STEREOTACTIC RADIOSURGERY

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CONCEPTS AND IMPLEMENTATION

ICTP School on Medical Physics for Radiation Therapy
Dosimetry and Treatment Planning for Basic and Advanced Applications
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Miramare, Trieste, Italy

Yakov Pipman, D.Sc.
Chair- International Educational Activities - AAPM

OUTLINE

Stereotactic Radiosurgery Concepts – targets and dose distributions

Some History

Commissioning and Quality Control

Image Fusion and Target delineation

Dose delivery methods

SRS treatment process

Stereotactic Radiosurgery

"A single high dose of radiation, stereotactically directed to an intra-cranial region of interest. May be from X-ray, gamma ray, protons or heavy particles." (Lars Leksell, 1951)

Historical Development of Stereotactic Ablative Radiotherapy
Timothy D. Solberg, Robert L. Siddon, and Brian Kavanagh

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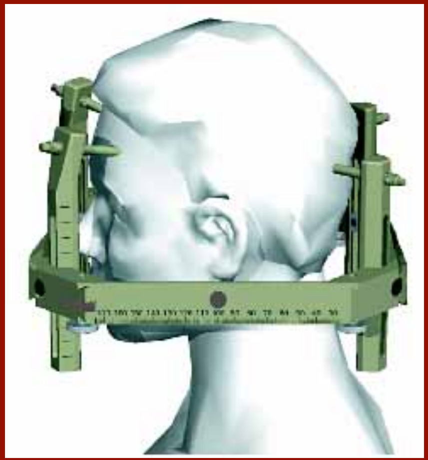
http://www.springer.com/cda/content/document/cda_downloaddocument/9783642256042-c2.pdf?SGWID=0-0-45-1346463-p174268967

Stereotactic Radiosurgery (SRS) – Stereotactic Radiotherapy (SRT)

SRS and SRT use a stereotactic system and high energy beams to irradiate a volume.

(1) Requires an image based volume defined and indexed to a stereotactic coordinate system.

(2) Planning and treatment delivery indexed to the same coordinate system.



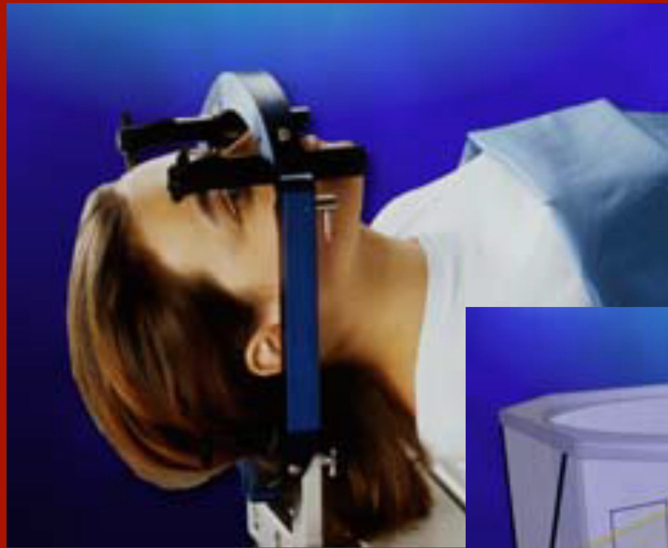
SRS and SRT produce a sharp dose gradient outside the treatment volume.

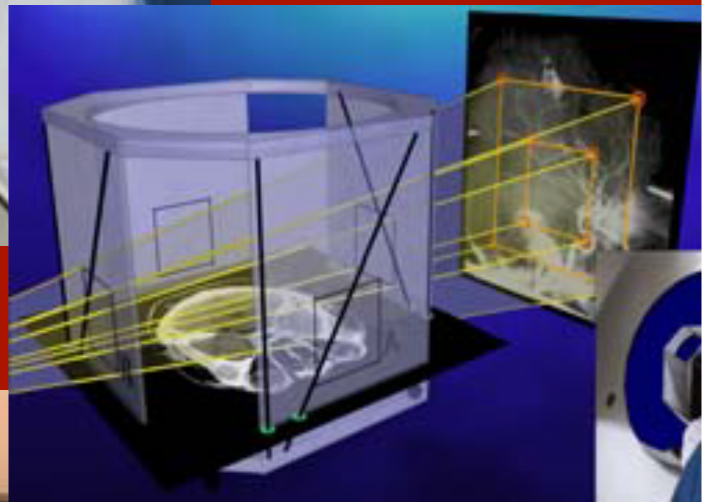
Stereotactic Localization

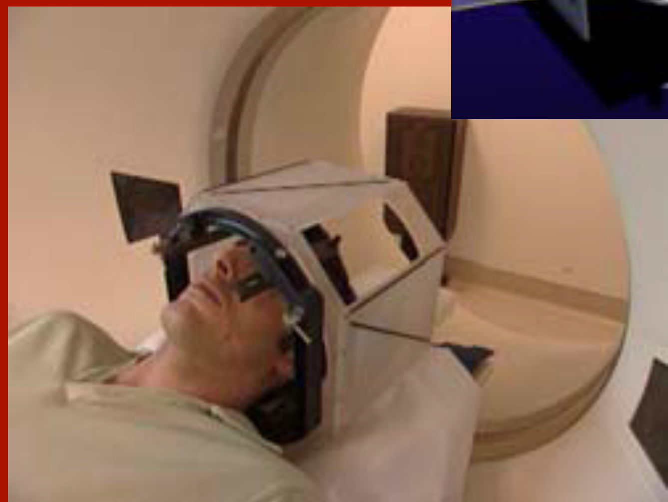
A localizer head frame, rigidly attached to the cranium, defines a precise and rigid frame of reference.

All points within that space can be referenced to a unique coordinate system.

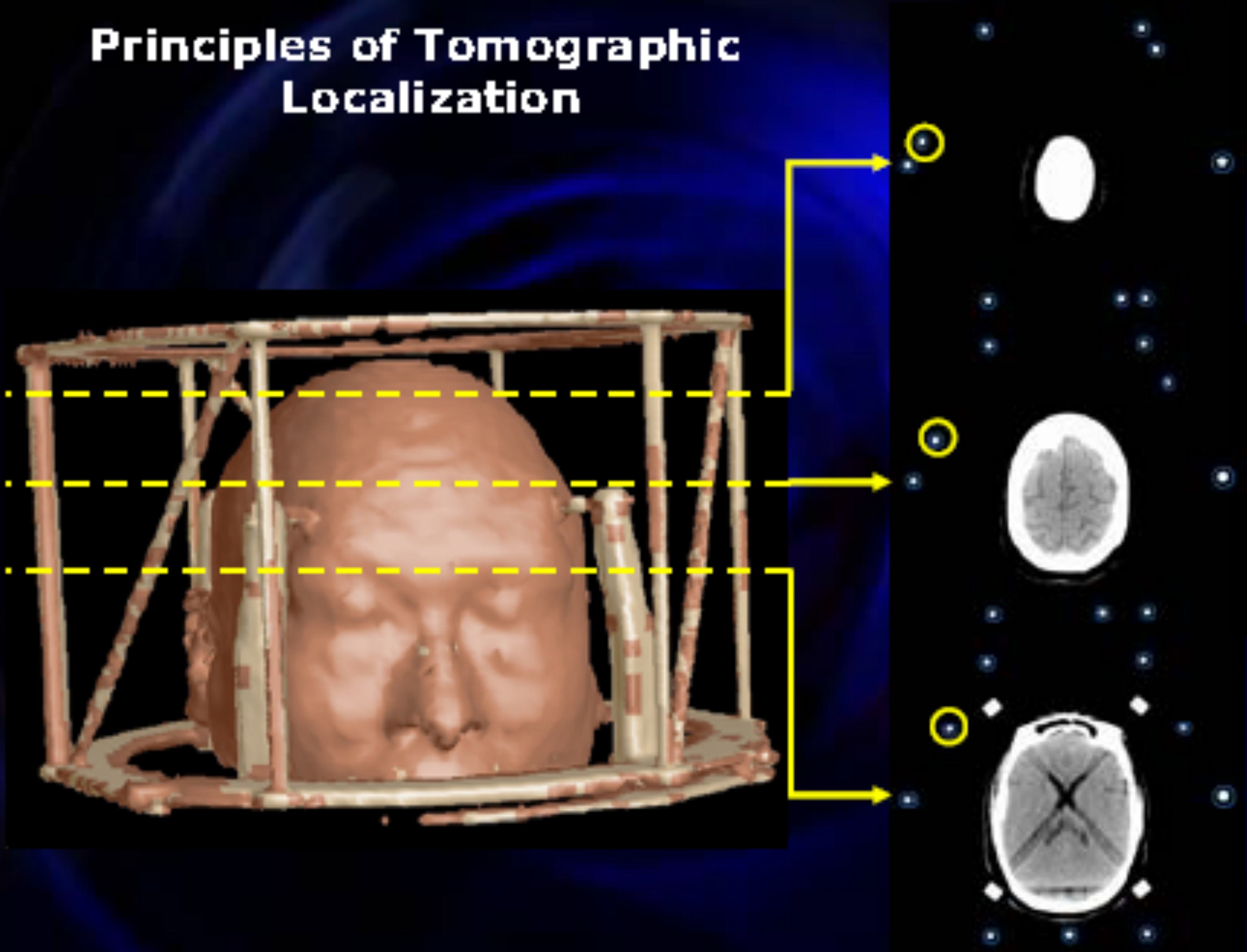
All structures and points can be identified in all the imaging studies that include the localization frame, which is uniquely and rigidly attached to the base frame.



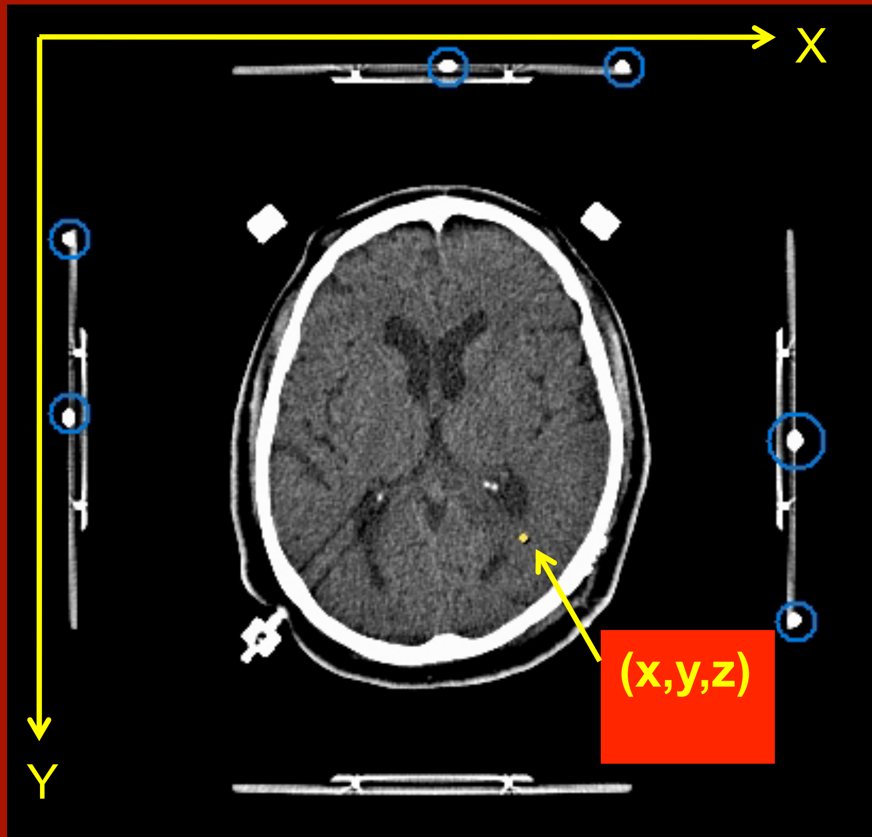




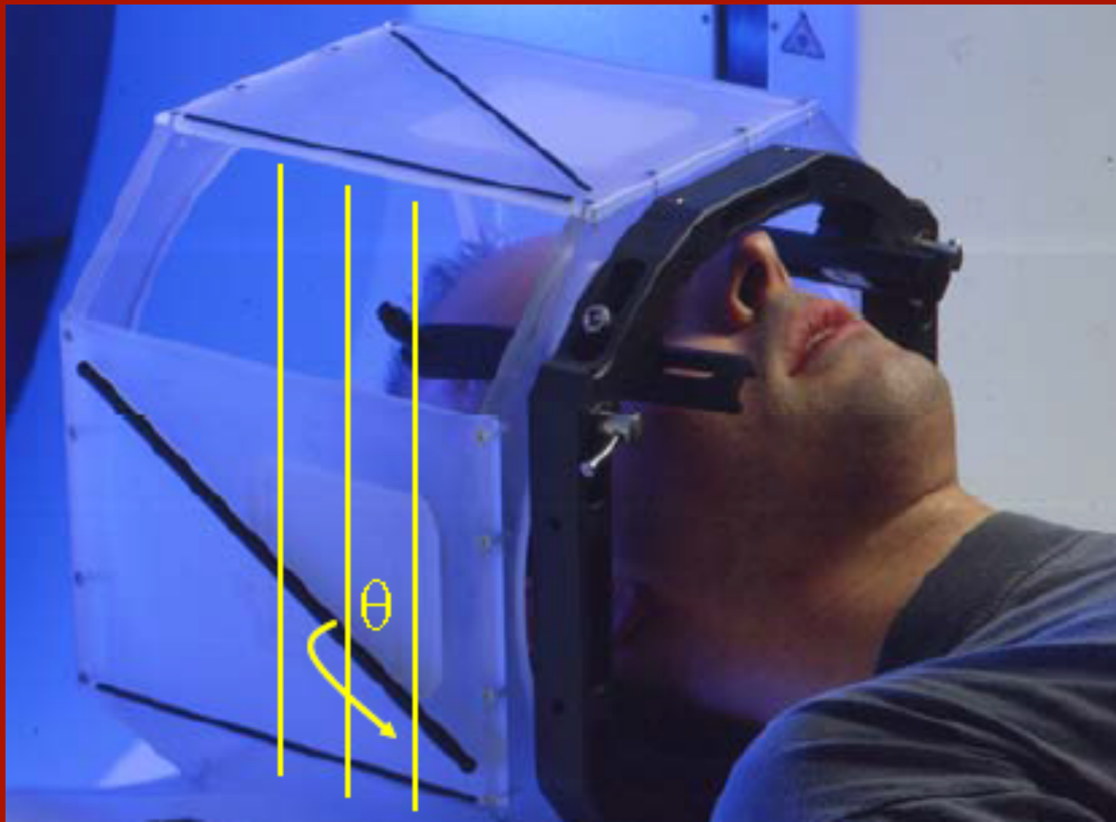
Principles of Tomographic Localization



Localization of points



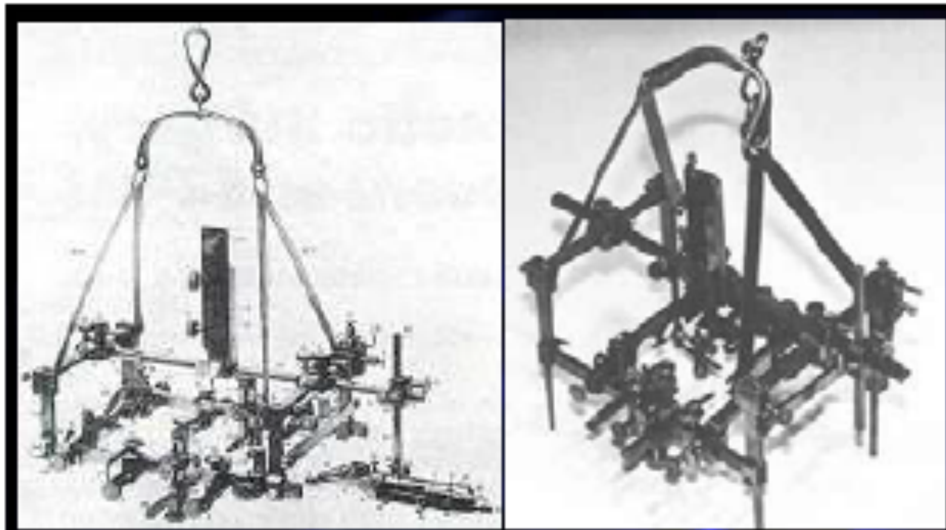
The “z” coordinate



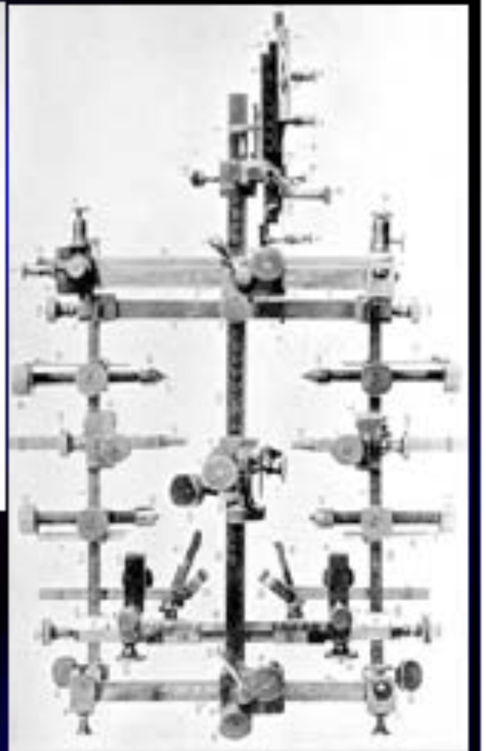
SRS treatment strategy

Position the point or volume to be treated at the point of convergence or intersection of all the beams

History



Original stereotactic frame



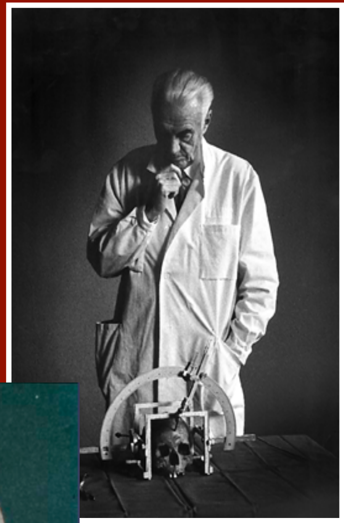
Clarke's stereotactic apparatus for directing an insulated needle by gradual movement in three planes (from, Horsley V, Clarke RH: The structure and functions of the cerebellum examined by a new method. Brain 31:45-124 1908).

Clarke RH, Horsley VA, On a method of investigating the deep ganglia and tracts of the central nervous system (cerebellum). Br Med J 1799-1800, 1906.

Horsley VA, Clarke RH, The structure and functions of the cerebellum examined by a new method. Brain 31:45-124, 1908.

History

- Dr. Lars Leksell (1951) introduced the concept of Radiosurgery as the ablation of a lesion by radiation in a single procedure, similar to surgery
- Initially used a 200kV x-ray tube
- In 1968 developed the "Gamma knife"
  - 179 Co-60 sources
  - A spherical cavity covering 60º x 160º



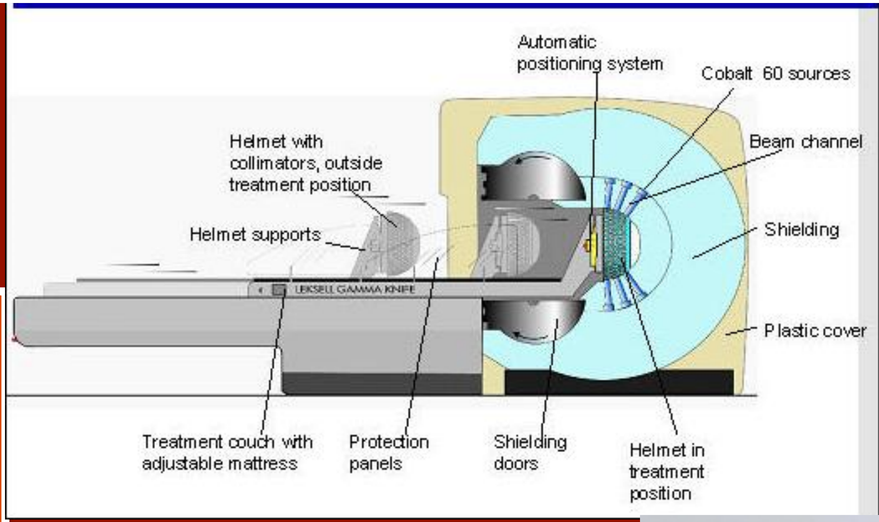
Gamma Knife

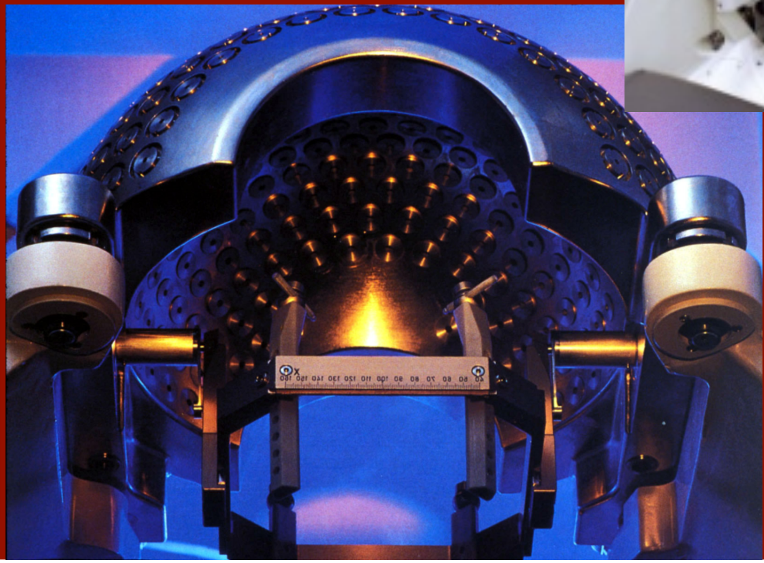
201 Co-60 sources arranged hemispherically around a common ‘focal’ point

The isocenter precision <0.5mm

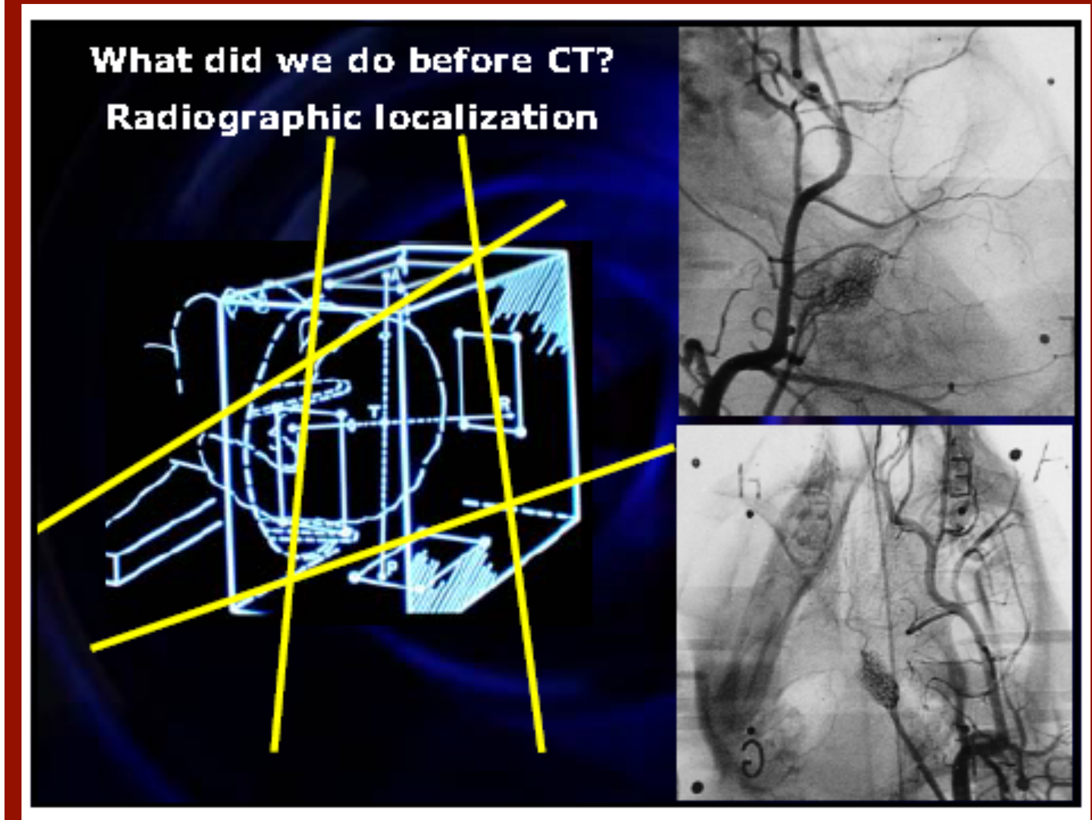
A system of collimators (4, 8, 14 and 18mm) (diameter of 50% isodose level on a 16cm phantom)

Used for spherical targets in one isocenter

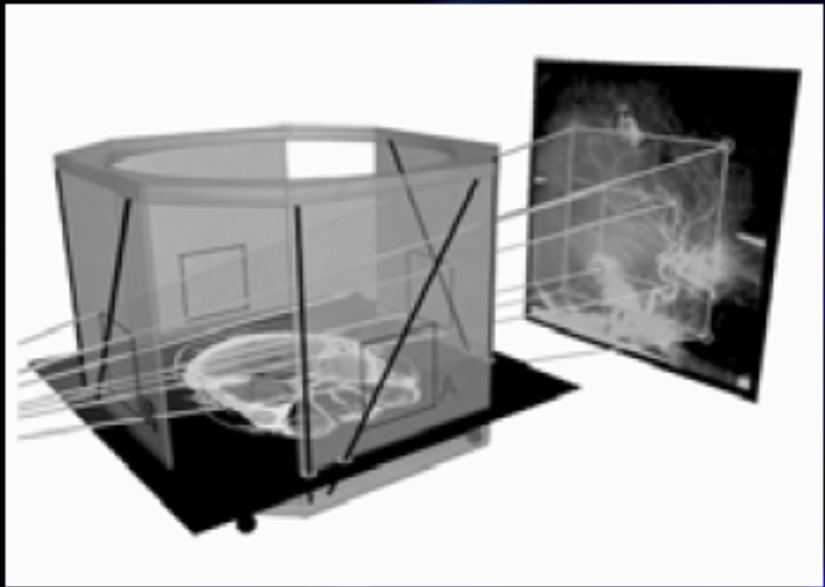


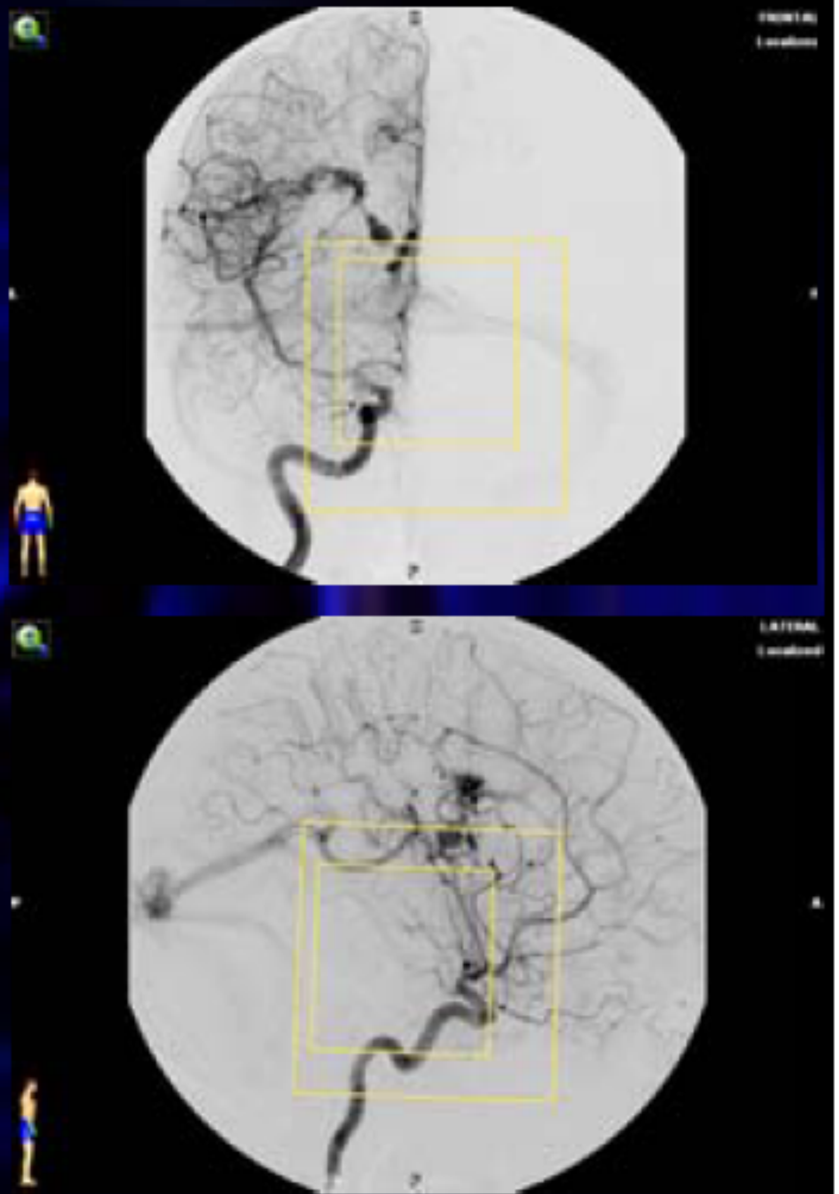


Initial application for treatment of artero-venous malformations (AVM)



DSA

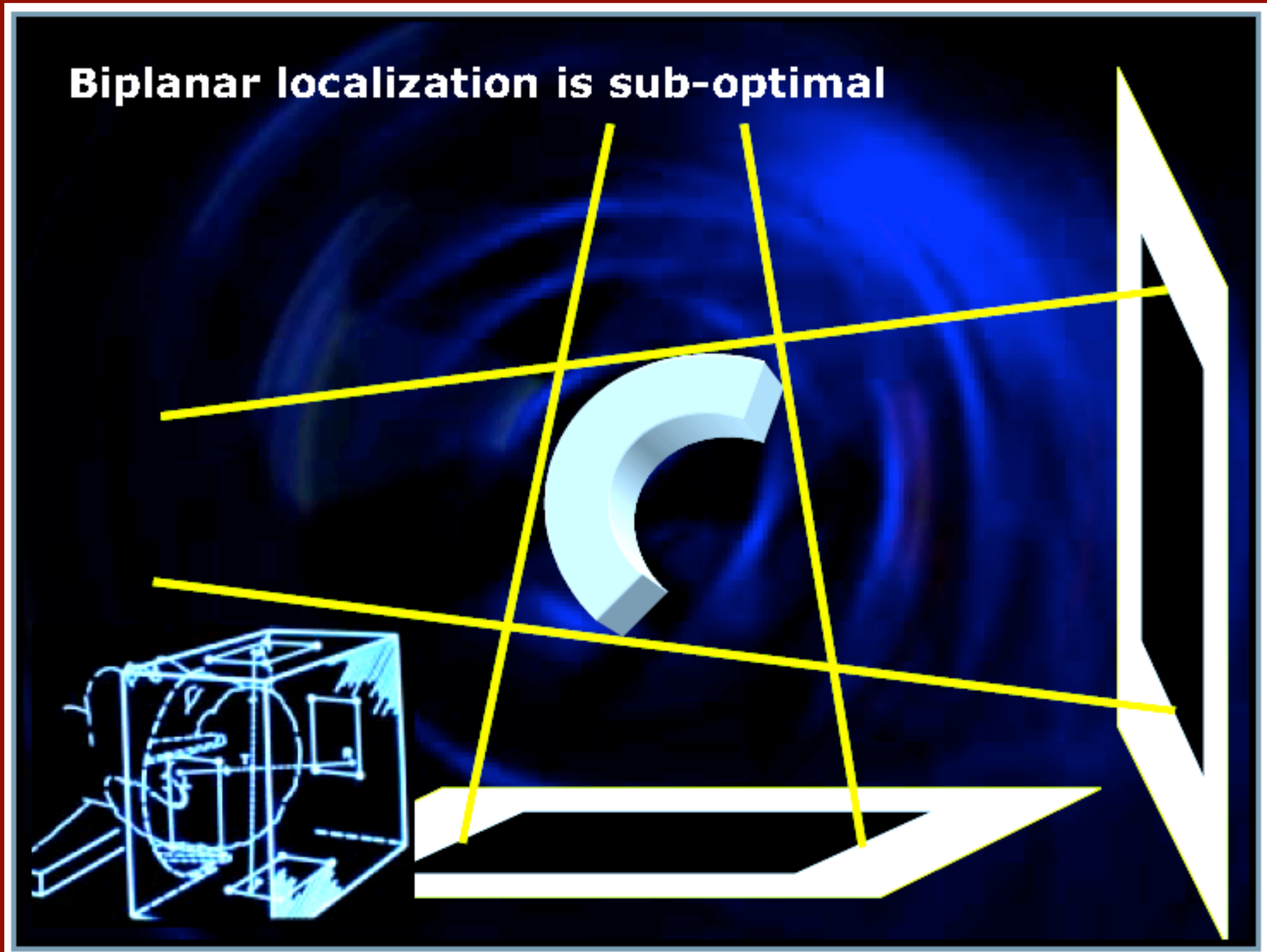




Radiographic localization requires a reference frame

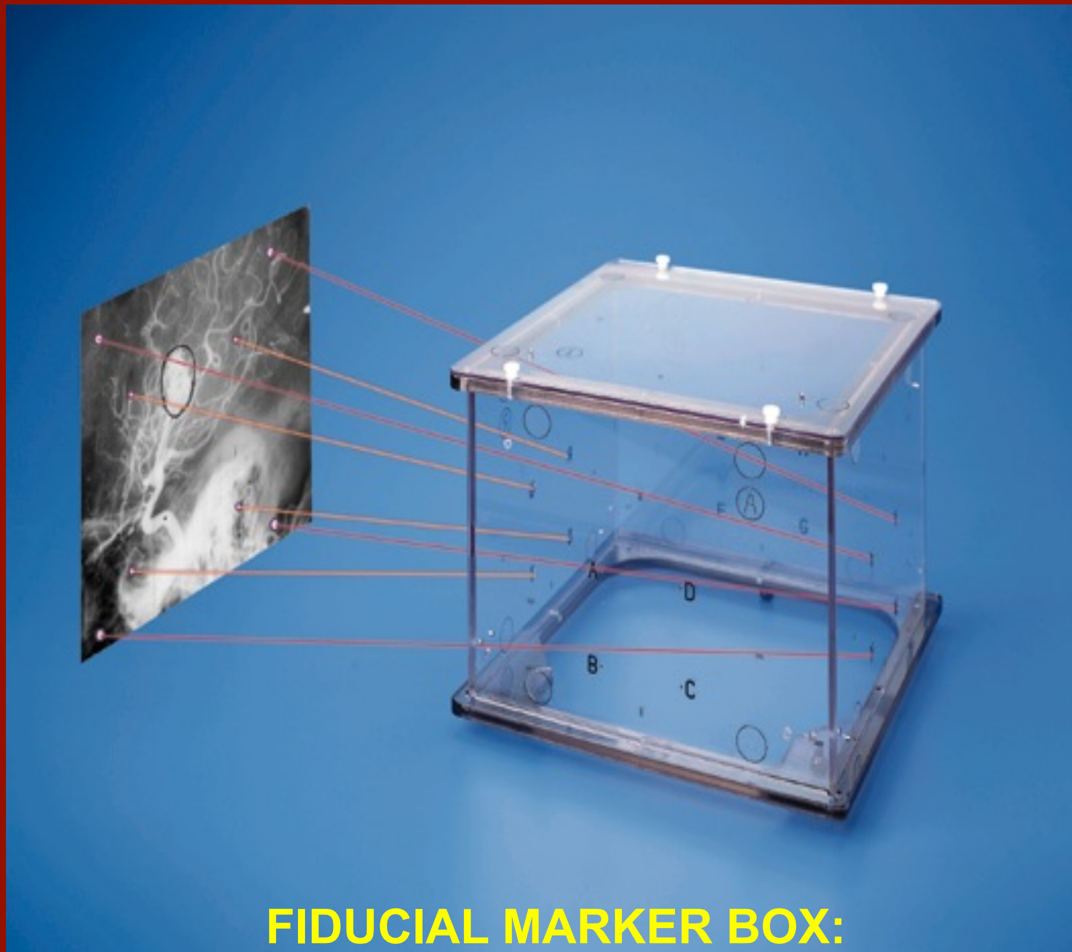
Images are registered, not fused. There is no such thing as "frameless" 2D angio localization, and you cannot "fuse" 2D angios.

Incomplete information



Laser-Angiographic Target Localizer (LATL)

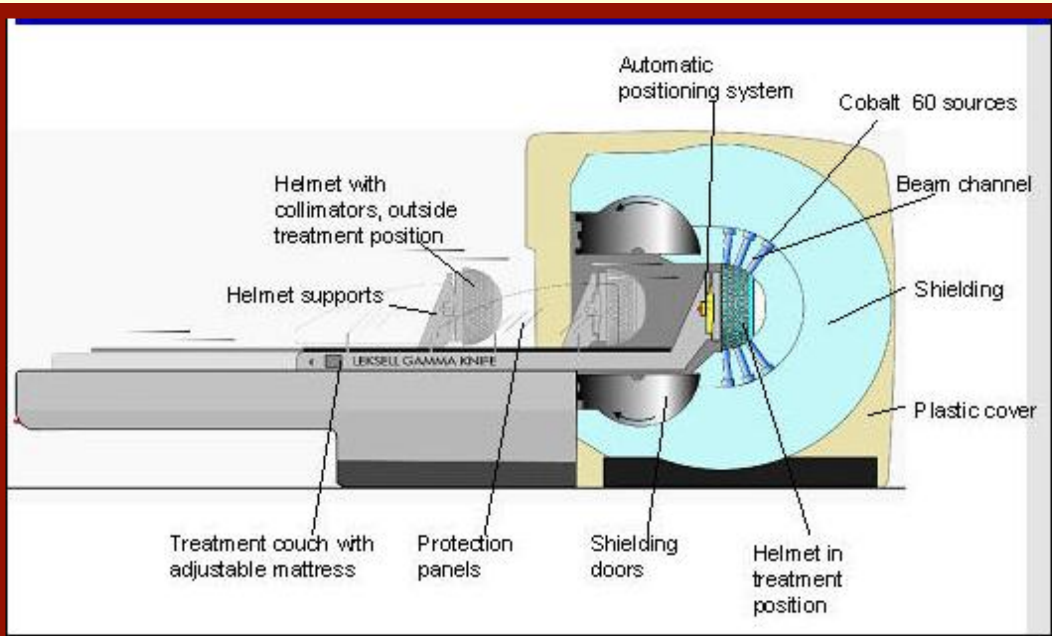
Used for Angiography to register the nidus to a CT data set



FIDUCIAL MARKER BOX:


Gamma-Knife
The Gamma Knife

Gamma knife



- **Irregular target volumes require multiple 'shots'**

X-Knife

- Collimator sizes: 5 to 45 mm in 2.5 mm steps
- Conformal SRT: with jaws/circles; mMLC; IMRT.
- Extra-cranial: head and neck; body localization, spine localization, other targets

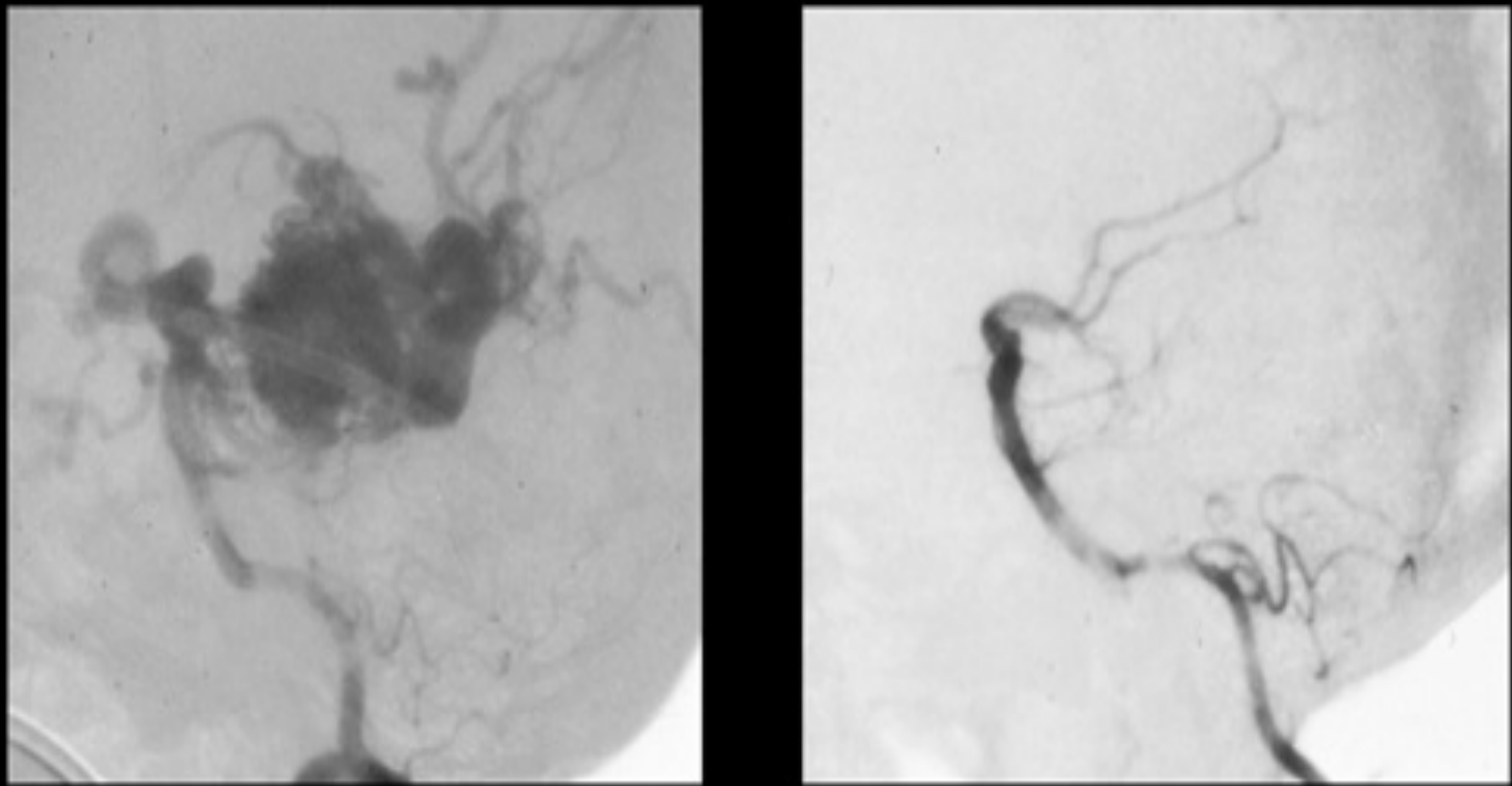
Gamma Knife

- Collimator sizes: 4,8,14,18 mm
- Conformal is only attained through multiple isocenters
- No extra-cranial targets possible

Radiosurgery AVM

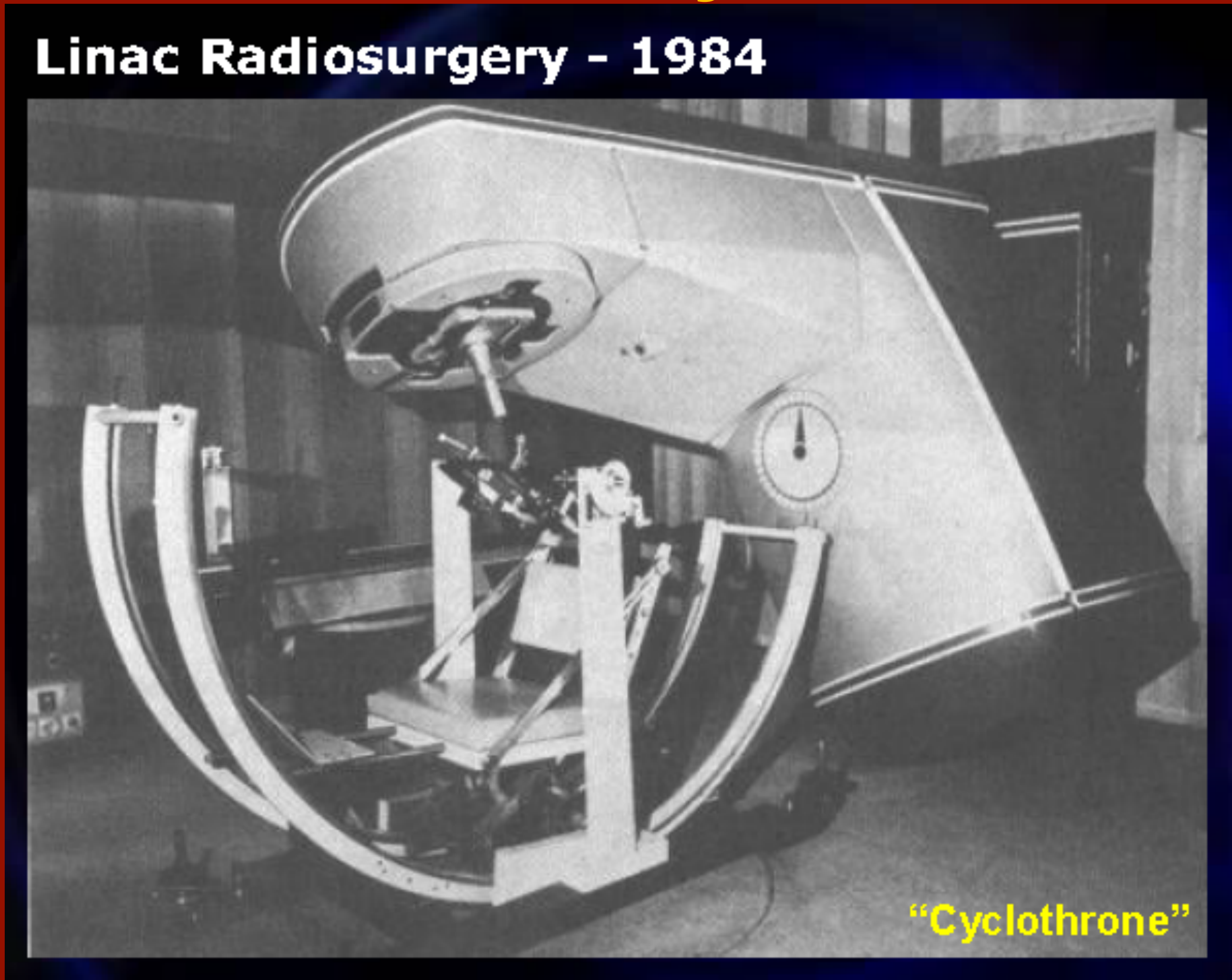
Pre-Radiosurgery

Post-Radiosurgery



6months

History



First linac- based SRS system. Betti et al., Buenos Aires, Argentina
Ref: Historical Development of Stereotactic Ablative Radiotherapy, by Timothy D. Solberg, Robert L. Siddon, and Brian Kavanagh. In S. S. Lo et al. (eds.), Stereotactic Body Radiation Therapy, Medical Radiology. Radiation Oncology,
DOI: 10.1007/174_2012_540, Springer-Verlag Berlin Heidelberg 2012

Radiation delivery techniques

Arcs with circular collimators

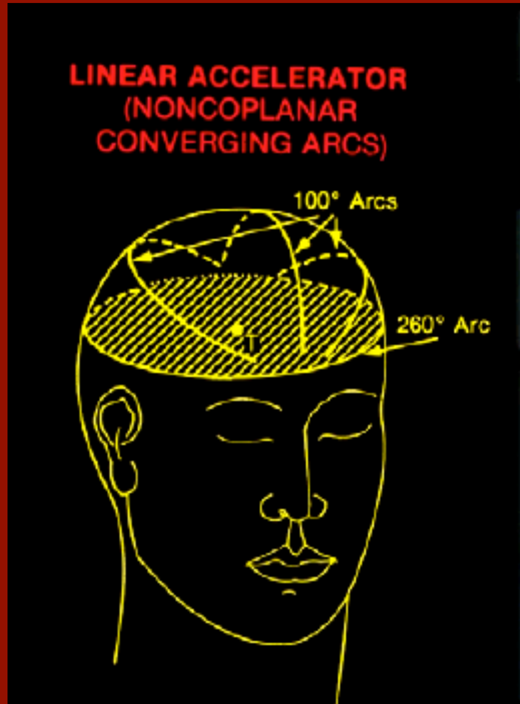
Conformal beams

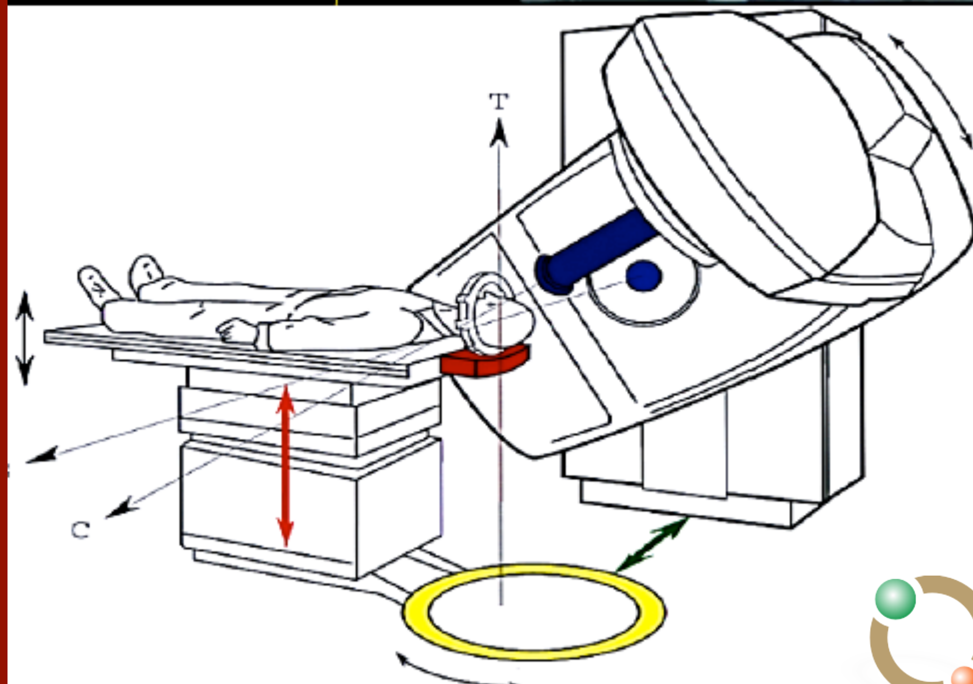
Arcs with Conformal Dynamic beams

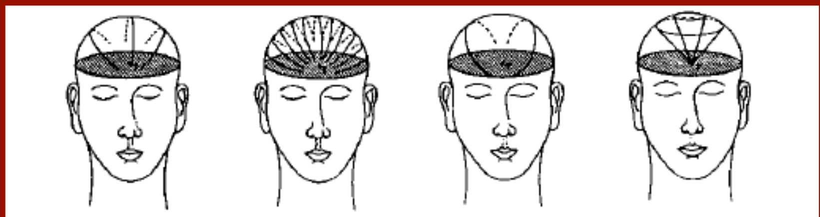
IMRT

Linac SRS with cones

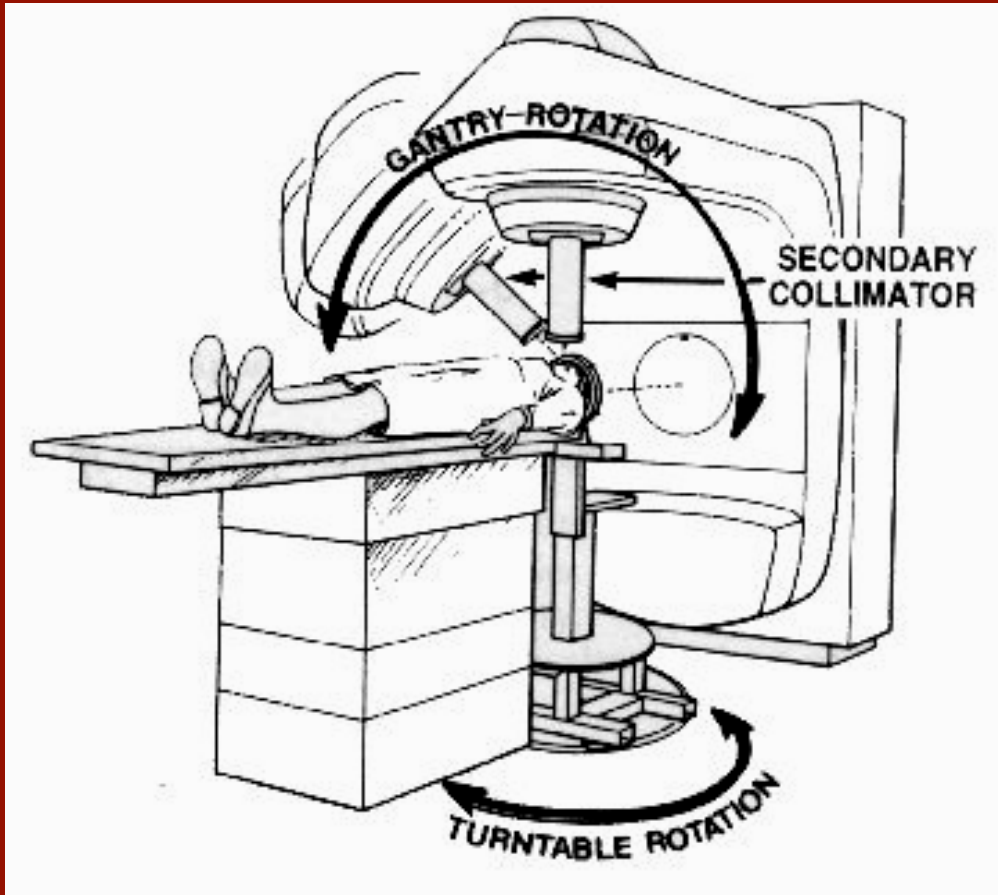
- One or more isocenters
- Multiple arcs per isocenter
  - Arcs of 100º to 160º
  - Fixed couch angle for each arc
  - Spherical dose distributions for each irradiación

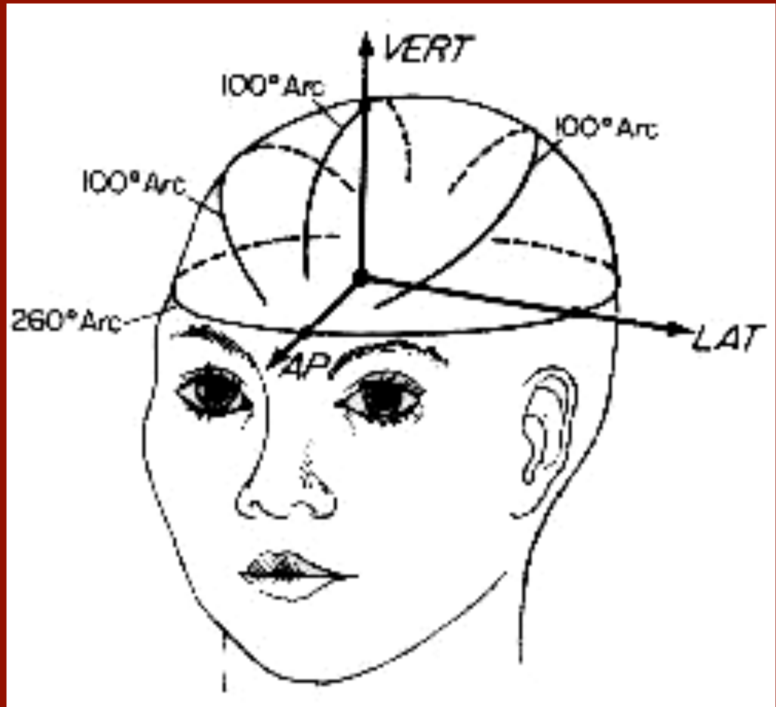






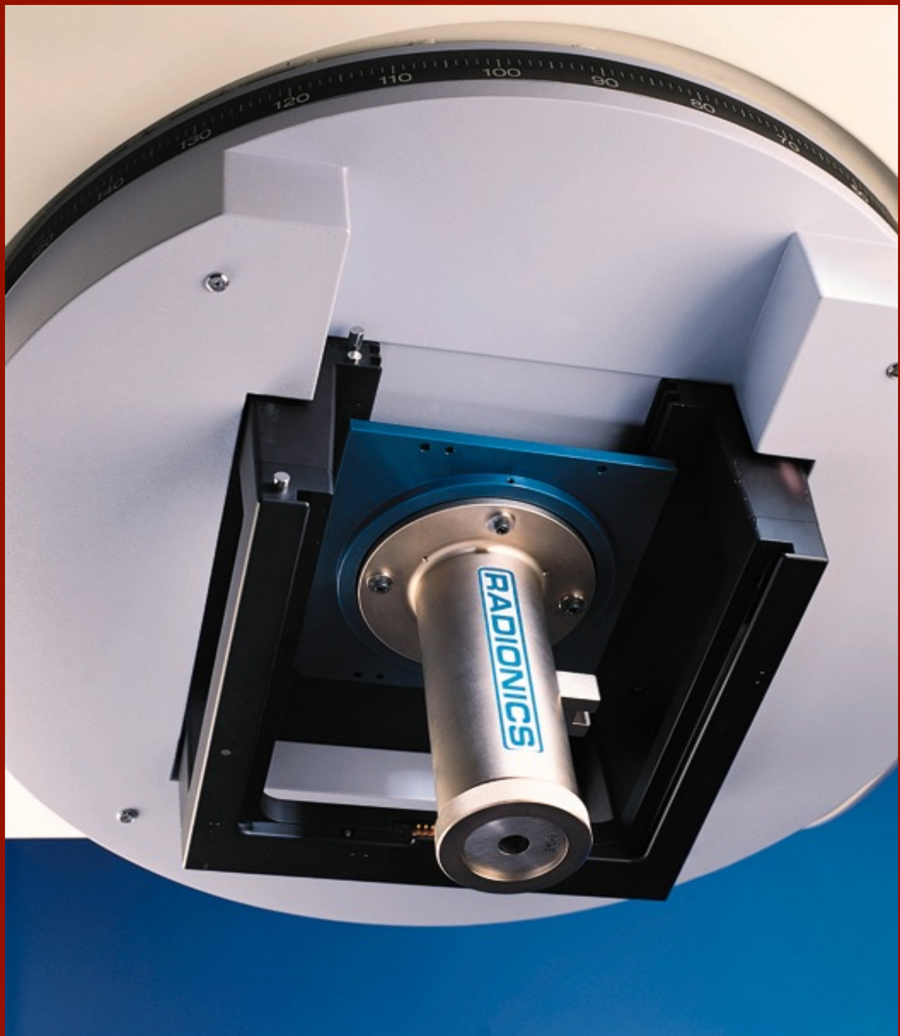
Arcs with circular cross sections are obtained by rotating the source (linac gantry) in various planes in the patient, corresponding to various couch angles.

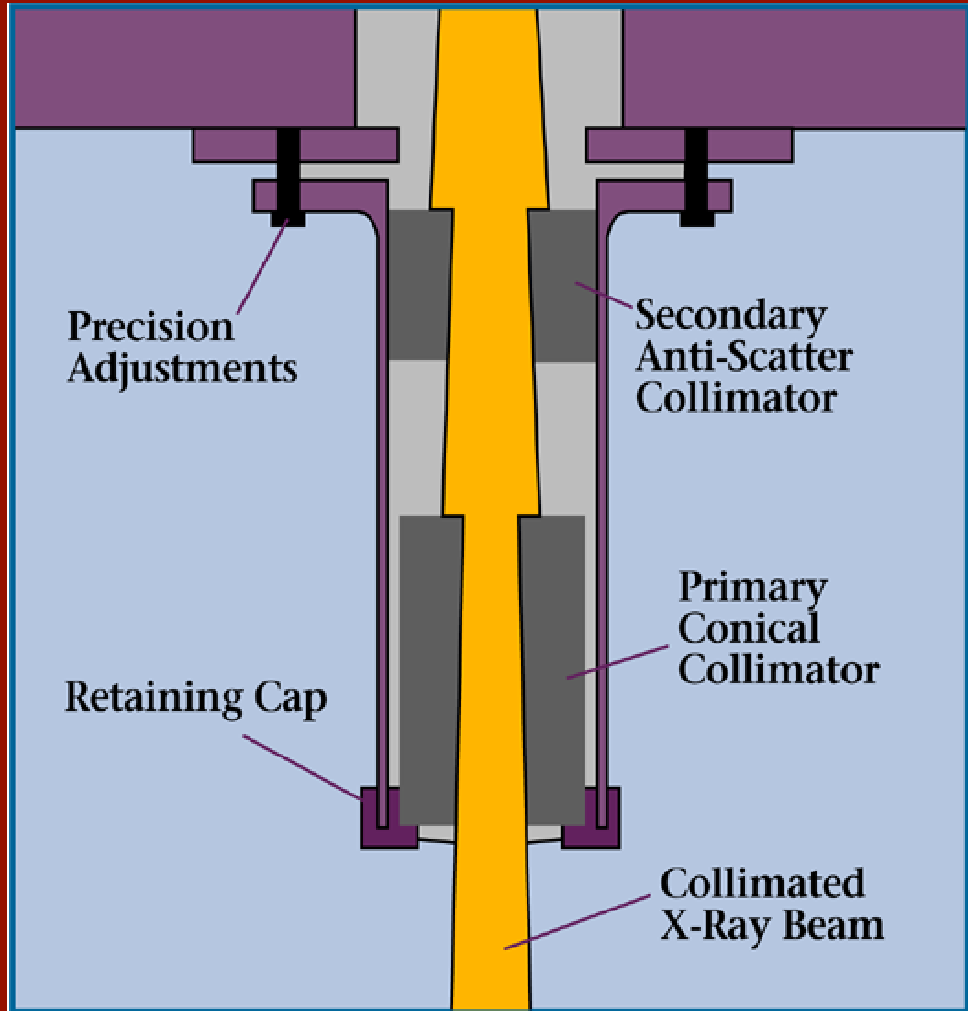




Tertiary Collimation Cone

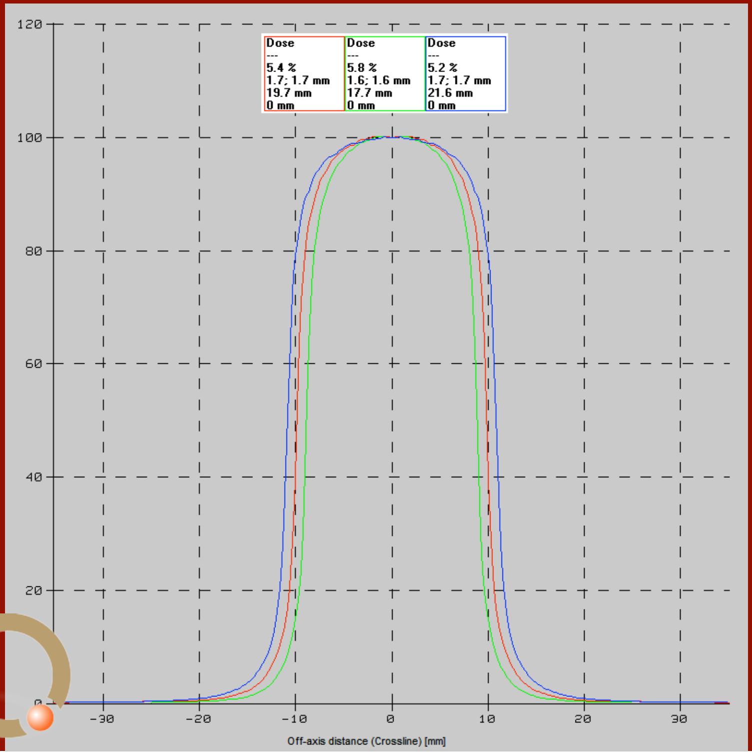
Collimation





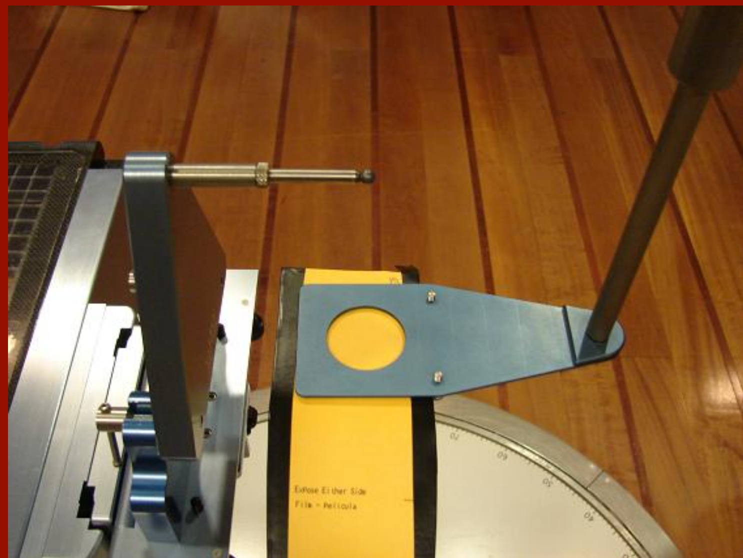
Linac SRS on Linac + cones

- 5-40mm diameter cone set
- Circular beam projection
- Collimator mounted assembly



Verification of gantry isocenter with cones

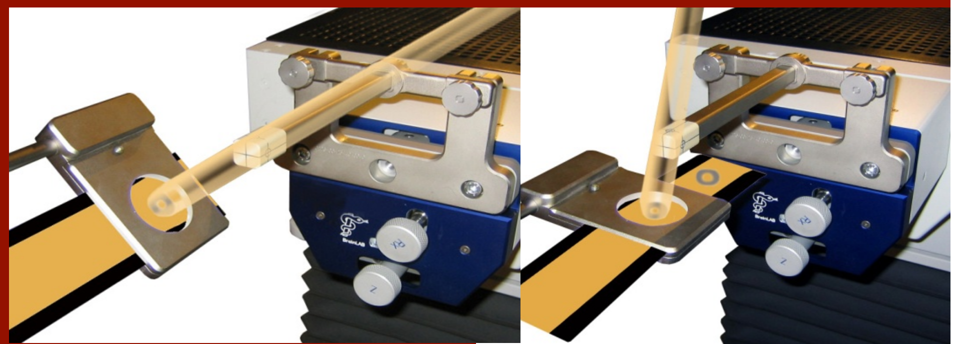
Laser alignment



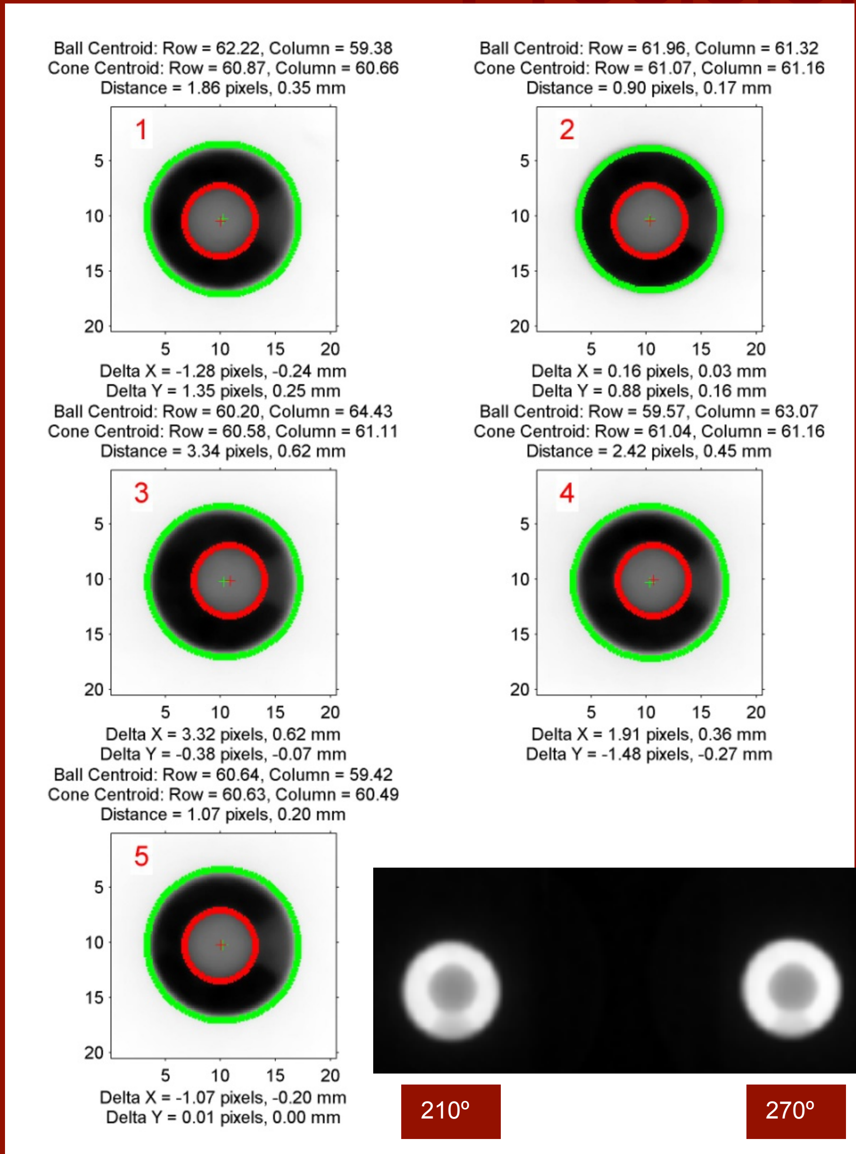
Stereotactic Set-up QA

Winston Lutz Quality Assurance

- Phantom Pointer verifies laser accuracy prior to SRS
- Embossed laser lines for easy alignment with wall lasers
- Integrated tungsten sphere for film verification
- Irradiation of film at different gantry angles
- Shadow in field center verifies accuracy

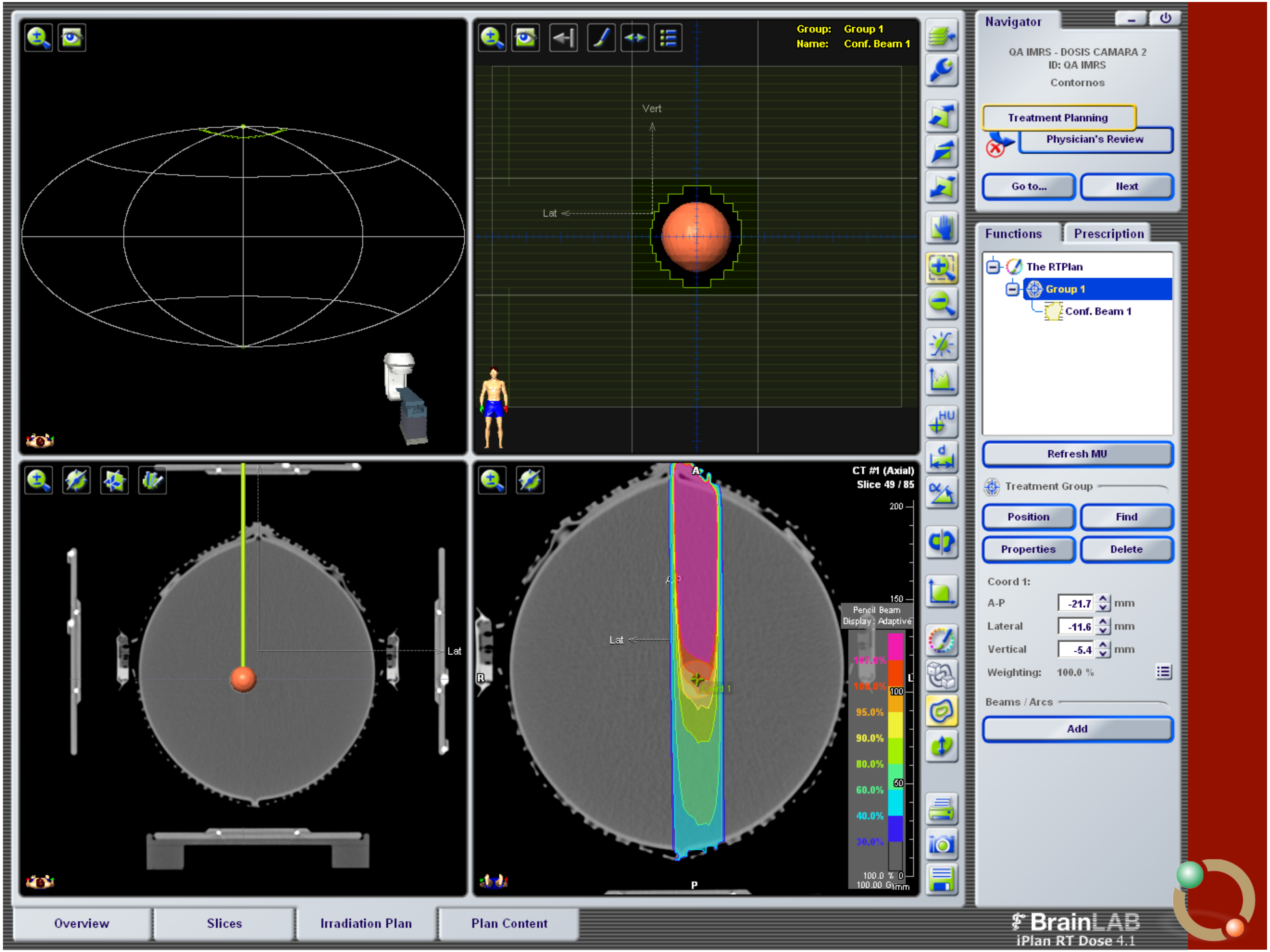


Precisión mecánica

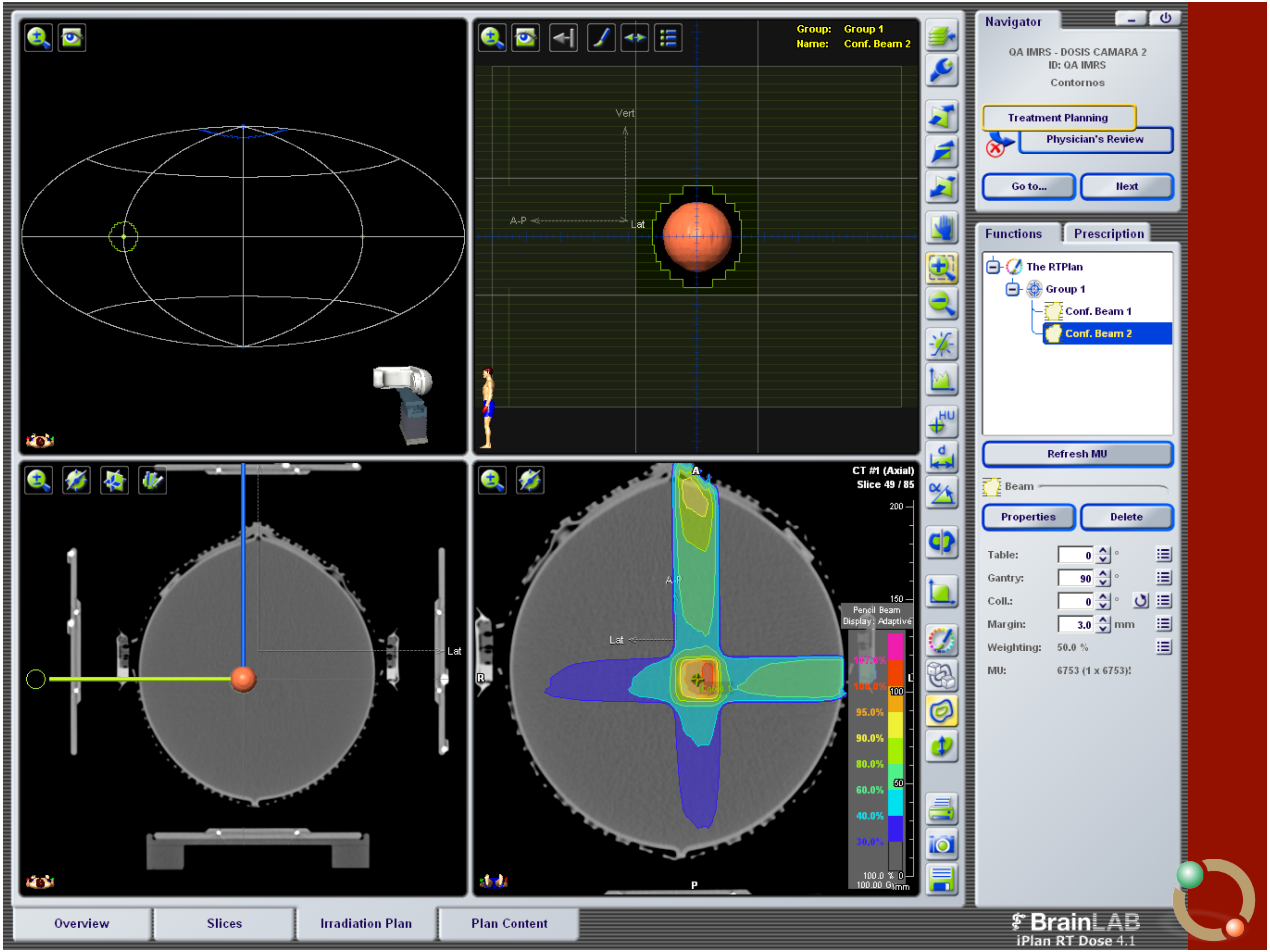


Gantry	210º	270º	0º	90º	150º
ΔGT (mm)	0.25	0.03	0.62	0.36	0.20
ΔAB (mm)	0.24	0.15	0.07	0.27	0.0
Vector (mm)	0.35	0.15	0.62	0.45	0.20

AAPM TG42: Tolerance = 1mm



Group: Group 1
Name: Conf. Beam 1
Vert
Lat
Lat
CT #1 (Axial)
Slice 49 / 85
Pencil Beam
Display: Adaptive
95.0%
90.0%
80.0%
60.0%
40.0%
30.0%
Navigator
QA IMRS - DOSIS CAMARA 2
ID: QA IMRS
Contornos
Treatment Planning
Physician's Review
Go to...
Next
Functions
Prescription
The RTPlan
Group 1
Conf. Beam 1
Refresh MU
Treatment Group
Position
Find
Properties
Delete
Coord 1:
A-P -21.7 mm
Lateral -11.6 mm
Vertical -5.4 mm
Weighting: 100.0 %
Beams / Arcs
Add
Overview
Slices
Irradiation Plan
Plan Content
BrainLAB
iPlan RT Dose 4.1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Name: Conf. Beam 2
Vert
A-P
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Contornos
Treatment Planning
Physician's Review
Go to...
Next
Functions
Prescription
The RTPlan
Group 1
Conf. Beam 1
Conf. Beam 2
Refresh MU
Beam
Properties
Delete
Table: 0 °
Gantry: 90 °
Coll.: 0 °
Margin: 3.0 mm
Weighting: 50.0 %
MU: 6753 (1 x 6753)!
CT #1 (Axial)
Slice 49 / 85
Pencil Beam
Display: Adaptive
107.0%
100.0%
95.0%
90.0%
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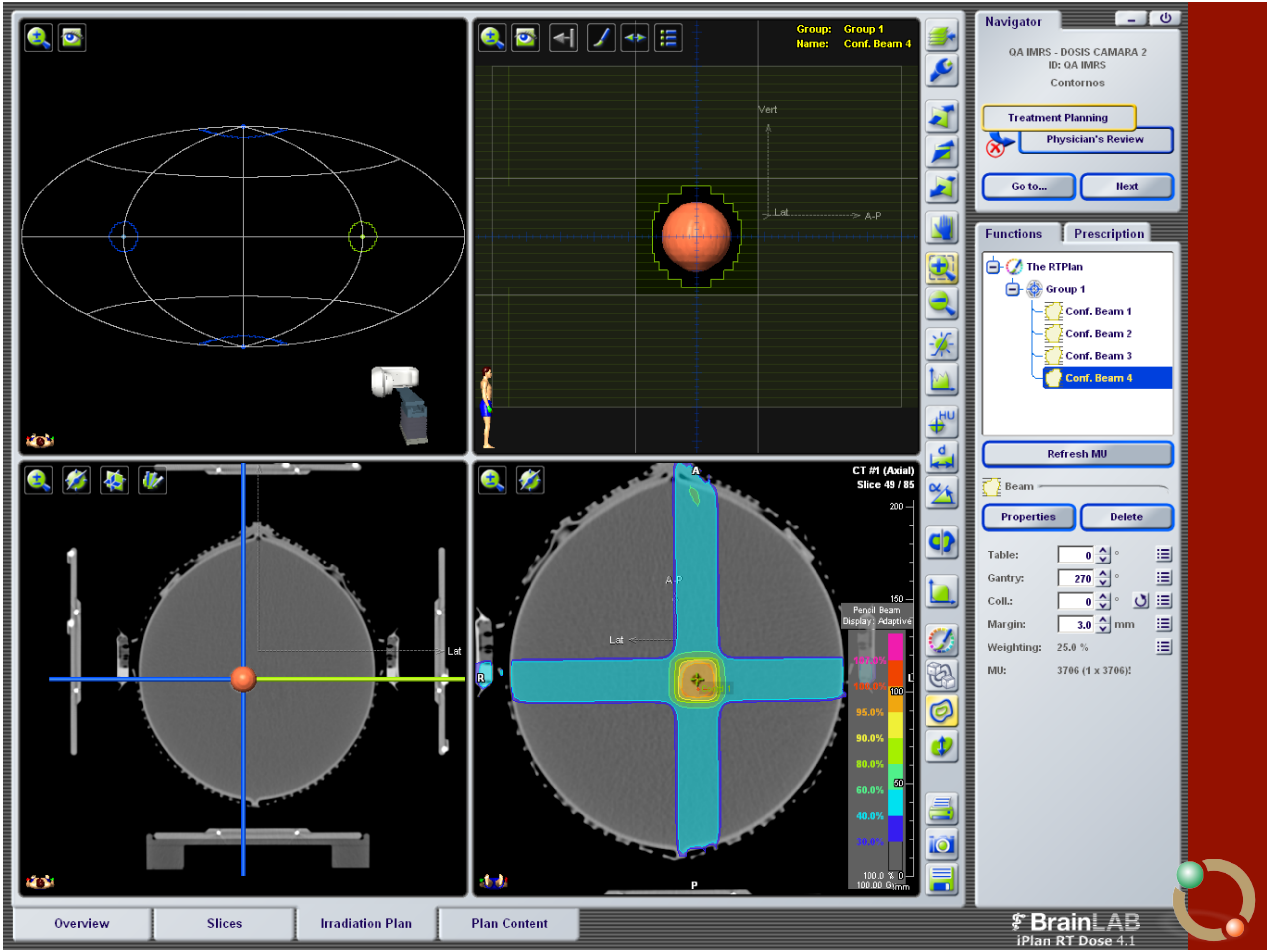
Overview
Slices
Irradiation Plan
Plan Content
BrainLAB
iPlan RT Dose 4.1



Group: Group 1
Name: Conf. Beam 4
Vert
Lat
A-P
Navigator
QA IMRS - DOSIS CAMARA 2
ID: QA IMRS
Contornos
Treatment Planning
Physician's Review
Go to...
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Functions
Prescription
The RTPlan
Group 1
Conf. Beam 1
Conf. Beam 2
Conf. Beam 3
Conf. Beam 4
Refresh MU
Beam
Properties
Delete
Table:
0
Gantry:
270
Coll.:
0
Margin:
3.0
mm
Weighting:
25.0 %
MU:
3706 (1 x 3706)!
CT #1 (Axial)
Slice 49 / 85
Pencil Beam
Display: Adaptive
95.0%
90.0%
80.0%
60.0%
40.0%
30.0%
Lat
A-P
Overview
Slices
Irradiation Plan
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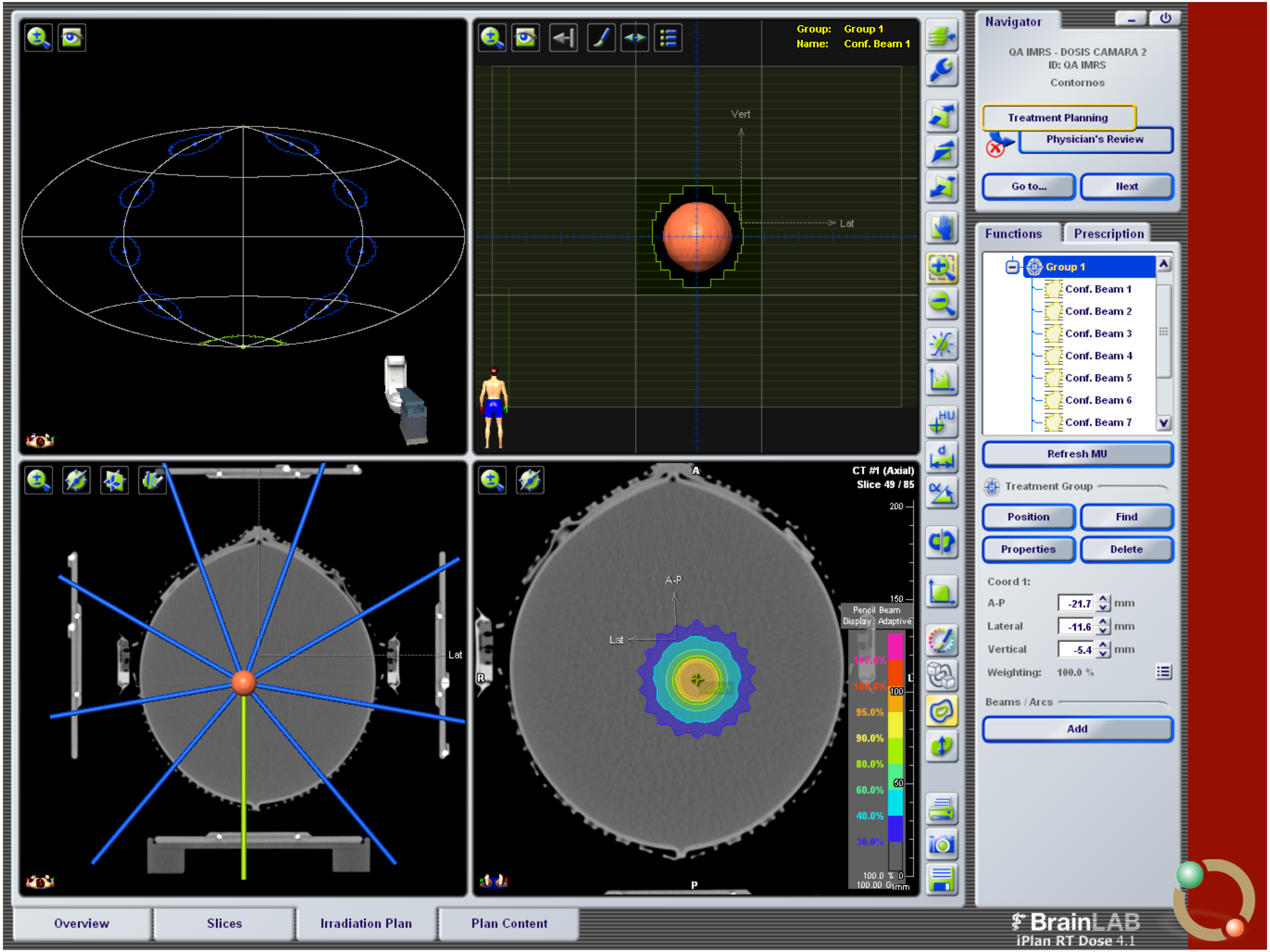
BrainLAB
iPlan RT Dose 4.1



Group: Group 1
Name: Conf. Beam 1
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CT #1 (Axial)
Slice 49 / 85
Pencil Beam
Display: Adaptive
95.0%
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80.0%
60.0%
40.0%
Navigator
QA IMRS - DOSIS CAMARA 2
ID: QA IMRS
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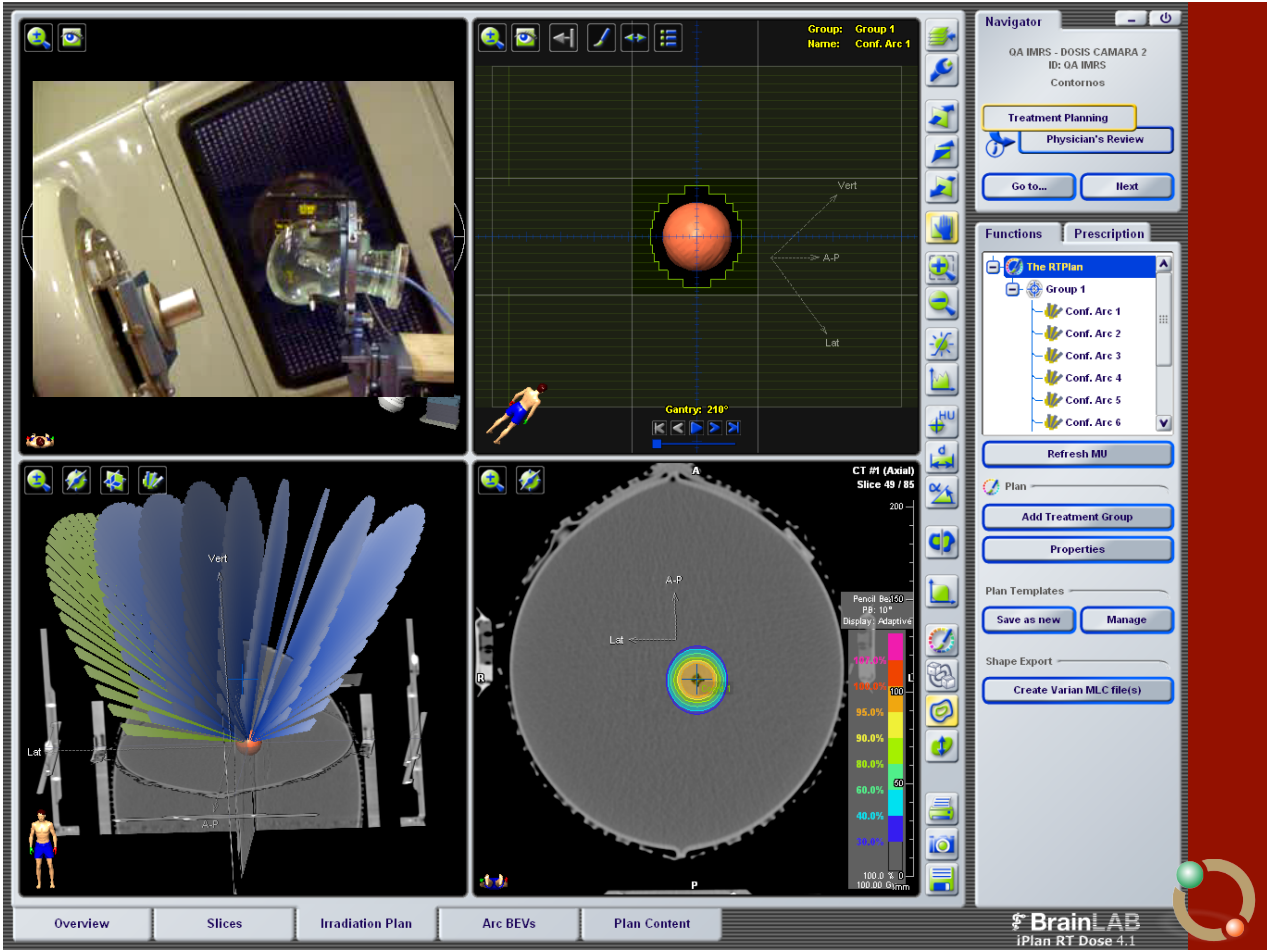
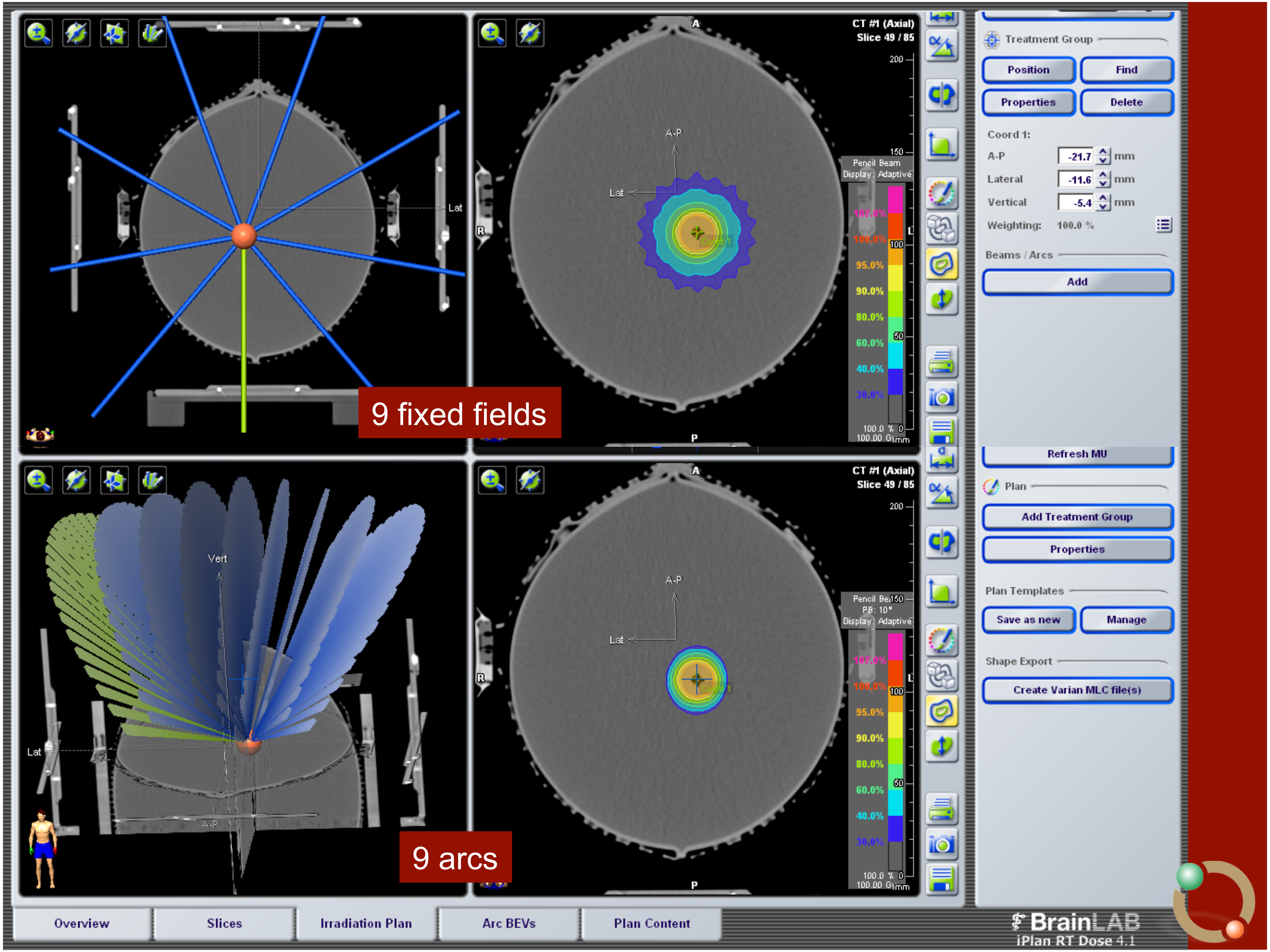
Treatment Planning
Physician's Review
Go to...
Next
Functions
Prescription
Group 1
Conf. Beam 1
Conf. Beam 2
Conf. Beam 3
Conf. Beam 4
Conf. Beam 5
Conf. Beam 6
Conf. Beam 7
Refresh MU
Treatment Group
Position
Find
Properties
Delete
Coord 1:
A-P -21.7 mm
Lateral -11.6 mm
Vertical -5.4 mm
Weighting: 100.0 %
Beams / Arcs
Add
Overview
Slices
Irradiation Plan
Plan Content
BrainLAB
iPlan RT Dose 4.1



Group: Group 1
Name: Conf. Arc 1
Vert
A-P
Lat
Gantry: 210°
Navigator
QA IMRS - DOSIS CAMARA 2
ID: QA IMRS
Contornos
Treatment Planning
Physician's Review
Go to...
Next
Functions
Prescription
The RTPlan
Group 1
Conf. Arc 1
Conf. Arc 2
Conf. Arc 3
Conf. Arc 4
Conf. Arc 5
Conf. Arc 6
Refresh MU
Plan
Add Treatment Group
Properties
Plan Templates
Save as new
Manage
Shape Export
Create Varian MLC file(s)
CT #1 (Axial)
Slice 49 / 85
95.0%
90.0%
80.0%
60.0%
40.0%
Overview
Slices
Irradiation Plan
Arc BEVs
Plan Content
BrainLAB
iPlan RT Dose 4.1


9 fixed fields
9 arcs
CT #1 (Axial)
Slice 49 / 85
Pencil Beam
Display: Adaptive
PB: 10°
107.0%
100.0%
95.0%
90.0%
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40.0%
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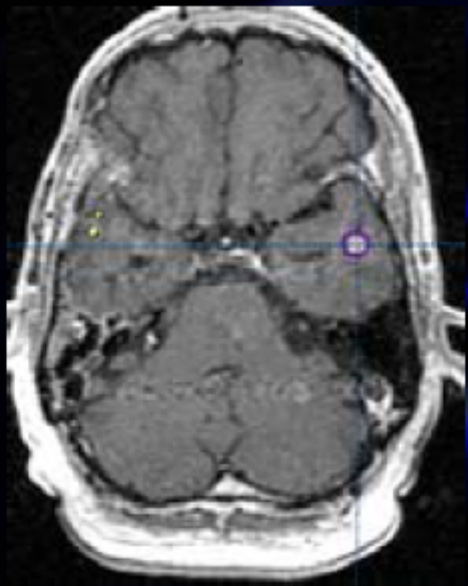
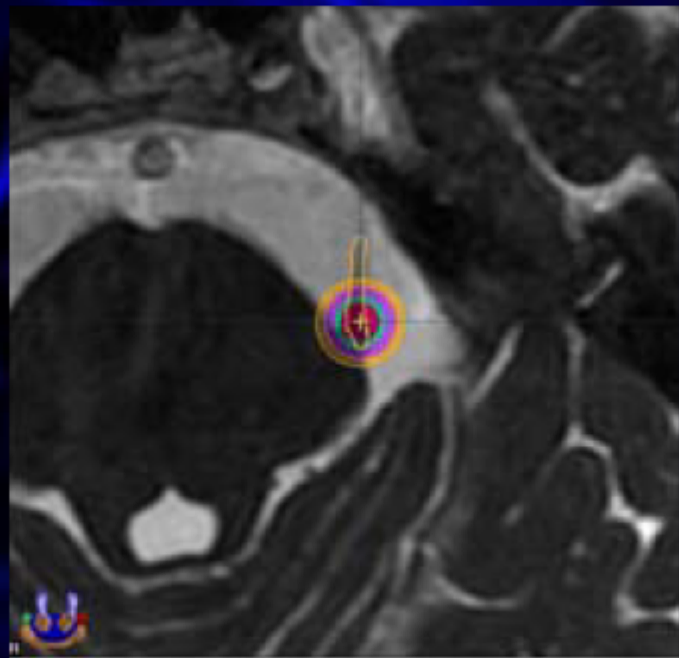
Treatment Group
Position
Find
Properties
Delete
Coord 1:
A-P -21.7 mm
Lateral -11.6 mm
Vertical -5.4 mm
Weighting: 100.0 %
Beams / Arcs
Add
Refresh MU
Plan
Add Treatment Group
Properties
Plan Templates
Save as new
Manage
Shape Export
Create Varian MLC file(s)
Overview
Slices
Irradiation Plan
Arc BEVs
Plan Content
BrainLAB
iPlan RT Dose 4.1

Circular Arc

When to use it?



Small, spherical Metastases

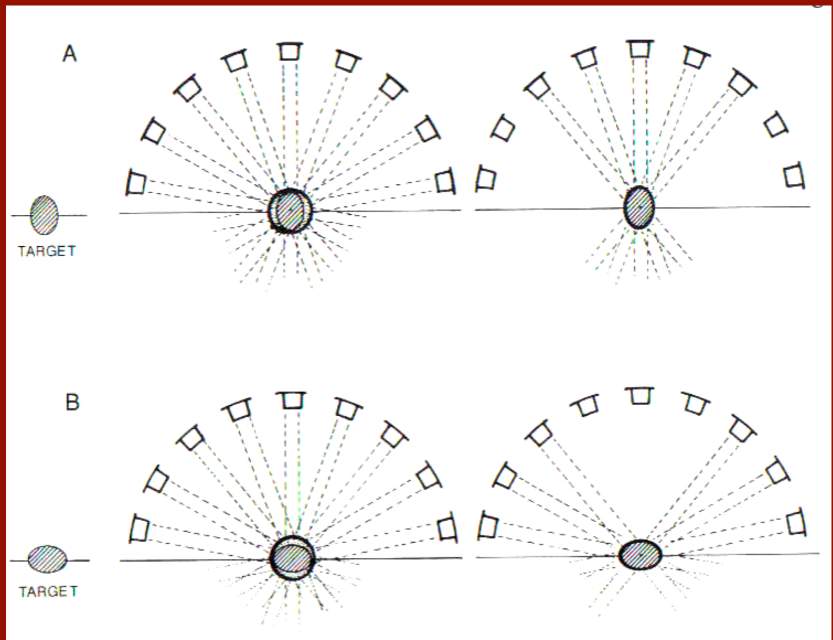


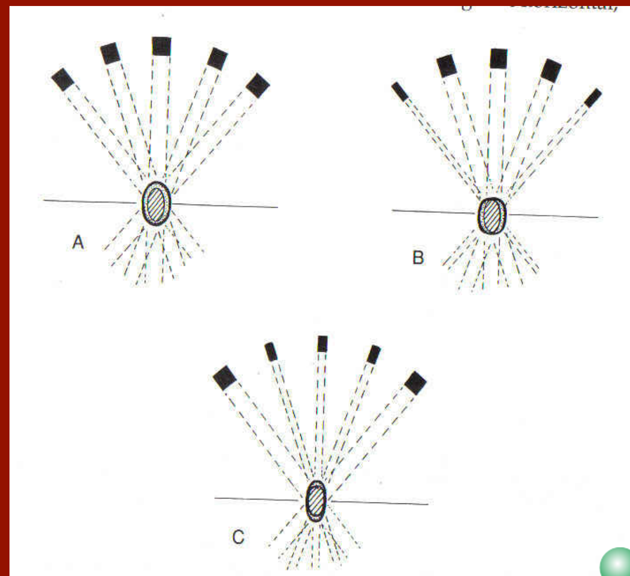
Trigeminal Neuralgia

Planning strategies for SRS with arcs

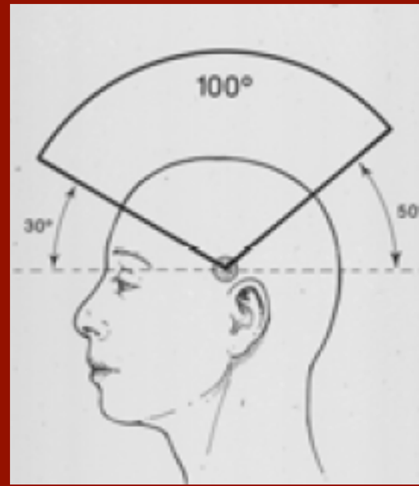
- **Spherical targets:**
  - **Use up to 9 arcs with collimator diameter corresponding to the target diameter**

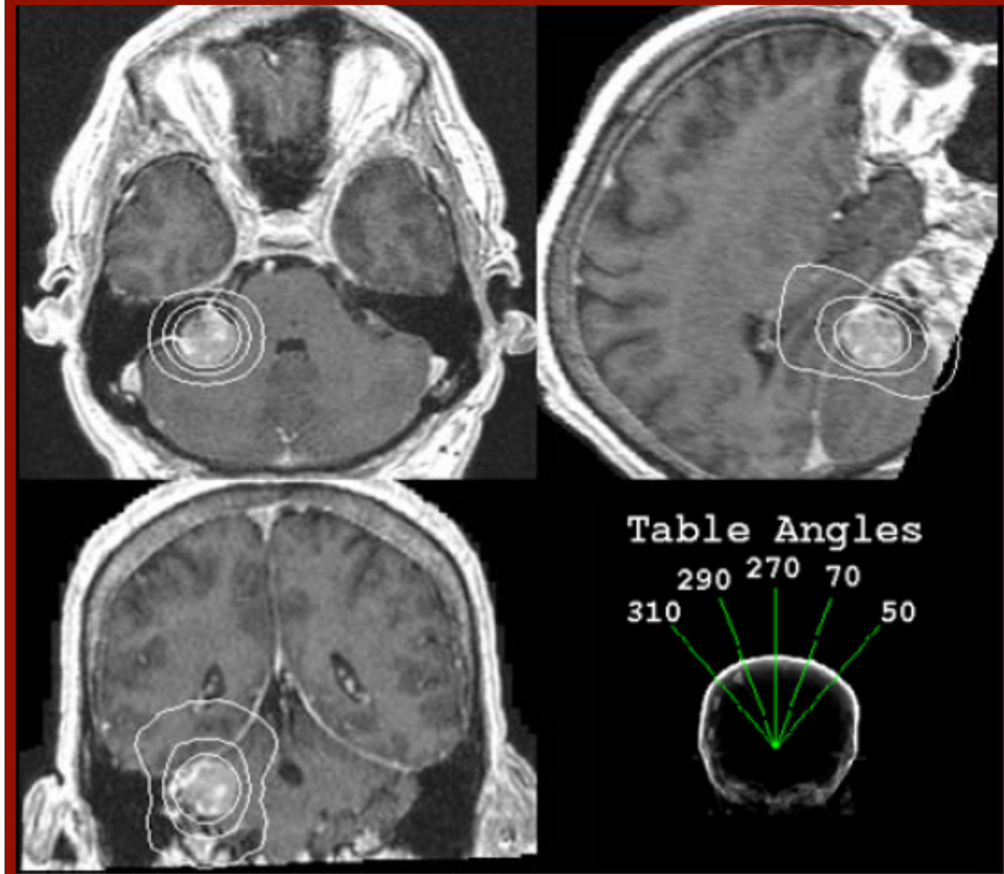
- **Elliptical targets:**
  - **If the major axis is in the coronal plane, eliminate perpendicular arcs, or use different cone sizes**

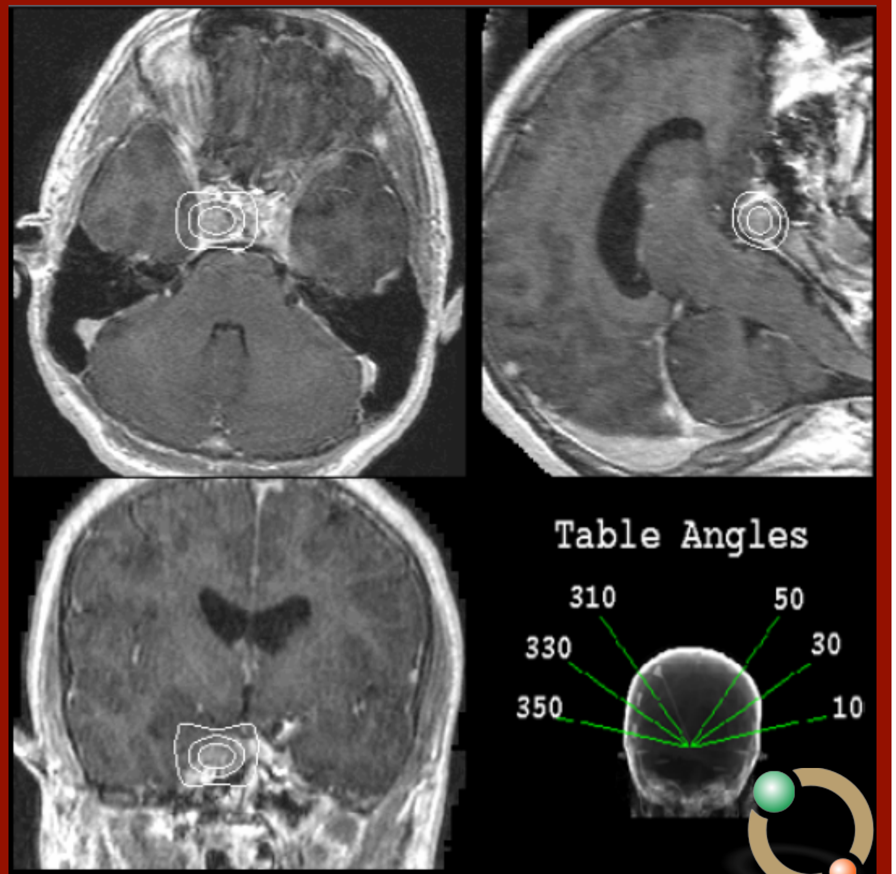




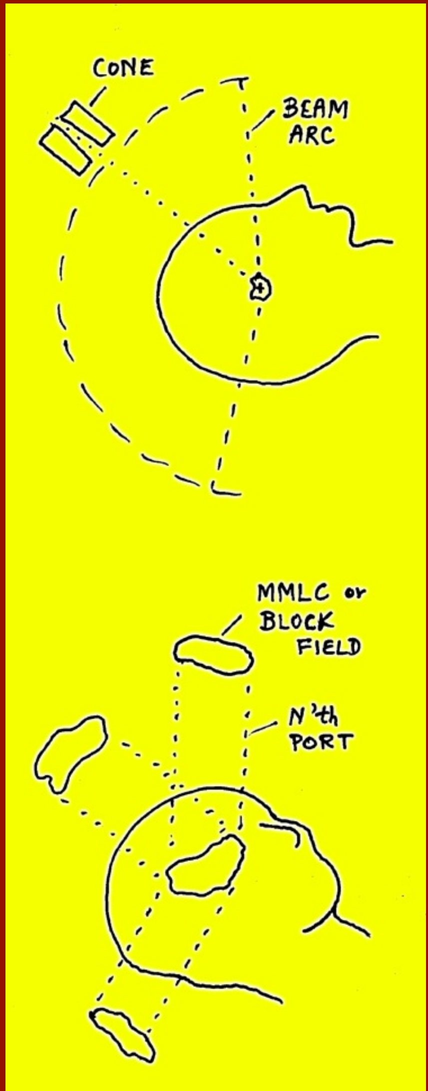
Circular collimators





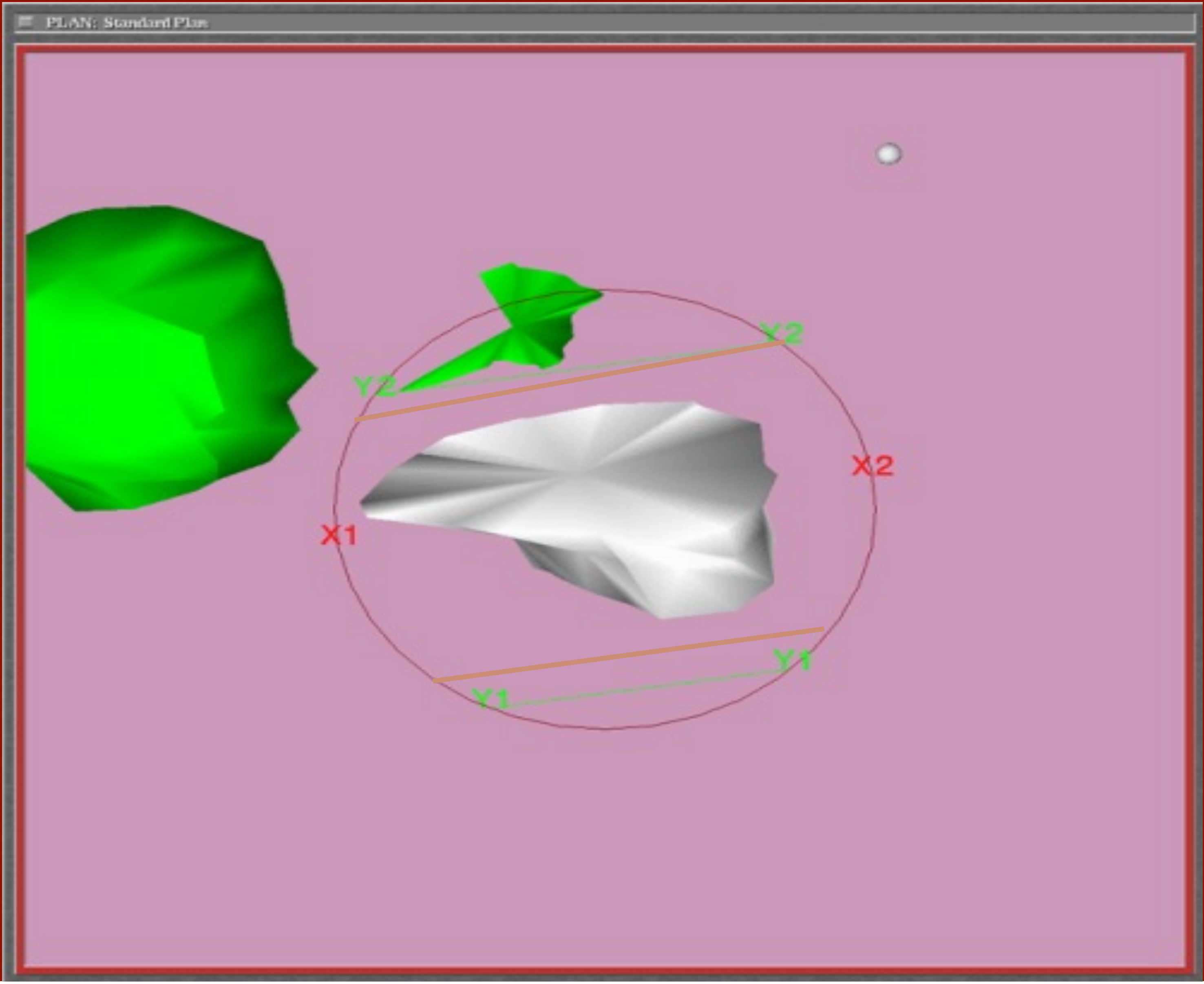


Considerations according to the type of target

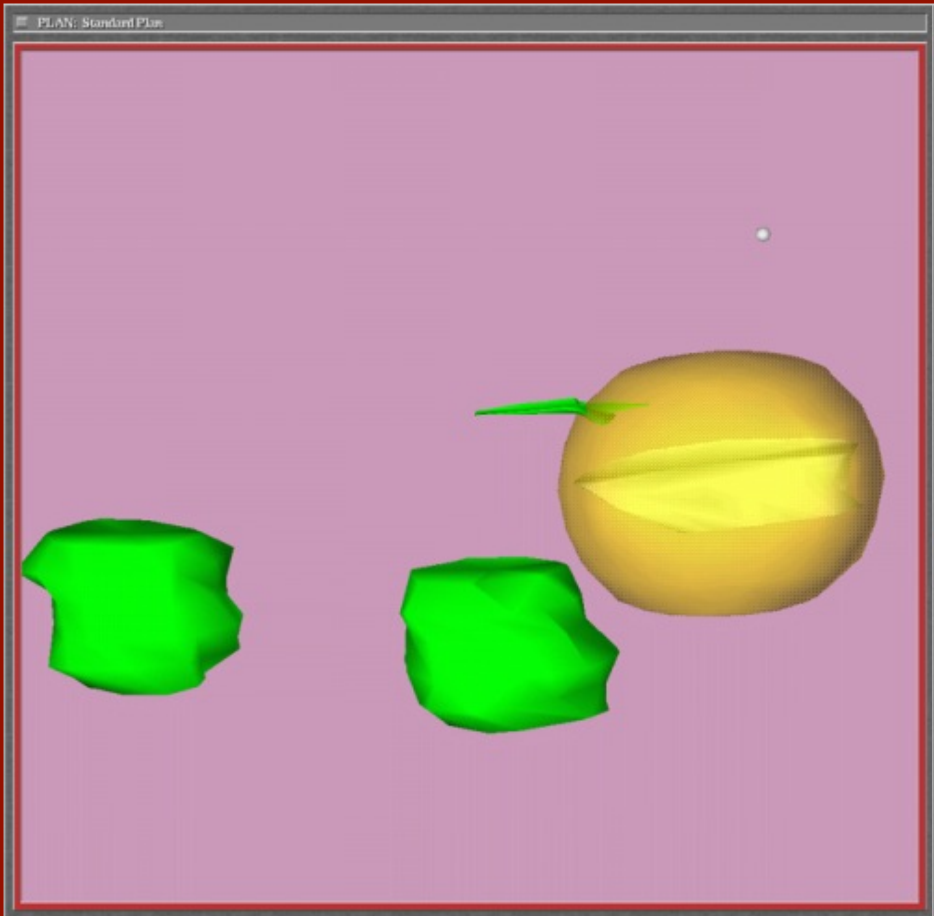


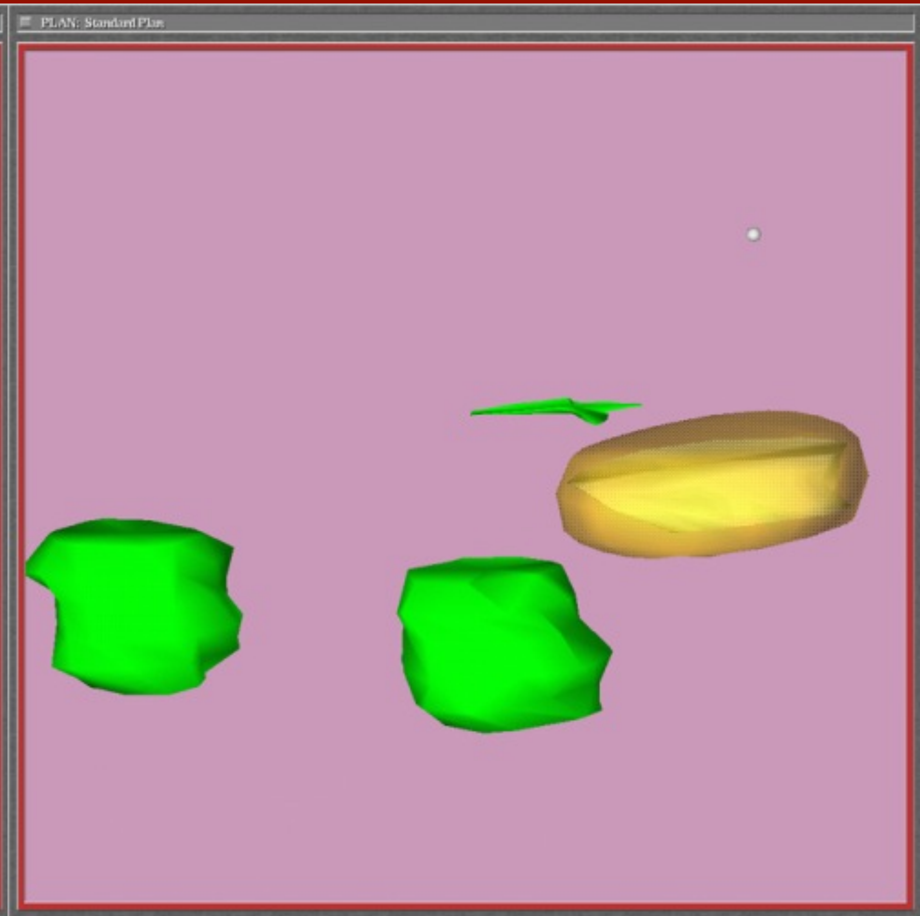
- < 3-4 cm
  - ***Circular Cones + Arcs Best***
  - ***Sharp Penumbra avoids OAR***
  - ***Precise Geometry***
  - ***Low Integral Dose to Brain***
- 3-6 cm
  - (a) XJaws = Jaws and Cones and Arcs
  - Simple
  - Low Integral Dose to Brain
  - Optimal Conformal Index
  - (b) MMLC Okay
  - Exact Conformation not an issue.

Conformal Arc BEV

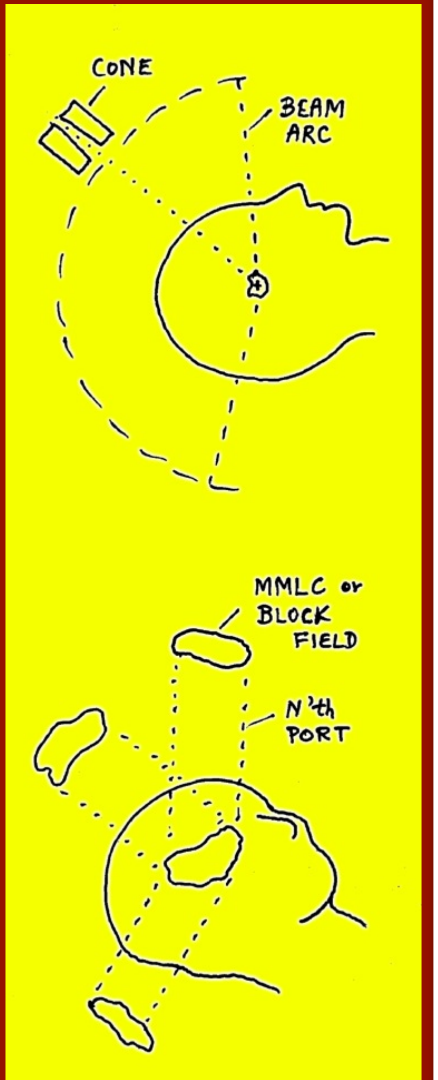


Standard Arc   Conformal Arc

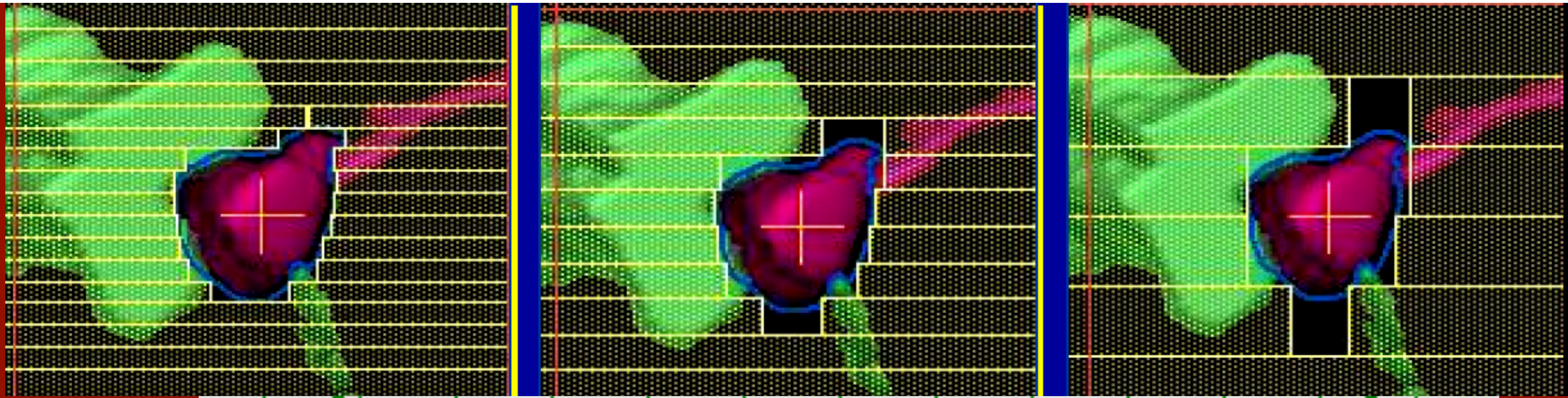


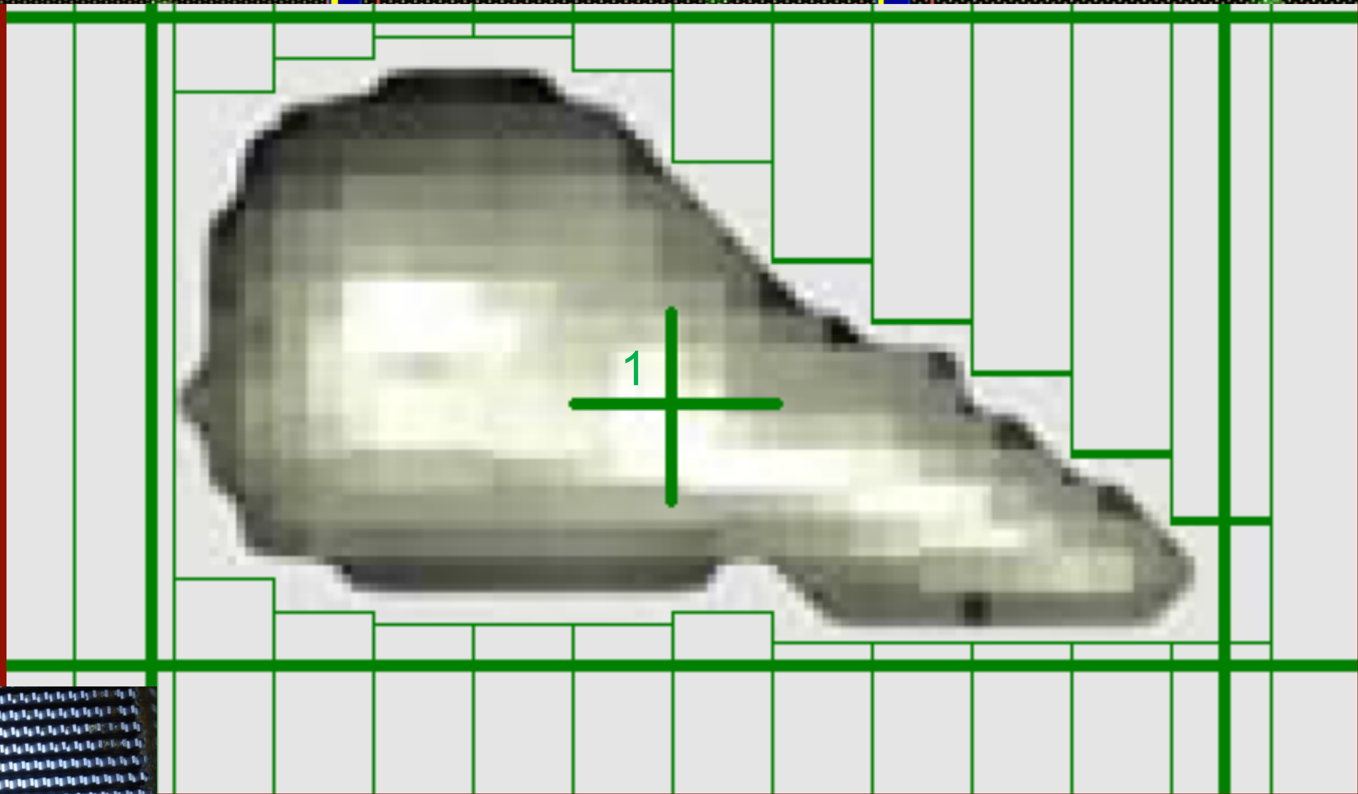


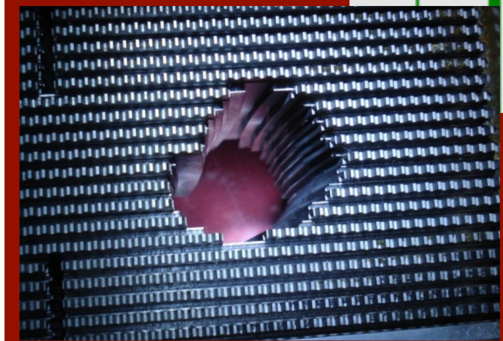
Considerations according to the type of target



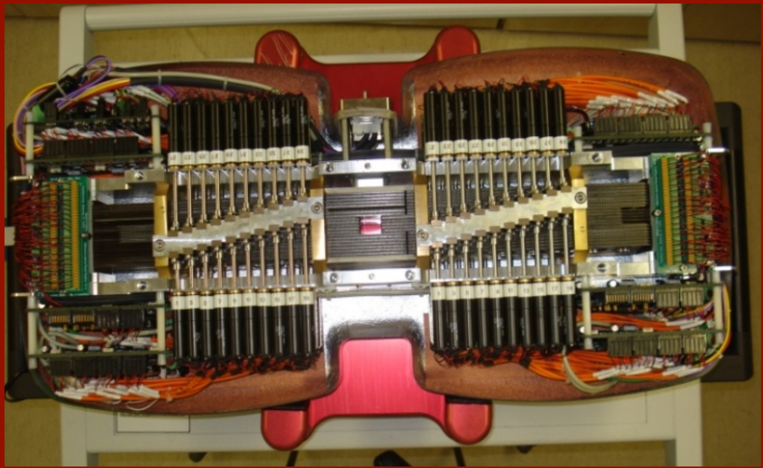
- < 3-4 cm
  - *Circular Cones + Arcs Best*
  - *Sharp Penumbra avoids OAR*
  - *Precise Geometry*
  - *Low Integral Dose to Brain*
- 3-6 cm
  - (a) XJaws = Jaws and Cones and Arcs
  - Simple
  - Low Integral Dose to Brain
  - Optimal Conformal Index
  - (b) MMLC Okay
  - Conformation not the issue.
- > 6 cm
  - Penumbra Increases, not very effective to use Cones and Arcs
  - Better N ≥ 6 Non-Coplanar Static Fields
  - Need XPlan, OAR, Beam Model
  - MMLC necessary.
  - 2 π Access Reduces IMRT Need.







Larger leaf width => increase in normal tissue irradiated

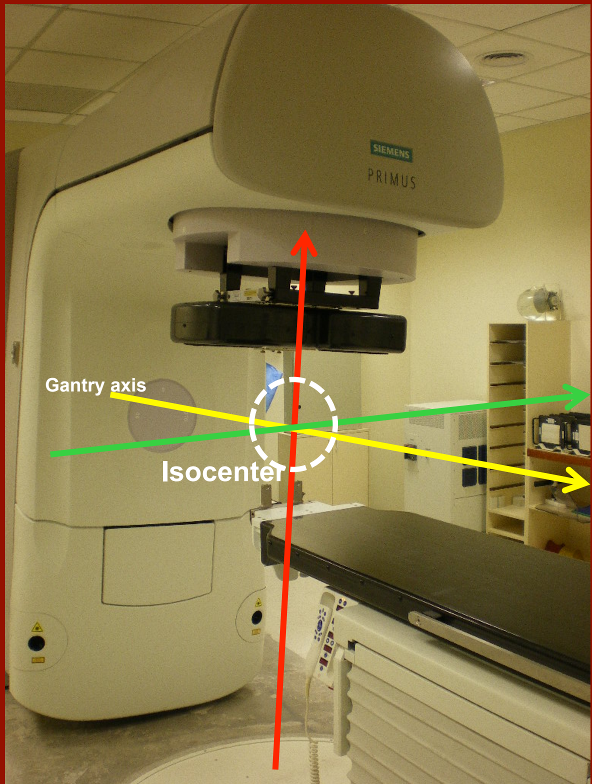


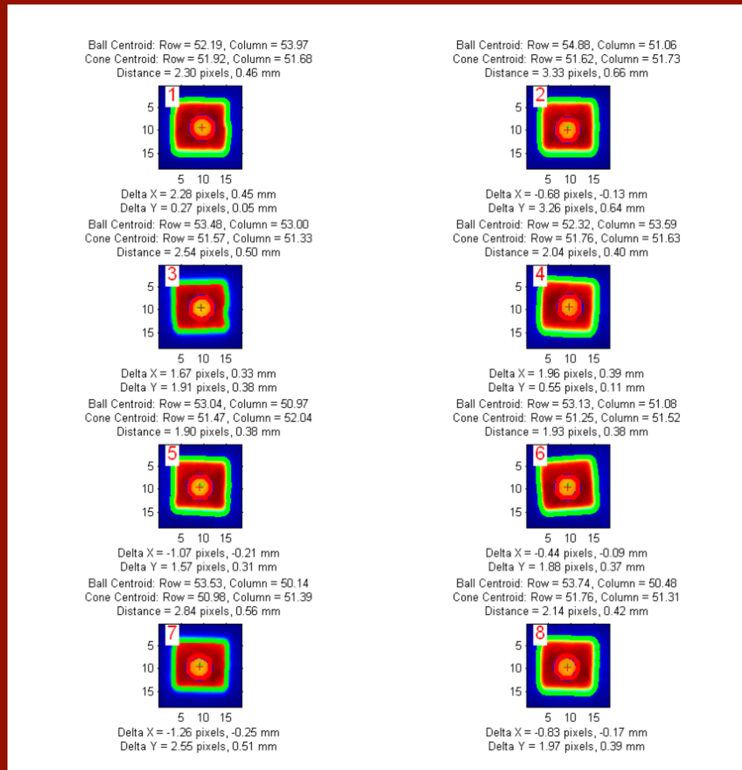
Micro MLC (mMLC)

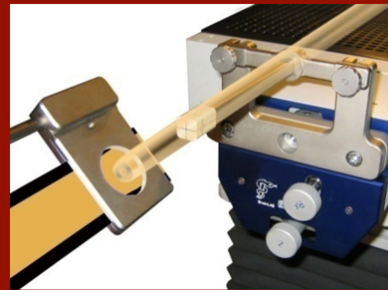
- Add-on system attached to the regular collimator
- MODULEAF, Siemens
  - 80 leaf
  - 40Kg (require special mount to move around)
  - Leaf width at isocenter - 2.5 mm
  - Positioning precision - 0.5 mm
  - Penumbra 2.5 – 3.5mm
  - Transmission < 2.5%
  - Maximum field size 12 x 10 cm^2

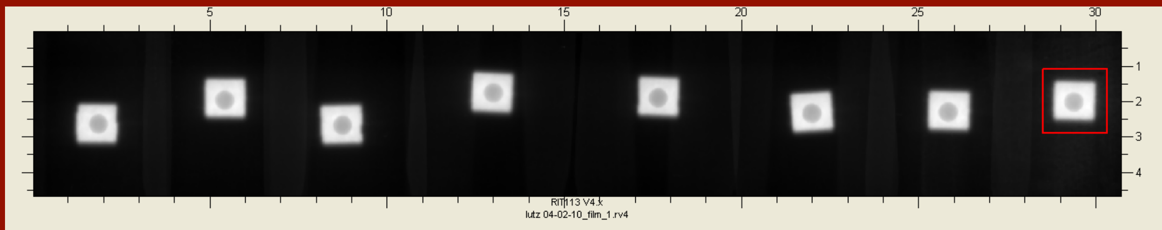
Isocenter precision

Winston - Lutz test



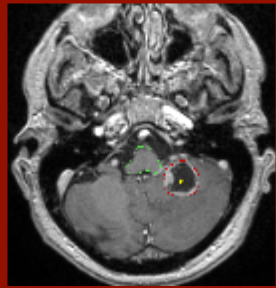






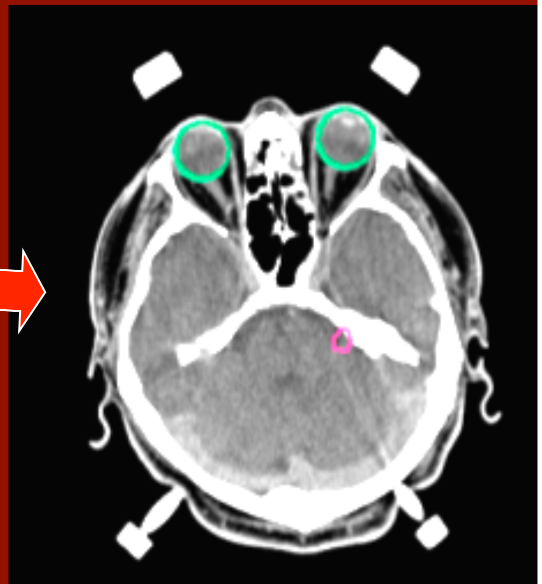
Procedure

MRI images

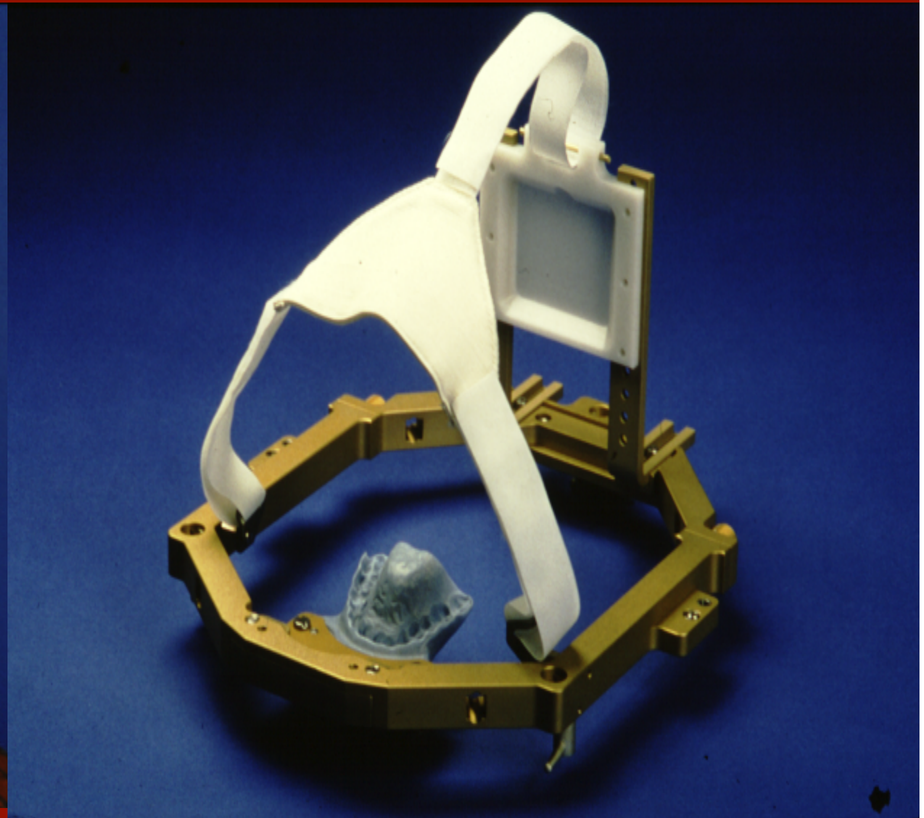


Patient preparation

Placement of Head Ring for SRS



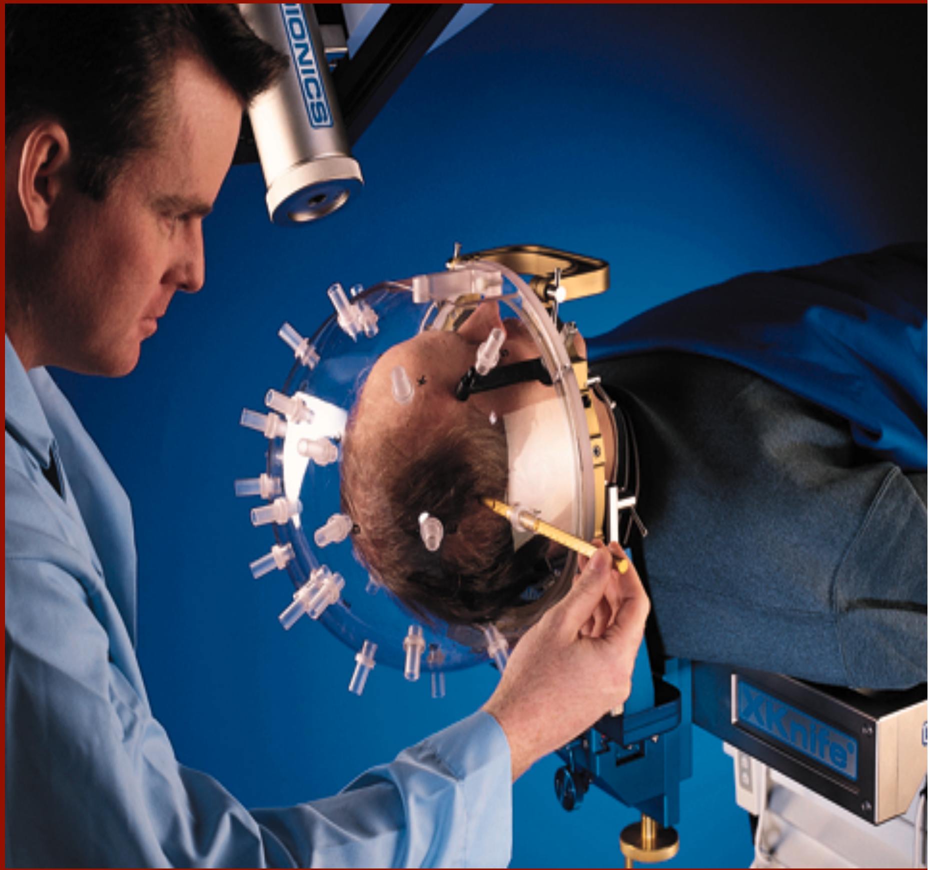
Relocatable Head Frame (Gill-Thomas-Cosman) for fractionated SRT



SRS with GTC relocatable head frame

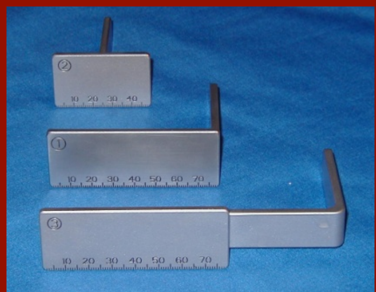
Daily reproducibility of the head frame position

<u>DEPTH CONFIRMATION HELMET</u>: **Mounts on stereotactic base ring; allows for 25 'helmet to scalp' measurements which are repeated following frame attachment, removal, replacement, and for SRT prior to each treatment (accuracy +/-1.5 mm)**



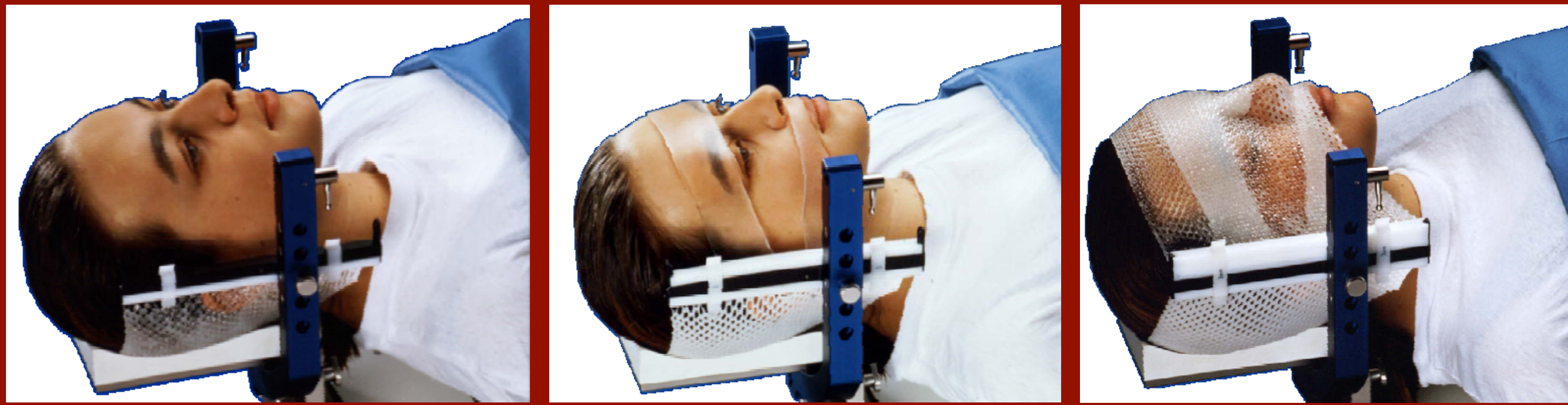
Patient Immobilization (SRT)

3 piece Mask System
Extends treatment area to T1
Set-up errors from 1.7 to 0.9 mm
Indexed bite plates
Carbon fiber
Tilt compensation for set-up
Suitable for elderly patients & children



Patient positioning accuracy in a thermoplastic mask with upper jaw support.
J. Ahlswede et al. AAPM Annual Meeting 2001 Poster Display

Frameless Immobilization

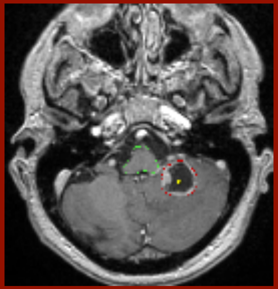


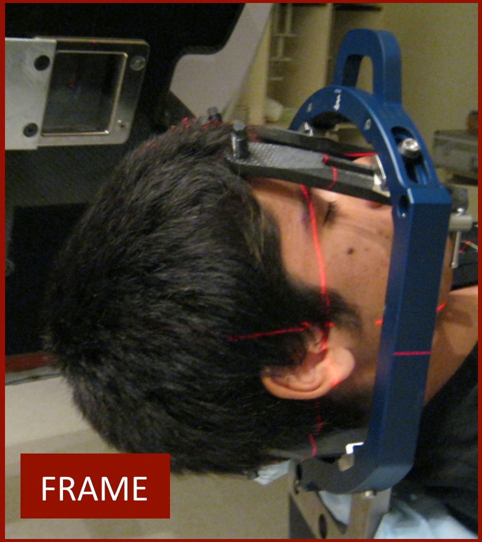
CT angiography

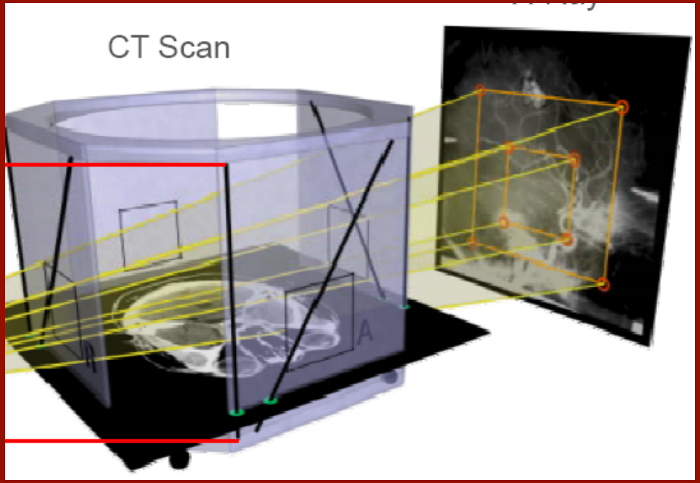
MRI

Patient setup

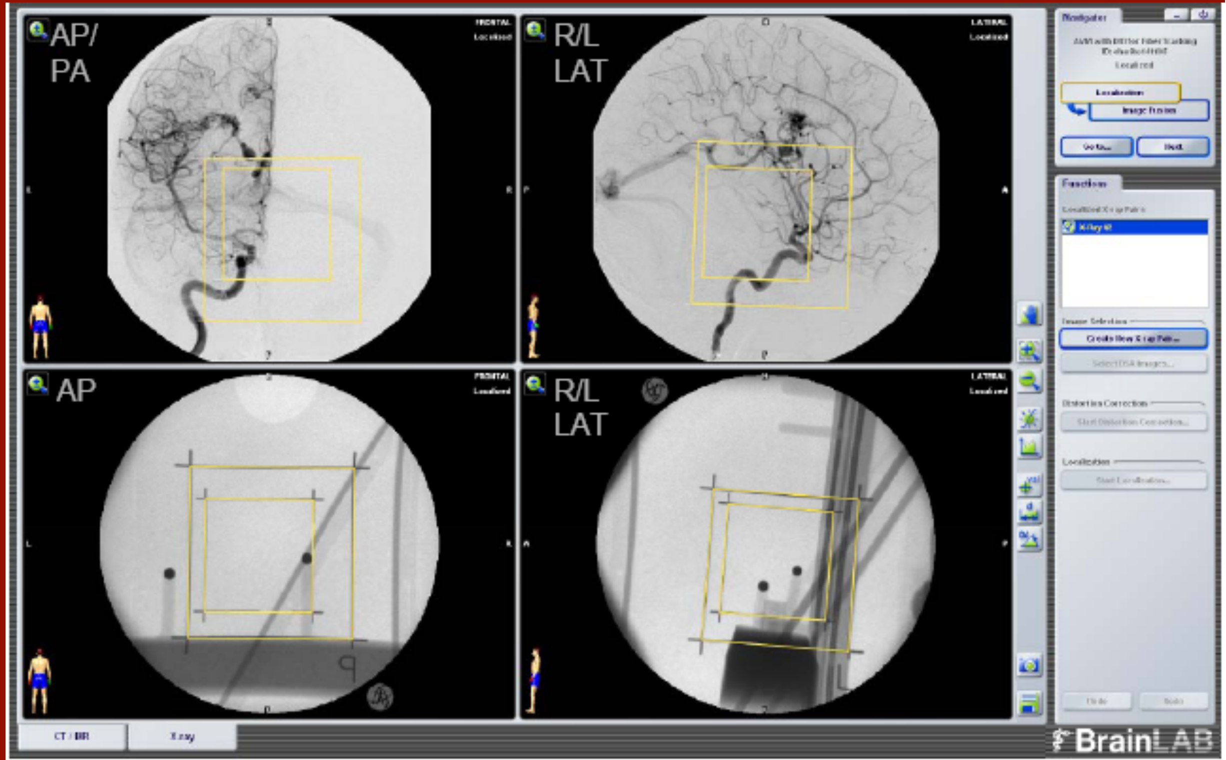
CT angiography



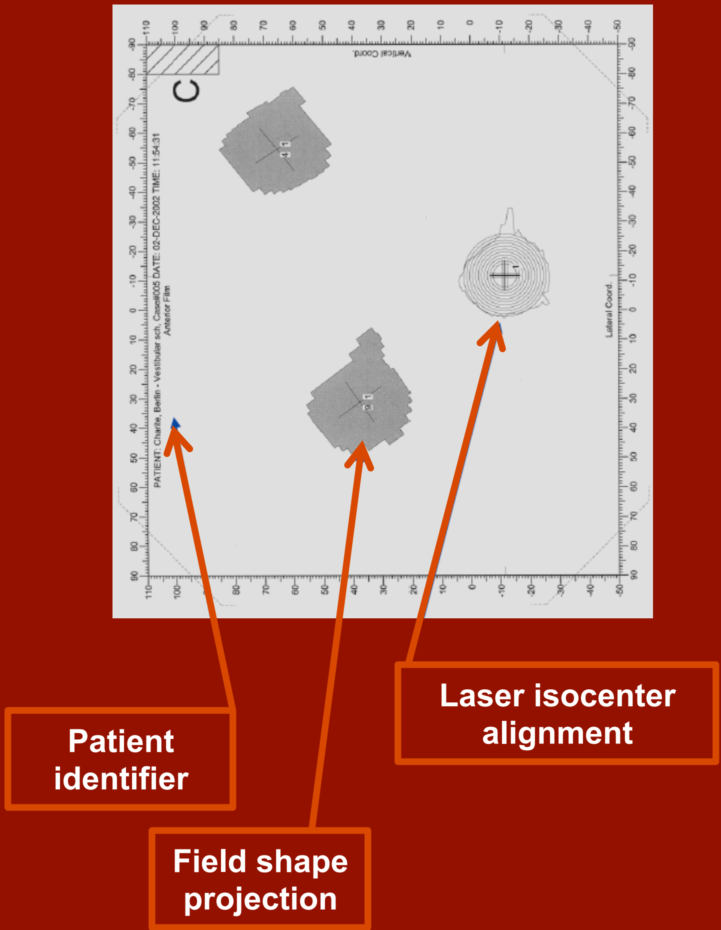




Angiography Localizer frames for Stereotactic Imaging

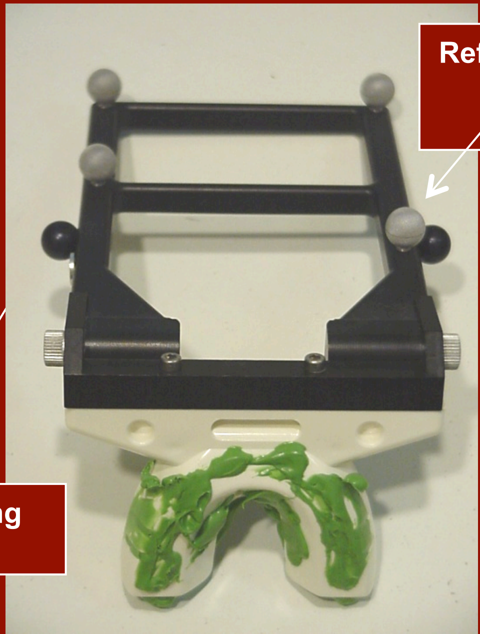


Transfer of Coordinates
TPS plan -> Treatment unit



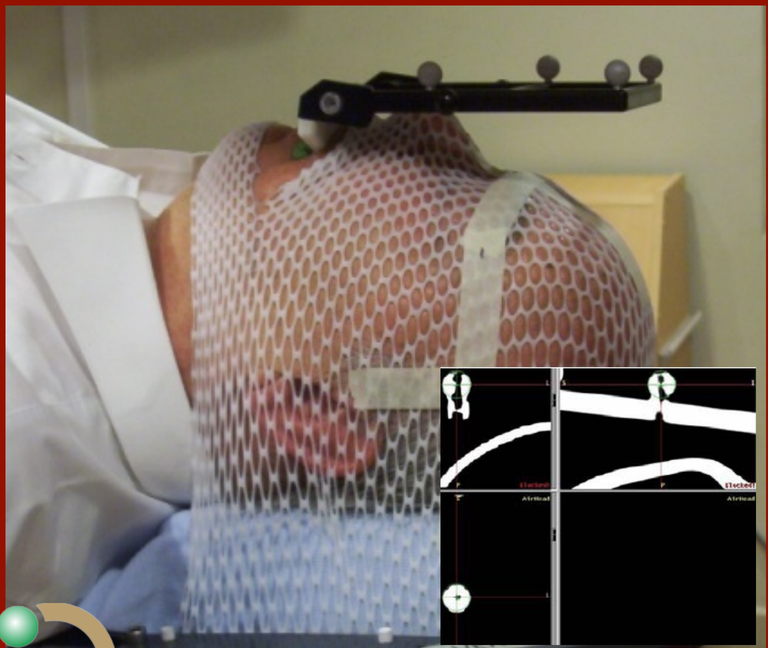
Optical tracking of Stereotactic position space

The CT images of the spheres are used to transfer the coordinate space to the treatment room



Reflecting spheres for optical tracking

CT localizing spheres



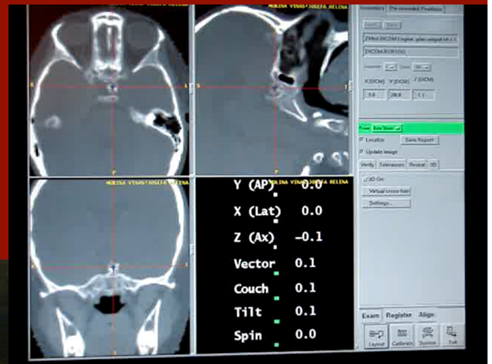
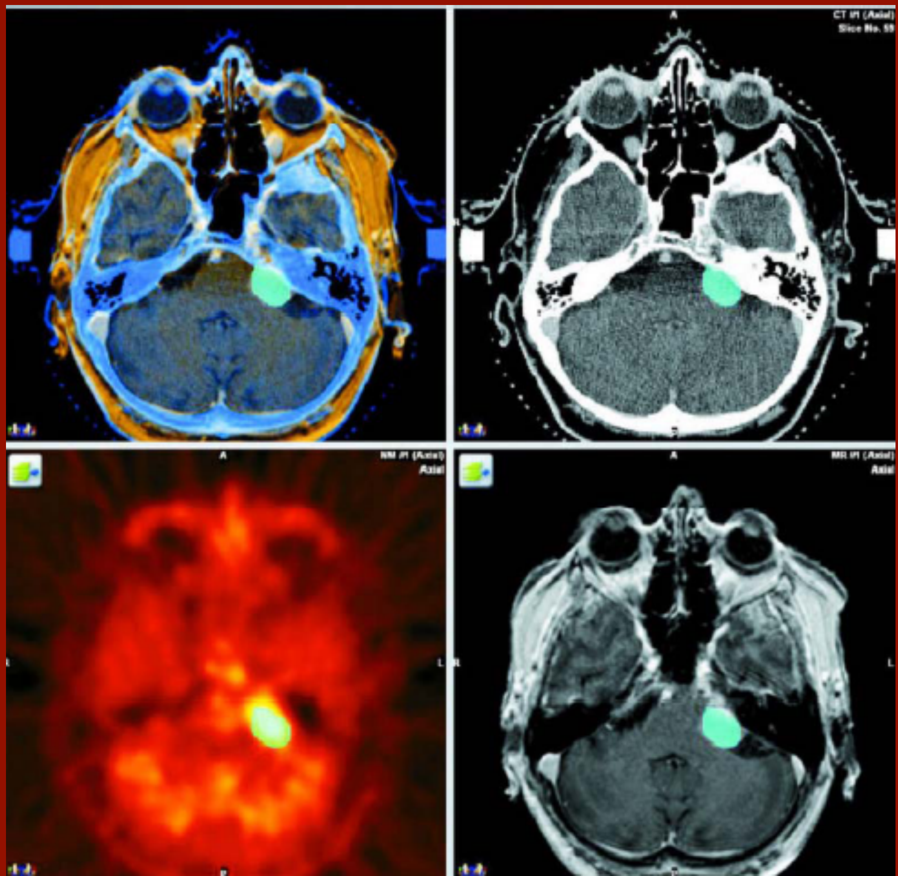
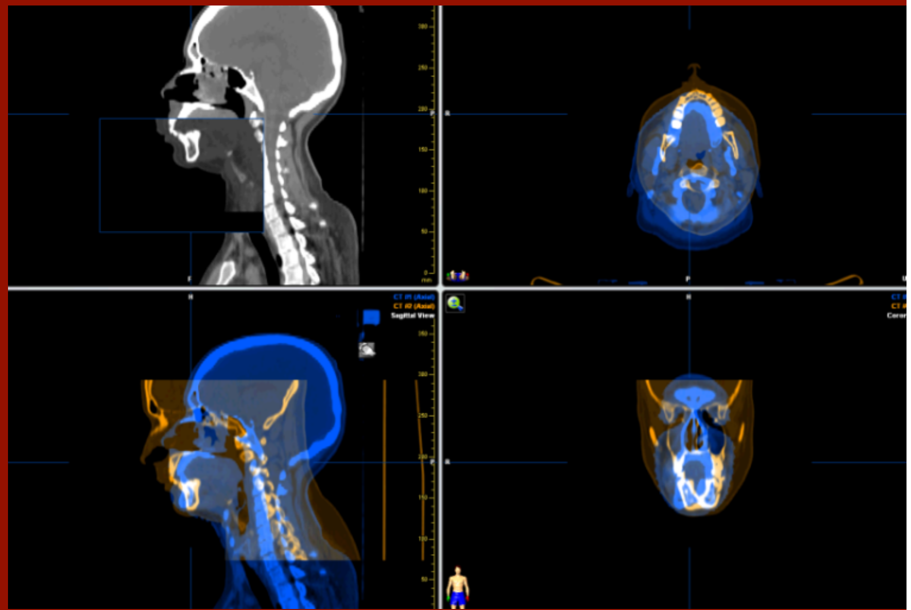
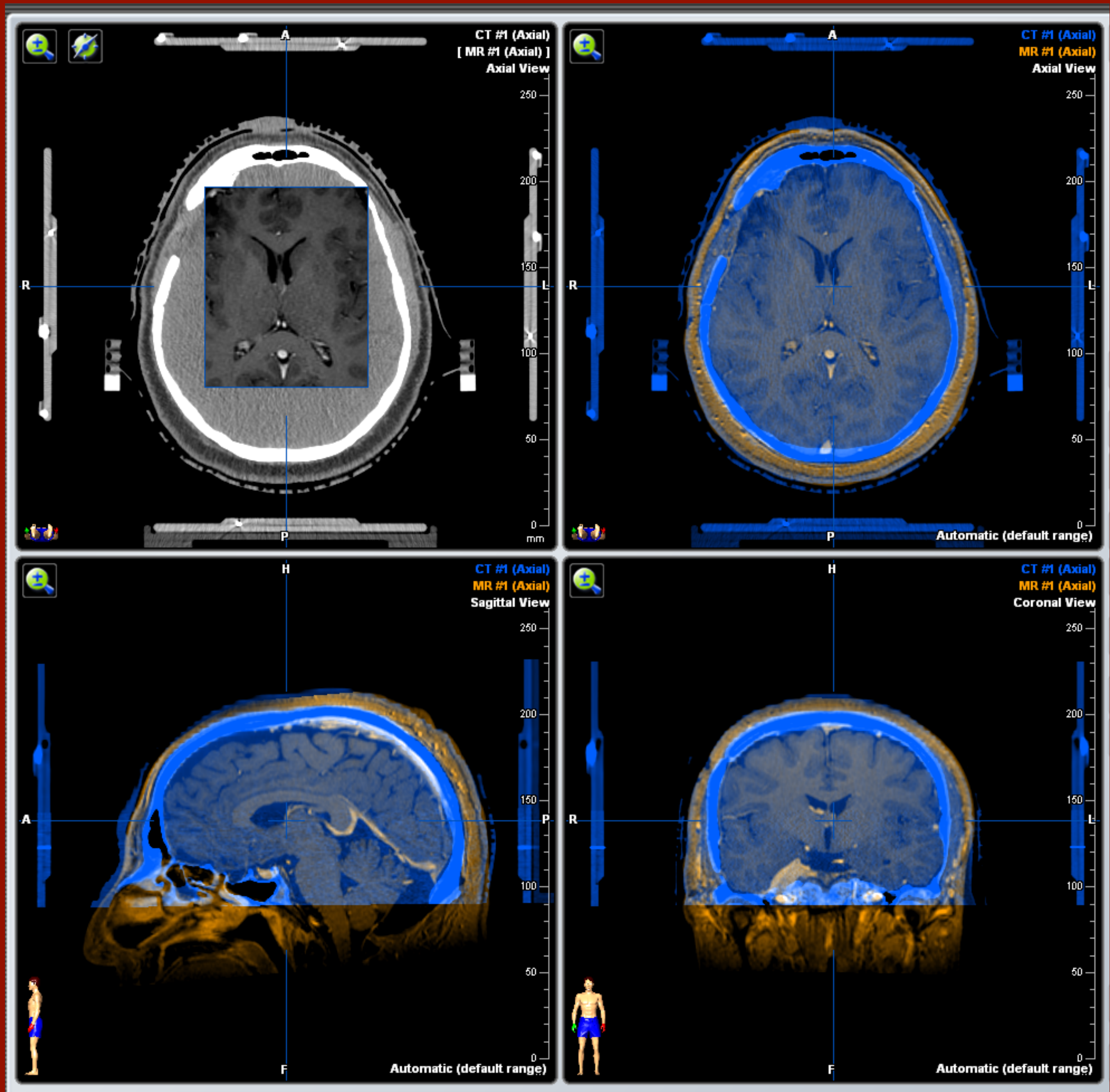


Image fusion or Registration





CT – MR – SPECT - PET


CT #1 (Axial)
[MR #1 (Axial)]
Axial View
CT #1 (Axial)
MR #1 (Axial)
Axial View
Automatic (default range)
CT #1 (Axial)
MR #1 (Axial)
Sagittal View
Automatic (default range)
CT #1 (Axial)
MR #1 (Axial)
Coronal View
Automatic (default range)

Patient setup

Stereo Images

Image fusion

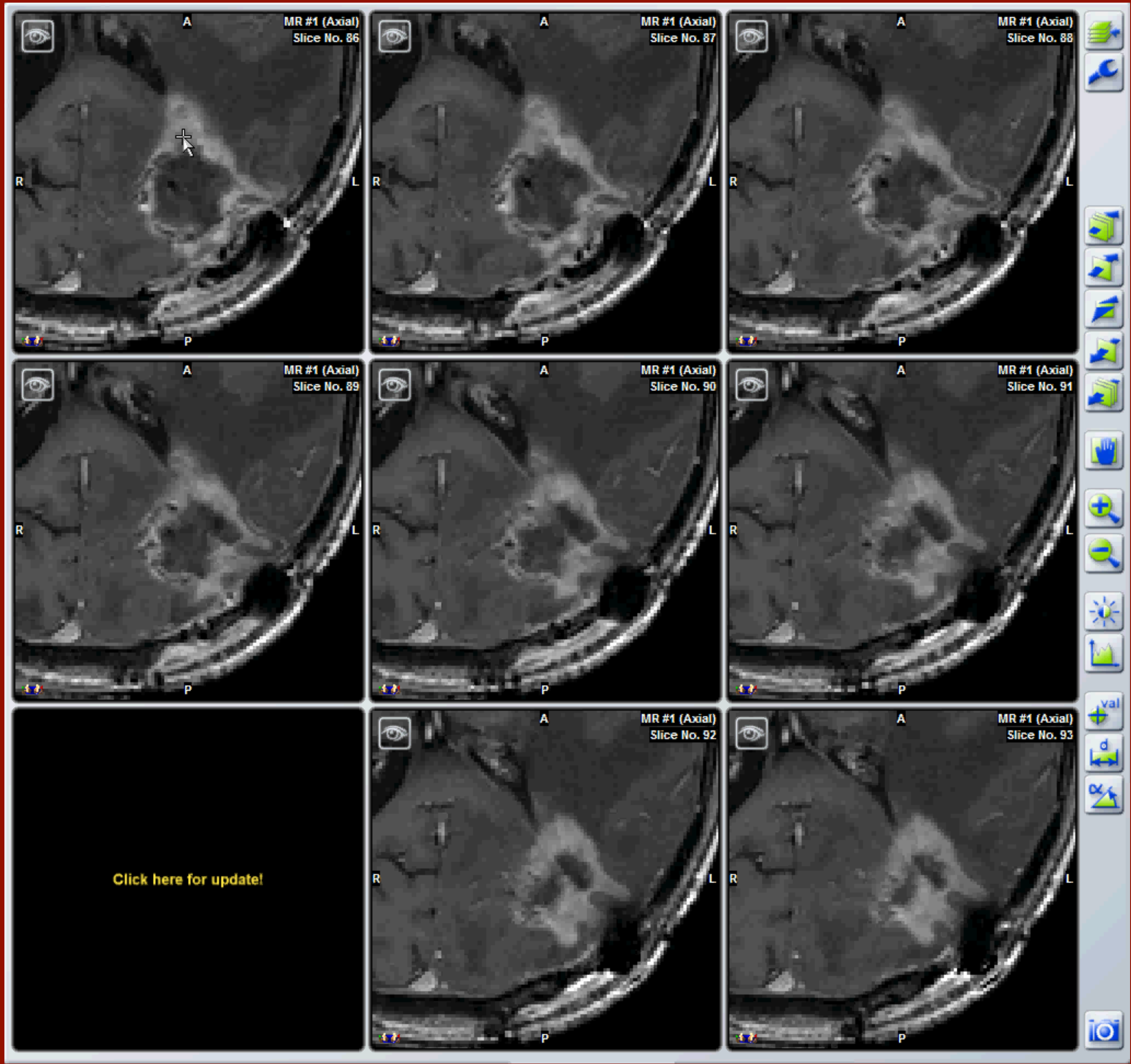
Volume definitions

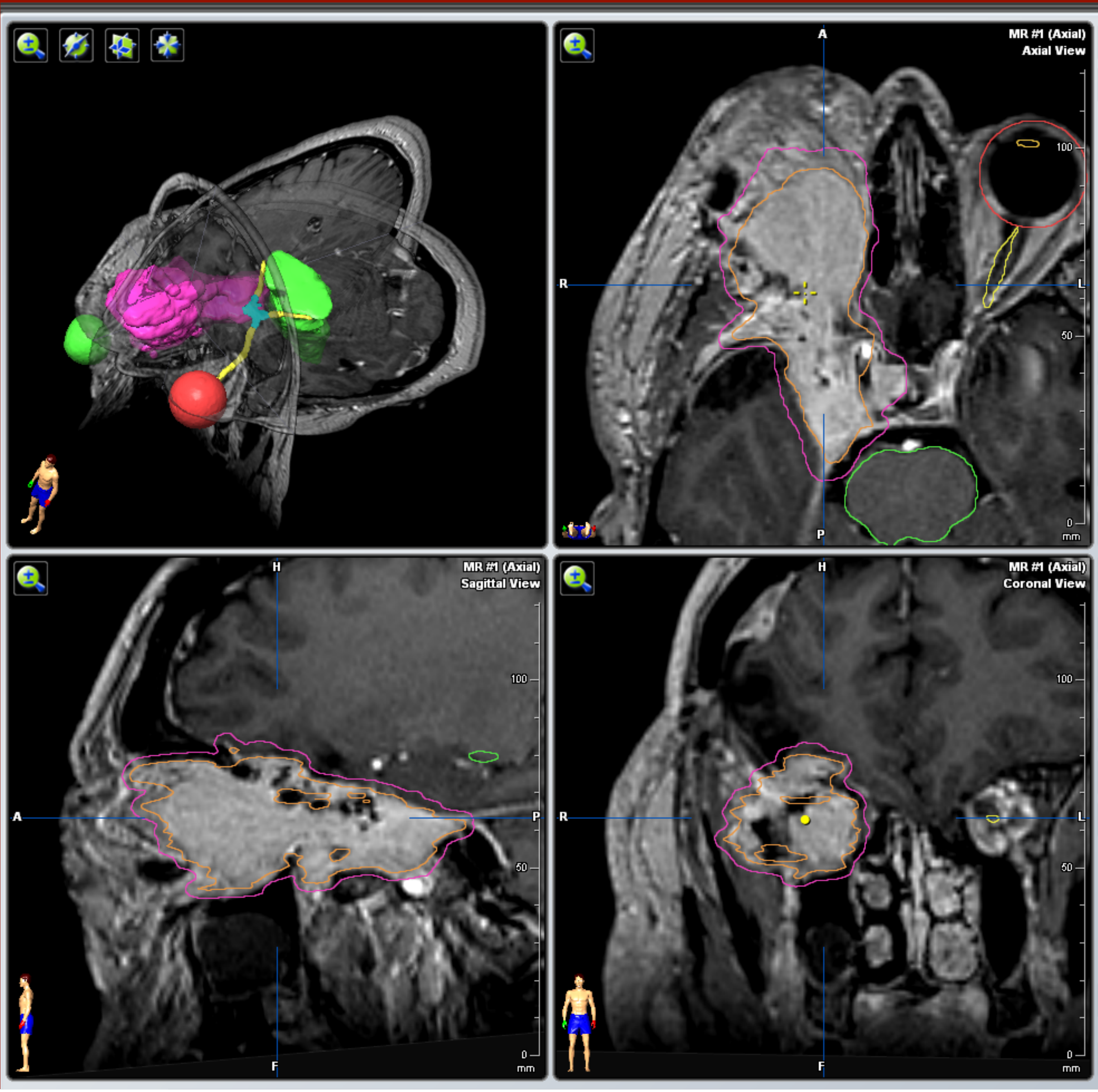
Patient setup

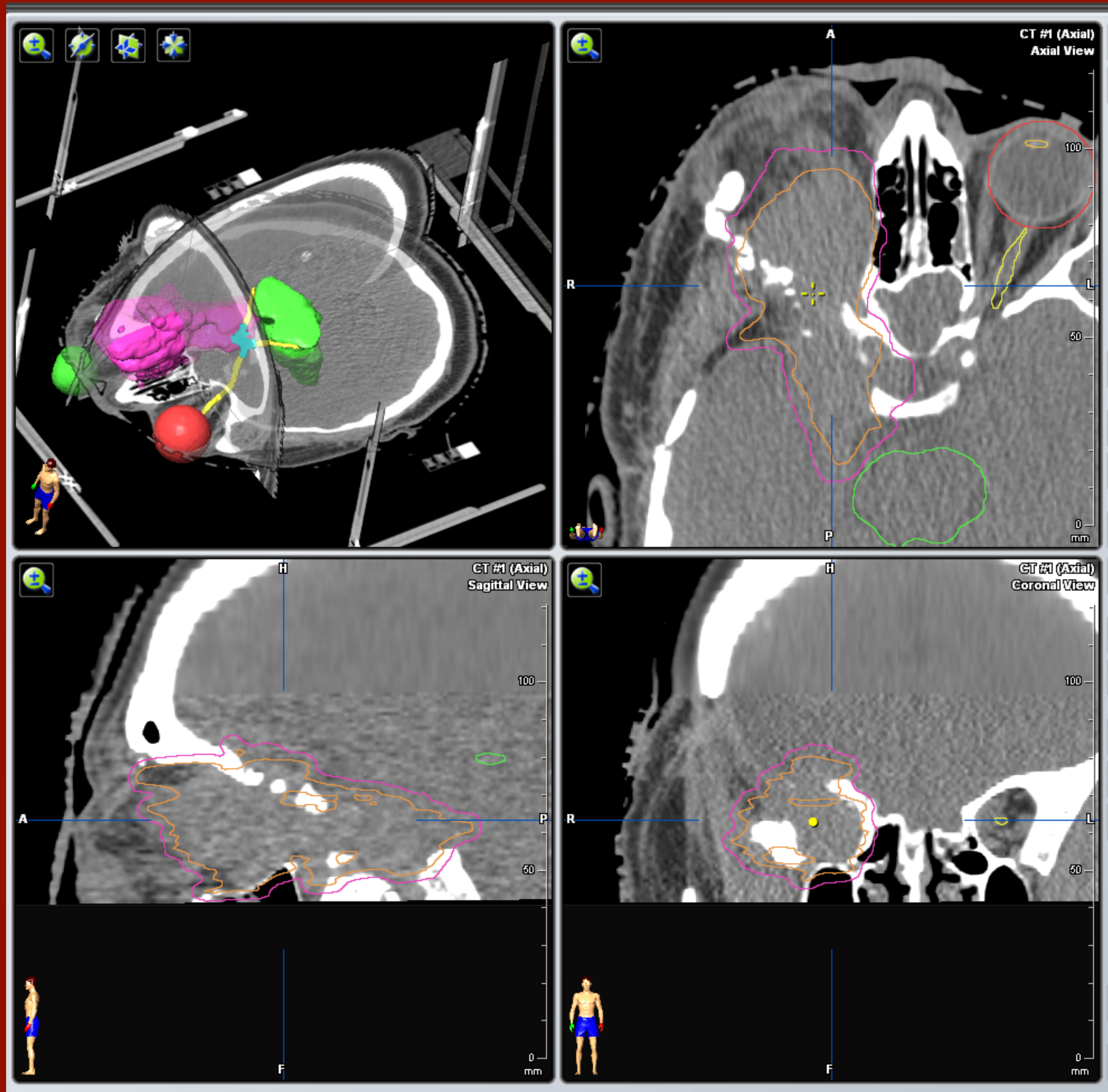
Stereo Images

Image fusion

Volume definitions




MR #1 (Axial)
Axial View
MR #1 (Axial)
Sagittal View
MR #1 (Axial)
Coronal View
A
P
R
L
H
F
100
50
0
mm



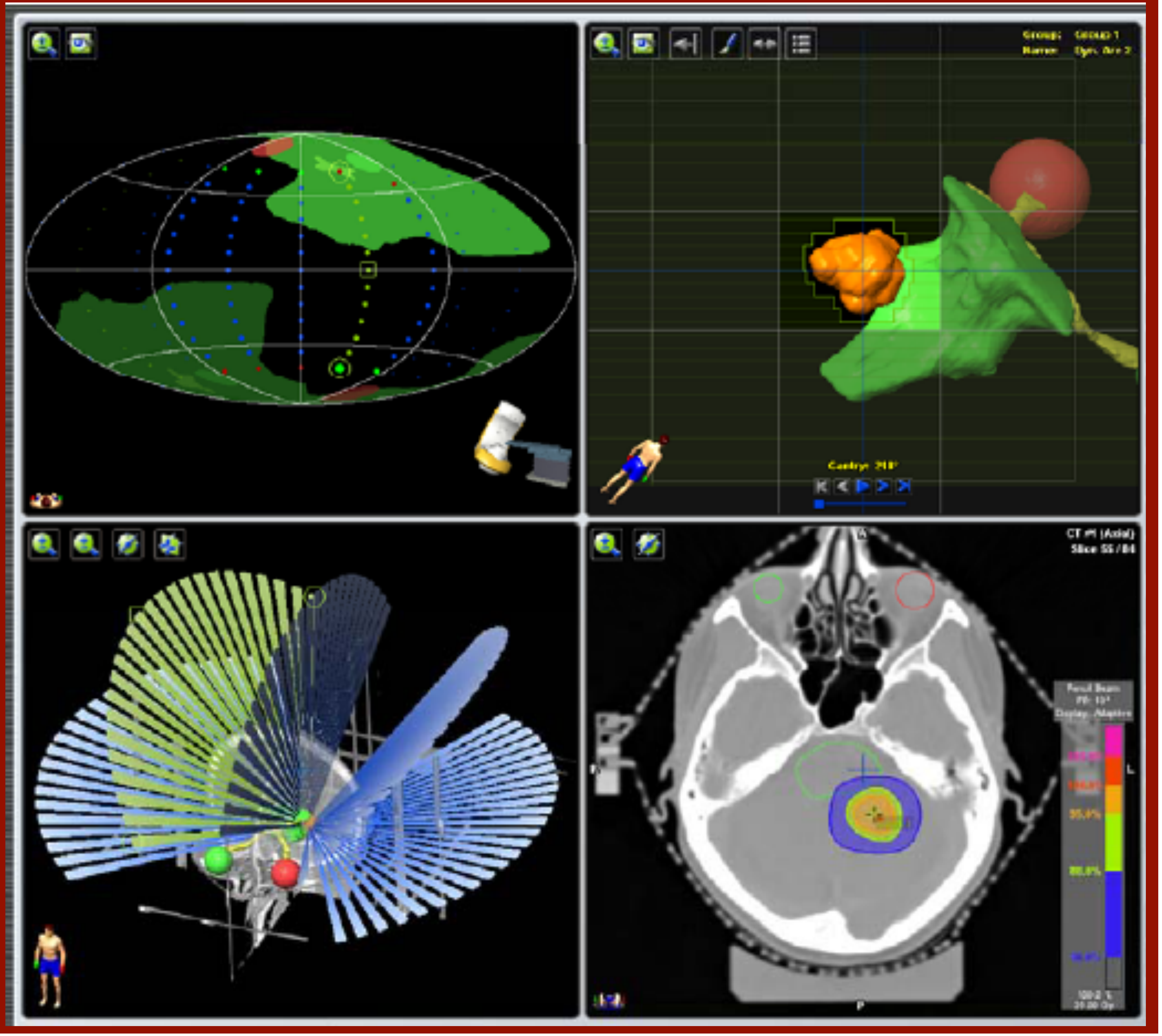
CT #1 (Axial)
Axial View
A
R
L
P
100
50
0
mm
H
CT #1 (Axial)
Sagittal View
A
P
F
100
50
0
mm
H
CT #1 (Axial)
Coronal View
R
L
F
100
50
0
mm

Uncertainties achievable in SRS

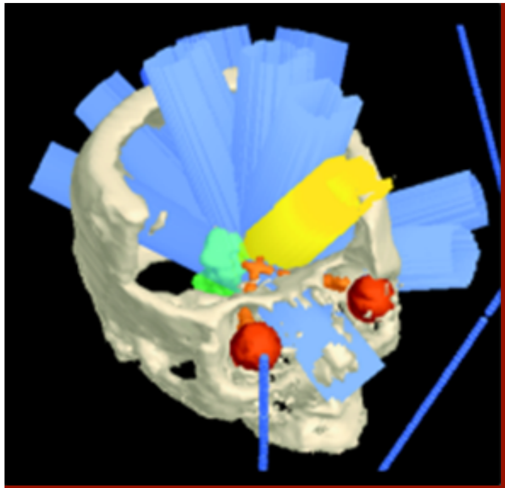
CT slice *Thickness*	1 mm	3 mm
Stereotactic Frame	1 mm	1 mm
Isocenter Alignment	1 mm	1 mm
CT Image resolution	1.7 mm	3.2 mm
Tissue Motion	1.0 mm	1 mm
Angio (Point identification)	0.3 mm	0.3 mm
Std. Dev. of Pos. Uncertainty	2.4 mm	3.7 mm

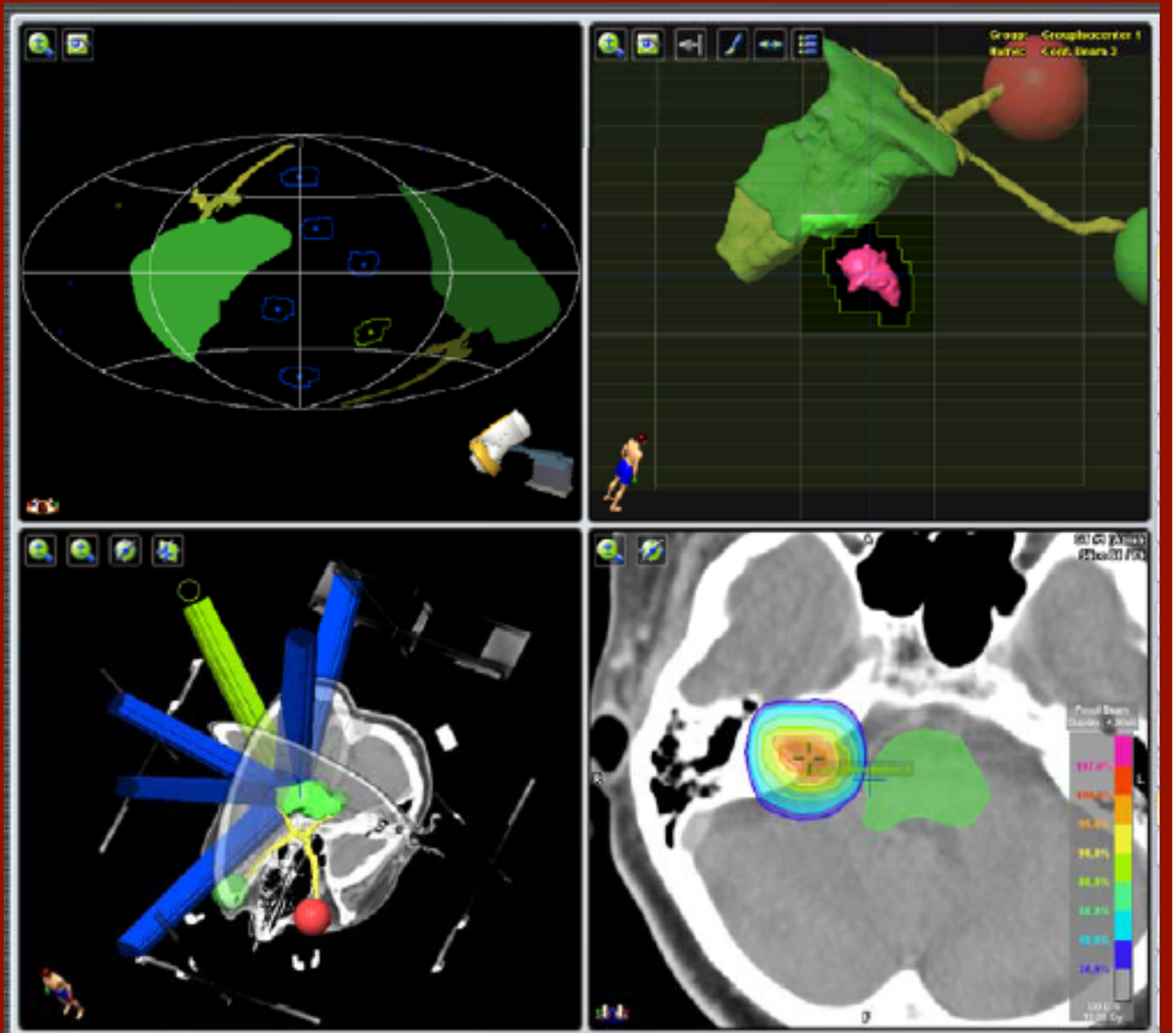
AAPM Report No 54:Stereotactic Radiosurgery

PLANING WITH CONFORMAL ARCS

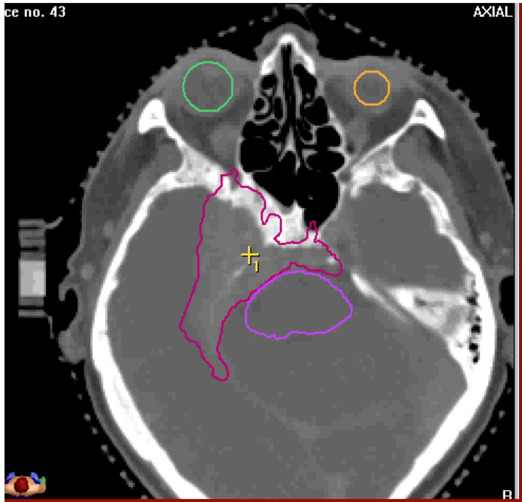


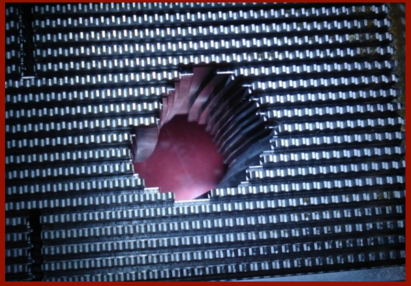
PLANING WITH CONFORMAL FIXED FIELDS

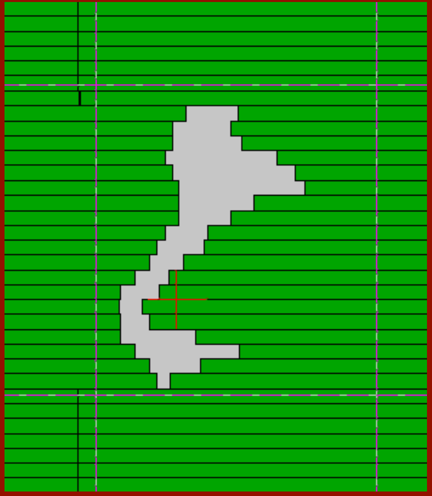


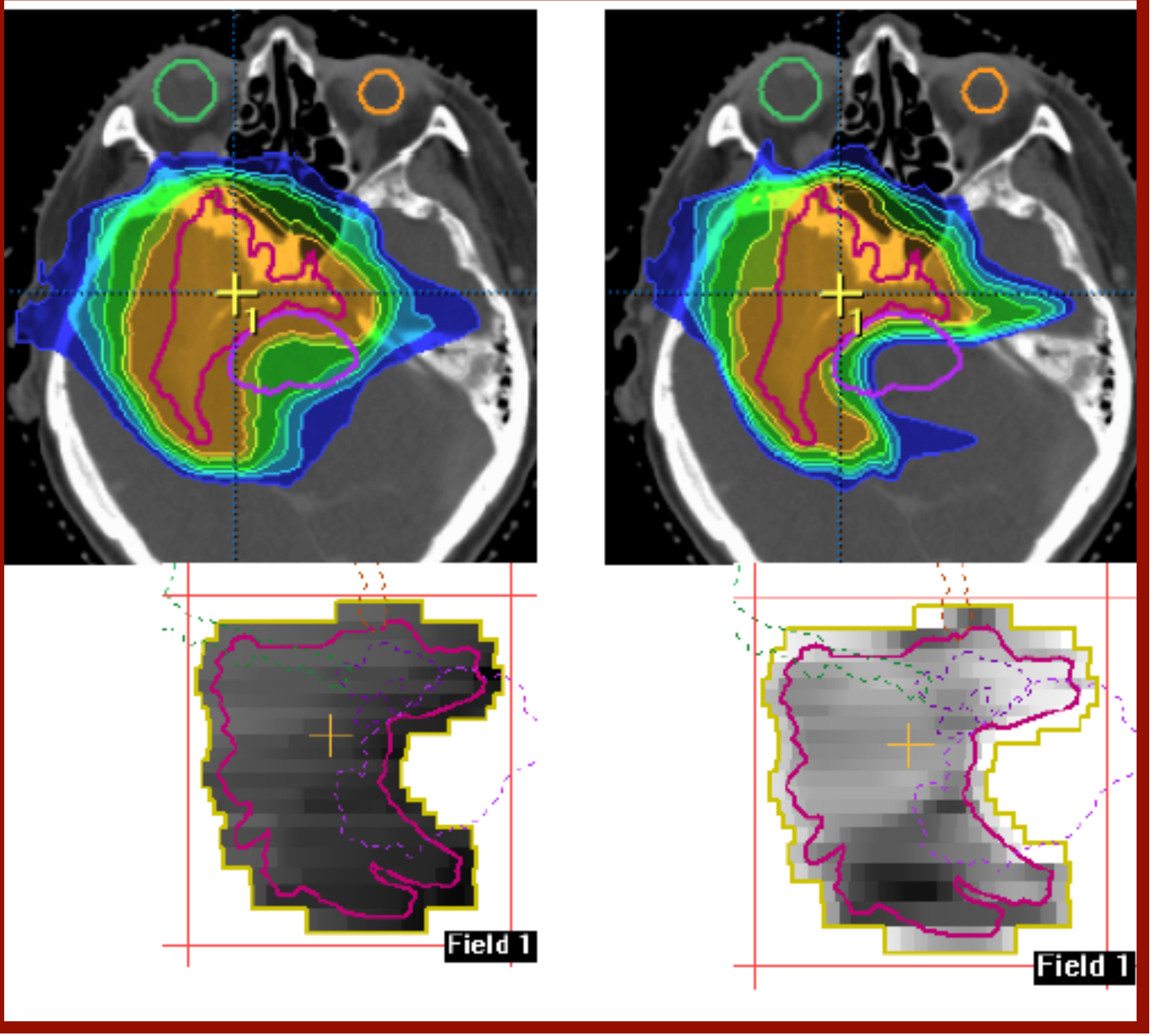


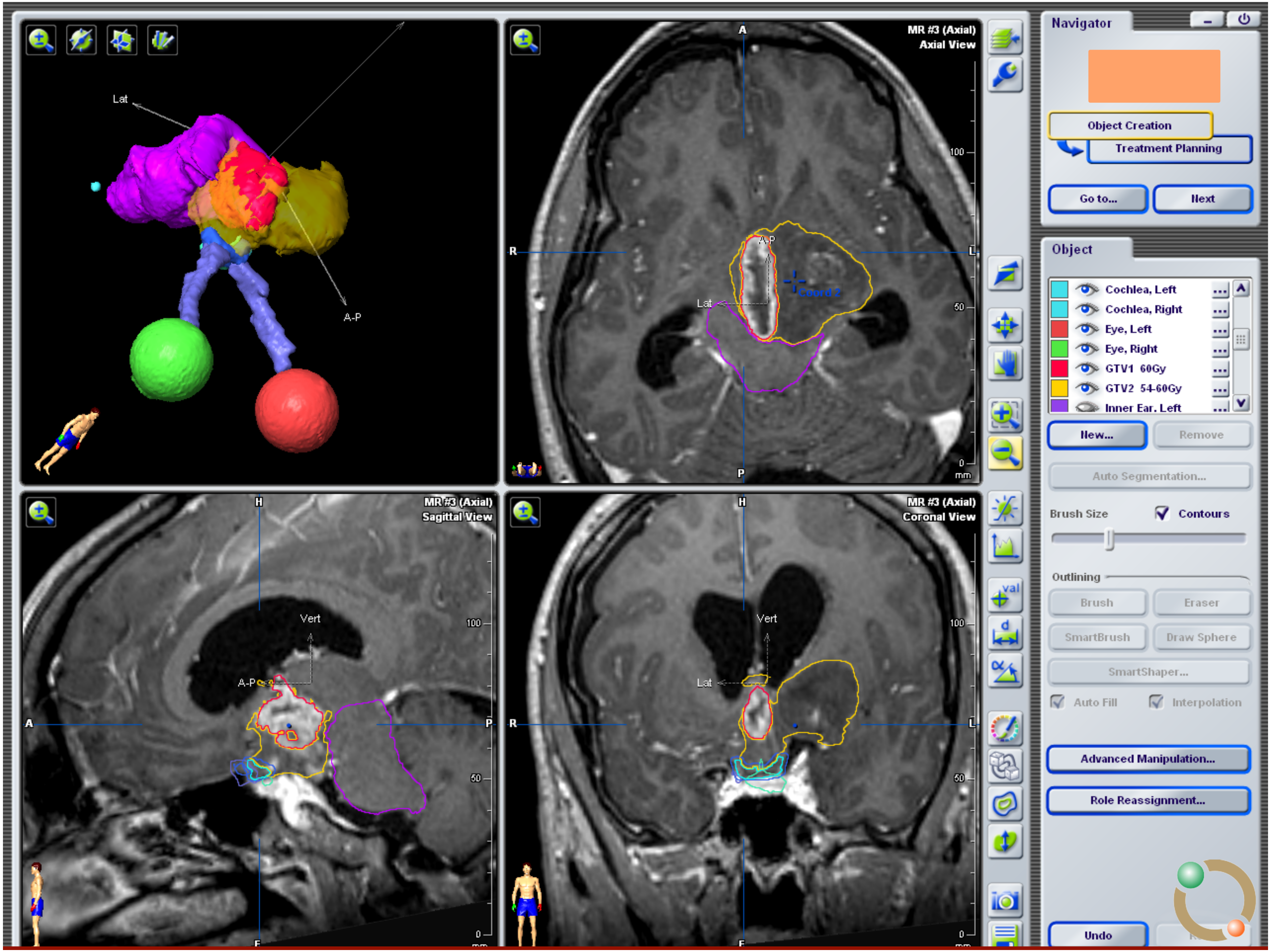
PLANING with Intensity Modulated Radio Surgery (IMRS)



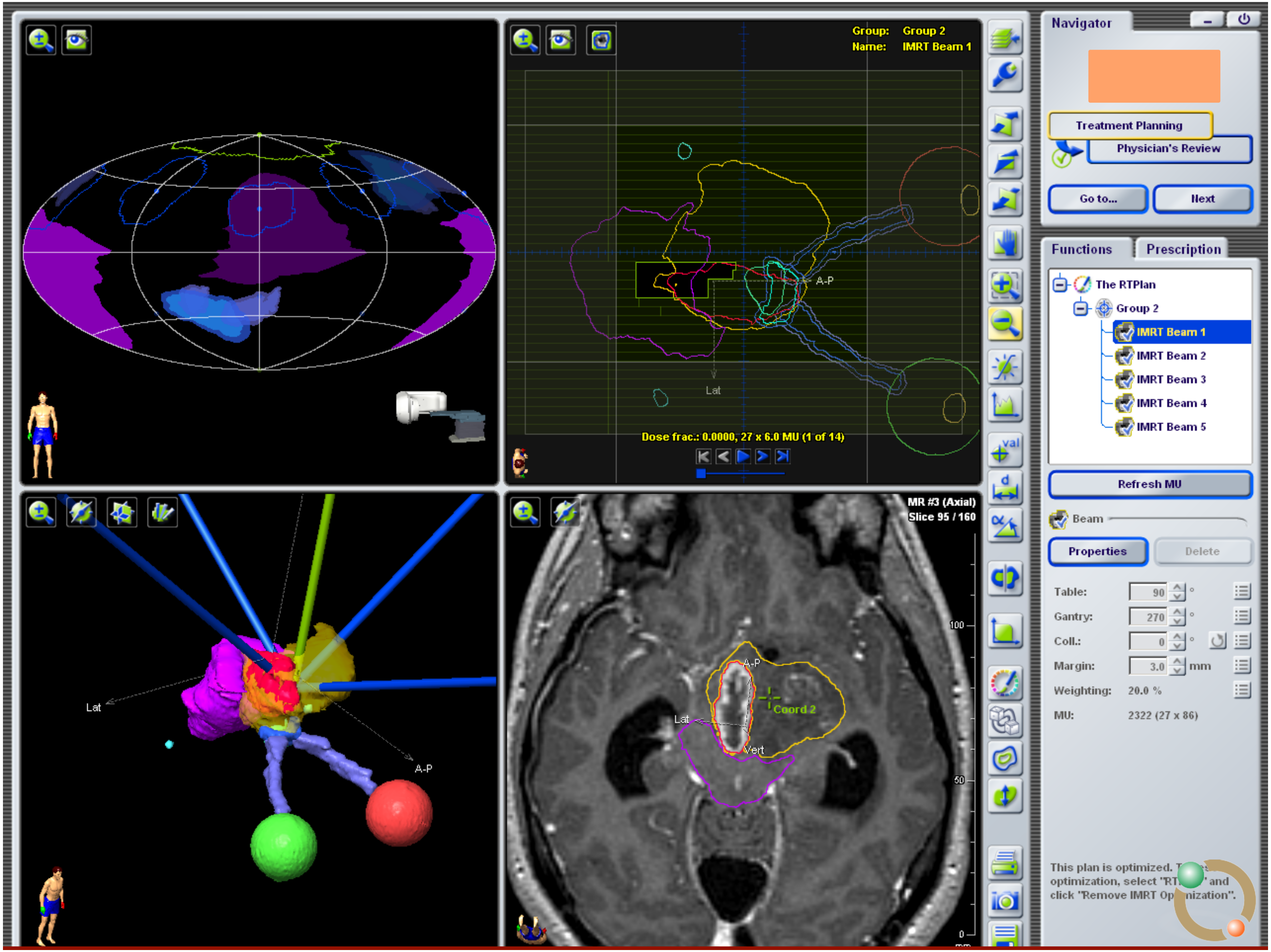




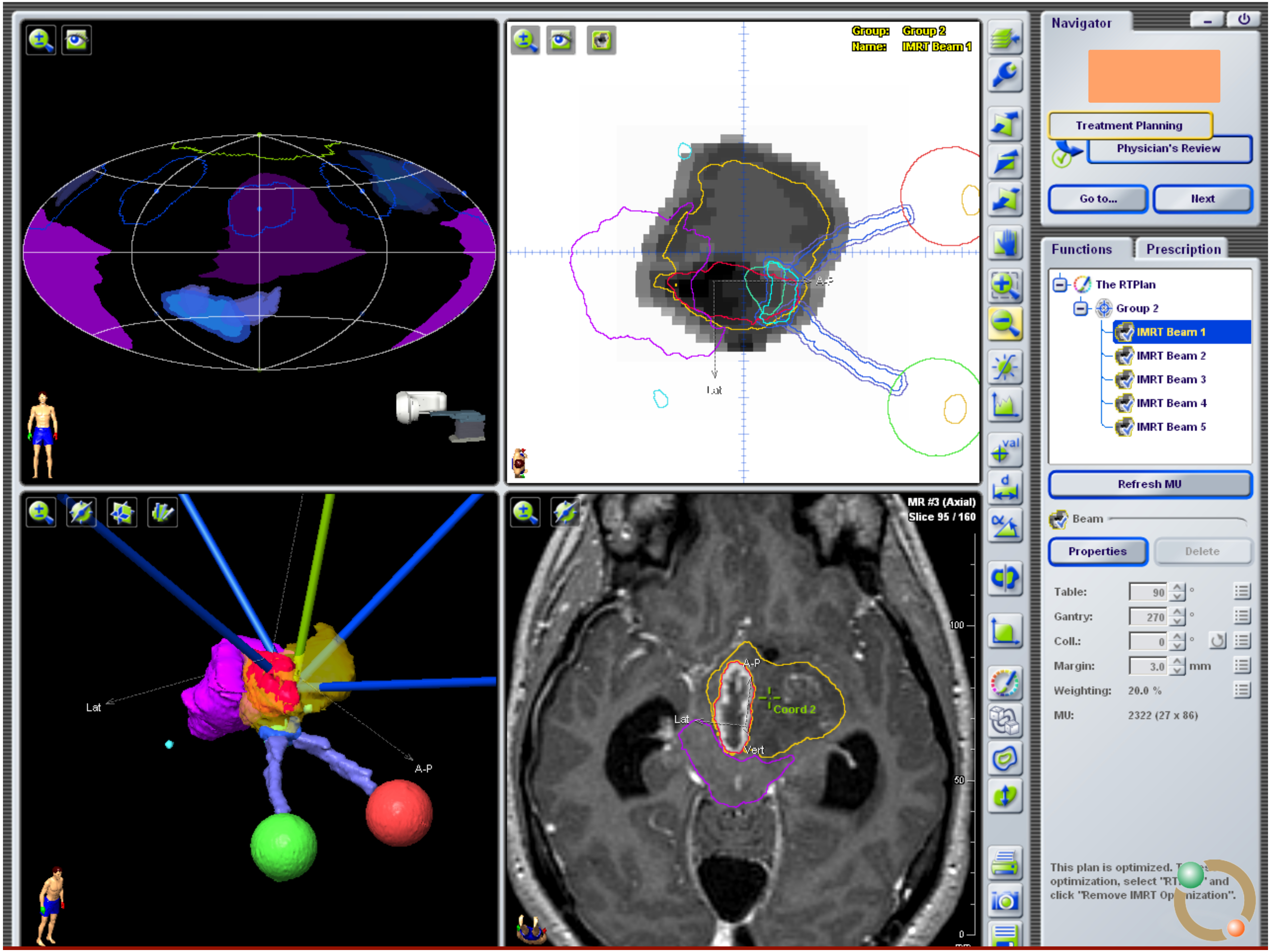




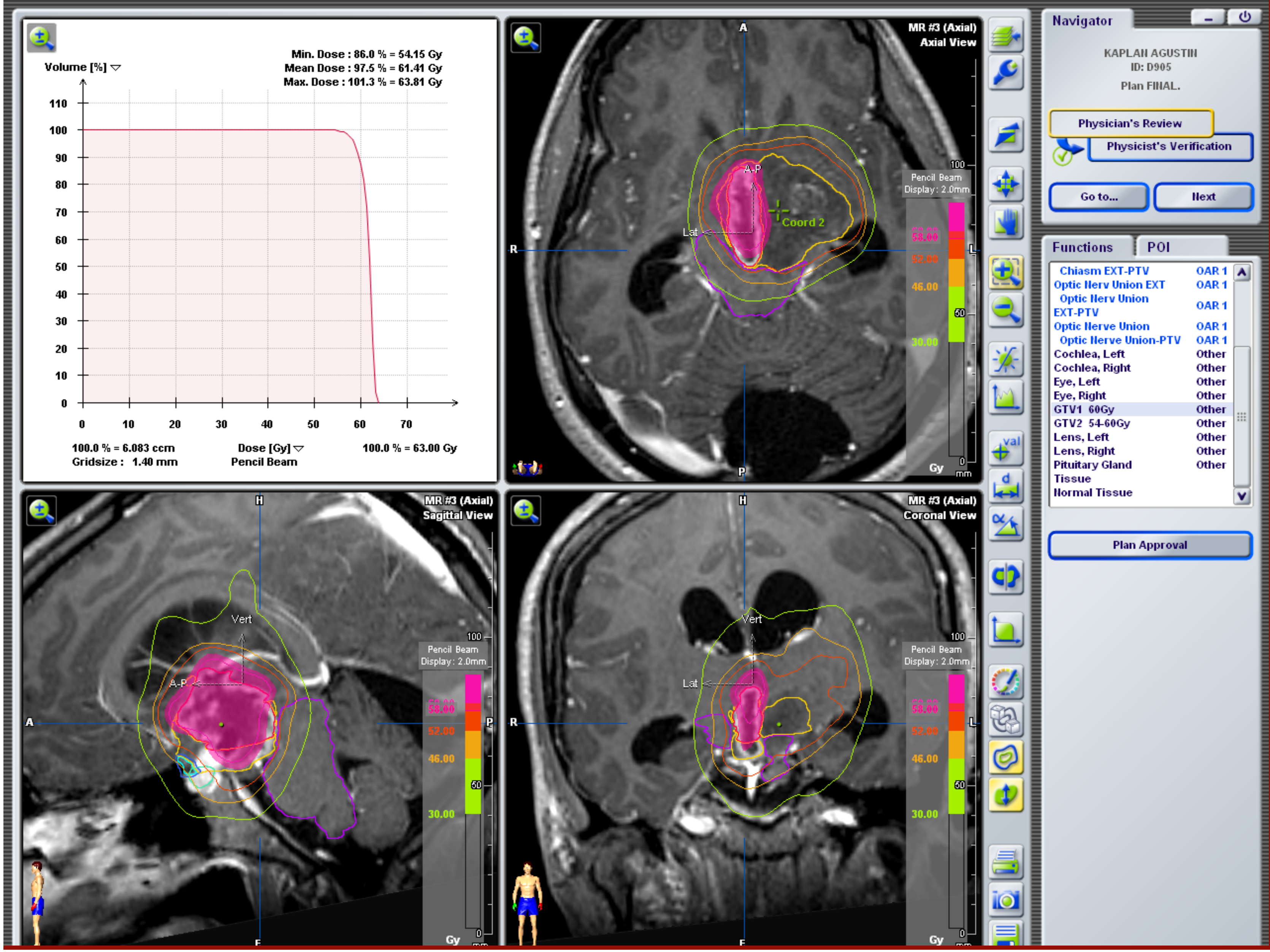
Lat
A-P
MR #3 (Axial)
Axial View
A
R
L
P
Coord 2
100
50
0
mm
MR #3 (Axial)
Sagittal View
H
Vert
A-P
F
MR #3 (Axial)
Coronal View
Navigator
Object Creation
Treatment Planning
Go to...
Next
Object
Cochlea, Left
Cochlea, Right
Eye, Left
Eye, Right
GTV1 60Gy
GTV2 54-60Gy
Inner Ear, Left
New...
Remove
Auto Segmentation...
Brush Size
Contours
Outlining
Brush
Eraser
SmartBrush
Draw Sphere
SmartShaper...
Auto Fill
Interpolation
Advanced Manipulation...
Role Reassignment...
Undo



Group: Group 2
Name: IMRT Beam 1
A-P
Lat
Dose frac.: 0.0000, 27 x 6.0 MU (1 of 14)
Navigator
Treatment Planning
Physician's Review
Go to...
Next
Functions
Prescription
The RTPlan
Group 2
IMRT Beam 1
IMRT Beam 2
IMRT Beam 3
IMRT Beam 4
IMRT Beam 5
Refresh MU
Beam
Properties
Delete
Table: 90 °
Gantry: 270 °
Coll.: 0 °
Margin: 3.0 mm
Weighting: 20.0 %
MU: 2322 (27 x 86)
MR #3 (Axial)
Slice 95 / 160
Coord 2
Vert

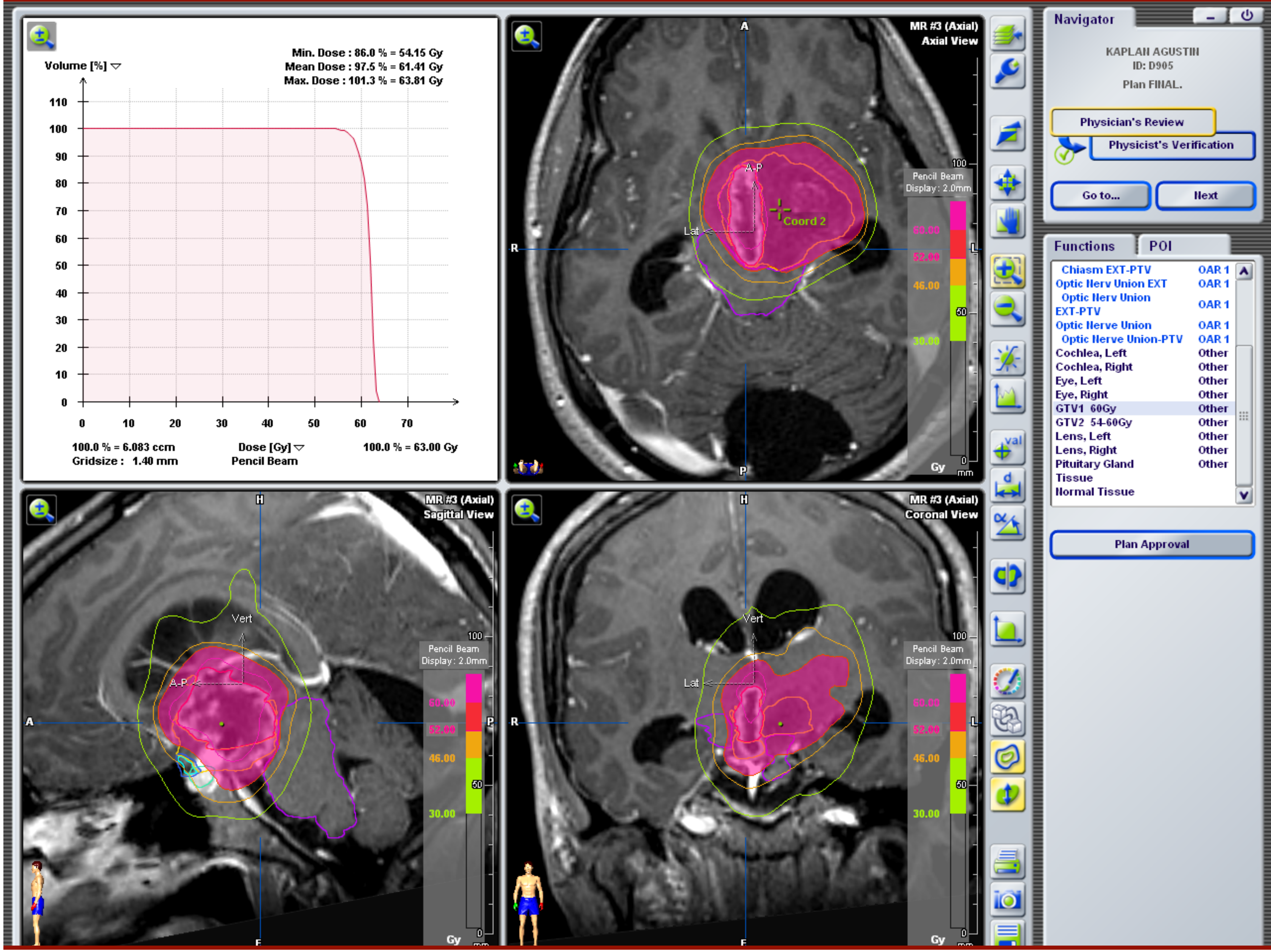


Group: Group 2
Name: IMRT Beam 1
A-P
Lat
Lat
A-P
MR #3 (Axial)
Slice 95 / 160
A-P
Coord 2
Lat
Vert
100
50
0
Navigator
Treatment Planning
Physician's Review
Go to...
Next
Functions
Prescription
The RTPlan
Group 2
IMRT Beam 1
IMRT Beam 2
IMRT Beam 3
IMRT Beam 4
IMRT Beam 5
Refresh MU
Beam
Properties
Delete
Table: 90 °
Gantry: 270 °
Coll.: 0 °
Margin: 3.0 mm
Weighting: 20.0 %
MU: 2322 (27 x 86)



Volume [%]
Min. Dose : 86.0 % = 54.15 Gy
Mean Dose : 97.5 % = 61.41 Gy
Max. Dose : 101.3 % = 63.81 Gy
100.0 % = 6.083 ccm
Gridsize : 1.40 mm
Dose [Gy]
Pencil Beam
100.0 % = 63.00 Gy
MR #3 (Axial)
Axial View
Coord 2
Pencil Beam
Display : 2.0mm
MR #3 (Axial)
Sagittal View
MR #3 (Axial)
Coronal View
Navigator
KAPLAN AGUSTIN
ID: D905
Plan FINAL.
Physician's Review
Physicist's Verification
Go to...
Next
Functions
POI
Chiasm EXT-PTV OAR 1
Optic Nerv Union EXT OAR 1
Optic Nerv Union EXT-PTV OAR 1
Optic Nerve Union OAR 1
Optic Nerve Union-PTV OAR 1
Cochlea, Left Other
Cochlea, Right Other
Eye, Left Other
Eye, Right Other
GTV1 60Gy Other
GTV2 54-60Gy Other
Lens, Left Other
Lens, Right Other
Pituitary Gland Other
Tissue
Normal Tissue
Plan Approval

Single isocenter for irregular targets with better conformality and homogeneity than cones

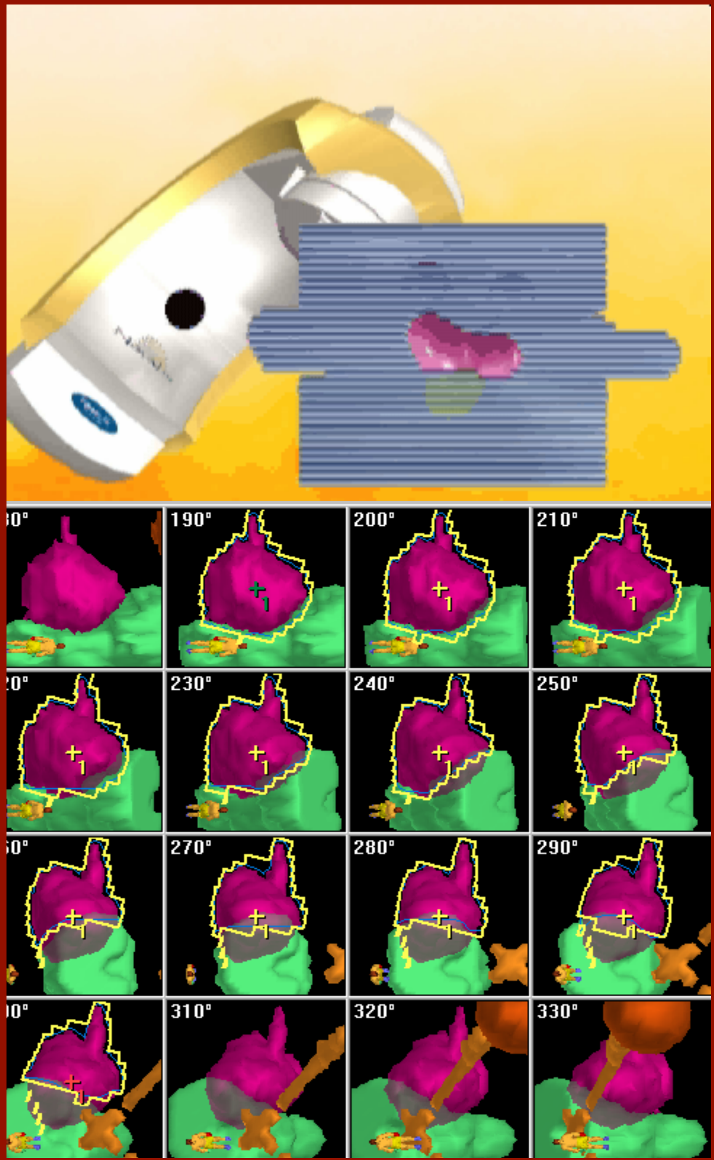


Dynamic Conformal Arc

- **Automatic leaf adaptation to tumor contour**
- **Straight-forward arc optimization with collision map**
- **MLC control must be synchronized with gantry rotation**

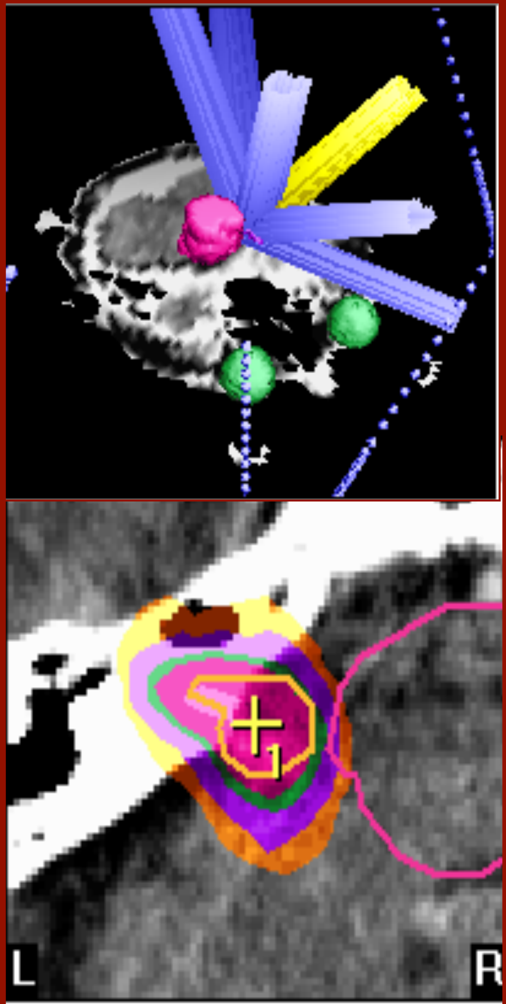
Advantages

- **Fast, semi-automatic single isocenter treatment planning**
- **Critical structures are easier to avoid for most beam angles**
- **Most conformal and homogeneous dose distribution with reduced irradiation of normal tissue**

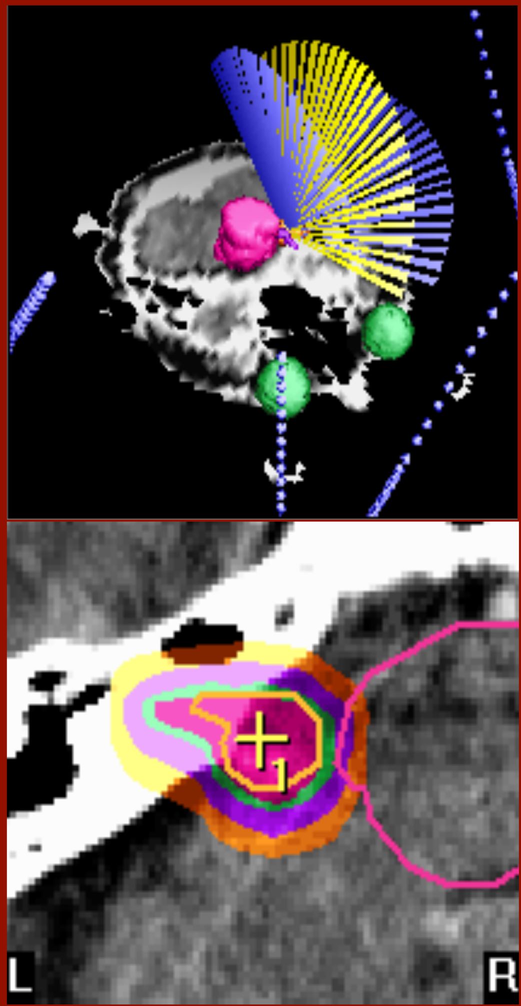


Comparison of plans

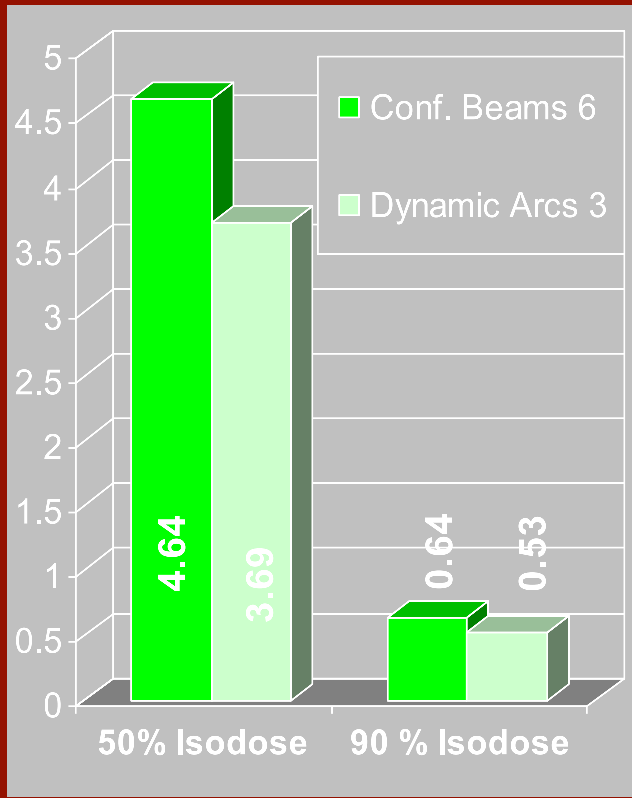
Conformal mMLC Plan
1 Isocenter -6 Static Fields



Dynamic Conformal Arc Plan
1 Isocenter - 3 Dynamic Arcs



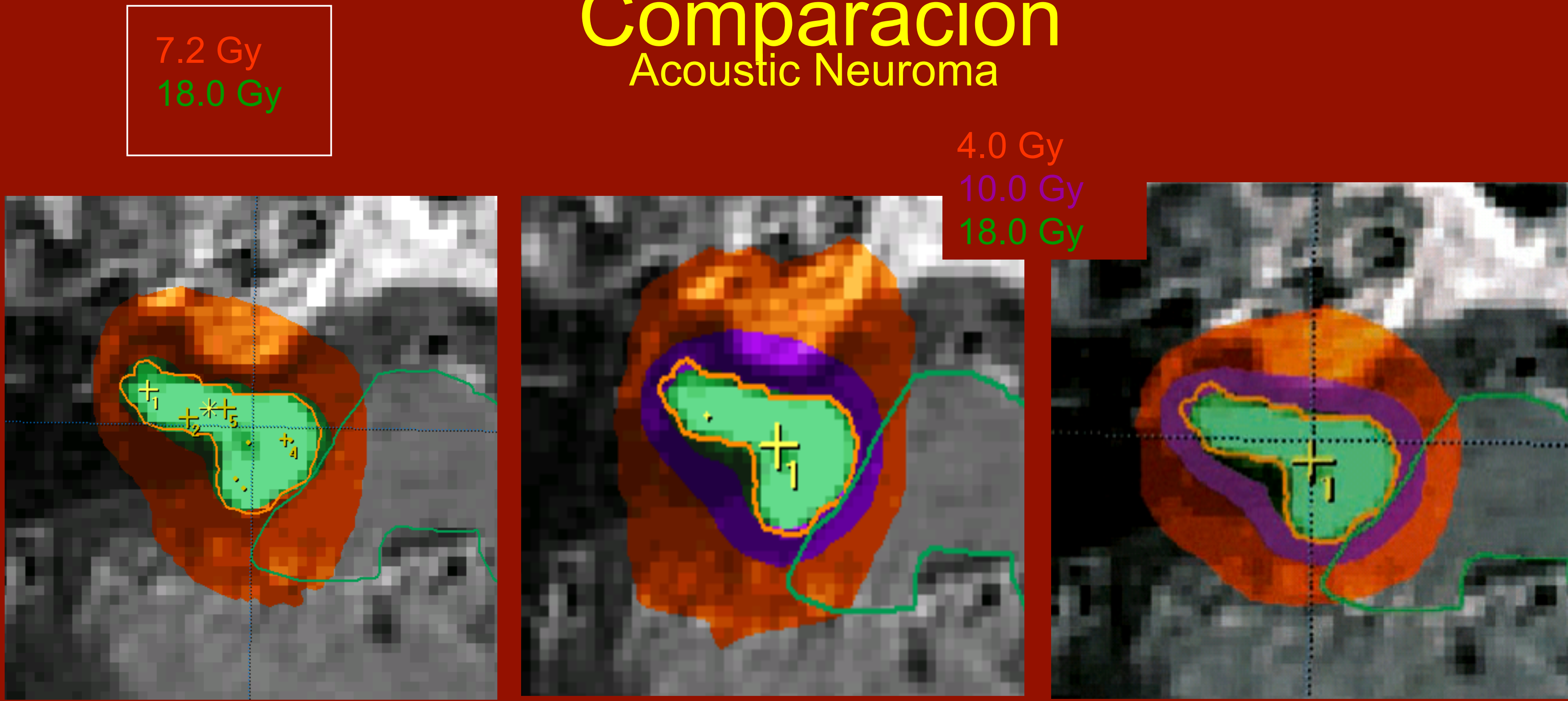
Volume of irradiated Normal Tissue (cm^3)



Courtesy of Universitätsklinkum Charité, Berlin

Comparacion

Acoustic Neuroma



Circular Arc, 8 Isocenters

Conformal Beam, 19 Beams (1 isocenter)

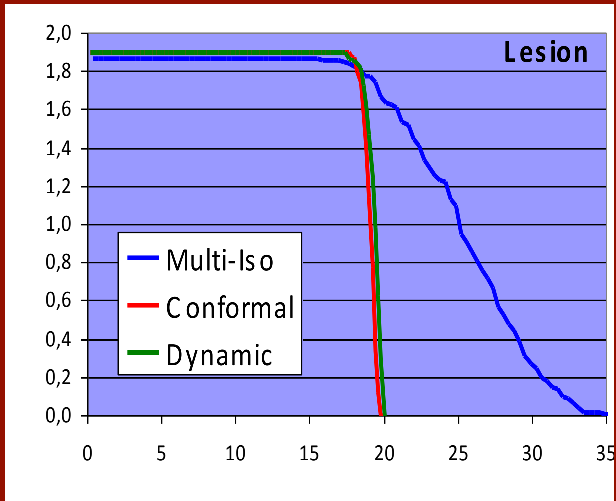
Dynamic Conformal Arc, 5 Arcs (1 isocenter)

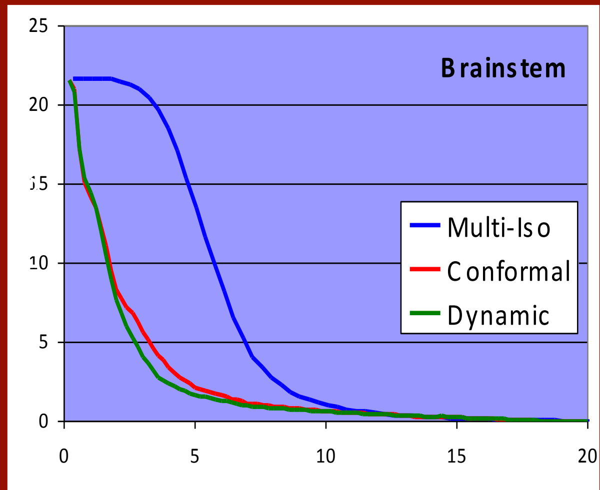
Improved normal tissue sparing
Tight margin around target

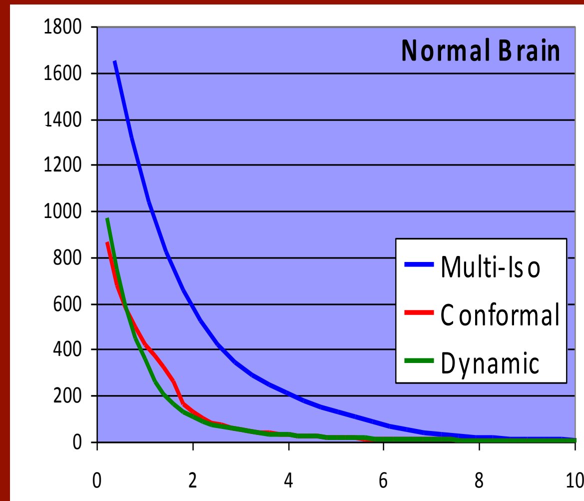
Dynamic Arc Radiosurgery Field Shaping: A Comparison with Static Field Conformal and non-coplanar circular arcs. T. Solberg *et al.* Int. J. Radiation Oncology Biol Physics. Vol 49, No. 5, pp1481–1491, 2001

Comparison
Acoustic Neuroma

Homogenous Dose Distribution
Greater sparing of normal tissue and structures at risk



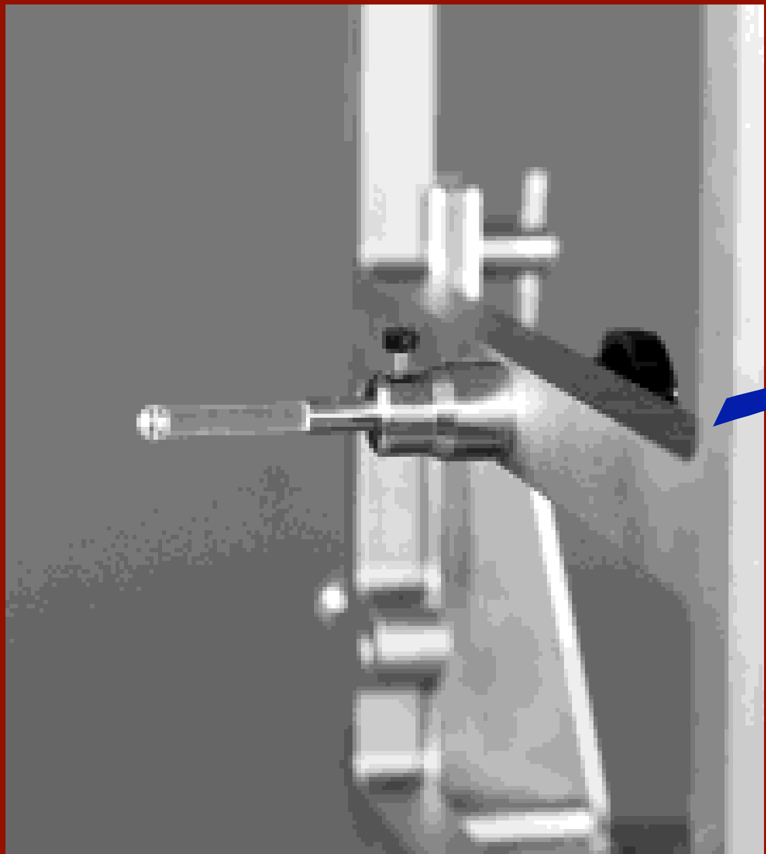


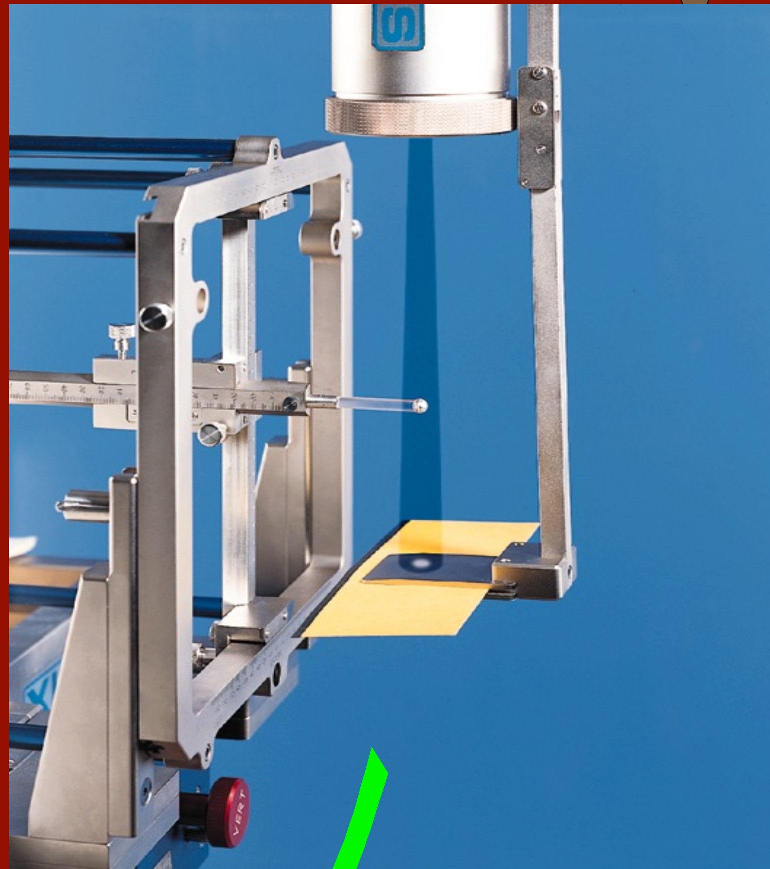


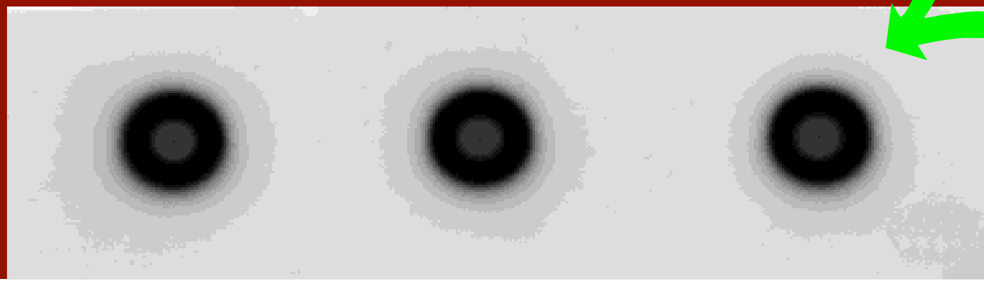
Dose (cGy) Dose (cGy) Dose (cGy)

Dynamic Arc Radiosurgery Field Shaping: A Comparison with Static Field Conformal and non-coplanar circular arcs. T. Solberg *et al.* Int. J. Radiation Oncology Biol Physics. Vol 49, No. 5, pp1481–1491, 2001

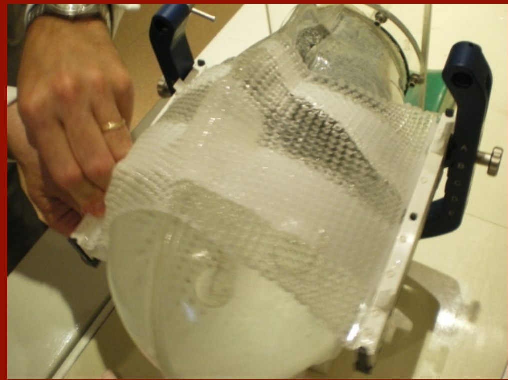
QA of Isocenter

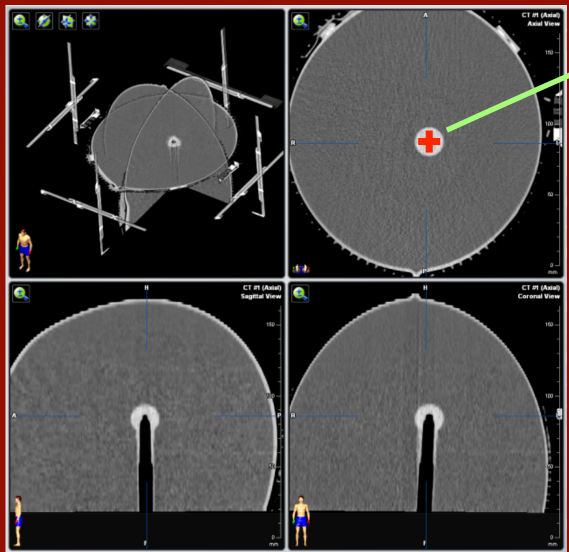


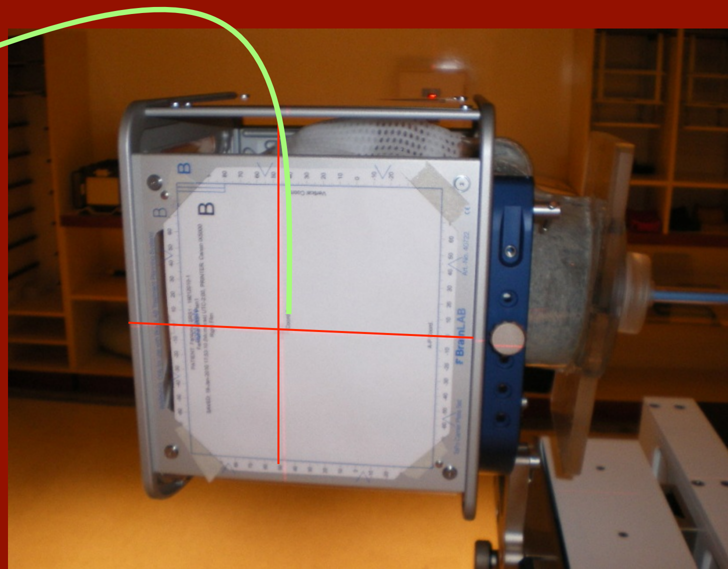




Coordinate verification
- Templates and Laser -

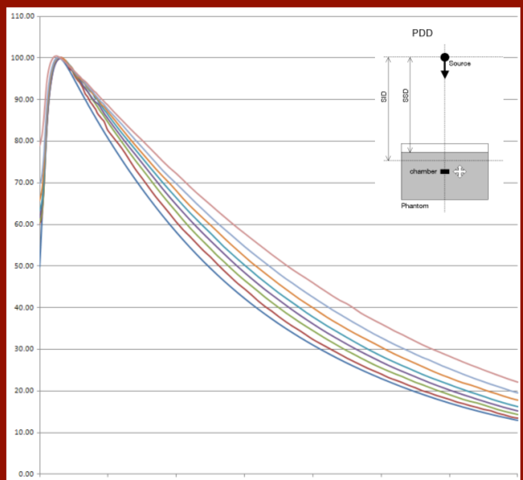


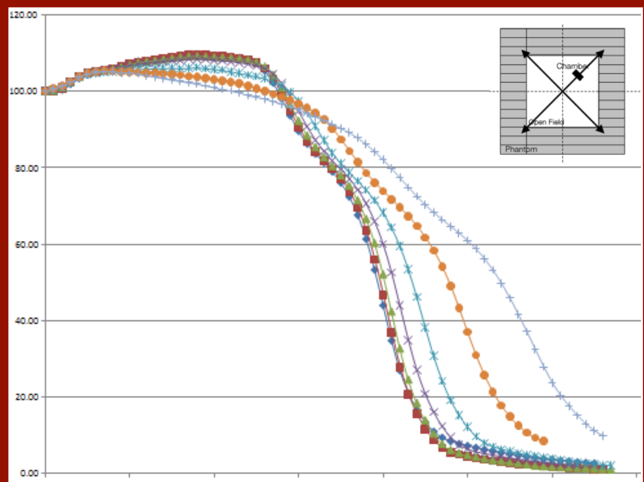


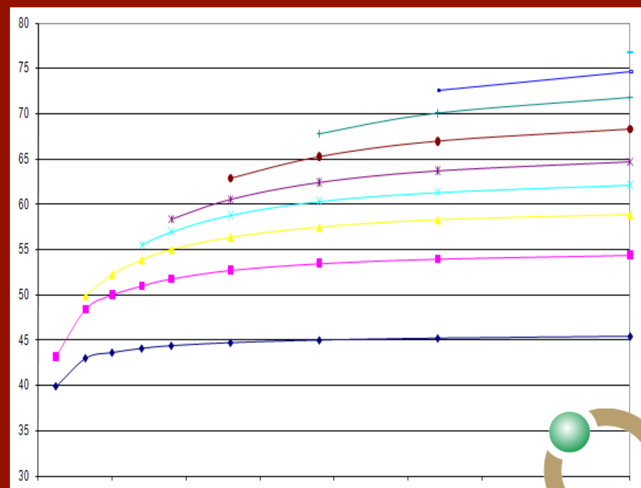


Beam dosimetry of small fields and treatment planning commisioning

- **Beam parameters**
  - ***PDD***
  - ***Profiles***
  - ***Field size dependent output factors***
  - ***Transmission***
  - ***<u>Absolute dose</u>***



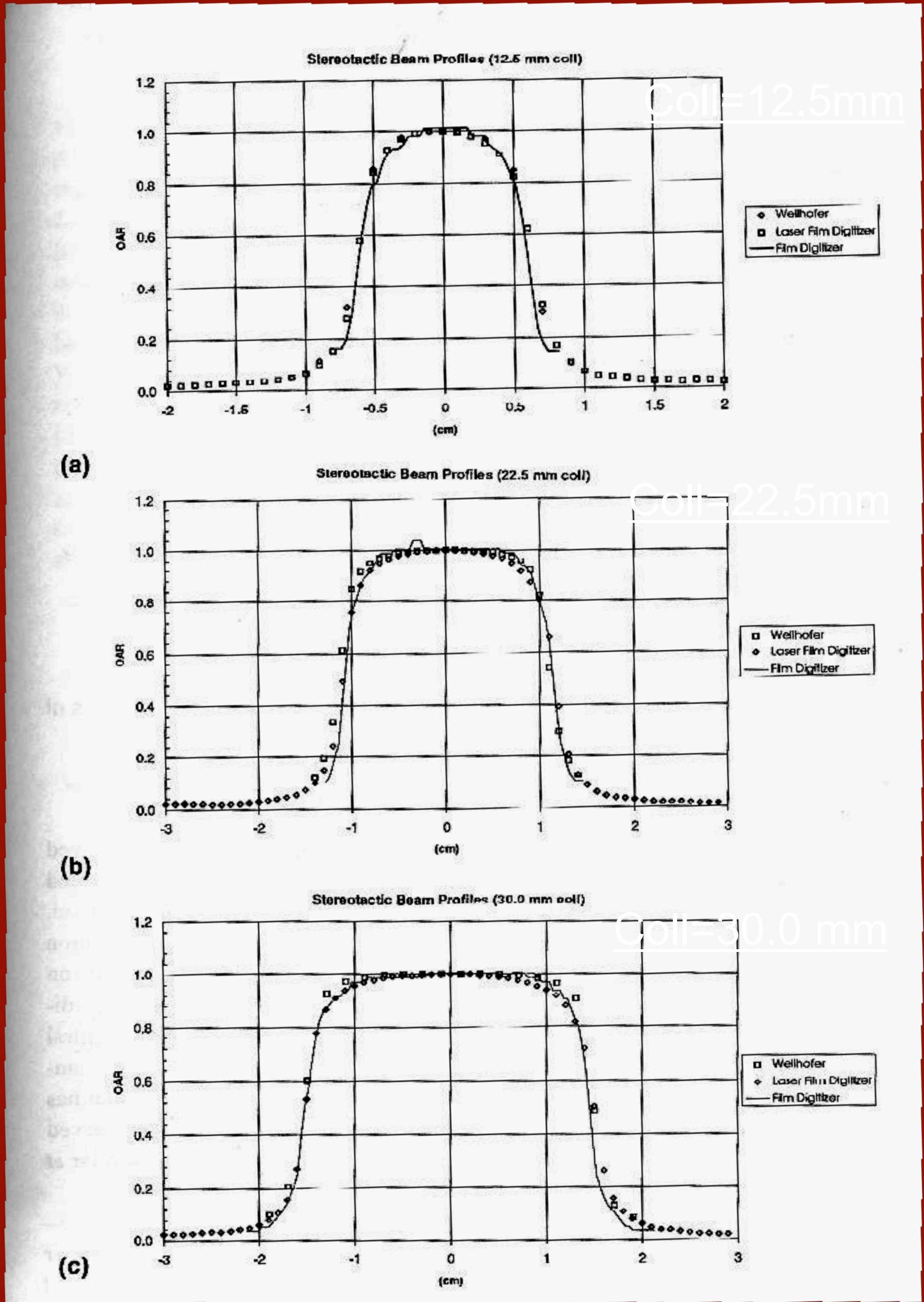




Beam Dose Measurements

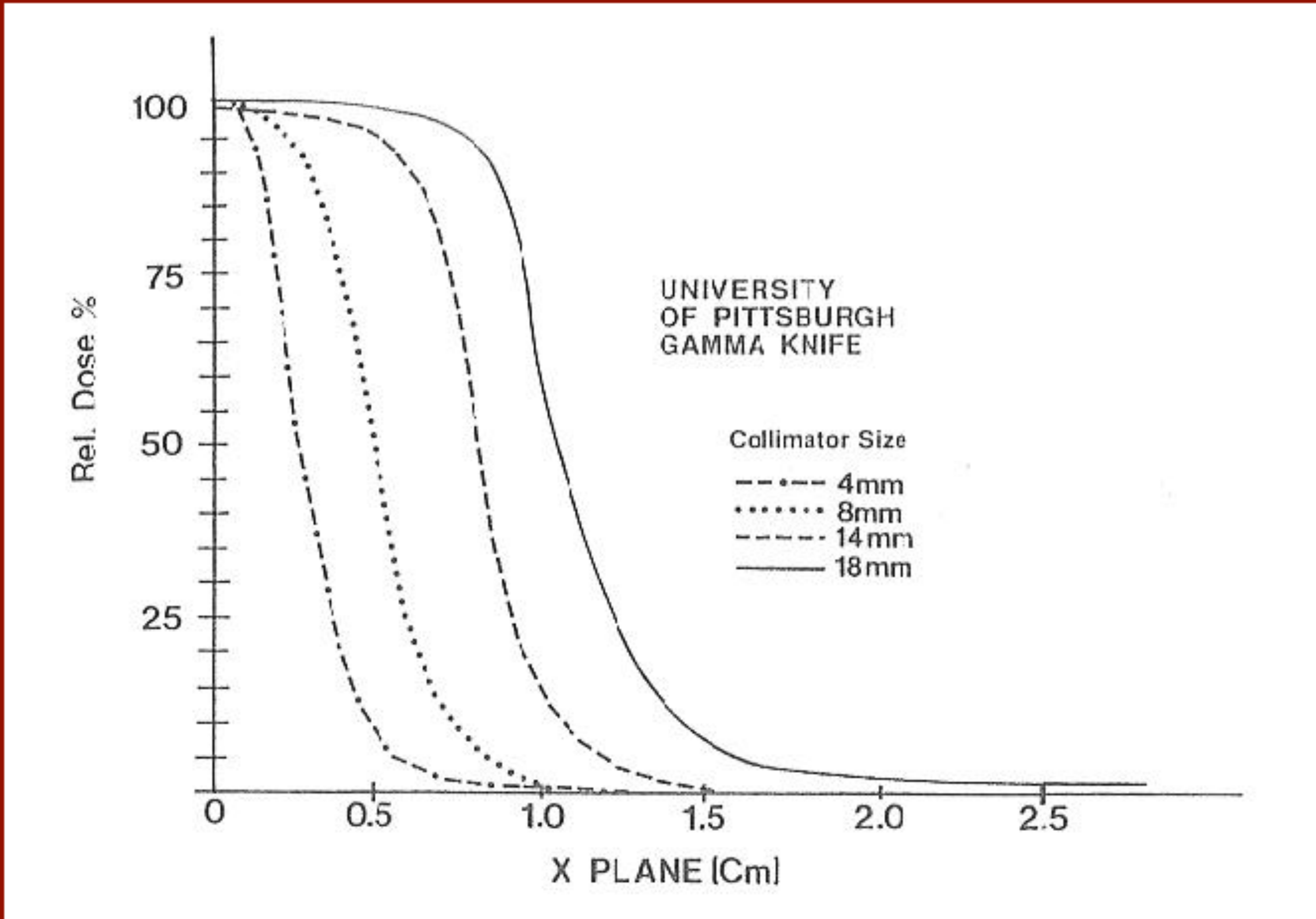
- **Issues with small field dosimetry:**
  - **Detector size vs. Small field dimensions**
  - **Lack of lateral charged particle equilibrium**
  - **Large dose gradients in SRS penumbra**
- **Equipment:**
  - **Water tank, polystyrene slabs, ion chamber, diodes, TLD's and Film**
  - **Very small Detector diameter required to reproduce a penumbra of ~1mm**

Beep Profiles

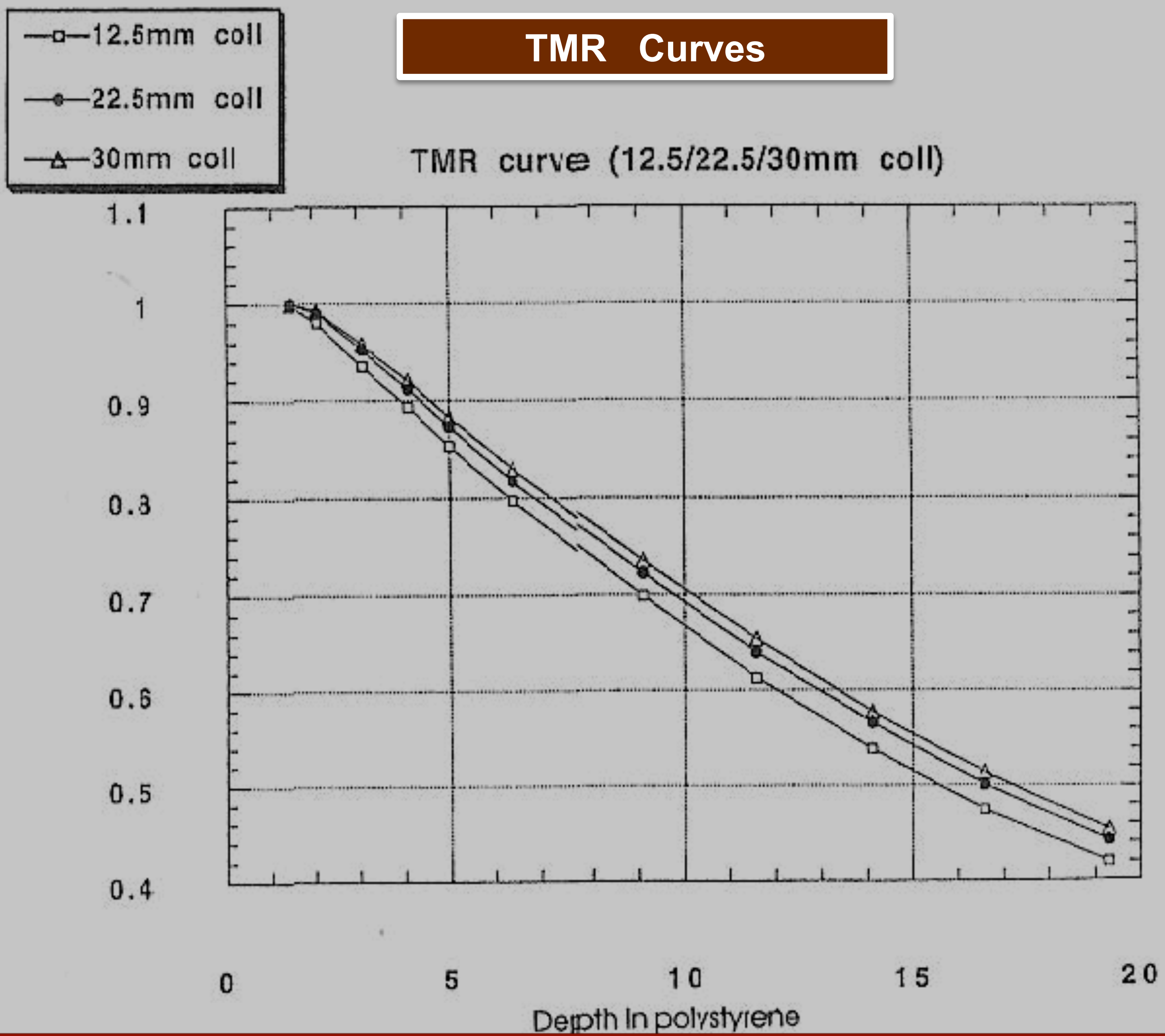


- ❖ Welhofer
- o Laser Film Digitizer (Lumisys)
- Film Digitizer

Gamma Knife - Beam profiles



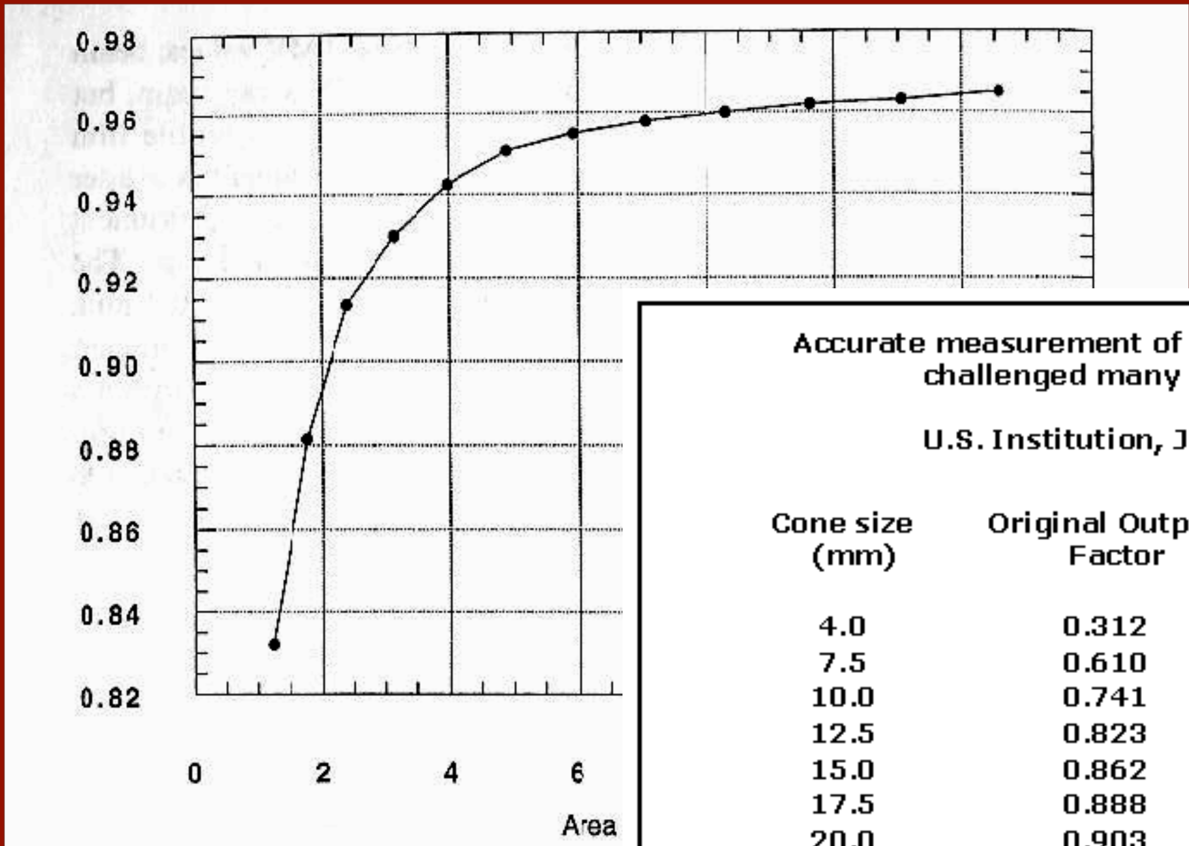
TMR Curves



12.5mm coll
22.5mm coll
30mm coll
TMR curve (12.5/22.5/30mm coll)
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0
5
10
15
20
Depth in polystyrene

Stereotatic Output Factor Curve
($S_t = S_c\ S_p$)
@ Isocenter, d_{max}

6 MV   Coll. Diam.:12.5mm to 20.0mm

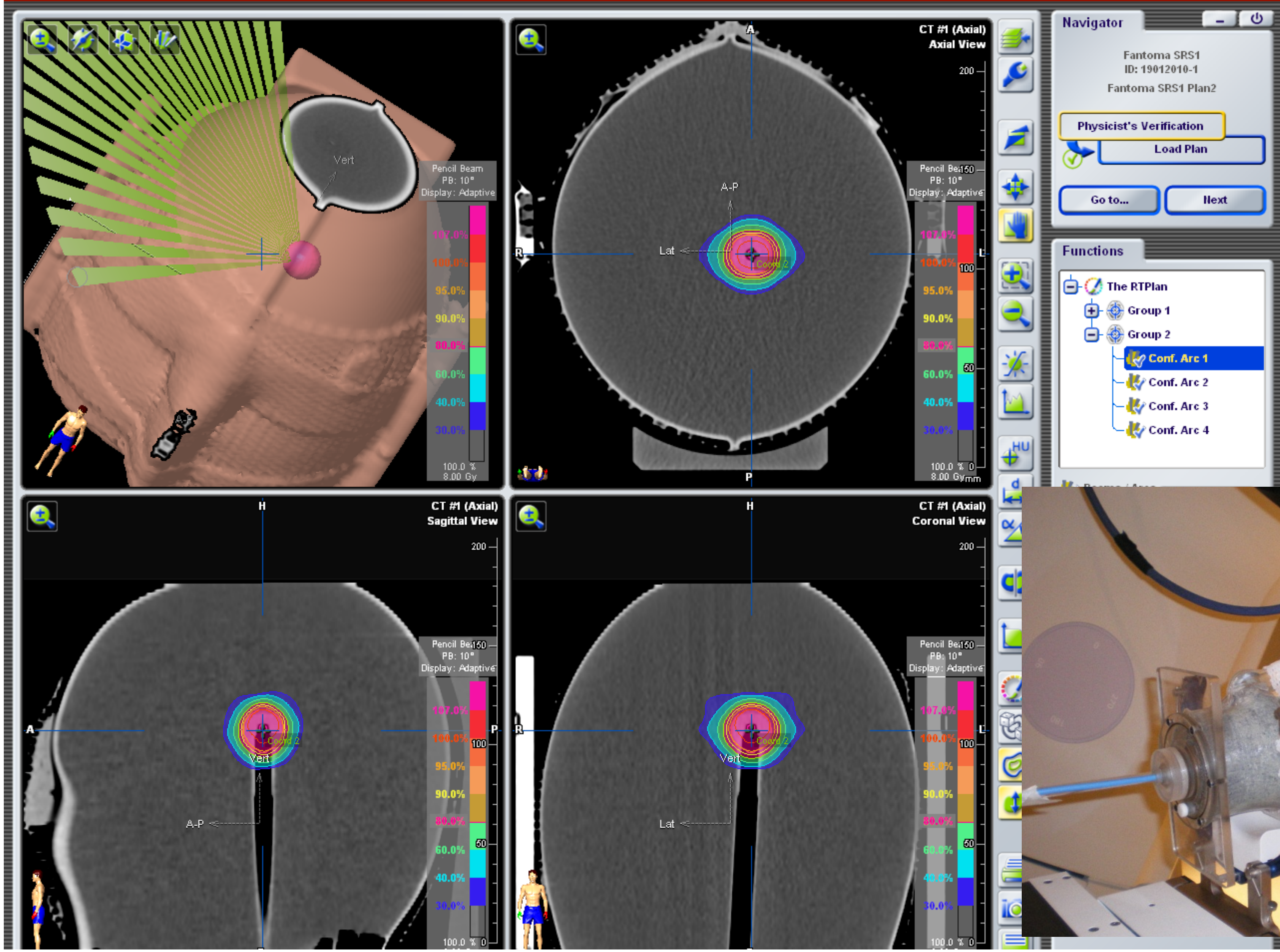


Accurate measurement of output factors has challenged many physicists

U.S. Institution, July, 2010

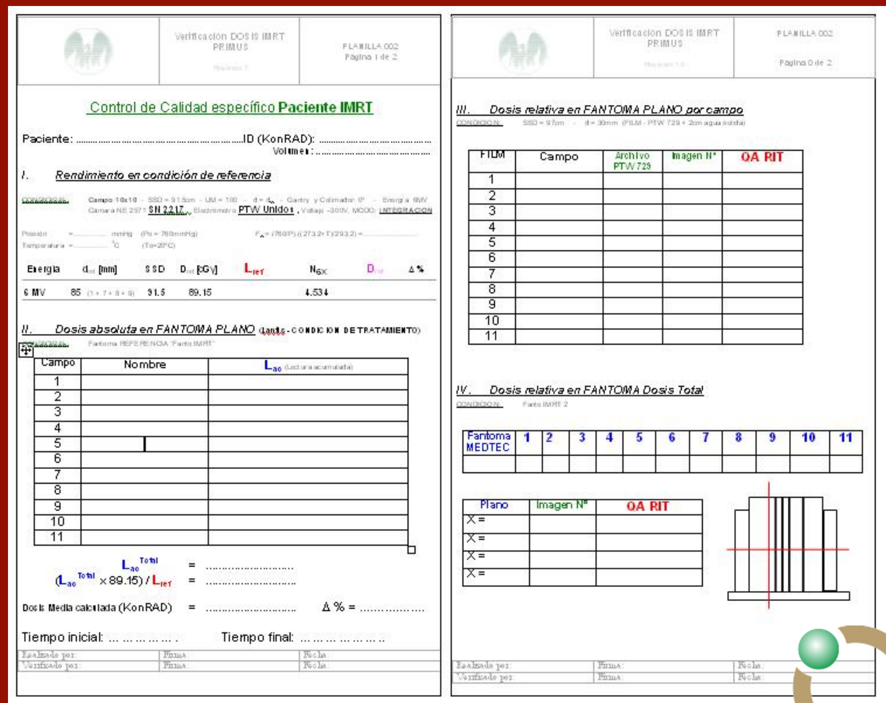
Cone size (mm)	Original Output Factor	Re-measured Output Factor
4.0	0.312	0.699
7.5	0.610	0.797
10.0	0.741	0.835
12.5	0.823	0.871
15.0	0.862	0.890
17.5	0.888	0.904
20.0	0.903	0.913
25.0	0.920	0.930
30.0	0.928	0.940

Verification of dose calculations



Verification of dose calculations

- **IMRS – Patient specific dose measurements**
  - Absolute total plan dose
  - Relative doses per field
  - Relative plan dose distribution



Verificación DOSIS IMRT PRIMUS — PLANILLA 002 — Página 1 de 2

Control de Calidad específico Paciente IMRT

Paciente: .... ID (KonRAD): ....
Volumen: ....

I. Rendimiento en condición de referencia

Energía	d_{ref} [mm]	SSD	D_{ref} [cGy]	L_{ref}	N_{SX}	D_{ref}	Δ %
6 MV	85	91.5	89.15		4.534		

II. Dosis absoluta en FANTOMA PLANO

Campo	Nombre	L_{ao}
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		

L_{ao}^{Total} = ...

$(L_{ao}^{Total} \times 89.15) / L_{ref}$ = ...

Dosis Media calculada (KonRAD) = ... Δ % = ...

Tiempo inicial: .... Tiempo final: ....

Realizado por: Firma: Fecha:
Verificado por: Firma: Fecha:

Verificación DOSIS IMRT PRIMUS — PLANILLA 002 — Página 2 de 2

III. Dosis relativa en FANTOMA PLANO por campo

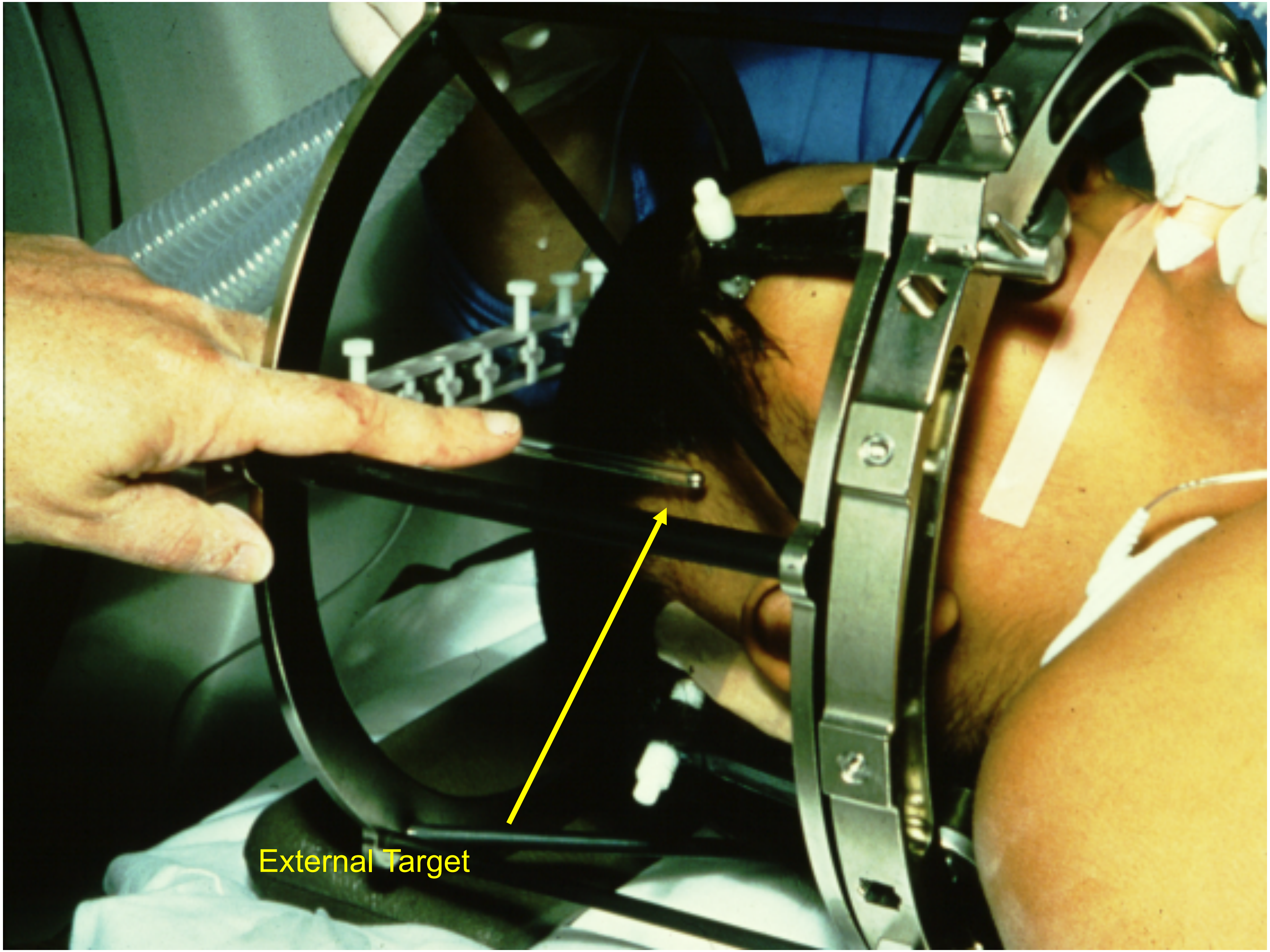
FILM	Campo	Archivo PTW 729	Imagen N°	OA RIT
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				

IV. Dosis relativa en FANTOMA Dosis Total

Fantoma MEDTEC	1	2	3	4	5	6	7	8	9	10	11

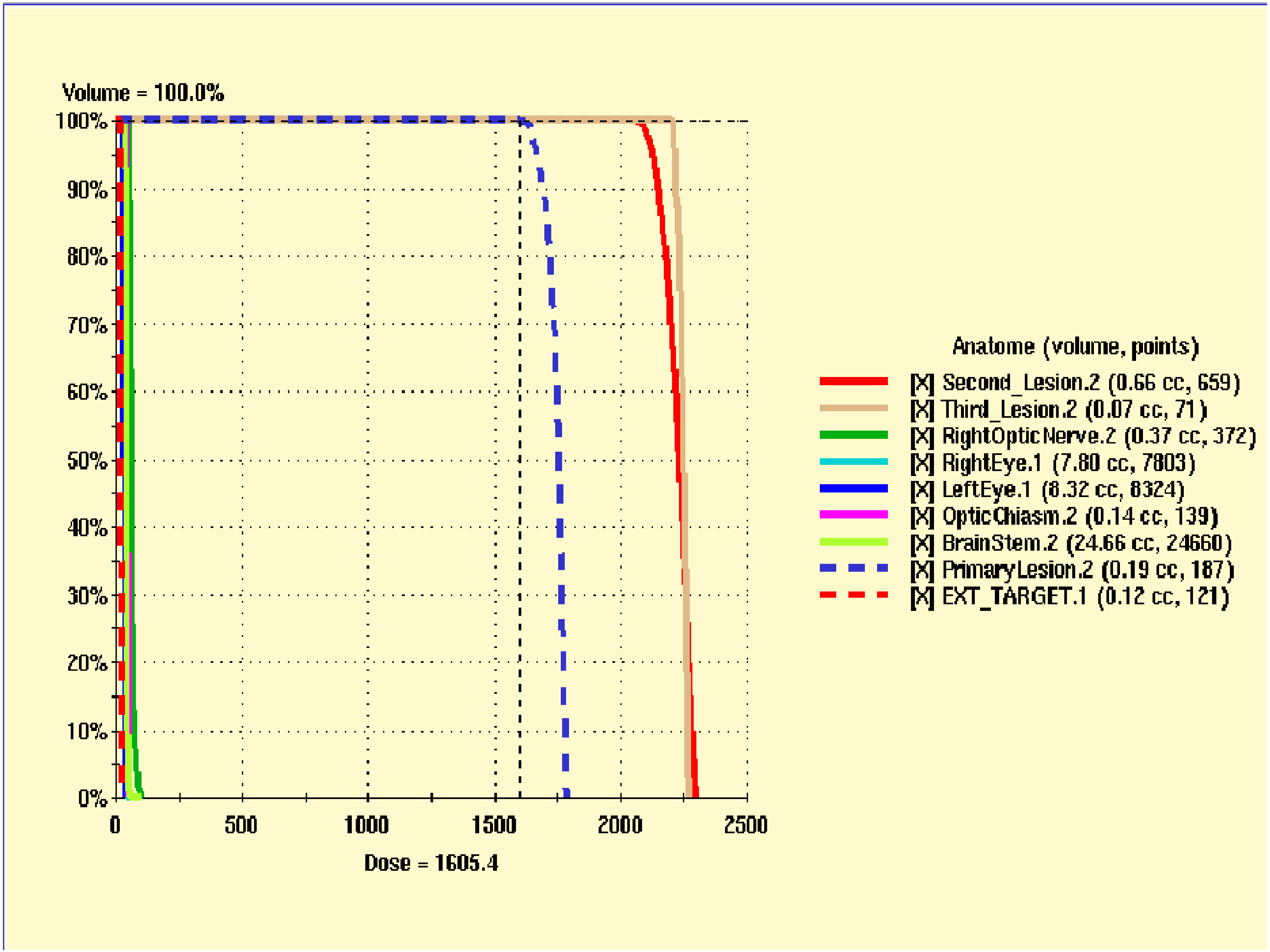
Plano	Imagen N°	OA RIT
X =		
X =		
X =		
X =		

Realizado por: Firma: Fecha:
Verificado por: Firma: Fecha:


External Target

Dose Evaluation Tools

- Volume Dose
- Surface Dose
- Dose Summary
- Slice Dose
- Dose Volume Histograms


Volume = 100.0%
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
500
1000
1500
2000
2500
Dose = 1605.4
Anatome (volume, points)
[X] Second_Lesion.2 (0.66 cc, 659)
[X] Third_Lesion.2 (0.07 cc, 71)
[X] RightOpticNerve.2 (0.37 cc, 372)
[X] RightEye.1 (7.80 cc, 7803)
[X] LeftEye.1 (8.32 cc, 8324)
[X] OpticChiasm.2 (0.14 cc, 139)
[X] BrainStem.2 (24.66 cc, 24660)
[X] PrimaryLesion.2 (0.19 cc, 187)
[X] EXT_TARGET.1 (0.12 cc, 121)

Plan quality indices

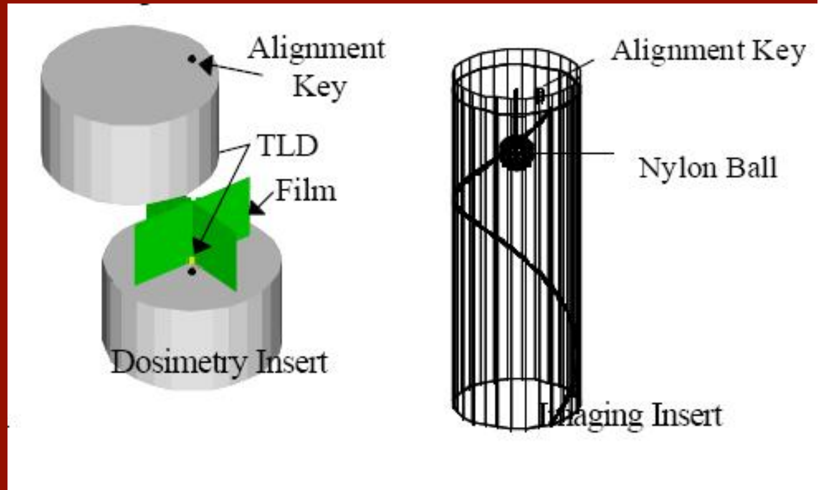
Conformity (CI): Ratio of the prescription isodose volume V(p)to the target Volume V(T)

Homogeneity (HI) Ratio of maximum dose D(max) to Prescription Dose D(p)

- Dose gradient : Ratio of V(T) to Volume of the 50% isodose ($V_{50\%}$)

	Conformity	Homogeneity	Gradient
Reference value	1 – 2	HI $\leq$ 2	$\geq$ 0.3
Minor deviation (acceptable)	0.9< CI < 1 o 2 < CI < 2.5	2 < HI $\leq$ 2.5	
Major deviation (unacceptable)	CI < 0.9 o CI $\geq$ 2.5	HI > 2.5	

Total system verification – external audit



- ***Plan according to "RTOG Quality Assurance Guidelines"***
- ***Phantom***
  - ***Target F = 19mm***
  - ***Gafchromic film in two orthogonal planes***
  - ***2 TLD-100at the target center***
  - http://rpc.mdanderson.org

THE UNIVERSITY OF TEXAS MD ANDERSON CANCER CENTER

Report

Preliminary studies suggest that the precision of the TLD is ±3%, and the localization precision from the film is ±1 mm.

Summary of results:

	Ratio	Criteria [a]
Dose to the center of the target (RPC/Institution)	0.98	0.95 - 1.05
Treated Volume [b]: (Measured/Institution)	0.78	0.75 - 1.25 [c]
Ratio of Measured Treated Volume to Target Volume [d]	1.17	1.00 - 2.00
Minimum Dose to Target (Minimum Dose/Prescription Dose)[e]	0.91	> 0.90

(a) Criteria are adapted from the RTOG QA guidelines. Int. J. Onc. Biol. Phys. 27, 1231-39, 1993.
(b) The treated volume is assumed to be an ellipsoid with diameters taken from the "Film Results" table.
(c) Average discrepancy of approximately 2 mm on each diameter.
(d) The target is the 1.9 cm. sphere.
(e) Minimum dose is taken from the 3 dose profiles.

TLD and Film Analysis by: Paola Alvarez, MS

TLD Results:

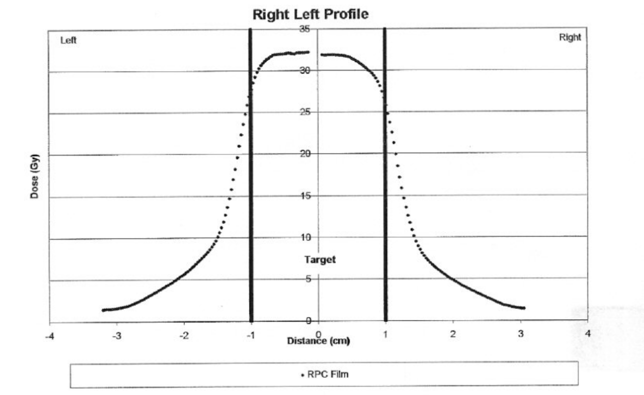
Dose to TLD Capsules (Gy)		Average Dose (Gy)	Institution Dose	Ratio
Upper	Lower	(Dose to Center)	(Gy)	Measured/Institution
30.5	29.4	30.0	30.5	0.982

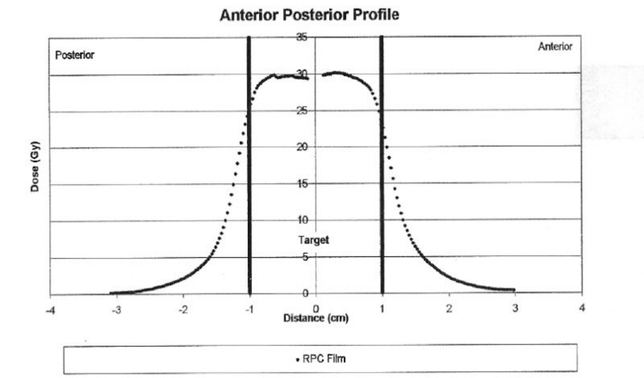
Film Results:

Measured Along	Field Size (80% Isodose Line) Measured (cm)	Institution (cm)	Measured - Institution	Offset (80% Line)* (cm)
Right/Left Profile (x)	2.1	2.2	-0.1	0.0
Anterior/Posterior Profile (y)	2.0	2.1	-0.2	0.0
Superior/Inferior Profile (z)	1.9	2.2	-0.3	-0.1

Treated Volume (cm^3)**	4.19	5.40

* Offset is the distance between the center of the specified isodose line and the center of the physical target.
** Treated Volume= (π•x•y•z)/6





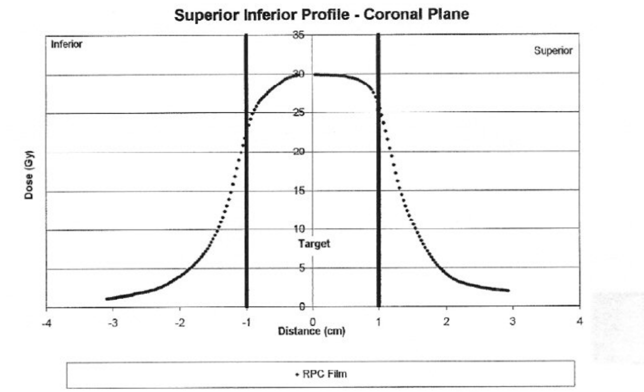


Table 1. List of radiosurgery events reported to the NRC during the period 2005-2010

Event Description	Treatment Implication
Patient orientation entered incorrectly at MR Scanner	Wrong location treated
Fiducial box not seated properly during CT imaging	Wrong location treated
Malfunction of automatic positioning mechanism following re-initialization	Wrong location treated
Right trigeminal nerve targeted instead of left	Wrong location treated
Facial nerve targeted instead of trigeminal nerve	Wrong location treated
Mistake in setting isocenter coordinates	Wrong location treated
Head not secured to stereotactic device (2 events)	Wrong location treated
Selected collimators did not match planned	Wrong dose/distribution delivered
Physician mistakenly typed 28 Gy instead of 18 Gy into planning system	Wrong dose delivered
Physicist calculated prescription to 50% isodose instead of 40%	Wrong dose delivered
Microphone dislodged, causing stereotactic device to break	Treatment halted after 2 of 5 fractions
Couch moved during treatment	None; personnel interrupted treatment

from: **Quality and safety in stereotactic radiosurgery and stereotactic body radiation therapy: can more be done? Timothy D. Solberg, and Paul M. Medin**
Jour. of Radiosurgery and SBRT, Vol. 1, pp. 13-19

LESSONS FROM RECENT ACCIDENTS IN RADIATION THERAPY IN FRANCE

S. Derreumaux*, C. Etard, C. Huet, F. Trompier, I. Clairand, J-F. Bottollier-Depois, B. Aubert and P. Gourmelon
Institut de Radioprotection et de Sûreté Nucléaire, Direction de la Radioprotection de l'Homme, IRSN, BP 17, F-92262 Fontenay-aux-Roses Cedex, France
Radiation Protection Dosimetry (2008), Vol. 131, No. 1, pp. 130–135

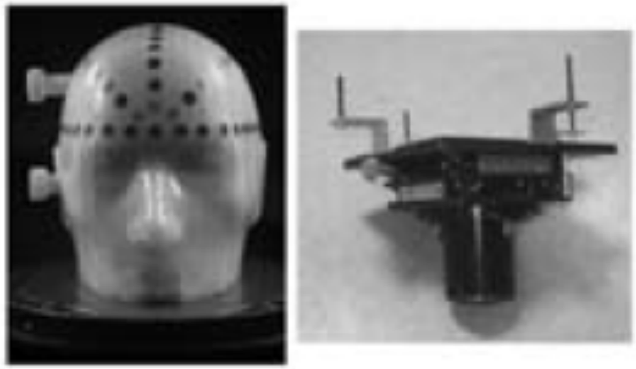


Figure 2. Stereotactic radiotherapy treatment delivery with successive beam entrance positions as a function of accelerator and table rotation angles (left). The plate used in the centre (Case 2) to hold the cylindrical additional collimator (right).

Single fraction SRS for AVM, November, 2004

Prescription dose not reported; plan/treatment used multiple isocenters, with collimators from 10 -30 mm

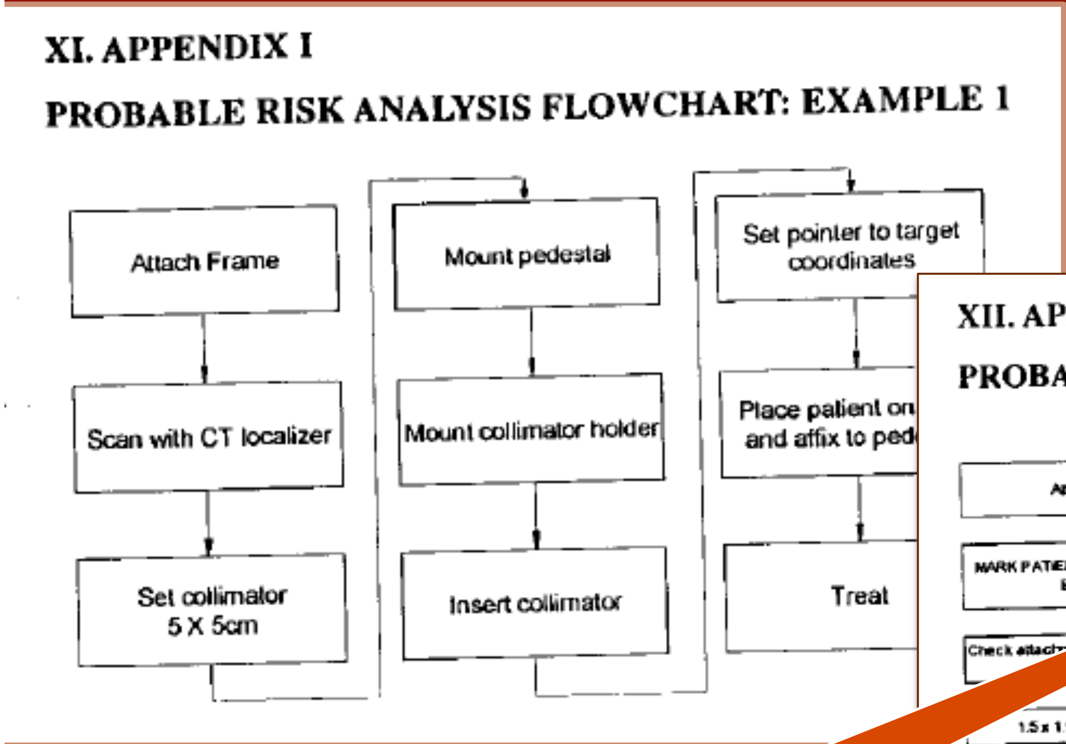
Jaws set to 40 x 40 cm^2 instead of 40 x 40 mm^2. Physicist told therapist "40 x 40"

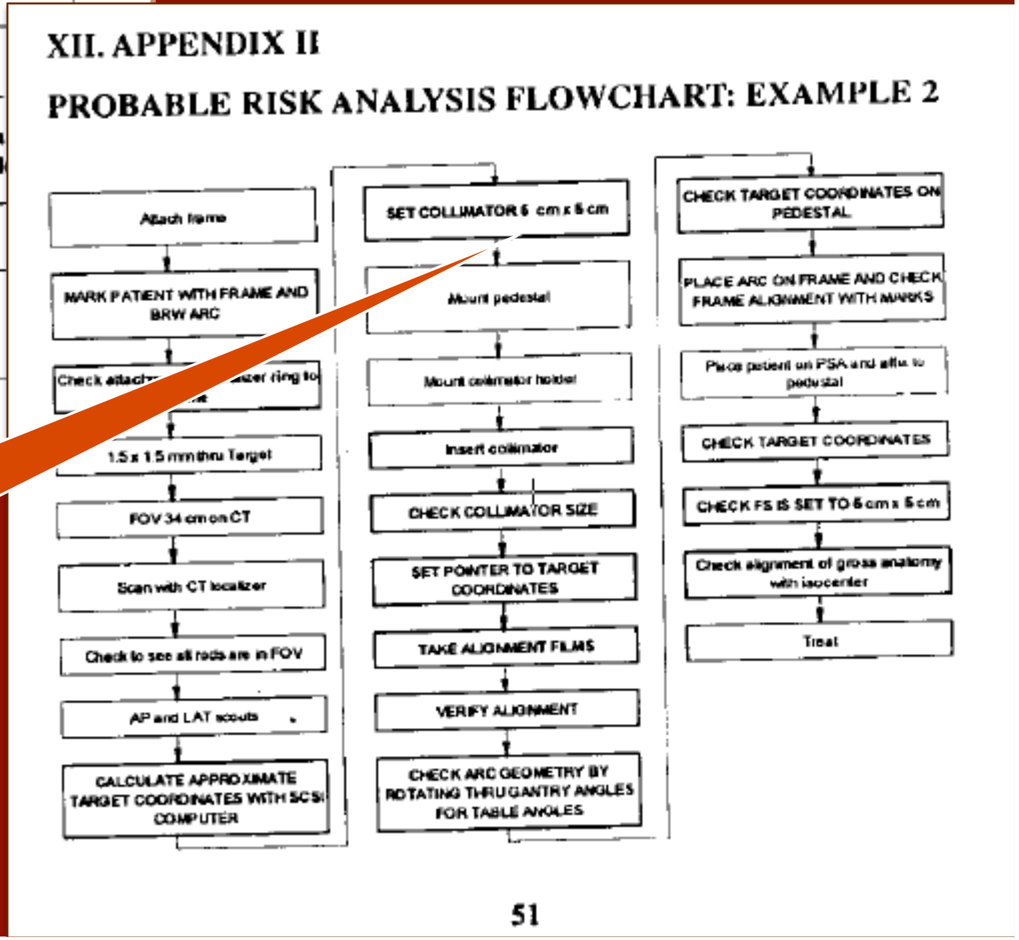
Some areas of normal brain received in more than dose to intended target

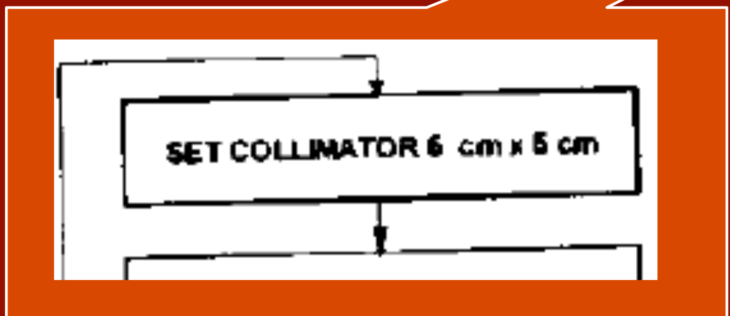
Severe complications: "fibrosis and oseo-tracheal fistula that required surgical operation." Patient died several days later as a result of a "brutal haemorrhage."

A written checklist system, and/or a proper R/V system can minimize events like this

AAPM Report 54 (1995) Task Group #42 - Stereotactic Radiosurgery







RADIOSURGERY PROCEDURE CHECK LIST

Patient Name:	Date:

ISOCENTER NAME :					
EXTERNAL TARGET	AP	LAT	VERT	SIGNATURE	
Phantom Base Measurements			+ 2.4 =		
Plan-32 Calculation					
External test target acceptable:					
TRUE TARGET (ISO)	AP	LAT	VERT		
Floor Stand (target) coord					
Floor Stand Redout Check					
Collimator size					
Collimator Inserted					
Jaw 5 x 5,Collimator:270°					
Target Simulator	AP	LAT	VERT		
Coordinates			+15.4 =		
Target Simulator Film Acceptabble	Exposure	Gantry	Couch		
	1	130 °	180 °		
	2	65 °	180 °		
	3	295 °	180 °		
	4	230 °	180 °		
	5	130 °	270 °		
	6	67 °	270 °		
	7	230°	90 °		
	8	297 °	90 °		
Anti-collision switches in place					
Couch Disabled					

LONG ISLAND JEWISH MEDICAL CENTER
DEPARTMENT OF RADIATION ONCOLOGY
RADIOSURGERY PROCEDURE CHECK LIST

Patient Name:	ID:	Date:

ISOCENTER NAME :

EXTERNAL TARGET	AP(Y)	LAT(X)	VERT(Z)	SIGNATURES	
Phantom Base Measurements			+ 2.4 =		
Radionics Calculation (mm)					
Treatment Planning System(mm)					
External test target acceptable	Yes		No		
TRUE TARGET (ISO)	AP(Y)	LAT(X)	VERT (Z)		
Rectilinear Phantom Pointer(RLPP)					
RLPP(target) Coordinates (mm)					
RLPP read out check (mm)					
Collimator (cone) size planed			mm (diameter)		
Collimator Inserted			mm (diameter)		
Jaw 5 x 5,Collimator: 0°	Yes		No		
Laser Target Localizer Frame (LTLF)	AP(Y)	LAT(X)	VERT(Z)		
LTLF Coordinates (mm)					

Target Simulator Film Acceptable	Exposure	Gantry	Couch		
	1	0°	90°		
Yes No	2	270°	0°		
	3	90°	0°		
	4	0°	270°		

Couch Motion Disabled	Yes	No		

Depth Confirmation Helmet Check	Point	Helmet Port	Depth (mm)		
	1				
	2				
	3				
	4				
	5				
	6				

תודה
Dankie Gracias
Спасибо شكراً
Merci Takk
Köszönjük Terima kasih
Grazie Dziękujemy Dėkojame
Ďakujeme Vielen Dank Paldies
Kiitos Täname teid 谢谢
Thank You
Tak
感謝您 Obrigado Teşekkür Ederiz
감사합니다
Σας ευχαριστούμε ขอบคุณ
Bedankt Děkujeme vám
ありがとうございます
Tack