A Review of Emerging Technologies in Robotic SRS/SBRT Delivery

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8/4/2016

CyberKnife® System Evolution

G3 CyberKnife
2002

G4 CyberKnife
2005

VSI CyberKnife
2009

CyberKnife® M6™ Series

Released in 2012

Image courtesy of Accuray Inc

The CyberKnife® System

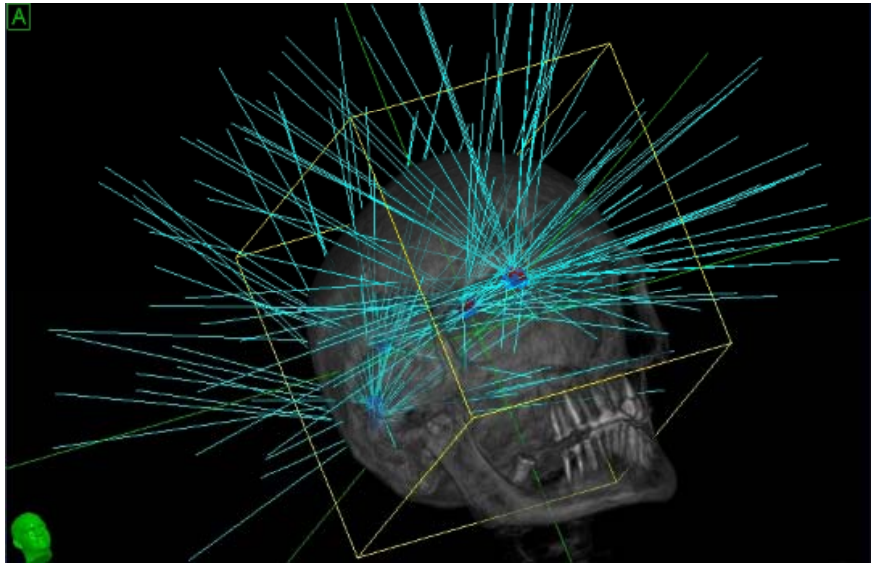
- X band Linac 6MV 1000MU/min
- 6 joint Robot manipulator
- Fixed, Iris, InCise™ MLC(M6 only)
- 6D freedom Robot Couch
- KV X-ray and imagers
- Synchrony

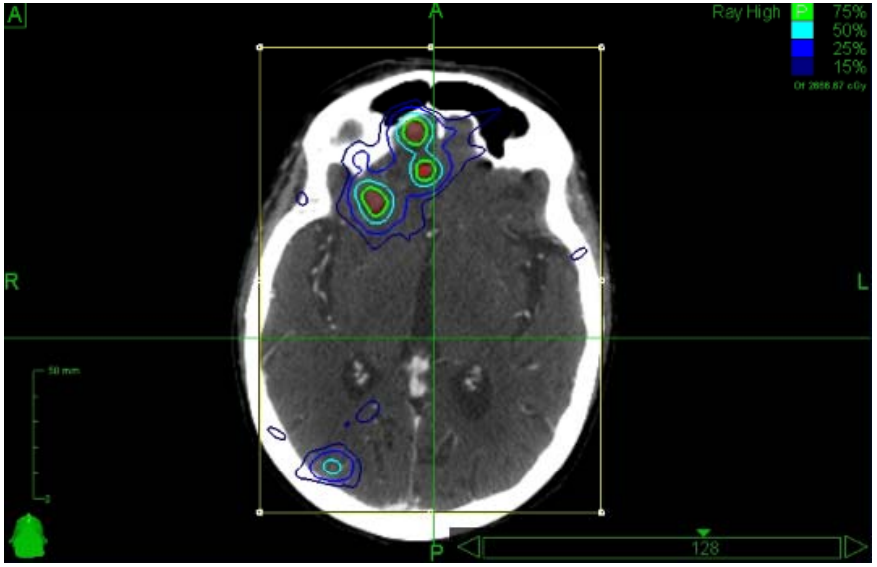
CyberKnife® M6™ Image courtesy of Accuray Inc

System Summary

- Brain and Body
- Tx lasts 15-60 minutes depending on lesion complexity
- 1-5 Fx to standard (180 cGy) fractionation scheme
- Non-isocentric delivery
- Real time tracking, motion management with Synchrony
- Specification of <0.95 mm dose placement accuracy as defined by **E2E test** (0.3-0.7 mm)

A Cyberknife Plan for Six Brain Mets

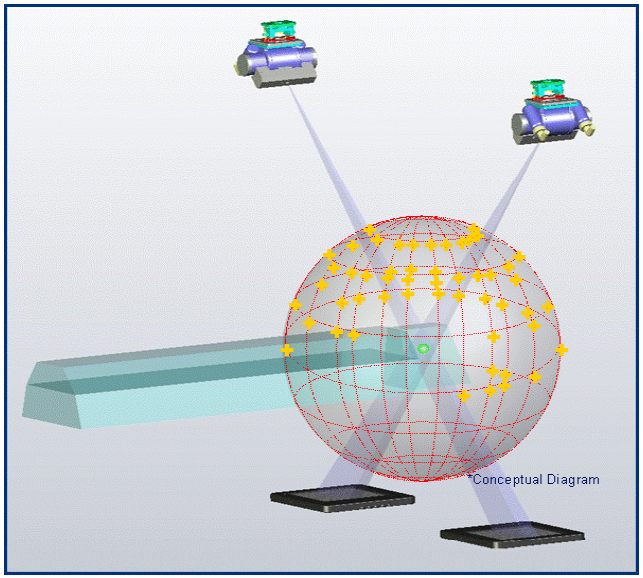




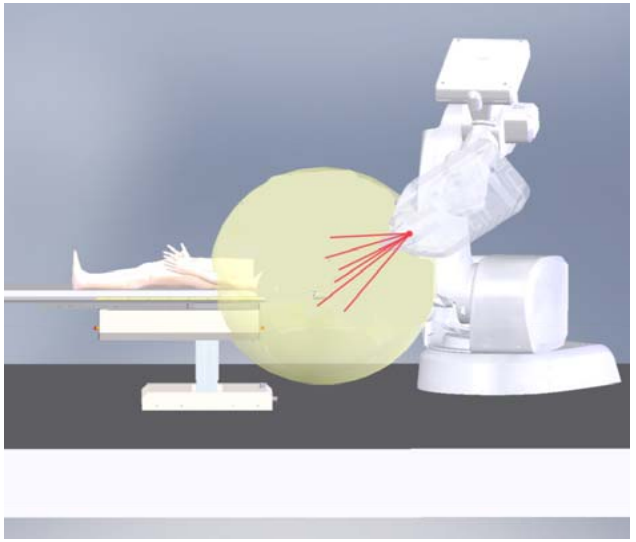
20Gy in 1 Fx, 143 beams, Tx time 51 minutes

Cyberknife Delivery

1. Time-based imaging (every 30-90 seconds)
2. Robot automatically adjusts:
   - 10 mm in translations
   - 1.5 degree in pitch and roll
   - 3 degrees in yaw



Nodes on a path



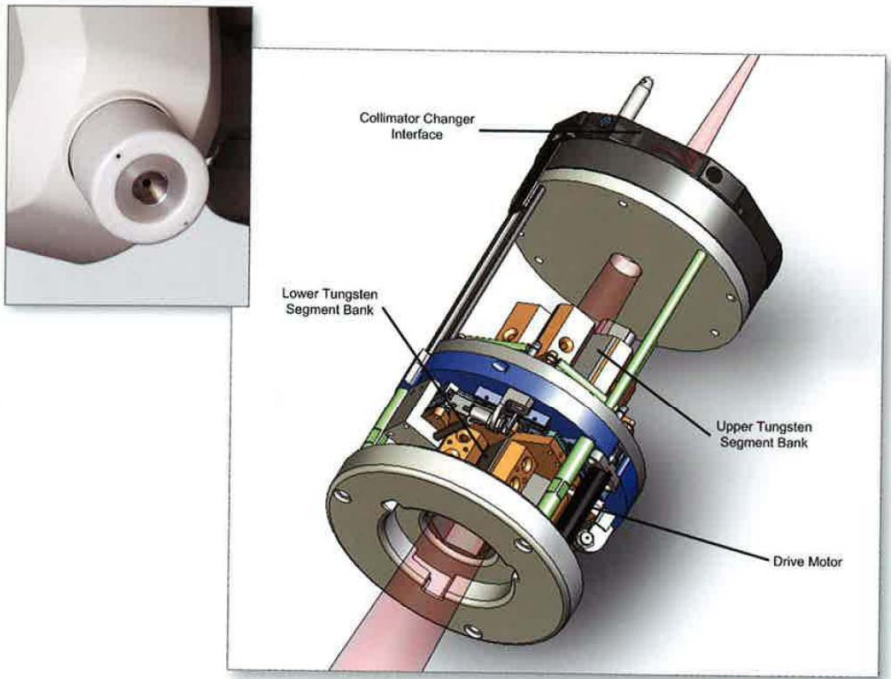
Beams from a node (up to 12)

The Circular Collimators

Fixed Collimators (5 mm – 60 mm)

IRIS Colimator:

- 12 discrete collimator sizes
- 2 collimator banks of
  6 leaves each
- Offset by 30 degrees
- accuracy 0.2mm at 800cm

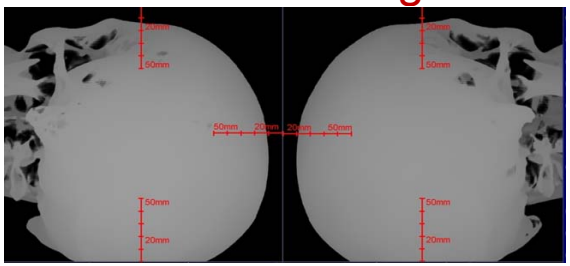


Iris Collimator

Iris treats through one path, reduces MU and Tx time with a better plan quality.

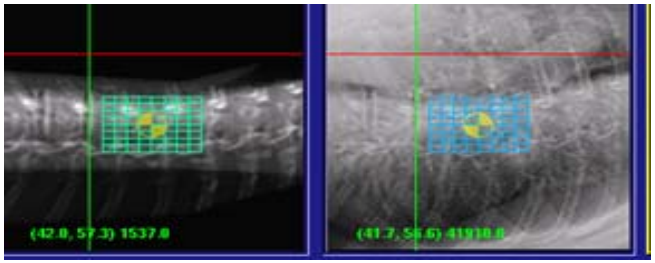
Tracking Algorithm: E2E test mean 0.3-0.7mm

Cranial tracking



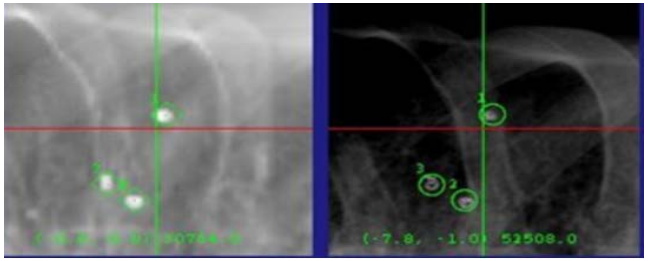
- Tracking Accuracy:<0.51mm within 10cm from rotation center (Dongshan Fu, et. al. 2008)

Spine tracking



- Accuracy overall: 0.61±0.27 mm (Ho et. al, 2007)
- Available with prone and Synchrony

Fiducial tracking



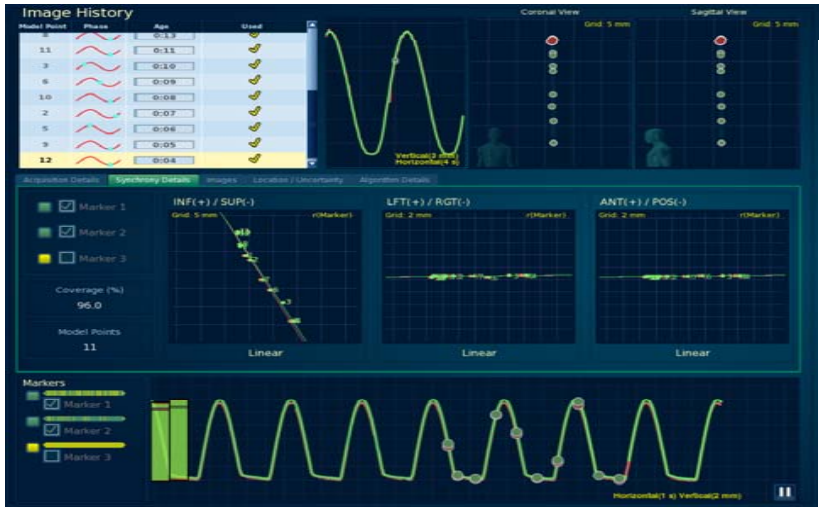
- Tracking accuracy: 0.29 ± 0.10 on G4 (Antypas et al. 2008)

Soft-tissue lung tumor tracking

- Peripheral tumors > 15 mm
- 2D tracking available through lung optimized treatment.

Motion Management: Synchrony

1. Tumor position and skin markers get correlated
2. Skin motion predicts tumor motion
3. Robot follows the tumor motion



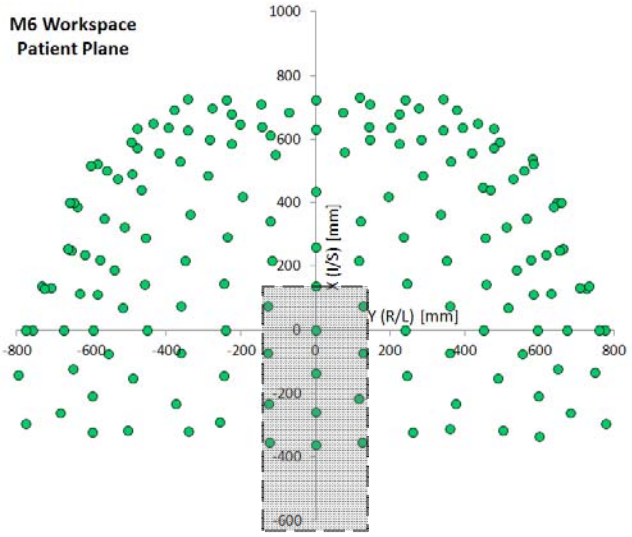
Accuracy: <1.5mm on Phantom

- Patient specific
- 2-5mm margin used in clinical

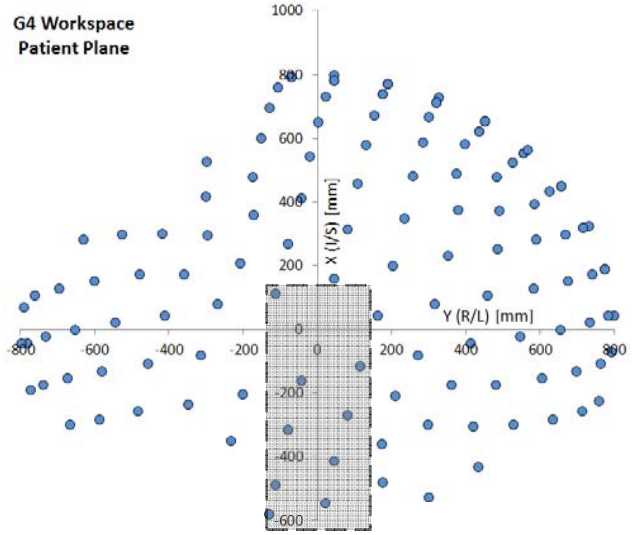
(Clinical study reported by Pepin at el. 2011)

The CyberKnife® Workspace: M6™ vs. G4

- Redesigned room layout with Robot aligned with couch
- Working space expanded
- Post lateral beams below horizontal ~20 degree.



Right : Left = 50% : 50%



Right : Left = 36% : 64%

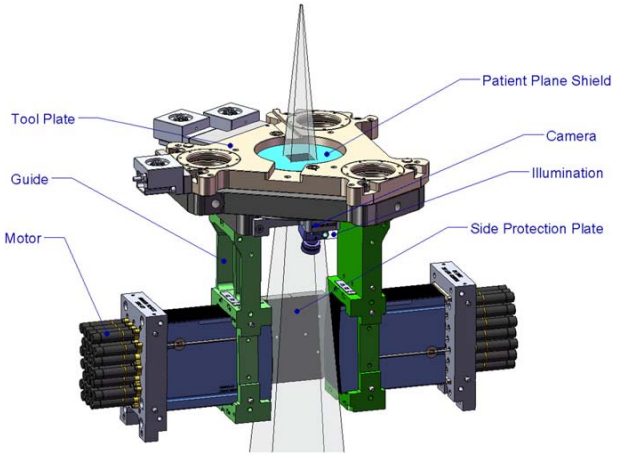
Image courtesy of Accuray Inc

InCise™2 MLC

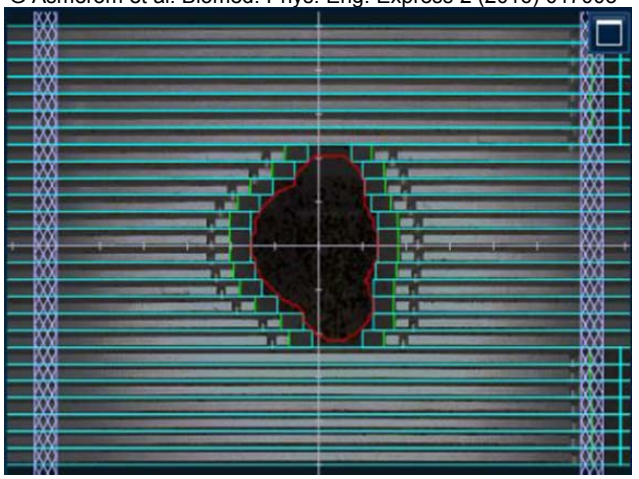
2nd generation

- Maximum clinical field size 115 mm x 100 mm at 800 mm SAD
- 2 banks of 26 leaves
- 3.85 mm leaf width at 800 mm SAD
- 100% over-travel
- Full interdigitation

•Camera based secondary feedback system resolution 1mm. Test performed before and after the beam on.



G Asmerom et al. Biomed. Phys. Eng. Express 2 (2016) 017003



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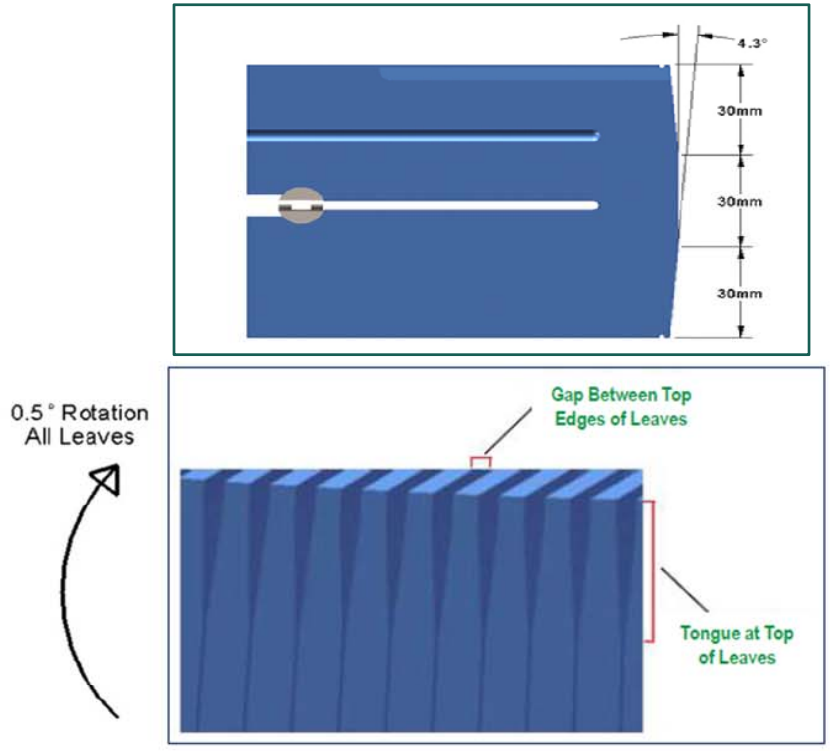
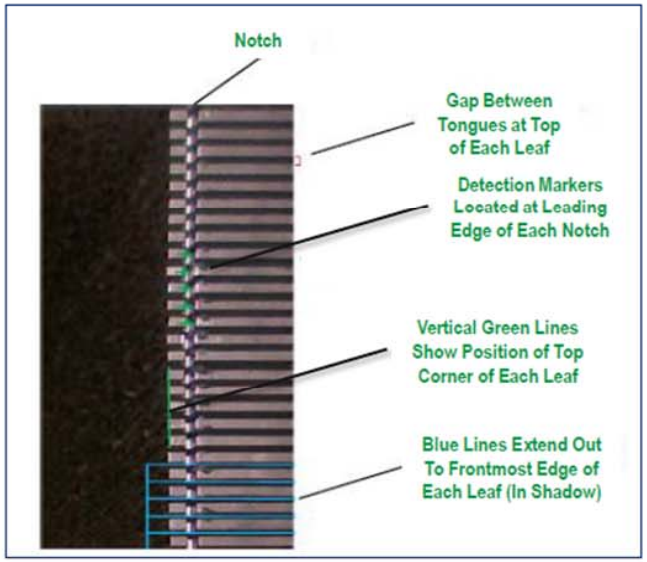
InCise™2 Leaf Geometry

Leaf shape



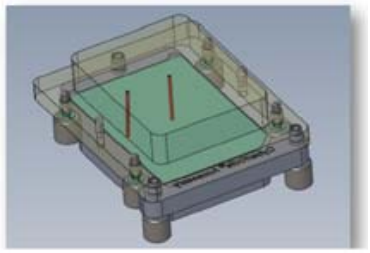
Correspondence between camera image and leaf structures

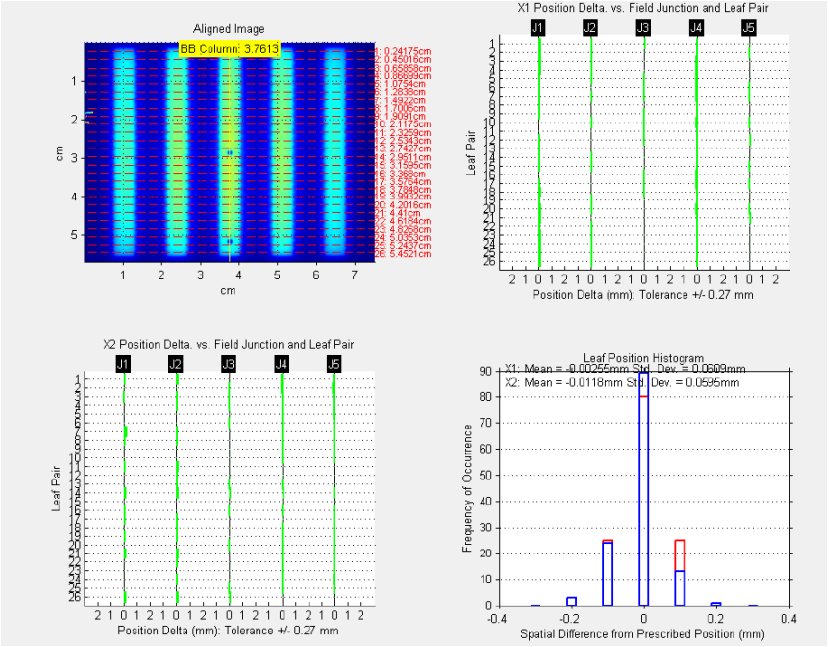


The max leaf transmission <0.5%

InCise™2 MLC QA

- Garden fence for quantitative test
- Picket fence for qualitative test
- Test at perch and arbitrary angles





Spec:

- Mean leaf deviation (80cm SAD) < 0.2mm.
- >90% of the leaf offsets <0.5mm.
- No offset > 0.95mm.

Ref. 1. G Asmerom et al. Biomed. Phys. Eng. Express 2 (2016) 017003

Ref. 2. Christoph Fürweger et al. Medical Physics **43**, 2063 (2016); doi: 10.1118/1.4944740

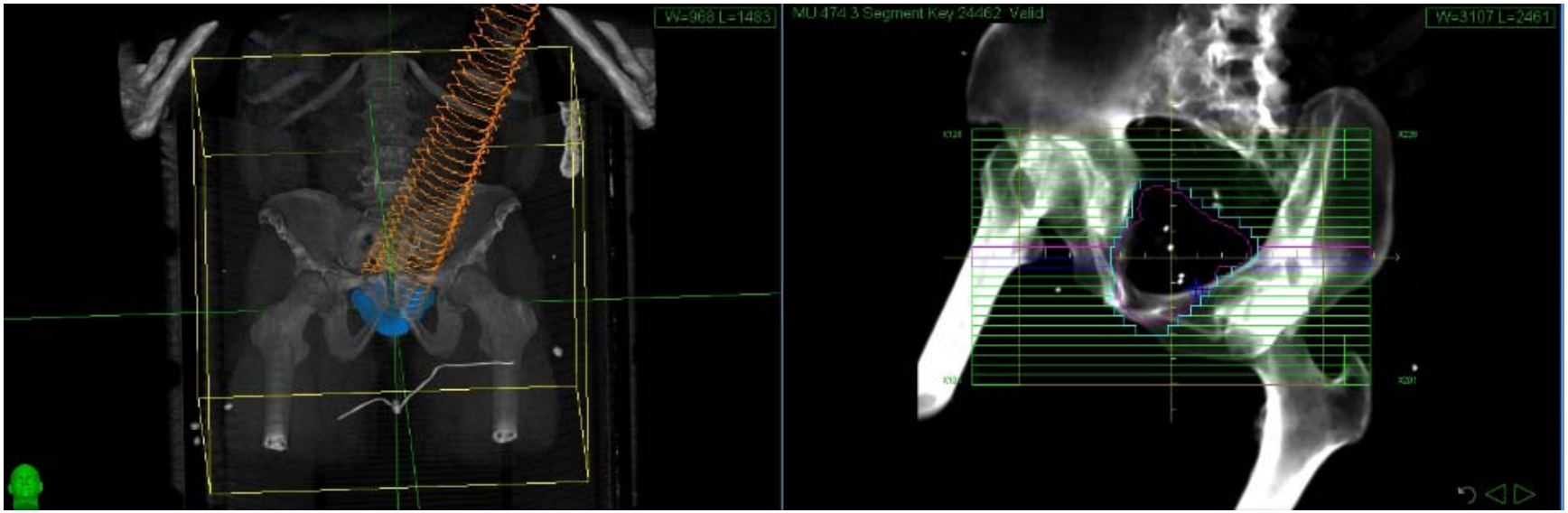
Treatment Plan with InCise™2 MLC

1. Step and shoot
2. Pre-created MLC apertures
3. Weight based sequential optimization
4. FSPB and MC

Major benefits:

MU and Tx time reduction

Better dose gradient



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The Clinical Application of InCise™2 MLC: Stanford Experience

Lei Wang et. al. AERO users' meeting 2016, San Francisco.

14 Spine and Brain Cases: Volume average 75cc (20 cc -258 cc)

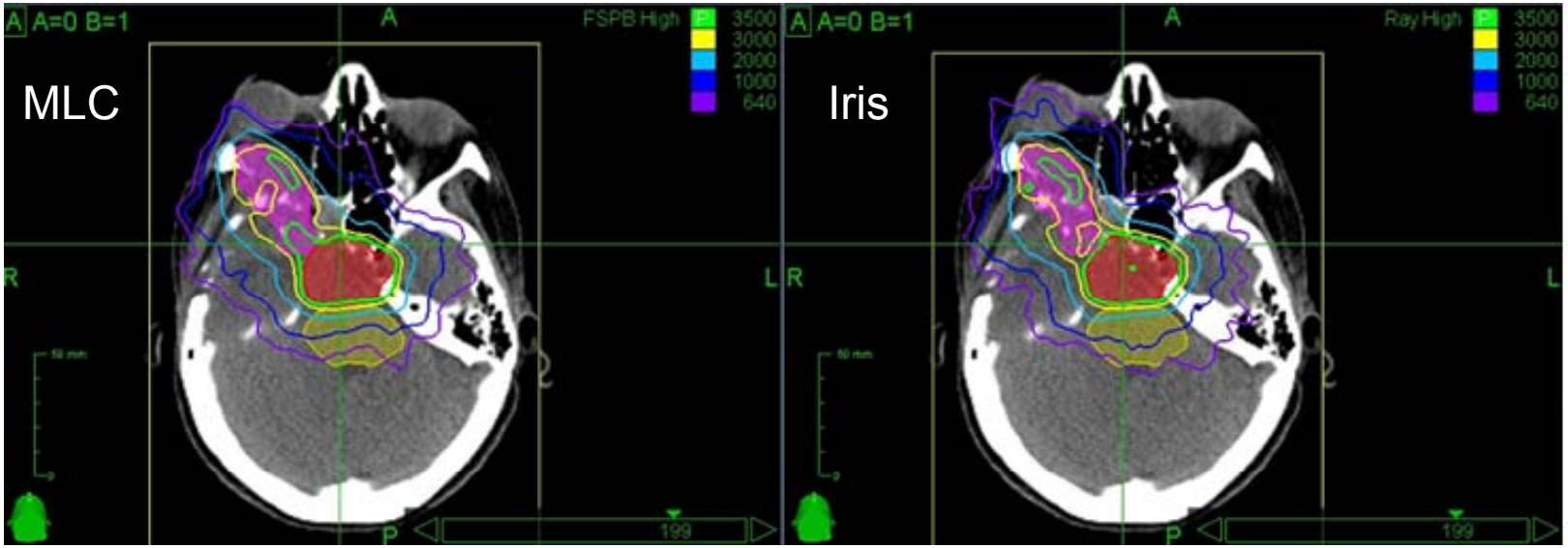
- Clinically similar plans created.
- MLC plans have 36% less MU and 35% less Tx time on average.
- V50% for MLC plans is about 10% less
- Lower minimum coverage dose was observed with MLC plans.

What do we treat with MLC?

- Prostate
- Brain cavities and mets
- Head and neck
- Large spine (Patient specific. Limited by cord dose.)

Theoretically anywhere, good for big targets. MC will be needed for Lung treatment!

A Brain Case: R Orbit

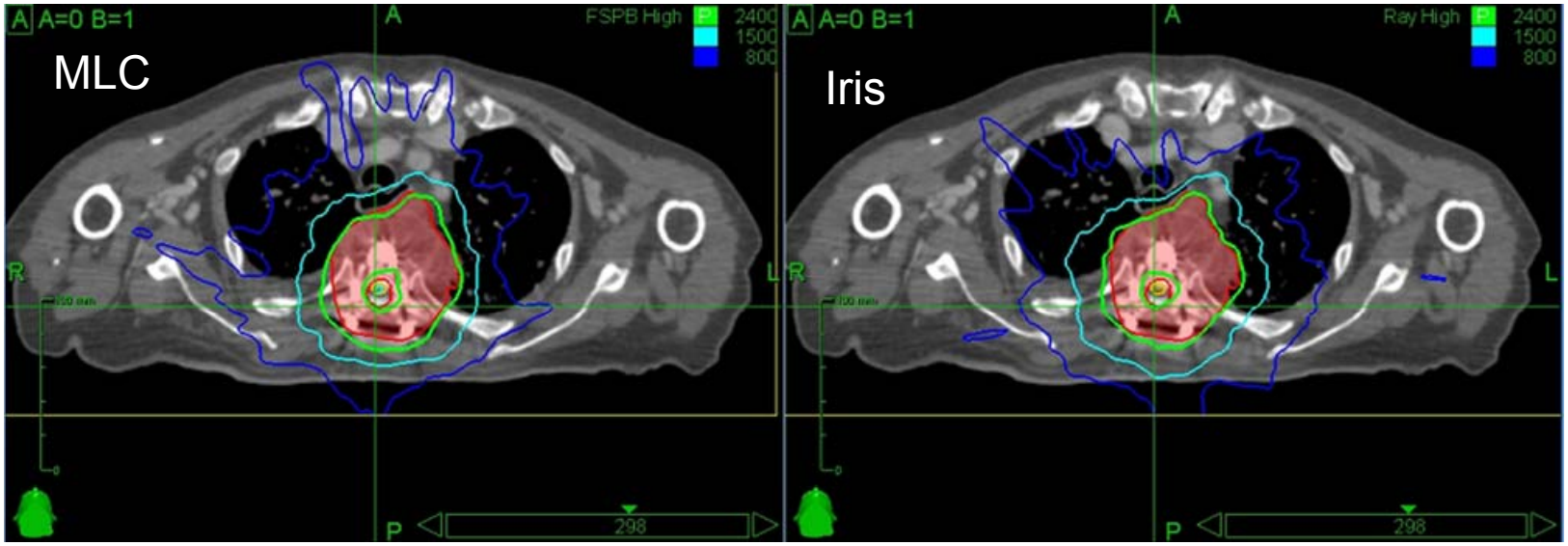


Volume : 52 cc. 35Gy/5Fxs

Time: 20 minutes (MLC) vs 40 minutes (Iris). **-50%**

MU: 12997(MLC) vs. 38669 (Iris). **-66%**

A Spine Case: T2-T4



24Gy in 3 Fxs, TV 258 cc.

Time: 36 min (MLC) vs 61 min (Iris). **-40%**

MU: 35265 (MLC) vs. 53556 (IRIS). **-35%**

Best for Prostate Hypo-fractionated Treatment

- Tx time 15-25 minutes
- MU reduction ~40%
- Tx time reduction ~36%
- Better dose gradient

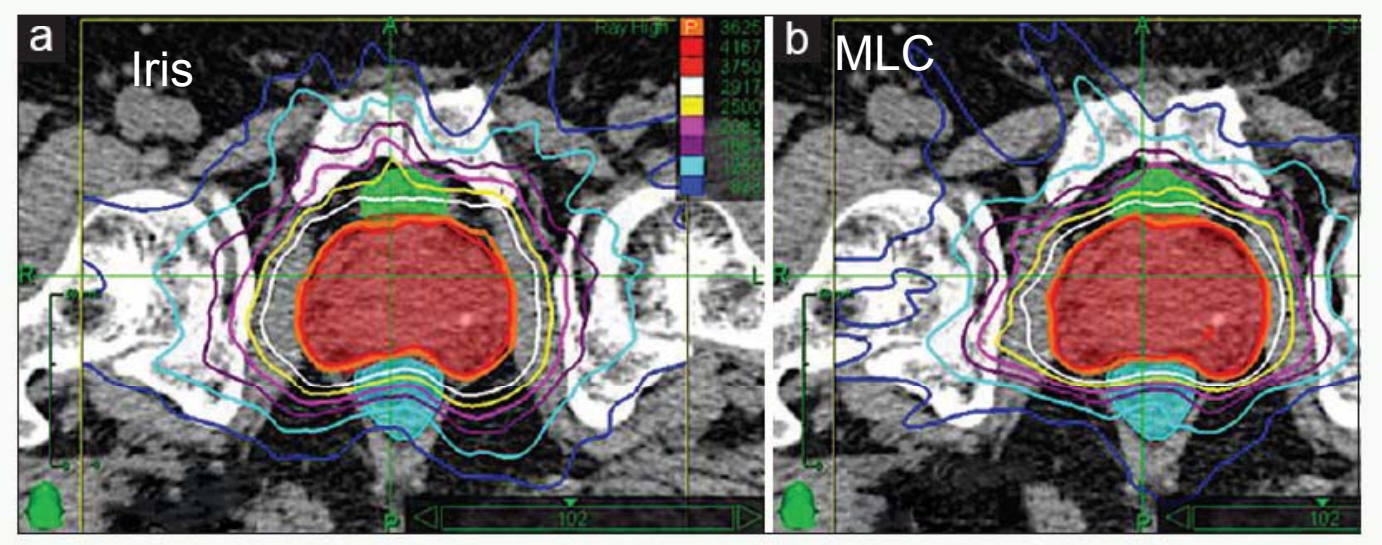


Figure and Data from reference [1]

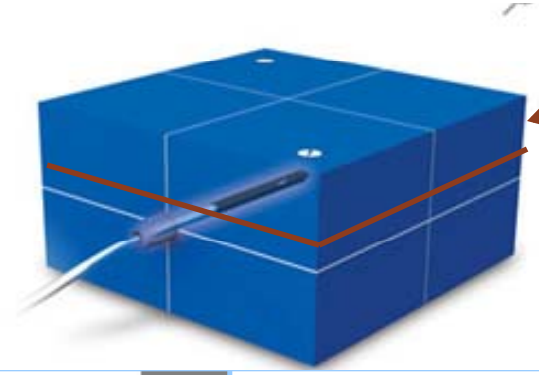
[1] Kathriarachchi et. al. J Med Phys. 2016, 41(2): 135–143.
[2] McGuinness et. al. J of App C Med Phys, 16 (5), 2015

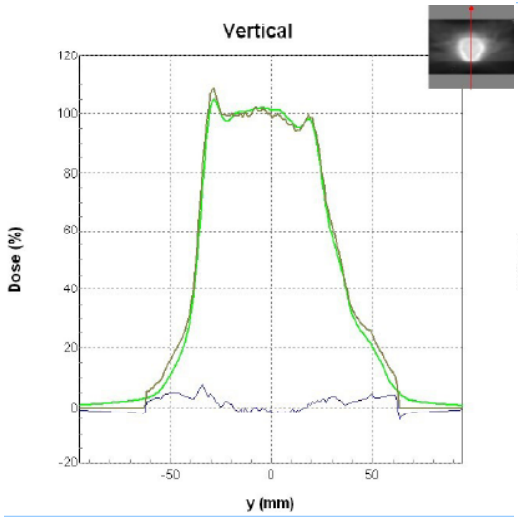
Patient QA

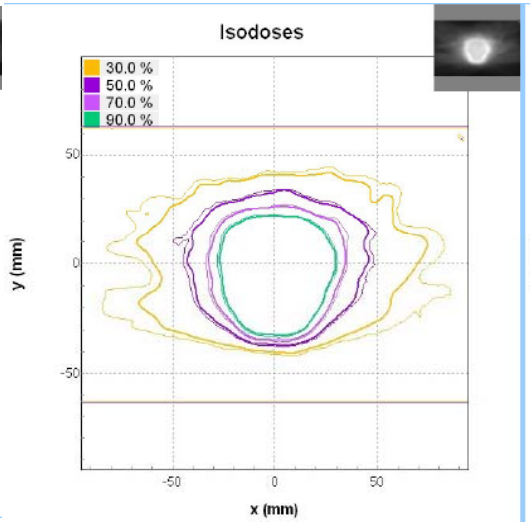
Galfchromic EBT3
Pinpoint or A16 micro ion chamber

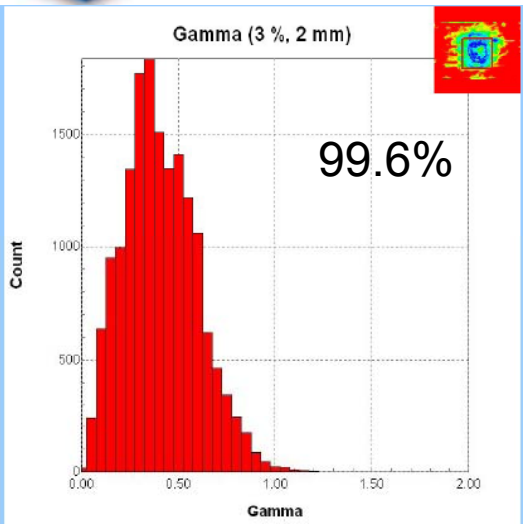
G(3%, 2mm)>90% (relative dose)
Point dose agrees <3%

SRS phantom with embedded fiducials



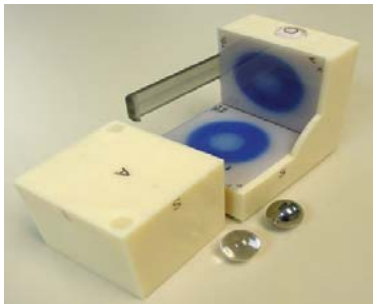






CyberKnife® QA

- AAPM task group report (TG135, TG51, TG142), and Vendor's suggestion
- Better and faster periodical QA and patient QA system are needed.

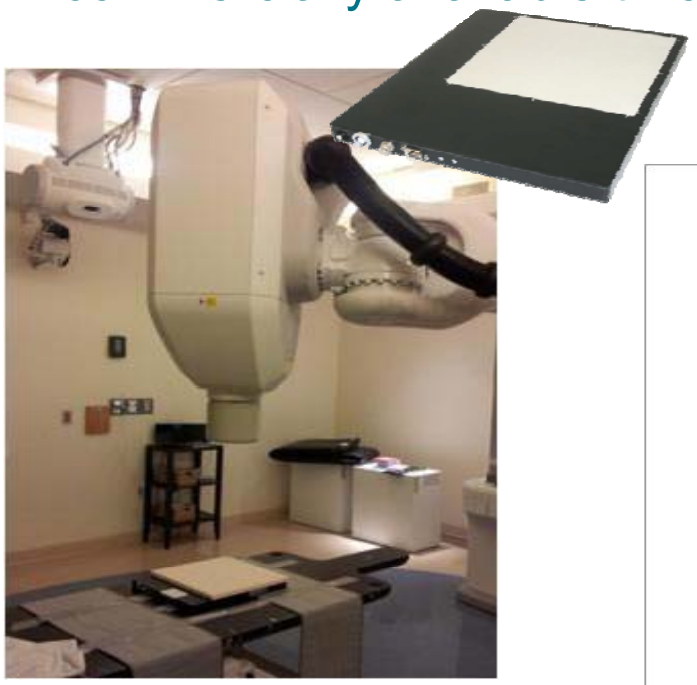


•AQA check daily targeting accuracy

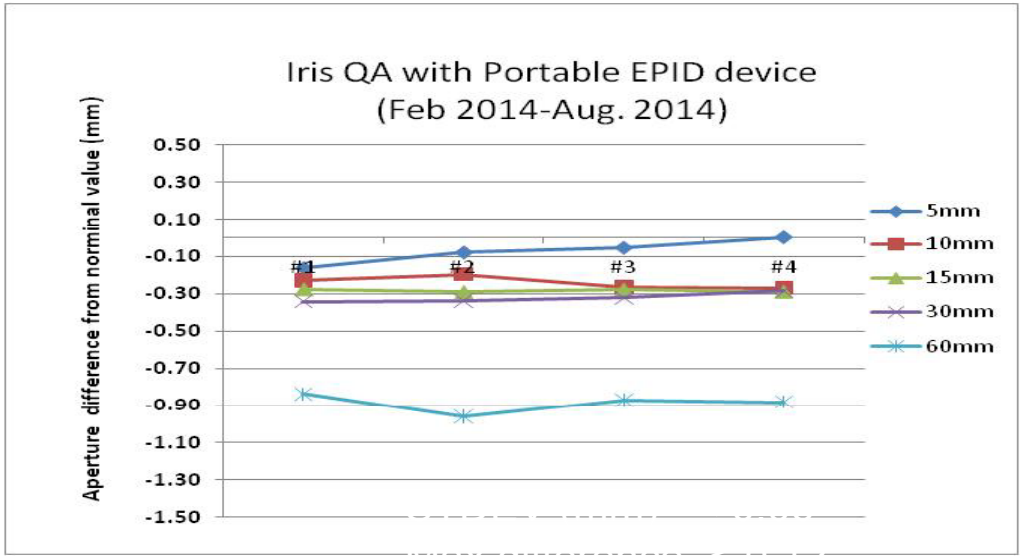
•With Ballcube and laser-cut films.
•Dose accuracy : 3%
•Targeting accuracy: <1mm
• Gamma (3%, 1mm) in high dose region: >90%

A EPID based QA system for Iris ™ and InCise™ collimators

Now commercially available through Standard Imaging



Targeting and profile/aperture consistency check, EPID dosimetry



Development of a High-Resolution and High-Efficiency Strategy for Robotic Radiosuregery QA

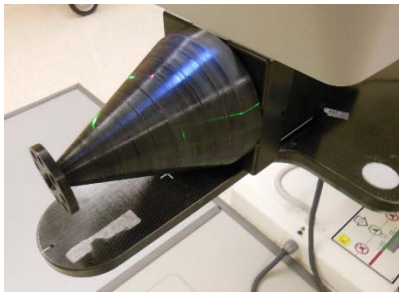
Bin Han, Aiping Ding, Lei Xing and Lei Wang

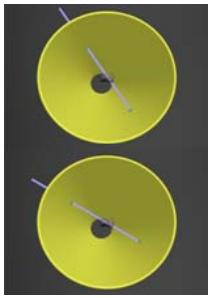
Dept. of Radiation Oncology, Stanford University School of Medicine, Stanford, CA email: hanbin@stanford.edu

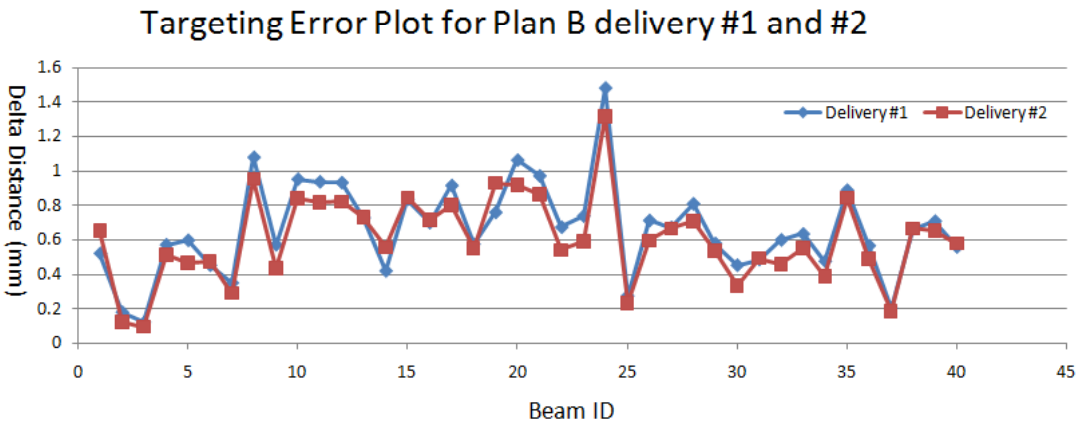
A Scintilator-CCD System: A potential End to End test system

Logos Systems Int'l, Scotts Valley, CA

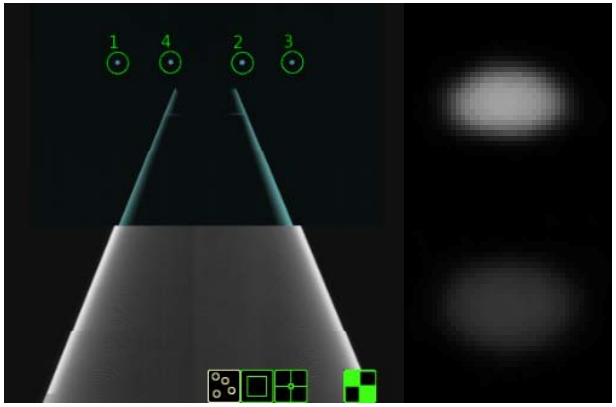
Beam by beam 3D accuracy
Excellent reproducibility (≤0.2mm)
Sensitive to beam spot size (<0.2mm)
Good for daily and monthly







Lei Wang et al. presented at RSS meeting 2014



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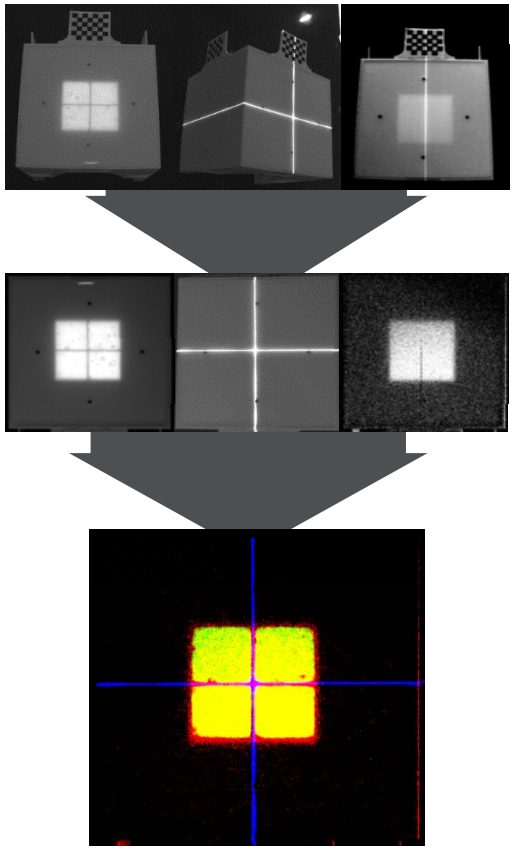
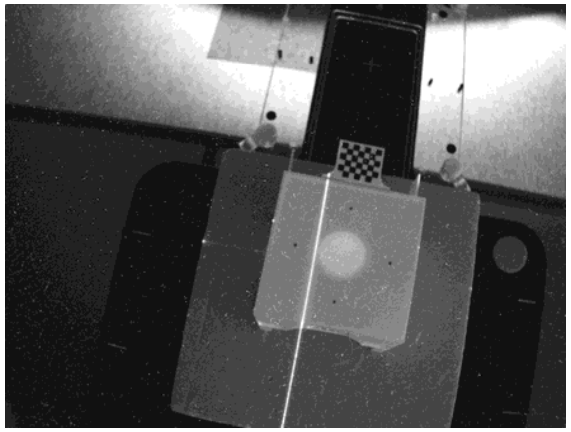
Automated QA with Scintillator Coated Phantom

- Scintillator coated phantom
  - Contains kV fiducials
  - Enables visualization of radiation fields and lasers
- Camera
  - Captures images
- Image processing
  - Self-calibration using fiducials
  - Fully automatic check

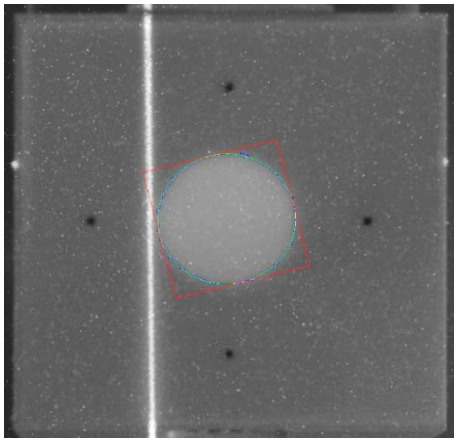


Provided by Cesare Jenkins, Stanford University

Raw Beam-On Image



Processed image



Summary

- CyberKnife is a very advanced SBRT delivery system with high dosimetric and targeting accuracy
- Knowledge about internal target position during treatment time only surpassed by Calypso electromagnetic tracking system
- The introduction of MLC opened the opportunity for treating larger tumors with significantly increased Tx efficiency
- Current system allows 15-30 min treatments
- Faster and better QA equipment are needed and being developed.

Thank you!

I would like to acknowledge Bin Han and Cesare Jenkins for their slides on EPID and automated QA.