Using population histogram distributions to guide training for IMRT treatment planning

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Aim

This poster uses data from a planning study assessing the dosimetric equivalence of volumetric modulated arc therapy (VMAT) compared to intensity modulated radiation therapy (IMRT) used for treatment of high risk prostate patients with significant risk of pelvic lymph node involvement at the Royal Hobart Hospital. The results of the planning study are presented in the poster entitled IMRT vs. VMAT: Assessing the dosimetric equivalence of two treatment delivery techniques via independent DICOM RT data analysis. [1]

Plans were assessed using 20 different scoring metrics generated by DICOM data analysis software. Plan quality scores were then collated to create a population histogram distribution for this cohort of patients.

The aim of this poster is to assess the use of population histograms and plan quality scores for individual patient metrics to identify plans that may be able to be improved and also assess the use of plan quality scores as a feedback mechanism to guide plan optimization and inform training for planners.
Methods and materials

This sub-study collates plan quality scores from a planning study assessing the dosimetric equivalence of VMAT compared to IMRT used for treatment of prostate gland and pelvic lymph nodes at the Royal Hobart Hospital. The method and results of the planning study are presented in a separate poster entitled IMRT vs. VMAT: Assessing the dosimetric equivalence of two treatment delivery techniques via independent DICOM RT data analysis. [1]

Brief summary of planning study

Plan quality scores were produced using a scoring algorithm consisting of 20 different scoring metrics based on our clinical protocol. The algorithm was generated using DICOM data analysis software (QualityReports Version 1.2, Sun Nuclear Corp. Florida, USA). Scores were then collated to create a population histogram distribution for this cohort of patients

Figure 1 shows the results of the planning study, comparing IMRT (Blue) to VMAT (Red). The plans for these patients were produced by eight different planners using the same clinical protocol. The data shows a range of plan scores. The focus of this poster is to use the plan scores as a feedback mechanism to planners to assist in improving the quality of their plans according to our clinical protocol.

The VMAT plans were chosen for this project as this is a priority for our department given the widely reported time savings in treatment delivery [2-7]. The planning study showed that VMAT was capable of producing dosimetrically equivalent plans to IMRT with a statistically significant higher mean score (p= 0.027). By focusing on the lower scoring plans (Figure 1. circled) it may be possible to further improve the mean scores and reduce the range of scores, thereby improving overall plan quality.

Plan Improvement Process

The three lowest scoring VMAT plans were identified from the population histogram. Figure 2 highlights these plans and their scores.

The patients summary score report was then produced from QR which lists the scores achieved for each metric in the plan quality algorithm based on the clinical protocol. A sample score sheet for patient 20 is shown in Figure 3.
Loss of points for individual metrics was then assessed to see where the biggest gains could be made for each patient. A common theme among the lower scoring plans was a loss of points for the target volumes (PTV78 & PTV56/58) receiving 100% of the prescription dose (see Figure 4 for example). Our clinical protocol states that 95% of the respective target volume should receive 100% of the prescribed dose.

Patient 20 demonstrates high scores for all of the organs at risk (OARs), yet receives a low overall score in the population distribution due to loss of points for the target metrics. The scoring structure was based on Radiation Oncology Resources Plan Challenge methodology with PTV coverage taking priority followed by organs at risk in order of clinical significance [8]. Notwithstanding the scoring system used the Plan Quality Score Sheet provides a quick visual reference to where possible improvements could be made.

Patient 12 shows similar results for metrics 1,3 and 8 in addition to low scores for the Rectal volume at 79.95Gy, Bladder V40 and Peripheral Tissue D0.03cc. (Figure 5) This may be due to individual patient factors such as PTV and rectal volumes overlapping, bladder size etc.

The score sheets for the three lowest scoring patients were provided to a radiation therapist on the VMAT implementation team at the RHH as a guide to re-optimization of these plans to see what improvements could be made.
Fig. 1: Results of planning study comparing IMRT and VMAT. Three lowest scoring plans circled.

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Fig. 2: Population distribution highlighting three lowest scoring VMAT plans

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Fig. 3: Sample Plan Quality score sheet (Patient 20)
Fig. 4: Metric results summary showing plan value location on cumulative DVH and score function for Patient 20. As the value (87.9784%) is located on the steep gradient a small change in plan normalization would have a major impact on the score.
**Fig. 5:** Plan Quality score sheet (Patient 12)

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Results

The treatment prescription for patient 20 was 2.00Gy to 98.5% of the mean dose to PTV78 for 39 fractions, which was maintained for the comparison plan study. The simple process of re-normalization of the prescription - 2.00Gy to 97.4% of PTV78 mean dose - makes a significant difference in the result with the overall score increasing from 96.29 to 134.34 (Figure 6). This is above the overall mean score for the comparison plans of 128.03.

There is a trade-off with re-normalization or "heating up" the plan. The Rectal V79.95 metric shows a reduction in score from full points for this metric (Maximum score = 7 if Rectal V79.95 # 2cc, zero points if >5cc) to 2.99 points (3.72cc >79.95Gy). Discussion with the original planner and Radiation Oncologist indicates this was one of the considerations during the initial plan assessment and approval of the clinical treatment plan.

Similarly the PTV78 conformation number (74.1Gy) has increased i.e. the 74.1Gy isodose is not as conformal as the original plan. The score sheet for the re-normalized plan can then be used to guide re-optimization of the plan; focusing on these metrics as well as the global maximum dose location which is outside the CTV78 and PTV78 (Figure 7) should improve the plan. (Note- the global maximum dose point was inside the PTV78 for the clinical IMRT treatment plan!)

Several VMAT comparison plans had maximum dose points outside the PTV. Setting an objective for the ring volume (Figure 8 - Orange region) may help control the max dose point location. Note - this was not required for the original IMRT plans and comparison plans used the same objectives. This may also assist with conformity.

Similarly for Patient 12 re-normalization increases the score from 87.11 to 124.88 (Figure 9). Trade-offs for re-normalization are increasing maximum dose, decreasing conformity, higher Rectum V65 and V79.95 (as well as other OAR doses). Again the score sheet can provide guidance for re-optimization of the plan.

For Patient 9 re-normalization had a dramatic result on the score, increasing from 100.46 to 141.84. (Figures 10 & 11) Time spent on re-optimization of this plan would be of questionable benefit however it may be possible to influence the location of the maximum dose point, pushing it into the CTV78, and reducing areas of 50Gy+ in the peripheral tissue with minimal effort. This would result in an extremely high scoring, and therefore high quality, plan according to our clinical protocol plan.
Re-normalization of the 3 lowest scoring plans has the effect of reducing the range of scores and increasing the mean, meeting the goal of an overall improvement in plan quality for this group of patients as displayed in Figure 12.

Re-optimization for Patient 9 resulted in a further improvement from 141.84 to 143.29 - a very high scoring plan (Figure 13). Note the Maximum dose is now within the CTV78 and there has been a slight improvement in peripheral tissue, which could possibly be further improved using a 'dose painting' contour & objective (Figure 14).

Re-optimization of Patient 12 resulted in a slight gain in score but increased rectal V79.95Gy & V65Gy (Figure 15).

Re-optimization for Patient 20 was able to produce a slightly higher score (136.46) but also resulted in an increase in rectal V79.95. The max dose in this case was located in the overlapping region of the PTV and anterior rectum (see Figure 16) which is not ideal (and would not be accepted by our clinician). Contouring this region (anterior rectum PRV) and re-optimizing with a maximum dose objective for this region may help (not done due to time limitations).

Overall the re-optimization of these three plans resulted in further improvement in the mean score (Figure 17). It is expected that continuing to work on these plans and re-optimization of other plans would further increase the mean score and reduce the variability or range of scores consistent with the intent of continuous quality improvement activities.
**Fig. 6:** Plan Quality score sheet (Patient 20) after re-normalization (98.5% > 97.4% of PTV78 mean dose)

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Fig. 7: Max Dose location re-normalized plan (Patient 20) Note the inferior extension of the 61 - 40Gy isodose lines on the coronal image (arrow). This was evident on several VMAT plans: a 'spiral' of dose extending beyond the inferior border of the PTV possibly due to the collimator angle used (15 degrees) for VMAT plans to reduce the effect of inter-leaf leakage

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Fig. 8: Max Dose point in Ring ROI (Orange)

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Fig. 9: Plan Quality score sheet (Patient 12) after re-normalization

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Fig. 10: Plan Quality score sheet (Patient 9)

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Fig. 11: Plan Quality score sheet (Patient 9) after re-normalization

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Fig. 12: Population distribution following re-normalization of the three lowest scoring plans. Mean score increased from 128.03 to 133.43

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Fig. 13: Plan Quality score sheet (Patient 9) after re-optimisation

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**Fig. 14:** Patient 9 isodoses after re-optimization. Note Max dose is now inside the CTV. The anterior area of 50Gy+ may be eliminated by using a ‘dose painting’ ROI and objective.

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**Plan Quality Scoresheet: Prostate 78Gy. V4**

<table>
<thead>
<tr>
<th>Plan 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>[PTV78] V[78.0Gy] (%)</td>
<td>≥ 95 (&gt; 95)</td>
<td>95.0705</td>
<td>30.00</td>
<td>30.00</td>
<td>100.0%</td>
</tr>
<tr>
<td>[PTV78] V[74.1Gy] (%)</td>
<td>≥ 99 (&gt; 97)</td>
<td>99.8422</td>
<td>30.00</td>
<td>30.00</td>
<td>100.0%</td>
</tr>
<tr>
<td>[PTV78] D[10cc] (Gy)</td>
<td>≤ 85.9 (&gt; 83.8)</td>
<td>84.7643</td>
<td>0.4%</td>
<td>1.00</td>
<td>33.0%</td>
</tr>
<tr>
<td>Global Max Location (ROI)</td>
<td>CTV78 [CTV78, PTV78]</td>
<td>2.50</td>
<td>1.00</td>
<td>1.00</td>
<td>60.0%</td>
</tr>
<tr>
<td>[PTV78] Conformation Number</td>
<td>≥ 0.8 (&gt; 0.8)</td>
<td>0.6881</td>
<td>2.00</td>
<td>5.00</td>
<td>44.1%</td>
</tr>
<tr>
<td>[PTV78] Mean dose (Gy)</td>
<td>[79.9 AND ≥ 81.4]</td>
<td>80.6386</td>
<td>3.00</td>
<td>3.00</td>
<td>100.0%</td>
</tr>
<tr>
<td>[PTV78] Homogeneity Index</td>
<td>[78.0Gy]</td>
<td>0.0898</td>
<td>2.00</td>
<td>2.00</td>
<td>100.0%</td>
</tr>
<tr>
<td>[PTV66] V[56.0Gy] (%)</td>
<td>≥ 95 (&gt; 93)</td>
<td>95.9267</td>
<td>10.00</td>
<td>10.00</td>
<td>100.0%</td>
</tr>
<tr>
<td>[PTV66] V[53.2Gy] (%)</td>
<td>≥ 99 (&gt; 95)</td>
<td>99.9755</td>
<td>10.00</td>
<td>10.00</td>
<td>100.0%</td>
</tr>
<tr>
<td>[RECTUM] V[63.0Gy] (%)</td>
<td>≤ 17 (&gt; 21)</td>
<td>19.0244</td>
<td>4.94</td>
<td>10.00</td>
<td>49.4%</td>
</tr>
<tr>
<td>[RECTUM] V[40.0Gy] (%)</td>
<td>≤ 35 (&gt; 40)</td>
<td>35.2616</td>
<td>8.76</td>
<td>10.00</td>
<td>87.6%</td>
</tr>
<tr>
<td>[RECTUM] Serial Slice Evaluation</td>
<td>(19.0Gy) PASS (PASS)</td>
<td>Pass</td>
<td>IIDEAL</td>
<td>[Pass/Fail]</td>
<td>83.8%</td>
</tr>
<tr>
<td>[RECTUM] V[79.9Gy] (cc)</td>
<td>≤ 2 (&gt; 5)</td>
<td>6.3440</td>
<td>0.00</td>
<td>0.00</td>
<td>100.0%</td>
</tr>
<tr>
<td>[BLADDER] V[65.0Gy] (%)</td>
<td>≤ 25 (&gt; 10)</td>
<td>12.7375</td>
<td>5.00</td>
<td>5.00</td>
<td>100.0%</td>
</tr>
<tr>
<td>[BLADDER] V[40.0Gy] (%)</td>
<td>≤ 50</td>
<td>41.9279</td>
<td>5.00</td>
<td>5.00</td>
<td>100.0%</td>
</tr>
<tr>
<td>[SMALL BOWEL] V[49.0Gy] (cc)</td>
<td>≤ 100</td>
<td>81.9120</td>
<td>5.00</td>
<td>5.00</td>
<td>100.0%</td>
</tr>
<tr>
<td>[SMALL BOWEL] V[66.0Gy] (cc)</td>
<td>≤ 200</td>
<td>0.4400</td>
<td>5.00</td>
<td>5.00</td>
<td>100.0%</td>
</tr>
<tr>
<td>[FEMUR R] V[56.0Gy] (%)</td>
<td>≤ 10</td>
<td>0.0000</td>
<td>1.00</td>
<td>1.00</td>
<td>100.0%</td>
</tr>
<tr>
<td>[FEMUR L] V[56.0Gy] (%)</td>
<td>≤ 10</td>
<td>0.0000</td>
<td>1.00</td>
<td>1.00</td>
<td>100.0%</td>
</tr>
<tr>
<td>[PERIPHERAL TISSUE] D[10cc] (Gy)</td>
<td>≤ 50 (&gt; 55)</td>
<td>46.8825</td>
<td>1.00</td>
<td>1.00</td>
<td>100.0%</td>
</tr>
</tbody>
</table>

**Total (20 Metrics)**: 127.35 150.00 84.9% (Hybrid)

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**Fig. 15:** Plan Quality score sheet (Patient 12) after re-optimization

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**Fig. 16:** Sagittal view of maximum dose location in anterior rectum. PTV = Green, Rectum = Brown, Overlap Anterior Rectum PRV = Blue. Note 81Gy isodose line (Orange) encompasses much of the Ant Rectum PRV. This would not be accepted clinically.

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Fig. 17: Population distribution following re-optimization of the three lowest scoring plans. Mean score increased from 128.03 to 133.63

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Conclusion

By recording individual plan scores and producing an overall population distribution / mean values a baseline for acceptable plan quality can be established. This baseline can then be used to

• guide training for new planners and
• ongoing appraisal of planner adherence to a protocol
• and/or maintenance of credentialing / performance appraisal
• monitoring quality improvement over time
• assessment of technique modifications (e.g. single arc, reduction in gantry range etc) or new equipment (e.g. new TPS, which is under consideration in our department, or patients with hydrogel spacer vs those without)

Different planning strategies (e.g. objectives used, optimization contours) may also be identified and potentially lead to greater consistency, efficiency and improvement in overall plan quality. As a result of this project our department now has data that can be used to benchmark clinical plans during the implementation of VMAT.

Using DICOM analysis software such as QR provides an interactive and efficient method of undertaking plan analysis. Figure 18 outlines where QR is used in the patient workflow. It can also help prevent omissions e.g. exclusion of a relevant organ at risk and identify outliers in the data quickly and easily for further investigation. In our department the Plan review step is a preliminary check of the plan by a senior RT prior to submitting the plan to the RO for approval. The flowchart (Figure 19) outlines the plan assessment process using QR.

The scoring methodology used in this project may not suit all departments or protocols. It is based on the Plan Challenge methodology reported by Nelms et al [8]. Allocation of points to a metric within a plan quality assessment algorithm is at the discretion of the user and a valid criticism of the algorithm used is that it may over-reward target coverage in favor of organ at risk dose and conformity.

One point to note is it may not be possible to achieve some protocol objectives due to anatomical variation between patients. Rectal V79.95 is an example. Patient 12 had 9.5cc of rectum overlapping PTV78, potentially making it impossible to achieve this metric without compromising PTV78 coverage. QR contains a module, Icarus*, which can help assess whether a metric can be met based on the protocol / plan quality algorithm, prior to a plan being undertaken. Icarus indicates achieving the upper threshold of this metric (<2cc) is "challenging" but the lower threshold (<5cc) is "achievable" for this patient.
The final assessment of plan quality is dependent on a thorough analysis of the plan, discussion with and approval by the prescribing Radiation Oncologist. Some aspects of the plans presented may be obvious and routinely considered (e.g. location of maximum dose point within the PTV), whilst others may have minimal clinical significance. Despite this QR is a valuable plan assessment and feedback tool.

QR also has the capability to identify issues with a plan without scoring (Figure 20). Nomenclature for the assessment is also user defined e.g. Pass/Fail, OK, Acceptable, Out of Tolerance, Check, Review etc.

An alternative method of analysis is to generate a 'metrics-of-interest' report, which identifies metrics where performance may need investigating. Figure 21 shows metrics for patient 20 (after re-optimization) where 2 or more points were lost or performance was below 90%. Again these values are customizable by the user.

Overall this poster shows Quality Reports is a flexible and efficient tool that can provide excellent feedback to planners and report data to assist in continual quality improvement of treatment plans using a plan quality algorithm generated to suit a department's clinical protocol and other requirements.

*Icarus produces a fictional, physically unachievable dose distribution based on the maximum achievable dose gradient for a given modality and the patient's 3D anatomy volumes. [9]
**Fig. 18:** Location of plan analysis in patient workflow (Courtesy of Ben Nelms, Canis Lupus LLC, USA)

© Ben Nelms, Canis Lupus LLC, USA
**Fig. 19:** Plan assessment process using Quality Reports

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![Quality Reports](image)

Plan Quality Score sheet: Prostate 78.0Gy_v4

This is the Plan Quality results spreadsheet for Plan Quality Algorithm: Prostate_78.0Gy_v4. The breakdown of results (metric by metric over all components) are shown in individual rows in the spreadsheet.

<table>
<thead>
<tr>
<th>Plan 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>(PTV78) V78.0Gy (%)</td>
<td>≥ 05 (≥ 05)</td>
<td>97.0705</td>
<td>IDEAL</td>
<td>Pass/Fail</td>
<td>IDEAL</td>
</tr>
<tr>
<td>(PTV78) V74.10Gy (%)</td>
<td>≥ 09 (≥ 09)</td>
<td>99.8422</td>
<td>IDEAL</td>
<td>Pass/Fail</td>
<td>IDEAL</td>
</tr>
<tr>
<td>(PTV78) D(0.05cc) (Gy)</td>
<td>≤ 85.0 (&lt; 85.0)</td>
<td>84.7463</td>
<td>ACCEPTABLE</td>
<td>Pass/Fail</td>
<td>ACCEPTABLE</td>
</tr>
<tr>
<td>Global Max Location (ROI)</td>
<td>CTV78 (CTV78 PTV78)</td>
<td>PTV78</td>
<td>ACCEPTABLE</td>
<td>Pass/Fail</td>
<td>ACCEPTABLE</td>
</tr>
<tr>
<td>(PTV78) Conformation Number (74.1Gy)</td>
<td>≥ 0.8 (&gt; 0.8)</td>
<td>0.6881</td>
<td>ACCEPTABLE</td>
<td>Pass/Fail</td>
<td>ACCEPTABLE</td>
</tr>
<tr>
<td>(PTV78) Mean dose (Gy)</td>
<td>(≤ 79.9 AND ≤ 81.4)</td>
<td>80.6386</td>
<td>IDEAL</td>
<td>Pass/Fail</td>
<td>IDEAL</td>
</tr>
<tr>
<td>(PTV78) Homogeneity Index (78.0Gy)</td>
<td>≤ 0.2 (&gt; 0.2)</td>
<td>0.0898</td>
<td>IDEAL</td>
<td>Pass/Fail</td>
<td>IDEAL</td>
</tr>
<tr>
<td>(PTV46) V36.0Gy (%)</td>
<td>≥ 09 (≥ 09)</td>
<td>95.9326</td>
<td>IDEAL</td>
<td>Pass/Fail</td>
<td>IDEAL</td>
</tr>
<tr>
<td>(PTV46) V34.2Gy (%)</td>
<td>≥ 95 (≥ 95)</td>
<td>99.9735</td>
<td>IDEAL</td>
<td>Pass/Fail</td>
<td>IDEAL</td>
</tr>
<tr>
<td>(RECTUM) V65.0Gy (%)</td>
<td>≤ 17 (≤ 21)</td>
<td>19.0244</td>
<td>ACCEPTABLE</td>
<td>Pass/Fail</td>
<td>ACCEPTABLE</td>
</tr>
<tr>
<td>(RECTUM) V41.0Gy (%)</td>
<td>≤ 35 (≤ 40)</td>
<td>35.6216</td>
<td>ACCEPTABLE</td>
<td>Pass/Fail</td>
<td>ACCEPTABLE</td>
</tr>
<tr>
<td>(RECTUM) Portal Slice Evaluation (19.0Gy)</td>
<td>PASS (PASS)</td>
<td>Pass</td>
<td>IDEAL</td>
<td>Pass/Fail</td>
<td>IDEAL</td>
</tr>
<tr>
<td>(RECTUM) V29.0Gy (cc)</td>
<td>≤ 2 (&lt; 5)</td>
<td>6.3440</td>
<td>FAIL</td>
<td>Pass/Fail</td>
<td>FAIL</td>
</tr>
<tr>
<td>(BLADDER) V65.0Gy (%)</td>
<td>≤ 25 (&lt; 30)</td>
<td>12.7375</td>
<td>IDEAL</td>
<td>Pass/Fail</td>
<td>IDEAL</td>
</tr>
<tr>
<td>(BLADDER) V40.0Gy (%)</td>
<td>≤ 50</td>
<td>41.9279</td>
<td>IDEAL</td>
<td>Pass/Fail</td>
<td>IDEAL</td>
</tr>
<tr>
<td>(SMALL BOWEL) V45.0Gy (cc)</td>
<td>≤ 100</td>
<td>81.9120</td>
<td>IDEAL</td>
<td>Pass/Fail</td>
<td>IDEAL</td>
</tr>
<tr>
<td>(SMALL BOWEL) V80.0Gy (cc)</td>
<td>≤ 2</td>
<td>0.4400</td>
<td>IDEAL</td>
<td>Pass/Fail</td>
<td>IDEAL</td>
</tr>
<tr>
<td>(FEMUR R) V150.0Gy (%)</td>
<td>≤ 10</td>
<td>0.0000</td>
<td>IDEAL</td>
<td>Pass/Fail</td>
<td>IDEAL</td>
</tr>
<tr>
<td>(FEMUR L) V150.0Gy (%)</td>
<td>≤ 10</td>
<td>0.0000</td>
<td>IDEAL</td>
<td>Pass/Fail</td>
<td>IDEAL</td>
</tr>
<tr>
<td>(PERIPHERAL TISSUE) D(0.03cc) (Gy)</td>
<td>≤ 50 (&lt; 53)</td>
<td>48.8925</td>
<td>IDEAL</td>
<td>Pass/Fail</td>
<td>IDEAL</td>
</tr>
</tbody>
</table>

**Total (20 Metrics):** 14/5/1 20 Metrics

**Fig. 20:** Plan Quality score sheet - non-scored version

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**Fig. 21**: Plan Quality Metrics of Interest report (Patient 20) after re-optimization

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1. Young, M. IMRT vs. VMAT: Assessing the dosimetric equivalence of two treatment delivery techniques via independent DICOM RT data analysis - Poster. 2014 Combined Scientific Meeting, Melbourne.


