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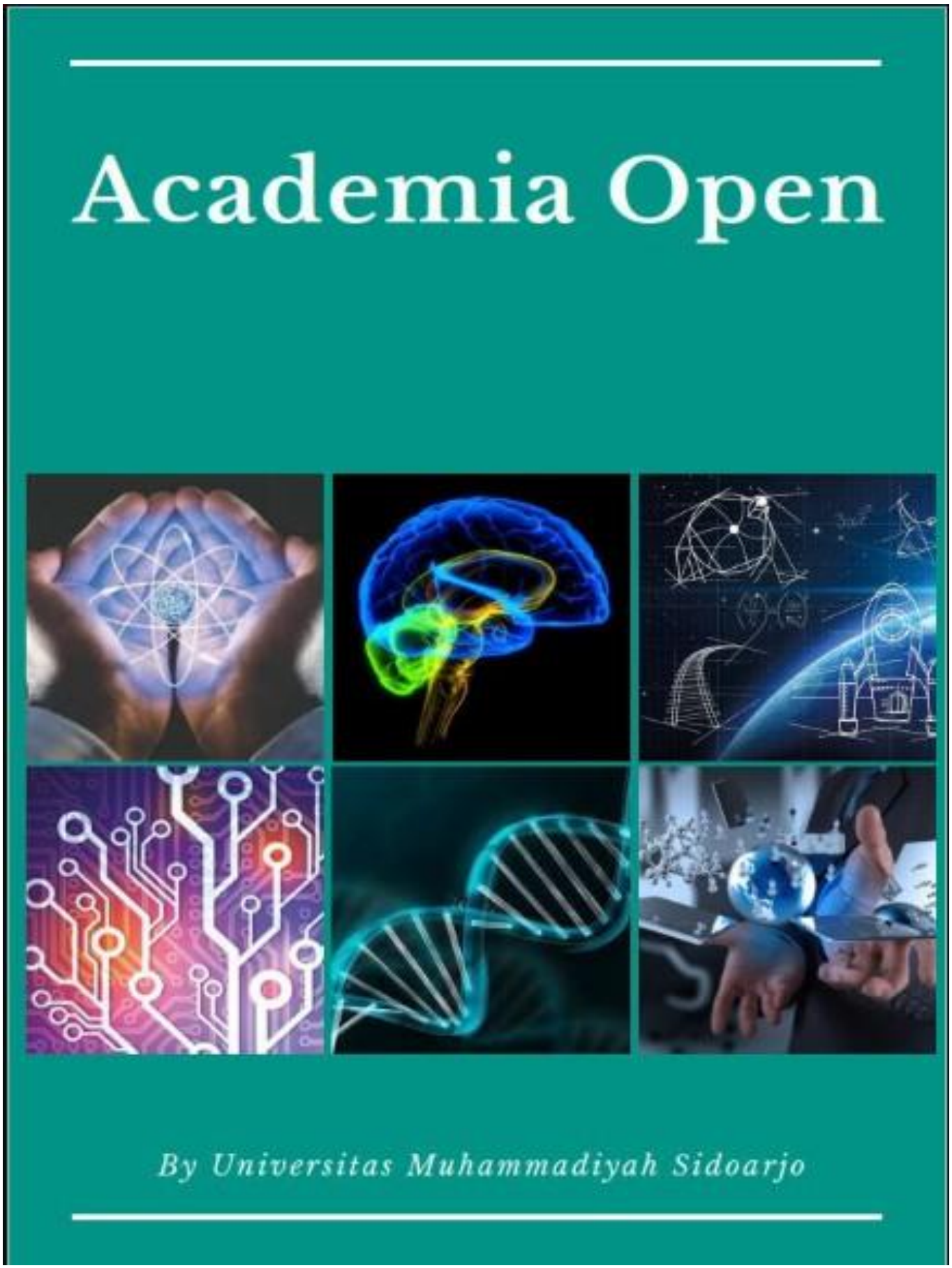

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Table Of Contents

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Comparative Study Between Global and Local Gamma Index for Evaluating Volumetric Modulated Arc Therapy (VMAT) for Prostate Cancer

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Abstract

General Background: Prostate cancer is a major malignancy among men, and Volumetric Modulated Arc Therapy (VMAT) is widely used in radiotherapy to deliver precise radiation doses while protecting surrounding organs at risk. **Specific Background:** The gamma index is commonly applied in radiotherapy quality assurance to evaluate agreement between planned and delivered dose distributions using global and local calculation methods. **Knowledge Gap:** However, uncertainty remains regarding which gamma index method provides more reliable verification for VMAT prostate cancer treatment. **Aims:** This study compares global and local gamma index approaches in evaluating VMAT treatment plans. **Results:** A prospective study involving 30 prostate cancer patients showed that VMAT achieved high tumour coverage (V98% = 97.03%) with minimal dose spread (V5% = 0.35%). The global gamma index consistently produced higher pass rates than the local gamma index across verification criteria (3%/3 mm: 0.95 vs 0.92; 2%/2 mm: 0.93 vs 0.81; 1%/1 mm: 0.69 vs 0.60) with significant differences. **Novelty:** The study provides comparative evidence of global and local gamma index performance in VMAT verification. **Implications:** The findings support the global g

Highlights:

- Vmat Planning Achieved High Target Coverage With V98% Reaching 97.03%.
- Global Gamma Evaluation Produced Consistently Higher Pass Rates Across All Verification Criteria.
- Significant Statistical Differences Observed Between Global and Local Dose Agreement Metrics.

Keywords: Prostate Cancer, Volumetric Modulated Arc Therapy, Gamma Index, Radiotherapy Quality Assurance, Dose Verification

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Introduction

Prostate cancer is among the most endemic types of cancer in males worldwide . Over the past decade, improvement in radiotherapy technology has made it possible to manage localised prostate cancer in surgery candidates or where patients opt for palliative treatment . Among all these developments, Volumetric Modulated Arc Therapy (VMAT) has emerged as a relatively promising delivery technique owing to high conformality, workability and the possibility of miniaturising the delivery time compared to other forms . VMAT permits the radiation to be delivered in an arc surrounding the patient to improve control of the doses central in distinguishing between prostate tumours and healthy tissues such as the bladder and rectum .

Quality assurance (QA) plays an important role in the radiation therapy treatment process to ensure that the delivered dose is similar to the predetermined dose . Errors in the planned and delivered dose may occur because of uncertainties during the patient positioning, organ position change and isocenter, and other factors involving the machine . To quantify these deviations, another gamma index is employed as the primary tool to measure the conformity between the prescribed and implemented dose distribution .

The gamma index is chosen to evaluate dose conformity VMAT, which provides the extent of correspondence between the planned dose and the delivered dose distribution in terms of spatial and dose tolerance . The gamma index is computed using two primary methodologies: the global gamma index, which takes the maximum dose of the whole volume as a reference, and the local gamma index, which takes the dose at a certain point inside the treatment field into consideration . Both approaches have unique strengths: the global gamma index offers an overall picture of dose conformity, but it may not be as accurate in terms of local discrepancies, which the local gamma index can be sensitive, but it may emphasise too many small differences, especially if it located on low dose region of the plan .

However, there is continuous controversy over whether the global or local gamma index is clinically useful, particularly in the VMAT technique. It may also result in improved quality assurance of the treatment of prostate cancer if the indices identified in both groups were compared and validated accurately.

This study aims to compare the global and local gamma indexes and assess their effectiveness in determining the clinical relevance of VMAT plans for prostate cancer patients to enhance the QA for prostate cancer treatment. By doing so, the study aims to positively advance knowledge of dose delivery in VMAT-based prostate cancer therapy and safer treatment outcomes.

Methodology

This prospective cross-sectional research study using a convenience sampling approach was completed at the Al-Amal National Hospital for Oncology over a period ranging from December 2023 to May 2024. Participants in this research consisted of 30 male patients with prostate cancer, aged between 36 and 52 years. It also excluded palliative patients. Before receiving the treatment, the patients were scanned using CT simulation to obtain information on the cancer anatomy and organs at risk (OAR). The CT simulation images were subsequently forwarded to the Monaco 5.11 TPS treatment planning system software. The oncologist delineates the tumour and organs at risk or OARs. Then, the plans were generated for the treatment of prostate cancer by Volumetric Modulated Arc Therapy (VMAT) treatment planning techniques. After that, the plans were forwarded to the ArcCHEK detector to measure the global and local gamma index. The criteria of gamma index were 3%/c mm and 1%/1 mm.

Results

The patient characteristics involved in this study are shown in Table (1). The mean age of 49.03 years with a standard deviation of 10.54 clearly shows a moderate age distribution among the patient sample. On average, the tumour size was 3.31 cm^3 and SD of 1.02, indicating that tumour volume was not identical in all cases. Concerning the extent of the disease, about 30% of the patients were diagnosed with stage I, 43% at stage II and only 27 at stage III. This distribution raises the speculation that the majority of patients were diagnosed with stage I or II prostate cancer but few patients with stage III or IV.

Table (1): Characteristics of parotta cancer patients.

Characteristics of patients	
Age (years)	49.03 ± 10.54
Tumour Size (cm^3)	3.31 ± 1.02
Tumour Stage	
I	10 (30%)
II	13 (43%)
III	7 (27%)

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The data in Table (2) are the plans' mean and corresponding standard deviations (SD) for tumour coverage and OAR dose exposure. In tumour dose, the percentage of coverage at 98% was 97.03% ± 5.22, showing that good tumour coverage was achieved in all cases. The target volume receiving 5% of the prescribed dose (V5%) was also low at 0.35 % with a small variation (SD 0.02), implying minimal dose spread to the other regions. Regarding OARs, the average dose to the rectum was 2804.11 cGy with a relatively large standard deviation, 902.33, because of variation in the distance from the target and individual anatomic differences. A higher mean dose of 2723.09 cGy was delivered to the bladder, although the high SD value of 7321.02 could have positional changes or patient-specific anatomical factors at the planning time.

Table (2): The coverage of tumour and OARs treated with VMAT for prostate cancer patients.

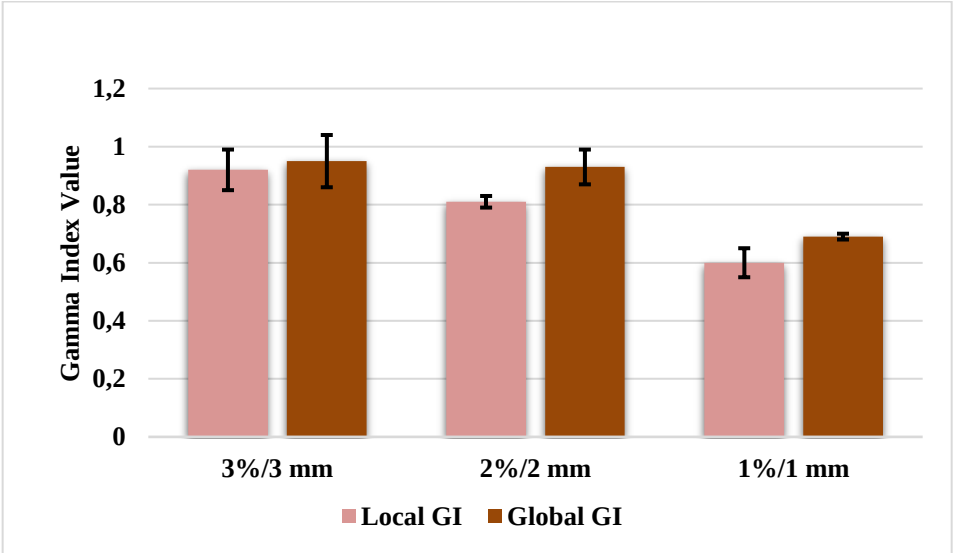
	Mean ± SD
Tumor Coverage	
V98%	97.03 ±5.22
V5%	0.35 ± 0.02
OARs	
Rectum (cGy)	2804.11 ± 902.33
Bladder (cGy)	2723.09 ± 7321.02

Table (3) and Figure (1) demonstrate the GI summary of the local and global group of patients with prostate cancer treated with VMAT, scored according to the various gamma criteria. Thus, the global gamma index was 0.95 for the 3%/3 mm criterion and significantly differed from the local index value of 0.92 with p = 0.00245, meaning that the global index is closer to the planned dose. Using the more stringent criteria of 2% / 2 mm, the overall index was higher than the local one, 0.93 and 0.81, respectively, t = 2.1059, p = 0.03451. At the highest level of 1%/1 mm, both indexes are less than the prior level; the global index equals 0.69, and the local – 0.60; however, p = 0.04052 still indicates its significance. The overall p-values between local and global gamma indices for all the criteria (p = 0.001592 for local and p = 0.04992 for global) were also significant; this means that the differences between local and global gamma indices are significant for all the criteria that were considered in this study. The information presented in this graph indicates that the global gamma index generally achieves a better pass rate than the local gamma index at increasing stringency, which could imply higher variance of the local gamma index due to localised differences in dose.

Table (3) compares the local and global indexes for prostate cancer patients treated with VMAT using different criteria.

Gamma Index Criteria	Local GI	Global GI	*p*-value
3%/3 mm	0.92 ± 0.07	0.95 ± 0.09	0.00245*
2%/2 mm	0.81 ± 0.02	0.93 ± 0.06	0.03451*
1%/1 mm	0.60 ± 0.05	0.69 ± 0.01	0.04052*
***p*-value**	0.001592*	0.04992*	
*** Significant difference if the p-value ≤ 0.05.**			

Figure (1): Comparison between the Gamma Index criteria for prostate cancer patients



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Discussion

This study involved patients with prostate cancer who had undergone VMAT treatment; their average age was 49.03 years, the mean tumour volume was 3.31 cm^3, and 73% of the patients were at the early stage. This distribution implies that early-stage prostate cancer patients are more likely to receive VMAT, as noted by Hunte et al. (2022) where in early to intermediate stages prefer VMAT due to precision and rapid dose delivery to the target volume while minimising OARs' exposure. Quan et al. (2012) study also pointed towards increased utilisation of VMAT for early stages of prostate cancer treatment and proved its efficacy in disease control and OAR constraining.

The V98% tumour dose in this study was an average of 97.03% (SD 5.22), and the result demonstrates that the target volume is adequately covered in almost all the cases. A low V5% value indicates a very low dose beyond the target, which also testifies to precise dose confirmation of VMAT, affirming the results of Du et al., 2024 who reported an excellent tumour coverage of 98% in their cohort of prostate cancer patients treated with VMAT and stated that arc-based delivery makes VMAT apt for achieving conformal dose to Similarly, Baroudi et al. (2023) also noted that VMAT's dose conformity also ensured lower OAR burden and that the low V5% observed here supports this notion, as was that though the average rectum dose of 2804.11 cGy, and the bladder dose of 2723.09 cGy contrasts with high standard deviations scores of 902.33 for rectum and 7321.02 for bladder, This variation could be arising from differences in patient anatomy and closeness of OAR about the target, as noted by Bostel et al., (2019) who observed that positional changes during treatment planning were common cause for higher bladder dose variability.

At the 3%/3 mm criterion, we have the global GI = 0.95 and the local GI = 0.92 with the p = 0.00245. A similar pattern of a higher global GI was maintained across even stricter criteria of 2%/2 mm and 1%/1 mm, where all global GI's were significantly higher than the respective local GI's. These data show that the global GI method offers a slightly improved pass rate and closer conformity to the planned dose distribution. As with our study, Park et al. (2018) found that the global gamma index is relatively larger than the local gamma index, pointing to the global method based on maximum dose as a reference counteracting localised large dose variation. In addition, Park et al. (2015) obtained the same results for VMAT prostate cancer treatments; the local gamma indices are more robust to fluctuations in the low-dose region area, which could account for the results shown here. They stated that although local GIs may draw attention to small differences in dose delivery, the global GI offers a directionally more meaningful overall evaluation of treatment precision, especially in high conformity plans such as VMAT.

The uniqueness of the criteria used in this study has provided the meaningful difference of global and local gamma indices in VMAT dose verification with p = 0.001592 for local and p = 0.04992 for global. These findings add more evidence to the debate regarding the use of global or local gamma index criteria in quality assurance in radiotherapy, on which Das et al. (2022) have stated that the global gamma index should be taken as the main QA parameter when using high-precision since it provides equal sensitivity across dose distributions and clinically meaningful metrics.

Conclusion

Therefore, conclusions made in this study regarding the effectiveness of VMAT and the necessity of employing global gamma index parameters for QA will benefit the field of radiation oncology. Therefore, this currently corroborates the potential of VMAT as a more effective treatment platform for prostate cancer, aiding clinicians to manage it better and reduce impacts on patients by improving accuracy and sensitivity in applying radiation.

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