VSI CyberKnife: Technical Specifications & Capabilities

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UCSF RADIATION ONCOLOGY UPDATE: PERSPECTIVE ON NEW TECHNOLOGIES, CLINICAL FINDINGS AND SAFETY

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Outline
- The CyberKnife VSI System
- Advances in CyberKnife technology
- The concept of Robotic IMRT (R-IMRT)
- New developments for R-IMRT
- Sequential Optimization
- Iris Variable Aperture Collimator
- Patient specific Quality Assurance

CyberKnife VSI System
- CK Software 9.0, Multiplan 4.0 (upgradable from previous version)
- 1000 MU/min, 6MV X-band linac
- Iris Variable Aperture Collimator
- Xchange Robotic Collimator Changer
- Synchrony Respiratory Tracking System
- Xsight Spine & Lung Tracking System
- InTempo Adaptive Imaging System
- Monte Carlo Dose Calculation
- Sequential Optimization
- AutoSegmentation
- QuickPlan

VSI versus G3
- Linac: 1000 MU/min
- Detectors mounted at 45°
- Iris collimator only
- Manual change of cones
- Upgraded 8.5/3.5 → 9.0/4.0
- Linac: 400 MU/min
- Detectors mounted at 45°
- Fixed collimator only
- Manual change of cones
- Software version 9.0/4.0
Installation at UCSF

- Site construction
- Delivery
- First patient
- Shielding
- Commissioning

Advances in CK Technology

<table>
<thead>
<tr>
<th>CK in 1999</th>
<th>VSI in 2010</th>
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<tbody>
<tr>
<td>Tracking methods</td>
<td></td>
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<tr>
<td>3D Skull tracking</td>
<td>6D Skull tracking</td>
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<tr>
<td>Spine tracking</td>
<td>Spine tracking</td>
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<tr>
<td>Fiducial marker tracking</td>
<td>Fiducial marker tracking</td>
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<tr>
<td>Lung tumor tracking</td>
<td>Lung tumor tracking</td>
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<tr>
<td>Synchrony MTS</td>
<td>Synchrony MTS</td>
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<tr>
<td>Manipulator precision</td>
<td>0.5 mm</td>
</tr>
<tr>
<td>Targeting accuracy (static)</td>
<td>0.6 mm – 2.5 mm</td>
</tr>
<tr>
<td>Targeting accuracy (motion)</td>
<td>n/a</td>
</tr>
<tr>
<td>Beam Collimation</td>
<td>Fixed cones</td>
</tr>
<tr>
<td>Dose-rate</td>
<td>300 MU/min</td>
</tr>
<tr>
<td></td>
<td>Iris and Fixed</td>
</tr>
<tr>
<td></td>
<td>1000 MU/min</td>
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<tr>
<td>Image detectors</td>
<td>Gadolinium (1.25 mm)</td>
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<tr>
<td></td>
<td>Amorphous silicon (0.4 mm)</td>
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<tr>
<td>Dose calculation algorithm</td>
<td>Ray Tracing</td>
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<tr>
<td></td>
<td>Monte-Carlo &amp; Ray Tracing</td>
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<tr>
<td>Robot path traversal</td>
<td>Through all nodes</td>
</tr>
<tr>
<td>Patient positioning system</td>
<td>Manual couch</td>
</tr>
<tr>
<td></td>
<td>5-DOF standard couch</td>
</tr>
<tr>
<td></td>
<td>6-DOF &amp; 7-DOF RoboCouch</td>
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Clinical Applications

- 1999: SRS
  - Brain
  - Upper spine
  - Skull
  - Fiducial
  - XST

- 2001: SRS
  - Spine

- 2003: SBRT
  - Prostate
  - Lung
  - Pancreas

- 2006: SBRT
  - Spine
  - H&N

- 2007: R-IMRT
  - Spine
  - H&N
  - Lung
  - Liver

- 2010: R-IMRT
  - Standard fractions

- Total patients treated
  - 1999: 30
  - 2000+: >90,000

Robotic IMRT

Robotic IMRT is the delivery of treatments with the CyberKnife using conventional fractionation regimens and radiosurgery precision.

- Like IMRT each field has optimized size, direction and weight.
- Like SBRT, each field is delivered with radiosurgical precision thanks to image guidance during treatment delivery and manipulator corrections.

Clinical applications:

- Well delineated target, for which the accepted fractionation scheme is greater than 5 fractions (i.e. prostate)
- Treatments for which hypo-fractionation would result in high toxicity (head & neck, intracranial lesions, recurrence)
Clinical Example

- Infindibular hemangioblastoma
- 54 Gy in 30 fractions to 85%
- Critical structures: optic chiasm, pituitary, hypothalamus, brain stem
- 80 Beams, 5 mm fixed collimator
- Treatment time: 18 minutes

R-IMRT: Prostate

- R-IMRT uses fewer beams than SBRT, resulting in faster treatment.
- R-IMRT uses more beams than conventional linac-based IMRT, resulting in steeper dose gradient and more conformal dose distribution.

Prostate boost

- Prostate SBRT plan
  - 200-300 beams
  - 2 Gy x 9 fx to 92%
  - 7 beams
  - 15 minutes
  - Rectum $V_{120Gy}=11\%$
  - Bladder $V_{120Gy}=20\%$

- Prostate R-IMRT plan
  - <100 beams

Prostate SBRT

- Comparison: nine prostate patients treated at 9.5 Gy/fraction

<table>
<thead>
<tr>
<th></th>
<th>G3</th>
<th>VSI</th>
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<tbody>
<tr>
<td>MU/fraction</td>
<td>17158</td>
<td>15538</td>
</tr>
<tr>
<td>Time</td>
<td>86 min</td>
<td>53 min</td>
</tr>
<tr>
<td>Rx IDL</td>
<td>68%</td>
<td>68%</td>
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<tr>
<td>Beams</td>
<td>207</td>
<td>257</td>
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<tr>
<td>PTV coverage</td>
<td>97.4%</td>
<td>95.6%</td>
</tr>
<tr>
<td>PTV nCI</td>
<td>1.19</td>
<td>1.16</td>
</tr>
<tr>
<td>Bladder V75</td>
<td>2.3 cc</td>
<td>1.7 cc</td>
</tr>
<tr>
<td>Bladder D$_{max}$/fx</td>
<td>9.4 Gy</td>
<td>9.4 Gy</td>
</tr>
<tr>
<td>Rectum V75</td>
<td>1.7 cc</td>
<td>2.1 cc</td>
</tr>
<tr>
<td>Rectum D$_{max}$/fx</td>
<td>9.3 Gy</td>
<td>9.6 Gy</td>
</tr>
<tr>
<td>Urethra V120</td>
<td>0.2%</td>
<td>1.9%</td>
</tr>
<tr>
<td>Urethra D$_{max}$/fx</td>
<td>11.3 Gy</td>
<td>11.5 Gy</td>
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</table>
The capability of CyberKnife to deliver R-IMRT treatments was enhanced by the following developments:

- Sequential Optimization
- Iris Variable Aperture Collimator
- Patient specific QA

These developments also resulted in improved SRS/SBRT treatments.

CyberKnife remains primarily a radiosurgery system.

In conventional optimization algorithms, multiple objectives are grouped in a single cost function. In sequential optimization, each objective (step) is optimized in sequence. The objective and the order of the steps define the clinical priorities.

- **Auto-shells** are tuning structures used to constrain the conformity and the extension of the low-dose region.
- **Beam reduction** removes all beams below a MU threshold and re-optimize the plans with the remaining beams while preserving the plan quality.
- **Time reduction** reduces the number of beams and nodes to achieve the user-defined time goal.

**Iris variable aperture collimator**

- Plans generated using multiple field size have better quality (conformality, homogeneity, coverage) and lower MU than plans generated using a single field size.
- However, using multiple fixed cones is not practical because it requires multiple paths traversal, and results in prohibitively long treatment time.
- Iris collimator allows to use of multiple field sizes without these limitations.
- The aperture is produced by 2 hexagonal banks of tungsten which produce a 12-sided radiation beam.
- The same twelve field sizes can be obtained: 5, 7.5, 10, 12.5, 15, 20, 25, 30, 35, 40, 50, 60 mm
- The beam characteristics are practically identical to the fixed cones.
Iris Challenges

- Iris mechanical tolerance is 0.2 mm for all field sizes.
- This results in intrinsic uncertainty in output factor, particularly for small fields.
- It is not recommended to use the 5 and 7.5 mm field sizes.
- Use the 10 mm only after careful assessment.
- Iris requires more commissioning measurements to characterize off center ratio, including at least 4 diagonals beam profiles.
- Iris requires more QA measurements, particularly to verify the reproducibility of field sizes.
- It requires more maintenance and calibration.
- Iris increased the overall machine “down time”
- Common Iris problems are due to excessive friction between segments, failure of the driving motors and failure of the temperature sensor.
- Iris has been completely redesigned, and Iris2 has been announced.

Iris QA

- IrisQA is a tool provided by Accuray to verify the reproducibility of Iris field sizes with an accuracy of 0.2 mm.
- Gafchromic EBT2 films are irradiated at standard SAD.
- Iris aperture is measured as equivalent diameter of OD threshold.

Patient specific QA

- The debate on patient specific QA for the CyberKnife is ongoing.
- There are currently no regulations enforcing it, nor reimbursement.
- About 15% of Centers perform some sort of patient specific QA.
- There are valid arguments both in support and against the need to perform patient specific QA.
  - Complex procedure – multiple/non-coplanar beams
  - High dose/hypo-fractionated procedure
  - Not “intensity-modulation” per se (for fixed collimator)
  - Stand alone system
  - Machine specific QA and E2E tests are sufficient to ensure optimal machine operation and patient safety
- Patient specific QA is required for IMRT coding and billing.
- Patient specific QA is imperative for new machines/new techniques.
- We have performed “Delivery QA” (DQA) for every patient so far.

New Plan QA

- Align center of patient’s target with center of phantom’s target.
- Calculate corresponding dose distribution
- Rescale MU ≤700 cGy.
- Deliver plan on phantom Gafchromic EBT2 films
- Axial & sagittal planes.
**Film Analysis**

- Planned dose
- Film

**Dose profile comparison**

**Statistical analysis**

- Points passing (%)
- Patient number

**DQA Results**

- MapCheck film analysis software
- Gamma Index 3%/3mm
- Absolute dose
- 48 plans
- Average score 97%

- FilmQA analysis software
- Gamma Index 2%/1mm
- Absolute dose
- 8 plans
- Average score 98%

**Summary**

- The capabilities of the CyberKnife system have significantly expanded over the last decade.
- New developments in CyberKnife technology enable delivery of Robotic-IMRT treatments.
- All development done towards robotic-IMRT results in improved SRS/SBRT treatments.
- While CyberKnife is becoming more versatile, it remains primarily a radiosurgery system.

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**UCSF CyberKnife Team**

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