A Review of Emerging Technologies in Robotic SRS/SBRT Delivery

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CyberKnife® System Evolution

G3 CyberKnife 2002

G4 CyberKnife 2005

VSI CyberKnife 2009

CyberKnife® M6™ Series
Released in 2012

Image courtesy of Accuray Inc

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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

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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)

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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 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)

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

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

- **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

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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.
InCise™2 Leaf Geometry

The max leaf transmission <0.5%

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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. 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
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/5Fx
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]

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
Film

99.6%
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 Radiosurgery QA

Bin Han, Aiping Ding, Lei Xing and Lei Wang

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A Scintillator-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
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.