RESEARCH ARTICLE

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Dosimetric Systems in Pre-Treatment QA for Stereotactic Treatments: Correlation Agreements and Target Volume Dependency

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Abstract

Aim: This study comprehensively investigated pre-treatment quality assurance (QA) for 100 cancer patients undergoing stereotactic treatments (SRS/SRT) using various detectors. **Methods:** The study conducted QA for SRS/SRT treatments planned with a 6MV SRS beam at a dose rate of 1,000 MU/min, utilizing Eclipse v13.6 Treatment Planning System (TPS). Point dose measurements employed 0.01cm^3 and 0.13cm^3 cylindrical ionization chambers, while planar dose verification utilized Gafchromic EBT-XD Film and Portal Imager (aS1000). Plans were categorized by target volume, and a thorough analysis compared point dose agreements, planar dose gamma pass rates, and their correlations with chamber volume mean dose, detector type, and point dose agreement. Additionally, the consistency between different ionization chambers was assessed. **Results:** Point dose agreement generally improved with increasing target volume, except for volumes over 10cm^3 with 0.01cm^3 chambers, showing a contrary trend. Significant differences ($p<0.05$) were observed between TPS and measured doses for both chambers. Gamma pass rate improved with increasing target volume in EBT XD and aS1000 analyses, except for the >10cm^3 group in EBT XD. EBT XD demonstrated better agreement with TPS for target volumes up to 10cm^3 compared to aS1000, with a statistically significant difference ($p<0.05$) between the detectors. Strong correlations were found between chamber point dose and chamber volume mean dose agreement, as well as between the two gamma criteria analyses of the same detector type in the planar dose correlation analysis. However, weak correlations were discovered for other analyses. **Conclusion:** This study found weak correlation between different detector types in pre-treatment QA for point dose and planar dose evaluation. However, within a specific detector type, strong correlation was observed for different point dose evaluation methods and gamma criteria. This highlights the importance of cautious interpretation of QA results, particularly for SRS QA, due to the lack of correlation between detector types.

Keywords: SRS PSQA- Film- Ion chamber- Portal Dosimetry- Small fields

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Introduction

Stereotactic Radiosurgery (SRS) and Stereotactic Radiotherapy (SRT) have emerged as a precise and effective treatment modality for various intracranial lesions. It delivers highly focused radiation doses while minimizing damage to surrounding healthy tissue, offering a promising non-invasive treatment option [1-4]. As SRS/SRT gains popularity in clinical practice, the accurate and precise delivery of treatment becomes paramount. Pre-treatment Quality Assurance (QA) plays a crucial role in validating and verifying the accuracy of radiation treatment plans in SRS/SRT. Given the sharp dose fall off and higher dose per fraction of SRS/SRT, the need for robust and reliable QA methods becomes even more significant [5, 6]. The primary objective of pre-treatment QA in SRS is to ensure the accurate delivery of the prescribed dose to the target volume.

Pre-treatment QA methods commonly include point dose measurement and planar dose measurement. Point dose measurement utilizes ionization chambers to measure the dose at specific points within the treatment field. Planar verification methods assess the delivered dose in the entire treatment field, in addition to point dose measurement. To efficiently assess the dose distribution in small treatment areas of SRS, planar verification requires high-resolution detectors [7, 8]. Film-based measurement and Electronic Portal Imaging Device (EPID)-based measurement are commonly employed techniques that offer the necessary spatial resolution for SRS, however various other detectors type with finer resolution are available commercially [9-11]. The availability of different detectors for point

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dose and planar dose verification in SRS presents a challenge when trying to interpret results in relation to established values. This challenge is further complicated by the utilization of diverse evaluation methods, such as chamber center point dose and chamber volume mean dose for point dose verification, as well as the adoption of varying gamma analysis criteria for planar dose analysis. Conducting correlation analyses among these detectors and methods can contribute to a better understanding of SRS/SRT pre-treatment QA results. However, the literature on these specific correlations is limited, with most studies primarily focusing on the correlation between plan complexity and gamma pass rate, as well as between gamma pass rate and dose-volume histogram (DVH) parameters [12,13]. Further research in this area specific to correlation of various detector results would be valuable for enhancing the interpretation of SRS/SRT pre-treatment QA results.

The objective of this article is to conduct a detailed analysis of the correlation between various pre-treatment QA methods commonly employed in SRS. By examining the relationship between point dose measurements, film-based measurements, and EPID-based measurements, we aim to provide valuable insights into the consistency and agreement among these techniques. This analysis will contribute to a better understanding of the strengths, weaknesses, and overall reliability of different QA tools and methods in SRS/SRT.

Materials and Methods

In this study, we conducted pre-treatment quality QA measurements for 100 SRS/SRT patients with single and multiple brain metastases, ranging in volumes from 0.1 cm^3 to 60 cm^3. We generated a non-coplanar volumetric modulated arc therapy (VMAT) plans using a 6 MV-SRS X-ray beam with a set dose rate of 1000MU/min and HD120-MLC of Trilogy linear accelerator (Varian Medical Systems, USA). The Phantoms were scanned with Bigbore CT scan with 1mm slice thickness. The verification plans were crafted in Eclipse v13.6 TPS for point and planar dose verification. The dose calculation used a resolution of 1.25mm.

Point dose measurements

Point dose measurements were performed using 0.01 cm^3 and 0.13 cm^3 cylindrical ionization chambers at a depth of 5 cm in a RW3 phantom with 5 cm below and above the chamber. In the point dose analysis, the dose at the center of the chamber volume and the mean dose within the chamber volume, calculated in the treatment planning system (TPS), were compared with the measured dose for both the 0.01 cm^3 and 0.13 cm^3 ionization chambers that were used. The mean dose of the chamber volume was determined by contouring the volume of the chamber, as depicted in Figure 1(a) and 1(b). The contoured volume matched the chamber volume specified by the manufacturer, and the volume of the chamber was assigned as water [14].

Planar dose measurements

Planar dose verification, on the other hand was conducted using two methods: Film dosimetry using Gafchromic EBT-XD film (Ashland, USA) and Portal Dosimetry using aS1000. For planar dose distribution verification with Gafchromic EBT-XD films, a specialized multi-cube phantom designed for Arc treatments was utilized to address uncertainties related to sharp edges during measurements. The films were placed at a depth of 6 cm, with an additional 6 cm below and above for comprehensive assessment [Figure 2: (a)]. The films were calibrated for a dose range of 0.5-40 Gy to facilitate precise film verification. They were scanned using an Epson Expression 10000XL 48-bit scanner at 72 dpi, consistently at a 24-hour post-exposure interval, with a 3 mm glass plate employed to flatten the film. Subsequent data analysis was conducted using Film QA Pro 2016 software (Ashland, USA). The dose analysis specifically focused on the red channel of the scanned films, as it exhibits higher dynamic dose range [Figure 2: (b)].

For portal dosimetry-based planar dose verification, the aS1000 detector was commissioned following vendor's recommendation. Due to the detector's demonstrated signal saturation at higher dose rates, it was positioned at a distance of 140 cm (SID) to mitigate this issue [15]. This placement allowed for a reduced dose rate at the detector plane, effectively avoiding saturation. The planar dose analysis was done using global gamma analysis by categorising plans into five groups based on target volume < 1.0 cm^3 with 24 patients, 1.0-3.0 cm^3 with 19 patients, 3.0-10.0 cm^3 with 29 patients, > 10.0 cm^3 with 20 patients and 8 cases with multiple metastasis (MM). Various gamma analysis criteria were applied, including 2% / 1mm with a 20% threshold and 3% / 1mm with a 20% threshold, following our departmental protocol, which is aligned with stereotactic treatments based on AAPM TG 218 [16].

Correlation analysis

The correlation between the point dose and volume mean dose agreements with measurements was analysed for both the chambers and the correlation of one chamber agreement with another chamber is also checked. In addition, the correlation of TPS and measured dose agreement with target volume is analysed. The correlation between the gamma pass rate, target volume, detector type, and point dose agreement has been thoroughly analyzed using a two-tailed Student's t-test with a significance level of the p-value (i.e., $p < 0.05$) and the Pearson correlation coefficient.

Results

Point dose analysis

The point dose agreement results are summarized in Table 1 for both chamber centre point dose and chamber volume mean doses of both the chambers.

The study revealed an overall improvement in the average point dose agreement with increasing target volume for both chambers, except for volumes exceeding 10 cm^3, where the 0.01 cm^3 chambers exhibited a contrary

Table 1. Point Dose Agreement Results for Both Chamber's Centre Point Dose and Volume Mean Dose

Volume Range (cm^3)	Minimum Field Size (cm^2)	No of Patients	Chamber Center Point % Dose Difference		Chamber Vol Mean % Dose Difference		p-value			
			0.13 cm^3 Mean±SD	0.01 cm^3 Mean±SD	0.13 cm^3 Mean±SD	0.13 cm^3 Mean±SD	A	B	C	D
< 1	3×3	24	2.87±0.92	1.37±0.63	2.12±1.15	1.23±0.65	< 0.05	< 0.05	< 0.05	< 0.05
1.0-3.0	5×5	19	1.50±0.86	1.07±0.61	1.57±1.30	0.79±0.56	< 0.05	< 0.05	< 0.05	< 0.05
3.0-10	6×6	29	1.68±1.08	0.66±0.50	1.36±0.96	0.65±0.63	< 0.05	> 0.05	< 0.05	> 0.05
> 10	8×8	20	1.57±0.66	0.88±0.51	1.23±0.81	0.88±0.53	< 0.05	0.08	< 0.05	0.1
MM	10×10	8	1.48±0.61	1.08±0.50	2.27±0.81	0.97±0.63	0.13	< 0.05	< 0.05	> 0.05
Total		100	1.89±1.04	0.99±0.61	1.63±1.1	0.89±0.63	< 0.05	< 0.05	< 0.05	< 0.05

Abbreviations: A – 0.13 cm^3 Point Dose vs 0.01 cm^3 Point Dose; B – 0.13 cm^3 Volume Mean Dose vs 0.01 cm3 Volume Mean Dose; C – 0.13 cm^3 Point Dose vs 0.13 cm^3 Volume Mean Dose; D – 0.01 cm^3 Point Dose vs 0.01 cm^3 Volume Mean Dose

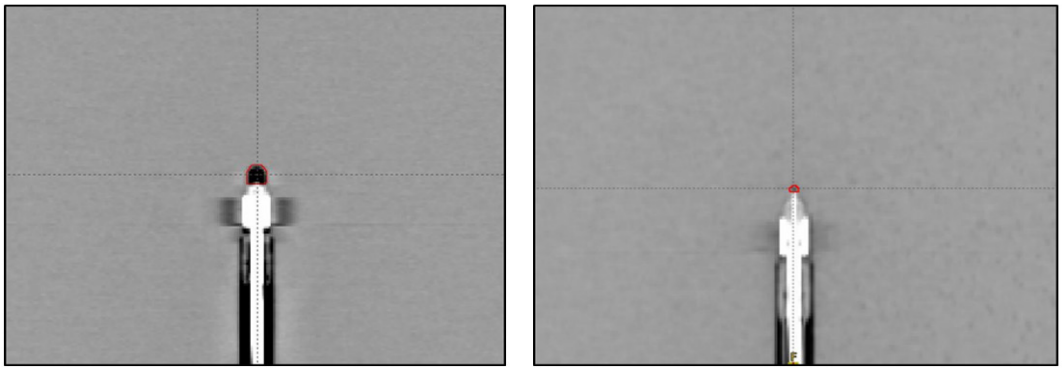


Figure 1. The Contoured Chamber Volume for Mean Dose Analysis: (a) 0.13 cm3 ionization chamber and (b) 0.01 cm^3 ionization chamber

trend, as indicated in the Table 1. The statistical analysis indicated significant differences ($p<0.05$) between the 0.13 cm^3 and 0.01 cm^3 cylindrical chambers in terms of the agreement between the TPS dose and the measured dose. These differences were observed for both the chamber center point dose and the chamber volume mean dose, with respective mean absolute differences of 1.03% and 1.04%. The agreement between the chamber center point dose and the chamber volume mean dose showed a statistically significant difference ($p<0.05$) for the 0.13 cm^3 chamber, with an average absolute difference of 0.76%. However, for the 0.01 cm^3 chamber, this difference was found to be statistically insignificant ($p>0.05$), with an average absolute difference of 0.48%.

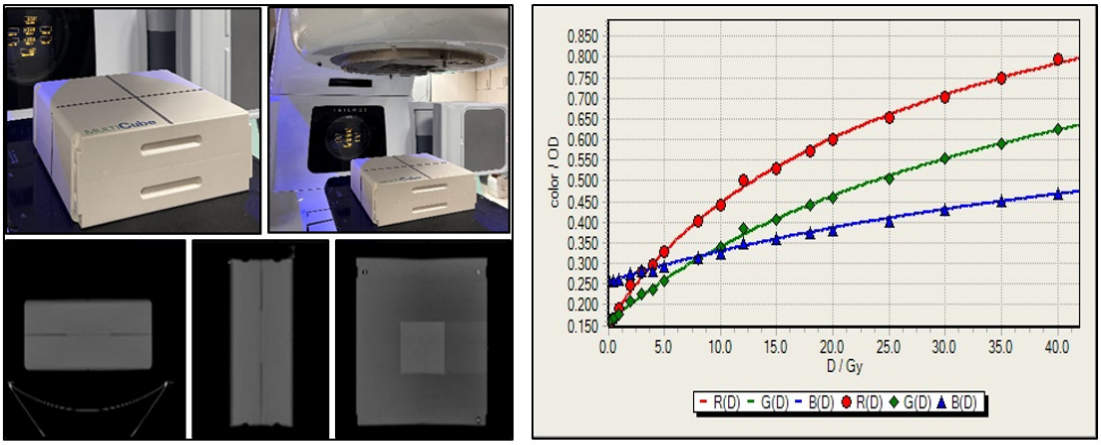
Planar dose analysis

The mean gamma pass rate showed improvement as the volume of the target increased for both EBT XD and aS1000 analyses, except for the >10 cm^3 group in EBT XD where a reverse trend was observed. This observation is similar to the point dose analysis, where the point dose agreement also improved with larger target volumes. In terms of agreement with the TPS, EBT XD demonstrated good agreement with TPS for target volume groups up to 10 cm^3, compared to aS1000. The difference between EBT XD and aS1000 was statistically significant ($p<0.05$) for both the gamma analysis criteria of 2%/1mm and 3%/1mm considered. However, for the >10 cm^3 target volume group, the difference between EBT XD and aS1000 was found to be insignificant ($p>0.05$). Furthermore, for both detectors, relaxing the gamma criteria from 2% to 3%

Table 2. Planar Dose Analysis Results for EBT XD Film and aS1000

Volume Range (cm^3)	Minimum Field Size (cm^2)	No of Patients	Film - Average Gamma Pass (%)		PD – Average Gamma Pass (%)		p-value			
			2%/1mm	3%/1mm	2%/1mm	3%/1mm	A	B	C	D
< 1	3×3	24	93.41	97.59	91.9	93.2	< 0.05	< 0.05	< 0.05	< 0.05
1.0-3.0	5×5	19	93.93	98.04	93.2	96.2	< 0.05	< 0.05	< 0.05	< 0.05
3.0-10	6×6	29	95.04	98.29	94.6	97.1	< 0.05	< 0.05	< 0.05	< 0.05
> 10	8×8	20	94.35	97.54	94.5	97.1	0.88	0.11	< 0.05	< 0.05
MM	10×10	8	94.01	97.1	95.3	97.6	0.44	0.51	< 0.05	< 0.05
Total		100	94.22	97.83	93.7	96.1	< 0.05	< 0.05	< 0.05	< 0.05

Abbreviations: A, Film vs PD (2%/1mm); B, Film vs PD (3%/1mm); C, Film (2%/1mm vs 3%/1mm); D, PD (2%/1mm vs 3%/1mm)



(a) (b)

Figure 2. (a), Setup for film dosimetry; (b), Film Calibration curve from 0.5 Gy to 40 Gy

significantly increased the gamma pass rate. The results of planar dose analysis are summarized in Table 2 for film and portal dose with various gamma criteria

Correlation Analysis

The various correlation analyses are presented in Table 3. In terms of point dose correlation analysis, a strong correlation was found between the chamber point dose and the chamber volume mean dose agreement with the TPS for both 0.13 cm^3 and 0.01 cm^3 chambers [Figure 3 (a)]. However, weak correlations were observed for all other analyses, including the correlation between the two chamber volumes, the correlation between chamber mean volume and target volume, and the correlation between point dose and planar dose [from Figure 3(b) to Figure 6(c)]. Regarding planar dose correlation analysis, strong correlations were observed only between the two gamma criteria analyses of the same detector type [Figure 6(d)]. On the other hand, weak correlations were observed for all other analyses, including the correlation between two detector types and the correlation between target volume and gamma pass rate.

Discussion

In SRS/SRT QA, the mean agreement between 0.01 cm^3 measurements and TPS calculated values is higher compared to the agreement observed for 0.13 cm^3 chambers, resulting in an improvement of approximately 1% in mean agreement. These findings are consistent with the observations made by Bora et al [17]. They reported average agreements of 0.3% and 1.8% with TPS for 0.01 cm^3 and 0.13 cm^3 chambers, respectively, in SRS and SBRT cases. Conversely, in conventional RapidArc treatments, Kumar SS et al, [18] reported better agreement for 0.13 cm^3 chambers when compared to 0.01 cm^3 chambers. They found an average agreement of 0.01% for the 0.13 cm^3 chamber and 1% for the 0.01 cm^3 chamber.

When comparing the agreements between chamber center point and chamber volume mean doses with TPS,

Table 3. Various Correlation Analyses

	A	B	C	D	E	F	G	H	I	J	K	L	M
A	1												
B	-0.02	1											
C	-0.14	0.75	1										
D	-0.02	0.12	0.28	1									
E	-0.03	0.07	0.34	0.66	1								
F	-0.25	0.11	0.18	0.19	0.09	1							
G	-0.23	0.21	0.34	0.09	0.07	0.68	1						
H	-0.15	-0.23	-0.08	-0.11	-0.12	0.46	0.31	1					
I	-0.14	-0.19	-0.14	-0.2	-0.31	0.31	0.25	0.52	1				
J	-0.05	-0.01	-0.02	-0.01	0.01	-0.21	-0.19	-0.2	-0.15	1			
K	0.48	0.12	0.02	-0.1	-0.09	-0.38	-0.35	-0.26	-0.24	0.45	1		
L	-0.14	0.07	0.04	-0.06	-0.01	-0.22	-0.17	-0.16	-0.14	0.83	0.29	1	
M	0.34	0.26	0.15	-0.15	-0.07	-0.47	-0.28	-0.33	-0.23	0.34	0.83	0.26	1

Abbreviations: A, Target Volume; B, 0.13 cm^3 Point % Dose Difference; C, 0.13 cm^3 Chamber Volume Mean % Dose Difference; D, 0.01 cm^3 Point % Dose Difference; E, 0.01 cm^3 Chamber Volume Mean % Dose Difference; F, 0.13 cm^3 Absolute Point % Dose Difference; G, 0.13 cm^3 Absolute Chamber Volume Mean % Dose Difference; H, 0.01 cm^3 Absolute Point % Dose Difference; I, 0.01 cm^3 Absolute Chamber Volume Mean % Dose Difference; J, Film 2%/1mm; K, PD 2%/1mm; L, Film 3%/1mm; M, PD 3%/1mm

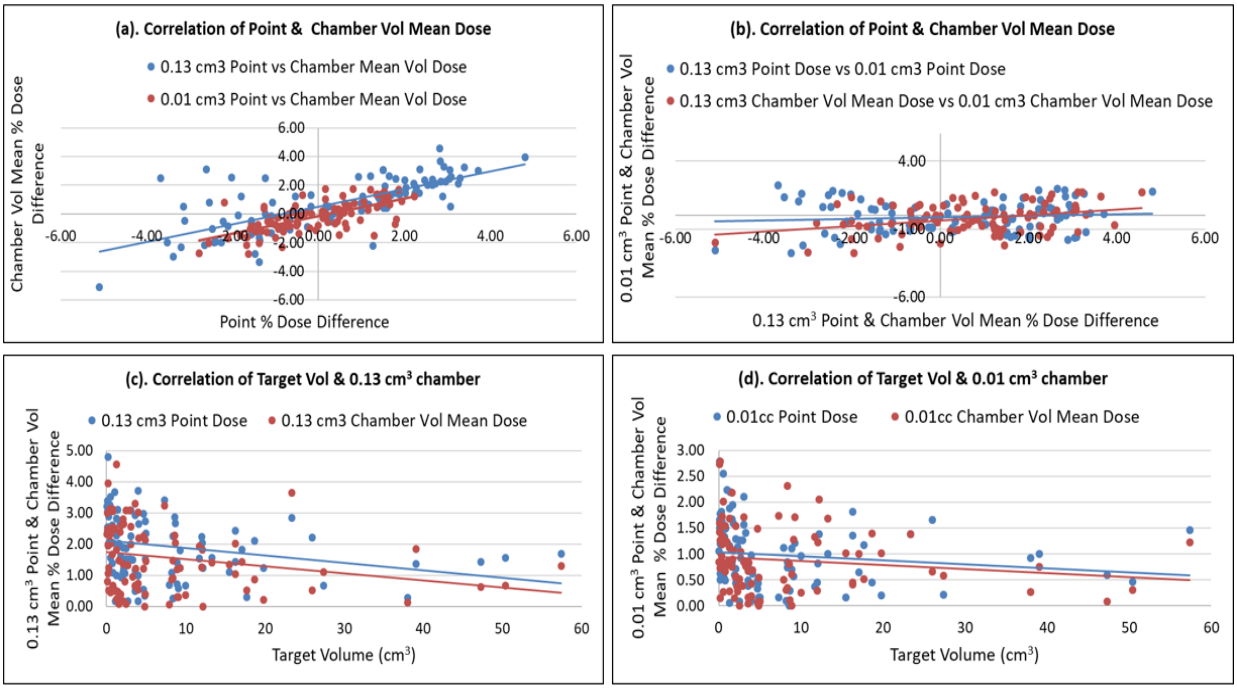


Figure 3. Correlation Analyses: (a), Point Dose % Dose Difference vs. Chamber Volume Mean % Dose Difference; (b), 0.13 cm^3 Point & Volume Mean % Dose Difference vs. 0.01 cm^3 Point & Volume Mean % Dose Difference; (c), Target Volume vs. 0.13 cm^3 Chamber (Point & Chamber Volume Mean % Dose Difference); (d), Target Volume vs. 0.01 cm^3 Chamber (Point & Chamber Volume Mean % Dose Difference)

it was observed that the 0.13 cm^3 chamber demonstrated a significant difference ($p<0.05$), whereas the 0.01 cm^3 chamber showed no significant difference ($p>0.05$). This discrepancy may be attributed to the negligible volume averaging effect and lesser variation in distribution within the chamber volume of 0.01 cm^3 compared to 0.13 cm^3. Additionally, it was observed that as the volume exceeded 10 cm^3 and larger field sizes were employed, there was an increase in the difference between the TPS and measured dose for the 0.01 cm^3 chamber. This increase in difference

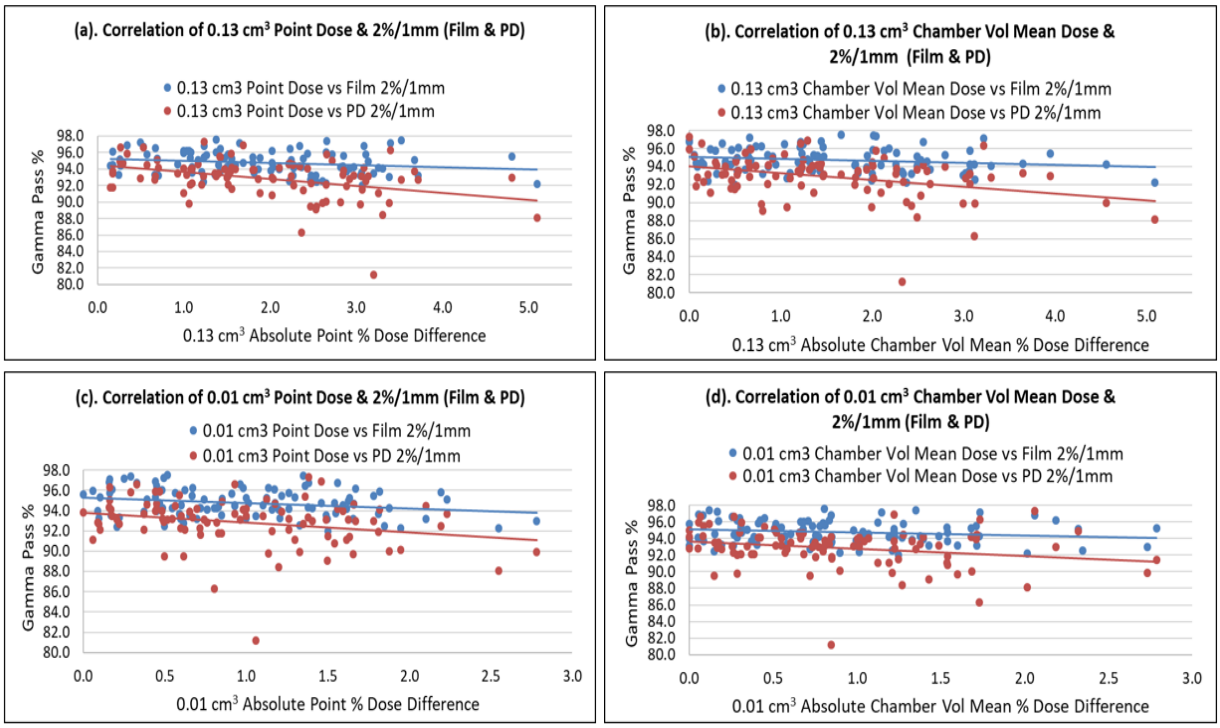


Figure 4. Correlation Analyses: (a), 0.13 cm^3 Absolute Point % Dose Difference vs. Gamma Pass % (2%/1mm); (b), 0.13 cm^3 Absolute Volume Mean % Dose Difference vs. Gamma Pass % (2%/1mm); (c), 0.01 cm^3 Absolute Point % Dose Difference vs. Gamma Pass % (2%/1mm); (d), 0.01 cm^3 Absolute Volume Mean % Dose Difference vs. Gamma Pass % (2%/1mm)

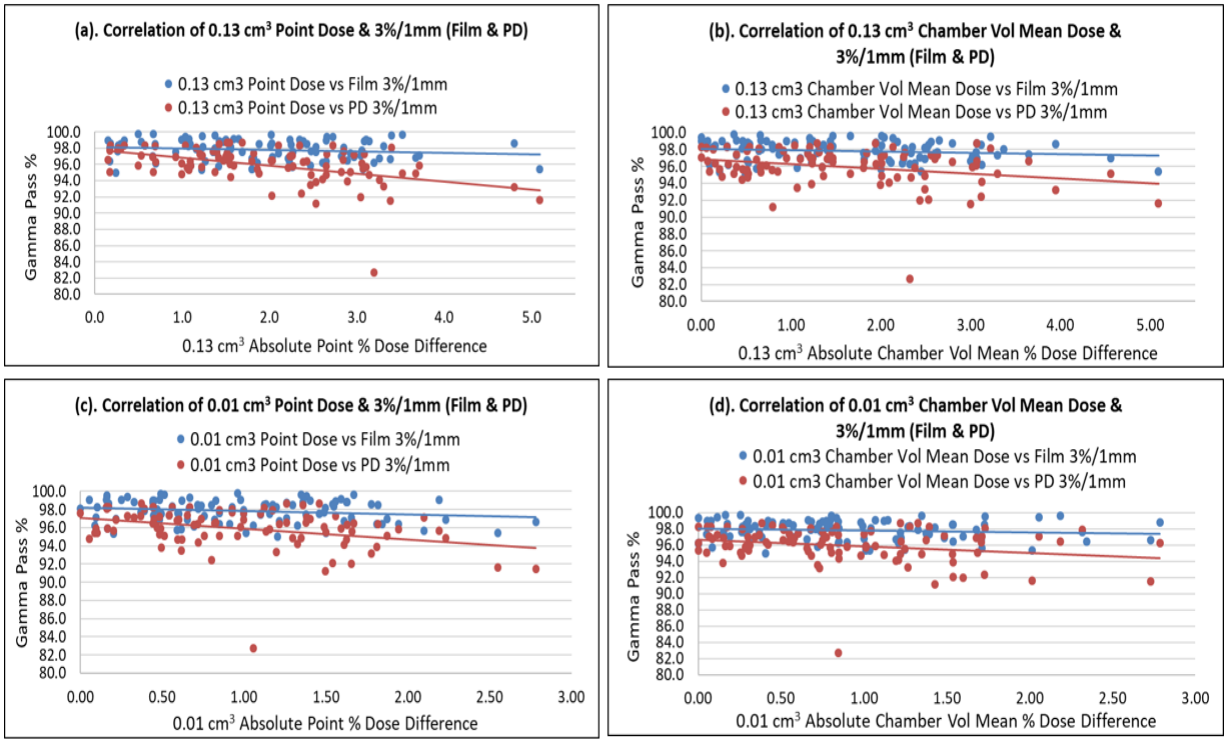


Figure 5. Correlation Analyses: (a), 0.13 cm3 Absolute Point % Dose Difference vs. Gamma Pass % (3%/1mm); (b), 0.13 cm^3 Absolute Volume Mean % Dose Difference vs. Gamma Pass % (3%/1mm); (c), 0.01 cm^3 Absolute Point % Dose Difference vs. Gamma Pass % (3%/1mm); (d), 0.01 cm^3 Absolute Volume Mean % Dose Difference vs. Gamma Pass % (3%/1mm)

could be attributed to the presence of a steel electrode, which introduces energy dependence, particularly in the presence of larger scatter radiation that occurs with larger field sizes.

Though both the chambers showed improvement in point dose agreement with TPS as the volume increased,

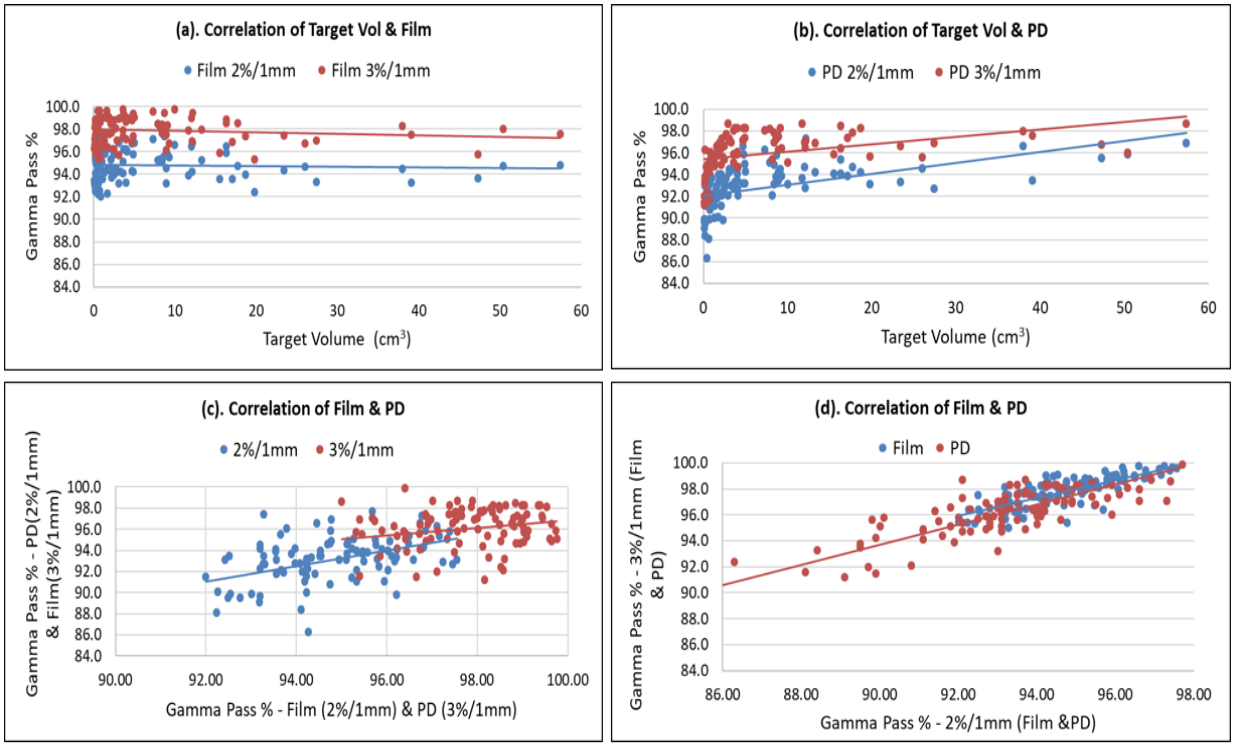


Figure 6. Correlation Analyses: (a), Target Volume vs. Film Gamma Pass % (2%/1mm & 3%/1mm); (b), Target Volume vs. PD Gamma Pass % (2%/1mm & 3%/1mm); (c), Film Gamma Pass % (2%/1mm) & PD Gamma Pass % (3%/1mm) vs. Film Gamma Pass % (2%/1mm) & PD Gamma Pass % (3%/1mm); (d), Film & PD Gamma Pass % (2%/1mm) vs. Film & PD Gamma Pass % (3%/1mm)

they exhibited weak correlation between them as well as with target volume. The lack of correlation between chambers and with target volume indicates need of special care that one should take when interpreting published point dose agreements with their result.

The EBT XD showed good gamma agreement with TPS calculation compared to aS1000 EPID with an average improvement of about 3%. For both the gamma criteria used. James S et al, [19] also observed better gamma agreement with EBT XD film compared EPID. They reported average gamma agreement of 96.7% and 95.9% for EBT XD and EPID respectively. The gamma agreement of both the detectors improved with target volume. Similar observation was reported by Stephanie Lang S et al, [20] although they have not mentioned the detector type for which they observed this pattern. The significant improvement in gamma agreement, when the dose difference criterion is relaxed from 2% to 3% for both detector types, indicates the need to consider different threshold levels for various criteria used in the analysis. The lack of correlation between EBT XD and EPID shows the importance of taking the detector type into consideration while interpreting data with published values.

Again the lack of correlation between point dose agreement and planar dose agreement stresses the need for planar dose analysis an addition to point dose verification as point dose verification may not pick the delivery errors in locations other than where it is measured. The limitations of this study need to be compared with high-resolution detectors developed in recent years, specifically designed for small-field stereotactic treatments.

In conclusion, understanding the correlation among various detector types and evaluation methods is crucial for interpreting pre-treatment QA results with published values. This study found weak correlation between studied detector types for both point and planar dose evaluation. However, strong correlation was observed within a detector type for different point dose evaluation methods and gamma criteria. The lack of correlation between detector types for SRS/SRT QA underscores the importance of caution when interpreting QA results with published values. For precise point dose measurement, proper chamber positioning is crucial, especially with smaller volumes, to account for geometric errors. A detector size between 0.01-0.1 cm^3 is optimal, enhancing agreement with TPS through volume averaging. For planar dose verification, employing gamma criteria of 3%/1mm ensures a reasonable pass rate across the target volume range.

Author Contribution Statement

The first author conducted the study concept, data collection, analysis, interpretation of results and drafted the manuscript. The corresponding author meticulously reviewed, corrected and approved the final version of the manuscript.

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Ethical Declaration

This article does not involve any studies with human participants or animals. Therefore, ethical committee approval is not applicable.

Declaration

This article has not been previously submitted, either in whole or in part, as an approved student thesis, nor has it been endorsed by any scientific body

Availability of data

Data sharing is not applicable to this article

Conflict of Interest

We wish to disclose that all authors who contributed to this study declare no conflicts of interest with regard to the manuscript.

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