INTRODUCING PLAN QUALITY METRICS
A Method to Customize and Automate the Measurement of Plan Quality

BEN NELMS, PH.D. (CANIS LUPUS LLC)

DISCLAIMERS

- SOURCES OF FUNDING
  - None to report, i.e. the research and work discussed here are unfunded.
  - Plan Challenges are voluntary and free to participants.
  - Plan Challenge design, evaluation, and analysis is a voluntary service provided by me and the team of dosimetrists from ROR.

- STATEMENTS OF CONFLICT OF INTEREST
  - I am a paid consultant to Sun Nuclear Corporation and the inventor of their products: EPIDOSE, MOTIONSIM, and 3DVH.
  - My company (Canis Lupus LLC) owns and develops the medical device software solution QUALITY REPORTS [EMR]®.
ACKNOWLEDGEMENTS

- **Below are some of my colleagues who were instrumental in this work:**
  - Greg Robinson, MS, CMD, RT(T)
  - Kyle Velasco, CMD, RT(T)
  - Adam Moore, CMD, RT(T)
  - Steve Boyd, CMD, RT(R)(T)

- **Other contributors include:**
  - Vladimir Feygelman, Ph.D.
  - “Project Icarus” research team (consists of a small, international group of dosimetrists and physicists from the USA, CAN, AUS, and the UK)

OUTLINE

- **Introduction: What is Plan Quality?**
- **Plan Quality Metrics (PQM)**
  - History: The International “Plan Challenges”
  - Description & Methods
  - Example Plan Challenge Results / Analysis
- **Applications (Per Patient)**
  - Per-Patient Workflow
  - Commissioning & Validation
  - Accreditation & Competency Testing
- **Other Applications (Quality Management Systems)**
  - Commissioning (TPS and Delivery)
  - Benchmarking & Comparative Effectiveness
  - Clinical Trials
WHAT IS PLAN QUALITY?

- **PLAN QUALITY ≠ DOSE ACCURACY (CALC & DELIVERY)**
  - You may be able to accurately calculate and deliver a plan...but if it’s a low quality plan to begin with, you produce a low quality result.
  - TPS dose algorithm accuracy ≠ plan quality
  - Machine delivery accuracy ≠ plan quality

Levels of Plan Quality

Levels of Dose Accuracy

Venn Diagram: Plan Quality & Dose Accuracy

I. Accurate calculation & delivery; but low quality plans
II. High quality plans; but inaccurate calculation [and/or] delivery
III. High quality plans; accurate calculation & delivery

WHAT IS PLAN QUALITY?

- **PLAN QUALITY ≠ ANY PARTICULAR MODALITY, BRAND, OR ACRONYM**
  - “IMRT” does not guarantee high quality plans
  - “VMAT” does not guarantee high quality plans
  - “Particle/Proton Therapy” does not guarantee high quality plans
  - [Insert New Fancy Product Name Here] does not guarantee high quality plans

- **FINDINGS FROM THE PLAN CHALLENGES**
  - Plenty of poor quality plans using latest modalities and products
  - Some of the very high quality plans are some of the least complex and using older equipment
WHAT IS PLAN QUALITY?

- **PLAN QUALITY ≠ PLANNER EXPERIENCE OR CERTIFICATION**
  - *Years Experience* does not guarantee high quality plans
  - *CMD* does not guarantee high quality plans (nor do: PhD, DABR, MD, etc.)
  - Currently, there is no objective testing of practical skills (i.e. contouring or planning) included in the CMD exams.

- **FINDINGS FROM THE PLAN CHALLENGES**
  - Plenty of poor quality plans from very experienced and certified planners.
  - Some of the highest quality plans have come from brand new (< 1 year) planners and dosimetry students.

WHAT IS PLAN QUALITY?

- **DEFINITION OF PLAN QUALITY**

**plan qual·i·ty** ['plan 'kwä-lƏ-tē ]

1. The objective measure of how well a 3-D dose distribution, when coupled with 3-D anatomy, meets clearly defined goals and priorities.
HISTORY: THE “PLAN CHALLENGE”

THE MISSION OF THE PLAN CHALLENGE INITIATIVE

- To perform controlled, scientifically-valid studies of the variation in Plan Quality across treatment planners and modalities, with the aims to: glean best practices, educate our peers, improve quality in radiation therapy, and inspire continual improvement.

PLAN CHALLENGE TIMELINE

<table>
<thead>
<tr>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
</tr>
</thead>
<tbody>
<tr>
<td>AAMD Head &amp; Neck</td>
<td>AAMD GYN</td>
<td>AAMD Prostate Fossa</td>
<td>AAMD Lung</td>
<td>AAMD Abdomen</td>
<td>AAMD Anal</td>
</tr>
</tbody>
</table>

AUS PUG Head & Neck | AUS PUG GYN | AUS PUG GYN | H&N | ASTRO PROS Head & Neck | AAPM Lung SBRT* |

* Planned
HISTORY: THE “PLAN CHALLENGES”

- **PLAN CHALLENGE ACCRUED DATABASE**
  - Over 10 different test datasets
    - CT imageset with required contours (provided)
    - Plan Quality Algorithms (i.e. Objectives & Scoring Methods)
  - Over 1800 submitted plans
    - DICOM RT Plan & Dose pairs
  - Over 30,000 metrics
    - Total Score (PQM) for each submitted dataset
    - Sub-metric results and sub-scores per metric
    - Performance distributions over population of planners

HISTORY: THE “PLAN CHALLENGES”

- **“THE CONVERSATION”**

<table>
<thead>
<tr>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
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</thead>
<tbody>
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</table>

**THE CONVERSATION:**
Can we measure Plan Quality in a way that is:
1) QUANTITATIVE, 2) COMPREHENSIVE, 3) CLEAR, 4) INARGUABLE, and 5) FULLY TRANSPARENT (i.e. fair)?
**METHOD: “PLAN QUALITY ALGORITHM”**

**DEFINE PLAN QUALITY ALGORITHM**

- **IDENTIFY CRITICAL SUB-METRICS.** Dose, DVH, or formulaic sub-metrics selected from a library of choices (currently 17 options)
- **DEFINE EACH SUB-METRIC’S PARAMETERS.** ROI, dose and/or volume levels, etc. Can also set “ROI Synonyms” to allow for some variability in ROI naming.
- **DEFINE EACH SUB-METRIC’S SCORE FUNCTION.** Specify priority (i.e. weight) along with “failure” level and a “goal” (e.g. ideal) level, and scoring in between.

**SCORE PLAN**

- **IMPORT DICOM DATA.** RT Plan, Structures, Dose, and CT images.
- **LOAD PLAN QUALITY ALGORITHM.** Generates score automatically along with full spreadsheet and per-metric “drill down” analysis.

**LIBRARY OF PLAN QUALITY SUB-METRICS**
**EXAMPLES: DEFINING SUB-METRICS**

### Defining Sub-Metrics: (PTV) V(48.00Gy)

![Image of (PTV) V(48.00Gy) sub-metric definition](image1)

- **Metric Type:** Metric ID
- **Weight:** 10.00
- **Score Function Graphic:**
  - For V(48.00Gy) ≤ 92
  - For V(48.00Gy) > 92
  - For V(48.00Gy) > 95

### Defining Sub-Metrics: Conformity Index

![Image of Conformity Index sub-metric definition](image2)

- **Metric Type:** Metric ID
- **Weight:** 3.00
- **Score Function Graphic:**
  - For Conformity Index ≤ 1.2
  - For 1.2 < Conformity Index ≤ 1.5
  - For Conformity Index > 1.5
**Example: RTOG 0915**

- **RTOG 0915 (ARM 2)**
  - Rendered as PQ Algorithm
  - 27 sub-metrics, each weighted equally (1.00)
  - 26 sub-metrics have “ideal” levels along with “acceptable” levels; one is pass/fail
  - 15 DVH-based
  - 9 Simple (i.e. min, max mean, etc.)
  - 3 Advanced or Formulaic (i.e. conformity indices, global max location, etc.)

**Example: 2013 PC**

- **2013 Plan Challenge PQ Algorithm**
  - 19 sub-metrics, variably weighted for a total score of 150.00
  - All 19 sub-metrics have “ideal” levels along with “acceptable” levels
  - 12 DVH-based
  - 1 Simple (i.e. min, max mean, etc.)
  - 6 Advanced or Formulaic (i.e. conformation numbers, conformity indices, homogeneity indices, global max location, etc.)
**Generating PQM Score**

<table>
<thead>
<tr>
<th>Ben Quality Metric Component</th>
<th>Objective(s)</th>
<th>Result</th>
<th>Score</th>
<th>Max Score</th>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>(PTV,50Gy)</td>
<td>V(50Gy) (%)</td>
<td>≥ 95 (&gt; 90)</td>
<td>94.5513</td>
<td>94.5513</td>
<td>94.5513</td>
</tr>
<tr>
<td>(PTV,50Gy)</td>
<td>V(10Gy) (%)</td>
<td>≥ 100 (&gt; 98)</td>
<td>99.9708</td>
<td>99.9708</td>
<td>99.9708</td>
</tr>
<tr>
<td>(PTV,50Gy)</td>
<td>V(2Gy) (%)</td>
<td>≥ 0 (&gt; 0)</td>
<td>0.0232</td>
<td>0.0232</td>
<td>0.0232</td>
</tr>
<tr>
<td>(PTV,40Gy)</td>
<td>D(0.1cc) (Gy)</td>
<td>≥ 52 (≥ 55)</td>
<td>52.9810</td>
<td>52.9810</td>
<td>52.9810</td>
</tr>
<tr>
<td>(PTV,40Gy)</td>
<td>Conformation Number (47.8Gy)</td>
<td>≥ 1 (&gt; 0)</td>
<td>0.5831</td>
<td>0.5831</td>
<td>0.5831</td>
</tr>
<tr>
<td>(CTV,40Gy)</td>
<td>V(40Gy) (%)</td>
<td>≥ 99 (&gt; 94)</td>
<td>99.3202</td>
<td>99.3202</td>
<td>99.3202</td>
</tr>
<tr>
<td>(CTV,40Gy)</td>
<td>D(0.1cc) (Gy)</td>
<td>≥ 15 (&gt; 10)</td>
<td>43.1094</td>
<td>43.1094</td>
<td>43.1094</td>
</tr>
<tr>
<td>(CTV,40Gy)</td>
<td>D(0.5cc) (Gy)</td>
<td>≥ 15 (&gt; 10)</td>
<td>4.1456</td>
<td>4.1456</td>
<td>4.1456</td>
</tr>
<tr>
<td>(D15)</td>
<td>Mean dose (Gy)</td>
<td>≥ 10 (&gt; 10)</td>
<td>16.0740</td>
<td>16.0740</td>
<td>16.0740</td>
</tr>
<tr>
<td>(D10)</td>
<td>Mean dose (Gy)</td>
<td>≥ 10 (&gt; 20)</td>
<td>5.7817</td>
<td>5.7817</td>
<td>5.7817</td>
</tr>
<tr>
<td>(D1)</td>
<td>Mean dose (Gy)</td>
<td>≥ 10 (&gt; 5)</td>
<td>3.9007</td>
<td>3.9007</td>
<td>3.9007</td>
</tr>
<tr>
<td>(D15)</td>
<td>Mean dose (Gy)</td>
<td>≥ 0 (&gt; 0)</td>
<td>2.5415</td>
<td>2.5415</td>
<td>2.5415</td>
</tr>
<tr>
<td>(D10)</td>
<td>Mean dose (Gy)</td>
<td>≥ 0 (&gt; 0)</td>
<td>8.5762</td>
<td>8.5762</td>
<td>8.5762</td>
</tr>
<tr>
<td>(D1)</td>
<td>Mean dose (Gy)</td>
<td>≥ 0 (&gt; 0)</td>
<td>2.0526</td>
<td>2.0526</td>
<td>2.0526</td>
</tr>
<tr>
<td>(D10)</td>
<td>Mean dose (Gy)</td>
<td>≥ 0 (&gt; 0)</td>
<td>0.8072</td>
<td>0.8072</td>
<td>0.8072</td>
</tr>
<tr>
<td>(D1)</td>
<td>Mean dose (Gy)</td>
<td>≥ 0 (&gt; 0)</td>
<td>0.0009</td>
<td>0.0009</td>
<td>0.0009</td>
</tr>
</tbody>
</table>

Global Max Location (RTE)  
CTV (CTV, PTV, 50Gy)  
PTV, 50Gy  
2.00  
3.00  
66.7%

Total (27 Metrics)  
184.51  
130.00  
86.1%

**Building a Performance Distribution**

Histogram of PQM Score  
127  
Min: 56.18  
Max: 142.47  
Median: 119.72  
Mean: 117.22  
Std Dev: 10.61
**SOME PLAN CHALLENGE CONCLUSIONS**

- Despite controlled inputs (CT and structures) and well-defined objectives (Plan Quality Algorithm), **THERE IS VERY HIGH VARIABILITY IN PLAN QUALITY.**

- **NO CORRELATION WITH:** Certification, Education, Experience, or Confidence.
SOME PLAN CHALLENGE CONCLUSIONS

- **VMAT IS NOT BETTER THAN IMRT (BUT IT IS LESS VARIABLE)**

![PQM Distribution (IMRT vs. Arc)](image1)

- No correlation with plan complexity.
- **PLAN QUALITY IS AN ART, DETERMINED BY SKILL LEVEL.**

![PQM vs. Number Beam Angles (IMRT)](image2)

![PQM vs. Monitor Units](image3)
**SOME PLAN CHALLENGE CONCLUSIONS**

- **There is a dependence on TPS** (especially if considering the max potential of Plan Quality).

**PLAN CHALLENGE [ANUS]**

<table>
<thead>
<tr>
<th>Software</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eclipse</td>
<td>146.79</td>
</tr>
<tr>
<td>Tomo</td>
<td>145.71</td>
</tr>
<tr>
<td>RayStation</td>
<td>141.35</td>
</tr>
<tr>
<td>Pinnacle</td>
<td>139.68</td>
</tr>
<tr>
<td>Monaco</td>
<td>133.71</td>
</tr>
<tr>
<td>XiO</td>
<td>118.82</td>
</tr>
</tbody>
</table>

**High Scores Per TPS**
**PLAN CHALLENGE [BRAIN]**

High Scores Per TPS
- Pinnacle: 144.99
- Eclipse: 144.39
- XiO: 131.51

**PLAN CHALLENGE [ABDOMEN]**

High Scores Per TPS
- Pinnacle: 145.57
- Tomo: 144.53
- Eclipse: 142.86
- XiO: 136.62
PQM APPLICATONS

- **Clearly the Plan Quality Algorithm and the “PQM” results are a powerful way to define and measure Plan Quality.**

- **What are applications beyond general assessments of standard plans?**
  - Per-Patient Workflow
  - System Commissioning and Validation
  - Accreditation, Competency Testing, & Training

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PQM APPLICATIONS (PER PATIENT)

<table>
<thead>
<tr>
<th>Pre-Treatment</th>
<th>Treatments &amp; Beyond</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plan Instructions &amp; Physician’s Intent</td>
<td>Plan Review &amp; CHART ROUNDS</td>
</tr>
<tr>
<td>3D Imaging &amp; Simulation</td>
<td>Efficient, Clinically-Relevant Dose QA</td>
</tr>
<tr>
<td>Anatomy Contouring</td>
<td>Patient Training</td>
</tr>
<tr>
<td>Treatment Planning</td>
<td>Treatments Fractions</td>
</tr>
<tr>
<td>Plan Review</td>
<td>Audit Contours &amp; Predict Achievability</td>
</tr>
<tr>
<td>Interactive, Efficient Plan Analysis</td>
<td>Physics Dose QA</td>
</tr>
<tr>
<td>Peer Review</td>
<td>PLAN INSTRUCTIONS &amp; PHYSICIAN’S INTENT</td>
</tr>
<tr>
<td>Efficient, Clinically-Relevant Dose QA</td>
<td>PEER REVIEW &amp; CHART ROUNDS</td>
</tr>
<tr>
<td>PER-FRACTION Dose QA &amp; ADAPTIVE RADIATION THERAPY</td>
<td></td>
</tr>
</tbody>
</table>

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PLAN INSTRUCTIONS & PHYSICIAN’S INTENT

- **REQUIRED**
- **MUST BE TRACEABLE TO WHAT IS EVENTUALLY ACHIEVED**
- **CONTAINS (BUT NOT LIMITED TO):**
  - Target prescription
  - Fractionation
  - OAR dose objectives
  - Required structures to be contoured
  - Physician’s approval

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PLAN INSTRUCTIONS & PHYSICIAN’S INTENT

- **TEMPLATES CREATED PER INSTITUTION; HIGHLY VARIABLE**
PLAN INSTRUCTIONS & PHYSICIAN’S INTENT

- **PLAN QUALITY ALGORITHM REPORT = PHYSICIAN’S INTENT & OBJECTIVES**
  - Target and critical OAR goals are much more clearly documented in the Plan Quality Algorithm reports
  - Standardized
  - Accessible
  - Same data is used to generate the results ➔ guaranteed traceability

AUDIT CONTOURS & PREDICT ACHIEVABILITY

- **AUDIT CONTOURS**
  - All critical target volumes and OARs (including preferred naming conventions) are stored in the Plan Quality Algorithm.
  - You can run the algorithm post-contouring (and pre-planning or during planning) to ensure all required contours have been defined.

- **PRE-PLAN PREDICTION OF ACHIEVABILITY**
  - “Icarus” feature predicts achievability of dose objectives taking into account the unique patient anatomy
  - Allows for: 1) setting of realistic expectations and/or 2) adjustment of dose objectives that cannot be met
  - Discussed further in the “Research” section of this presentation
I NTERACTIVE, E FFICIENT P LAN R EVIEW

- A UTOmATED & IMMEDIATE F EEDBACK OF ALL VITAL OBJECTIVES
  - Target and OAR objectives assessed immediately and efficiently
  - Identifies failing metrics or areas for improvement
  - Feedback into optimization process
  - Guarantees that plan objectives are not a “moving target”; ideal and acceptable levels are clear
  - Mitigates risk of omission

<table>
<thead>
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<th>Anatomic Contouring</th>
<th>Treatment Planning</th>
<th>Plan Review</th>
<th>Peer Review</th>
<th>Physics Dose QA</th>
<th>Patient Training</th>
<th>Treatment Fractions</th>
</tr>
</thead>
</table>

3D I MAGING & S IMULATION
P LAN I NSTRUCTIONS & PHYSICIAN’S CONTENT
A NATOMY C ONTOURING
T REATMENT P LANNING
P LAN R EVIEW
PEER REVIEW & CHART ROUNDS

- **PEER REVIEW & CHART ROUNDS**
  - Much more efficient because all the critical objectives and results are organized and scored
  - Clinical team is trained and vested in their Plan Quality Algorithms, so their peer reviews are standardized and effective
  - Compare each plan’s performance vs. population of similar plans

EFFICIENT & RELEVANT PER-PATIENT DOSE QA

- **PER-PATIENT, PRE-TREATMENT DOSE QA HAS EVOLVED TO USE CLINICALLY-RELEVANT METRICS**
  - Plan Quality Algorithm can create PQM scoresheets that are much more efficient than per-metric analyses
  - Captures clinical impact as defined by the PQM metrics and priorities
  - \( PQM_{Plan} \leftrightarrow PQM_{DoseQA} \):
    - Efficient
    - Comprehensive
**EFFICIENT & RELEVANT PER-PATIENT DOSE QA**

Results from Dose QA that estimates impact of TPS or delivery errors on patient dose

<table>
<thead>
<tr>
<th>Plan Quality Metric Component</th>
<th>Objective(s)</th>
<th>Result</th>
<th>Score</th>
<th>Max Score</th>
<th>PLAN</th>
<th>Dose QA</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTV &amp; 50% V(50.4Gy) (%)</td>
<td>≥ 95 (≥ 90)</td>
<td>95.1586</td>
<td>30.00</td>
<td>30.00</td>
<td>100.0%</td>
<td></td>
</tr>
<tr>
<td>PTV &amp; 50% V(78.8Gy) (%)</td>
<td>≥ 100 (≥ 90)</td>
<td>99.8887</td>
<td>24.67</td>
<td>25.00</td>
<td>98.7%</td>
<td></td>
</tr>
<tr>
<td>PTV &amp; 50% V(51.9Gy) (%)</td>
<td>≤ 0 (≤ 10)</td>
<td>0.0000</td>
<td>10.00</td>
<td>10.00</td>
<td>100.0%</td>
<td></td>
</tr>
<tr>
<td>D(O.1cc) (6Gy)</td>
<td>≤ 52 (≤ 55)</td>
<td>52.8496</td>
<td>7.19</td>
<td>10.00</td>
<td>73.9%</td>
<td></td>
</tr>
<tr>
<td>D(O.1cc) (47.8Gy)</td>
<td>≤ 51 (≤ 50)</td>
<td>51.8924</td>
<td>3.08</td>
<td>3.00</td>
<td>83.8%</td>
<td></td>
</tr>
<tr>
<td>[(CTV) V(39.4Gy)] (%)</td>
<td>≥ 99 (≥ 94)</td>
<td>98.5541</td>
<td>24.09</td>
<td>25.00</td>
<td>99.6%</td>
<td></td>
</tr>
<tr>
<td>[OPTIC CHAMBER] D(O.1cc) (6Gy)</td>
<td>≤ 0.35 (≤ 0.40)</td>
<td>0.0000</td>
<td>7.29</td>
<td>8.00</td>
<td>100.0%</td>
<td></td>
</tr>
<tr>
<td>B. T. ORBIT Mean dose (Gy)</td>
<td>≤ 1 (&lt; 10)</td>
<td>1.7026</td>
<td>4.77</td>
<td>5.00</td>
<td>95.3%</td>
<td></td>
</tr>
<tr>
<td>B. T. OPTIC NERVE [D(O.1cc) (6Gy)]</td>
<td>≤ 0.27 (≤ 0.40)</td>
<td>0.2655</td>
<td>0.00</td>
<td>0.00</td>
<td>100.0%</td>
<td></td>
</tr>
<tr>
<td>B. T. CO-LEA [D(O.1cc) (6Gy)]</td>
<td>≤ 1 (&lt; 10)</td>
<td>0.4528</td>
<td>4.27</td>
<td>5.00</td>
<td>85.9%</td>
<td></td>
</tr>
<tr>
<td>B. T. LENS [D(O.1cc) (6Gy)]</td>
<td>≤ 0 (&lt; 5)</td>
<td>2.8033</td>
<td>0.88</td>
<td>5.00</td>
<td>97.7%</td>
<td></td>
</tr>
<tr>
<td>PTV ORBIT Mean dose (Gy)</td>
<td>≤ 0 (≤ 10)</td>
<td>0.9762</td>
<td>2.67</td>
<td>3.00</td>
<td>98.1%</td>
<td></td>
</tr>
<tr>
<td>PTV OPTIC NERVE [D(O.1cc) (6Gy)]</td>
<td>≤ 0.10 (≤ 0.20)</td>
<td>0.1061</td>
<td>1.72</td>
<td>5.00</td>
<td>57.4%</td>
<td></td>
</tr>
<tr>
<td>PTV LENS [D(O.1cc) (6Gy)]</td>
<td>≤ 0.5 (&lt; 1)</td>
<td>0.8444</td>
<td>2.83</td>
<td>3.00</td>
<td>94.3%</td>
<td></td>
</tr>
<tr>
<td>CORD (D(O.1cc) (6Gy))</td>
<td>≤ 0.48</td>
<td>0.017</td>
<td>0.00</td>
<td>0.00</td>
<td>100.0%</td>
<td></td>
</tr>
<tr>
<td>BRAINSTEM [D(O.1cc) (6Gy)]</td>
<td>≤ 0.48</td>
<td>0.8444</td>
<td>0.00</td>
<td>0.00</td>
<td>100.0%</td>
<td></td>
</tr>
<tr>
<td>Global Max Location (ROI)</td>
<td>CTV (CTV, PTV, 50% V)</td>
<td>2.00</td>
<td>3.00</td>
<td>66.7%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total (17 Metrics)</td>
<td>139.41</td>
<td>150.00</td>
<td>92.9%</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**PER-FRACTION DOSE QA & ADAPTIVE RT**

- **PER-FRACTION**
  - Per-fraction needs to be as automated as possible to avoid being a high-inspection, resource drain
  - Run PQM results and set tolerances on score degradation levels, creating “red flag” events

- **ADAPTIVE RADIATION THERAPY**
  - Cumulative dose accrued over all fractions analyzed with Plan Quality and \( \text{PQM}_{\text{Achieved}} \) compared directly to \( \text{PQM}_{\text{Planned}} \)
**OTHER PQM APPLICATIONS (QUALITY MANAGEMENT)**

**COMMISSIONING, VALIDATION**
- **TPS Commissioning**
- **MACHINE Commissioning**
- **TPS UPGRDES & VERSION TESTING**

**ACCREDITATION, COMPETENCY TESTING & TRAINING**
- **MOC PROJECTS**
- **PLANNER ASSESSMENT**
- **CONTINUING EDUCATION**

**EVIDENCE-BASED / COMPARATIVE EFFECTIVENESS**
- Sound strategy based on objective evidence
- Statistical Process Control
- Imperative in a “Pay-for-Performance” future

**COMPARATIVE EFFECTIVENESS**

**Good Result**
- Better Average Quality
- Lower Variation

**Poor Result**
- Lower Average Quality
**POTENTIAL: PROTOCOLS & CLINICAL TRIALS**

- **EASY AUDIT OF SUBMITTED PLANS (E.G. RTOG)**
  - Removes the high resource cost of generating metric results vs. goals
  - Removes the variability of methods

- **RETROSPECTIVE ANALYSIS OF DIFFERENT PQM ALGORITHMS VS. CLINICAL OUTCOMES**
  - Connect PQM Score with Outcomes.
  - Allows standardization of:
    - Plan Objectives
    - Plan Strategies
    - Plan Review Methods
    - Peer Review

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**SUMMARY OF PQM APPLICATIONS**

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**Pre-Treatment**
- Plan Instructions & Physician’s Intent
- 3D Imaging & Simulation
- Anatomy Contouring
- Treatment Planning
- Plan Review
- Peer Review
- Physics Dose QA
- Patient Training
- Treatment Fractions

**Treatments & Beyond**
- Plan Instructions & Physician’s Intent
- Audit Contours & Predict Achievability
- Interactive, Efficient Plan Analysis
- Plan Review
- Peer Review & Chart Rounds
- Efficient, Clinically Relevant Dose QA
- Per-Fraction Dose QA & Adaptive Radiation Therapy