Tips and Tricks Gleaned from the 2016 Plan Study

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Disclosure

• I am an employee of .decimal and ProKnow Systems
Who here participated in the 2016 Plan Study?

- SBRT Prostate Plan
- 420 participants
- All over the world
  - US
  - Israel
  - Germany
  - United Kingdom
  - Australia
Why do we do plan studies?
Purpose

• Using rigorous scientific methods, compare different systems and modalities in order to:
  • Identify best practices
  • Share results with the community

Ultimate Goal-
Drive out variation and improve plan quality
What are we measuring and why?

• We are measuring: plan quality… □
• In order to: study variation.

• What is so interesting about variation?
Variation in Biology

• When you first think of variation…
• Often, our first introduction to variation is in the context of biology and evolution.
• In this context, variation is good.
• Genetic variation > variable traits > some traits will be more fit to survive and reproduce through a dynamic environment.
Variation in Manufactured Products

• □But concerning manufacturing and quality…
  • In this context, variation is not good.
  • Variation is a by-product of imperfect methods and/or processes.
  • Variation is never good for the “customer.”
  • Variation causes waste and risk.
Variation in Measured Quality

- High variation □
- Average quality is low □
- Lots of low quality items □
- Few high quality items □

- Lower variation □
- Average quality is higher □
- Fewer low quality items □
- More high quality items □
Methods

Scientific Design “101”

• Control variables
• Independent variables
• Dependent variables
• Try to remove sources of bias
• Try to remove risks of bad data
Control Variables

• A control variable is kept the same throughout
• Any change in a control variable would invalidate the correlation of dependent variables to the independent variables thus skewing the results

• Patient models (CT images)
• Patient anatomy (RT structure set)
• Planning goals- i.e. plan scoring algorithm
• Scoring software to eliminate the inter-TPS variation in DVH calculation methods
Control Variables

• As controlled as we can:
  • Modern dose calculation algorithm
    • Superposition or better
  • Minimum calc grid resolution and size
    • <3mm covering all scored structures
  • Practical expenditure of time planning*
  • Practical delivery time*

*We captured approximate planning time for this years study
* We audited this via estimations of “beam on” time
Independent Variables

- Planner
  - Dosimetrist
  - Physicist
  - MD
  - Student
  - Other
- Treatment modality
  - IMRT
  - VMAT
  - Robotic
  - Proton
- Treatment planning system
- Energy
- Planning techniques
Dependent Variables

- Composite plan score
- Per metric scores
- Delivery time (estimated)
Attention to Potential Bias

• The population represented the “real planning population”
  • Communicated through organizations- AAMD, RSS, etc.
  • Communicated through all applicable vendors- TPS, delivery, etc.
  • Looked for pathways to garner international participation- FaceBook groups, known international contacts.

• Tried to remove the bias of people not participating due to worries about their experience or scores
  • Anonymous (except for high performers and peer educators)
  • No real penalty for poor performance
  • Could keep submitting to better score
  • Keep plan scoring “open” after the study is completed
Try to Minimize Bad Data

• Tried to ensure data was realistic
  • Monitor delivery time estimates
  • Collect treatment planning time estimates (honor system)

• Spot checking for bad behavior
  • Unfortunately there are ways to “cheat” in a plan study
  • We did strategic spot checks for the most notable tricks
  • We could not analyze every single plan
  • We relied on “community conscience”
The Data Set
Plan Scoring

- **Identify Critical Metrics.** Dose, DVH, or formulaic metrics selected from a vast library of options.

- **Define Each Metric’s Parameters.** Select applicable structure, dose- or volume- levels, or other input parameters to derive the metric result.

- **Define Each Metric’s Scoring.** For each metric, capture what defines success, i.e. specify priority along with: 1) minimally required result, 2) ideal result, and 3) variable scoring in between.

**Composite Plan Score Using PlanIQ Scoring Methodology**
The Plan Objectives

15 Key Metrics  Total Points 150

<table>
<thead>
<tr>
<th>#</th>
<th>METRIC ID</th>
<th>GOAL (MIN REQ)</th>
<th>GOAL (IDEAL)</th>
<th>WEIGHT (150 Total)</th>
</tr>
</thead>
<tbody>
<tr>
<td>[01]</td>
<td>Volume (%) of the PTV covered by 36.25 (Gy)</td>
<td>90</td>
<td>95</td>
<td>35 points</td>
</tr>
<tr>
<td>[02]</td>
<td>Volume (%) of the PROSTATE covered by 40 (Gy)</td>
<td>90</td>
<td>100</td>
<td>20 points</td>
</tr>
<tr>
<td>[03]</td>
<td>Dose (Gy) covering whole PTV minus 0.03 (cc)</td>
<td>29</td>
<td>36.25</td>
<td>10 points</td>
</tr>
<tr>
<td>[04]</td>
<td>Conformation Number [36.25 (Gy), PTV]</td>
<td>0.6</td>
<td>1</td>
<td>10 points</td>
</tr>
<tr>
<td>[05]</td>
<td>Volume (cc) of the RECTUM covered by 36 (Gy)</td>
<td>2</td>
<td>0</td>
<td>15 points</td>
</tr>
<tr>
<td>[06]</td>
<td>Volume (cc) of the BLADDER covered by 37 (Gy)</td>
<td>5</td>
<td>0</td>
<td>15 points</td>
</tr>
<tr>
<td>[07]</td>
<td>Dose (Gy) covering 40 (%) of the RECTUM</td>
<td>20</td>
<td>10</td>
<td>12 points</td>
</tr>
<tr>
<td>[08]</td>
<td>Dose (Gy) covering 20 (%) of the URETHRA</td>
<td>44</td>
<td>40</td>
<td>10 points</td>
</tr>
<tr>
<td>[09]</td>
<td>Dose (Gy) covering 1 (cc) of the BOWEL</td>
<td>30</td>
<td>0</td>
<td>5 points</td>
</tr>
<tr>
<td>[10]</td>
<td>Dose (Gy) covering 0.1 (cc) of the PENILE BULB</td>
<td>29.5</td>
<td>10</td>
<td>3 points</td>
</tr>
<tr>
<td>[11]</td>
<td>Dose (Gy) covering 50 (%) of the NEUROVASCULAR BUNDLES</td>
<td>40</td>
<td>37.5</td>
<td>3 points</td>
</tr>
<tr>
<td>[12]</td>
<td>Maximum dose (Gy) inside the RIGHT FEMORAL HEAD</td>
<td>27.5</td>
<td>10</td>
<td>3 points</td>
</tr>
<tr>
<td>[13]</td>
<td>Maximum dose (Gy) inside the LEFT FEMORAL HEAD</td>
<td>27.5</td>
<td>10</td>
<td>3 points</td>
</tr>
<tr>
<td>[14]</td>
<td>Maximum dose (Gy) inside the SKIN</td>
<td>30</td>
<td>10</td>
<td>3 points</td>
</tr>
<tr>
<td>[15]</td>
<td>Maximum dose (Gy) inside the TESTES</td>
<td>2</td>
<td>0</td>
<td>3 points</td>
</tr>
<tr>
<td>[16]</td>
<td>Estimated ‘beam-on’ time, all beams (minutes)</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
</tbody>
</table>
## Example Plan Scoresheet

<table>
<thead>
<tr>
<th>METRIC</th>
<th>RESULT</th>
<th>GOAL (MIN REQ)</th>
<th>GOAL (IDEAL)</th>
<th>POINTS</th>
<th>POINTS (MAX)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume (%) of the PTV covered by 36.25 (Gy)</td>
<td>98.41</td>
<td>90</td>
<td>100.0% (*NLS)</td>
<td>95</td>
<td>35.00</td>
</tr>
<tr>
<td>Volume (%) of the PROSTATE covered by 40 (Gy)</td>
<td>99.72</td>
<td>90</td>
<td>97.2% (*NLS)</td>
<td>100</td>
<td>19.89</td>
</tr>
<tr>
<td>Dose (Gy) covering whole PTV minus 0.03 (cc)</td>
<td>31.80</td>
<td>29</td>
<td>38.6% (*NLS)</td>
<td>36.25</td>
<td>6.17</td>
</tr>
<tr>
<td>Conformation Number [36.25 (Gy), PTV]</td>
<td>0.85</td>
<td>0.6</td>
<td>61.7%</td>
<td>1</td>
<td>6.17</td>
</tr>
<tr>
<td>Volume (cc) of the RECTUM covered by 36 (Gy)</td>
<td>0.00</td>
<td>2</td>
<td>99.8% (*NLS)</td>
<td>0</td>
<td>14.99</td>
</tr>
<tr>
<td>Volume (cc) of the BLADDER covered by 37 (Gy)</td>
<td>0.06</td>
<td>5</td>
<td>98.8% (*NLS)</td>
<td>0</td>
<td>14.97</td>
</tr>
<tr>
<td>Dose (Gy) covering 40 (%) of the RECTUM</td>
<td>14.01</td>
<td>20</td>
<td>59.9% (*NLS)</td>
<td>10</td>
<td>10.40</td>
</tr>
<tr>
<td>Dose (Gy) covering 20 (%) of the URETHRA</td>
<td>41.33</td>
<td>44</td>
<td>66.9%</td>
<td>40</td>
<td>6.69</td>
</tr>
<tr>
<td>Dose (Gy) covering 1 (cc) of the BOWEL</td>
<td>1.72</td>
<td>30</td>
<td>94.3%</td>
<td>0</td>
<td>4.71</td>
</tr>
<tr>
<td>Dose (Gy) covering 0.1 (cc) of the PENILE BULB</td>
<td>1.94</td>
<td>29.5</td>
<td>100.0%</td>
<td>10</td>
<td>3.00</td>
</tr>
<tr>
<td>Dose (Gy) covering 50 (%) of the NEUROVASCULAR BUNDLES</td>
<td>37.30</td>
<td>40</td>
<td>100.0%</td>
<td>37.5</td>
<td>3.00</td>
</tr>
<tr>
<td>Maximum dose (Gy) inside the RIGHT FEMORAL HEAD</td>
<td>8.05</td>
<td>27.5</td>
<td>100.0% (*NLS)</td>
<td>10</td>
<td>3.00</td>
</tr>
<tr>
<td>Maximum dose (Gy) inside the LEFT FEMORAL HEAD</td>
<td>7.94</td>
<td>27.5</td>
<td>100.0% (*NLS)</td>
<td>10</td>
<td>3.00</td>
</tr>
<tr>
<td>Maximum dose (Gy) inside the SKIN</td>
<td>8.66</td>
<td>30</td>
<td>100.0%</td>
<td>10</td>
<td>3.00</td>
</tr>
<tr>
<td>Maximum dose (Gy) inside the TESTES</td>
<td>0.31</td>
<td>2</td>
<td>84.7%</td>
<td>0</td>
<td>2.54</td>
</tr>
<tr>
<td>Estimated 'beam-on' time, all beams (minutes)</td>
<td>2.26</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>TOTALS</td>
<td>15 (of 15)</td>
<td>6 (of 15)</td>
<td>136.53</td>
<td>150.00</td>
<td></td>
</tr>
</tbody>
</table>
The ProKnow System

User

DOWNLOAD
DICOM Images (CT)
DICOM RT Structure Set
Instructions (PDF)

IMPORT to TPS
CT and Structures

CREATE PLAN

UPLOAD
RT Plan and Dose

SCORE PLAN
Review results
Produce report

SUBMIT
Register results

STUDY
Review results
Compare to population

Web Interface

Download

Upload (Plan, Dose)

Review Results Report

“Submit”

Study-wide Reports

ProKnow Cloud Engine

Download file library

Dynamic library of uploaded files

Plan Score Results

Plan Score Calculator

Record Submission

Submission Library

Interactive Analytics

Analytics Engine
Participation by Year

Plan Study Participation (By Year)

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of Plans Submitted (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>100</td>
</tr>
<tr>
<td>2012</td>
<td>100</td>
</tr>
<tr>
<td>2013</td>
<td>200</td>
</tr>
<tr>
<td>2014</td>
<td>300</td>
</tr>
<tr>
<td>2015</td>
<td>400</td>
</tr>
<tr>
<td>2016</td>
<td>420</td>
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</tbody>
</table>
## Participation by Role

<table>
<thead>
<tr>
<th>Clinical Role</th>
<th>N</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dosimetrist</td>
<td>201</td>
<td>47.9</td>
</tr>
<tr>
<td>Physicist</td>
<td>172</td>
<td>41.0</td>
</tr>
<tr>
<td>Student</td>
<td>22</td>
<td>5.2</td>
</tr>
<tr>
<td>Therapist</td>
<td>12</td>
<td>2.9</td>
</tr>
<tr>
<td>Other</td>
<td>8</td>
<td>1.9</td>
</tr>
<tr>
<td>Physician</td>
<td>5</td>
<td>1.2</td>
</tr>
</tbody>
</table>
### Participation by Modality

<table>
<thead>
<tr>
<th>Modality</th>
<th>N</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>VMAT</td>
<td>335</td>
<td>79.8</td>
</tr>
<tr>
<td>IMRT</td>
<td>31</td>
<td>7.4</td>
</tr>
<tr>
<td>Robotic</td>
<td>28</td>
<td>6.7</td>
</tr>
<tr>
<td>Helical Tomotherapy</td>
<td>20</td>
<td>4.8</td>
</tr>
<tr>
<td>Proton</td>
<td>6</td>
<td>1.4</td>
</tr>
</tbody>
</table>
## Participation by TPS

<table>
<thead>
<tr>
<th>TPS</th>
<th>N</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Varian Eclipse</td>
<td>199</td>
<td>47.4</td>
</tr>
<tr>
<td>Philips Pinnacle</td>
<td>72</td>
<td>17.1</td>
</tr>
<tr>
<td>Elekta Monaco</td>
<td>58</td>
<td>13.8</td>
</tr>
<tr>
<td>RaySearch RayStation</td>
<td>40</td>
<td>9.5</td>
</tr>
<tr>
<td>Accuray CyberKnife (MultiPlan)</td>
<td>28</td>
<td>6.7</td>
</tr>
<tr>
<td>Accuray Tomotherapy (Hi Art)</td>
<td>20</td>
<td>4.8</td>
</tr>
<tr>
<td>Nucletron Oncentra</td>
<td>2</td>
<td>0.5</td>
</tr>
<tr>
<td>BrainLab iPlan</td>
<td>1</td>
<td>0.2</td>
</tr>
</tbody>
</table>
Sanity Check: Simple 3D Conformal

* 3D plan courtesy of Vanessa Magliari (St. Anthony's Medical Center)

Modality: 3D Conformal*
Summary: 9 Beam (15 MV)
Total Score: **101.17 / 150.0**
Min. Req. Met: 14 / 15
Sanity Check: High Quality VMAT

* VMAT plan courtesy of Vanessa Magliari (St. Anthony’s Medical Center)

<table>
<thead>
<tr>
<th>METRIC</th>
<th>RESULT</th>
<th>GOAL</th>
<th>MAX RQ</th>
<th>GOAL</th>
<th>LEAK</th>
<th>POINTS</th>
<th>POINTS MAX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vmax (% of PTV covered by 100% isodose)</td>
<td>96.18</td>
<td>96</td>
<td>96</td>
<td>96</td>
<td>100</td>
<td>35.00</td>
<td>35.00</td>
</tr>
<tr>
<td>Vmax (% of PTV covered by 80% isodose)</td>
<td>96.89</td>
<td>96</td>
<td>96</td>
<td>96</td>
<td>100</td>
<td>35.00</td>
<td>35.00</td>
</tr>
<tr>
<td>Dose (cGy) covering whole PTV minus 95% (cc)</td>
<td>36.15</td>
<td>36.25</td>
<td>36.25</td>
<td>9.17</td>
<td>10.00</td>
<td>10.00</td>
<td></td>
</tr>
<tr>
<td>Conformation Number (MLC, 6L, 7L)</td>
<td>0.95</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>10.00</td>
<td>10.00</td>
</tr>
<tr>
<td>Vmax (% of integrity covered by 100% isodose)</td>
<td>0.05</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>14.02</td>
<td>15.00</td>
<td>15.00</td>
</tr>
<tr>
<td>Vmax (% of bladder covered by 100% isodose)</td>
<td>0.13</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>14.02</td>
<td>15.00</td>
<td>15.00</td>
</tr>
<tr>
<td>Dose (cGy) covering 10% (cc) of the rectum</td>
<td>9.06</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10.00</td>
<td>10.00</td>
<td></td>
</tr>
<tr>
<td>Dose (cGy) covering 30% (cc) of the Bladder</td>
<td>40.61</td>
<td>40</td>
<td>40</td>
<td>40</td>
<td>40.00</td>
<td>40.00</td>
<td></td>
</tr>
<tr>
<td>Dose (cGy) covering 5% (cc) of the bowel</td>
<td>1.18</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>4.75</td>
<td>5.00</td>
<td></td>
</tr>
<tr>
<td>Dose (cGy) covering 1% (cc) of the prune belly syndrome</td>
<td>1.72</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>3.00</td>
<td>3.00</td>
<td></td>
</tr>
<tr>
<td>Dose (cGy) covering 5% (cc) of the Neurovascular bundle</td>
<td>35.84</td>
<td>35</td>
<td>35</td>
<td>35</td>
<td>35.00</td>
<td>35.00</td>
<td></td>
</tr>
<tr>
<td>Maximum dose (cGy) inside the right femoral head</td>
<td>9.64</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10.00</td>
<td>10.00</td>
<td></td>
</tr>
<tr>
<td>Maximum dose (cGy) inside the left femoral head</td>
<td>9.82</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10.00</td>
<td>10.00</td>
<td></td>
</tr>
<tr>
<td>Maximum dose (cGy) inside the skin</td>
<td>5.76</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5.00</td>
<td>5.00</td>
<td></td>
</tr>
<tr>
<td>Maximum dose (cGy) inside the testes</td>
<td>0.23</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2.66</td>
<td>3.00</td>
<td></td>
</tr>
<tr>
<td>Estimated beam-on time, all beams (minutes)</td>
<td>0.37</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td></td>
</tr>
</tbody>
</table>

TOTALS | 15 of 15 | 0 of 15 | 145.68 | 150.00 |

- **Modality**: VMAT*
- **Summary**: 3 Arcs (15 MV)
- **Total Score**: 145.88 / 150.0
- **Min. Req. Met**: 15 / 15
# Simple 3D vs High Quality VMAT

<table>
<thead>
<tr>
<th>Metric</th>
<th>Result</th>
<th>Goal (MIN REQ)</th>
<th>Goal (DICAL)</th>
<th>Points</th>
<th>Points (MAX)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume (%) of the PTV covered by 36.25 Gy</td>
<td>99.99</td>
<td>99</td>
<td>86% (86.2%)</td>
<td>95</td>
<td>35.00</td>
</tr>
<tr>
<td>Volume (%) of the PROSTATE covered by 40 Gy</td>
<td>96.73</td>
<td>96</td>
<td>67.1% (67.1%)</td>
<td>100</td>
<td>18.70</td>
</tr>
<tr>
<td>Dose (Gy) covering whole PTV minus OAR (cc)</td>
<td>36.67</td>
<td>38</td>
<td>100% (100.0%)</td>
<td>36.63</td>
<td>10.00</td>
</tr>
<tr>
<td>Conformation Number (36.25 Gy, PTV)</td>
<td>0.74</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>3.51</td>
</tr>
<tr>
<td>Volume (cc) of the RECTUM covered by 36 Gy</td>
<td>2.28</td>
<td>2</td>
<td>0.00</td>
<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td>Volume (cc) of the BLADDER covered by 37 Gy</td>
<td>3.95</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Dose (Gy) covering 40% of the RECTUM</td>
<td>9.88</td>
<td>9.60</td>
<td>4.7% (4.7%)</td>
<td>10</td>
<td>2.41</td>
</tr>
<tr>
<td>Dose (Gy) covering 20% of the URINARY BLADDER</td>
<td>40.81</td>
<td>44</td>
<td>79.6%</td>
<td>40</td>
<td>7.96</td>
</tr>
<tr>
<td>Dose (Gy) covering 1% (cc) of the BOWEL</td>
<td>2.09</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>4.65</td>
</tr>
<tr>
<td>Dose (Gy) covering 0.1% (cc) of the PENILE BULB</td>
<td>2.52</td>
<td>2.5</td>
<td>0</td>
<td>0</td>
<td>3.00</td>
</tr>
<tr>
<td>Dose (Gy) covering 50% of the NEUROVASCULAR BUNDLES</td>
<td>39.33</td>
<td>39</td>
<td>89.2%</td>
<td>37.3</td>
<td>9.36</td>
</tr>
<tr>
<td>Maximum dose (Gy) inside the RIGHT FEMORAL HEAD</td>
<td>20.35</td>
<td>20.8</td>
<td>10</td>
<td>1.43</td>
<td>3.00</td>
</tr>
<tr>
<td>Maximum dose (Gy) inside the LEFT FEMORAL HEAD</td>
<td>20.51</td>
<td>20.8</td>
<td>10</td>
<td>1.39</td>
<td>3.00</td>
</tr>
<tr>
<td>Maximum dose (Gy) inside the SKIN</td>
<td>10.81</td>
<td>10</td>
<td>35.1%</td>
<td>10</td>
<td>2.88</td>
</tr>
<tr>
<td>Maximum dose (Gy) inside the TESTES</td>
<td>0.27</td>
<td>2</td>
<td>0</td>
<td>0.60</td>
<td>3.00</td>
</tr>
<tr>
<td>Estimated beam-on time, all beams (minutes)</td>
<td>4.15</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td><strong>TOTALS</strong></td>
<td>14 (of 15)</td>
<td>3 (of 15)</td>
<td>101.17</td>
<td>150.00</td>
<td></td>
</tr>
</tbody>
</table>

### Modality Summary
- **3D Conformal**
- **Total Score**: 101.17 / 150.0
- **Min. Req. Met**: 14 / 15

---

<table>
<thead>
<tr>
<th>Metric</th>
<th>Result</th>
<th>Goal (MIN REQ)</th>
<th>Goal (DICAL)</th>
<th>Points</th>
<th>Points (MAX)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume (%) of the PTV covered by 36.25 Gy</td>
<td>98.18</td>
<td>99</td>
<td>86% (86.2%)</td>
<td>95</td>
<td>35.00</td>
</tr>
<tr>
<td>Volume (%) of the PROSTATE covered by 40 Gy</td>
<td>96.89</td>
<td>96</td>
<td>64.9% (64.9%)</td>
<td>100</td>
<td>18.73</td>
</tr>
<tr>
<td>Dose (Gy) covering whole PTV minus OAR (cc)</td>
<td>34.75</td>
<td>35</td>
<td>79.9% (79.9%)</td>
<td>36.25</td>
<td>9.17</td>
</tr>
<tr>
<td>Conformation Number (36.25 Gy, PTV)</td>
<td>0.95</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>8.76</td>
</tr>
<tr>
<td>Volume (cc) of the RECTUM covered by 36 Gy</td>
<td>0.05</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>14.92</td>
</tr>
<tr>
<td>Volume (cc) of the BLADDER covered by 37 Gy</td>
<td>0.13</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>14.92</td>
</tr>
<tr>
<td>Dose (Gy) covering 40% of the RECTUM</td>
<td>9.06</td>
<td>9</td>
<td>86% (86%)</td>
<td>10</td>
<td>1.30</td>
</tr>
<tr>
<td>Dose (Gy) covering 20% of the URINARY BLADDER</td>
<td>40.01</td>
<td>44</td>
<td>99.9%</td>
<td>40</td>
<td>9.68</td>
</tr>
<tr>
<td>Dose (Gy) covering 1% (cc) of the BOWEL</td>
<td>1.48</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>4.75</td>
</tr>
<tr>
<td>Dose (Gy) covering 0.1% (cc) of the PENILE BULB</td>
<td>1.72</td>
<td>1.5</td>
<td>0</td>
<td>0</td>
<td>3.00</td>
</tr>
<tr>
<td>Dose (Gy) covering 50% of the NEUROVASCULAR BUNDLES</td>
<td>37.54</td>
<td>37</td>
<td>89.3%</td>
<td>37.3</td>
<td>2.95</td>
</tr>
<tr>
<td>Maximum dose (Gy) inside the RIGHT FEMORAL HEAD</td>
<td>3.64</td>
<td>3.5</td>
<td>0</td>
<td>0</td>
<td>3.00</td>
</tr>
<tr>
<td>Maximum dose (Gy) inside the LEFT FEMORAL HEAD</td>
<td>9.82</td>
<td>9.5</td>
<td>0</td>
<td>0</td>
<td>3.00</td>
</tr>
<tr>
<td>Maximum dose (Gy) inside the SKIN</td>
<td>5.76</td>
<td>5</td>
<td>100%</td>
<td>5</td>
<td>1.00</td>
</tr>
<tr>
<td>Maximum dose (Gy) inside the TESTES</td>
<td>0.23</td>
<td>0</td>
<td>0</td>
<td>0.66</td>
<td>3.00</td>
</tr>
<tr>
<td>Estimated beam-on time, all beams (minutes)</td>
<td>6.37</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td><strong>TOTALS</strong></td>
<td>15 (of 15)</td>
<td>6 (of 15)</td>
<td>145.88</td>
<td>150.00</td>
<td></td>
</tr>
</tbody>
</table>

### VMAT*
- **3 Arcs (15 MV)**
- **Total Score**: 145.88 / 150.0
- **Min. Req. Met**: 15 / 15

---

*Both plans courtesy of Vanessa Magliari (St. Anthony's Medical Center)
## Results: Meeting Min Requirements

<table>
<thead>
<tr>
<th># Min Requirements Achieved</th>
<th>N</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 (out of 15)</td>
<td>383</td>
<td>91.2</td>
</tr>
<tr>
<td>14</td>
<td>30</td>
<td>7.1</td>
</tr>
<tr>
<td>13</td>
<td>3</td>
<td>0.7</td>
</tr>
<tr>
<td>12</td>
<td>2</td>
<td>0.5</td>
</tr>
<tr>
<td>11</td>
<td>1</td>
<td>0.2</td>
</tr>
<tr>
<td>10</td>
<td>1</td>
<td>0.2</td>
</tr>
<tr>
<td>&lt; 10</td>
<td>0</td>
<td>0.0</td>
</tr>
</tbody>
</table>
Results: Score Distribution (All)

Histogram of Total [POINTS]
N: 420 | Min: 78.94 | Max: 147.17 | Median: 141.00 | Mean: 138.18 | Std Dev: 8.28
Improvement Over the Years

2011

Histogram of 2011 (Prostate Fossa)
N: 126  Min: 58.18  Max: 142.47  Median: 119.69  Mean: 117.10  Std Dev: 16.42

2012

Histogram of 2012 (Abdomen)
N: 97  Min: 87.60  Max: 145.45  Median: 130.14  Mean: 128.88  Std Dev: 10.06

2013

Histogram of 2013 (Anus)
N: 157  Min: 47.61  Max: 146.79  Median: 124.14  Mean: 121.72  Std Dev: 16.92

2014

Histogram of 2014 (Breast)
N: 81  Min: 85.45  Max: 149.45  Median: 134.59  Mean: 131.40  Std Dev: 13.50

2015

Histogram of 2015 (Hippocampal Sparing)
N: 223  Min: 38.73  Max: 146.12  Median: 127.08  Mean: 123.00  Std Dev: 17.72

2016

Histogram of 2016 (SBRT Prostate)
N: 420  Min: 78.94  Max: 147.17  Median: 141.00  Mean: 138.18  Std Dev: 8.29
Results per Modality

VMAT

Proton

IMRT

Helical Tomotherapy

Robotic
# Results per Modality

<table>
<thead>
<tr>
<th>TPS</th>
<th>N</th>
<th>MIN</th>
<th>MEDIAN</th>
<th>MAX</th>
<th>ST DEV</th>
</tr>
</thead>
<tbody>
<tr>
<td>VMAT</td>
<td>335</td>
<td>78.94</td>
<td>141.65</td>
<td>147.17</td>
<td>6.57</td>
</tr>
<tr>
<td>Proton</td>
<td>6</td>
<td>135.95</td>
<td>143.04</td>
<td>146.32</td>
<td>3.79</td>
</tr>
<tr>
<td>IMRT</td>
<td>31</td>
<td>110.72</td>
<td>134.60</td>
<td>144.12</td>
<td>6.29</td>
</tr>
<tr>
<td>Tomotherapy</td>
<td>20</td>
<td>122.58</td>
<td>135.00</td>
<td>143.58</td>
<td>6.22</td>
</tr>
<tr>
<td>Robotic</td>
<td>28</td>
<td>90.24</td>
<td>131.58</td>
<td>143.38</td>
<td>14.03</td>
</tr>
</tbody>
</table>
Results per TPS

Eclipse
RayStation
Monaco
Pinnacle
Tomotherapy (Hi-Art)
CyberKnife (MultiPlan)
### Results per TPS

<table>
<thead>
<tr>
<th>TPS</th>
<th>N (n)</th>
<th>MIN</th>
<th>MEDIAN</th>
<th>MAX</th>
<th>ST DEV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eclipse</td>
<td>199 (1)</td>
<td>78.94</td>
<td>141.67</td>
<td>147.17</td>
<td>7.08</td>
</tr>
<tr>
<td>RayStation</td>
<td>40 (2)</td>
<td>118.55</td>
<td>143.99</td>
<td>146.37</td>
<td>6.46</td>
</tr>
<tr>
<td>Monaco</td>
<td>58 (22)</td>
<td>119.48</td>
<td>141.24</td>
<td>145.79</td>
<td>6.29</td>
</tr>
<tr>
<td>Pinnacle</td>
<td>72 (3)</td>
<td>103.71</td>
<td>139.36</td>
<td>145.30</td>
<td>7.43</td>
</tr>
<tr>
<td>Tomotherapy</td>
<td>20 (3)</td>
<td><strong>122.58</strong></td>
<td>135.00</td>
<td>143.58</td>
<td>6.22</td>
</tr>
<tr>
<td>CyberKnife</td>
<td>28 (2)</td>
<td>90.24</td>
<td>131.58</td>
<td>143.38</td>
<td>14.03</td>
</tr>
<tr>
<td>Oncentra</td>
<td>2 (0)</td>
<td>141.43</td>
<td>n/a</td>
<td>142.36</td>
<td>n/a</td>
</tr>
<tr>
<td>BrainLab</td>
<td>1 (0)</td>
<td>n/a</td>
<td>n/a</td>
<td>135.18</td>
<td>n/a</td>
</tr>
</tbody>
</table>

**N** = Number of plans per TPS  
**n** = Number of plans submitted by the TPS vendor’s employees
Results per Role

Dosimetrists

Physicists

Students

Therapists

Physicians
Dosimetrist vs. Physicist

Dosimetrists

Histogram of Dosimetrist
N: 201 Min: 90.24 Max: 147.17 Median: 141.30 Mean: 139.06 Std Dev: 7.53

Physicists

Histogram of Physicist
N: 172 Min: 103.71 Max: 146.37 Median: 140.26 Mean: 137.39 Std Dev: 7.91
Results: Energies Used in top 50

<table>
<thead>
<tr>
<th>Energy</th>
<th>N</th>
<th>% of Top 50</th>
</tr>
</thead>
<tbody>
<tr>
<td>6FFF</td>
<td>6</td>
<td>12%</td>
</tr>
<tr>
<td>6</td>
<td>8</td>
<td>16%</td>
</tr>
<tr>
<td>Mixed</td>
<td>2</td>
<td>4%</td>
</tr>
<tr>
<td>10FFF</td>
<td>14</td>
<td>28%</td>
</tr>
<tr>
<td>10</td>
<td>7</td>
<td>14%</td>
</tr>
<tr>
<td>&gt; 10</td>
<td>11</td>
<td>20%</td>
</tr>
<tr>
<td>Proton</td>
<td>2</td>
<td>4%</td>
</tr>
</tbody>
</table>

Frequency vs. Beam Energies
Results: %PTV and %GTV Coverage

Histogram of % PTV Coverage (36.25 Gy)
N: 420  Min: 92.55  Max: 100.00  Median: 98.34  Mean: 98.05  Std Dev: 1.35

Histogram of % GTV Coverage (40.0 Gy)
N: 420  Min: 0.00  Max: 100.00  Median: 97.44  Mean: 96.79  Std Dev: 7.37

Oops.
Forgot the 40 Gy GTV prescription?
Results: %PTV and %GTV Coverage

Histogram of % PTV Coverage (36.25 Gy)
N: 420  Min: 92.55  Max: 100.00  Median: 98.34  Mean: 98.05  Std Dev: 1.35

Histogram of % GTV Coverage (40.0 Gy)
N: 416  Min: 91.80  Max: 100.00  Median: 97.45  Mean: 97.40  Std Dev: 1.62
Results: High Performers

*Some plans were < 142 but in top 20% for particular TPS

David Littlejohn
Thomas Costantino
Bruce Phillips
Jade Griffin
Frank Simac
Mikel Byrne
Anthony Magliari
Mihai Ene
Timothy Burns
Ben Archibald-Heeren
Christopher Peck
Jill Brooks
Adam Cohen
Cameron Ditty
Ross McCall
Rolland Julien
Richard Shores
Vanessa Magliari
Laura Sawicki
Paul Barry
Thomas Kendra
Scott Downs
Fazal Khan
Jonathan Stenbeck
Tom Sullivan
Karen
shaomin zhang
Mikhail Diachenko
Matthew Squires
Dinesh Kumar Mynampati
Bruno Bosco
Ludovic
Abdul Wahab Sharfo
Sarah Ghandour
Gail VanDerbeck
Randy Larson
Amy Longsdon
Angleraud
George
Tomas Prochazka
Zuo Zhang
Chris Huff
Nelly Ju
George Tolekidis
Lisa
Kathleen Broche-Gardner
Jallon
dupas
Mark Arends
Jason Metzger
Mark Addington
dare
Tchong Len
Kayla Brown
Zhiqiang Han
Luke Mackowiak
Thamizhaisi Swaminathan
Josh Russell
Carol
Jennifer Back
Rodney Hood
Brandon Van Asten
Jason Edwards
Joakim Nilsson
nguyen Daniel
Yu-Wen Chang
Bridget
anthony rosain
Alex Nevelsky
John Paul Zenone
Hisato Nagano
Mattia Di Martino
Jamie Christ
Lisbet Williams
Andrew Mercurio
Joong-Yeol Woo
Shaun
Dustin Alex Whittington
Rui Silva
Nara Elaidoost
sangjun Son
Fares
Brett
Matt Brennan
Steven Murphy
Jane McNamara
nader
Antonio Ruiz
Daniel Bryant
Qiwei Hu
Boris Zhelondz
Brian Doozan
James WARD
Qianyi Xu
Martin Pavlat
Kyle Riffe
Jeremy Mulligan
Peter Teon
Christopher Amaloo
Akos Gulyan
Peter Kovacs
Ray Dalsen
Megan Tattersall
Brandie
Chavanon Apinoraethkul
Jong Ho
Sneha Cloake
Anthony Huynh
Andrew Lyubinskiy
Albert
Wesley Groves
Elaine C. Almeida
Shenpeng Jiang
Kent Powell
Wei Loong
Catherine Vogesang
Jake Jackson
Stephen Jones
Jason
Perry Hunter
Vanessa Monteiro
Matthew Thomas
Rik Westendorp
Yan Chen
Collin
James Buckley
Jennifer Porosky
Udai Kumar
Teo Yuan Xin
Michael Oliver
sopaul seng
Stuart Williams
Danny
Greg Bartlett
Maryellen Kassab
Valerie Wright
Luke Arentsen
Nadir
Susannah Jansen van Rensburg
Trevor Williams
Jessica Stanley
Leslie Humpal
Danny Tran
Brais Rodriguez
Aneta Kawa-Iwanicka
Justin
Arun Gandhi
Justin Gilles
Timothy Atkins
Mark McGee
LuoShoubang
Stela Paltrinier Nardi
Kenny Guida
David Ly
Carol McRee
Kevin Burke
Lei Fu
Christina Schipper
Shane Hagler
Jeremy Donaghe
Colin Sims
Michele Wolfe
Santosh Ladsaria
Eric Lobb
Eric Ehler
Oliver Blanck
Christopher Peck
Omar Chibani
Rick Scherer
Tips and Techniques

• Information gathered by interviewing top performers across the various TPS vendors
Tips and Techniques: General

• Analyze contours and prescription
  • Is what you are being asked achievable?
  • Is there a need to “break up” OAR’s that intersect the GTV/PTV?
  • Do any new structures need creating?
    • Try to minimize dose specific structures
Tips and Techniques: General

- Do a starting/base plan first
- Get a “feel” for the plan
- Keep constraints simple
- Set realistic objectives
- Fine tune
- Focus on target coverage first
- Then work on OAR’s
Tips and Techniques: General

• Don’t forget about lose dose regions

• Don’t overdo table kicks

• Don’t be afraid to try 10X
  • Or even 15X if you have it commissioned for IMRT/VMAT treatment

• Try to keep MU’s to 2x the daily dose
  • Helps with modulation
Tips and Techniques: ECLIPSE

• The planner needs to have an understanding on how to use the NTO (Normal Tissue Optimizer) properly

• If don’t use NTO there is a need to incorporate rings
  • Most common rings used
    • .1 to .5cm around PTV
    • 1 to 1.5cm around PTV
    • .1 to .3 cm around urethra and NVB

• About 50% utilized a combination of rings and NTO
Tips and Techniques: ECLIPSE

• Pay attention to priorities

• Pause the optimizer often
  • Make tweaks if needed
  • Especially in level one and two

• Collimator angles of 10-90 degrees used
Tips and Techniques: MONACO

• Try to get the best results you can on the first stage
  • Only little tweaks on second stage

• Set calculation grid to 2mm

• Get a good grasp on how the cost functions work

• Use Quadratic Overdose in the Body to create rings
Tips and Techniques: MONACO

• Make sure your constraints are in the correct order

• Consider manually weighting your target

• Watch the iso-constraints and relative impacts
  • Compare
    • Will you really gain by your adjustment
Tips and Techniques: CyberKnife

• Forget everything you have learned in other TPS
  • Per Dr. Oliver Blanck (one of the creators of the CyberKnife algorithm)

• Use shell structures to control:
  • Dose conformity
  • Dose fall off
  • Hot spots outside of the target area
Tips and Techniques: CyberKnife

• Set MU limit
  • 350-600 MU per beam

• Consider using the IRIS collimator
  • Gives the optimizer more options
  • Reduces treatment time

• Be patient
  • Try again and again and again and again
  • You never know what you may end up with
Tips and Techniques: PINNACLE

• Watch your optimizer
  • If you don’t get your coverage in the first 50 or so iterations re-evaluate your objectives

• Start with small dose grid then expand

• Limit your 50% dose to 2cm away
  • Good starting point for compact distribution
  • Then work on OAR’s
Tips and Techniques: Conclusion

• KISS principle!!!!

• Know how your optimizer works

• Small adjustments can bring big rewards

• Don’t overcomplicate the process

• Common sense is your best friend
Big Surprise Found

- When the expert physicians drew the PTV they didn’t extend it into the rectum
  - Panel of seven physicians & physicists
  - Was not noted until halfway through study
  - Made it easier to accomplish the set goal
  - Even experts make mistakes
  - Decision made to continue with study but not to publish a paper on the results (RSS)
- Talks were given at AAMD National Conference and RSS National Conference
The Importance of Contouring

• What will be wrong if there are contouring errors?
  • Plan Optimization will be compromised
    • The dose will be shaped to the wrong volumes
  • Plan acceptance criteria will not be valid
    • The acceptance criteria (DVH points, max ROI dose, etc) will not be accurate
  • IGRT and Adaptive RT will also suffer
    • IGRT set up based on ROI shape/location will have errant volumes as the reference.
    • Adaptive based planning based on morphing target and OAE volumes will be wrong
  • The patient may be mistreated
    • Dose will be delivered to the wrong place or not delivered to the right place
• No TPS or modality will correct for contouring errors
If It’s So Important, Why So Little Attention?

• If contouring accuracy is so important, why does the industry give it much less attention that new technology or algorithms?
  • Big money and curb appeal has been in new technology (especially heavy iron- LINACS) not in continual improvement
  • People agree that it is important but there is not quality standard or proof of performance for accreditation or reimbursement
  • Some people do not know or acknowledge that there is need for improvement
What structures exhibit the most variation?

<table>
<thead>
<tr>
<th>Low Variability</th>
<th>Medium Variability</th>
<th>High Variability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brain</td>
<td>Brainstem</td>
<td>Brachial Plexus</td>
</tr>
<tr>
<td>Mandible</td>
<td>Parotid</td>
<td>Larynx</td>
</tr>
<tr>
<td>Lung</td>
<td>Seminal Ves</td>
<td>Glottis</td>
</tr>
<tr>
<td>Bladder</td>
<td>Prostate</td>
<td>Submandibular</td>
</tr>
<tr>
<td>Skin</td>
<td></td>
<td>Hippocampus</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Chiasm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rectum</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Small Bowel</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sigmoid</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Large Bowel</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Penile Bulb</td>
</tr>
</tbody>
</table>

- Contouring Challenge 1.0 and 2.0 (2010 and 2011).
An example from the AAMD Contouring Workshop - 2016

Rectum

Sigmoid

Small Bowel

Large Bowel
The Impact on Contouring Accuracy

You draw these.

But these were correct.

You plan this.
The Impact of Contouring Accuracy


There was significant inter-clinician variation in OAR contouring. The degree of variation is organ-dependent. We found substantial dose differences resulting strictly from contouring variation (differences ranging from −289% to 56% for mean OAR dose; −22% to 35% for maximum dose).
The Impact of Contouring Accuracy

Variability of Target and Normal Structure Delineation for Breast Cancer Radiotherapy: An RTOG Multi-Institutional and Multiobserver Study

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Differences in target and OAR delineation for breast irradiation between institutions/observers appear to be clinically and dosimetrically significant. A systematic consensus is highly desirable, particularly in the era of intensity-modulated and image-guided RT.
Can we increase accuracy and decrease variation?

**Physics Contribution**

**A System for Continual Quality Improvement of Normal Tissue Delineation for Radiation Therapy Treatment Planning**

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The results of this study indicate the feasibility of applying the PDCA cycle to assess competence in the delineation of individual organs…With testing, guidance, and re-evaluation, contouring consistency can be obtained across multiple dosimetrists…Continual quality improvement using the PDCA approach will ensure more accurate treatments and dose assessment in treatment planning and delivery.
Can we increase accuracy and decrease variation?
What’s next?

• What’s is next years study?

• The requirements:
  • The plan has a novel purpose or angle- challenging case study
  • The results are presented at a national meeting and/or published in a peer-reviewed journal

We want the Medical Dosimetry community to decide!
Send us your ideas!
What’s next?

• “Next level” studies we plan to do
  • Plan Quality + QA Accuracy
    • Study not only plan quality but also QA scores
      • Deliver the plan to a 3D dosimetry phantom
      • Submit both plan and QA scores
    • Both the TPS dose calculation and dose delivery are audited
  • Start October 10, 2016 (?)
  • Planning Efficiency
    • Time limit imposed
    • Who and what can create the highest quality plans in a restricted amount of time
  • “John Henry vs the Steam Engine”
    • Treatment planners vs TPS auto-planning
Questions?
Thanks!!

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