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Volume difference between Internal Target Volume (ITV) and Deformable Image Registration (DIR_ITV): A comparative analysis

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ABSTRACT

This study investigates the essential role of Radiation Therapy Quality Assurance (RTQA) procedures in modern radiotherapy treatments, particularly focusing on Stereotactic Body Radiation Therapy (SBRT) for centrally located lung malignancies. This study aims to compare the effectiveness of three commonly used metrics DSC (Dice Similarity Coefficient), GMI (Geometric Miss Index), and DI (Discordance Index) in assessing patients with specify condition/population. We focus on three key aspects: the Initial Tumor Volume (ITV) as delineated at 0 of the prescribed dose (ITV_0% P_DIR), 50% of the prescribed dose (ITV_50% P_DIR), and Maximum Intensity Projection (ITV_MIP). The analysis reveals significant differences among the metrics in evaluating tumor characteristics at different dose levels and imaging perspectives. Notably, DSC provided distinct insights into tumor perfusion dynamics, particularly evident in the delineation of ITV_0 P_DIR and ITV_50% P_DIR. GMI exhibited strengths in capturing subtle variations in tumor morphology, with ITV_0 P_DIR comparisons showing its utility. DI has turned out to be a valuable tool in delineating spatial heterogeneity, with significant findings observed between ITV_50% P_DIR and ITV_MIP. These findings underscore the importance of selecting appropriate metrics tailored to the specific diagnostic or prognostic objectives in patients with specify condition/population.

Keywords: Stereotactic Body Radiotherapy (SBRT), Dice Similarity Coefficient (DSC), Geographical Miss Index (GMI) and Discordance Index (DI), Four-Dimensional Computed Tomography (4DCT) images

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INTRODUCTION

Stereotactic Body Radiation Therapy (SBRT) is the best treatment for lung ablative treatment in non-invasive procedures with minimal clinical management by the physicians. For the SBRT treatments, the patient selection criteria are critical. The SABR UK consortium has recommended protocols for SBRT treatment, which take into account the tumor size and location and determine the prescription radiation dose [1]. ICRU-62 recommends Internal Target Volume (ITV) accounting for the motion encompassing the CTV that varies in position, shape, and size [2-4]. Compared with generalized PTV, it decreased the high-dose therapy's Planning Target Volume (PTV). Given the inherent dynamics of lung movements, which are involuntary and influenced by factors such as tumor location, displacement, and deformation during natural breathing. It influences motion from 1 mm to more than 2 cm, as explained and reported by most authors, along with organs, liver, pancreas, and kidneys, prostate [5, 6].

The breathing motion patterns are involved with variation in the amplitude of the chest, breathing period, and variability in repeatability of the breathing pattern of the individual patients during imaging and treatment sessions, as discussed by many authors, along with the advice to the patients and audio-video communication to improve the respiratory imaging protocol session and treatment session [7-10]. The parameters mentioned earlier result in image artifacts, blurring images and missing or overextended information of organs and incorrect position and volumetric information of tumors image artifacts, ring simulation image during acquisition session and treatment session in free breath condition of the patients [11, 12]. For overcoming the organ motion and other influences induced image artifacts and degradation in image quality issues, proposed many of the motion management technical solution approaches were proposed such as external surrogate tracking methods using Infra-Red (IR) reflector, IR illuminator placed over the vest of the patient, pressure sensing Ansi belts, etc [12].

Accurate delineation of target volumes is a cornerstone in radiation oncology treatment planning, ensuring optimal therapeutic outcomes while minimizing the risk of complications. In this work, Internal Target Volume (ITV) and Deformable Image Registration Internal Target Volume (DIR_ITV) are two pivotal concepts that play crucial roles in accommodating anatomical variations and ensuring target coverage throughout the treatment process.

ITV delineates the volume of tissue that encompasses the target area over the entirety of the breathing cycle, accounting for physiological motion such as respiration and cardiac activity. This dynamic representation of the target volume is essential for compensating for motion-induced uncertainties during treatment delivery. On the other hand, DIR_ITV facilitates the alignment of images acquired at different time points or under varying physiological conditions by incorporating deformable transformations. By capturing anatomical deformations, DIR_ITV provides insights into the spatial changes within the patient's anatomy, aiding in treatment planning and evaluation.

While both ITV and DIR_ITV serve indispensable roles in radiation therapy planning, disparities often exist between the volumes delineated by these methods. Understanding the nature and extent of these volume differences is crucial for optimizing treatment strategies and ensuring precise radiation delivery. Therefore, this comparative analysis aims to elucidate the factors contributing to the volume disparities between ITV and DIR_ITV, shedding light on their clinical implications.

Through a comprehensive examination of respiratory motion, anatomical deformations, image registration accuracy, and spatial resolution, this analysis seeks to provide insights into the mechanisms underlying the volume differences observed between ITV and DIR_ITV. By delineating the intricacies of these factors, clinicians can enhance their understanding of treatment planning uncertainties and refine their strategies to achieve improved treatment outcomes.

In summary, this comparative analysis serves as a critical exploration of the volume differences between ITV and DIR_ITV, offering valuable insights into their implications for radiation oncology practice. By elucidating the factors influencing these disparities, this study aims to inform clinical decision-making and foster advancements in treatment precision and efficacy.

MATERIAL AND METHOD

The volume difference between ITV and DIR_ITV is an important consideration in radiation oncology treatment planning.

Internal Target Volume (ITV)

ITV represents the volume of tissue that encompasses the target area within the patient during the entire breathing cycle. It takes into account the motion of the target due to respiration, cardiac activity, or other physiological factors. ITV is typically delineated based on various imaging modalities such as CT scans acquired at different phases of the respiratory cycle or 4D CT scans.

Deformable Image Registration Internal Volume (DIR_ITV)

DIR_ITV is a computational technique used to align medical images acquired at different times or under different conditions. It allows for the mapping of structures and tissues from one image to another, considering the deformations that may have occurred between the acquisitions. This is particularly useful in radiation therapy planning when merging images from different modalities or different stages of treatment.

Sample dataset

In this retrospective analysis, a cohort of 38 patients who underwent 4DCT scans as part of their radiation treatment was selected. The scans were performed using Varian machines, specifically Novalis Tx and True Beam STx, with SBRT administered using Volumetric Modulated Arc Therapy treatment delivery (RapidArc). The consulting physician manually delineated both the Internal Target Volume (ITV) and Planning Target Volume (PTV) [13-17]. Table 1 presents the patient dataset along with the manually delineated ITV and PTV on average CT scan.

Tab. 1. Shows that the patient's dataset

Site	Side	Prescribed Dose/ No of Fractions	Treatment Percentage (%)	Manually Drawn PTV in Ave. CT	Manually Drawn ITV in Ave. CT	Manually Drawn ITV in MIP CT
LLUP	LT	60/8	80%	75.4	31	33.5
RSP	RT	60/8	78%	58.8	23.1	19.8
RSLP	RT	60/8	81%	10.43	1.74	1.7
LLM	LT	60/8	80%	86.9	41.3	39.33
LMS	LT	60/5	80%	44.1	17.5	16.1
RMP	RT	60/8	81%	39.9	15.3	15.3
RSA	RT	60/8	80%	18	4.9	27
RMM	RT	60/8	76%	64.2	27	16.8
LMA	LT	60/8	75%	86.9	41.3	16.7
LIPO	LT	60/5	100%	58	0.7	18.2
RLP	RT	55/5	100%	61.3	3.9	22.9
RLP	RT	55/6	78.6%	33.9	54.7	11.6
LSA	LT	60/8	78%	62.3	32.5	25.4
LMA	LT	60/8	90.2%	16.7	9.6	3.9
RLI	RT	55/5	80.5%	115.8	4	54.7
RSA	RT	55/5	79.8%	72.4	9.4	32.5

RMM	RT	60/8	82%	29.3	18.7	9.6
LMM	LT	60/8	82.2%	14.6	2.4	4
RPS	RT	60/8	81.5%	27	31.5	9.4
RPM	RT	60/8	80%	50.1	7.8	18.7
RMA	RT	54/3	81.3%	11.2	8	2.4
RAI	RT	60/8	81.7%	78.5	4.1	31.5
LMM	LT	60/8	78.9%	24.2	25.4	7.8
RPM	LT	54/3	81.6%	27.7	37.9	8
LSP	RT	60/5	85.1%	14.6	15.8	4.1
LLM	RT	60/8	80.6%	64	0.5	25.4
RMM	RT	60/5	82.8%	76	30.5	37.9
RMP	RT	54/3	82.8%	42.8	3.5	15.8
RSP	RT	55/5	83.9%	4.7	38.4	0.5
RPM	RT	60/5	85%	71.1	3.3	30.5
LPS	LT	60/8	78.5%	90.8	12.7	38.4
RLM	LT	60/8	87%	14	27	3.3
LPS	LT	55/5	80%	28.9	2	9.5
RSS	LT	60/5	78%	38	15.1	12.7
RMM	RT	60/5	83%	59.6	14.1	27
RPM	RT	55/5	82.4%	9.9	6.9	2
LML	LT	60/5	80.9%	39.4	15.1	15.1
LLMS	LT	60/5	78.3%	38.6	14.1	14.1

Clinical evaluation for patient's data

For this retrospective study, 38 lung cancer patients who underwent 4DCT scans for radiotherapy treatment were selected. These patients received Stereotactic Body Radiation Therapy (SBRT) administered via Volumetric Modulated Arc Therapy (RapidArc) using Varian machines, specifically the Novalis Tx and True Beam STx. Physicians contoured the patients using the Maximum Intensity Projection (MIP) series to delineate Maximum Intensity Projection Internal Target Volume (ITV_MIP) as the standard treatment protocol. The ITV_MIP contours were meticulously verified using a 10-phase series for treatment planning, and the Planning Target Volume (PTV) was subsequently expanded isotropically by 5 mm [14]. The ITV and PTV, along with contours of organs at risk, were migrated to the Average Intensity Projection (AVG IP) series for treatment planning. Doses for all patients were prescribed within the ranges of 60 Gy in 5 fractions and 8 fractions, 54 Gy in 3 fractions, 52 Gy in 8 fractions, 55 Gy in 5 fractions, and 48 Gy in 6 fractions [15].

Experimental 4DCT data model

During the patient's free breathing, the total motion of the breathing cycle was captured using axial 4 DCT scans facilitated by the Real-time Position Management (RPM) V1.7 MR2 IR video-based Systems. This system utilized an IR reflector external surrogate to track the lung tumor's motion during free-breath scans. A six-dot domino pattern IR reflector box was placed on the patient's abdominal surface area and traced by an IR camera. Within this setup, an acrylic insert containing derlin material inserts with diameters of 2 cm and 1 cm and a 3 cm × 3 cm × 3 cm cube represented the tumor motion. Additionally, a quasar motion programmed phantom was used with a programmed breathing rate of five Breaths per Minute (BPM) and 1 cm vertical displacement for the surrogate placed over a breathing motion platform [14, 15].

For the analysis, a 4 DCT scan was performed on the phantom with the RPM camera and CT machine, with settings determined based on the measured or read breathing period displayed every 5 seconds in the RPM Varian system [16]. The 4 DCT scan was conducted under various linear displacement platform settings: 0 mm (0 mm+0 mm) for static as a baseline, 4 mm (2 mm+2 mm), 6 mm (3 mm+3 mm), 8 mm (4 mm+4 mm), and 10 mm (5 mm+5 mm) longitudinal displacement distances for the moving acrylic phantom.

The scanned 4DCT images were divided into 10 phase bins ranging from 0 to 90% phases, resulting in 10 unique series. Additionally, Maximum Intensity Projection (MIP), Average Intensity Projection (AIP), and Minimum Intensity Projection (Min-IP) CT image series were generated [17]. Ten binned CT images and three derived series were then transferred to Eclipse Varian for further processing.

The Internal Target Volume (ITV) was delineated using the MIP series set in the lung contrast window width within the contouring module of Eclipse V15.1. The Average Intensity Projection (AIP) image set was utilized to adjust the ITV contour for subsequent dose calculation and dosimetry requirements figure 1.

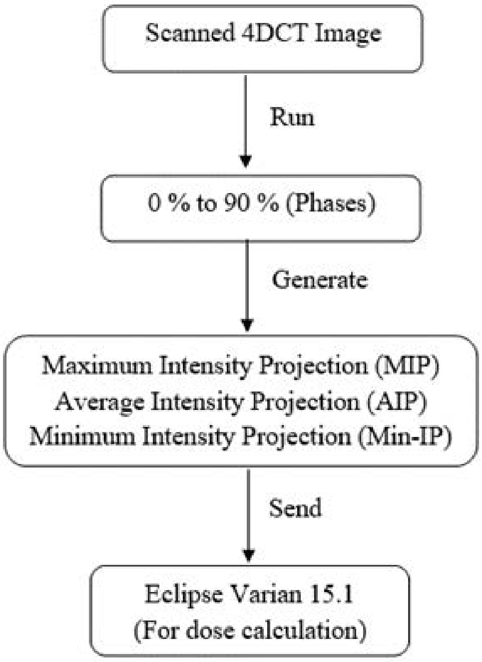


Fig. 1. Flowchart for performance of 4DCT scan analysis

The Internal Target Volume (ITV) was generated by combining the three derived series, followed by examination of the remaining nine phases to ensure continuous coverage of the tumor within the ITV. The baseline Gross Tumor Volume (GTV) was determined and propagated to the other nine phases for consistency [18, 19]. A comparison was made between the manually drawn MIP volume ITV and the ITV MIP propagated and merged using all 10 phases based on MIP CT. The Deformable Image Registration software utilized a modified accelerated demons algorithm to propagate the ITV, resulting in the creation of iGTV_MIP across all 10 phases with the baseline of manual MIP contour. The ITV_MIP_DIR contour was merged using the 'copy Accumulated Structures to Image' option in the 4D module.

Baseline GTV (Gross Tumor Volume):

This is the visible extent of the tumor as seen in medical imaging. In our case, it is delineated (outlined) at two specific points in the breathing cycle: at the end of exhale (0 phase) and at the end of inhale (50% phase).

DIR (Deformable Image Registration):

This is a technique used in medical imaging to align images taken at different times or under different conditions. In radiation therapy, it is often used to propagate contours drawn on one phase (e.g., 0 or 50% phase) to other phases, considering the deformations caused by physiological motion, such as breathing.

ITV (Internal Target Volume):

This represents the volume encompassing the tumor's motion due to breathing or other physiological processes. ITV_0 P_DIR and ITV_50% P_DIR are ITV volumes derived from the baseline GTV at 0 and 50% phases, respectively, using deformable image registration.

The comparison between the manual ITV (MIP volume) and the ITV volumes derived from DIR at 0 and 50% phases

- DSC- Measures how well the ITV volumes derived from DIR overlap with the manual ITV. Higher values indicate better agreement.
- GMI- Compares the sizes of the volumes. Ideally, GMI should be close to 1, indicating similar volumes.
- DI- Similar to DSC, it measures the overlap. Higher values indicate better agreement.

Comparison between ITV_0 P_DIR and ITV_50% P_DIR

- DSC, GMI, and DI would also be calculated here to assess the similarity between the ITV volumes derived from different phases.
- Differences in DSC, GMI, and DI values would indicate how much the tumor's motion affects the delineation of the ITV.

Overall, these comparisons provide insights into the accuracy and consistency of the ITV delineation process, considering both manual delineation and automated methods using deformable image registration and how tumor motion impacts the delineated volumes.

Analysing Gross Tumor Volume (GTV) in various shifts is crucial for understanding how it behaves or changes over time, which can suggest treatment planning and evaluation. For example, limitations could include small sample size, variability in measurement techniques, or the potential for measurement error shown in table 2.

Tab. 2. Analysis of the gross tumor volume in various shifts

	0 + 0 Shift			2 mm+2 mm Shift			3 mm+3 mm Shift			4 mm+4 mm Shift			5 mm+5 mm Shift		
Pinned % of phase	**ITV 2 cm sphere**	**ITV 1 cm sphere**	**ITV 3×3 cube**	**ITV 2 cm sphere**	**ITV 1 cm sphere**	**ITV 3×3 cube**	**ITV 2 cm sphere**	**ITV 1 cm sphere**	**ITV 3×3 cube**	**ITV 2 cm sphere**	**ITV 1 cm sphere**	**ITV 3×3 cube**	**ITV 2 cm sphere**	**ITV 1 cm sphere**	**ITV 3×3 cube**
0	6.6	0.9	22.6	7.8	1.2	27.1	4.9	0.7	25.9	7.7	1.3	40.7	8.1	1.4	41.9
10	6.5	1	34.5	7.8	1.2	39.6	4.9	0.7	38.3	8.2	1.3	41.6	7.8	1.4	41.9
20	6.5	1	34.5	7.8	1.3	27.5	4.9	0.8	28	8.6	1.5	29.4	8.4	1.5	42.2
30	6.6	1	22.4	7.9	1.3	26.6	5.1	0.8	31.2	5.2	0.7	29.1	8.7	1.5	41.4
40	6.7	1	34.1	7.9	1.1	27.6	5.4	0.9	27.7	5.3	0.7	29.5	9	1.5	44.5
50	6.7	0.9	33.6	9.1	1.1	27.8	5.4	0.8	31.7	8.2	1.4	41.8	8.4	1.4	43.4
60	6.6	0.9	22.4	7.9	1.1	28.1	5.5	0.8	36.5	5.1	0.6	29.8	8.5	1.3	44.3
70	6.5	0.9	22.3	8.1	1.2	27.6	5.2	0.8	27.9	4.9	0.7	28.9	8.8	1.4	43.5
80	6.5	0.9	22.3	8	1.2	27.6	5	0.8	27	7.9	1.4	39.5	8.5	1.5	42.5
90	6.4	1	34.6	7.8	1.3	38.5	4.9	0.8	37.2	7.9	1.4	40.5	8.6	1.5	41.2
Min	3.6	0.3	22.3	8.1	1.2	25.8	5.9	0.8	24.3	5.9	0.7	45.3	9.2	1.4	42.4
Planned_AVG	4.6	0.6	31.3	5.6	0.8	35.4	6.4	1.1	35.4	6.7	1.1	37.2	7.1	1.2	38.7
Planned_MIP	4.6	0.6	31.3	5.6	0.8	35.4	6.4	1.1	35.4	6.7	1.1	37.2	7.1	1.2	38.7
ITV_AVG CT planned	4.6	0.6	31.3	5.6	0.8	35.4	6.4	1.1	35.4	6.7	1.1	37.2	7.1	1.2	38.7
ITV_MIP CT planned	4.6	0.6	31.3	5.6	0.8	35.4	6.4	1.1	35.4	6.7	1.1	37.2	7.1	1.2	38.7
ITVAcc_DIR_ITV	7.2	1.1	35.5	9.6	1.7	41.3	6.7	1.2	42.5	10.1	2	46.9	11.3	2.3	49.9

Statistical analysis

For statistical analysis, we employ the volume values in the Dice Similarity Coefficient (DSC), Geographical Miss Index (GMI), and Discordance Index (DI).

Dice Similarity Coefficient (DSC)

The Dice Similarity coefficient (DSC) is a statistical measure of the similarity between the manually generated tumor volume and automated DIR_ITV in each of the phases. It indicates the overall agreement between the two volumes [20-23]. Following is a definition of the dice coefficient:

$$Dice\ Similarity\ Coefficient(DSI) = 2x\,\frac{(A \cap B)}{(A+B)}$$

Then contrast the outline produced by the technique with the manual contour created by a qualified doctor, and we compare the two sets A and B. A value of 1 indicates that the manual and analytic contours entirely coincide.

Geographical Miss Index (GMI)

Geographical Miss Index (GMI) defines the "ITV manual (reference volume) missed by the automated generated DIR_ITV volume (evaluation volume) as a fraction of the ITV manual volume. A GMI of 0 represents no miss, whereas a GMI of 1 represents that the entire ITV manual volume (reference volume) has been missed by the automated generated DIR_ITV volume (evaluation volume)".

$$Gepgraphical\ Miss\ Index(GMI) = B - \frac{(A \cap B)}{B}$$

Discordance Index (DI)

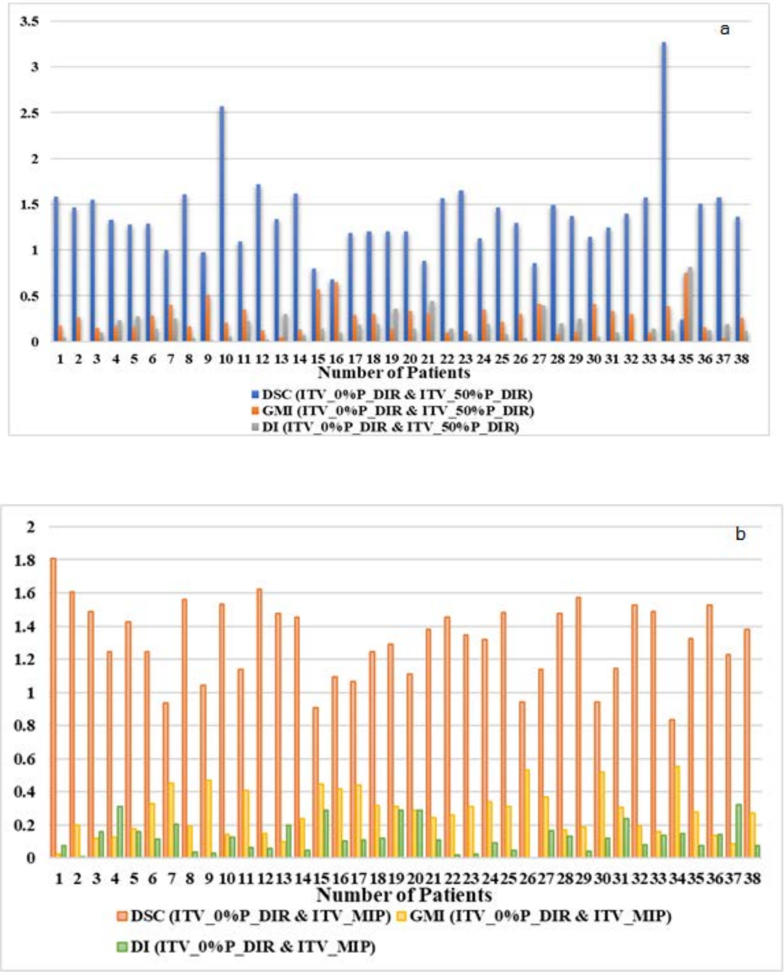
On the other hand, we defined "discordance" as the case when the results of the two contrasted approaches for the index under study were inconsistent. As a result, we counted both the false positive and false negative indices as "discordance." For "not-diagnostic" indices, we define "apparent advantage of MIP-CT" if the index was regarded "diagnostic" with MIP-CT but "not-diagnostic" with standard index, and "missense of MIP-CT" if the index was declared "not-diagnostic" with MIP-CT but "diagnostic" with ordinary index.

$$Discordance\ Index\ \ (DI) = 1 - \frac{(A \cap B)}{A}$$

RESULT AND DISCUSSION

Comparison between DSC, GMI and DI

A higher DSC and lower GMI and DI values indicate better agreement between the volumes being compared. If DSC is high and GMI/DI is low, it suggests good agreement in both volume and spatial distribution. Deviations from these expectations might indicate variability in tumor motion or inaccuracies in image registration (Figure 2).



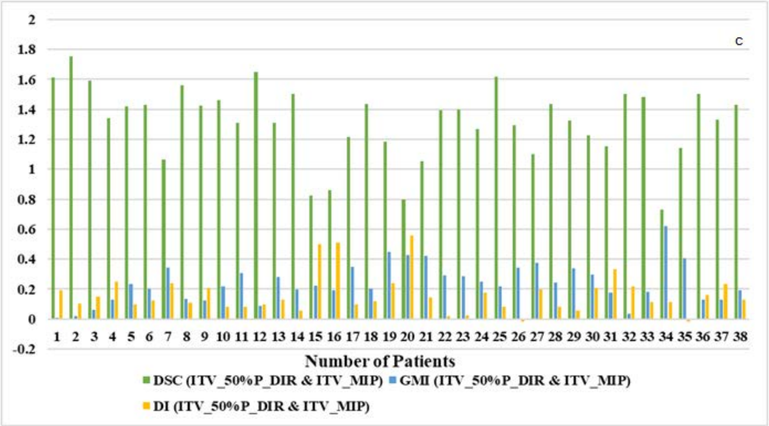


Fig. 2. Comparison between DSC, GMI and DI on patients **a.** ITV_0 P_DIR & ITV_50% P_DIR **b.** ITV_0 P_DIR and ITV_MIP **c.** ITV_50% P_DIR and ITV_MIP

Clinically, understanding these metrics helps in assessing the reliability of different imaging techniques for target delineation and treatment planning in SBRT, aiding in optimizing treatment accuracy and efficacy. This comparison provides valuable insights into the consistency and accuracy of target volumes delineated using different imaging modalities and at different phases of the respiratory cycle, which is (to be added) crucial for effective SBRT treatment planning and delivery.

Dice similarity coefficient measures the overlap between two volumes. A higher DSC indicates better agreement or overlap between ITV_0 P_DIR and ITV_50% P_DIR in the phantom study. Geometric miss index calculates the geometric miss of the relative volume differences between the two volumes. A lower GMI suggests less volume difference between ITV_0 P_DIR and ITV_50% P_DIR. The discordance index measures the average distance between the surfaces of the two volumes. A lower DI indicates less difference in spatial distribution between ITV_0 P_DIR and ITV_50% P_DIR shown in figure 3.

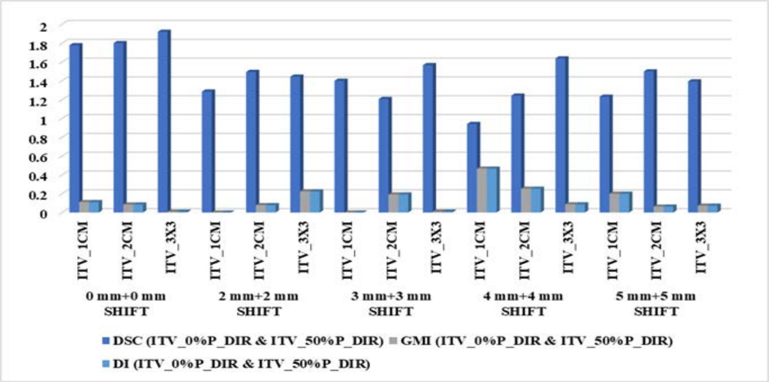


Fig. 3. Comparison between DSC, GMI and DI on phantom study ITV_0 P_DIR and ITV_50% P_DIR

The figure 4 comparison involves the Internal Target Volume (ITV) delineated based on the physician's guidance (ITV_P) and the ITV delineated with accumulated data from DSC (ITV_Acc DIR_DSI). This comparison could reveal how well the accumulated data matches with the physician-guided delineation. Similarly, this comparison involves the Planning Target Volume (PTV) delineated based on the physician's guidance (PTV_P) and the PTV delineated with accumulated data from DSC (PTV_Acc DIR_DSI). It assesses the agreement between the planned target volume and the accumulated dose. This comparison seems to involve the agreement between the physician-guided PTV and the ITV delineated with accumulated data from DSC. It may highlight any discrepancies between the planned target volume and the accumulated ITV.

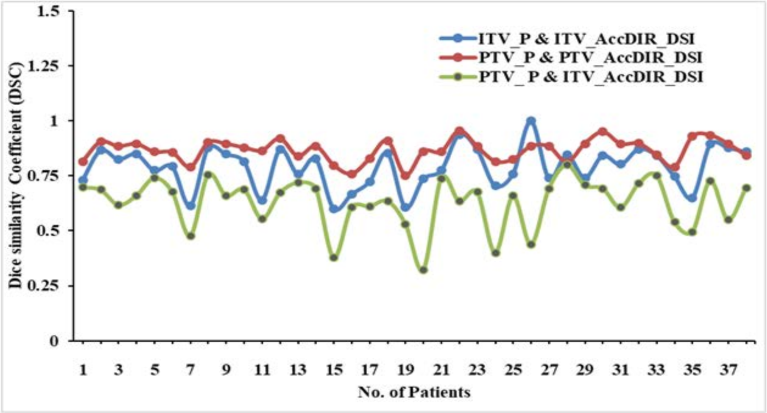


Fig. 4. Shows that the dice similarity coefficients

From the figure 5 comparisons likely involves the Geographical Miss Index between the Internal Target Volume delineated by the physician (ITV_P) and the ITV delineated with accumulated data from GMI (ITV_Acc DIR_GMI). This comparison aims to assess the spatial deviation or miss between the physician-guided ITV and the accumulated ITV. Similarly, this comparison involves the Geographical Miss Index between the Planning Target Volume delineated by the physician (PTV_P), and the PTV delineated with accumulated data from GMI (PTV_Acc DIR_GMI). It evaluates the spatial deviation between the planned PTV and the accumulated PTV. This comparison assesses the Geographical Miss Index between the physician-guided PTV and the ITV delineated with accumulated data from GMI. It looks at the spatial deviation between the planned target volume and the accumulated ITV.

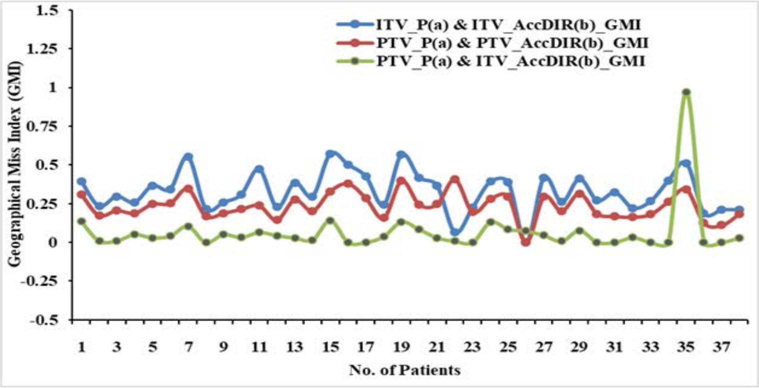


Fig. 5. Shows that the geographical miss index

From the figure 6, this is a metric used in radiation therapy planning to evaluate the agreement or discordance between different treatment plans or structures. It helps assess how similar or dissimilar the two plans are in terms of target coverage and dose distribution. This refers to the Internal Target Volume (ITV) for the planning phase (a). ITV represents the Clinical Target Volume (CTV) plus a margin to account for internal motion and setup uncertainty. This seems to indicate the Discordance Index for the ITV when using accumulated dose deformation image registration (ITVAccDIR) for phase (a). ITVAccDIR is a technique used to incorporate changes in anatomy over the course of treatment into the treatment planning process. Planning Target Volume (PTV) for phase (a). PTV includes the ITV plus additional margins for setup uncertainty and internal motion. This indicates the Discordance Index for the PTV when using PTVAccDIR for phase (a), similar to the ITV_AccDIR(a)_DI but for the PTV.

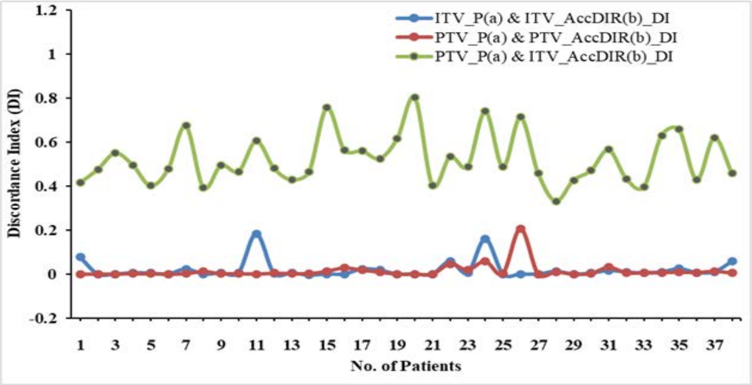


Fig. 6. Shows that the Discordance Index

From the figures 4-6, in the context of SBRT, where precision and accuracy are paramount due to the high doses per fraction and steep dose gradients, analyzing DSC and GMI values can provide valuable insights into treatment quality and efficacy. These metrics help evaluate the adequacy of treatment planning and delivery processes, highlighting areas for improvement to optimize patient outcomes while minimizing potential side effects.

For instance, if DSC values are consistently high and GMI values are low across a cohort of patients, it suggests that the treatment planning and delivery techniques are effectively targeting the intended areas while minimizing geographic misses. Conversely, if DSC values are low or if GMI values are high, it indicates a need for further investigation into potential causes such as inaccuracies in target delineation, patient motion during treatment, or limitations in treatment delivery systems.

ITV:

This represents a static volume that encompasses the motion of the target over the respiratory cycle, but it is essentially a fusion of delineated volumes from different phases.

DIR_ITV:

Provides a more dynamic representation of the target volume, accounting for deformation and displacement throughout the respiratory cycle, potentially capturing a more accurate representation of the target volume's shape and position.

In summary of figure 7, while both ITV and DIR_ITV are used to account for motion in radiation therapy planning using 4DCT, the key difference lies in how they handle the representation of the target volume over time. ITV is static and represents a fusion of delineated volumes, while DIR_ITV is dynamic, incorporating deformable image registration to model the target volume's motion.

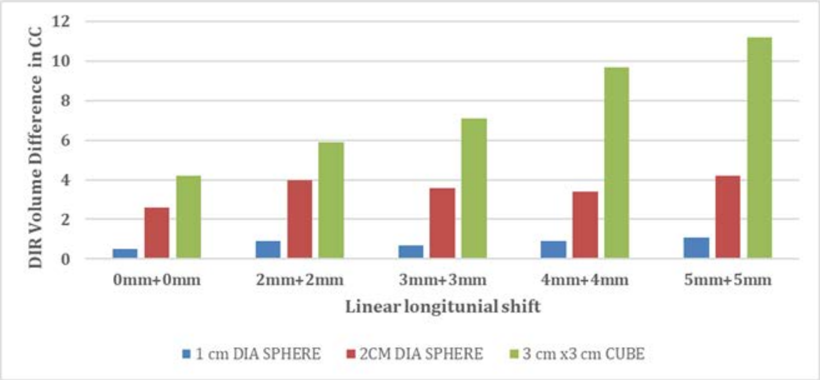


Fig. 7. Results of the volume difference of ITV vs DIR_ITV

The use of DIR_ITV registration between the 4DCT component phase images facilitates the extraction of motion and physiological data, such as heart wall motion or breathing patterns. Compared to 3D technology, employing 4DCT can reduce the expansion from Internal Target Volume (ITV) to Planning Target Volume (PTV), thereby minimizing the dosage delivered to normal tissues and allowing for prescription dose escalation [24]. However, contouring all 10 phases (0 to 90%) can significantly prolong the contouring process, presenting practical challenges and requiring different contouring techniques for each phase.

In cases where a contrast medium is utilized in 4 DCT, managing the timing of contrast injection is more challenging compared to 3D planning. Additionally, contrast distribution may be suboptimal, and delineating mediastinal lymph nodes can become more challenging [25].

High DSC values indicate strong agreement and overlap between ITV_0 P_DIR and ITV_50% P_DIR in the phantom study, suggesting accurate delineation of the target volume across different phases of the respiratory cycle. Low GMI values imply minimal volume differences between ITV_0 P_DIR and ITV_50% P_DIR, further supporting the consistency of target volume delineation. Low DI values indicate minimal spatial distribution differences between ITV_0 P_DIR and ITV_50% P_DIR, indicating that the location and shape of the target volume are consistent across different phases of the respiratory cycle. Consistent and accurate delineation of target volumes across respiratory phases is crucial for SBRT treatment planning, as it ensures that the tumor receives the intended radiation dose regardless of respiratory motion.

Any discrepancies observed in DSC, GMI, and DI values may indicate limitations or inaccuracies in the imaging or registration techniques used for target volume delineation, highlighting areas for improvement in the SBRT treatment planning process.

Overall, the comparison of DSC, GMI, and DI values provides valuable insights into the accuracy and consistency of target volume delineation in SBRT phantom studies, helping to optimize treatment-planning techniques and ensure effective delivery of radiation therapy.

Volume differences

ITV represents the target volume considering motion, while DIR_ITV accounts for deformations in the anatomy. The volume difference between ITV and DIR_ITV can occur due to several factors:

Respiration and motion:

ITV typically encompasses the target volume during the entire breathing cycle, while DIR_ITV may align images acquired at different phases of respiration. Therefore, the volume difference may arise from the motion of the target during breathing.

Deformations:

DIR_ITV accounts for deformations in the anatomy, which may not be fully captured in ITV delineation. These deformations can occur due to factors such as changes in organ shape, position, or volume over time. Consequently, the volume difference between ITV and DIR_ITV may reflect these anatomical changes.

Image Registration Accuracy:

The accuracy of DIR_ITV can affect the volume difference between ITV and DIR_ITV. If the registration is not precise, it may lead to discrepancies in the delineated volumes.

Spatial Resolution:

Differences in spatial resolution between imaging modalities used for ITV delineation and DIR_ITV can also contribute to volume differences. Higher resolution images may capture finer anatomical details, potentially leading to variations in delineated volumes.

Clinical Implications:

In conclusion, iGTV 0 phase and iGTV 0 phase lung SBRT represent promising advancements in radiation therapy for lung tumors, offering improved accuracy, efficacy, and patient outcomes compared to traditional techniques.

Understanding the volume difference between ITV and DIR_ ITV is crucial for radiation therapy planning and delivery. It helps ensure accurate targeting of the tumor while minimizing radiation exposure to surrounding healthy tissues. Clinicians need to account for these differences during treatment planning and may adjust treatment margins or techniques accordingly.

In summary, the volume difference between ITV and DIR_ITV arises from differences in how motion and deformations are accounted for in each approach. Clinicians must consider these differences to ensure accurate and effective radiation therapy delivery.

CONCLUSION

In conclusion, the integration of iGTV 0 phase and iGTV 50% phase lung SBRT represents promising advancements in radiation therapy for lung tumors, offering enhanced accuracy, efficacy, and patient outcomes compared to traditional techniques. However, our study highlights limitations in the accuracy of Eclipse software's DIR_ITV-based ITV estimation, particularly concerning tissue overlaps with the ITV, such as rib bone, chest wall, and diaphragm. These findings underscore the need for caution and modification when utilizing DIR_ITV-based techniques, especially where tissue overlap may impact volume estimation accuracy. When delineation methods consistently yield higher DSC, lower GMI, and higher DI values compared to others, it suggests superior accuracy and precision in target delineation for SBRT patients. Discrepancies between manual ITV and ITV_0 P_DIR / ITV_50%P_DIR delineation methods in terms of DSC, GMI, and DI values highlight the potential limitations or strengths of each method. These findings have significant clinical implications for treatment planning, delivery accuracy, and, ultimately, patient outcomes.

Recommendations for clinical practice and further research include standardizing delineation protocols, implementing advanced imaging techniques, and refining treatment-planning algorithms. We firmly believe that our study does provide valuable insights into the accuracy, precision, and clinical relevance of different target delineation methods in SBRT radiotherapy and hence we envisage that the results and inferences of this study would turn out to be invaluable information for further research in this field.

AUTHOR CONTRIBUTION

Concept and data collection by Arun Balakrishnan, Guidance and supervision by P. Ramesh Babu; Manuscript evaluation and modification by Arun Balakrishnan and P. Ramesh Babu.

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ETHICAL DECLARATION

This project involves publicly available datasets. It does not involve patients or healthy volunteers. The study was approved by the Institution Review Board, Protocol Waiver NO: EC/WV/TMC/21/24.

REFERENCES

1. UK SABR Consortium. Stereotactic Ablative Radiation Therapy (SABR): A resource. Technol Cancer Res Treat. 2019;6:1-131.
2. Cusumano D, Dhont J, Boldrini L, Chiloiro G, Teodoli S, et al. Predicting tumour motion during the whole radiotherapy treatment: a systematic approach for thoracic and abdominal lesions based on real time MR. Radiother Oncol. 2018;129:456-462.
3. Steiner E, Shieh CC, Caillet V, Booth J, O'Brien R, et al. Both four-dimensional computed tomography and four-dimensional cone beam computed tomography under-predict lung target motion during radiotherapy. Radiother Oncol. 2019;135:65-73.
4. Huang YH, Ren G, Xiao H, Yang D, Kong FM, et al. Volumetric multiphase ventilation imaging based on four-dimensional computed tomography for functional lung avoidance radiotherapy. Med Phys. 2022;49:7237-7246.
5. Choi JH, Lee S. Real-time tumor motion tracking in 3D using planning 4D CT images during image-guided radiation therapy. Algorithms. 2018;11:155.
6. Ueda Y, Tsujii M, Ohira S, Sumida I, Miyazaki M, et al. Residual Set Up Errors of the Surrogate-guided Registration Using Four-dimensional CT Images and Breath Holding Ones in Respiratory Gated Radiotherapy for Liver Cancer. In Vivo. 2021;35:2089-2098.
7. Seppenwoolde Y, Shirato H, Kitamura K, Shimizu S, Van Herk M, et al. Precise and real-time measurement of 3D tumor motion in lung due to breathing and heartbeat, measured during radiotherapy. Int J Radiat Oncol Biol Phys. 2002;53:822-834.
8. Vedam SS, Kini VR, Keall PJ, Ramakrishnan V, Mostafavi H, et al. Quantifying the predictability of diaphragm motion during respiration with a noninvasive external marker. Med Phys. 2003;30:505-513.
9. Neicu T, Berbeco R, Wolfgang J, Jiang SB. Synchronized moving aperture radiation therapy (SMART): improvement of breathing pattern reproducibility using respiratory coaching. Phys Med Biol. 2006;51:617.
10. George R, Vedam SS, Chung TD, Ramakrishnan V, Keall PJ. The application of the sinusoidal model to lung cancer patient respiratory motion. Med Phys. 2005;32:2850-2861.
11. Mafi M, Moghadam SM. Real-time prediction of tumor motion using a dynamic neural network. Med Biol Eng Comput. 2020;58:529-539.
12. Grootjans W, Dhont J, Gobets B, Verellen D. Management of Respiratory-Induced Tumour Motion for Tailoring Target Volumes during Radiation Therapy. Imaging Interv Radiol Radiat Oncol. 2020:47-68.
13. De Dios NR, Navarro-Martin A, Cigarral C, Chicas-Sett R, García R, et al. GOECP/SEOR radiotheraphy guidelines for non-small-cell lung cancer. World J Clin Oncol. 2022;13:237-266.
14. Muirhead R, McNee SG, Featherstone C, Moore K, Muscat S. Use of maximum intensity projections (MIPs) for target outlining in 4DCT radiotherapy planning. J Thorac Oncol. 2008;3:1433-1438.
15. Lacornerie T, Lisbona A, Mirabel X, Lartigau E, Reynaert N. GTV-based prescription in SBRT for lung lesions using advanced dose calculation algorithms. Radiat Oncol. 2014;9:1-10.
16. Prunaretty J, Boisselier P, Aillères N, Riou O, Simeon S, et al. Tracking, gating, free-breathing, which technique to use for lung stereotactic treatments? A dosimetric comparison. Rep Pract Oncol Radiother. 2019;24:97-104.
17. Didierlaurent D, Ribes S, Batatia H, Jaudet C, Dierickx LO, et al. The retrospective binning method improves the consistency of phase binning in respiratory-gated PET/CT. Phys Med Biol. 2012;57:7829.
18. Khamfongkhruea C, Thongsawad S, Tannanonta C, Chamchod S. Comparison of CT images with average intensity projection, free breathing, and mid-ventilation for dose calculation in lung cancer. J Appl Clin Med Phys. 2017;18:26-36.
19. Ramadaan IS, Peick K, Hamilton DA, Evans J, Iupati D, et al. Validation of Varian's SmartAdapt® deformable image registration algorithm for clinical application. Radiat Oncol. 2015;10:1-9.
20. Zou KH, Warfield SK, Bharatha A, Tempany CM, et al. Statistical validation of image segmentation quality based on a spatial overlap index1: scientific reports. Acad Radiol. 2004;11:178-189.
21. Cusumano D, Dhont J, Boldrini L, Chiloiro G, Romano A, et al. Reliability of ITV approach to varying treatment fraction time: a retrospective analysis based on 2D cine MR images. Radiat Oncol. 2020;15:1-9.
22. Holyoake DL, Robinson M, Grose D, McIntosh D, Sebag-Montefiore D, et al. Conformity analysis to demonstrate reproducibility of target volumes for Margin-Intense Stereotactic Radiotherapy for borderline-resectable pancreatic cancer. Radiother Oncol. 2016;121:86-91.
23. Slotman BJ, Lagerwaard FJ, Senan S. 4D imaging for target definition in stereotactic radiotherapy for lung cancer. Acta Oncol. 2006;45:966-972.
24. Li H, Dong L, Bert C, Chang J, Flampouri S, et al. AAPM Task Group Report 290: Respiratory motion management for particle therapy. Med Phys. 2022;49:50-81.
25. Helou J, Karotki A, Milot L, Chu W, Erler D, et al. 4DCT simulation with synchronized contrast injection in liver SBRT patients. Technol Cancer Res Treat. 2016;15:55-59.