Process-based IMRT analytics

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Purpose

Since the inception of IMRT, patient-specific QA has played an important role in ensuring the safety and quality of complex treatments. The TG-218 report provides a comprehensive review aimed at improving the consistency of the IMRT QA process by recommending tolerance limits and methodologies.[2]

The primary aim of this report is to clinically implement IMRT QA tolerance and action limits in the manner recommended by TG-218. In addition, we have provided a novel, process-based approach to the IMRT QA workflow that is geared towards analyzing the root cause of failing plans.

Methods

A total of 80 patient-specific VMAT QA plans were analyzed using the equipment specified in Table 1. The plans consisted of 20 initial prostate, 20 prostate boosts, 20 initial head and neck and 20 head and neck boosts.

Table 1: Equipment Specifications

Measurement Device	ArcCHECK, Sun Nuclear Corporation, LLC
Measurement Analysis Software	SNC Patient Software Version 6.6
Linac Manufacturer	Elekta
Accelerator Model	Infinity (Agility MLC)
Treatment Planning System	RayStation 9A
Dose Calculation Algorithm	Collapsed Cone Convolution

The global gamma analysis criteria of 3%/3mm was compared with the new standard, 3%/2mm, using a 10% dose threshold. The equations used to determine the process-based tolerance and action limits are summarized in Table 2.

Table 2: Equations used to determine process-based tolerance and action limits[2]

Equation:	Description:	Comments:
$TL = \left[\left(\frac{1}{n}\sum_{1}^{n} x\right) - 2.660 * \overline{mR}\right]$	Institutional Tolerance Limit	x = an individual IMRT QA measurement n = total number of measurements $\overline{mR}$ = moving range
$\overline{mR} = \frac{1}{n-1}\sum_{i=2}^{n}\lvert x_i - x_{i-1}\rvert$	Moving range	Used to determine institutional tolerance limit in equation 1
$\Delta A = \beta\sqrt{\sigma^2 + (\bar{x} - T)^2}$	Institutional Action Limit	β = constant (usually $\beta = 6.0$) T = process target value (100% for Y analysis) σ^2 = process variance $\bar{x}$ = process mean * Action limit calculated as $100 - \Delta A/2$

Using the TG-100 guidelines, a process map of the IMRT QA process was created. The process map provided guidance in Root Cause Analysis of treatment plans that failed the gamma analysis.

Finally, a systematic error was introduced to determine the sensitivity of the new passing criteria to failure modes in the IMRT QA process, the true and erroneous values are summarized in Table 3.

Table 3: Systematic error investigation

Energy	True Absolute Dose Value	Erroneous Absolute Dose Value
6 MV	248.6 cGy	253.0 cGy
10 MV	260.3 cGy	262.0 cGy
15 MV	262.2 cGy	266.0 cGy

Results

When transitioning to a 3%/2mm criteria, bulk analysis of all 80 plans showed an average absolute dose passing rate reduction of ~1.3% (99.3% to 98.0%). From these plans, our institutional tolerance and action limits for the new standard were calculated using equation 1 to be 93% and 92%, respectively.

The bulk analysis results are shown in the box and whisker plots in Figure 1. The process-based action limits, shown in Table 2, were 94% for the Initial Prostate and Initial H&N, and 90% for the Prostate Boost and H&N Boost.

The passing rates showed no clear trend when comparing prostate to head and neck plans. However, for both treatment sites, boost plans showed a significant reduction in passing rates when compared to initial plans.

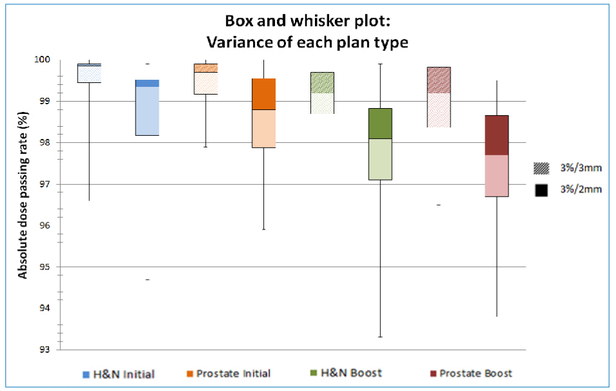

Figure 1: Box and whisker plots showing median, interquartile range and error bars are shown (right to left) for the H&N initial, prostate initial, H&N boost and prostate boost plan types.

Table 4: ChristianaCare's institutional, process-based, tolerance and action limits based on plan type. These values were calculated using the results that were measured with the 3%/2mm gamma criteria.

Plan type	H&N Initial	Prostate Initial	H&N Boost	Prostate Boost	**Institutional standard**
Tolerance limit	95.0	94.3	91.3	91.3	**93.4**
Action limit	94.4	94.2	90.7	90.5	**92.4**

The process map for guidance in root cause analysis according to TG-100 guidelines is shown in Figure 2. A library of IMRT QA plans that fall below the tolerance criteria can be evaluated for systematic error. These systematic errors can be categorized into bins according to this process map and, when possible, mitigated or eliminated.

In order to investigate the impact of systematic error, an absolute dose calibration error of ~1.5% was introduced, and the effects on patient-specific passing rates for both the 3%/3mm and 3%/2mm criteria are pictured in Figure 3. This systematic error reduced passing rates of individual plans by up to 10%, and ~2% on average.

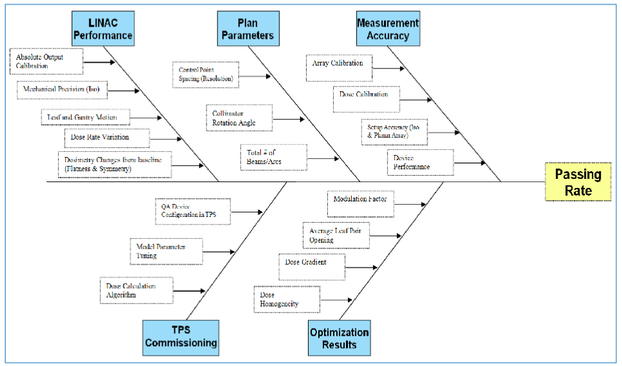

Figure 2: IMRT QA process map.

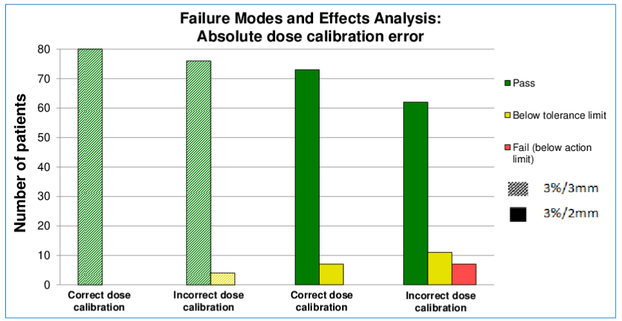

Figure 3: FMEA, used as a tool to evaluate the sensitivity of the new criteria to a systematic error

Discussion

Transitioning to the TG-218 recommended 3%/2mm criteria resulted in increased sensitivity of our IMRT QA process. The overall IMRT QA plan passing rate was reduced from 100% to 95%, following the introduction of the new criteria. Sensitivity is an important aspect of any QA process. If QA never, or very rarely, detects problems, it is recommended that the QA process be reevaluated, which was the case with the old criteria.[1]

Failure modes and effects analysis was used to evaluate the ability of the criteria to detect a possible systematic error. Figure 3 shows that despite the error, 76 of the 80 plans analyzed still passed when using the old criteria. Only 62 of the 80 plans passed with the new criteria. This further emphasizes the increased sensitivity of the new criteria.

This increased sensitivity also revealed the passing rate dependency on plan type. We suspect this reduction is due to the device used being less suitable for the lower number of data points and dose distributions often seen in boost plans. These hypotheses are still under investigation.

Tolerance and action limits are meant to establish a minimum level of process performance. But an institution's QA process may vary based on equipment used, plan type and experience of the physicist, thus universal limits aren't always adequate.[2] Establishing process-based limits allow an institution to realize when their own process is exhibiting abnormal behavior. When paired with a process map, the source of abnormal behavior may be determined and corrected for.

The IMRT QA process map represents variables that may affect the passing rate and demonstrates the inter-relationship of these variables from process start to finish. It inherently offers a workflow for root cause analysis of failing QA plans. The plan may be evaluated for errors by working down the diagram to determine the bin (or bins) causing a plan's passing rate to fall below the tolerance limit.

Conclusion

TG-218 recommends a 3%/2mm passing criteria to provide increased sensitivity to errors in the planning and treatment process. Implementing this criteria clinically requires the identification and mitigation of any systematic errors at each institution. In addition to applying TG-218 we have established a process-map to further identify the root causes of plans with poor QA results. Moving forward, a larger library of failing QA plans will be compiled with hopes to correlate these results with specific plan parameters. If established, the correlation may be addressed to further improve our institution's treatment process.

References

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2. Miften, M., Olch, A., Mihailidis, D., Moran, J., Pawlicki, T., Molineu, A., . . . Low, D. A. (2018). Tolerance limits and methodologies for IMRT measurement-based verification QA: Recommendations of AAPM Task Group No. 218. *Medical Physics, 45*(4). doi:10.1002/mp.12810

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