Mid-Ventilation PTV Approach for Stereotactic Ablative Body Radiotherapy in Stage I Non-Small-Cell Lung Carcinoma

Kendell Shields-Dowton[1], Joel Poder[1,2,3], Johnson Yuen[1,4,5], Laurel Schmidt[1], and Yaw Sinn Chin[1,6]

[1]*Department of Radiation Oncology, St George Cancer Care Centre, Kogarah, NSW, Australia*
[2]*Centre for Medical Radiation Physics, University of Wollongong, Wollongong, NSW, Australia*
[3]*School of Physics, University of Sydney, Camperdown, NSW, Australia*
[4]*Ingham Institute for Applied Medical Research, Sydney, Australia*
[5]*South Western Clinical School, University of New South Wales, Sydney, Australia*
[6]*St. George & Sutherland Clinical School, UNSW Medicine*

Corresponding author: Kendell Shields-Dowton

St. George Hospital, Cancer Care Centre, Gray Street
KOGARAH, NSW 2217
Australia
Phone: 0432639951
Email : kendell.shieldsdowton@health.nsw.gov.au

2021/ETH11990: Implementation of Mid-Ventilation Stereotactic Ablative Body Radiotherapy for Stage I Non-Small-Cell Lung Carcinoma. This application was reviewed as a low- or negligible-risk review pathway.

KEYWORDS

Lung SABR, Mid-Ventilation & Early-Stage Lung Cancer

ABSTRACT

Stereotactic ablative body radiotherapy (SABR) is a curative treatment option for medically inoperable patients diagnosed with early-stage non-small-cell lung carcinoma (NSCLC). Target volume delineation for SABR is mainly achieved using 4-dimensional computed tomography (4DCT) to generate an internal target volume (ITV), contouring the gross tumor volume in all 10 phases of respiration. Then, a planning target volume (PTV) is created by margin expansion. The mid-ventilation approach is an alternative to the ITV method, aiming to reduce PTV volumes, minimizing the volume of the normal lung tissue irradiated and potentially reducing damage to normal surrounding lung tissues whilst providing very high local control rates.

This study aimed to outline the development and validation of a coherent mid-ventilation workflow developed at St George Hospital using the Eclipse (v15.6) treatment planning system (TPS) and Aria (v16.0) oncology information system, which are the current systems employed for routine clinical use. This workflow is a combination of deformable image registration (DIR) of 4DCT images, generation of 4D contour statistics in Eclipse, and an embedded PTV calculation spreadsheet in Aria with the purpose of creating an integrated, efficient, and seamless workflow.

The workflow was tested on 10 patients who had previously participated in the Phase II Study of Stereotactic Ablative Body Radiotherapy for Stage I NSCLC (SSBROC 002). Treatment plans were generated and compared using both ITV and mid-ventilation methods. Mid-ventilation treatment plans demonstrated a clinically significant PTV reduction compared with the ITV treatment plans (P =.0119) with a corresponding significant reduction in the Mean Lung Dose (MLD) (P =0.0009) and the percentage of normal lung receiving 20Gy (V20Gy) (P =0.0064). The geometric performance of the Eclipse DIR algorithm yielded a mean distance to agreement of 0.86 mm relative to the manual user contours.

The results of this study confirmed the clinical feasibility and application of the mid-ventilation workflow using Eclipse and Aria. It is postulated that the ease and integrated nature of this mid-ventilation workflow in a single TPS will facilitate the uptake of this contouring and treatment method, reducing radiation damage to surrounding normal lung tissue and potentially minimizing its associated impact on long-term lung function.

INTRODUCTION

Stereotactic ablative body radiotherapy (SABR) is a noninvasive alternative to surgery in the treatment of early-stage NSCLC particularly for patients who are medically inoperable, decline surgery and have peripherally located disease. It is particularly relevant for elderly patients or patients with considerable medical comorbidities[1,2]. SABR irradiates with extreme precision to a target using a high dose per fraction, while sparing surrounding organs at risk (OAR)[2]. Treatment with SABR has demonstrated high rates of local control and improved survival, with low toxicity levels, in patients who were previously deemed unsuitable for curative management[3,4]. The TROG 09.02 CHISEL randomized trial demonstrated improved overall survival in patients treated with SABR compared with those treated with conventionally fractionated radiation therapy4. Patients with NSCLC treated with lung SABR using an internal target volume (ITV) method exhibited a statistically significant decline in forced expiratory volume (FEV1) 18 months posttreatment[1].

The ITV method considers the tumor excursion throughout all phases of the respiratory cycle, but it can result in unnecessarily large PTVs[5,6,7]. The mid-ventilation method also considers the gross tumor volume (GTV) in all phases of the breathing cycle. However, the GTV is contoured as a single 3-dimensional computed tomography (3DCT) structure from a 4D dataset at the phase closest to the GTV's time-weighted average position. Several studies have now demonstrated that planning on a mid-ventilation phase–based PTV can reduce volumes of up to 20%[5,6,7,8], while maintaining 2-year local control rates of 98%[7]. An international survey of respiratory motion management conducted in 2020 revealed that only 1% of cancer centers worldwide use the mid-ventilation technique[9]. A European pattern of practice study revealed that most radiotherapy centers use the ITV–planning target volume (PTV) method, with only 6% of centers using the mid-ventilation PTV method[10]. Similarly, the predominant motion management technique for lung SABR in Australia uses the ITV–PTV method[11].

We hypothesize that most treatment centers still employ an ITV–PTV method because of the difficulties in:

a. Time-efficient contouring of the GTV on all phases of the 4DCT
b. Determining the mid-ventilation phase in commercially available treatment planning systems
c. Determining individualized PTV margin calculation.

In a previous study by St George Hospital[12], manual contouring on all phases of 4DCT was compared using Varian's Velocity (v3.2.0) deformable image registration (DIR) propagated contours for 5 retrospective patients. The findings revealed an agreement between manual and DIR contours of 1.6 ± 0.8 mm (k = 1). Despite the accuracy achieved in the previous study, clinical use was not implemented because multiple software platforms were required to complete a disjointed workflow. A streamlined, efficient DIR-based workflow was therefore proposed to facilitate more widespread implementation of this technique.

Consequently, this study aimed to outline the development and validation of a streamlined mid-ventilation PTV workflow using the Varian Eclipse (v15.6) treatment planning system (TPS) utilizing its DIR and four-dimensional contour statistics functionality, and to verify its functionality by clinically testing it using available imaging data.

METHODS

I. DEVELOPMENT OF MID-VENTILATON WORKFLOW

A mid-ventilation workflow (Figure. 1) was developed using Eclipse TPS v15.6 (Varian Medical Systems Inc., CA, US), following the feasibility study described in a previous study[12]. Data from the last 10 consecutive patients treated at St George Hospital from the Phase II Lung SABR trial SSBROC 00213 were used in this study to assess the proposed workflow. Ethics approval was obtained from the South-Eastern Sydney Local Health District Human Ethics Committee (2021/ETH11990) to retrospectively access data of patients who had participated in SSBROC 002. These 10 patients included would have a diagnosis of early-stage non-small cell lung cancer who were recommended to be treated with curative intent but were unsuitable for surgical resection due to medical reasons or patient's wishes. The full inclusion and exclusion criteria can be found in Table 1 which was obtained from the SSBROC 00213 protocol. Previously archived patient 4DCT datasets were imported into and anonymized in Eclipse TPS (v15.6).

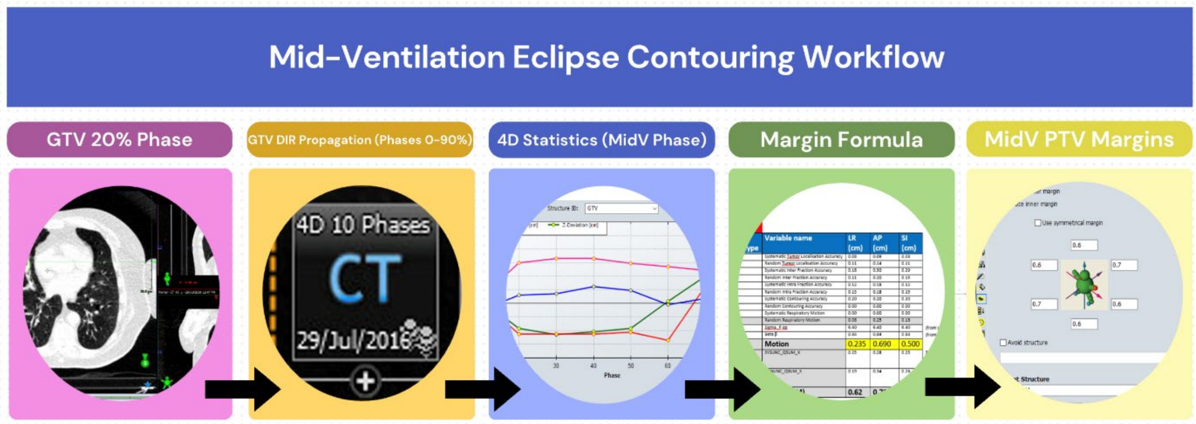


FIGURE 1
Mid-ventilation Eclipse (v15.6) treatment planning system (TPS) and Aria (v16.0) oncology information system contouring workflow. DIR, Deformable image registration; GTV, gross tumor volume; MIDV, mid-ventilation; PTV, PTV, planning target volume.

TABLE 1

Patient inclusion/exclusion criteria from SSBROC 002 trial protocol.

Criteria	Details
Diagnosis	Non-small cell lung cancer
Pathological Diagnosis	Desirable where achievable
Diagnosis Based on Imaging	Requires evidence that lesion/s increasing in size on 2 consecutive CT scans and/or increased uptake on PET
Patient Age	18 years or older
ECOG Performance Status	<=2
Stage	T1-T2, N0M0 (AJCC Staging, 6th Ed.) with tumour size ≤5 cm based upon: History and physical examination 4 weeks prior to registration, CT chest, abdomen and pelvis and/or FDG PET-CT scan
Compliance	Patients must be able to lie flat and comply with simulation and treatment requirements
Previous Thoracic Radiotherapy	Permitted if V20<15% on previous treatment and no overlap with intended current radiotherapy field
Previous Malignancy	Included if in remission and current lung lesion likely primary rather than metastatic after MDT discussion
Exclusion Criteria	Pregnant women and patients with the inability to lie flat and tolerate immobilization for duration of planning and treatment

As the first step of the mid-ventilation workflow, all 10 phases of respiration were opened in the contouring workspace after importing the datasets. A GTV was contoured by a lung expert radiation oncologist (RO) with over 20 years of experience, on a reference phase, which was the mid-inhalation phase (20%)[14] on the 4DCT dataset. This phase was chosen as it was more likely to be closer to the mid-ventilation phase compared with the other extreme phases of respiration (0% and 50%) and would therefore result in a more accurate internal GTV (iGTV) using the DIR. The GTV was then converted to a “high-resolution segment” to help with contour propagation. In the contouring workspace, the RO then selected “copy structures to other phases,” using the DIR algorithm to propagate this volume to all other phases (from 0% to 90%) (Figure 2), resulting in an iGTV.

The RO visually verified the 4D-adapted GTV contours and ensured that the propagation adequately covered the tumor in all breathing phases, editing contours if required.

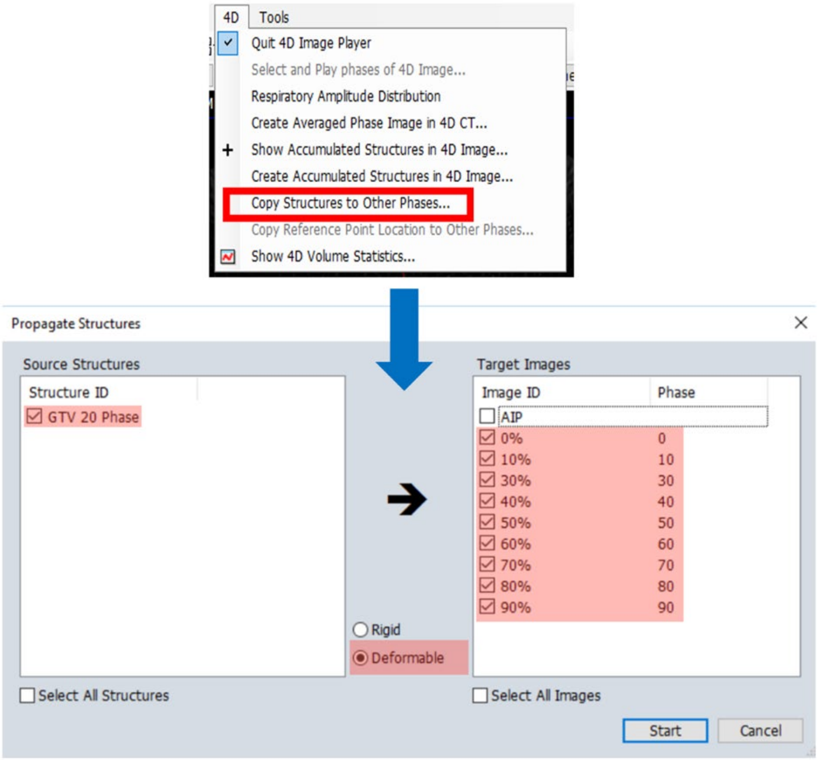


FIGURE 2
Structure propagation tab in contouring workspace in Eclipse (v15.6). DIR of GTV on 20% reference phase to phases 0%-90%. AIP, Average image projection; DIR, Deformable image registration; GTV, gross tumor volume

The Eclipse "4D statistics" function was employed to determine the mid-ventilation phase, based on the centroid of the GTV in all 10 phases. In this graph (Figure 3), the volume type selected was "center of mass" and the structure ID was "GTV." In the 4D statistics graph, the total average deviation (magenta plotted line) was used to determine the average X, Y, and Z deviations from the mid-ventilation position. The phase with the lowest deviation from the mid-ventilation position was chosen as the mid-ventilation phase for contouring (Figure 3). The 4D statistics graph also demonstrated the total amplitude of the GTV in the X, Y, and Z directions (Figure 4).

The GTV motion values with the amplitude of the GTV in the *X*, *Y*, and *Z* directions were used in the mid-ventilation PTV margin calculation (Figure 5) based on a modified department-specific version of the margin formula of Van Herk[15]. A margin calculation template in Microsoft Excel was created and embedded within ARIA (v15.6, Varian Medical Systems, CA, USA) documents to:

a. Calculate and apply the determined PTV margin according to the margin formula.

b. Create a record and verify the system for the patients' individualized margins and mid-ventilation phase.

The total amplitude of the *X*, *Y*, and *Z* values were entered into the margin calculation template to generate the PTV margins for left/right (*X)*, anterior/posterior *(Y),* and superior/inferior *(Z)* directions. These margins were then applied to the GTV on the mid-ventilation phase (instead of the iGTV) to generate the mid-ventilation PTV, which was then copied to the average planning scan to continue through the normal planning process.

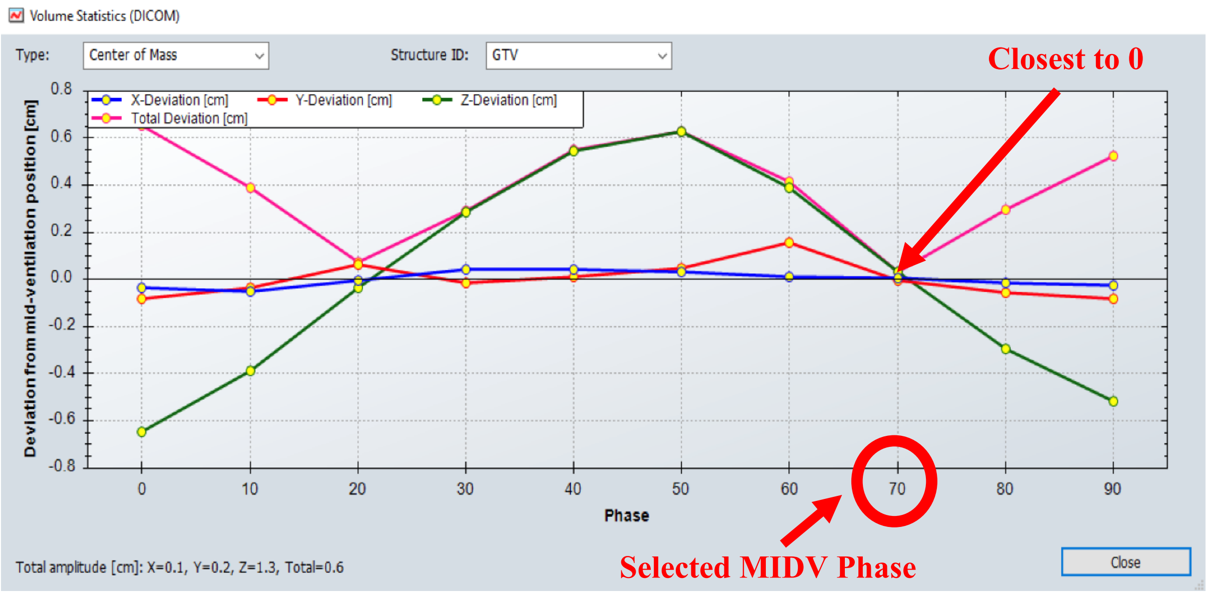


FIGURE 3
Eclipse (v15.6) 4D volume statistics graph. In this case, the phase with the lowest deviation from the mid-ventilation position is the 70% phase; therefore, it was chosen as the mid-ventilation phase. DICOM, Digital imaging and communications in medicine; GTV, Gross tumor volume; MIDV, Mid-ventilation

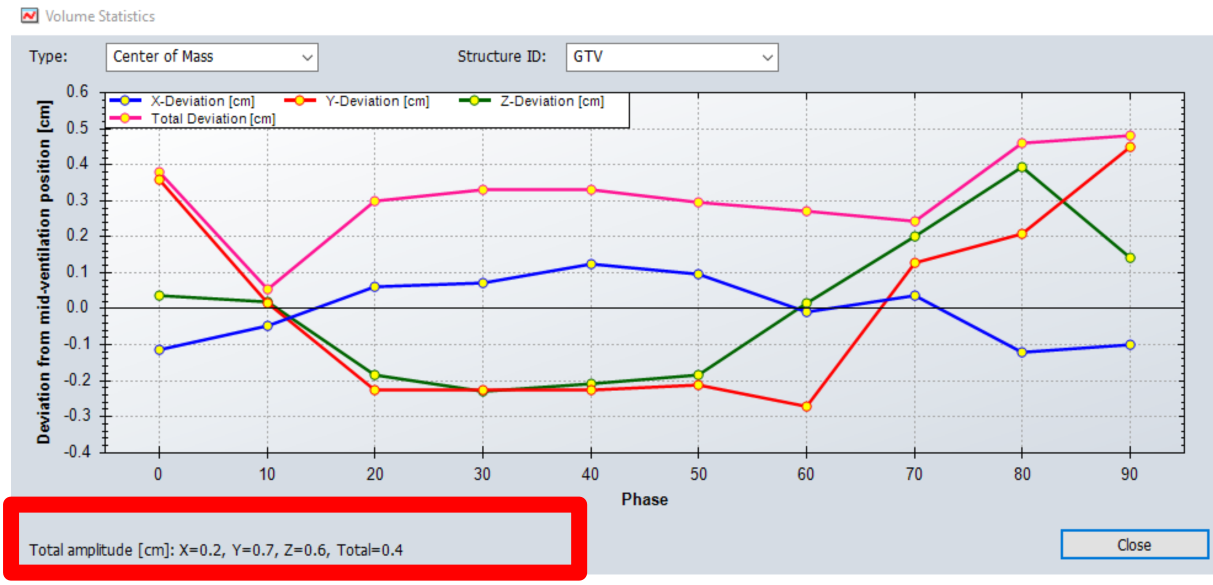
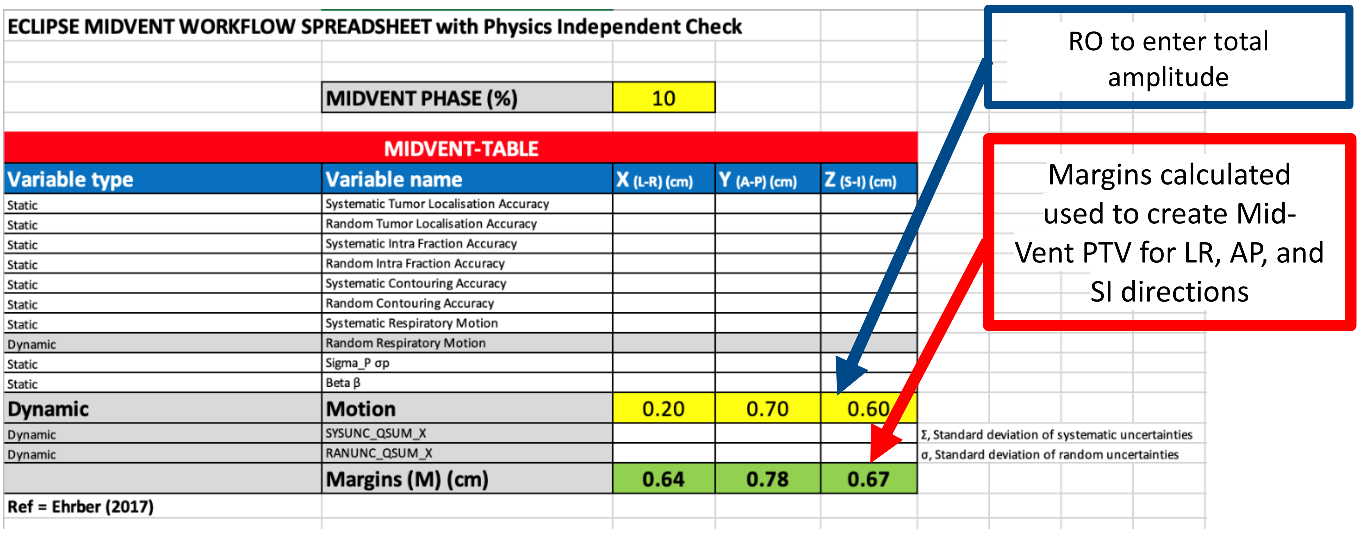


FIGURE 4
Eclipse (v15.6) 4D volume statistics graph highlighting the total amplitude of the GTV in the X, Y, and Z directions, which was used in the mid-ventilation PTV margin calculation spreadsheet to generate the mid-ventilation PTV margins. GTV, Gross tumor volume; PTV, planning target volume.



ECLIPSE MIDVENT WORKFLOW SPREADSHEET with Physics Independent Check				
	MIDVENT PHASE (%)	10		
MIDVENT-TABLE				
Variable type	Variable name	X (L-R) (cm)	Y (A-P) (cm)	Z (S-I) (cm)
Static	Systematic Tumor Localisation Accuracy			
Static	Random Tumor Localisation Accuracy			
Static	Systematic Intra Fraction Accuracy			
Static	Random Intra Fraction Accuracy			
Static	Systematic Contouring Accuracy			
Static	Random Contouring Accuracy			
Static	Systematic Respiratory Motion			
Dynamic	Random Respiratory Motion			
Static	Sigma_P σp			
Static	Beta β			
Dynamic	**Motion**	0.20	0.70	0.60
Dynamic	SYSUNC_QSUM_X			
Dynamic	RANUNC_QSUM_X			
	Margins (M) (cm)	0.64	0.78	0.67
Ref = Ehrber (2017)				

FIGURE 5
Eclipse mid-ventilation workflow spreadsheet – Department-specific version of the margin formula of Van Herk. Departments need to use their own values of static variables in this spreadsheet that are not included in this figure (e.g., systematic and random tumor localization accuracy, intra-fraction accuracy, and contouring accuracy). Anterior/Posterior; Left/Right; PTV, planning target volume; RO, radiation oncologist; Superior/Inferior.

Besides the normal pre-treatment quality assurance checks, a Medical Physics quality assurance task was created to independently assess the mid-ventilation process pre-planning. This included the 4D-contouring process, mid-ventilation phase determination and accurate PTV margin calculation (details described in Table 2).

TABLE 2

Pre-planning quality assurance tests for mid-ventilation PTV generation; (A) tolerance of deviation of mid-ventilation phase from mid-ventilation position of 2 mm is a clinical decision; (B) tolerance of independent Thomas linear margin calculation of 2 mm is based on limitation of the linear model up to motion of 20 mm.

Workflow	Test	Tolerance	Out of tolerance action
4D contouring	Naming check	Exact	Resolve with MDT team to ensure the clinical GTV contour has the same name in each phase
Mid-ventilation phase determination	Mid-V phase correct	Exact	Resolve with MDT team that the appropriate phase is used (implication of phase difference varies)
	Deviation of Mid-ventilation phase from Mid-ventilation position	2 mm[(a)]	Resolve with clinical team to discuss and managing this uncertainty. Planning, treatment, and patient factors should be considered.
	Appropriate GTV on appropriate phase propagated	Exact	Resolve with MDT team by propagating the correct GTV and overriding the incorrect GTV. PTV may need to be expanded again if they exist.
PTV margin calculation	Physics independent margin calculation	Exact	Resolve with MDT team any typos
	Thomas independent margin calculation	2 mm[(b)]	Resolve with MDT team by consideration of margin calculation variations. Clinical use may involve use of the conservative margin.

TABLE 3

Organ at-risk objectives for planning study (as per Phase II Lung SABR Trial)

Organ at risk	48 Gy/4# (Peripheral zone)	50 Gy/5# (Central zone)	54 Gy/3# (>1.5 cm from chest wall)
Spinal cord	<1.2 cc <13.6 Gy <0.35 cc <20.8 Gy Max point dose < 25 Gy (<28 Gy = minor deviation)	<0.5 cc <13.5 Gy 0.25 cc <22.5 Gy Max point dose < 25 Gy (<28 Gy = minor deviation)	Max point dose < 18 Gy (<22 Gy = minor deviation)
Lungs **ITV** **GTV**	Mean < 4 Gy V20 < 8%	Mean < 4 Gy V20 < 8%	Mean < 4 Gy V20 < 8%
Trachea and proximal bronchi	<4 cc <15.6 Gy < 1 cc <32 Gy (<35 Gy = minor deviation)	<4 cc <18 Gy Max point dose < 52.5 Gy	<1 cc <30 Gy (<32 Gy = minor deviation)
Heart/Pericardium	<1 cc <27 Gy (<29 Gy = minor deviation)	<15 cc <32 Gy Max point dose <52.5 Gy	<1 cc <24 Gy (<26 Gy = minor deviation)
Esophagus	<5 cc <18.8 Gy <1 cc <27 Gy (<28.5 Gy = minor deviation)	<5 cc <27.5 Gy Max point dose <52.5 Gy	<1 cc <24 Gy (<26 Gy = minor deviation)
Ipsilateral brachial plexus	<3 cc <23.6 Gy <1 cc <27 Gy (<29 Gy = minor deviation)	<3 cc <30 Gy Max point dose <52.5 Gy	<1 cc <24 Gy (<26 Gy = minor deviation)
Great vessels	<10 cc <39 Gy Max point dose <45 Gy	<10 cc <47 Gy Max point dose < 52.5 Gy	<10 cc <39 Gy Max point dose < 45 Gy
Skin	<10 cc <24 Gy	<10 cc <24 Gy	<10 cc <24 Gy
Chest wall	<30 cc <30 Gy	<30 cc <30 Gy	<30 cc <30 Gy

GTV, Gross tumor volume; ITV, internal target volume; SABR, stereotactic ablative body radiotherapy.

4D contouring naming checks ensures the GTV has the same name in each phase for the mid-ventilation process to work accurately. The total deviation (3D) of the mid-ventilation phase from the mid-ventilation position is also checked and patient-specific assessment would follow if the deviation were more than 2 mm. The validation of the Van Herk margin consists of an independent physics secondary Van Herk calculation to verify the validity of the result within the spreadsheet. An additional check involves the use of the Thomas mid-ventilation calculation5:

$$Margin\ with\ breathing = Margin\ without\ breathing + 0.15\ x\ Range\ of\ motion$$

Differences exceeding 2 mm are discussed with the clinical team, noting that clinical use trends towards the more conservative (larger) margin especially as the linear approximation underestimates margin for larger motions (>20 mm).

The same RO manually contoured the GTV on all 10 phases for each patient, to validate the Eclipse DIR algorithm. The manually contoured GTV was then compared with the Eclipse DIR–generated GTV (as previously outlined) using the mean distance to agreement (MDA) and dice similarity coefficient (DSC). Additionally, the mid-ventilation phase selection by each method was compared.

On treatment, the average scan served as the reference scan for online image matching, aligned with both the mid-ventilation GTV and PTV. In addition, a 4D cone-beam CT was used to verify treatment images to further validate the mid-ventilation technique. This assured users that with the tumor motion, the mid-ventilation PTV encompassed the tumor in the selected mid-ventilation phase.

II. PLANNING STUDY

Contouring

PTVs were generated using the ITV and mid-ventilation methods (Figure 6) for each patient and therefore 2 Eclipse plans were created for all 10 patients using the ITV and the mid-ventilation methods. OARs were contoured as per the Phase II Lung SABR trial SSBROC 002[13] outlined in Table 3.

Beam Configuration and Optimization

The volume-modulated arc therapy technique was used with 2 partial arcs and a beam energy of 6FFF at a 1400 dose rate. An AcurosXB v15.6.04 (Varian Medical Systems Inc., CA, US) dose calculation algorithm was used with a 1 mm calculation resolution. The target coverage was normalized to be the same for each plan to maintain consistency between various planning methods (ITV and mid-ventilation) so that 48, 50, and 54 Gy received the same percentage volume coverage, >98%. The OARs were optimized as per departmental protocol to achieve Phase II Study[13] goals.

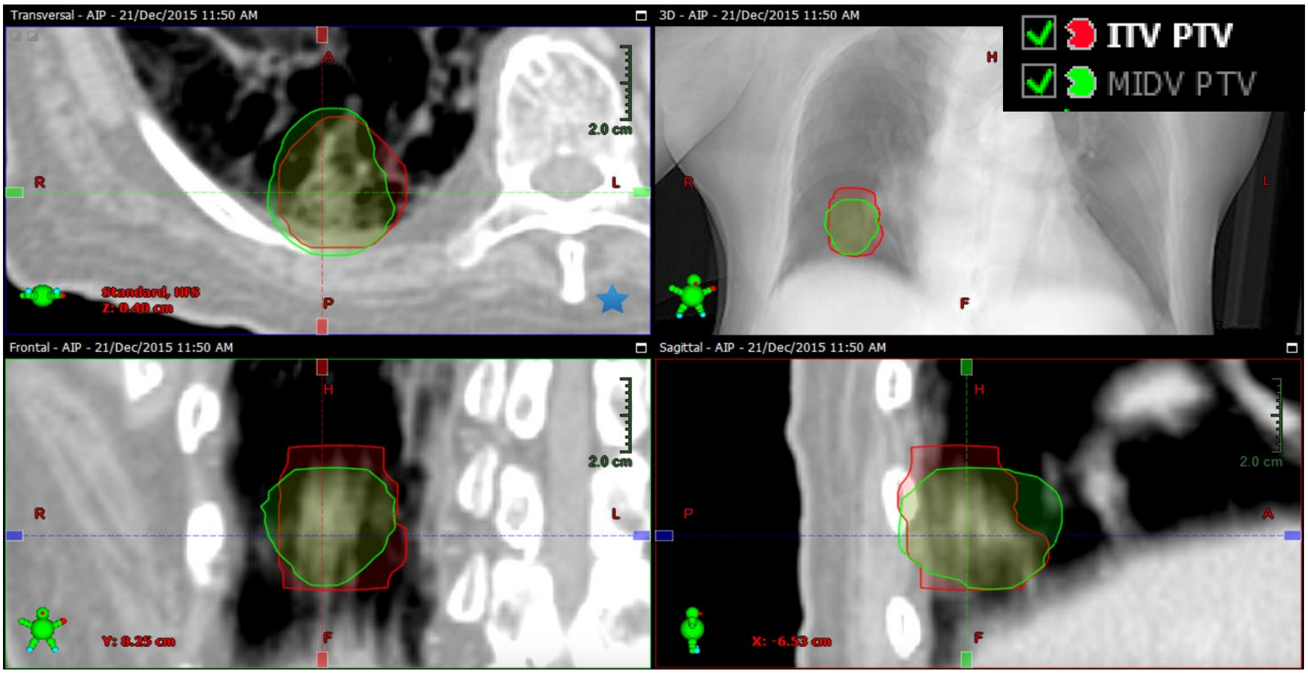


FIGURE 6

Reduced PTV based on mid-ventilation technique versus ITV technique. ITV, Internal target volume; MIDV, mid-ventilation; PTV, planning target volume.

Prescription and OAR Goals

Planning followed the guidelines of the Phase II Study[13]. Doses were set at 48 Gy in 4 fractions, 50 Gy in 5 fractions, or 54 Gy in 3 fractions. OAR constraints were applied according to the Phase II Study[13] and are outlined in Table 3. For this planning study, the PTV volumes (cm^3) were compared and analyzed between techniques. The OAR-achieved doses for lung minus ITV and mid-ventilation GTV (Gy) were analyzed and compared between the 2 methods using dose-volume histogram indices. Statistical analysis was performed using a paired 2-sample *t* test in Excel (v16.86) with a *P* value <0.05 indicating statistical significance.

RESULTS

I. DEVELOPMENT OF MID-VENTILATION WORKFLOW

The geometric performance of the Eclipse DIR algorithm within our mid-ventilation workflow yielded an average MDA of 0.86 mm (range, 0.0-2.3 mm) and an average DSC of 0.86 (range, 0.72-1.00) relative to manual expert RO contours. The mid-ventilation phase selected by the DIR method was within 10% for all 10 patients in the study compared with the manually contoured selected phase. All 10 patients in this study met all pre-planning quality assurance tests for mid-ventilation PTV generation and no modifications to the GTV or PTV were needed.

II. PLANNING STUDY

As presented in Table 4, the Eclipse workflow demonstrated a clinically significant PTV reduction using the mid-ventilation method (mean = 47.04 cm^3 ± 25) compared with the ITV–PTV method (mean = 54.62 cm^3 ± 25) (*P* =0.0119). In addition, the mid-ventilation method resulted in dose reductions to the lungs with statistically significant reductions in the Mean Lung Dose (MLD) (mean = 2.97 Gy ± 0.8) compared with the ITV–PTV method (mean = 3.46 Gy ± 0.8) (*P* =0.0009) and lung V20Gy (mean = 3.19% ± 1) compared with the ITV–PTV method (mean = 3.78% ± 1) (*P* =0.0064).

TABLE 4
Planning study results of mean, standard deviation, and P values

PTV/OAR goal	ITV mean ± SD	MIDV mean ± SD	Mean difference	*P* value
PTV volume (cm^3)	54.62 ± 25	47.04 ± 25	7.58	**<0.0119**
Lung mean < 4 Gy	3.46 ± 0.8	2.97 ± 0.8	0.49	**<0.0009**
Lung V20Gy < 8%	3.78 ± 1	3.19 ± 1	0.59	**<0.0064**

ITV, Internal target volume; MIDV, Mid-ventilation; OAR, organs at risk; PTV, planning target volume; SD, standard deviation.

DISCUSSION

This study has demonstrated an efficient and unified software workflow generating a mid-ventilation based PTV for lung SABR. Concordant with previous studies, the mid-ventilation method was able to result in statistically significant reductions in MLD and V20Gy relative to the ITV method. The main hurdle in the general clinical adoption of utilizing mid-ventilation technique in lung SABR is the complex workflow in all the processes involved[8,11]. This includes contouring on all phases of the 4DCT images, determining the mid-ventilation phase, and calculating the individualized PTV margins. Institutions have overcome this in various ways, such as with manual identification of the mid-ventilation phase[16], customized in-house processes for mid-ventilation phase detection[6,17], and the use of non-TPS imaging software[18].

Our institution has managed to develop a simple workflow which combines all these processes, utilizing a single software solution within the Eclipse TPS. We validated and tested the following key features of this workflow:

a. 4D contouring tool
b. 4D DIR propagation for automated contouring
c. 4D contour statistics to determine the mid-ventilation phase
d. Integrated record and verified system worksheets to calculate individualized PTV margins.

Manual 4D contouring is both time-consuming and impractical[19]. A limitation to this study is that timing studies were not performed but the use of DIR for contouring provides apparent benefits compared to manual contouring. In some patient cases, reliance on DIR for automatic contouring may be limited by certain clinical scenarios. For example, errors in DIR contour propagation occur when a small tumor is located next to the chest wall (a phenomenon known as deformable vector field discontinuity[20]).

This scenario can result in suboptimal DIR contouring in certain phases of respiration, and inaccurate calculation of tumor motion. Suboptimal DIR contouring (both in terms of the clinical scenario and DIR technical parameters) may lead to inconsistencies in determining the mid-ventilation phase[21], inaccuracies in mid-ventilation GTV, and inaccuracies in tumor motion derived from 4D contouring errors with subsequent PTV margin calculation errors[22]. Therefore, the RO should visually verify the 4D-adapted iGTV contours and make appropriate modifications to ensure that the automatic propagation contours accurately reflect the tumor position in all phases when following this workflow. Further, we also recommend robust commissioning of the DIR algorithm under a range of clinical scenarios (GTV location and motion amplitudes)[23].

Previous studies have analyzed the accuracy of DIR for 4DCT, including evaluation of DIR algorithms for the lung[24,25], deep-learning to mimic existing DIR algorithms[26], DIR for tumor motion estimation[27], and DIR for reducing time for 4D contouring[28]. Researchers have also examined DIR specifically for the mid-ventilation technique, including its use in generating mid-position image[29], assessing target dose coverage[7], investigating PTV margins[30,31], and comparing measured dose with planned mid-ventilation dose[32]. However, how the process (contouring or registration strategy) can affect automated 4D contouring accuracy for the mid-ventilation technique and how 4D contouring accuracy is affected by specific tumor motion have not been investigated.

Patients with lung cancer often have multiple medical comorbidities including chronic obstructive pulmonary disease and cardiovascular disease. These respiratory motion management strategies, such as deep or end-inspiration breath-hold techniques, may be technically challenging to deliver to these patients. Even for the minority of patients that can hold their breath reliably, this would add significant amount of treatment time compared to free breathing techniques as suggested in a motion management study[33]. Our mid-ventilation study demonstrated a practical and easy-to-implement technique that allows for radiation therapy to be delivered during free breathing with minimal interruption to the normal treatment time.

In our initial study[12] exploring the mid-ventilation approach in our institution, the PTV volume decreased by an average of 24.5% (range, 19.8%-33.7%) compared with the ITV–PTV method in 5 patients. This corresponded to an average decrease in irradiated healthy lungs (17.1 ± 6.5 cm^3) [12]. The decrease in PTV volume was greater for patients with a larger craniocaudal tumor motion, with a linear relationship noted between the 2 (R° = 09951).

A statistically significant reduction in the PTV volume was demonstrated (P =0.0119) when using the mid-ventilation PTV method compared with the ITV–PTV method. Furthermore, a statistically significant reduction in the MLD (P =0.0009) and V20Gy lung dose (P =0.0064) was demonstrated. We aimed to validate these findings further by collaborating with other institutions that are adopting this workflow in their lung SABR program. We hope to demonstrate that this technique could reduce the decline in lung function, which has been observed in lung SABR treatment using the ITV method[1].

Delineation and validation of this workflow in Eclipse have allowed a unified workflow ready for clinical implementation. The single TPS nature of the workflow has eliminated the dangers and difficulties of transferring data across multiple platforms. A limitation of this study is that it is a single institution in nature. Future studies need to focus on the generalizability of this method by adopting this workflow for lung SABR with a larger sample size over multiple radiation oncology departments.

CONCLUSIONS

Our Study has demonstrated the validity and efficacy of a mid-ventilation workflow in a single TPS and information management system. The comparison of the planning dosimetric parameters between mid-ventilation and ITV methods resulted in consistent volume reductions concordant with current published data. It is hoped that uptake of the mid-ventilation PTV method by other institutions will be facilitated by the elimination of the need to have multiple platforms.

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AUTHORS CONTRIBUTIONS

YC concept development. YC, KD, JY and LS participated in the data collection. Data analysis completed by KD and JY. Manuscript writing completed by KD, YC, JY and JP. All authors read and finally approved the manuscript.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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