I have no disclosures with this presentation
Today I’d like to share with you the Miami Cancer Institute’s concept of **Multi-Technology RT (MTRT)**

MTRT is the use of any and all RT delivery systems to provide a tailored course of treatment using the techniques best suited for the individual patient’s needs.

This can be based on…

- Tumor size and location
- Ability to track or gate target
- Underlying conditions such as ability to hold breath or to not move
- Prior treatments or other health conditions
- Severe claustrophobia
Miami Cancer Institute

An entire “tool box” to skillfully use according to their unique properties. Our goal is customized delivery for each patient’s unique circumstances.

Varian® True Beam™
CyberKnife® M6™
Radixact™
Gamma Knife® Icon™

Viewray® MRIdian™
Linac
Brachytherapy & HDR

Proton Therapy - PBS
Easy transportation between rooms
There are many radiation therapy delivery systems on the market and with the speed at which technology is growing new applications are continually emerging.

When given a choice of delivery systems for each patient we are facing a unique situation with little experience to draw from therefore we do not always know the best answer.
One of our goals is to compare planning on multiple systems depending on the best solution for the patient. Not only about isodose lines.

Multi-Technology RT approach for the best “lifespan results”!

*Long (and short) term side effects
Plan specific dose distributions

4 Field Box  VMAT, yet dose bath  Protons, integral dose

But which is better?

Fastest treatment because patient cannot hold still…3D (shortest beam-on times)
Conformal tissue sparing for a 70yo…CyberKnife, VMAT or Proton
Lowest Integral dose dose for a 40yo…Proton
Plan specific dose distributions

4 Field Box
VMAT, yet dose bath
Protons, integral dose

If your primary criteria is high to intermediate conformal doses which would you choose?

Which is the best backup when the primary machine needs maintenance?
## First Impressions...

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TrueBeam Varian
3 Linear Accelerators (one HD120)

- Linear Accelerator (6X, 10X, 15X and electrons)
- Millenium MLC 120 leaves (central 20cm FS with 5mm and peripheral with 10mm)
- 40 X 40 field size
- HD MLC 120 leaves (central 8cm FS with 2.5mm and peripheral with 5mm)
- 34 X 22 max FS
- IGRT:
  - CBCT
  - Vision RT (SGRT)
- High Doserate Output (MU/min) for TBI, TBE, Grid Therapy (.decimal), etc.

TPS: Eclipse and RayStation

Multifunctional, sufficient and efficient for most cases
Relatively quick treatment for high throughput
3D, IMRT, VMAT, SBRT
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TomoTherapy Radixact Helical Linac

- Linac based helical delivery system (6X)
- MLC 64 Binary, 6mm width
- Jaws settings 1cm, 2.5cm, 5cm
- No collimator rotation
- All axial-helical delivery (co-planar)
- 85cm bore
- Couch lateral shift and roll
- MVCT (artifact reduction) 10rpm
- 1000 MU/min dose rate
- Shift from outside lasers to treatment position is 70cm

TPS: Precision and RayStation (MCO)

Larger, longer, more convexed targets especially abutting OARs (H&N, Breast, Pelvis, Spine, Pediatrics)
IMRT, Tomo Direct
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CyberKnife M6 Robotic Linac

- Linac on a Robotic pedestal and Robo-couch (6X)

- Aperture attachment:
  - Cones (12 “fixed collimators from 5mm to 60mm)
  - Iris (Double layered offset hexagonal leaves)
  - MLCs (3.85mm at 80cm SAD with 10cm X 11.5cm max FS, Step and Shoot)

- Stereotactic Realtime Image Guidance
- Target tracking
- Non-Isocentric with variable SAD per beam

TPS: Precision

Can be very conformal
SBRT: Intracranial, Spine, Lung

Trackable solid tumors or a surrogate (if you see it, you can track it)
Synchrony tracking
CyberKnife M6 Tracking

- Intracranial
- Spine
- Lung
- Soft Tissues
- Prostate

X-ray Sources

Image Detectors
CyberKnife M6 Tracking
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GammaKnife Icon
Radiosurgery

- Radiosurgery delivery system
- 192 Cobalt-60 sources in a circular array to focus the radiation
- Collimator spot sizes are 4mm, 8mm and 16mm
- Frame-based for single fraction treatment
- Frameless treatment (mask) for fractionated treatment
- CBCT

TPS: GammaPlan
Planned with pre-treatment imaging then evaluated with CBCT to make adjustments to coordinates with Adaptive DoseControl

High precision in the Brain
Smaller targets in the Brain
Very conformal
# First Impressions...

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- **Inter-fraction:**
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  - MVCT
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  - kV-CBCT
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  - kV-CBCT, kV/kV, SIG

- **Intra-fraction:**
  - kV triggered imaging, Calypso, SIG
  - Surface Image Guidance
  - Cine kV
  - Infrared Marker
  - Planar Cine MR
  - SIG

**Ideal clinical indications:**
- Universal
- H&N, Comp. Breast, Long Tx Fields, Junction fields
- Motion tracking, non-coplanar delivery
- Cranial Stereo.
- Diaphragmatic motion, adaptive capability
- Universal, lower integral dose, pediatrics, re-irradiation
MRIdian – MR Linac ViewRay

- This is the Linac based system (6MV FFF)
  - legacy model was Cobalt
- 138 MLCs (5mm at isocenter) double stacked
- 24 X 27 field size
- No collimator rotation
- All co-planar beam arrangement
- Static Step and Shoot

- 90cm SAD

0.35 Tesla MR for IGRT with Gating
Promising pretreatment Adaptive planning
Shift from outside lasers to treatment position is 155cm
Couch has capacity for a +/- 7cm lateral shift

IMRT Lung, Liver, any target with motion or abutting an OAR
MRgRT

- 0.35T MR
- 6MV, FFF linear accelerator
- Adaptive radiotherapy
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Proton Therapy PBS
IBA - 3 Gantry system

- 3 Beam-matched treatment rooms with identical environments
- PBS
- 6D robotic patient positioning
- IGRT: CBCT
- C-Rad Catalyst and 4D Sentinel (SIGRT)
- Ambient lighting from Philips
- Validating a Script generated Grid and Lattice Therapies

SFUD, IMPT, Hybrid techniques
Why are stopping power and spot distribution an advantage?

Lower entrance dose and steep dose drop-off
When are stopping power and spot distribution an advantage?

- Relatively efficient dose delivery
- Discrete location and intensity

**Spot spacing, weight and layers**

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Energy Layers
Distal Avoid to PRV

Optic Chiasm expanded 3mm then avoid spot placement on this PRV
Metal Artifacts
Unusually Challenging Cases

19 cm deep and 20 cm wide
Unusually Challenging Cases

Provides great dose distribution with some challenges
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Technology Triage

Early Stage Lung Cancer

TrueBeam
- Breath-hold?
- Compression (ITV)?
- Fast delivery?
- Volumetric imaging?

Yes?

Tomotherapy
- Claustrophobic
- Volumetric imaging?
- Non-coplanar?

Yes?

CyberKnife
- Trackable?
- Fiducials?
- Arms restriction?
- Large motion

Yes?

MR Linac
- Breath-hold?
- FB gating?
- Claustrophobic?
- Lateral lesion?
- Volumetric imaging?

Yes?

Proton-IMPT
- Large motion?
- Insurance?
- Volumetric imaging?
- Breath-hold?

Yes?

Comparative Plans

Treat patient with best quality plan
Pillars of RT Planning

Target Coverage
The reason for RT

Target

OAR
Pillars of RT Planning

Target Coverage
The reason for RT

OAR protection
“Do no harm”
Pillars of RT Planning

Target Coverage
The reason for RT

OAR

Dose Homogeneity
*except for Stereotactic RT

Target

OAR

OAR protection
“Do no harm”
Pillars of RT Planning

Target Coverage
The reason for RT

Dose Homogeneity
*except for Stereotactic RT

Dose conformity
ALARA, Integral dose

OAR protection
“Do no harm”
• Methods to modulate TI:
  – Radiosensitizers/Radioprotectors
  – Fractionation
  – Dose rate
  – Technology

The maximum radiation dose by which death of cancer cells is locally controlled and the minimum radiation dose by which cells in normal tissues have low acute and late morbidity (Thoms J, Bristow RG)

Ratio: Effective dose to Toxic dose
Integral Dose=the mean dose times the volume
Prostate SBRT
## Clinical Objectives

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<th>Constraint</th>
<th>TrueBeam/RapidArc</th>
<th>IBA Proton PBS</th>
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<td>Rectum</td>
<td>(D_{\text{max}} \leq 41.2 \text{ Gy})</td>
<td>✔</td>
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<tr>
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<td>(D_{1cc} \leq 38.5 \text{ Gy})</td>
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<td></td>
<td>(V_{24Gy} \leq 25%)</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td></td>
<td>(D_{\text{mean}} \leq 16.4 \text{ Gy})</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td></td>
<td>(V_{30.15Gy} \leq 8 \text{ cc})</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>Urethra</td>
<td>(D_{\text{max}} \leq 42 \text{ Gy})</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td></td>
<td>(D_{1cc} \leq 40 \text{ Gy})</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>Bladder</td>
<td>(D_{\text{max}} \leq 42 \text{ Gy})</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td></td>
<td>(V_{36Gy} \leq 10%)</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td></td>
<td>(V_{20Gy} \leq 50%)</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>Large Bowel</td>
<td>(D_{\text{max}} \leq 29 \text{ Gy})</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>Small Bowel</td>
<td>(D_{\text{max}} \leq 25 \text{ Gy})</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>Femoral Heads</td>
<td>(D_{\text{max}} \leq 31 \text{ Gy})</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td></td>
<td>(V_{21.6Gy} \leq 10 \text{ cc})</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>Penile Bulb</td>
<td>(D_{\text{max}} \leq 40 \text{ Gy})</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td></td>
<td>(D_{3cc} \leq 21.6 \text{ Gy})</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
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</tbody>
</table>
Proton therapy may reduce the low-dose exposure of the brain, however, can be disadvantageous for tumors abutting critical structures.
<table>
<thead>
<tr>
<th></th>
<th>PROTONS</th>
<th>CYBERKNIFE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Max Dose (Gy)</td>
<td>Mean Dose (Gy)</td>
</tr>
<tr>
<td>Hippocampus_R</td>
<td>0.0</td>
<td>0.3</td>
</tr>
<tr>
<td>Hippocampus_L</td>
<td>12.7</td>
<td>2.0</td>
</tr>
<tr>
<td>Optic Nerve_R</td>
<td>3.1</td>
<td>0.5</td>
</tr>
<tr>
<td>Optic Nerve_L</td>
<td>24.2</td>
<td>16.1</td>
</tr>
<tr>
<td>Optic Chiasm</td>
<td>15.8</td>
<td>8.8</td>
</tr>
<tr>
<td>Brainstem</td>
<td>11.0</td>
<td>0.5</td>
</tr>
<tr>
<td>Cochlea_L</td>
<td>10.8</td>
<td>10.6</td>
</tr>
<tr>
<td>Pituitary</td>
<td>20.2</td>
<td>12.9</td>
</tr>
<tr>
<td></td>
<td>Max Dose (Gy)</td>
<td>Mean Dose (Gy)</td>
</tr>
<tr>
<td></td>
<td>0.8</td>
<td>0.9</td>
</tr>
<tr>
<td></td>
<td>0.9</td>
<td>3.1</td>
</tr>
<tr>
<td></td>
<td>1.0</td>
<td>2.2</td>
</tr>
<tr>
<td></td>
<td>3.2</td>
<td>2.2</td>
</tr>
<tr>
<td></td>
<td>0.9</td>
<td>0.9</td>
</tr>
<tr>
<td></td>
<td>1.0</td>
<td>3.7</td>
</tr>
</tbody>
</table>
Treatment Precision

- For SRS planning, the maximum dose to the adjacent critical structure is primarily evaluated for plan safety / quality.
- For proton planning, assessment of the maximum dose alone may not account for possible LET enhancements.

DISTAL END OF EACH BEAM END RANGES ON OPTIC CHIASM

Courtesy of MCI (R. Kotecha/K Greco)
Treatment Fidelity

- For SRS planning, spatial integrity of dose deposition is accurate
- For proton planning, the coverage and OAR constraints, there is uncertainty in dose deposition due to range uncertainty

Pituitary

<table>
<thead>
<tr>
<th>Nominal Plan Uncertainty</th>
<th>-3mm shift in the x-plane</th>
<th>-3.5% Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>29.98 Gy</td>
<td>35.82 Gy</td>
<td>35.18 Gy</td>
</tr>
</tbody>
</table>
Treatment Heterogeneity

Proton: Solid

CyberKnife: Dotted

[Graph showing dose volume histograms (DVH) with different colors representing various organs at risk and treatment plans.]
Pituitary Adenoma

Proton therapy

Photon therapy
Pituitary Adenoma

Extra dose with photons compared to protons
<table>
<thead>
<tr>
<th>Organ at Risk Doses</th>
<th>Proton</th>
<th>VMAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean dose to the Cochlea_R</td>
<td>.08 Gy</td>
<td>18.81 Gy</td>
</tr>
<tr>
<td>Mean dose to the Cochlea_L</td>
<td>.02 Gy</td>
<td>13.58 Gy</td>
</tr>
<tr>
<td>Mean dose to the Hippocampus_R</td>
<td>1.90 Gy</td>
<td>16.84 Gy</td>
</tr>
<tr>
<td>Mean dose to the Hippocampus_L</td>
<td>.80 Gy</td>
<td>16.86 Gy</td>
</tr>
<tr>
<td>Mean dose to the TemporalLobe_R</td>
<td>6.10 Gy</td>
<td>24.45 Gy</td>
</tr>
<tr>
<td>Mean dose to the TemporalLobe_L</td>
<td>3.85 Gy</td>
<td>22.72 Gy</td>
</tr>
<tr>
<td>Max dose (.03cc) to the Globe_R</td>
<td>.22 Gy</td>
<td>11.68 Gy</td>
</tr>
<tr>
<td>Max dose (.03cc) to the Globe_L</td>
<td>.16 Gy</td>
<td>10.55 Gy</td>
</tr>
<tr>
<td>Max dose (.03cc) to the Lens_R</td>
<td>.01 Gy</td>
<td>6.23 Gy</td>
</tr>
<tr>
<td>Max dose (.03cc) to the Lens_L</td>
<td>0 Gy</td>
<td>5.73 Gy</td>
</tr>
</tbody>
</table>
Re-irradiation for meningioma

Proton therapy

Photon therapy

Difference
Pancreatic Cancer

**IMRT / X-Rays**
Dose to bowel

**Protons**
Bowel Sparing

Beams

Proton Beam
Anal Cancer

Vulvar exposure = severe dermatitis / mucositis

Bowel exposure: acute diarrhea

Vulvar: sparing eliminates acute dermatitis/mucositis

Courtesy Zelig T. U Penn
For early stage breast cancer, prone photon RT is a good option to lower heart dose.

Most patients treated to breast only are suitable for prone setup and will not require Protons.

Ares et al., IJROBP 2009
Coronary Exposure to Radiation in Conventional Radiotherapy for Breast Cancer can lead to Coronary Stenosis

Stenosis of the main coronary artery left anterior descending (LAD)
Use Protons

Spare the heart and coronaries
Breast Cancer
Photons vs. Protons

3D, Breath-hold  VMAT, Free-B  Protons, Free-B

Mean heart dose

3D: 302 cGy  VMAT: 1075 cGy  IMPT: 4 cGy
Think Electrons without as much lateral scatter

Bilateral Breast with a midline robust junction

Slightly lower chestwall (ribs) and skin surface

Lower lung and heart doses
Patient position can have subtle differences
CSI Techniques

3D Photon
TomoTherapy
Proton
CSI Techniques

Heart

3D Photon

Proton

TomoTherapy
CSI Techniques

Dose to Heart

<table>
<thead>
<tr>
<th>Dose</th>
<th>ROI</th>
<th>ROI vol. [cm³]</th>
<th>Dose [Gy]</th>
<th>% outside grid</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>D99</td>
<td>D98</td>
</tr>
<tr>
<td>Plan dose: CSI 3D (CT 1)</td>
<td>Heart</td>
<td>161.37</td>
<td>1.98</td>
<td>2.09</td>
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<tr>
<td>Plan dose: 00-Tomo (C...)</td>
<td>Heart</td>
<td>161.38</td>
<td>2.12</td>
<td>2.23</td>
</tr>
<tr>
<td>Plan dose: CSI PRto...</td>
<td>Heart</td>
<td>161.37</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>
CSI Techniques

Bowels

3D Photon  TomoTherapy  Proton
CSI Techniques

Bowels

3D Photon  TomoTherapy  Proton
CSI PBS Robust Junctioning

Dose Per Field
- Image1: Composite
- Image2: UpperSpine Fld
- Image3: Brain Fields
- Image4: LowerSpine Fld
Dose Profile For Upper and Lower Spine Fields
Protons vs. IMRT: Head and Neck

Tomotherapy

3 field IMPT

20-25 Gy “savings” to the oral cavity:

What Does This Mean?

Widesott et al, IJROBP 2008
*25 Gy (25 Sv) of Unnecessary Radiation

Slide courtesy of Steve Frank, MDACCC

12,500 H&N CTs (2 mSv)
5,000,000 Intraoral X-Rays (0.002 mSv)
25,000x General Public Annual Limit (1.0 mSv)
+83% Additional Cancer Risk* (12,500 CTs, 65 yo)

Orig Diag ALL at age 2 (Cobalt) remission
34yo Multifocal Meningioma, 3 surgeries
Recurrent Atypical Meningioma Lt Cavernous sinus
42yo Male
Proton Therapy

Protons to the Vertex of the head for Meningioma 54Gy / 30fx
Atypical Meningioma
Dose difference

Life long consequences of Radiation and Chemo

Near optic apparatus

Multifocal lesions

CK to Lt Temporal Lobe lesion
25Gy / 5fx

*warmer colors are more dose from P+ than from CK
Vertex Too large for CK (Proton)
Lesion in the Cavernous Sinus (CK) 25Gy / 5fx
Vertex Too large for CK (Proton)

Lesion in the Cavernous Sinus (CK) 25Gy / 5fx
<table>
<thead>
<tr>
<th></th>
<th>PROTON</th>
<th>CyberKnife</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>MaxDose (Gy)</td>
<td>MeanDose (Gy)</td>
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<tr>
<td>Brain</td>
<td>25.9</td>
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<td>0.3</td>
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<tr>
<td>Hippocampi</td>
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</tr>
<tr>
<td>Pituitary</td>
<td>20.2</td>
<td>12.9</td>
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</tbody>
</table>
Integral dose and Cognitive performance
Paranasal Comparison
Comparison Esophagus

3DCRT: 4-field static photons; IMRT: 5-field modulated photons; PBT: 2-field passive scatter protons (PA/LPO)
Liver Comparison

Proton

VMAT
Lymphoma Comparison

Photon (VMAT)

Proton
Lymphoma Comparison

Solid Lines=Photon
Dashed=Proton

Most Organs receive lower doses with proton.

<table>
<thead>
<tr>
<th>Dose</th>
<th>ROI</th>
<th>ROI vol. [cm²]</th>
<th>D99</th>
<th>D98</th>
<th>D95</th>
<th>Average</th>
<th>D50</th>
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<td>492.48</td>
<td>52</td>
<td>63</td>
<td>87</td>
<td>959</td>
<td>780</td>
<td>2196</td>
<td>2213</td>
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<td>LAD</td>
<td>1.46</td>
<td>77</td>
<td>77</td>
<td>87</td>
<td>1719</td>
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<td>Lung_L</td>
<td>1344.29</td>
<td>32</td>
<td>39</td>
<td>55</td>
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<td>537</td>
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<td>Lung_R</td>
<td>1344.06</td>
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<td>393</td>
<td>66</td>
<td>2123</td>
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<td></td>
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<td>461.79</td>
<td>1955</td>
<td>1983</td>
<td>2027</td>
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<td>2158</td>
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<tr>
<td>Plan</td>
<td>0-0 VMAT (C.</td>
<td>SpinalCord</td>
<td>27.42</td>
<td>20</td>
<td>21</td>
<td>25</td>
<td>644</td>
<td>557</td>
<td>1393</td>
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<tr>
<td>dose</td>
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<td></td>
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</tbody>
</table>
Sometimes other factors
MCI is one of only a few cancer treatment centers in the world to have every available radiation therapy technology in one location. We feel we have a responsibility to identifying our best practice to use each technology in compliment with one another.

**Combined techniques**

- VMAT Whole Ventricle 18Gy
- Proton - PBS Pineal Boost 12Gy
- Composite 30Gy
Latest Challenge
Clival Chordoma

Initial PTV 54 Gy + Boost PTV 19.8 Gy
BrainStem Surface 67
BrainStem Core 64
Optic Chiasm and Nerves 60 Gy
Latest Challenge
Clival Chordoma

Proton to 54 PTV
Latest Challenge
Clival Chordoma

Goals for the Initial are full Target coverage while reducing OAR doses as much as possible

Boost comparison: VMAT non-coplanar CyberKnife Proton
On going lessons...

We are still early in the process...

• Difficult to guess the best technology for some cases
• Temptation to become over zealous so our goal is to learn from each comparison case
• When comparing the dosimetry we believe the Multi-technology RT approach is beneficial in many cases
Physics/Dosimetry Team
Credits: Thank you for your help

Alonso Gutierrez
Grayden MacLennan
Gus Luciani
Minesh Mehta
Marcio Fagundes
Michael Chuong
Rupesh Kotecha
Matt Hall
Kevin Greco

Armando Acha
Fazal Khan
Man Yam
David DeBlois
Curtis Wilgenbusch
Craig Kozarek
Rene Hernandez
Hayden Guerrero
Jairo Mercado
Thanks for your attention