Objectives

- Components and work flow of CyberKnife
- Motion management of CyberKnife
- Dosimetry characteristics of CyberKnife
- New development of CyberKnife
- QA of CyberKnife
CyberKnife Components & treatment
Motion management
Dosimetry
Quality Assurance
CyberKnife® Components

- Diagnostic X-Ray Source
- Linear Accelerator
- Robotic Arm
- Image Detectors
- Treatment Couch
Linear Accelerator

- 330 lbs.
- 6 MV X-ray
- 1000 MU/min
- Three set collimators
  - 5 – 60 mm circular collimators
  - 5 – 60 mm dodecagonal (12-sided) IRIS variable aperture collimators
  - 100 x 120 mm MLC
Robot Specifications
Made by KUKA of Germany

- 6 axis / joint motion
- 1,525 kg (w/Linac)
- 210 kg payload
- 208 VAC, 3 Phase (PDU)
- 0-45 ºC operating range
- <75% Relative humidity
- 13 ft x 16 ft operating envelope (3 m reach)
- 0.12 mm repeatability
5° Treatment Couch (Axum)

- Accommodates up to 159 kg patient (350 lbs)
- Motorized control with 5 degrees of freedom
  - Inferior-superior
  - Anterior-posterior
  - Right - left
  - Roll
  - Pitch
Image Tracking System

- 2 diagnostic X-Ray sources
  + 2 ASi image detectors (cameras)

- Patient imaged at 45° orthogonal angles

- Real-time, live images compared against DRRs generated from CT

- During treatment, Robot adjusts position based on the comparison
Development of CyberKnife

G4

Fixed Cones

IRIS

M6

MLC
* 41 leaf pairs
  * 2.5 mm leaf thickness @ 800 mm
  * 120 mm x 100 mm field size
  * 90.0 mm leaf height
  * 0.5 mm leaf position accuracy
  * 0.4 mm reproducibility

* Transmission: <0.3% avg
  (<0.5% max)
* Full leaf inter-digitation
* Full leaf over-travel
* Single Focus MLC
Cyberknife G4 -> M6

Digital Platform
Different Robot position

MLC -> IMRT capable
  SBRT: faster, slightly better SBRT plan
  IMRT: comparable with Linac based
SBRT Plan Comparison

MLC

Fixed Cones
CyberKnife Components & treatment
Motion management
Dosimetry
Quality Assurance
Case Specific Tracking Modalities

- Skull Tracking       ----  Brain tumor
- X-site (spine) Tracking  ----  Spine tumor
- Fiducial Tracking     ----  Soft tissue
- Synchrony Tracking   ----  Moving Soft tissue
- X-sight Lung         ----  Moving visible lung tumor
- Lung Optimization Treatment  ---  a full set of tracking for lung tumor without fiducial
Tracking Methodology

- DRR (Digitally Reconstructed Radiographs) library used as references.
- X-ray images acquired in real time
- Registration between 2 DRR and X-ray images
- The patient’s rigid transformation calculated
Skull Tracking and Correction

Accuracy - Overall translation error ~ 0.5mm, rotation error ~ 0.5 degree.
Spinal Tracking and Correction

Special application: Bony Structures
Fiducial Tracking and Correction

Special application: Surgical Clips
Tumor Respiratory Motion Consideration

Breath Hold

Gating
Synchrony Motion Tracking and real-time Correction
Synchrony Motion Tracking and real-time Correction
Xsight-Lung Tracking and real-time Correction

Special application: Sternum, Metal Stent, Large Calcification
Lung tumor tracking without fiducials

Xsight® Lung Tracking
Radiosurgical margins

Similarity Measure

Maximum similarity
Lung tumor tracking without fiducials

**Xsight® Lung Tracking**
Radiosurgical margins

![View A](image1)
![View B](image2)
Lung tumor tracking without fiducials

*Xsight® Lung Tracking*
Radiosurgical margins

*1-View Tracking*
ITV expansion in non-tracked direction
Lung tumor tracking without fiducials

*Xsight® Lung Tracking*
Radiosurgical margins

*1-View Tracking*
ITV expansion in non-tracked direction

*0-View Tracking*
ITV expansion in all directions
Targeting Accuracy

- Mechanical accuracy
  - 0.12 mm (Kuka Specification 2004)

- Targeting accuracy for targets not affected by respiration
  - 0.95 mm (Xsight® Specification)
  - 0.52 +/- 0.22 mm (Muacevic et. Al. 2006)
  - 0.49 +/- 0.22 mm (Ho et. al. 2008)
  - 0.4 +/- 0.2 mm (Antypas and Pantelis 2008)
  - 0.47 +/- 0.24 mm (Drexler & Furweger 2009)

- Targeting accuracy for targets that move with respiration
  - 1.5 mm (Synchrony® Respiratory Tracking System specification)
  - 0.70 +/- 0.33 mm (Dieterich et. Al. 2004)
  - 0.47 +/- 0.24 mm (Drexler and Furweger 2009)

CyberKnife Components & treatment
Motion management
Dosimetry
Quality Assurance
Dosimetry: various beam arrangements

- Isocentric
  -- single shot
  -- multiple shots

- Non-isocentric
  -- Conformal
Non-coplanar beams

7 Beam IMRT

“Tomo”, single Plane RT

Cyberknife – 80 Beam SRS
Applications – Plan Evaluation

Conformal Non-isocentric Plan

Fast Fall-off Isocentric Plan
CyberKnife Components & treatment
Motion management
Dosimetry
Quality Assurance
Quality Assurance

- End 2 End test
- BB test
- AQA
- Beam analysis
- Plan dose verification
- Image system test
- Daily, Monthly, Quarterly and Annually QA QA
### IV.B. Daily QA

<table>
<thead>
<tr>
<th>Section</th>
<th>Item</th>
<th>Tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>II.A.2</td>
<td>Safety interlocks (Door, console EMO, Key)</td>
<td>Functional</td>
</tr>
<tr>
<td></td>
<td>CCTV cameras and monitors</td>
<td>Functional</td>
</tr>
<tr>
<td></td>
<td>Audio monitor</td>
<td>Functional</td>
</tr>
<tr>
<td>II.B.1</td>
<td>Collimator assembly collision detector</td>
<td>Functional</td>
</tr>
<tr>
<td></td>
<td>Accelerator warm-up: 6000 MU for open chambers, 3000 MU for sealed chambers</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>Accelerator output</td>
<td>&lt;2%: no change needed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt;2%: adjust calibration</td>
</tr>
<tr>
<td></td>
<td>Detection of incorrect and missing secondary collimator</td>
<td>Functional</td>
</tr>
<tr>
<td>III.B.2</td>
<td>Visual check of beam laser and a standard floor mark</td>
<td>&lt;1 mm</td>
</tr>
<tr>
<td>III.C.1</td>
<td>AQA test</td>
<td>&lt;1 mm from baseline</td>
</tr>
</tbody>
</table>

### IV.C. Monthly QA

<table>
<thead>
<tr>
<th>Section</th>
<th>Item</th>
<th>Tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>II.A.2</td>
<td>Safety interlocks.</td>
<td>Functional</td>
</tr>
<tr>
<td>II.B.2</td>
<td>Energy constancy.</td>
<td>2%</td>
</tr>
<tr>
<td></td>
<td>Beam symmetry.</td>
<td>&gt;2%</td>
</tr>
<tr>
<td></td>
<td>Beam shape.</td>
<td>Compared to beam data</td>
</tr>
<tr>
<td></td>
<td>Output.</td>
<td>&gt;2%</td>
</tr>
<tr>
<td>II.C.1</td>
<td>Imager alignment.</td>
<td>1 mm or center pixel ≥ 2 pixels</td>
</tr>
<tr>
<td>II.C.3</td>
<td>Contrast, noise, and spatial resolution of amorphous silicon detector.</td>
<td>To be decided by user based on available literature</td>
</tr>
<tr>
<td>II.D</td>
<td>Custom CT model. CT QA (spatial accuracy, electron density).</td>
<td>See TG 66 (Ref. 29)</td>
</tr>
<tr>
<td>III.B.1</td>
<td>Verify relative location of beam laser vs. radiation CAX has not changed.</td>
<td>0.5 mm</td>
</tr>
<tr>
<td>III.B.2</td>
<td>Visually check isocentric plan to verify beam laser illuminates isocrystal; rotate through path sets each month</td>
<td>Laser on isocrystal for each node</td>
</tr>
<tr>
<td>III.C.2</td>
<td>Intracranial and extracranial E2E; set schedule to cycle through each clinically used tracking method and path.</td>
<td>&lt;0.95 mm or &lt;1.5 mm for motion tracking</td>
</tr>
<tr>
<td>III.C.3</td>
<td>Nonisocentric patient QA or DQA; ideally performed quarterly.</td>
<td>DTA 2 mm/2%; Synchrony DTA 3%/3 mm</td>
</tr>
<tr>
<td>III.D</td>
<td>Observe Synchrony treatment or simulation; listen for unusual noise and visually check for vibrations.</td>
<td>No significant change</td>
</tr>
</tbody>
</table>

### IV.D. Annual QA

<table>
<thead>
<tr>
<th>Section</th>
<th>Item</th>
<th>Tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>II.A.2</td>
<td>EPO button</td>
<td>Functional</td>
</tr>
<tr>
<td>II.B.3</td>
<td>TG 51 or IAEA TRS-398, including secondary independent check.</td>
<td>Adjust calibration if &gt;1% difference is found</td>
</tr>
<tr>
<td></td>
<td>Beam data checks on at least three collimators, including largest and smallest collimator (TPR or PDD, OCR, output factors).</td>
<td>To be decided by user</td>
</tr>
<tr>
<td></td>
<td>Dose output linearity to lowest MU/beam used.</td>
<td>1%</td>
</tr>
<tr>
<td>II.C.2</td>
<td>Imager kVp accuracy, mA station exposure linearity, exposure reproducibility, focal spot size.</td>
<td>See Table 1 for references</td>
</tr>
<tr>
<td>II.C.3</td>
<td>Signal to noise ratio, contrast-to-noise ratio, relative modulation transfer function, imager sensitivity stability, bad pixel count and pattern, uniformity corrected images, detector centering, and imager gain statistics.</td>
<td>Compare to baseline</td>
</tr>
<tr>
<td>II.D</td>
<td>TG 53 as applicable. CT QA (in addition to monthly).</td>
<td>TG 53 (Ref. 26)</td>
</tr>
<tr>
<td></td>
<td>Data security and verification.</td>
<td>See TG 66 (Ref. 29)</td>
</tr>
<tr>
<td>III.B.2</td>
<td>2nd Order Path Calibration; currently only possible with the help of a service engineer.</td>
<td>Functional</td>
</tr>
<tr>
<td>III.D</td>
<td>Check noise level of optical markers.</td>
<td>Each node &lt; 0.5 mm RMS &lt; 0.3 mm</td>
</tr>
<tr>
<td>IV.C</td>
<td>Run Synchrony E2E test with at least 20 deg phase shift; analyze penumbra spread.</td>
<td>&lt;0.2 mm</td>
</tr>
<tr>
<td>IV.C</td>
<td>Monthly QA.</td>
<td>To be decided by user</td>
</tr>
<tr>
<td>IV.B</td>
<td>Daily QA.</td>
<td>In addition to tolerances listed above, update all parameters and checklists Update parameters</td>
</tr>
</tbody>
</table>
### Table 2: Minimum equipment QA and tolerances for robotic linac systems

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Test</th>
<th>Tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily*</td>
<td>Head laser alignment check</td>
<td>1.0 mm</td>
</tr>
<tr>
<td><strong>On days of clinical use</strong></td>
<td>Safety interlocks</td>
<td>Functional</td>
</tr>
<tr>
<td></td>
<td>Automatic QA (AQA) test*</td>
<td>Total targeting ≤ 1.0 mm from baseline, not exceeding manufacturer’s specification</td>
</tr>
<tr>
<td></td>
<td>*If the clinic has both fixed cones and Iris\textsuperscript{TM} collimator, the AQA test should alternate between fixed cones and Iris\textsuperscript{TM}, with each system tested at least weekly</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Accelerator output constancy</td>
<td>± 3%</td>
</tr>
<tr>
<td>Monthly</td>
<td>Energy constancy</td>
<td>± 2%</td>
</tr>
<tr>
<td></td>
<td>Beam symmetry, relative</td>
<td>± 3% for 40 mm field, ± 4% for 60 mm field,</td>
</tr>
<tr>
<td></td>
<td>Accelerator output constancy</td>
<td>± 2%</td>
</tr>
<tr>
<td></td>
<td>Imager alignment</td>
<td>1 mm or center pixels</td>
</tr>
<tr>
<td></td>
<td>Iris Field size spot check</td>
<td>± 2 pixels</td>
</tr>
<tr>
<td></td>
<td>Picket fence for MLC (if applicable)</td>
<td>Visual check</td>
</tr>
<tr>
<td>Quarterly</td>
<td>E2E localization assessment (Each tracking mode used clinically)</td>
<td>1.0 mm static target, 1.5 mm motion tracking</td>
</tr>
<tr>
<td>Anually</td>
<td>Emergency Power Off (EPO) button, safety interlocks</td>
<td>Functional</td>
</tr>
<tr>
<td></td>
<td>Accelerator output</td>
<td>± 2.0%</td>
</tr>
<tr>
<td></td>
<td>MU linearity (&gt;10 MU to highest MU used clinically)</td>
<td>± 2%</td>
</tr>
<tr>
<td></td>
<td>Path verification</td>
<td>≤0.5 mm maximum per node, ≤0.3 mm average</td>
</tr>
<tr>
<td></td>
<td>Imager kVp accuracy, mA station exposure linearity, isopost alignment with center pixel</td>
<td>± 10%, ± 20%, and 1 mm respectively</td>
</tr>
<tr>
<td></td>
<td>Beam laser and radiation beam alignment for cone, Iris and MLC</td>
<td>0.5 mm from baseline</td>
</tr>
<tr>
<td></td>
<td>AQA baseline</td>
<td>Re-check AQA baseline</td>
</tr>
<tr>
<td></td>
<td>Beam data verification - Relative output factors for cones, Iris and/or MLC covering the range used clinically</td>
<td>± 2% from baseline for &gt; 1.0 cm apertures, ± 5% from baseline for ≤ 1.0 cm apertures</td>
</tr>
</tbody>
</table>
Morning QA - Output
Morning QA – AQA W-L test
Monthly QA- Output/Energy
Monthly QA – Symmetry and Flatness/ Laser Alignment
Monthly QA – IRIS Collimator Field Sizes
Monthly QA – E2E
Monthly QA – Imaging Center
Which of these following tracking modalities used in the lung cancer treatment can accommodate expiratory motion?

1 Xsight-lung tracking  
2 Spine tracking  
3 Synchrony Tracking (using fiducial)  
4 Lung Optimization Treatment  

A: 1,  B: 1, 2, 3  C: 1, 3, 4  D: 1, 2, 3, 4

Ans: C only the spine tracking in the list uses bony information of spinal skeleton as tracking landmark.

Ref: TG135 “Report of AAPM TG 135: Quality assurance for robotic radiosurgery”
What is not true for Cyberknife

a. Allows multiple non-coplanar beams
b. Allows single isocentric or non-isocentric shots, but not multiple isocentric shots
c. Fully optimized with inverse planning
d. Allows motion correction during treatment delivery

Answer: B

Thanks