Ventura, CA

SRS & SBRT Quality Assurance

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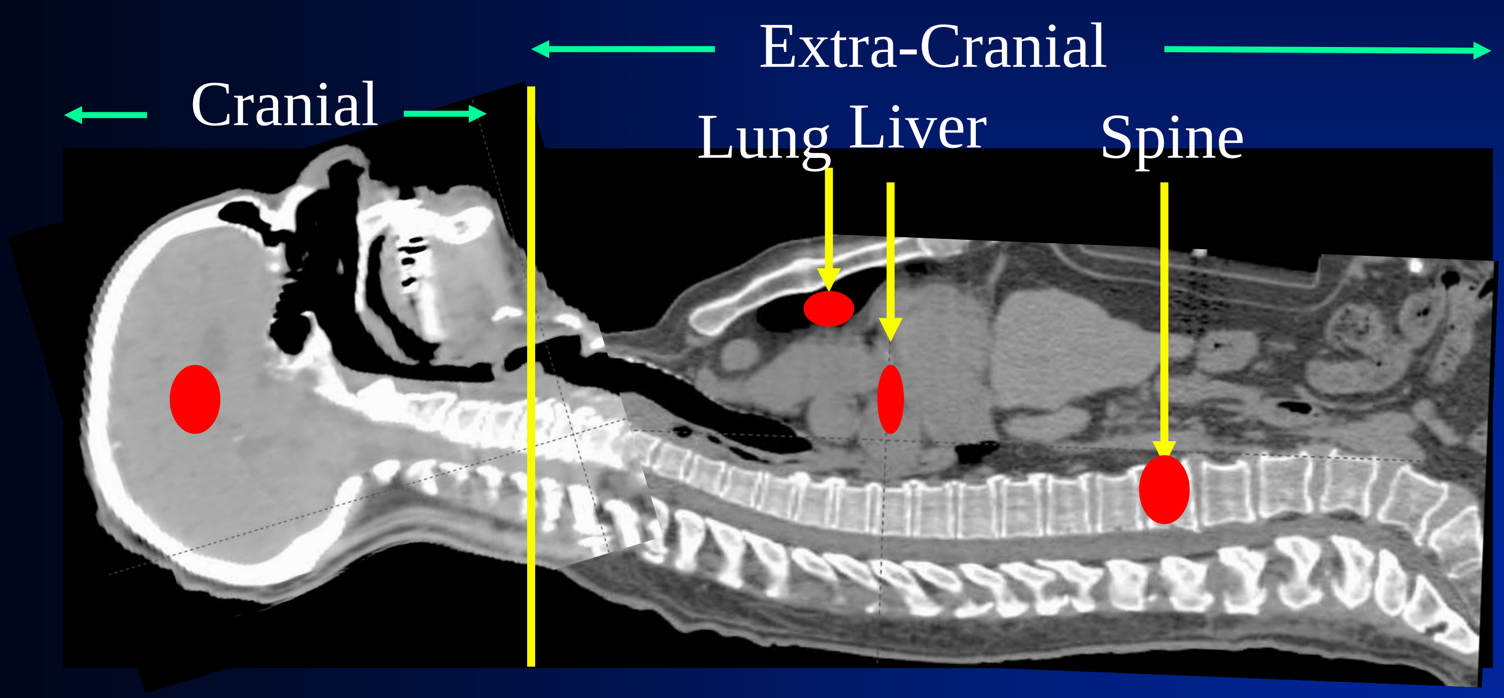
Stereotactic RadioSurgery

- Cranial (Head & Brain) (SRS, SRT)
- Extra Cranial (lung, liver, pancreas, spine) (SBRT, SABR)



Klein *et al.*: Task Gro

TABLE I. Dail

Procedure
Dosimetry
X-ray output
Electron outp
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Mechanical
Laser localiz
Distance indi
Collimator si
Safety
Door interloc
Door closing
Audiovisual
Stereotactic i
Radiation are
Beam on indi

TABLE II. Monthly.

Procedure
Dosimetry
X-ray output constancy
Electron output constancy
Backup monitor chamber constancy
Typical dose rate[a] output constancy
Photon beam profile constancy
Electron beam profile constancy
Electron beam energy constancy
Mechanical
Light/radiation field coincidence[b]
Light/radiation field coincidence[b] (asymmetric)
Distance check device for lasers compared with front pointer
Gantry/collimator angle indicators (@ cardinal angles) (digital only)
Accessory trays (i.e., port film graticle tray)
Jaw position indicators (symmetric)[c]
Jaw position indicators (asymmetric)[d]
Cross-hair centering (walkout)
Treatment couch position indicators[e]
Wedge placement accuracy
Compensator placement accuracy[f]
Latching of wedges, blocking tray[g]
Localizing lasers
Safety
Laser guard-interlock test
Respiratory gating
Beam output constancy
Phase, amplitude beam control
In-room respiratory monitoring system
Gating interlock

TABLE III. Annual.

	Machine-type tolerance		
Procedure	Non-IMRT	IMRT	SRS/SBRT
Dosimetry			
X-ray flatness change from baseline		1%	
X-ray symmetry change from baseline		±1%	
Electron flatness change from baseline		1%	
Electron symmetry change from baseline		±1%	
SRS arc rotation mode (range: 0.5–10 MU/deg)	NA	NA	Monitor units set vs delivered: 1.0 MU or 2% (whichever is greater) Gantry arc set vs delivered: 1.0° or 2% (whichever is greater)
X-ray/electron output calibration (TG-51)		±1% (absolute)	
Spot check of field size dependent output factors for x ray (two or more FSs)		2% for field size $<4\times4$ cm^2, 1% $\geq 4\times4$ cm^2	
Output factors for electron applicators (spot check of one applicator/energy)		±2% from baseline	
X-ray beam quality (PDD_{10} or TMR^{20}_{10})		±1% from baseline	
Electron beam quality (R_{50})		±1 mm	
Physical wedge transmission factor constancy		±2%	
X-ray monitor unit linearity (output constancy)	±2% ≥5 MU	±5% (2–4 MU), ±2% ≥5 MU	±5% (2–4 MU), ±2% ≥5 MU
Electron monitor unit linearity (output constancy)		±2% ≥5 MU	
X-ray output constancy vs dose rate		±2% from baseline	
X-ray output constancy vs gantry angle		±1% from baseline	
Electron output constancy vs gantry angle		±1% from baseline	
Electron and x-ray off-axis factor constancy vs gantry angle		±1% from baseline	
Arc mode (expected MU, degrees)		±1% from baseline	
TBI/TSET mode		Functional	
PDD or TMR and OAF constancy		1% (TBI) or 1 mm PDD shift (TSET) from baseline	
TBI/TSET output calibration		2% from baseline	
TBI/TSET accessories		2% from baseline	
Mechanical			
Collimator rotation isocenter		±1 mm from baseline	
Gantry rotation isocenter		±1 mm from baseline	
Couch rotation isocenter		±1 mm from baseline	
Electron applicator interlocks		Functional	
Coincidence of radiation and mechanical isocenter	±2 mm from baseline	±2 mm from baseline	±1 mm from baseline
Table top sag		2 mm from baseline	
Table angle		1°	
Table travel maximum range movement in all directions		±2 mm	
Stereotactic accessories, lockouts, etc.	NA	NA	Functional
Safety			
Follow manufacturer's test procedures		Functional	
Respiratory gating			
Beam energy constancy		2%	
Temporal accuracy of phase/amplitude gate on		100 ms of expected	
Calibration of surrogate for respiratory phase/amplitude		100 ms of expected	
Interlock testing		Functional	

IJDas, (3)

TG-142, Klein et al,

INDIANA UNIVERSITY
SCHOOL OF MEDICINE

Accuracy

SRS => 1-2 mm

SBRT=> 2-5 mm

AAPM REPORT NO. 54

STEREOTACTIC RADIOSURGERY

Report of Task Group 42
Radiation Therapy Committee

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David A. Larson (Consultant)
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June 1995

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Stereotactic body radiation therapy: The report of AAPM Task Group 101

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Medical Physics, 37(8), 4078- 4101, 2010

Summer School 2014

Delivery Systems

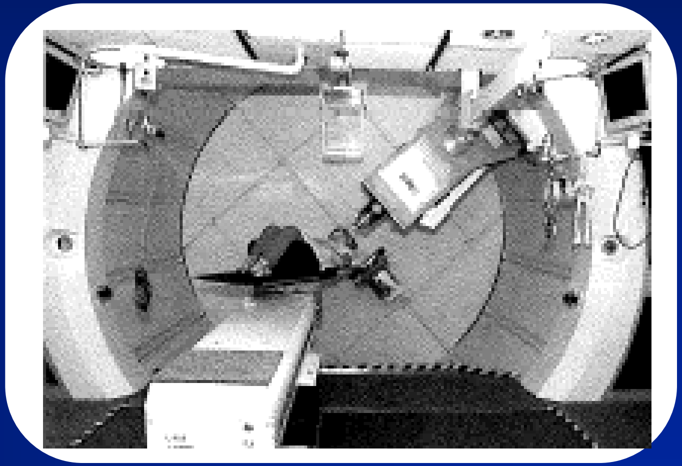
Linear Accelerator

Novalis Radiosurgery

Cyber Knife

Tomotherapy

Gamma Knife

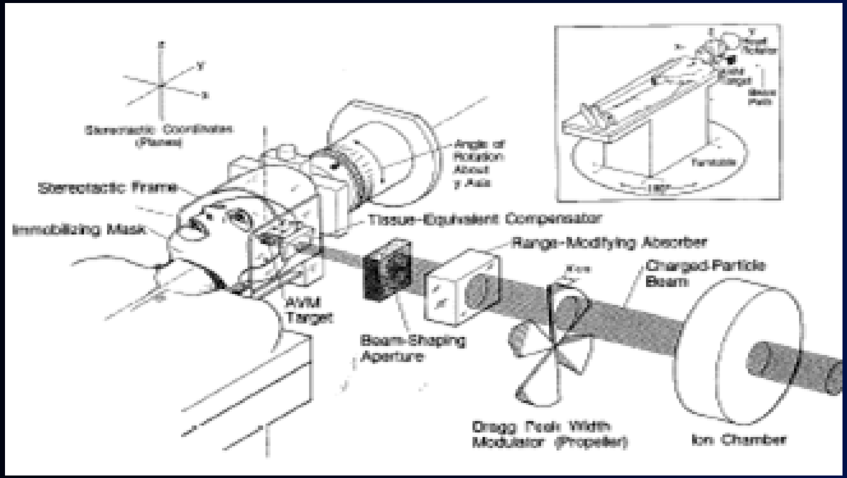


Proton Beam

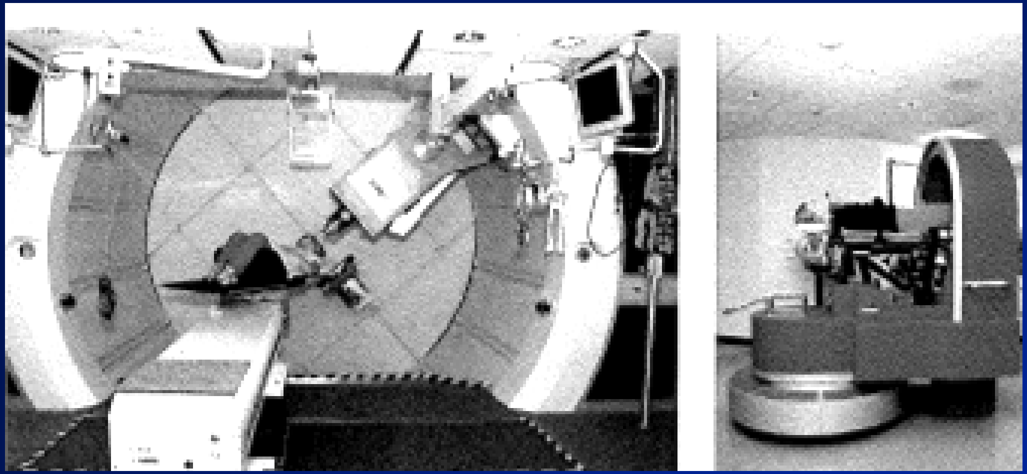
Proton Beam SRS

Cyclotron, Osaka

Synchrotron, Hyogo

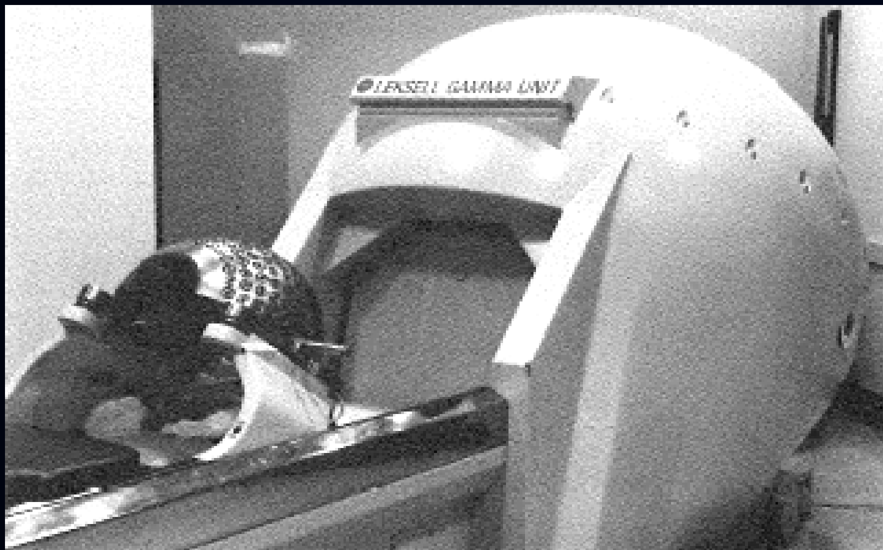


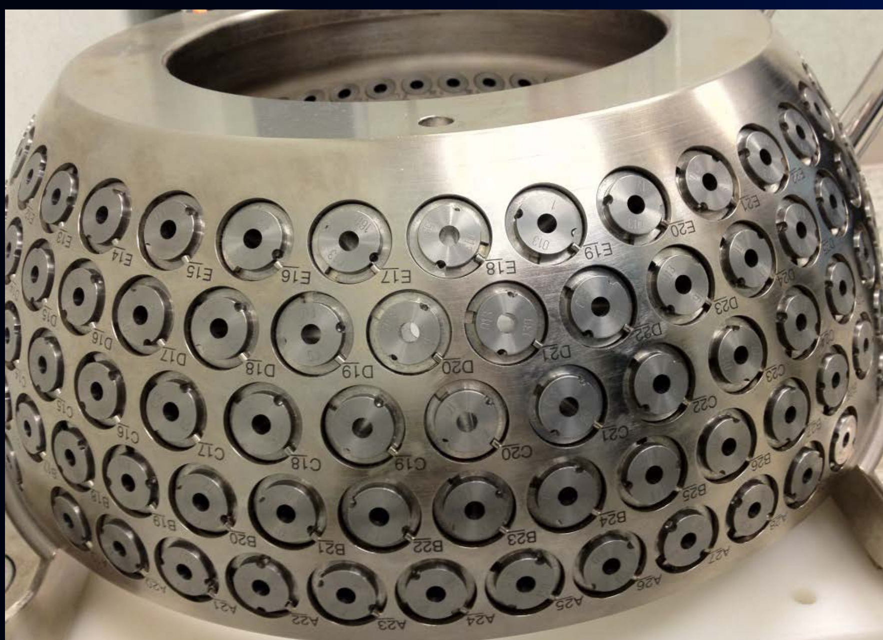
Treatment Schematic



Harvard/MGH SRS system

Gamma Knife SRS

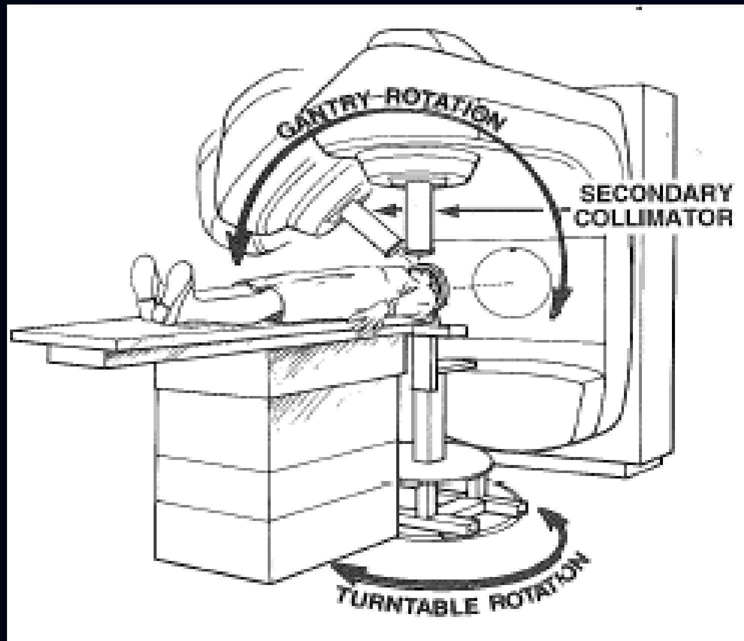


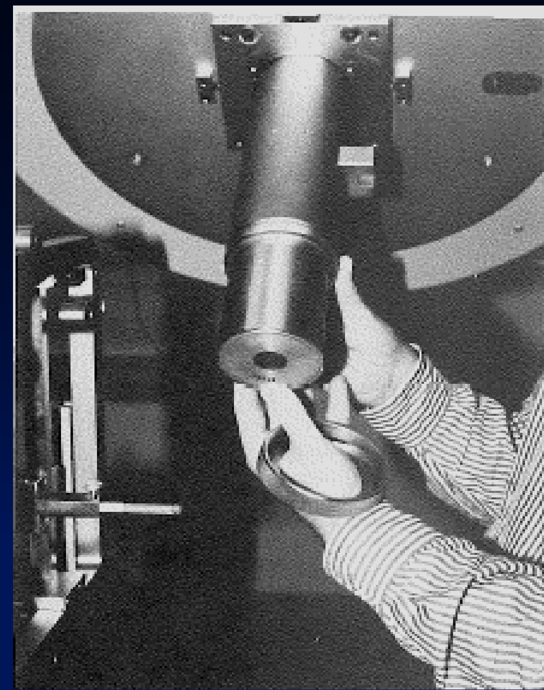


Plug sizes

4 mm, 8 mm, 14 mm, 18 mm

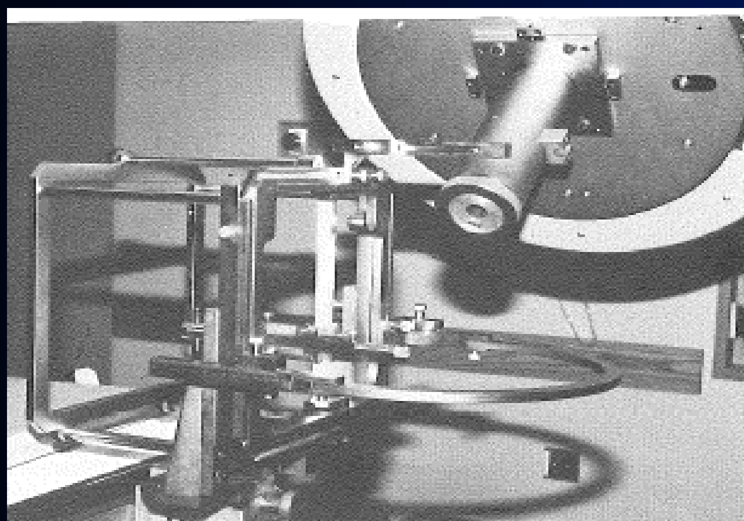
Linac Based SRS





Cone Sizes

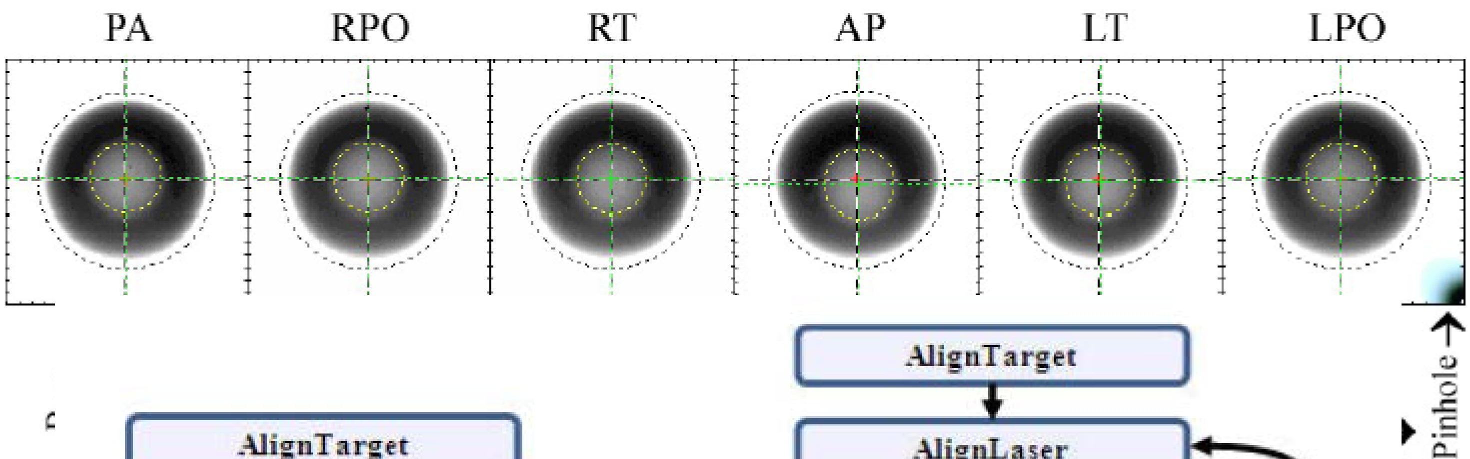
5-40 mm at an interval of 5 mm

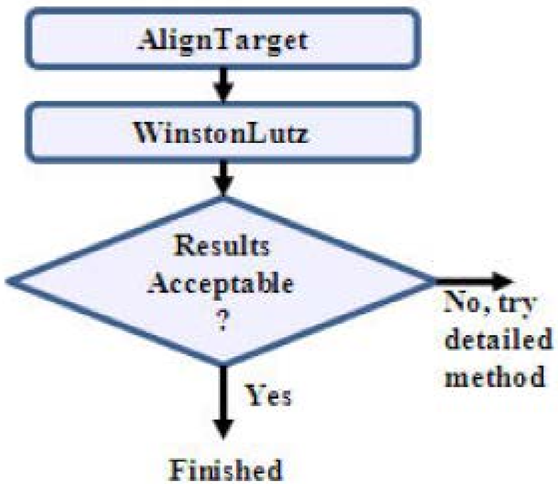


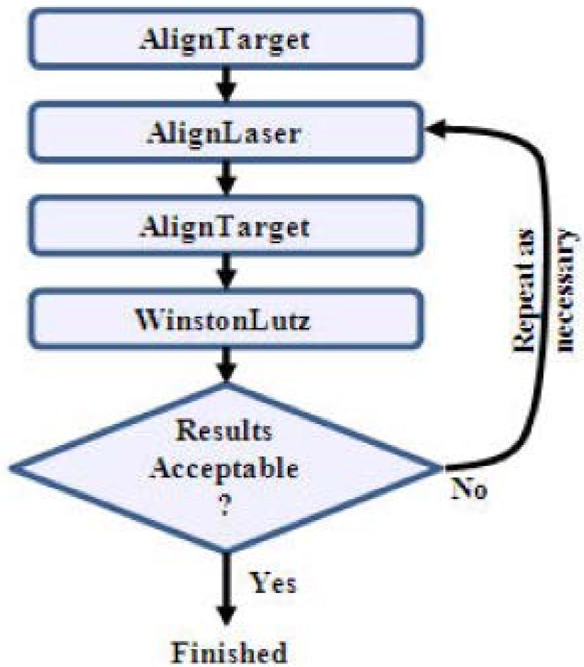
JOURNAL OF APPLIED CLINICAL MEDICAL PHYSICS, VOLUME 12, NUMBER 1, WINTER 2011

A quality assurance method with submillimeter accuracy for stereotactic linear accelerators

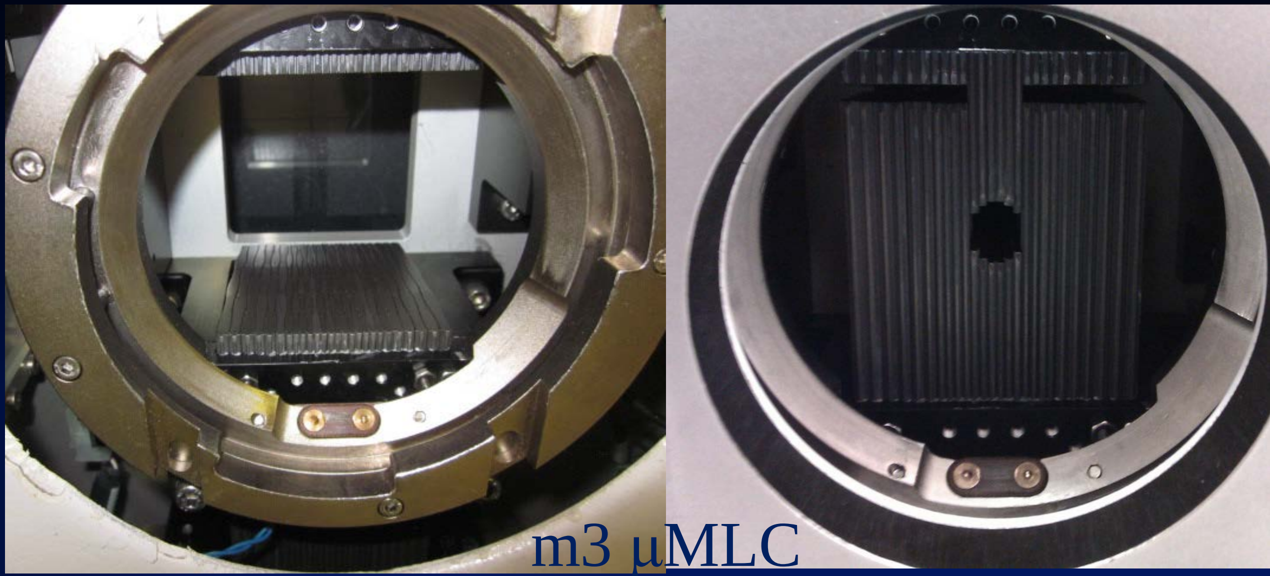
Jimm Grimm,[1a] Shu-Ya Lisa Grimm,[2] Indra J. Das,[3] Yunping Zhu,[1]
Inhwan Yeo,[1] Jinyu Xue,[1] Larry Simpson,[4] Dayee Jacob,[4] Abhirup Sarkar[4]







BrainLab Novalis, SRS/SRT/IMRS

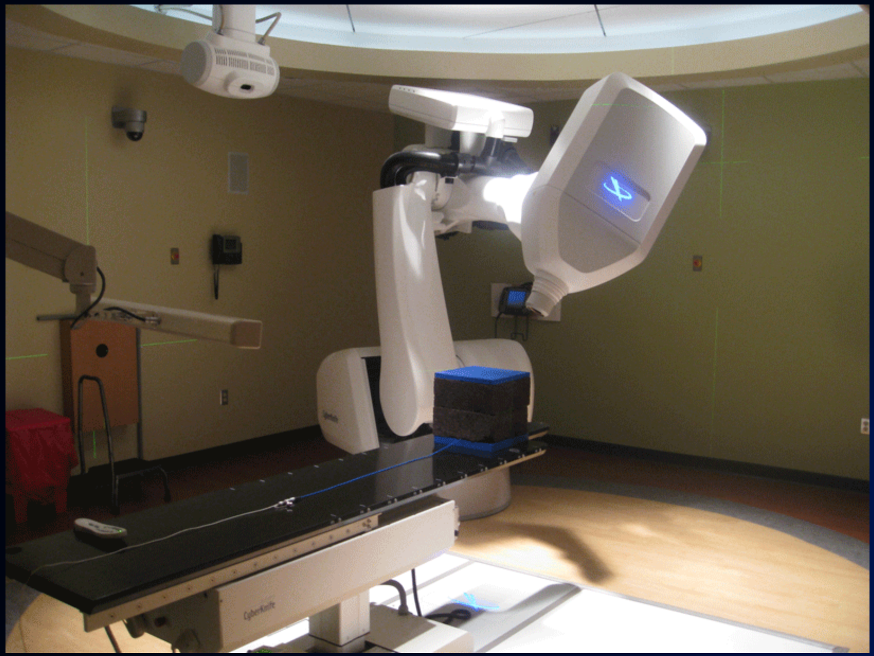


m3 μMLC

Novalis Head rings

BrainLab Cone: 4mm-20mm diameter

Cyber Knife Based SRS



- Robotic treatment
- IGRT
- Intra-treatment imaging
- Orthogonal kV imaging

Cone Size from 5 mm to 60 mm

SBRT

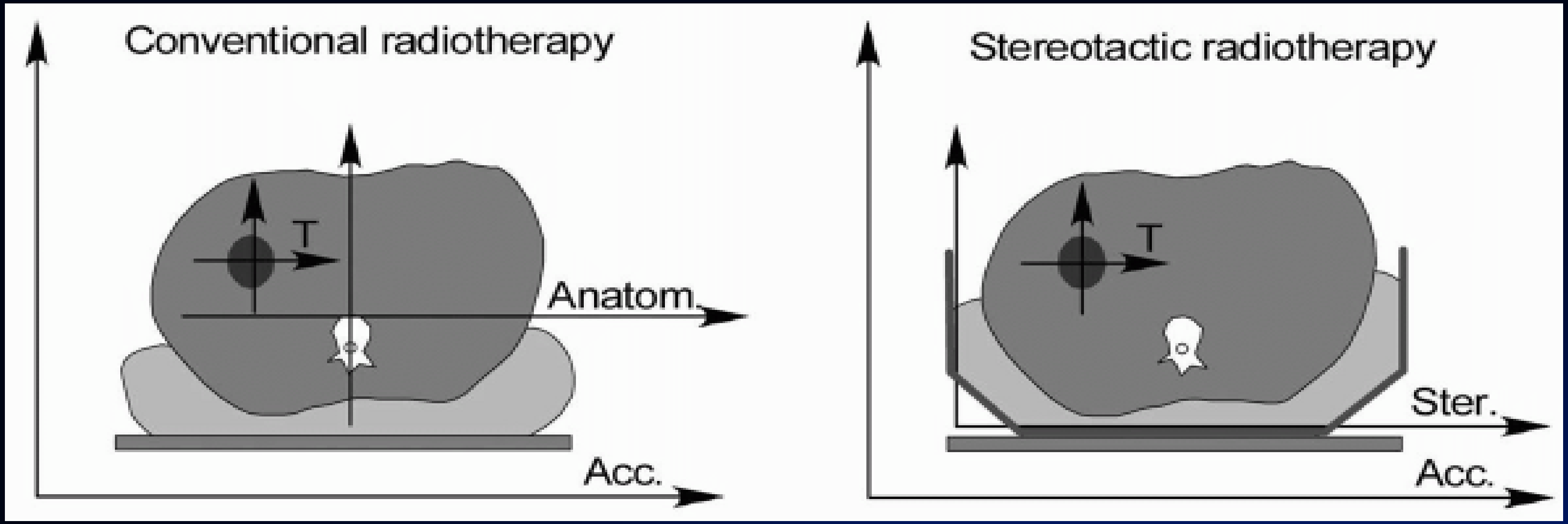
- High dose of radiation delivered in a hypofractionated regimen (single fraction or 3-5 fractions)
- High target accuracy
  - Stereotactic reference - target is localized relative to a known 3D coordinate system through the use of external fiducial markers
  - Patient immobilization is important
- Rapid dose falloff (sharp dose gradient)
  - Multiple conformal beams
  - Coplanar or Non-Coplanar

Chang et al, Clin Trans Oncol 15(9), 720-724, 2013

Systems for SBRT

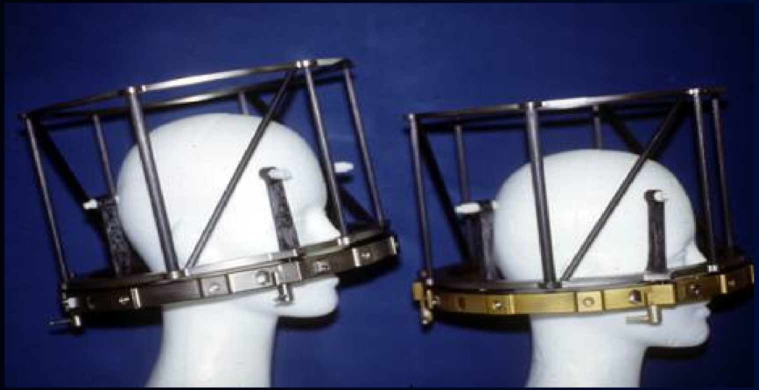
- Linear Accelerator Based SBRT
  - Rapid Arc
  - True Beam
  - Body Frame with linear accelerator
    - Elekta
    - Varian
    - Pro-Lock System
- Dedicated Delivery Systems
  - Gamma Knife
  - Novalis, Brain Lab
  - Tomotherapy
  - Cyber-Knife
  - Proton beam

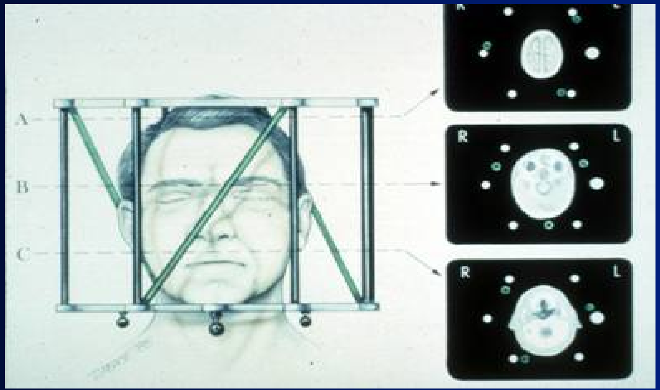
Stereotactic reference

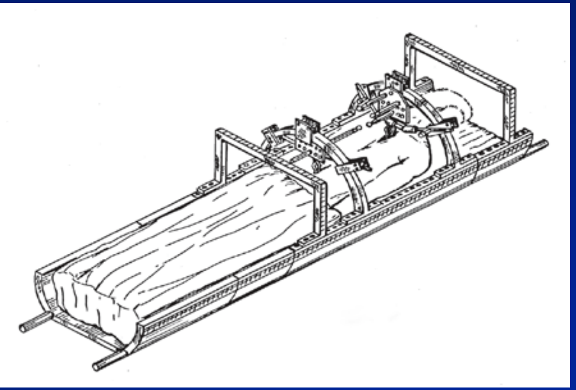


Patient set up based on anatomic reference

Patient set up based on stereotactic reference

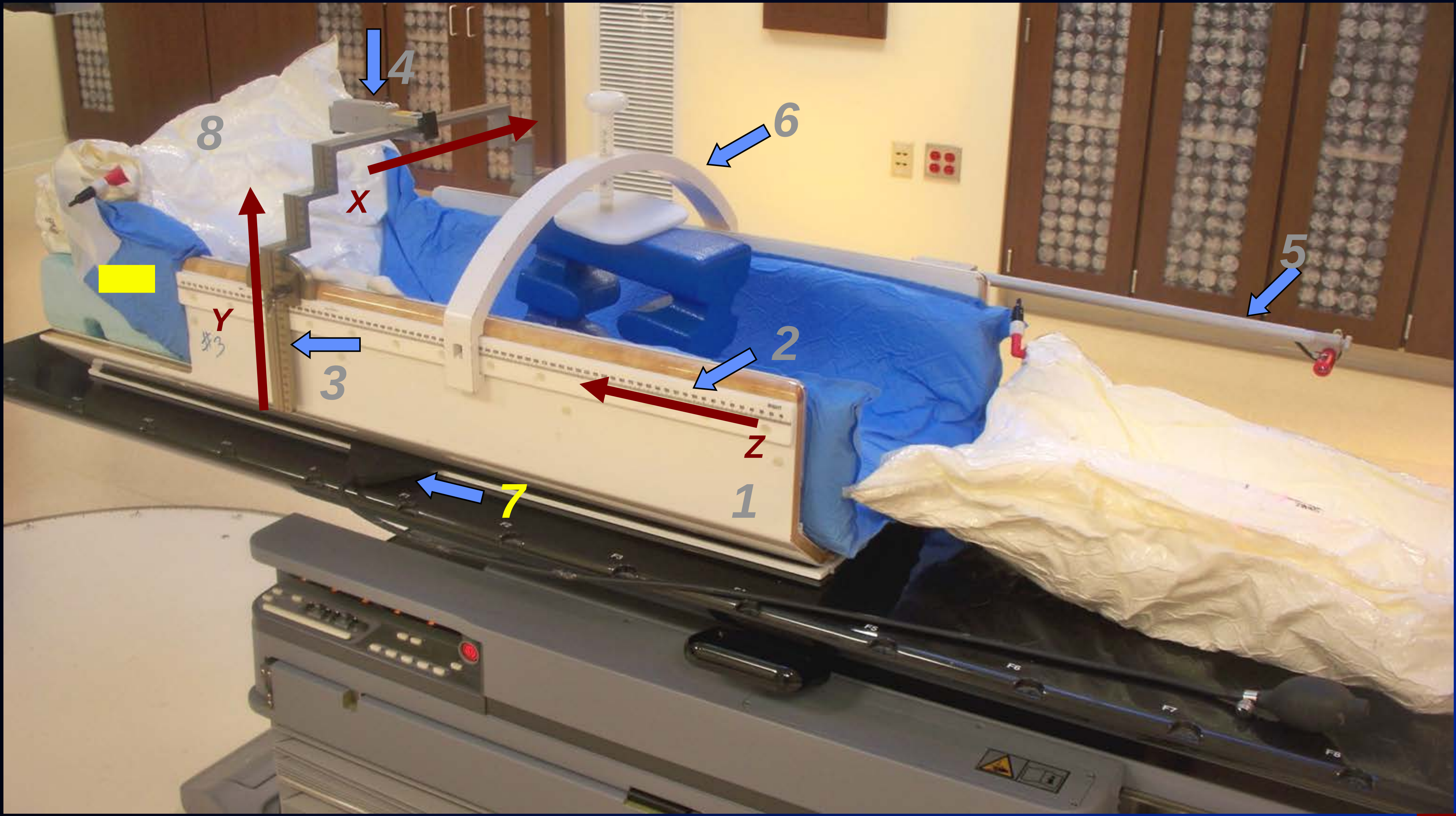






Kavanagh B, Timmerman R. "Stereotactic body Radiation Therapy", Lippincott Williams & Wilkins 2005

Elekta Stereotactic Body Frame



Different Systems

Elekta Stereotactic body frame

❖ Small box frame system tightly restricts patient motion

❖ Stereotactic reference system to localize target

❖ Can not be indexed to treatment couch

❖ Respiration compression plate

CIVCO Body Pro-Lok™ system

❖ Modular structures highly adaptable to individual patient

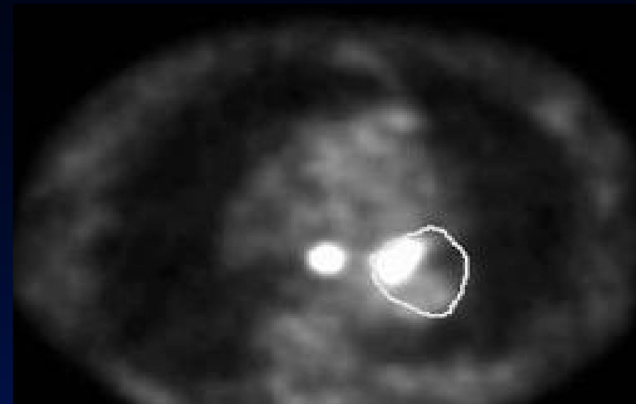
❖ Isocenter setup relies on skin marks/tattoos

❖ Indexed to treatment couch

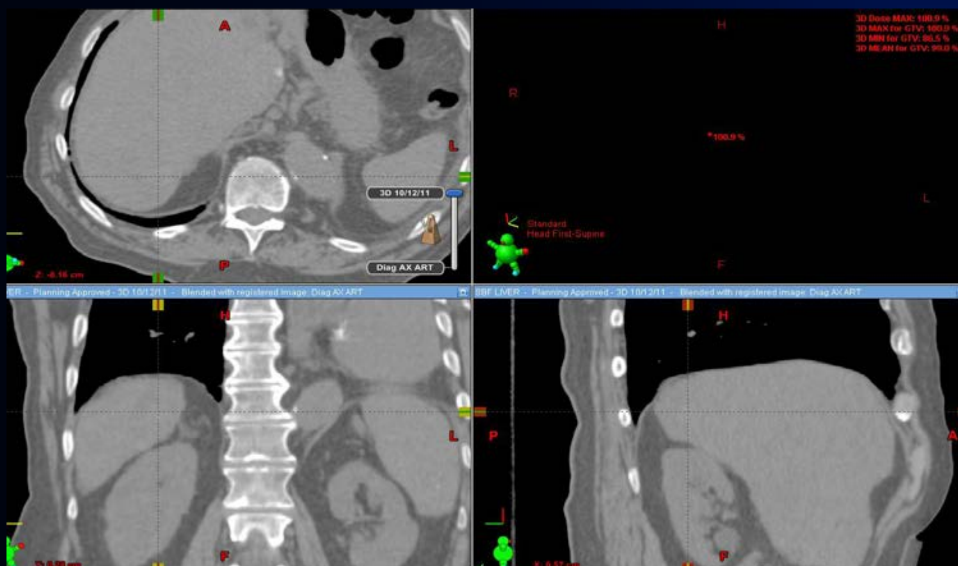
❖ Respiration compression plate and belt

Multi Modality Imaging

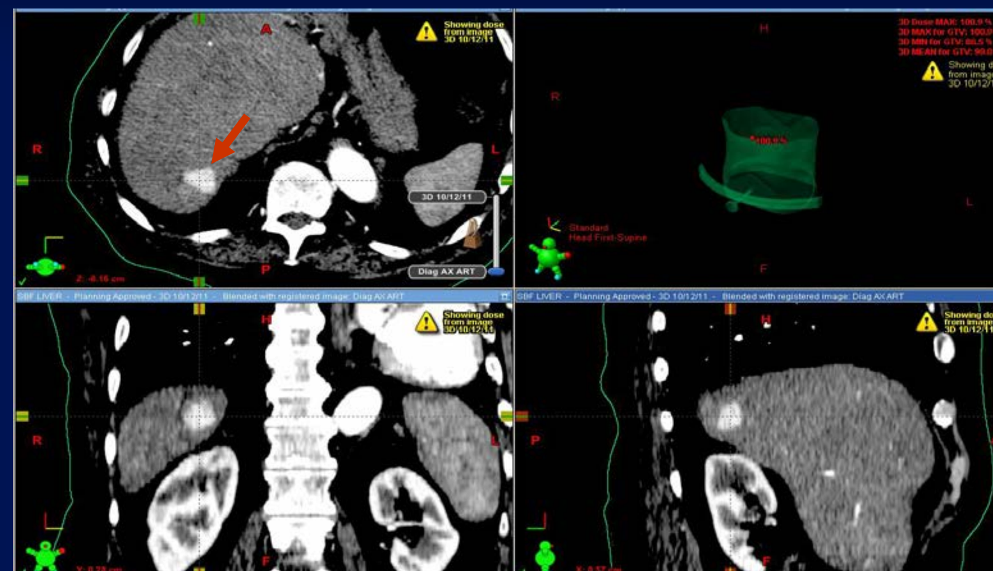
CT



PET



Regular CT



Dual phase CT

Erdi *et. al.* Radiotherapy and Oncology 62 (2002) 51-60

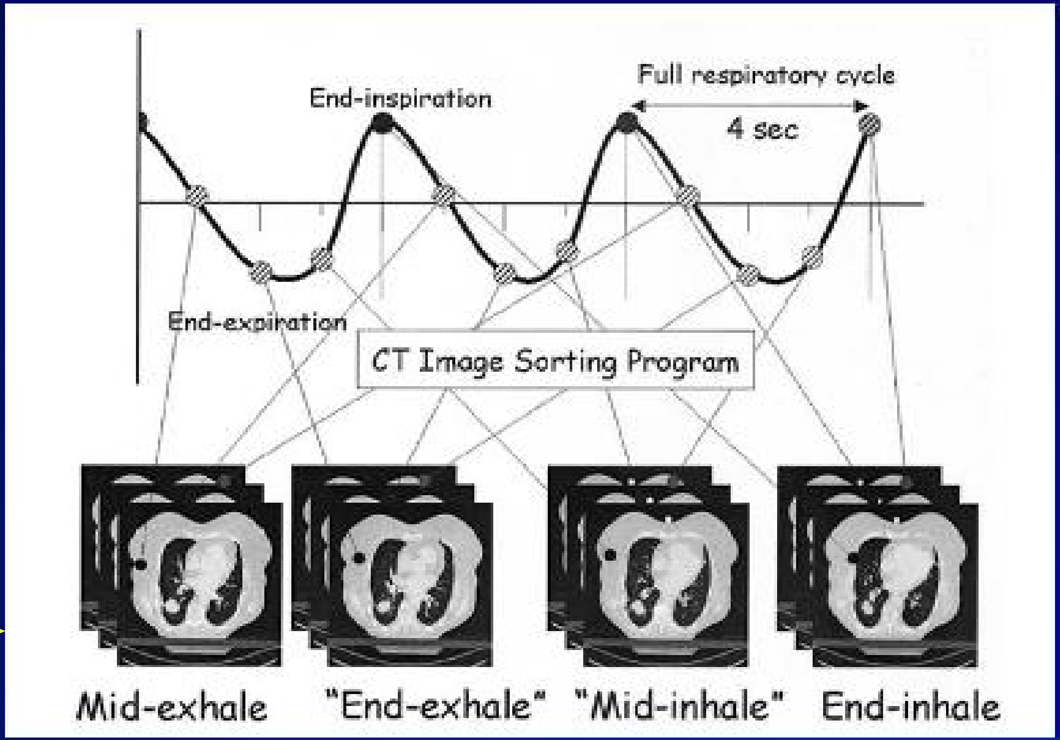
4D-CT

Spatial X, Y, Z + Temporal => 4D

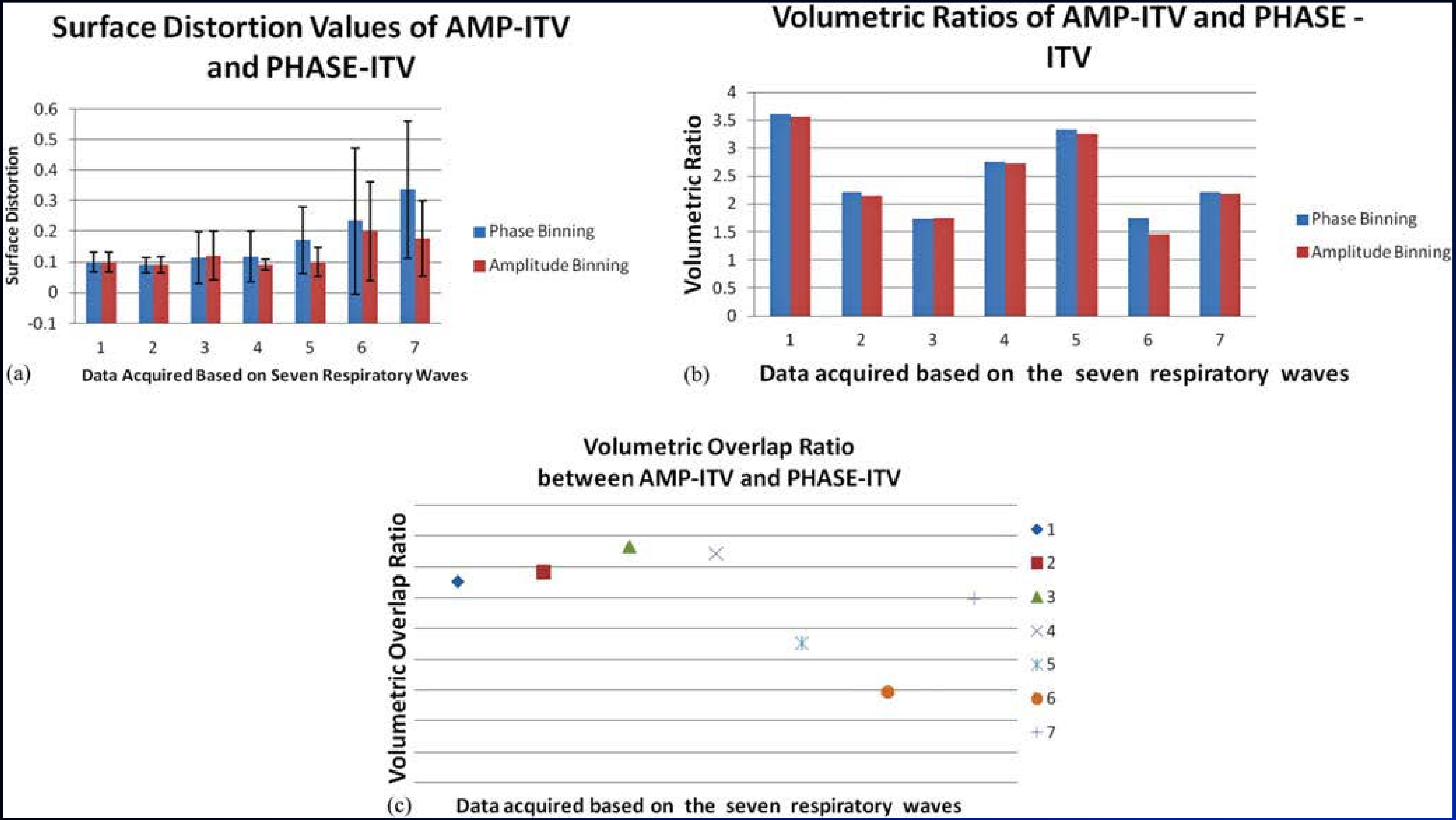
CT Raw Data/ Images

Respiration Signal

CT Acquisition Software



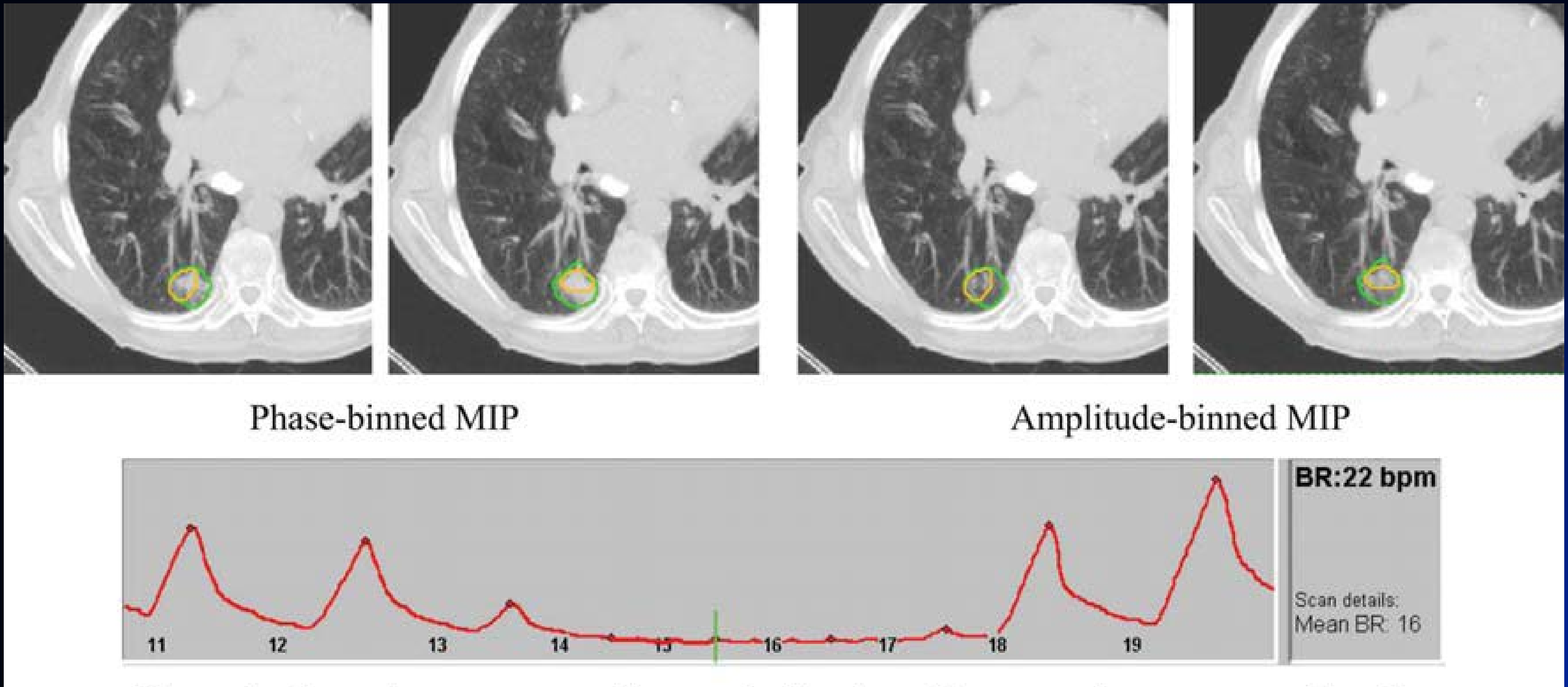
Phase & Amplitude Binning



IJDas, (20)

Li et al, Med Phys, 39(2), 922-932, 2012

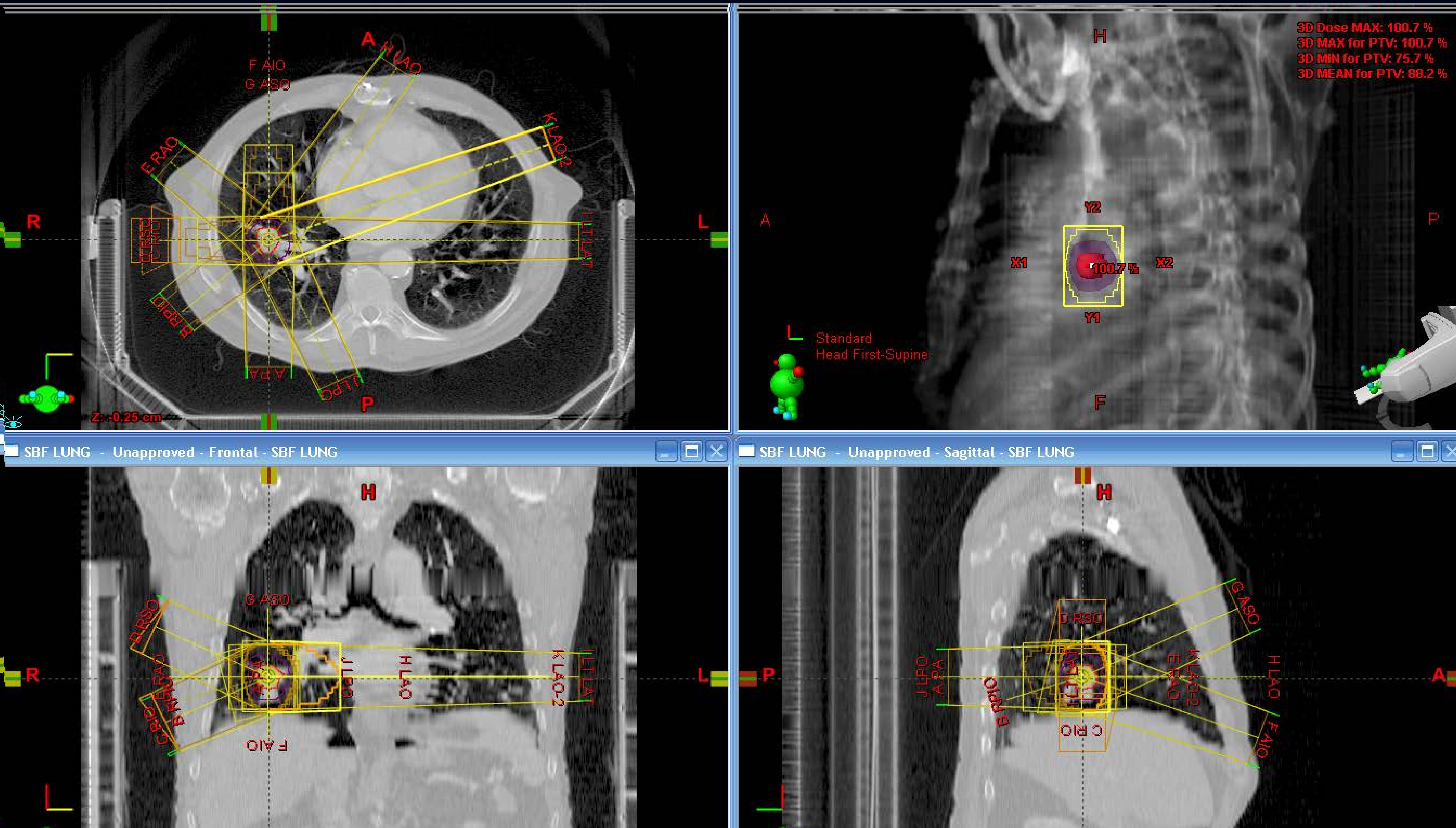
Amplitude Binning



The patient's respiratory wave with very shallow breathing occurring over several cycles.

Li et al, Med Phys, 39(2), 922-932, 2012

Planning and Beam Delivery

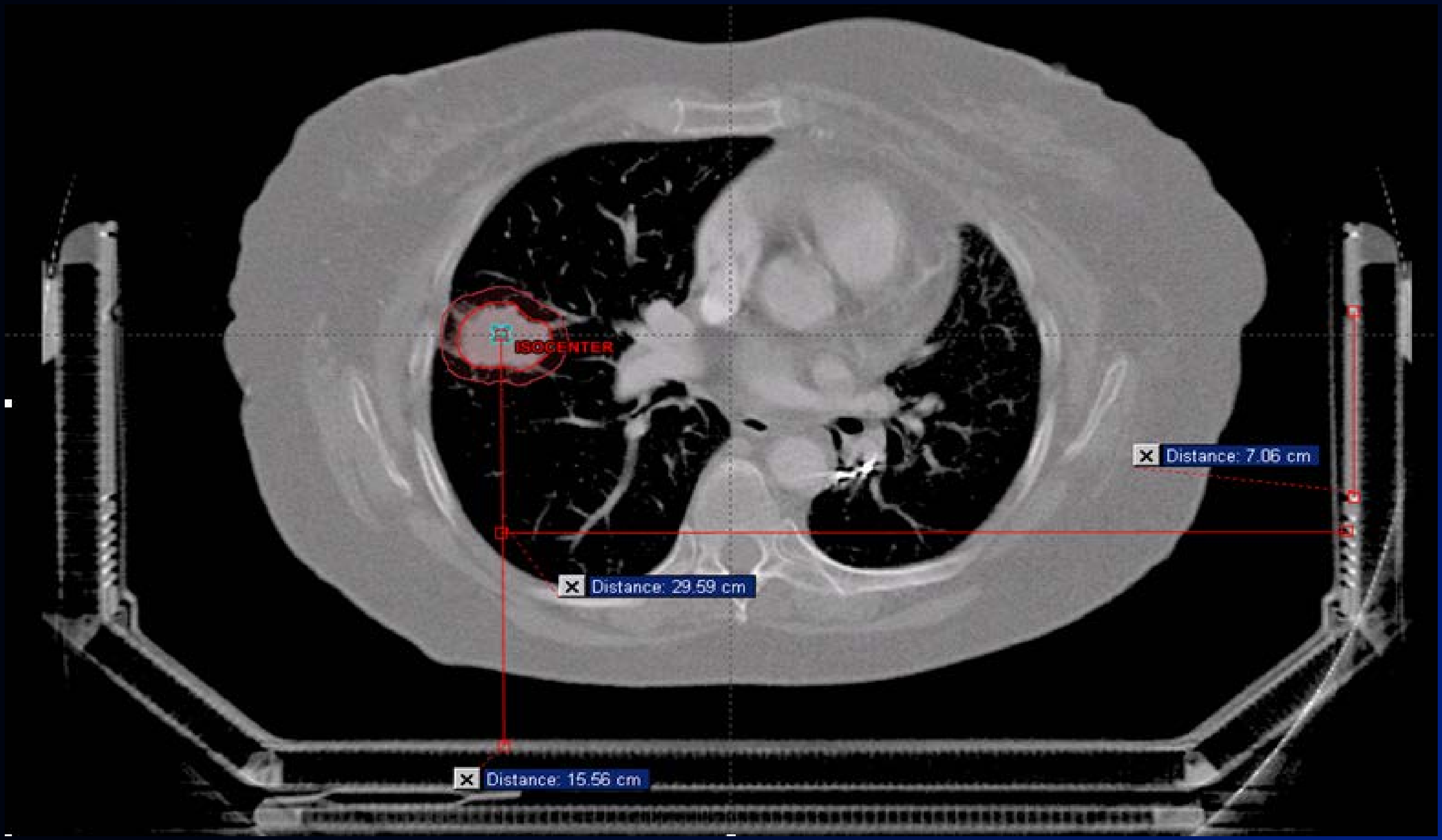


Plan Evaluation

- Target coverage
- Target dose heterogeneity
- Normal tissue constraints
- Conformity indices
  - High dose spillage
  - Low dose spillage

RTOG 0236
AAPM TG-101
Timmerman R. Semin. Radiat. Oncol. 18: p215-222. 2008

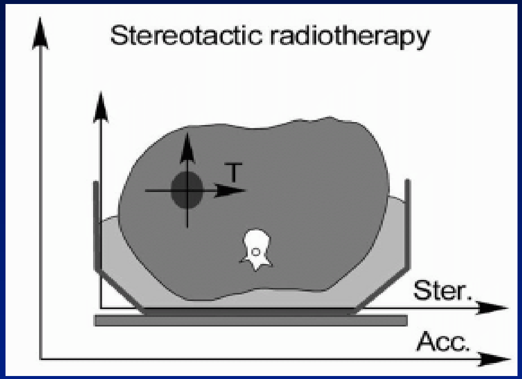
Treatment Planning – Isocenter Coordinates



$$X_{iso} = X_{measure} + 85$$

$$Y_{iso} = Y_{meaasure}$$

$$Z_{iso} = Z_{meaasure} + n \times 100$$



Treatment Day

- Patient setup in frame according to simulation parameters
- Isocenter setup by stereotactic reference system
- Image acquisition and treatment verification
- Online correction through couch adjustment
- Treat

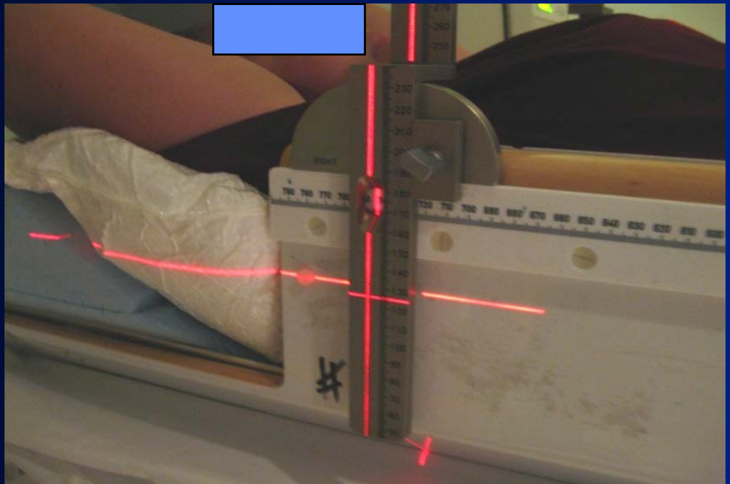


Image Guided Treatment Verification

- Purpose: to verify patient position on the treatment day is the same as the planned and to provide correction guidance if deviation is discovered

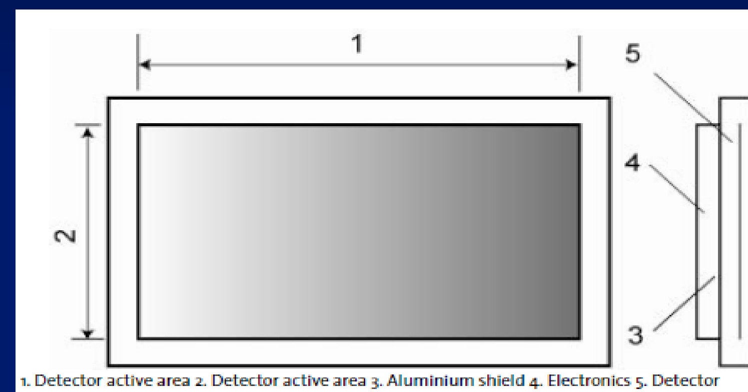
- IGRT systems
  - Fixed or rotating kV and MV imagers (2D imaging)
  - 3D volumetric imaging

Onboard Imager (OBI) system

kV x-ray source

Solid state detector

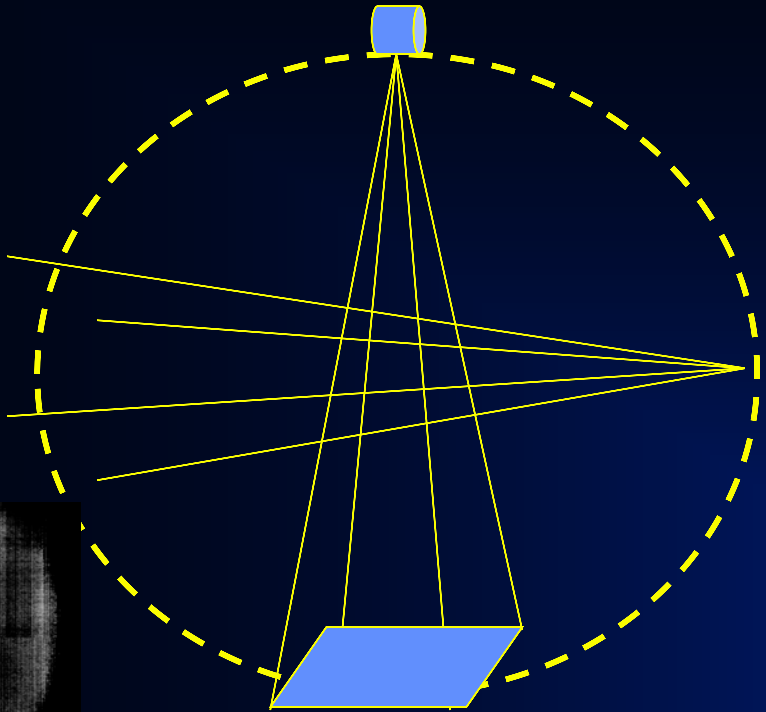
Source to isocenter distance: **100cm**



Active area: 397mm x 298mm

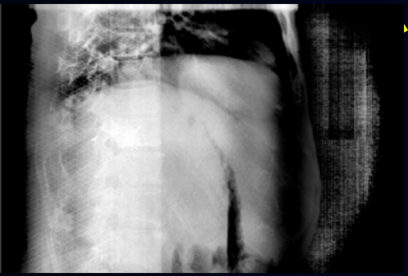
Detector to isocenter distance: **50cm**

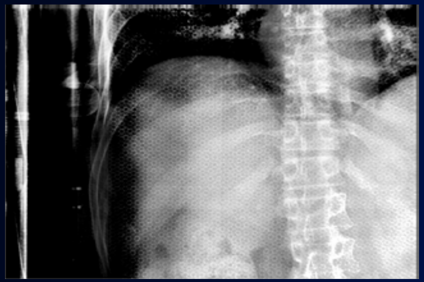
2D Orthogonal Image Match



Varian® OBI system

Image courtesy of Varian





compare

Planning reference Images

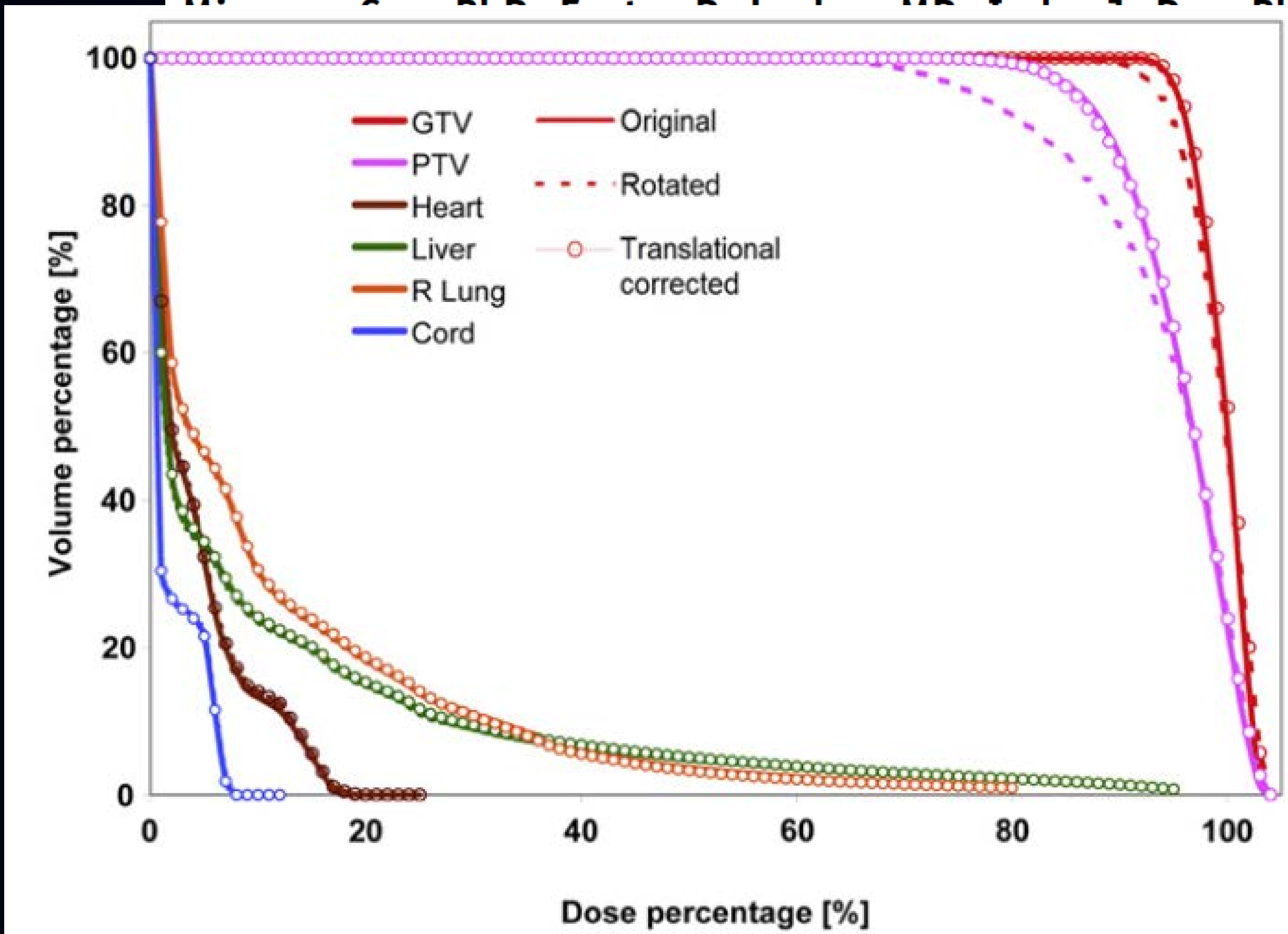
Rotational Issues in SBRT

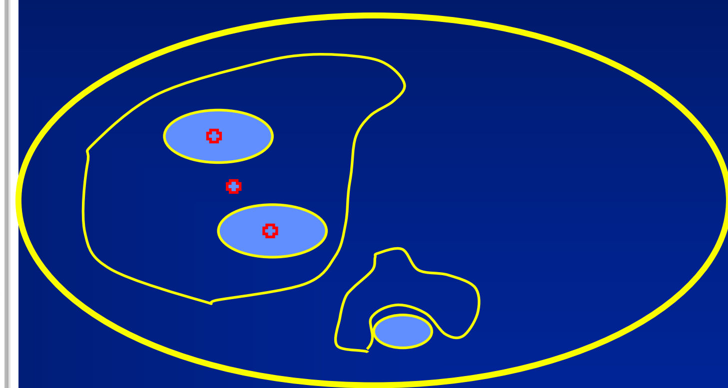
Evaluation of Rotational Errors in Treatment Setup of Stereotactic Body Radiation Therapy of Liver Cancer

hD, FACR, FASTRO,
iginia R. Cardenes, MD, PhD

napolis, Indiana

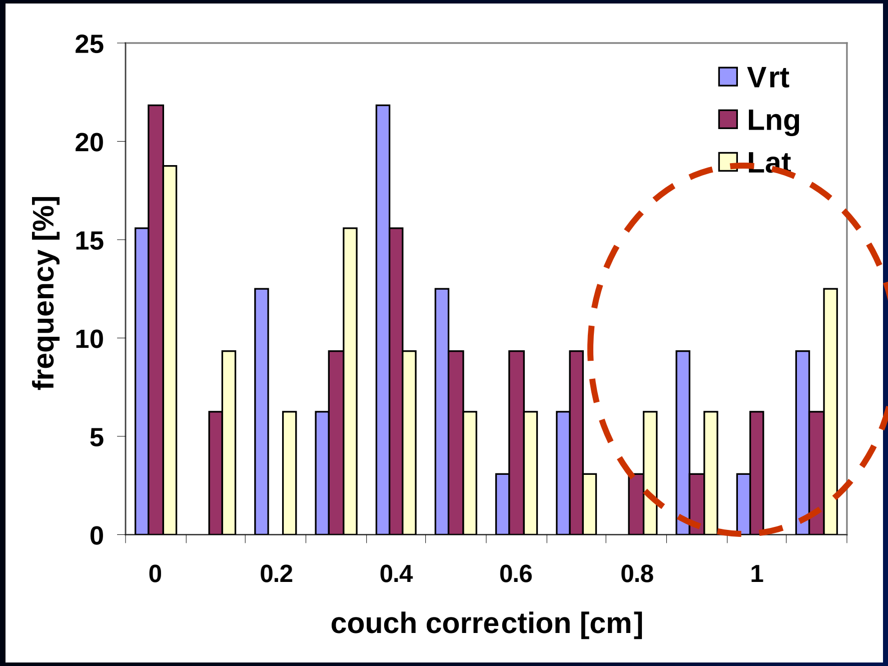
, pp. e435—e440, 2012



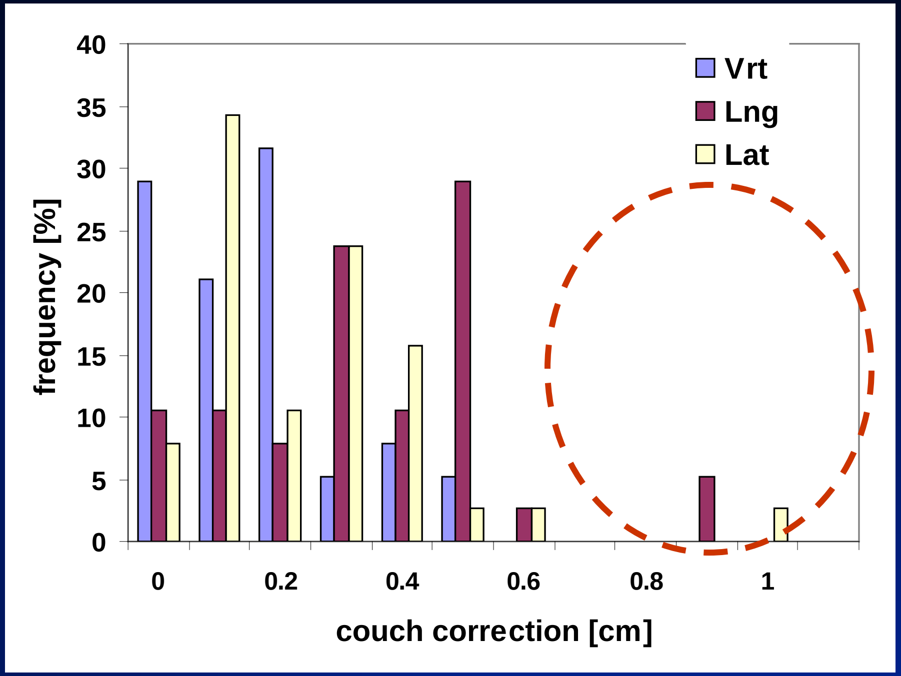


Histograms of inter-fractional couch corrections of liver patient setup

Pro-lok System

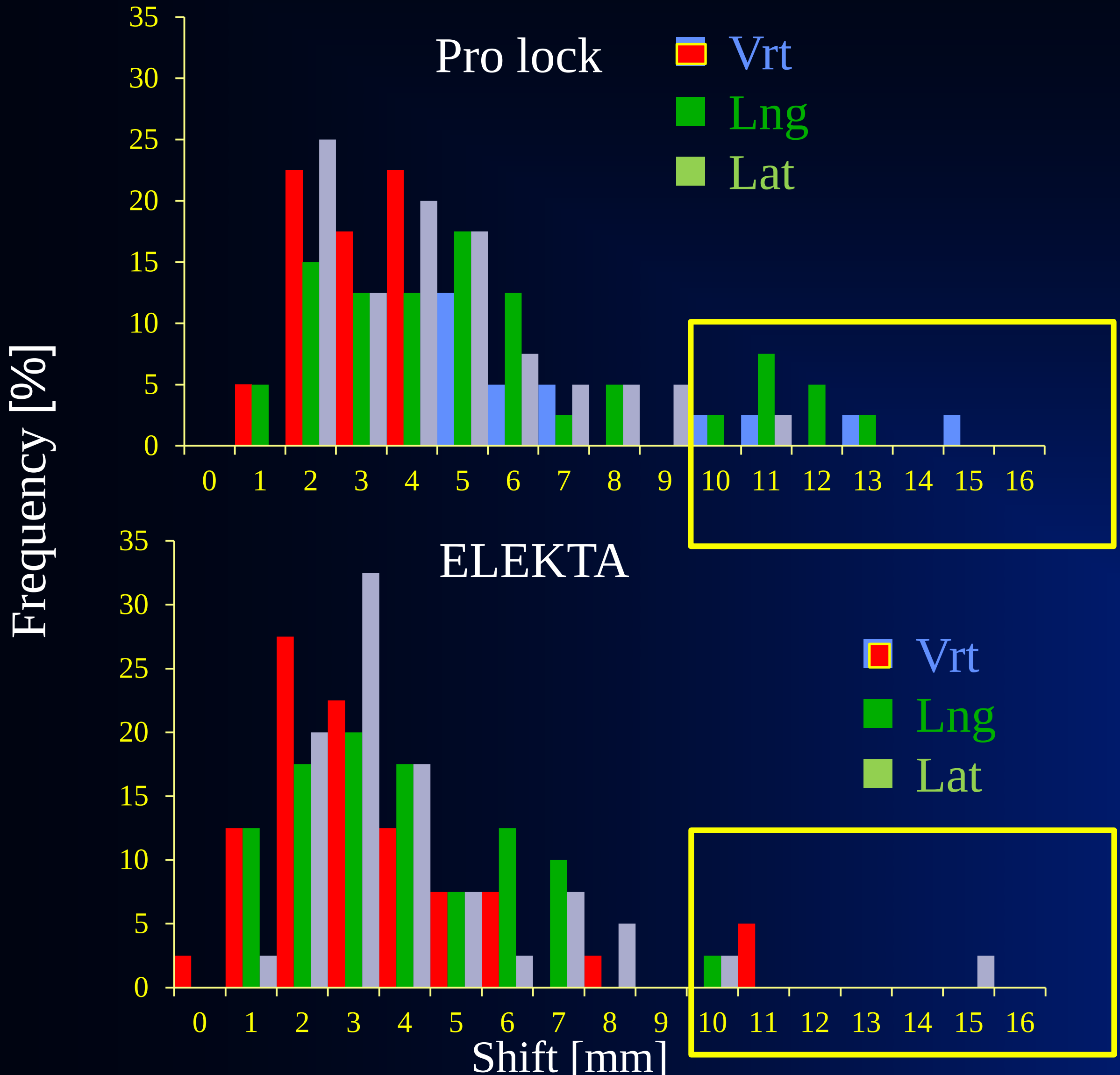


Elekta System



For large couch corrections, repeated CBCTs are often performed to verify the correction. For Pro-lok system, 40.7% of all the fractions ended up with repeated CBCT. Only 13.6% of fractions have repeated CBCT when Elekta body frame was used

2 SBRT Systems



Errors more than 5.0 mm[%]

Vrt	Lng	Lat
20.0	37.5	25.0

Errors more than 10.0 mm[%]

Vrt	Lng	Lat
7.5	15	2.5

Errors more than 5.0 mm[%]

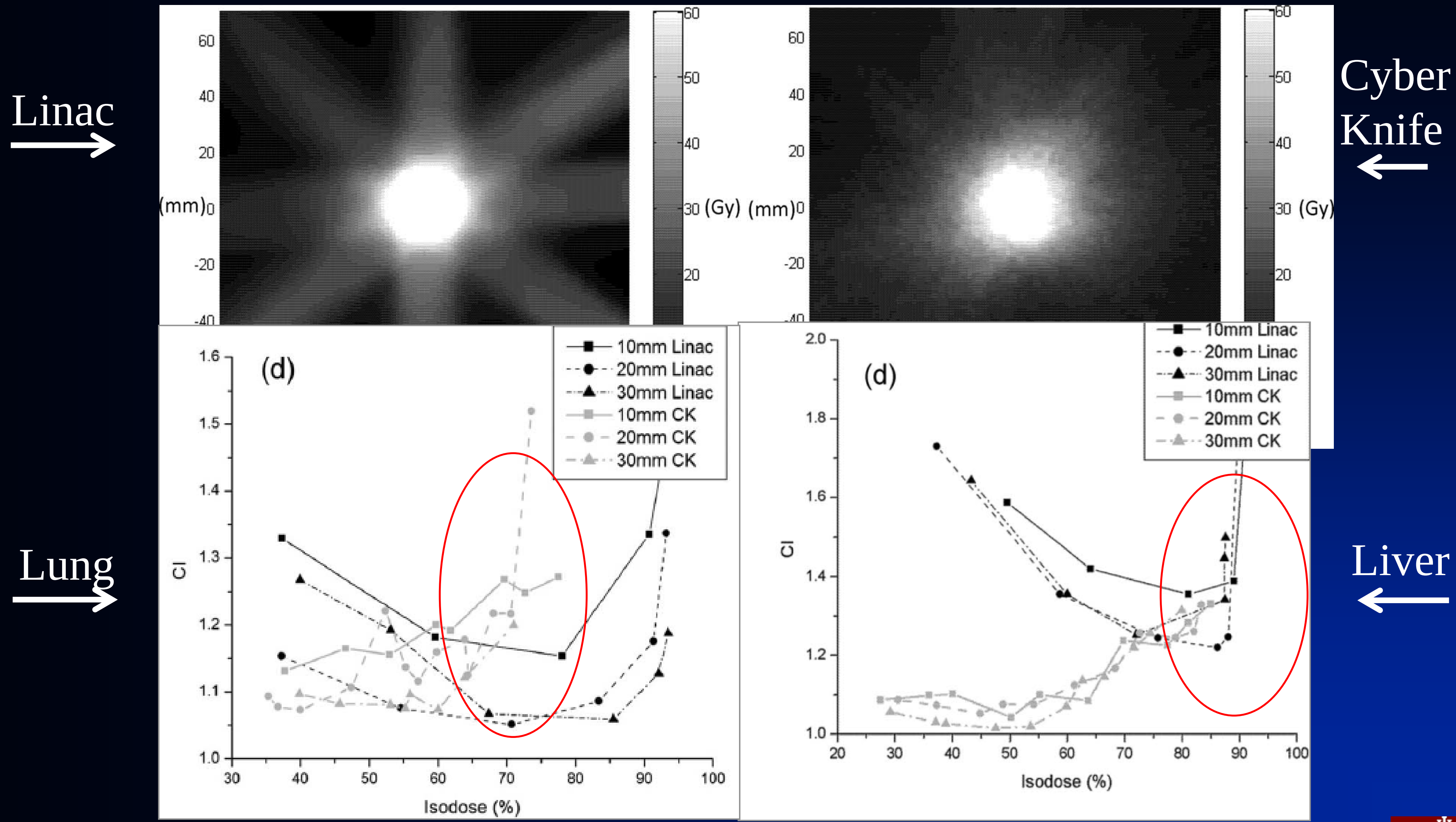
Vrt	Lng	Lat
12.5	25.0	20.0

Errors more than 10.0 mm[%]

Vrt	Lng	Lat
5.0	0.0	2.5

Ueda Y, Das IJ, Cardenes H, Teshima T, Int J Radiat Oncol Biol Phys 90(1S) S836, 2014

Linac vs CyberKnife



IJDas, (32)

Ding et al, Med Phys, 40(5), **051705, 2013**

PTV Prescription

- Gamma Knife 50%
- CyberKnife 50-70%
  - Lung (40-48%) Ding et al, 2013
  - Liver (67-77%) Ding et al, 2013
- Novalis 70-80%
- Accelerator 80%
- 3DCRT 95-100%
- IMRT 100%

Dosimetric Accuracy in CyberKnife Lung Treatment

Collimator Size (mm)	Diode SFD reading (nC)	Diode Dose (cGy)	Ray Tracing Dose (cGy)	Monte Carlo Dose (cGy)	Ray Tracing Error	Monte Carlo Error
5.0	995.2	554.4	648.4	546.5	17.0%	-1.4%
7.5	1196.0	666.2	764.1	676.5	14.7%	1.5%
10.0	1266.0	705.2	804.3	712.8	14.1%	1.1%
12.5	1322.0	736.4	838.7	739.0	13.9%	0.4%
15.0	1355.0	754.8	860.6	750.1	14.0%	-0.6%
20.0	1384.0	770.9	888.6	767.6	15.3%	-0.4%
25.0	1402.0	781.0	900.8	785.8	15.3%	0.6%
30.0	1419.0	790.4	911.3	800.6	15.3%	1.3%
40.0	1444.0	804.3	925.5	820.4	15.1%	2.0%
60.0	1480.0	824.4	947.6	836.1	14.9%	1.4%

Summary

- SRS/SRT/SBRT/IMRS is now widely used for hypo-fractionated treatment world wide with good outcome
- Image guidance for treatment planning and treatment verification is very critical to the success of SBRT radiation therapy
- Quality assurance and Small Field dosimetry as well as continuous monitoring of the QA and process is critical
- For SBRT, image-guided localization techniques **shall** be used to guarantee the spatial accuracy of the derived dose distribution
- For thoracic and abdominal targets, a patient-specific tumor motion assessment is also recommended
- AAPM has Task Group report on each of the SRS Modalities that can be referred.


Thanks