Treatment Planning for the CyberKnife® Treatment Delivery System and InCise™ Multileaf Collimator:

a Literature Review

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Disclosure

- I am an employee of Accuray® Incorporated
Overview

Reported User Experience

• Planning the Basics:
  Comparison between InCise™ MLC and Fixed/Iris™ for SBRT:
  – Prostate
  – Brain metastases
  – Liver

• Focus on:
  – Tumor size, shape, & location

• Expanding Treatment Possibilities:
  – Conventional fractional
Search Criteria

- Peer-reviewed publications
- Peer-reviewed conference submissions
- Search engines include PubMed, Google Scholar, individual journal searches (Medical Physics, Red Journal, JACMP)
- Search terms include “InCise MLC” AND “CyberKnife” OR “robotic”
- Abstracts/papers shared with us by users
## Prostate SBRT: MLC Compared to Fixed/Iris™

### Results

<table>
<thead>
<tr>
<th>Study</th>
<th>N</th>
<th>PTV vol (cc)</th>
<th>MU reduction</th>
<th>Tx time reduction</th>
<th>InCise™ MLC plan outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>McGuinness (2015)</td>
<td>5</td>
<td>33 – 85</td>
<td>37% (p=0.01)</td>
<td>45% (p=0.001)</td>
<td>gEUD&lt;sub&gt;MLC&lt;/sub&gt; to bladder lower by 25% (p=0.005)</td>
</tr>
<tr>
<td>Kathriarachchi (2016)</td>
<td>10</td>
<td>61 – 139</td>
<td>42% (p=0.002)</td>
<td>40%* (p=0.006)</td>
<td>GI&lt;sub&gt;MLC&lt;/sub&gt; lower by 29% (p=0.002)</td>
</tr>
<tr>
<td>Murai (2017)</td>
<td>10</td>
<td>35 – 132</td>
<td>equiv.</td>
<td>19%** (p=0.003)</td>
<td>rectal dose&lt;sub&gt;MLC&lt;/sub&gt;: V&lt;sub&gt;50%&lt;/sub&gt;, V&lt;sub&gt;80%&lt;/sub&gt;, V&lt;sub&gt;90%&lt;/sub&gt; lower by ≥30% (p&lt;0.04)</td>
</tr>
<tr>
<td>Tomida (2017)</td>
<td>10</td>
<td>n/a</td>
<td>27% (p&lt;0.05)</td>
<td>30%/20%** F/I (p&lt;0.05)</td>
<td>Bladder V&lt;sub&gt;50%&lt;/sub&gt; lower by 30% (p&lt;0.05)</td>
</tr>
</tbody>
</table>

- *the time reported in the study included a 5 min set-up. The percentage time reduction recalculated without the set-up time for consistency with the other studies.
- **not known if set-up time is incorporated into the figures reported
- gEUD: generalized equivalent uniform dose, GI: gradient index, V<sub>50%</sub> volume receiving 50% of prescribed dose

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Prostate SBRT: MLC Compared to Fixed/Iris™

Figures

Average DVH from McGuinness et al. demonstrating superior bladder sparing with the InCise™ MLC plans

Example from Kathriarachchi et al. demonstrating the steeper dose gradient with the InCise™ MLC

McGuinness et al., JACMP 16, 2015

Kathriarachchi et al., JMP 41, 2016
Prostate SBRT: MLC Compared to Fixed/Iris™

Conclusions

• McGuinness:
  - The “SBRT plans demonstrate superior performance for the CK-MLC compared to the CyberKnife with circular collimators”.

• Kathriarachchi:
  - “the InCise™ MLC of CK M6™ was able to produce dosimetrically comparable plans with the IRIS™ collimator for prostate SBRT.”

• Murai:
  - “MLC treatment is considered advantageous in cases with overlaps with critical organs”
  - “the MLC mode should be the first option in stereotactic body radiotherapy.”

• Tomida:
  - “In this study, the advantages of MLCs over other types of collimators in robotic radiosurgery systems for prostrate SBRT treatment planning were clarified.”
# Brain SBRT: MLC Compared to Fixed/Iris™

## Results

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<tr>
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<tbody>
<tr>
<td>McGuinness (2015)</td>
<td>5</td>
<td>7 – 70</td>
<td>67% (p=0.085)</td>
<td>45% (p=0.056)</td>
<td>- $gEUD_{MLC}$ to the optical chiasm and brainstem generally lower (p&gt;0.05)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- $R_{50%(MLC)}$ lower by 48% (p=0.05)</td>
</tr>
<tr>
<td>Jang (2016)</td>
<td>25</td>
<td>0.09 - 47</td>
<td>58% (p&lt;0.05)</td>
<td>40%* (p&lt;0.05)</td>
<td>- 7% less conformal (p=0.035)</td>
</tr>
<tr>
<td>Limoges (2017)</td>
<td>10</td>
<td>3 - 34</td>
<td>37% (p=n/a)</td>
<td>26%* (p=n/a)</td>
<td>- $GI_{MLC}$ lower by 10% (p=n/a)</td>
</tr>
</tbody>
</table>

*the time reported in the study included a 5 min set-up. The percentage time reduction recalculated without the set-up time for consistency with the other studies.

**not known if set-up time is incorporated into the figures reported

gEUD: generalized equivalent uniform dose, GI: gradient index=$V_{50\%RXIDL}/V_{RXIDL}$, $R_{50\%}=V_{50\%RXIDL}/PTV$
Brain SBRT: MLC Compared to Fixed/Iris™

Conclusions

• McGuinness:
  – The “SBRT plans demonstrate superior performance for the CK-MLC compared to the CyberKnife with circular collimators”.

• Jang:
  – “The present study showed that the delivery of intracranial SRS using the InCise1 MLC was dosimetrically feasible...However, small targets (size < 7.6 mm × 7.5 mm) might not be good candidates for MLC-based planning. Overall, the InCise1 MLC is a useful delivery modality for cases in which delivery time is a limiting factor or for multitarget cases”

• Limoges:
  – “The use of the InCise MLC for Cyberknife stereotactic radiotherapy allows a significant reduction of MU and treatment time compared to Iris collimator while maintaining a high degree of conformity and a steep dose gradient.”
# Liver SBRT: MLC Compared to Fixed/Iris™

## Results

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<tr>
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<th>Tx time reduction</th>
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</thead>
<tbody>
<tr>
<td>Murai (2017)</td>
<td>10</td>
<td>26 – 283</td>
<td>69%</td>
<td>37%** (p=0.001)</td>
<td>- D$_{\text{max}}$(MLC): stomach, esophagus, spinal cord reduced by &gt;30% (p&gt;0.5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.6 – 8.1</td>
<td>(p=0.002)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Doro (2017)</td>
<td>27</td>
<td>25.7 – 643</td>
<td>16%</td>
<td>23%** (p&lt;0.001)</td>
<td>- GI$_{\text{MLC}}$ lower by 15% (p&lt;0.001)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.7-10.7</td>
<td>(p=0.02)</td>
<td></td>
<td>- Bowel$_{\text{mean}}$ lower by 54% (p=0.002)</td>
</tr>
<tr>
<td>Limoges (2017)</td>
<td>10</td>
<td>59 - 387</td>
<td>-8%</td>
<td>17%*** (p=n/a)</td>
<td>- GI$_{\text{MLC}}$ lower by 15% (p=n/a)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.8 - 9</td>
<td>(p=n/a)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(Publication/Presentation)

- *diameter of equivalent sphere, calculated from the volume for this presentation
- **not known if set-up time is incorporated into the figures reported
- ***the time reported in the study included a 15 min set-up. The percentage time reduction recalculated without the set-up time for consistency with the other studies.
- GI: gradient index, D$_{\text{max}}$: maximum dose
Liver SBRT: MLC Compared to Fixed/Iris™

Conclusions

• Murai:
  – “MLC treatment is considered advantageous in cases with overlaps with critical organs”
  – “the MLC mode should be the first option in stereotactic body radiotherapy.”

• Doro:
  – “The results demonstrate that MLC is a good alternative to IRIS for CyberKnife Liver SBRT”

• Limoges:
  – “The use of the InCise MLC for Cyberknife stereotactic radiotherapy allows a significant reduction of MU and treatment time compared to Iris collimator while maintaining a high degree of conformality and a steep dose gradient.”
Focus on: Tumor Size or Shape

Limoges et al:

- 10 acoustic neuromas
- 10 spine cases

- Inferior conformality with MLC - by 20% for AN, 3% for spine, (p=n/a)
- "Circular collimators should be still preferred for small targets < 2 cc and challenging spine cases"

Limoges et al. *Radiotherapy and Onc.* 123, 2017
Focus on: Tumor Size

Murai et al

- Contoured spherical PTVs: 1, 3, 5, 7 cm (0.5-180 cc)
- Compared plans for circular collimators and MLC
- Assumed no critical organs

"...unless the priority of conformity is higher than that of any other factors, the MLC mode is recommended."
Focus on: Tumor Abutting OAR or with Complex Shape

Jang et al

- Brain mets study
- 7 plans had tumor abutting OAR or irregular tumor shape (0.3-47 cc)
- Iris™ plans better coverage with comparable OAR dose
- $C_{I_{\text{Iris}}} \text{ 13\% lower than } C_{I_{\text{MLC}}} \text{ (p=0.097)}$
- Iris™ plans had slightly faster dose fall-off (p=0.805)
- “MLC-based plans might be less favorable for cases where conformal dose distribution is a limiting factor”

Fig. 3. Axial dose distributions (top) and dose-volume histogram (bottom) of MLC-based and cone/Iris-based CyberKnife plan. The target lesion is shown in red color and isodose lines are shown as contours. Solid and dotted lines on the dose-volume histogram represent MLC-based and cone/Iris-based plan, respectively. It was a case with a circular-shaped target abutting with brainstem, and the prescription dose was 15 Gy in 1 fraction.
Focus on: Tumor Abutting OAR

Chaw et al

- Nodal metastases located in pelvis and abdomen, 20 patients
- PTV: 4.2 - 48 cc \textit{(private communication – paper in preparation)}
- Within 10mm of OAR
- Equivalent PTV coverage and CI
- % improvement with InCise\textsuperscript{TM} MLC \((p<0.01)\):
  - GI: 13\%, treatment time: 47\%, monitor units: 45\%
  - Mean small bowel dose: 53\%, Mean large bowel dose: 20\%

Figure 3 showed examples of cases. PTV of abdomino-pelvic metastases delineated in dark blue (left: right common iliac node, middle: retrocaval node; right: left obturator node).

“…demonstrated the dosimetric feasibility of MLC in delivering SBRT for patients presented with abdomino-pelvic oligometastatic nodal disease in close proximity to critical structures with improved delivery efficiency compared to Iris.”
Conventional Fractionation with CyberKnife® System InCise™ MLC

McGuinness et al

<table>
<thead>
<tr>
<th>Study</th>
<th>N</th>
<th>PTV vol (cc)</th>
<th>Prescription isodose line (%)</th>
<th>Reduction in R50%</th>
<th>CyberKnife MLC Tx time</th>
<th>Increase in MU</th>
</tr>
</thead>
<tbody>
<tr>
<td>whole pelvis</td>
<td>5</td>
<td>426-761</td>
<td>86</td>
<td>29% (p=0.0007)</td>
<td>24.8 mins</td>
<td>3x</td>
</tr>
<tr>
<td>intracranial</td>
<td>5</td>
<td>46-219</td>
<td>92</td>
<td>28% (p=0.16)</td>
<td>19 mins</td>
<td>1.4x</td>
</tr>
</tbody>
</table>

- Same margins used for CyberKnife® System and linac planning
- CyberKnife prescription isodose line within 2-3% of conventional linac
- Equivalent conformity, dose to OARs
- Reasonable treatment time – 4 of 5 IC plans < 20 mins
- Plan quality and efficiency drop when max 2D target projection exceeds the maximum field size – whole pelvis plans.
- CyberKnife® System with InCise MLC, “in select clinical cases, might be a potential alternative for standard fractionated treatments”
Conventional Fractionation with CyberKnife® System InCise™ MLC

McGuinness et al – example of whole pelvis treatment

Fig. 6. CT images are shown with isodose lines for Case 11. The top row of images corresponds to the CK-MLC plan and the bottom row of images corresponds to the clinically approved IMRT plan. Isodose lines are shown for 54, 45, 33.75, 22.5, 10, and 5 Gy for a prescription of 45 Gy in 25 fractions.

McGuinness et al., JACMP 16, 2015
**Conventional Fractionation with CyberKnife® System InCise™ MLC**

<table>
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<tr>
<th>Study</th>
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<th>PTV vol (cc)</th>
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</tr>
</thead>
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<tr>
<td>Jin (2016) Liver</td>
<td>6</td>
<td>175-1123</td>
<td>20-23 mins</td>
</tr>
<tr>
<td>Bichay (2016) pancreas, head &amp; neck, prostate, anal, esophagus</td>
<td>5</td>
<td>127-1321 (average diameter = 7-13 cm)</td>
<td>9-38 mins</td>
</tr>
</tbody>
</table>

- **Jin:**
  - Conventional linac and InCise™ MLC CyberKnife® System plans dosimetrically similar
  - Mean CyberKnife® System treatment time is 21 min – *may be considered as clinically acceptable*

- **Bichay:**
  - Target coverage (>95%) and dose to critical structures within a clinically acceptable range
  - *“CyberKnife can provide an alternative to traditional treatment modalities for large volume tumors.”*
Additional MLC planning studies

- **Prostate**

- **Breast**

- **Peri-orbit carcinoma**

- **Ventricular Tachycardia**

- **Prone Treatments**
Summary

- InCise™ MLC plans are *dosimetrically equivalent or superior* to CyberKnife® System plans with circular collimators for prostate, brain, liver.

- InCise™ MLC plans are *more efficient* than CyberKnife® System plans with circular collimators for prostate, brain, liver.

- Circular collimators may provide superior plans for small and irregularly-shaped tumors abutting an OAR.

- *Conventional fractionation* on CyberKnife® System is feasible with the MLC.
References


References


• **Chaw** C L, VanAs N J, Khoo V S. *Cyberknife Iris based versus InCise based plans for 20 cases of prostate oligonodal metastases*. Radiotherapy and Oncology. 2017 May; 123 S1:S834.


Thank You

Precise, innovative tumor treatments™