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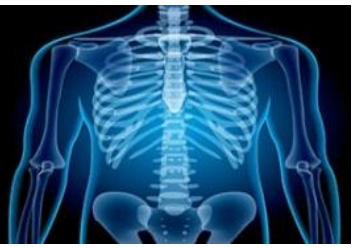

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Dosimetric comparisons between local and global Gamma index for lung cancer radiation therapy

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Abstract
Background: Patients undergoing Intensity Modulation Radiation Treatment (IMRT) for lung cancer were the focus of this research, which sought to compare the global gamma index with the local index.
Purpose: This study compares the local and global gamma indices for plans for lung cancer patients treated with the Intensity Modulation Radiotherapy Technique (IMRT).
Methods: A cross-sectional clinical research study was conducted at Al-Amal National Hospital for Radiotherapy and Nuclear Medicine in Baghdad from January to July 2024. The study involved 45 patients with unilateral lung cancer aged 40-70 years who were forwarded radiation therapy. Patients underwent a CT simulation for treatment planning via MONACO version 5.1 preparation. They were treated with a 6 MV or 10 MV X-ray photon beam from the agility linear accelerator manufactured by ELEKTA, with a gamma index criterion of 3%/3 mm.
Results: This study compares local and global gamma indices for two-dimensional gamma indices (2D) and three-dimensional gamma indices (3D). The results show that the global gamma index (%GP) passing rate is higher than the local gamma index for 2D and 3D. The three-dimensional gamma passing index is also greater than the two-dimensional gamma passing index. The analysis reveals a significant correlation between the number of segments and monitor units and the local and global gamma indices, with an inversely proportional relationship. This effect is also observed in the 3D gamma index.
Conclusions: The 3D global gamma index is more accurate than the 2D local gamma index. This finding indicates that Quality Assurance (QA) is necessary for complex treatments, such as IMRT, where high modulation is crucial for achieving therapeutic goals. Understanding this can optimize radiotherapy quality, particularly for techniques such as IMRT and Volumetric Modulated Arc Therapy (VMAT), which require a high degree of modulation for effective treatment.

Keywords: Gamma index, local, global, lung cancer, dosimetry

Introduction

The existence of a reverse correlation between gamma passing rates and treatment complexity, as determined by the number of segments and MUs, emphasizes the importance of conducting rigorous plan quality assessment in complex treatments [1], [2], [3], [4]. These findings greatly enhance the optimization of quality assurance in radiotherapy, specifically for techniques such as intensity-modulated radiation therapy (IMRT), where achieving therapeutic goals heavily relies on high modulation. These insights significantly enhance quality assurance in radiotherapy, focusing on techniques such as IMRT that require meticulous modulation to achieve therapeutic goals [5], [6]. The utilization of radiation is of utmost importance in effectively managing thoracic tumors, covering all aspects of oncologic care, ranging from curative approaches to palliative interventions. However, IMRT treatment plans for lung cancer can be more diverse because of the low electron density of lung tissue. Low-dose washing in healthy lungs may increase the risk of pneumonitis, exacerbated by many IMRT beams. IMRT should be used cautiously to avoid geographic isolation due to the increased conformity of high-dose zones, especially when treating mobile lung tumors. Investigating the efficacy of low-dose washes is crucial for reducing toxicity. Despite these risks, IMRT offers significant benefits for lung radiation patients, including superior normal tissue sparing and the ability to deliver a larger dose [7], [8]. Owing to the increased dose calculation uncertainty, the intended dose distribution which is calculated during the treatment process via a small or irregularly shaped beam opening is not delivered to a patient during the treatment of a VMAT plan with a high degree of modulation; this is more common with small or irregularly shaped beam apertures, which are typically used in excessively altered VMAT plans [9, 10].

Previous studies have documented specific issues with the gamma analysis of indices despite their frequent utilization in the clinical setting. The gamma index technique employs the distance to agreement and Dose Differences (DDs) to determine the degree to which the predicted and actual dose concentrations are similar. One can utilize the global or local gamma index method to calculate the DD, which are distinct approaches. The DDs are calculated via the maximum dosage (or prescribed dosage) in the global gamma index analysis and the doses at each evaluated location in the local gamma index analysis. Because of the percentage composition of DDs, the DDs of low-dose areas may be underestimated by local gamma indices and overestimated by the global gamma index technique [11, 12].

Each clinic has a policy regarding which gamma analysis to utilize as a pretreatment method of patient-specific quality assessment for VMAT because there are no universal guidelines. However, it is unclear whether the gamma index from global analysis can be directly applied to local analysis or vice versa. Heilemann *et al*. [13] demonstrated that a 90% global average of gamma rays passing through 2 mm of thickness could be misdiagnosed as clinically significant problems because large errors in planning intentionally introduce MLC deficits. This discovery is pertinent to the maximum tolerances of gamma frequency passing rates. However, the gamma frequency of IMRT or VMAT depends on the dosimeter type.

The frequency of gamma rays in IMRT and VMAT depends on the type of dosimeter, as demonstrated by Hussein *et al*. [14] and Fredh *et al*. [15]. Their claims indicate that the detector's design and resolution accurately predict the gamma frequency passage rates. As a result, a particular institution's dosimeter may not always comply with the accepted limits of tolerance previously researched or standardized. Additionally, whether the gamma index can detect the exactness of VMAT administration is debatable. There appears to have been much research into the dependability of the gamma index despite the index's common usage in clinical situations. This study aimed to compare the local and global gamma indices for plans for lung cancer patients treated with the Intensity Modulation Radiotherapy Technique (IMRT).

Materials and Methods

Study design and setting

A cross-sectional clinical study was conducted from January 2024 to July 2024 at Al-Amal National Hospital for Radiotherapy and Nuclear Medicine in Baghdad, Iraq. The study employed a convenience sampling technique.

Ethical approval and patient consent

The study protocol was approved by the Ethics Committee of the College of Basic Education, Mustansiriyah University. Written informed consent was obtained from all participating patients.

Patient selection

A total of 45 patients diagnosed with unilateral lung cancer and undergoing radiation therapy were included. Eligibility criteria included patients aged between 40 and 70 years with non-small cell lung cancer (NSCLC). Patients with metastatic disease were excluded from the study.

Treatment planning and delivery

All patients underwent CT simulation for radiation therapy planning using MONACO software, version 5.1. Treatment was delivered using VMAT via a linear accelerator (ELEKTA Agility) with 6 MU or 10 MU X-ray photon beams.

Dosimetric evaluation

The gamma index analysis was performed with a criterion of 3% dose difference and 3 mm distance to agreement (3%/3 mm) to assess the quality of the treatment plans.

Statistical analysis

Data analysis was conducted using SPSS software, version 28 used t-tests and Pearson correlation coefficients (r). A p-value of ≤ 0.05 was considered statistically significant.

Results

The Table 1 and Fig. 1 show the comparative results between the local and global gamma indices for both the two- and three-dimensional gamma indices. The analysis revealed that the global gamma index (%GP) passing rate is significantly higher than the local gamma index for both 2D and 3D. The three-dimensional gamma passing index is significantly greater than the two-dimensional gamma passing index.

Table 1: Local and global gamma passing rates for the 2D and 3D gamma indices

Parameters	2D gamma index	3D gamma index	*p*-value
Local	77.59 ± 4.06	86.03 ± 6.22	0.0384*
Global	94.95 ± 5.39	97.02 ± 3.02	0.0402*
p-value	≤0.0001*	0.0002*	
* Significant difference at *p-value* equal to or less than 0.05			

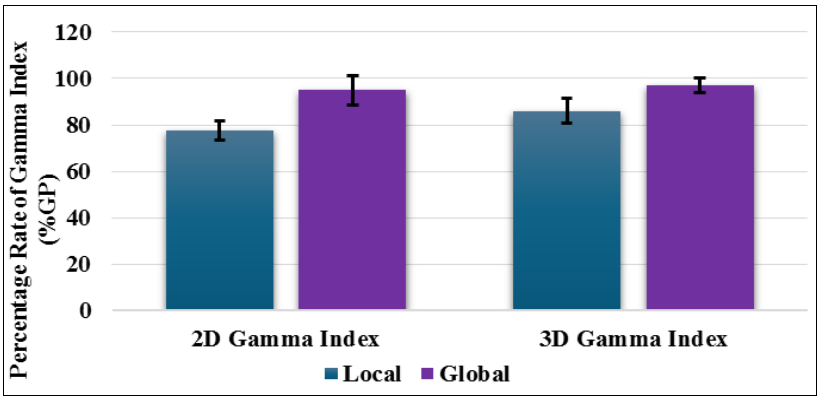

Fig 1: Comparison between the local and global gamma passing rates for the 2D and 3D gamma indices

Dosimetric parameters that could be acquired from the planning and included in this study were the number of segments used in the plan and the Monitor Units (MUs) per fraction of each plan. The results of the number of segments and MUs are shown in Table 2. The analysis revealed a significant correlation between the number of segments and monitor units (MUs) and the local and global gamma indices. The relationship was inversely proportional. This means that the passing rate increases when the number of segments increases. Moreover, the same effect was found for the 3D gamma index, as shown in Table 3.

Table 2: Number of segments and monitoring units in the 2D gamma index

Parameters	Local gamma index		Global gamma index	
	r	***p-value***	*r*	***p-value***
No. of MUs	-0.932	≤0.0001*	-0.843	≤0.0001*
No. of segments	-0.799	≤0.0001*	-0.896	≤0.0001*

Table 3: Number of segments and the number of monitoring units in the 3D Gamma index

Parameters	Local gamma index		Global gamma index	
	r	***p-value***	*r*	***p-value***
No. of MUs	-0.917	≤0.0001*	-0.822	≤0.0001*
No. of segments	-0.765	≤0.0001*	-0.809	≤0.0001*

Discussion

This research offers an exhaustive comparison of the Local Dose-based (LD) and Global Dose-based (GD) gamma index in the framework of VMAT lung cancer treatment plans, applying both 2D and 3D evaluations. The results showed that gamma passing rates were higher with global gamma indexing than local indexing in both 2D and 3D analyses. The periodic behaviors observed are explained by the very nature of these metrics: GD analysis references the global maximal dose, which is more lenient as a point of reference; conversely, LD assessment checking for dose differences at each measurement point is comparably stricter particularly where high gradients exist.

Moreover, 3D gamma analysis has been shown to be more effective than 2D analyses in the detection of spatial dose deviations. The accuracy of treatment planning is evaluated with greater precision in 3D analysis because it considers volumetric contouring compared to planar snapshots. This supports earlier research, which stated that the clinical applicability and sensitivity of the technique is better with three-dimensional gamma evaluation especially for highly modulated techniques like IMRT and VMAT. Also supporting this view are Anetai *et al*. [11], Hussein *et al*. [16], and Bai *et al*. [17] support the notion that 3D gamma metrics have better capability to measure clinically significant gaps in target doses awarded than others.

As shown in Tables 2 and 3, there was a statistically significant inverse relationship between gamma passing rates with number of Monitor Units (MUs) and number of segments. These findings imply that more elaborate plans come with higher chances of dose errors. More segments and MUs usually indicate greater modulation and detail because finer resolution increases the likelihood of a gap between the intended and actual doses delivered. This underscores QA precision measures, particularly for plans requiring high modulation, supports Bresciani *et al*.'s (2013) [18] report on QA trends in tomotherapy.

Notably, the investigation reviewed 240 VMAT plans for 45 patients of nonmetastatic and unilateral NSCLC from at the same institution. Each plan simulated clinical diversity with varying arc configurations comprising either single or dual arcs and segment count between 70 to 100 as well as energy settings of either 6 MV or 10 MV. The study incorporated linac log files to compute the mechanical delivery parameters for beam shaping geometry, which facilitates describing discrepancies during delivery more granularly. This approach made it possible to detect not only dosimetric discrepancies but also geometric errors like gantry rotation speed, MLC position during layering, and dose rate alterations [19].

This approach also highlighted the limitation of using gamma index results in isolation. The performance of the gamma index is influenced not only by plan complexity and modulation but also by the dosimetric system employed. For instance, detectors with limited spatial resolution may fail to capture fine variations in highly modulated plans. As supported by Hussein *et al*. [14] and Fredh *et al*. [15] different dosimeters yield varying gamma passing rates even for identical plans, indicating that QA thresholds should be adapted to the characteristics of each measurement system.

The findings of this study suggest that while global gamma analysis can offer higher pass rates, it may overlook significant errors in low-dose regions. On the other hand, local gamma analysis despite its stricter nature can be more effective in identifying small-scale but clinically relevant discrepancies. Therefore, using a combination of LD and GD, particularly in 3D gamma analysis, may provide a balanced perspective for QA in complex treatments.

Conclusion

The 3D gamma index is more forgiving than the global gamma index and is more accurate than 2D gamma analysis. The fact that the gamma passing rates increased with the complexity of the treatment defined in terms of the number of segments and MUs indicates the QA (quality assurance) that needs to be done on the plan for such complex treatments. This understanding would greatly improve the optimization of radiotherapy quality assurance, especially for techniques such as IMRT and VMAT, where high modulation is needed to achieve their respective therapeutic goals.

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