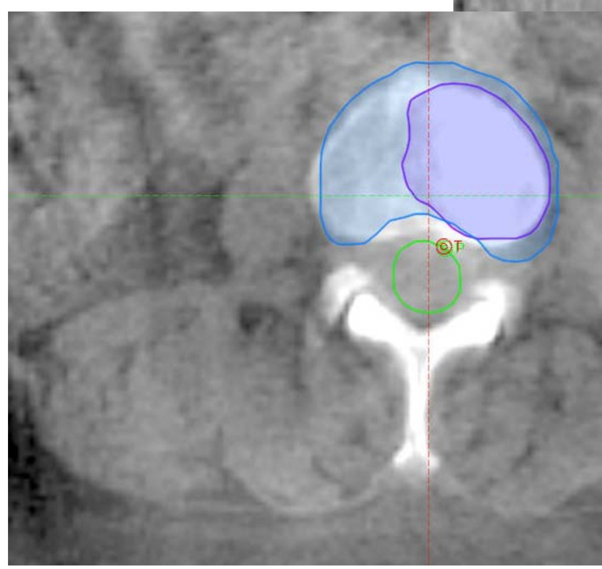
- High risk – adjacent to spinal cord.
- Stable vac-lock bag high up around abdomen, compression or Body-Fix saran wrap for stability

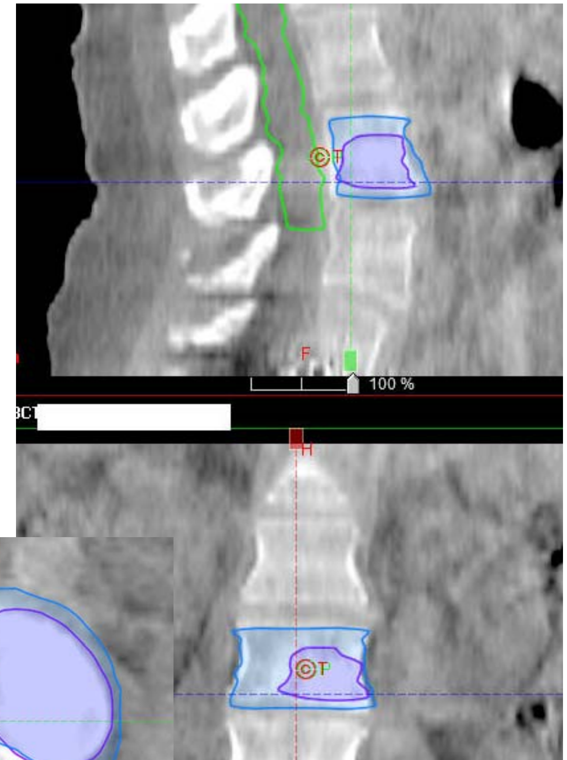


Spine

- Pre-treatment alignment
  - Cbct 3D-volume intuitive for setup
  - ExacTrac oblique images
    - tougher to interpret and QA image match (can use fiducial markers)







Images courtesy of VCU

Summary

- SRS / SBRT place high demands on immobilization
  - Improve patient positioning (*Intra-* and *Inter-*fraction)

- Choose image guidance based on treatment site and immobilization uncertainties.

- “QA” your device. Do you understand the device’s limitations? Is it performing as you anticipated?

- Patient comfort, training and feedback loops important components to minimize intra-fraction motion

For intracranial SRS, which system provides the best rigid immobilization?

3%	1.	3-piece thermoplastic mask system
93%	2.	Invasive head frame
1%	3.	Frameless optical tracking
2%	4.	Bite block with active soft palatte suction
1%	5.	Elekta BodyFix

For intracranial SRS, which system provides the best rigid immobilization?

1. 3-piece thermoplastic mask system
2. Invasive head frame
3. Frameless optical tracking
4. Bite block with active soft palate suction
5. Elekta BodyFix

ANSWER = 2: refs = Heck 2007 and Hong 2009

[1]B. Heck, et al. "Accuracy and stability of positioning in radiosurgery: long-term results of the Gamma Knife system," Med Phys **34** (4), 1487-95 (2007)

[2]L. X. Hong, et al. "Clinical experiences with onboard imager KV images for linear accelerator-based stereotactic radiosurgery and radiotherapy setup," Int J Radiat Oncol Biol Phys **73** (2), 556-61 (2009).

Frame-based single fraction SRS treatment geometric accuracy is generally quoted as:

2%	1.	< 0.25 mm
3%	2.	< 0.5 cm
94%	3.	< 1 mm
0%	4.	< 2 cm
1%	5.	< 3 mm

Frame-based single fraction SRS treatment geometric accuracy is generally quoted as:

1. < 0.25 mm
2. < 0.5 cm
3. < 1 mm
4. < 2 cm
5. < 3 mm

ANSWER = 3 < 1mm: ref = TG-42 1995

Compression techniques have been demonstrated to minimize lung tumor motion roughly on the order of ____ (free-breathing) to _____ (compression):

9%	1.	10 mm to 4 mm
2%	2.	20 mm to 15 mm
4%	3.	3.0 cm to 1.5 cm
83%	4.	14 mm to 8 mm
1%	5.	20 mm to 3 mm

Compression techniques have been demonstrated to minimize lung tumor motion roughly on the order of ____ (free-breathing) to _____ (compression):

1. 10 mm to 4 mm
2. 20 mm to 15 mm
3. 3.0 cm to 1.5 cm
4. 14 mm to 8 mm
5. 20 mm to 3 mm

[1]J. H. Heinzerling, et al., "Four-dimensional computed tomography scan analysis of tumor and organ motion at varying levels of abdominal compression during stereotactic treatment of lung and liver," Int J Radiat Oncol Biol Phys **70** (5), 1571-8 (2008).

[2]Y. Negoro, et al., "The effectiveness of an immobilization device in conformal radiotherapy for lung tumor: reduction of respiratory tumor movement and evaluation of the daily setup accuracy," Int J Radiat Oncol Biol Phys **50** (4), 889-98 (2001).

ANSWER = 4: refs = Heinzerling 2008 & Negoro 2001

Daily soft-tissue pre-treatment image guidance is indicated for lung sbrt with Active Breath-hold techniques because:

- 41% — 1. Data shows inter-fraction random setup variability to be on the order of 5 mm
- 24% — 2. Data shows intra-fraction uncertainty to be on the order of 2 mm
- 5% — 3. Data shows inter-fraction random setup variabilifty to be on the order of 1 mm
- 21% — 4. Data shows intra-fraction breath-hold reproducibility to be on the order of 10 mm
- 9% — 5. Enough with the data already, I just love pre-treatment imaging

Daily soft-tissue pre-treatment image guidance is indicated for lung sbrt with Active Breath-hold techniques because:

1. Data shows inter-fraction random setup variability to be on the order of 5 mm
2. Data shows intra-fraction uncertainty to be on the order of 2 mm
3. Data shows inter-fraction random setup variabilifty to be on the order of 1 mm
4. Data shows intra-fraction breath-hold reproducibility to be on the order of 10 mm
5. Enough with the data already, I just love pre-treatment imaging

ANSWER = 1: refs = Weiss 2012, Gilde-hurst 2010, Kashani 2006

[1]E. Weiss, et al. “Tumor, lymph node, and lymph node-to-tumor displacements over a radiotherapy series: analysis of interfraction and intrafraction variations using active breathing control (ABC) in lung cancer,” Int J Radiat Oncol Biol Phys **82** (4), e639-45 (2012).

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- K. Han, *et al.*, "A comparison of two immobilization systems for stereotactic body radiation therapy of lung tumors," Radiother Oncol **95** (1), 103-8 (2010).
- C. Shah, *et al.*, "Intrafraction variation of mean tumor position during image-guided hypofractionated stereotactic body radiotherapy for lung cancer," Int J Radiat Oncol Biol Phys **82** (5), 1636-41 (2012).

Breathing Monitoring Systems

Krishni Wijesooriya

In part two of this session Respiratory Management Systems will be introduced, and several breathing induced motion management systems used in SBRT will be discussed. Commercially available devices that assess 2D and 3D motion detection will be presented, and a complete clinical process starting from the 4DCT simulation to motion managed treatment will be explained, with additional time spent on imaging artifacts and their advantages/disadvantages. Audio-visual bio feedback devices that help patients breathe reproducibly will also be presented. This session will conclude with strategies on performing end to end QA for a motion management program.