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Getting started with VERIQA RT EPID 3D:

Recommendations for evaluation criteria and tolerance limits for pre-treatment and in vivo EPID dosimetry

Motivation

EPID dosimetry is a powerful tool to improve quality and safety in an ever more complex radiotherapy landscape. It offers the possibility for both pre-treatment and in vivo dosimetric verification. In the radiotherapy community, there is a lot of experience with pre-treatment patient-specific quality assurance (PSQA). Several reports with recommendations have been published, such as the report of AAPM TG 218 [1]. However, one has to keep in mind that PSQA, especially in a phantom geometry, is a surrogate for verification of the actual patient treatment. EPID dosimetry facilitates large-scale in vivo verification of patient treatments [2], allowing for the detection of clinically significant errors related to planning, data transfer, delivery and patient-related factors.

EPID in vivo dosimetry systems show larger uncertainties than array-based pre-treatment PSQA due to indirect dose measurement, additional scatter contributions (e.g. in and onto the EPID) and a less controlled geometry (patient versus phantom). As a result, tolerance limits should be relaxed when compared to phantom based PSQA as suggested in the AAPM TG report 307 [3]. Ultimately, these values should be based on the treatment intent (palliative vs. curative), treatment site and other clinical considerations. They should offer sufficient sensitivity to detect clinically relevant errors while avoiding false positives for non-clinically relevant errors. Such a subdivision of tolerance limits needs to be based on the clinical experience in a specific center. According to ref [3], one approach to determining tolerance levels is to begin with values used by experienced centers. Later, the best balance between false positive and false negative results can be determined by statistical analysis on a sufficiently large number of institutional cases.

The PTW product VERIQA RT EPID 3D is based on the direct back-projection EPID dose reconstruction algorithm developed by the Netherlands Cancer Institute – Antoni van Leeuwenhoek Hospital (NKI-AVL), which has been extensively used in a clinical environment for more than fifteen years [4,5]. To support radiotherapy centers with the clinical introduction of VERIQA RT EPID 3D, we report from the clinical experience of the NKI-AVL what to expect and give a primer for evaluation criteria and tolerance limits for both pre-treatment and in vivo 3D EPID dosimetry.

Evaluation criteria

In the NKI-AVL, all external beam treatments on conventional linacs are verified using 3D in vivo EPID dosimetry, except treatments with field size exceeding the size of the EPID panel (26x26 cm^2) and treatments with couch angles prohibiting image acquisition.
Over the years, gamma and DVH evaluation parameters and acceptance criteria for different treatment sites [6] have evolved, for example from 2D to 3D evaluation. To reduce complexity, we recommend the following adequate but rather simple evaluation criteria as starting point:

- Region of Interest (ROI): Intermediate Dose Volume (IDV) – a ROI defined by the volume encompassing 50 % of the maximal planned dose. The IDV is defined as "VERIQAISODose" in VERIQA. The motivation for the IDV is that it reflects clinical relevance: it is substantially larger than the target area but excludes the low dose areas. Including low dose areas, which are less clinically relevant, can undesirably influence overall criteria like the gamma passing rate (GPR). Furthermore, the IDV can be calculated from any dose distribution, making it a more robust approach compared to relying on naming conventions for the ROI selection.
- Gamma passing rate (GPR): 3 % and 3 mm global, analyzing the gamma passing rate within the IDV. The vast majority of clinical results from 3D EPID dosimetry has been obtained using these parameters.
- DVH: The relative difference in median dose (ΔD50) in the IDV between TPS and EPID reconstructed dose.

As the direct comparison of pre-treatment and in vivo evaluation results offers the opportunity to identify patient-related errors, we recommend using these evaluation criteria for both pre-treatment and in vivo EPID dosimetry.

Tolerance limits

To demonstrate what to expect from applying these evaluation criteria clinically, data from 2389 treatment fractions (IMRT and VMAT) acquired from October 2023 to October 2024 covering a variety of treatment sites were analyzed. Beam energies 6 and 10 MV were used, both with and without flattening filter.

Figure 1 shows the distributions of the GPR and ΔD50 within the IDV. The average and standard deviation of the ΔD50 was 0.8 ± 2.6 % with 60 % of treatments having a GPR > 90 %. Tolerance limits can be based on either of the evaluation criteria, or on a combination. Table 1 presents the percentage of treatments that fall outside one of the evaluation criteria (alert) for various tolerance limits. For example, when using the combination of GPR = 75 % and ΔD50 = 4 %, an alert rate of 21 % is to be expected. Alternatively, the combination of GPR = 80 % and ΔD50 = 5 % would give an alert rate of 23 %. Note that a gamma passing rate of 0 % and infinite ΔD50 indicate the alert rate as if this evaluation criterion would not have been taken into account.

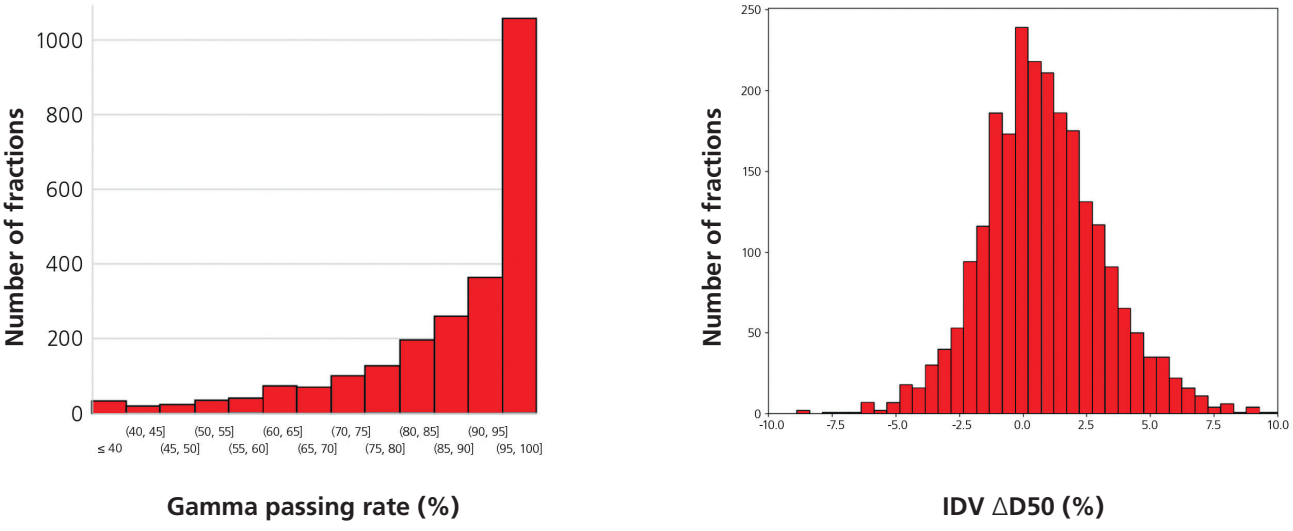

Figure 1: Distribution of the gamma passing rate (left) and ΔD50 in the IDV (right) from 2389 VMAT and IMRT treatment fractions.

Alert rate		IDV ΔD50 (%)				
		3.5	4	4.5	5	inf
Gamma passing rate (%)	0	16 %	12 %	9 %	6 %	0 %
	70	20 %	18 %	16 %	15 %	12 %
	75	23 %	21 %	19 %	18 %	16 %
	80	26 %	25 %	24 %	23 %	21 %
	85	33 %	32 %	31 %	30 %	29 %

Table 1: Alert rate as a function of gamma passing rate and ΔD50 within the IDV.

Evaluation of alerts

The process of alert handling for in vivo EPID dosimetry is quite different from 'classical' analysis of pre-treatment PSQA results as deviations between the delivered and the planned dose distribution can arise from a combination of multiple error types. A systematic way of reviewing alerts can include:

1. Check for image acquisition errors (e.g. ill-positioned panel, incomplete acquisition). The acquired EPID images can be reviewed in the BEAM INFORMATION table on the plan evaluation page in VERIQA. Note that, in case of an acquisition error, no valid verification result can be obtained.
2. Check for reconstruction errors (e.g. wrong alignment of EPID image). The calculated DISPLACEMENT values for the acquired EPID images can be reviewed in the BEAM INFORMATION TABLE on the plan evaluation page. Check if the displayed TPS field outline nicely matches the outline of the acquired fields. Note, however, that these values are not adjustable.
3. Check for known back-projection reconstruction model limitations (e.g. metal implants or dose reconstruction in the build-up region)
4. Inspection of in-room imaging data for anatomical changes (e.g. cone-beam CT data, surface guidance systems, etc)
5. If no origin of the discrepancies can be identified, the following alternatives are possible:
   a. If acceptable, dosimetric evaluation of an extra treatment fraction
   b. Pre-treatment EPID dosimetry [9] to exclude plan delivery issues
   c. Re-evaluate the in vivo result with 'EPID transmission'
   d. Recalculate the patient plan on a homogeneous phantom geometry (e.g. RW3 slab phantom). Perform pre-treatment EPID dosimetry for this treatment plan to exclude model limitations such as e.g. metal implants.
   e. Classic PSQA using a detector array in a phantom geometry

For pre-treatment EPID dosimetry, all steps except for step 4 are equally valid.

Discussion

The frequency of true positives, i.e. clinically relevant deviations that needed corrective action, was around 0.3 % of plans (slightly above 1 % of alerts) [5,6]. Note that the majority of these errors would not have been detected using traditional pre-treatment PSQA. Investigation of the origin of alerts [5] showed that 52 % of alerts involved back-projection model limitations, 42 % involved patient related issues (e.g. anatomical changes or setup), 35 % involved external issues (e.g. image acquisition) and 12 % of alerts had unknown origin.

Besides inspection of alerted plans, time trends of all results can give valuable information on the quality of the complete dose delivery chain. For example, we were able to identify growing dose discrepancies in prostate VMAT treatments, leading to the improvement of beam fits in the TPS [10].

One can consider less strict criteria for simple palliative treatments to reduce alert inspection work. The required accuracy for these treatments is not as demanding as for treatments with curative intend. For palliative treatments we therefore focus on detection of errors larger than 10 % only. Therefore, we apply gamma parameters 9 % and 3 mm global in combination with tolerance levels of 0.9 for the mean gamma and 10 % for ΔD50 in the IDV.

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