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Research Article

Assessing Surface Guided Radiation Therapy Benefits for Paediatric Cancer Patients: Dosimetric Implications of Intrafractional Motion - An Institutional Review

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Abstract

Introduction/Background: SGRT, a real-time imaging technique, offers continuous monitoring and motion control during *treatment*. The investigation aims to assess potential dosimetric alterations in target coverage due to intrafractional motion, considering its impact on patient safety and treatment efficiency. *Materials and Methods*: A retrospective chart review was conducted to assess intrafractional shifts in 18 paediatric cancer patients. Patient setup employed SGRT using AlignRT (Vision RT Ltd., UK), and the PTV was aligned with CBCT. The study introduced induced shifts of 3 mm, 5 mm, and 7 mm during treatment delivery, assessing their impact on portal dosimetry results for both treatment fields. The gamma index criteria (3%, 3 mm) were employed to evaluate dosimetric accuracy. *Results*: A total of 18 patients were included, and induced shifts were analyzed for their impact on the planned gamma index values. Significant differences were observed between the Planned Gamma Index and induced shifts of 3 mm, 5 mm, and 7 mm for both treatment fields, highlighting the dosimetric implications of intrafractional motion in paediatric cases. *Conclusion*: Surface Guided Radiation Therapy (SGRT) is concluded to offer a comprehensive array of benefits for paediatric cases. The dosimetric implications of induced shifts underscore the importance of SGRT in ensuring accurate and safe treatment for paediatric cancer patients.

Keywords

Surface Guided Radiotherapy, Paediatric Cancer, Dosimetry

1. Introduction/Background

The growing acceptance and validation of Surface Guided Radiation Therapy (SGRT) as a promising imaging technique has supported its recent adoption. SGRT offers real-time feedback for patient positioning, continuous monitoring during treatment sessions, and motion control (such as beam-gating during free-breathing or deep-inspiration breath-hold). Recent advancements in SGRT are particularly notable in specialized radiotherapy areas, such as accelerated partial breast irradiation and particle radiotherapy. [1]

SGRT systems utilize a combination of a projector and one or multiple camera units to record a real-time 3D surface of patients. The calculation of necessary corrections for the pa-

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tient's position in translational and rotational directions is based on a reference surface relative to the treatment isocenter position. There are four primary optical surface scanning technologies applied in radiotherapy, namely laser scanners, time-of-flight systems, stereovision systems, and structured light systems [2-7] Optical surface scanners, valued for their elevated spatial and temporal resolution, have demonstrated their significance in enhancing the radiation therapy process, particularly in terms of patient positioning and monitoring. [8, 9]

SGRT functions as a tool embodying a "four-eyes principle," facilitating constant monitoring of patient positioning. This contributes to the enhancement of patient safety and comfort, while concurrently establishing standardized workflows with increased precision and reproducibility. [10-14] It possesses the capability to enhance clinical outcomes by ensuring precise irradiation of the target while minimizing exposure to surrounding healthy tissue. [15]

In the context of patient positioning, SGRT emerges as a highly effective tool with the potential to reduce overall treatment duration and minimize imaging dose. This effectiveness stems from various factors: firstly, SGRT furnishes real-time, in-room information regarding the complete surface and positioning of the patient. Secondly, for superficial tumors, where surface deviations can serve as a reliable indicator of tumor motion, SGRT offers more precise positioning compared to traditional 3-point lasers. This improved precision may even lead to a reduction in the frequency of required daily imaging in specific cases. Lastly, for deeper-seated tumors without a direct correlation between surface deviations and tumor movement, daily imaging remains essential. However, SGRT plays a crucial role in expediting the image registration process, thereby mitigating the need for multiple imaging sessions. [16, 17] As suggested in AAPM TG 75 for the reduction of imaging dose, SGRT can be recognized as a step in image guidance that can be carried out without the use of ionizing radiation. [18]

In the context of paediatric treatments, the utilization of SGRT for intra-fraction monitoring is not a widespread practice and there is limited existing literature on this subject. [19] Radiation Therapy is generally painless and non-invasive, but it can distress children due to unfamiliarity with the procedure, new faces, separation from parents, and the equipment's sounds. Maintaining stillness during RT is essential for optimal results and safety, often requiring repeated sedation or even general anesthesia for the youngest patients. [20]

SGRT systems have been integrated into paediatric treatments as a safety measure to facilitate patient positioning and offer an additional layer of error detection. If there are deviations in parts of the patient's surface from the reference position established during the planning CT set-up, or if the calculated isocentric deviations surpass a specified threshold, the beam can be halted. The objective of this study is to investigate the potential dosimetric alterations affecting target coverage as a result of intra-fractional motion in paediatric patients treated with or without general anaesthesia.

2. Materials and Methods

A retrospective chart review was undertaken to assess intrafractional shifts in 18 paediatric cancer patients. Patient setup employed SGRT using AlignRT (Vision RT Ltd., UK) and the planning target volume (PTV) was aligned with CBCT. Following the acquisition of a new SGRT reference image, patients were continuously monitored during treatment. If SGRT detected any intrafractional shift exceeding 3 mm in any direction for more than 2 seconds, the Auto Beam hold feature paused treatment. Subsequently, CBCT scans were repeated, and shift measurements were recorded. These patients were evaluated for intrafractional shifts greater than 3 mm, based on the standard Gamma index criteria (3%, 3mm), to assess potential dosimetric impacts on PTV coverage and the minimum and maximum PTV doses. The gamma index serves as a valuable dosimetric verification tool, assessing the conformity of a Treatment Planning System (TPS) plan with the measured plan and offering a quantitative measure of dose agreement. It is commonly employed in patient-specific Intensity-Modulated Radiation Therapy (IMRT) Quality Assurance (QA). In clinical practice, a widely accepted criterion for the gamma index is 3 mm distance-to-agreement and 3% dose-difference, achieving a passing rate of 90%. The reported detection limit for this evaluation is 4.07 mm distance-to-agreement and 4.07% dose-difference. [21-23] TrueBeam STx linear accelerator from Varian Medical Systems (Palo Alto, CA, USA) equipped with high-definition multileaf collimator (HD-MLC), which uses 32 central 2.5 mm-width leaves and 28 outer 5 mm-width leaves on each MLC bank (widths projected to isocenter). AlignRT features an automatic beam-hold capability that activates when patient movements or rotations exceed a threshold of 3 mm in any direction. In such instances, the system automatically interrupts the beam to ensure precise and accurate radiation delivery. All patients were treated with Dual Arc Volumetric Modulated Arc Therapy (VMAT). Patient specific QA for VMAT plans was performed using Varian’s Portal Dosimetry.

In our retrospective analysis using the treatment planning system, we evaluated portal dosimetry results for both Arc 1 and Arc 2 treatment fields. For each arc, we assessed whether the delivered plan met the gamma index criteria (3%, 3 mm). Subsequently, we introduced induced shifts of 3 mm, 5 mm, and 7 mm—derived from SGRT real-time monitoring—applied either laterally or longitudinally during treatment delivery. It's essential to highlight that these shifts were induced artificially, and during actual treatment, the automatic beam hold activates when patient movements exceed 3 mm. After applying these induced shifts, we recalculated the portal dosimetry to determine if the planned gamma index criteria were still satisfied.

3. Results

A total of 18 patients were included in the study. Patient characteristics are described in Table 1. In terms of lateral shift, the median Planned Gamma Index value was 98.15, while 3mm was 94.50, 5mm was 86.80 and 7mm was 82.15 for field 1. Explain gamma index. Normality of the data was tested using the Shapiro-Wilk test. A Wilcoxon signed-rank test showed that there was a significant difference between the Planned Gamma Index and 3 mm (p-value = 0.000). Also, there was a significant difference between the Planned Gamma Index and 5 mm (p-value = 0.000). There was a significant difference between the Planned Gamma Index and 7 mm (p-value = 0.000). The median Planned Gamma Index value was 97.90, while 3mm was 92.80, 5mm was 85.85 and 7mm was 81.30 for field 2. A Wilcoxon signed-rank test showed that there was a significant difference between the Planned Gamma Index and 3 mm (p-value = 0.000). Also, there was a significant difference between the Planned Gamma Index and 5 mm (p-value = 0.000). There was a significant difference between the Planned Gamma Index and 7 mm (p-value = 0.000). [Table 2]

Table 1. *Patient Characteristics.*

Sr. No	Age	Diagnosis	Site
1	3	Embryonal Rhabdomyosarcoma Forearm with D2 Spine metastasis	Spine + Forearm
2	2	Right Neuroblastoma	Abdomen + Pelvis
3	14	Classic Hodgkins Lymphoma of Mediastinum	Thorax
4	3	Mediastinal Neuroblastoma	Abdomen
5	2	High Grade Non-Infantile Left Neuroblastoma	Abdomen + Pelvis
6	4	Metastatic Neuroblastoma	Abdomen
7	4	Wilms Tumor for Lung Bath	Thorax
8	3	Wilms Tumor for Lung Bath	Thorax
9	2	Retroperitoneal PNET	Abdomen + Pelvis
10	8	Ewings Sarcoma Left Pelvic Bone with Lung Metastasis	Thorax + Pelvis
11	9	Ewing's Sarcoma	Abdomen
12	9	Ewing's Sarcoma	Thorax
13	9	Classical Hodgkin's Lymphoma	Neck
14	6	Pelvic Embryonal Rhabdomyosarcoma	Pelvis
15	2	Metastatic Germ Cell Tumor	Pelvis
16	6	Wilm's tumor	Abdomen + Pelvis
17	4	Neuroblastoma	Abdomen+ Pelvis
18	1	Wilm's tumor	Abdomen

Table 2. *Lateral shift.*

Variable	Frequency	Mean	SD	p50	IQR	p-value
Arc 1						
Planned Gamma Index	18	97.82	1.59	98.15	2.80	
3mm	18	91.28	9.25	94.50	5.70	0.000
5 mm	18	79.22	16.95	86.80	13.80	0.000
7 mm	18	73.22	20.61	82.15	18.20	0.000
Arc 2						

Variable	Frequency	Mean	SD	p50	IQR	p-value
Planned Gamma Index	18	97.69	1.52	97.90	2.50	
3mm	18	90.58	6.99	92.80	3.90	0.000
5 mm	18	78.68	15.08	85.85	21.10	0.000
7 mm	18	72.55	18.61	81.30	26.20	0.000

Table 3. *Longitudinal shift.*

Variable	Frequency	Mean	SD	p50	IQR	p-value
Arc 1						
Planned Gamma Index	18	97.82	1.59	98.15	2.80	
3mm	18	90.61	6.59	93.60	8.70	0.000
5 mm	18	81.05	13.01	86.20	13.30	0.000
7 mm	18	75.48	16.51	82.35	14.40	0.000
Arc 2						
Planned Gamma Index	18	97.69	1.52	97.90	2.50	
3mm	18	91.29	5.79	92.65	7.40	0.000
5 mm	18	81.54	11.44	87.15	8.60	0.000
7 mm	18	75.87	14.95	82.90	9.70	0.000

The median Planned Gamma Index value was 98.15, while 3mm was 93.60, 5mm was 86.20 and 7mm was 82.35 for arc 2. Normality of the data was tested using the Shapiro-Wilk test. A Wilcoxon signed-rank test showed that there was a significant difference between the Planned Gamma Index and 3 mm (p-value = 0.000). Also, there was a significant difference between the Planned Gamma Index and 5 mm (p-value = 0.000). There was a significant difference between the Planned Gamma Index and 7 mm (p-value = 0.000). The median Planned Gamma Index value was 97.90, while 3mm was 92.65, 5mm was 87.15 and 7mm was 82.90 for field 2. A Wilcoxon signed-rank test showed that there was a significant difference between the Planned Gamma Index and 3 mm (p-value = 0.000). Also, there was a significant difference between the Planned Gamma Index and 5 mm (p-value = 0.000). There was a significant difference between the Planned Gamma Index and 7 mm (p-value = 0.000). [Table 3]

4. Discussion

Intra-fraction monitoring of paediatric treatments using SGRT is not extensively adopted, and there is limited literature available on the subject. [19]

In a documented case where SGRT was employed in conjunction with a linear accelerator operating in the Flattening Filter-Free (FFF) mode, the case involved palliative radiation treatment for an 18-month-old boy experiencing a recurrence of Wilms tumor. The child presented with a substantial anterior mediastinal mass causing a critical obstruction in the airway. Notably, the use of SGRT allowed for the administration of the treatment in a brief duration without the need for anesthesia. [24]

Arthur J Olch et. al at Children's Hospital, Los Angeles specialized in the exclusive treatment of children, adolescents, and young adults using SGRT at their setup. SGRT provides real-time information on the alignment between the patient's pose at treatment setup and simulation, enabling correction of setup errors before acquiring X-ray-based setup verification images in image-guided radiation therapy (IGRT). This capability reduces the use of ionizing radiation for patient positioning and minimizes setup and imaging time. Specifically, SGRT's ability to detect translational and rotational shifts proves more beneficial for treating long segments of the spine compared to reliance solely on skin marks. SGRT facilitates rapid adjustments in multiple directions, such as correcting lateral position, pitch, and roll simultaneously, which is challenging with external lasers and skin marks alone. Prior to using SGRT, maintaining skin marks on children throughout treatment was problematic. Permanent markers and transparent medical dressings were used, but challenges arose due to factors like sweating, vigorous play, bathing, and fading, leading to mark loss. SGRT

eliminates the stress and difficulties associated with skin marks for both patients and staff. Without SGRT, treatment staff relies on closed-circuit television images, with manual interruption required if movement is detected during treatment. SGRT's direct hardware interface with the linear accelerator allows automatic pausing when movement exceeds predefined thresholds, providing confidence in correct treatment positioning. With SGRT monitoring, at their centre children as young as 4 years old could be treated without anaesthesia, as the system automatically detects and adjusts for movement within set tolerances. Real-time intra-fraction monitoring with SGRT enables safe and efficient treatment, even in palliative cases where anaesthesia is not ideal, allowing treatment for young patients with large mediastinal masses who would not have been candidates otherwise. [25]

5. Conclusion

In conclusion, SGRT offers a comprehensive array of benefits for paediatric cases. Notably, SGRT excels in real-time monitoring and detecting intrafraction motion during paediatric treatment. It enables safe and precise treatment without additional radiation exposure, no tattooing, boasts a high-resolution 3D topographic imaging system, and offers a large field of view with excellent immobilization verification accuracy. Additionally, SGRT seamlessly integrates with IGRT, reducing setup time in pediatric patients, enhancing workflow consistency, and minimizing operator variability.

Abbreviations

SGRT	Surface Guided Radiation Therapy
AAPM TG-75	The American Association of Physicists in Medicine Task Group - 75
PTV	Planning Target Volume
IMRT	Intensity Modulated Radiation Therapy
QA	Quality Assurance
HD-MLC	High-Definition Multileaf Collimator
VMAT	Volumetric Modulated Arc Therapy
FFF	Flattening Filter Free
IGRT	Image Guided Radiation Therapy

Author Contributions

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Ethics Statement

Our study didn't involve humans or animals and didn't require ethics approval.

Conflicts of Interest

The authors declare no conflicts of interests.

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