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Experiencing In-Vivo Dosimetry Verification in Malaysia: A Patient-Specific EPID-Based Approach

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Abstract

Real-time dosimetry is crucial for patient-specific quality assurance in radiotherapy facilities across Europe, and the same demand extends to advanced countries like Malaysia. Our study aimed to assess the need for in vitro diagnostic (IVD) testing in Malaysia, exploring the use of Electronic Portal Imaging Device (EPID)-based dose verification to simplify complex methods. In this research, we assessed the accuracy of in-vivo dose reconstruction using EPIgrayTM (DOSIsoft, Cachan, France) for 20 cohorts of patients who underwent breast and prostate Intensity-Modulated Radiation Therapy (IMRT) and Volumetric Modulated Arc Therapy (VMAT), and compared the results with the dose calculated by the Treatment Planning System (TPS). Initially, we set a default tolerance level of 7-10% for dose acceptance. Our study found that the majority of patients in the cohort met the 10% tolerance level when validated with EPIgrayTM in vivo dosimetry. Specifically, 12 out of 15 patients who underwent VMAT treatment were within this tolerance range. Additionally, for IMRT treatment, 4 out of 6 patients achieved the 10% tolerance level. These initial findings demonstrate the potential of EPIgrayTM as a valuable tool for verifying in vivo dosimetry for advanced treatment techniques. For VMAT plans, more than 85% of the points were in agreement with the 10% tolerance level for 11 out of 15 patients. For IMRT plans, more than 90% of the points met the set tolerance level for 4 out of 15 patients. By understanding the agreement and variability of EPID-based IVD, we can further refine the utilization of EPID-based IVD as a relevant tool in ensuring accurate and reliable dose delivery during radiotherapy treatments.

1. Introduction

Patient-specific in-vivo dosimetry (IVD) verification plays a pivotal role in modern radiation therapy by ensuring the precise and accurate delivery of radiation doses [1]. External beam radiation therapy, a widely employed treatment modality for various cancer types, utilizes high-energy X-rays or electron beams.

Accurate measurement and verification of the delivered radiation doses are paramount for achieving optimal treatment outcomes while minimizing potential side effects [1–3]. Various in-vivo dosimetry techniques have been developed to directly measure the radiation dose received by patients during treatment. These include MOSFET dosimeters [4], Radiochromic film [5,6], Semiconductor detectors [7], and Fiber-optic dosimeters [8,9].

Each technique has its advantages and limitations, with the choice depending on factors like treatment modality and desired accuracy.

One of the main challenges in radiation therapy stems from the uncertainties associated with dose calculations and delivery. Although advanced treatment planning systems can estimate the radiation dose distribution within a patient's anatomical structure, several factors can introduce discrepancies between the planned and actual doses. These factors include patient-specific anatomical changes, organ motion, setup errors, and the inherent limitations of treatment planning algorithms.

Methods of in-vivo dosimetry techniques have been devised to address these issues including directly measuring the actual radiation dose received by the patient during treatment. One such technique is the Electronic Portal Imaging Device (EPID), commonly used for verifying patient positioning [10]. EPID consists of a specialized detector system integrated into the linear accelerator gantry, capturing images of the radiation beam as it exits the patient's body [11–13].

Consequently, there has been an increasing demand for the development of patient-specific EPID-based in-vivo dosimetry techniques capable of accurately measuring the delivered radiation dose based on the patient's specific anatomy and treatment plan worldwide including Malaysia [14–17]. While in vivo treatment verification aids in the detection of possible errors, lessons learned from out-tolerance IVD results can improve departmental protocols. Several commercial solutions available to perform IVD require time and whole departmental resource commitment from the first it is commissioned and maintained on a regular basis (e.g., investigating deviations in in vivo dosimetry results). Hence, a thorough and comprehensive commissioning procedure is essential to provide the department with a thorough grasp of the capabilities and constraints of their selected EPID-based in vivo dosimetry (IVD) system.

EPIgray™ (Dosisoft, Cachan, France) is the commercially available software installed for EPID-based IVD dose reconstruction at Gleneagles Medical Centre (GMC). It has not yet been clinically implemented for routine IVD in GMC but has gone through a detailed commissioning process and early characterization [18]. At the time of writing, there is no published literature specifically describing the clinical experience using EPIgray™ IVD system for radiotherapy verification since it was the first to be installed in Malaysia. For this reason, it was considered important to conduct a pilot study before clinical release to verify that the EPIgray™ IVD system is appropriate to use for radiotherapy plans delivered at GMC. The objective of this work is to determine the level of agreement and potential variations, allowing for the clinical implementation of EPIgray™ dosimetry system as a relevant tool for ensuring precise and reliable radiation dose delivery in radiotherapy treatments in our clinic.

2. Materials and Methods

2.1 EPIgray™ IVD Workflow

In this study, we used EPIgray™, a web-based software by DOSIsoft, Cachan, France version 2.0.6 along with the iViewGT (PerkinElmer, USA) Amorphous Silicon (a-Si) flat panel imager from Elekta Versa HDTM (Stockholm, Sweden) available in Gleneagles Medical Centre, Penang.

The imager, which was integrated into the treatment system, had a sensitive layer consisting of 1024 × 1024 pixels with high resolution for in-vivo dose verification. EPIgray™ reconstructs real-time dose distribution using Electronic Portal Imaging Device (EPID) measurements to assess delivered radiation doses during treatments. Monaco TPS was utilized using Monte Carlo calculation algorithm. All required plan parameters were transferred to the linac control system using the Elekta Mosaiq record and verify system. Prior to this work, EPIgray™ underwent commissioning according to the vendor's instructions and guidelines to establish accurate clinical treatment's beam modeling and a comprehensive beam data library module. This process involved measurements to determine calibration and conversion factors for the EPID signal to accurately calculate the dose in water at the maximum depth (d_{max}). Following the commissioning and installation, accuracy of EPIgray™ has been validated with water phantom measurement successfully [18].

EPIgray™ utilizes the EPID's transmitted signal to reconstruct the dose at one or multiple points of interest within the patient detailed elsewhere beyond the scope of this paper [19–22]. It calculates the dose for each monitored fraction, allowing the determination of the total dose per plan as well as the mean deviation of 50 randomly placed dose points (autogenerated) in the high dose region of the plan [23]. The relative deviation between EPIgray™ and TPS dose values is expressed as a percentage for each fraction, beam, or interest point.

2.2 Patient Selection

Retrospectively, a cohort of 21 patients were evaluated for dose reconstructed analysis over a two-year period (Oct 2019-Jan 2023), which included examination per technique and energy also treatment sites.

Treatment's techniques include 15 patients receiving IMRT and 5 patients receiving VMAT (main treatment sites were prostate and breast). At our clinic, the default acceptance tolerance level is set at ±5% IMRT/VMAT IVD dose deviation. Following completion of the study, a decision regarding clinical release is made based on the

Emerging Advances in Integrated Technology Vol. 5 No. 1 (2024) p. 1-6

results of the pilot study. Assuming the clinical pilot proved feasibility of clinical use of IMRT/VMAT IVD, review on the appropriate tolerance range and any specific exclusions for clinical cases would be made later. This guarantees resilience and accommodates any potential variations that could occur in the treatment planning phase.

3. Results and Discussion

From a total number of 21 patient's plans were involved in this study underwent the IMRT and VMAT technique for breast and prostate treatments, 16 of them were in good tolerance level within 10%. Fig. 1 and Fig. 2 shows mean percentage difference between $D_{EPIgray}$ and D_{TPS} for IMRT and VMAT for all patients, respectively. There were two out of six IMRT patients were out of 10% tolerance set by the clinic as depicted by patient 4 and 5 given poorer percentage of points that passed more that 90%.

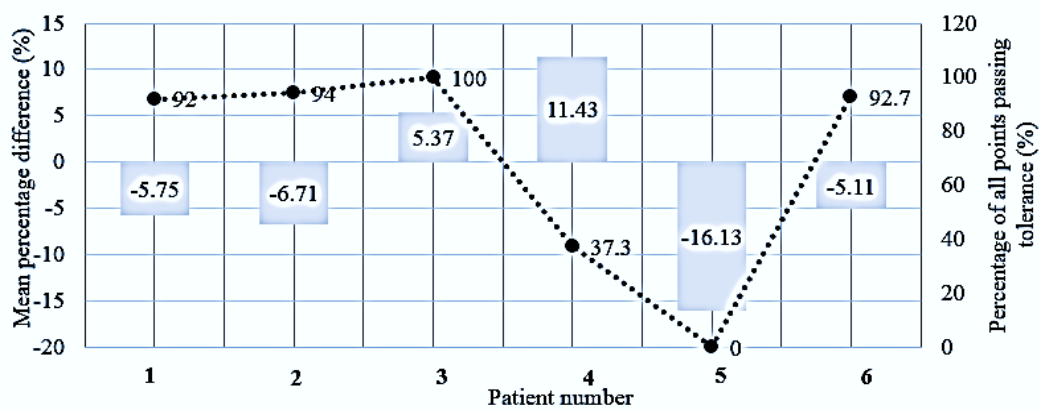

Fig. 1 *Mean percentage difference between $D_{EPIgray}$ and D_{TPS} for IMRT treatment plans. The dotted line represents points passing tolerance level in percentage (%)*

However, for VMAT cases in Fig. 2, better performance shown as 12 out of 15 patients were within tolerance. A histogram in Fig. 3 shows number of patients which scored the percentage of dose deviation during the verification for all 21 patients. As we can see the distribution is skewed to the left (negatively skewed) given by larger discrepancies in dose reconstruction by EPIgray™. However, the reason is remained under investigation. Implementing a routine quality assurance (QA) process to verify the model's validity is essential. Therefore, it is advisable to conduct monthly spot-checks on commissioning measurements as routine practice prior to clinical implementation. Additionally, validation measurements should be carried out following the recalibration of the EPID.

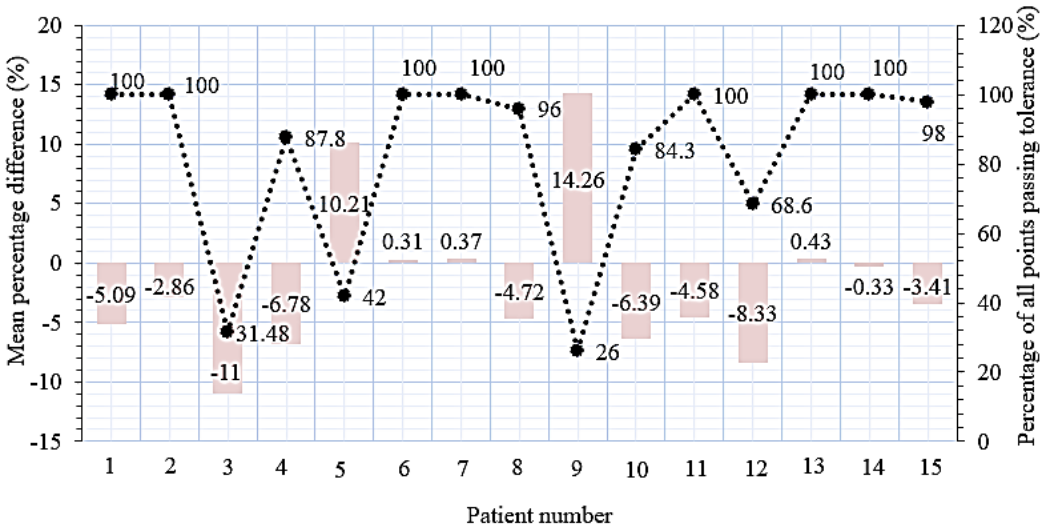

Fig. 2 *Mean percentage difference between $D_{EPIgray}$ and D_{TPS} for VMAT treatment plans. The dotted line represents points passing tolerance level in percentage (%)*

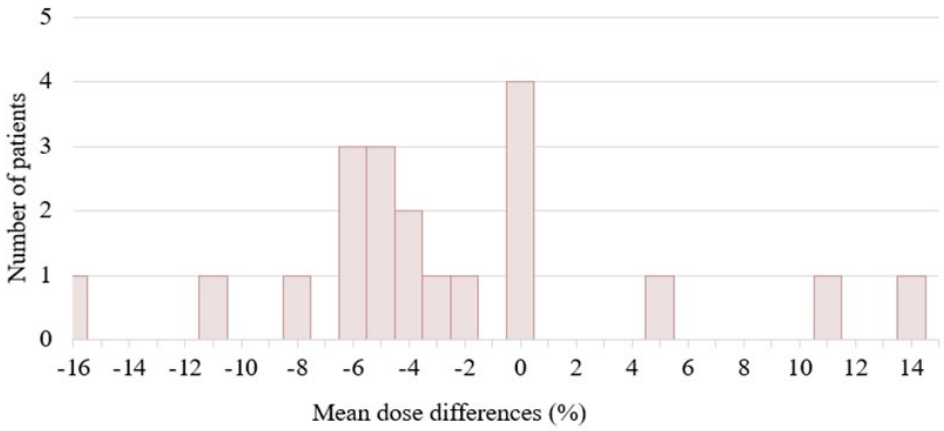

Fig. 3 *Dose difference distribution of the IVD results for the period of October 2019 to January 2023*

The complexity might also arise from examination of local dose variations of EPIgray™, particularly sensitive to low doses. This sensitivity could account for certain discrepancies observed in intensity-modulated radiation therapy (IMRT) plans, as these plans involve smaller segments compared to three-dimensional (3D) plans. Additionally, points situated beyond the treatment field exhibited inadequate passing rates.

Furthermore, the average dose difference is calculated for the entire treatment fraction, offering statistical significance compared to analyse individual beams. This approach has the potential to further minimize the observed discrepancies in intensity-modulated radiation therapy (IMRT) plans. In this study, all points were automatically selected via EPIgray™. This work proposes that a ±7% threshold might be suitable for triggering notifications for analysis and potential intervention.

As experience grows and a baseline performance for complex plans is established, there could be a consideration to raise the threshold up to 5-7% for individual beams. On another note, is that EPIgray™ presents the relative deviation of the dose in the dose plan summary. However, relying solely on this as a passing criterion might not be optimal without considering its standard deviation. This is crucial because individual points could still fall outside the defined threshold, warranting careful consideration.

Although the data set available for this study is limited, the initial experience of clinical release of this IMRT/VMAT IVD at GMC indicates that the tolerance range of ±7% was an appropriate choice. At the time of writing, EPIgray™ has been used for additional verification unofficially for IMRT and VMAT plans at GMC and fewer than 20% of analyses outside the ±7%. Thus, our results align well with the available literature [17], although a meaningful comparison between studies with different patient's plan especially complex treatment like Head-and-Neck remains difficult and beyond the scope of this study.

In summary, undeniably, EPIgray™ serves as a valuable tool for EPID-based IVD, facilitating inter-fractional dose monitoring to ensure radiation delivery within intended 5% of the planned dose at the isocenter. However, based on the results, it is not advisable to replace patient-specific pre-treatment quality assurance (QA) procedures at GMC currently.

4. Conclusions

Conducting a clinical pilot study was crucial for the effective integration of the EPID-based in vivo dosimetry (IVD) system into routine treatments at GMC's radiotherapy department.

The study's findings allowed for the establishment of suitable tolerance ranges tailored to the treatment type and site, as indicated by the specific outcomes. This pilot study adds valuable insights to the existing literature on the adoption of EPID-based IVD solutions prior to clinical deployment, enhancing the department's capacity to conduct in vivo dosimetry for all feasible treatments. It is also important to emphasize that, while EPIgray™ is not intended to replace the patient-specific quality assurance protocols currently in place in Malaysia, this initial evaluation suggests that EPIgray™ can be beneficial as an additional safety measure for continuous verification of patient treatment.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design****: Yasmin Md Radzi (corresponding author), Ghassan Haleem Mohsin, Noor Naslinda Noor Rizan and Azhar Abdul Rahman;* ***data collection****: Ghassan Haleem Mohsin;* ***analysis and interpretation of results****: Yasmin Md Radzi, Ghassan Haleem Mohsin and Noor Naslinda Noor Rizan;* ***draft manuscript preparation****: Yasmin Md Radzi, Ghassan Haleem Mohsin. All authors reviewed the results and approved the final version of the manuscript.*

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