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Short communication

Experience with remote electronic portal imaging device-based dosimetric auditing for static and rotational intensity modulated radiotherapy

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ABSTRACT

The aim of this work was to evaluate results of a remote electronic portal imaging based dosimetric auditing method using Task-Group 218 clinical gamma evaluation criteria (3%,2 mm, 10% dose threshold). For intensity modulated radiation therapy the results were (mean ± 1 SD) 97.9 ± 4.5% with 31/34 audits passing (optimal level, ≥ 95%) and 3/34 audits failing (action level, < 90%). For volumetric modulated arc therapy the results were 98.5 ± 2.3% with 32/36 audits passing (optimal level) and 4/36 passing (tolerance level, ≥ 90% and < 95%). The audit has been successfully applied globally for clinical trial quality assurance.

1. Introduction

Dosimetric auditing plays an important role in ensuring and improving global radiation therapy quality as well as maintaining clinical trial data quality [1]. Audits assist centres world-wide with delivering accurate doses, particularly the International Atomic Energy Agency (IAEA) beam output auditing program. It is normally a fundamental requirement for centre participation in clinical trials, to ensure that centres are delivering and reporting accurate doses. It plays a significant role in the safe roll-out of new and advanced technologies and enables centres to benchmark their performance against more established centres.

Performing an end-to-end audit remotely using postal phantoms and dosimeters is an attractive alternative to more expensive and logistically challenging on-site audits and has been performed on a large-scale by the Imaging and Radiation Oncology Core (IROC) centre [2]. A limitation has been the high tolerance limits on the comparison of planned and delivered dose, which will reduce sensitivity. Nevertheless the IROC program has played a very important role in radiation therapy quality. [3,4].

An alternative low-cost remote auditing method using the electronic portal imaging device (EPID) has been developed [5,6]. While some preliminary audit results using 2D dose-plane analysis have been reported, the full audit results using 3D dose analysis from 70 audits conducted over the past decade have not been presented.

The aim of this work was to provide a comprehensive evaluation of the results from a remote EPID-based audit program. All audit results were regenerated with a more advanced image to 3D dose in phantom conversion method. The paper analyses the results of the audit with regard to current recommended intensity modulated radiation therapy (IMRT) gamma evaluation criteria. The influence of the EPID type on the audit results was also investigated.

2. Methods and materials

2.1. Audit method overview

The Virtual Epid Standard Phantom Audit (VESPA) method is a Level-II (treatment planning system (TPS)-planned) audit for IMRT or volumetric modulated arc therapy (VMAT) performed remotely and without cost to the participating centre. The general principles including limitations of the VESPA auditing method have been introduced previously [7]. Briefly as an overview of the VESPA process, centres transfer their site-generated plan to a standardized water-equivalent cylindrical phantom dataset in the TPS and calculate dose in the phantom. The plan is delivered, and images recorded in-air on the EPID along with some calibration field images. The data is sent to the VESPA data coordinating and analysis centre for analysis where the dose in the (virtual) cylindrical phantom is reconstructed using an EPID image to 3D dose conversion algorithm and compared to the TPS dose using 3D gamma evaluation.

2.2. Planning and delivery

Using a 20 cm diameter virtual phantom (Jan 2015–May 2020) 28 and 20 audits were conducted for IMRT and VMAT respectively. Using

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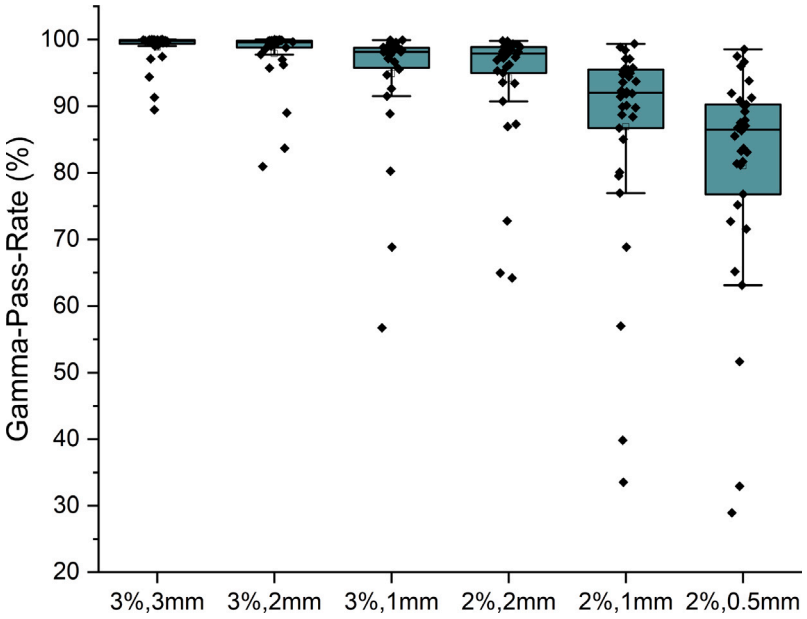

Fig. 1. Results for the IMRT audits for different gamma criteria.

a 30 cm diameter virtual phantom (June 2020–May 2024) these were 6 and 16 respectively. The slice thickness was 0.2 cm and length 40 cm. Comparisons of the dose calculation and gamma evaluation for the two phantoms were performed at the data coordinating centre with 184 patient 20 cm phantom results compared to 165 patient 30 cm phantom results. The mean gamma at 1%,1 mm criteria differed by only 0.12% between the 20 cm and 30 cm phantom results showing no influence of phantom size. Initially for VESPA auditing a head and neck plan (with prescribed dose of 70 Gy in 35 fractions (n = 18) and a post-prostatectomy plan with prescribed dose of 64 Gy in 32 fractions (n = 28) were utilized. More recently centres have used benchmark plans generated for the credentialing process for the particular trial for which they wished to participate. These included prostate stereotactic body radiation therapy (SBRT) at 20 Gy in 2 fractions (n = 1), prostate at 36 Gy in 12 fractions (n = 2) and other sites with standard-of-care radiation including prostate (n = 12), prostate SBRT (n = 1), breast (n = 5), endometrium (n = 1), head and neck (n = 1) and gastric cancer (n = 1). For the IMRT audits, 32 were at 6 MV energy and 2 at 10 MV. For the VMAT audits 29 were 6 MV, 5 were 6FFF, and 2 were 10 MV energy. For the IMRT audits 16 were Varian (Vendor-1) C-Series/aS1000, 3 were Varian TrueBeam/aS1000, 7 TrueBeam/aS1200 and 8 were Elekta (Vendor-2)/iView. For the VMAT audits 11 were C-Series/aS1000, 6 TrueBeam/aS1000, 15 TrueBeam/aS1200 and 4 Elekta/iView. The TPS types were Eclipse(TPS-1) (41), Pinnacle(TPS-2) (16), Monaco(TPS-3) (12) and RayStation(TPS-4) (1).

2.3. Dose in virtual phantom calculation

All audit results were regenerated with an improved EPID image to 3D dose conversion algorithm. The core of the dose calculation algorithm remained the same as previously used [8,9]. This algorithm estimates dose at a particular depth in flat water phantom from an EPID image. The parameters of the analytical model are derived by fitting to measured profiles and output factors in water-tank. Only data measured at the data coordinating centre were used to fit the model. Previously dose was only estimated at 10 cm depth, the mid-plane of the 20 cm diameter phantom and extrapolated through the phantom using a percentage depth dose (PDD) model [10]. This meant that differences in scatter and output factor with depth were not accounted for and accuracy reduced for other depths. A new method was developed where separate image to dose conversion models were derived for discrete depths in flat water phantom (e.g. 5, 10, 15, 20, 25, 30 cm). The image was converted to dose at these depths and 3D dose then determined by interpolating these depths using a spline model. To estimate the build-up region dose this was combined with an simple exponential model (1-A.exp(-μ.d)) where d is the vertical distance of the dose plane to the flat water surface [10]. The exponential factor μ is field-size dependent with the average equivalent square field size for the beam calculated and used to determine the factor. A one-dimensional correction for the cylindrical phantom contour was then applied using an exponential model (exp(-μ.d(x))) where d is the missing-tissue distance calculated at the phantom mid-plane for each off-axis distance x. The same correction was applied for all other depths with a single energy-dependent attenuation factor used. The 3D dose now estimated in the cylinder is rotated by the gantry angle recorded for the image and doses for all images acquired summed to produce the estimated 3D dose in phantom.

2.4. Data analysis

The TPS calculated dose and the EPID derived dose in the virtual phantom were compared with 3D gamma evaluation. Multiple criteria were evaluated all with 10% of maximum global dose as the dose threshold including 3%,3 mm, 3%,2 mm, 3%,1 mm, 2%,2 mm, 2%,1 mm and 2%,0.5 mm. The results were evaluated with the TG218 gamma (γ) criteria recommended for in-house IMRT dose evaluation (3%,2 mm, 10% dose threshold) [11]. The percentage of points with γ value ≤ 1 was used. A case was considered passed (optimal level) if $\geq$ 95% of points meet $\gamma \leq 1$. A case was considered passed (tolerance level) if $\geq$ 90% and < 95% of points meet $\gamma \leq 1$. A case was considered to fail (action level) if < 90% of points meet $\gamma \leq 1$. Results were also compared for different EPID types.

3. Results

Fig. 1 shows a boxplot of the gamma evaluation results for the IMRT audits. For IMRT audits the results for 3D gamma analysis at 3%,2 mm criteria and 10% low dose threshold were (mean ± 1 SD) 97.9 ± 4.5% (Range 81.0%–100.0%). Using the above acceptance criteria, 31/34 audits passed at optimal level and 3/34 audits failed at Action level. Applying the TG218 statistical process control (SPC) methodology to the results resulted in a lower control limit (LCL) of 83.0% due to the presence of outlier low results in a relatively small dataset. Removal of

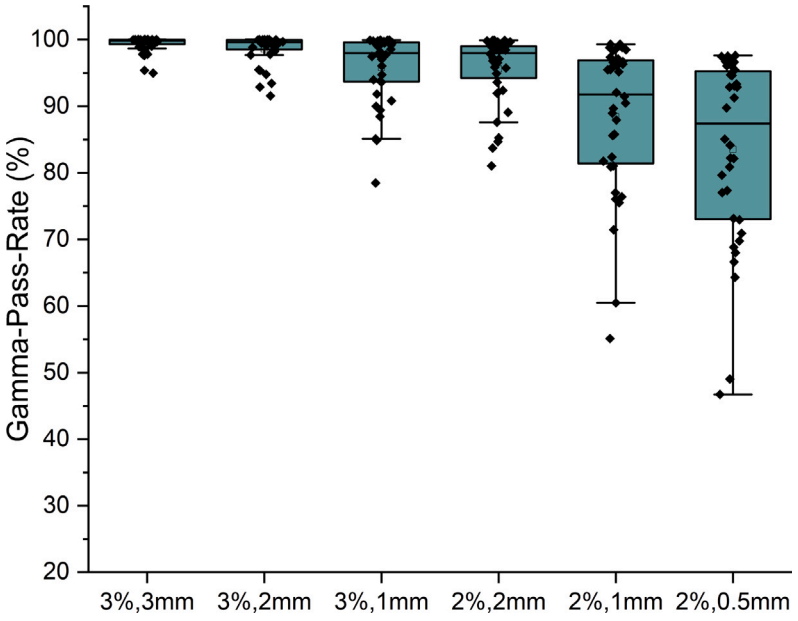

Fig. 2. Results for the VMAT audits for different gamma criteria.

the six outlier results identified as outside the inter-quartile range with the 3%,2 mm boxplot analysis resulted in a LCL of 97.5%. Separation of the audit results according to EPID type (Vendor-1 aS1000, Vendor-1 aS1200, Vendor-2) gave results of 98.7 ± 3.7% (n = 19), 99.4 ± 0.8% (n = 7), and 94.7 ± 6.5% (n = 8) respectively.

Fig. 2 shows a boxplot of the gamma evaluation results for the VMAT audits. At the TG218 criteria the gamma pass-rates were 98.5 ± 2.3% (Range 91.6–100.0%). Using the above acceptance criteria, 32/36 audits passed at Optimal level and 4/36 passed at Tolerance level. Applying the SPC methodology resulted in a LCL of 90.5% and removal of the outlier values at 3%,2 mm criteria resulted in a LCL of 97.1%. Separation of the audit results according to EPID type gave 97.4 ± 2.9% (n = 17), 99.6 ± 0.7% (n = 15), and 99.8 ± 0.1% (n = 4) for aS1000, aS1200, and iView respectively.

4. Discussion

This paper evaluates the 3D dose comparison results of the VESPA remote EPID-based audit using the TG218 recommended criteria for 70 audits conducted over the last decade. The results suggest that a statistically-based lower control limit for the audit in the range of 97.1–97.5% could be used. Only 3 audits failed the audit with pass-rates below 90%.

Two of the IMRT audits that failed at Action level were on older Vendor-2 units. At the time of these two audits in 2014 the EPID to dose conversion method was different and a tolerance of over 90% pass-rate at 3%,3 mm were applied. Both of these audits achieved over 90% pass-rates at 3%,3 mm criteria at the time and were not failed or further investigated. The third audit result performed on a Vendor-1 linac did not pass at the 3%,3 mm criteria and was followed-up with the centre. The audit was repeated with similar results. Due to significant changes in equipment about to occur at this centre, the centre decided to not further follow-up these results. Pass-rates for IMRT audits on the older Vendor-2 EPID panels were lower than for VMAT with newer EPID panels. This is likely to be the main contribution to the lower pass-rates for IMRT compared to VMAT with 5/6 outliers on these platforms, although other reasons such as TPS calculation accuracy cannot be excluded. Differences in measured and planned doses can occur for a variety of reasons and can be difficult to establish based on the audit dosimetric comparison alone. The intention of the VESPA audit was to evaluate the adequacy of a centre's dosimetry practice and subsequently gain accreditation for clinical trials. With large and standardized datasets and other resources including independent dose calculations IROC has been able to shed light on the sources of discrepancies in their audits [4,12,13] however this was not feasible in the VESPA audit with small data sizes and fewer resources.

For the IMRT audits the results for TPS-1 were very consistent with all results above 97.8%. The 6 outlier centres from the boxplot results at 3%,2 mm were TPS-2/3 systems but with some TPS-2/3 results also being very high. For the VMAT results TPS-1 V15.5 and above results were very consistent and all above 99.4%. For earlier TPS-1 versions the results were much more variable. The 6 outlier centres from the boxplot results were from TPS-1, 2 and 4. TPS-3 results were all high while TPS-2 results were lower and more variable. There are other factors that could influence these results.

VESPA pass-rates are higher at more stringent gamma criteria than some other audits including the IROC postal phantom audit [2,14]. It is difficult to compare auditing methods especially ones that are very different in equipment and process. Factors could include that with the postal-film based process and the effect of phantom setup (where a 2D planar dose measurement can be very sensitive to positioning where dose gradients are present), that the uncertainties may be higher than in VESPA. The use of 2D versus 3D gamma should not significantly impact the results. The centre sizes and to a large extent the geographical catchments of the audits are also very different and this could play a role. A comparative study of the sensitivity of several auditing methodologies including VESPA is currently underway.

VESPA audit results show high gamma pass-rates for the 3D dose analysis at the TG218 recommended criteria. The VESPA auditing method has provided an environmentally friendly and cost-effective auditing option.

CRediT authorship contribution statement

Peter B. Greer: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Roles/Writing – original draft, Writing – review & editing. **Joerg Lehmann:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Roles/Writing – original draft, Writing – review & editing. **Alisha Moore:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Methodology, Project administration, Resources, Roles/Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.phro.2024.100674.

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