What Are We Really Catching with Patient-Specific QA? a Six-Year, 8516-Case Analysis of Detection Efficiency and Site-Specific Variability

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This study introduces an efficiency-focused evaluation of phantom-based PSQA using a hypothetical GPR <95% threshold to estimate resource cost per flagged plan. By linking QA outcomes to time investment across treatment sites and years, it provides actionable data for optimizing QA workload and policy, bridging a key gap between quality assurance and operational efficiency in radiotherapy.

INTRODUCTION

Patient-specific QA using phantom-based measurements with ion chamber arrays is standard in IMRT/VMAT, ensuring plan deliverability prior to treatment. While TG-218 provides recommendations on gamma passing thresholds, little is known about the resource efficiency of these processes. Institutions also lack benchmarks on failure rates by treatment sites. This six-year retrospective study of 8516 PSQA cases applies a consistent hypothetical GPR <95% threshold to estimate failure-capture efficiency and identify high-variability anatomical regions, with the goal of informing risk-adaptive QA policies that optimize clinical and operational performance.

PURPOSE

To evaluate temporal and site-specific patterns in phantom-based patient-specific quality assurance (PSQA) performance and estimate failure-capture efficiency using a hypothetical gamma passing rate (GPR) threshold of <95%, based on 8516 IMRT/VMAT plans from 2019–2024.

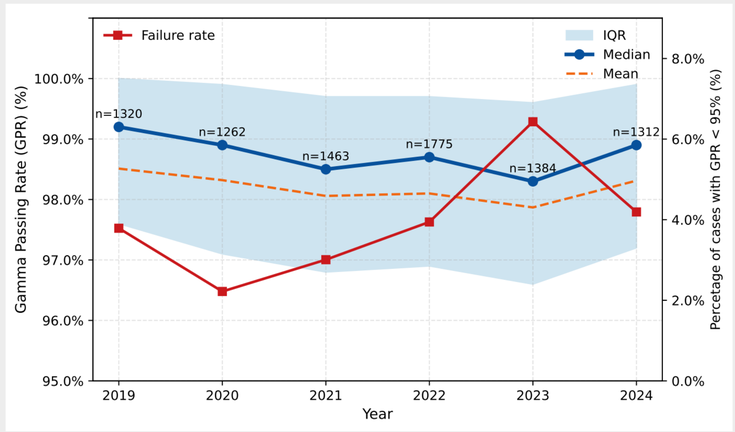

Figure 1 Annual distribution of gamma passing rates (GPR) with corresponding failure rates from 2019 to 2024.

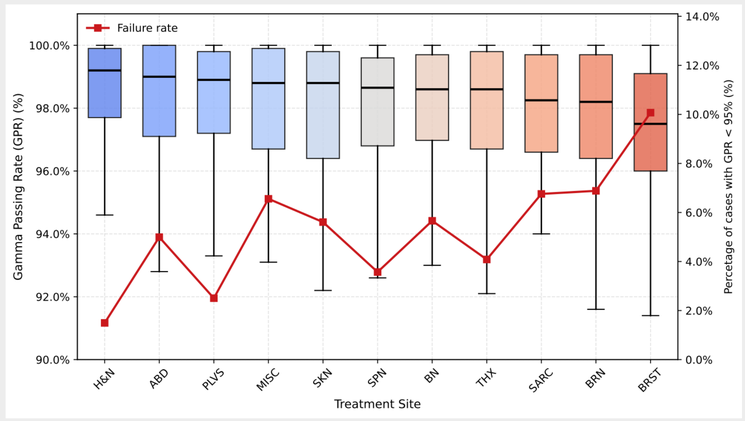

Figure 2. Site-specific distribution of GPR with failure rates. (H&N: Head and Neck (n=1470), ABD: Abdomen (n=861), PLVS: Pelvis (n=2715), SKN: Skin (n=107), BN: Bone (n=212), THX: Thorax (n=1004), SARC: Sarcoma (n=74), BRN: Brain (n=959), BRST: Breast (n=427), MISC: Miscellaneous (n=183))

METHODS

All PSQA measurements were performed using the PTW Octavius 1500 ion chamber array within an octagonal phantom under true composite geometry. Standard analysis followed TG-218 criteria (2%/3 mm, 10% dose threshold). For plans with GPR <90%, a qualified medical physicist may request replanning, repeat measurements, or adjust the evaluation criteria (e.g., 2mm/4% for SBRT/SRS or 3mm/3% for conventional cases). While all plans passed institutional criteria (GPR >90%), a retrospective failure threshold of GPR <95% was hypothetically applied to assess detection efficiency. PSQA reports were extracted via automated Python scripts. Statistical tests included Kruskal–Wallis for temporal GPR variation, chi-square for site-specific failure rates, and Levene's test for GPR variability. Workload was estimated at 0.3 hours per plan.

RESULTS

Among 8,516 plans, 336 (3.9%) fell below the GPR <95% threshold. GPR differed significantly across years (Kruskal–Wallis H = 132.56, $p < 0.001$), with the lowest median (97.87%) and highest failure rate (6.1%) in 2023. Failure rates varied significantly by site (Chi-square = 112.22, $p < 0.001$), with breast (10.3%) and brain (7.0%) plans showing the highest rates and variability (Levene's test, $p < 0.01$). A heatmap showed persistent failure clustering in brain, pelvis, and abdomen. Total QA workload was 2,129 hours over six years (~0.21 FTE/year), equating to 7.6 labor hours per flagged case.

CONCLUSIONS

Although all plans met clinical acceptance, applying a hypothetical GPR <95% threshold revealed 336 flagged cases (3.9%) over six years, requiring over 2,000 labor hours to detect. Temporal and anatomical variability suggests that risk-adaptive, site-specific QA strategies may improve the balance between safety and efficiency in radiotherapy quality assurance.

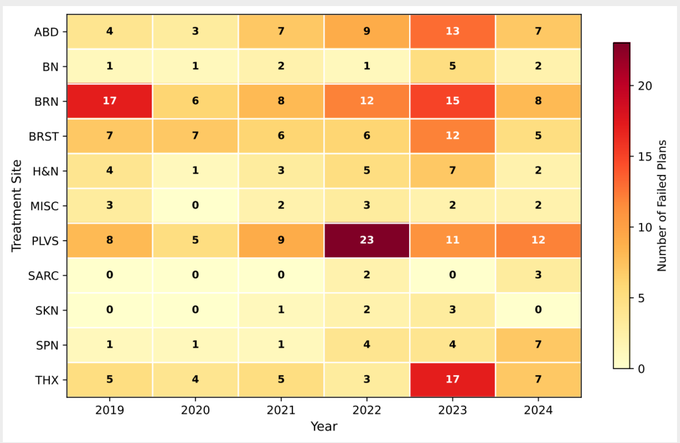

Figure 3. Heatmap showing annual counts of the hypothetically failed PSQA plans (GPR <95%) by treatment site. (H&N: Head and Neck (n=1470), ABD: Abdomen (n=861), PLVS: Pelvis (n=2715), SKN: Skin (n=107), BN: Bone (n=212), THX: Thorax (n=1004), SARC: Sarcoma (n=74), BRN: Brain (n=959), BRST: Breast (n=427), MISC: Miscellaneous (n=183))

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