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Scientific Article

Intrafraction Imaging Can Replace the Midtreatment Cone Beam Tomography for Lung Stereotactic Ablative Radiation Therapy Patients for Increased Treatment Efficiency

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Purpose: To determine the feasibility of replacing the mid treatment cone beam computed tomography (MT CBCT) image with Intrafraction Imaging (IFI) acquired concurrently during dose delivery in lung Stereotactic Ablative Body Radiation therapy (SABR) patients, and thus improve treatment efficiency.

Methods and Materials: A review of departmental imaging data was performed on ten lung SABR patients treated with dual arc volumetric modulated arc therapy (VMAT) on an Elekta Versa HD linear accelerator with XVI imaging software.

IFI data was extracted and a database of the translational (T_X, T_Y, T_Z) and the rotational (R_X, R_Y, R_Z) position errors was created for retrospective comparison, with the values of the MT CBCT for the same patients, treated between March 2021 and March 2022 at our center. The data was evaluated for correlation between the values in all 6° of freedom.

Results: The inter-class correlation (ICC) coefficient for T_x was 0.89 (95% CI, 0.80-0.94), T_y was 0.69 (95% CI, 0.49-0.82), T_z was 0.89 (95% CI, 0.82-0.95) in the translational planes, and R_x was 0.79 (95% CI, 0.65-0.88), R_y was 0.79 (95% CI, 0.65-0.88), and R_z was 0.91 (95% CI, 0.84-0.95) in rotational planes.

The Bland-Altman (BA) statistics for T_x had a bias of -1.22×10^{-3}, with an upper limit of agreement (UOA) of 0.07, and a lower limit of agreement (LOA) of −0.07, for T_y the bias was 0.01 (UOA: 0.18; LOA: −0.16), T_z bias was 2.6×10^{-3}(UOA: 0.10; LOA: −0.09), R_x bias was 0.09 (UOA: 0.82; LOA: −0.64), R_y bias was −0.04 (UOA: 1.08; LOA: −1.16) and R_z was −0.03 (UOA: 0.44; LOA: −0.51).

Conclusions: The ICC was excellent for T_x, T_z, $R_{x, y, z}$, and good for T_y. The data demonstrated promising correlation between IFI and MT CBCT values, and therefore supports the use of IFI for clinical decision making and improving treatment efficiency.

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Research data are stored in an institutional repository and will be shared upon request to the corresponding author.

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Introduction

A motion management strategy should be employed for patients undergoing Stereotactic Ablative Body Radiation therapy (SABR) to the lung to minimize the effect of respiration-induced tumor motion. Monitoring the patient position during treatment is crucial for these patients for accurate treatment delivery to the target, especially because of the steep dose gradient and large fractional doses of SABR treatments.[1-3] A mid treatment cone beam computed tomography (MT CBCT) is a commonly used motion management strategy for these treatments, to correct for patient motion occurring during the first half of treatment using the treatment planning CT as a reference.[3]

Image guidance for lung SABR patients in our department includes the acquisition of a pre-correction CBCT, a post-correction CBCT, a mid-treatment CBCT, and a post-treatment CBCT; similar to that reported in literature.[3] This can be a time-consuming process, as any positional adjustments are confirmed with subsequent imaging before treatment resumes.

Lung SABR patients are often positioned with their arms up to avoid dose delivery through them. This can be strenuous and prove to be uncomfortable for the prolonged treatment times for these cases.

Second, the discomfort experienced by patients makes it difficult for them to maintain their position throughout the entire treatment, leading to potential mismatches in positioning. As a result, additional time may be required to correct significant positioning errors to ensure accurate treatment delivery. Radiation oncology departments are actively exploring ongoing measures to enhance patient comfort, improve treatment efficiency, and reduce overall treatment time. To ensure the precise delivery of the intended dose to the target area, imaging simultaneously with treatment has naturally emerged as a viable strategy. Intrafraction imaging (IFI) refers to the acquisition of a CBCT during volumetric modulated arc therapy (VMAT) dose delivery and has the potential to improve treatment efficiency and reduce overall treatment time. Previous studies have investigated the use of IFI in various aspects, including the influence of Mega Voltage (MV) scatter on image quality, the effect of dose rate, and the utilization of a flattening filter free beam.[4−7] To the best of our knowledge, no other studies have quantifiably demonstrated correlation between the isocenter shifts observed between an MT CBCT acquired after the first arc, and an IFI acquired during arc delivery.

In this study, we present our findings on the image guided radiation therapy (IGRT) of lung SABR patients using an Elekta Versa HD linear accelerator with XVI imaging software. Ten patients were selected for this study at our center to determine whether it is feasible to replace the MT CBCT with an IFI. The purpose of this research was to compare the translational (Tx, Ty, Tz) and rotational (Rx, Ry, Rz) positional errors observed through IFI and a standard MT CBCT.

Methods and Materials

Patient characteristics and eligibility

A group of 10 previous patients diagnosed with lung cancer and who underwent treatment between March 2021 and March 2022 and had an IFI and a MT CBCT acquired for their treatment were chosen for this study. The treatment involved using a dual arc VMAT technique administered using an Elekta Versa HD linear accelerator. All patients received SABR treatments in 3, 4, or 5 fractions, using a 6MV field with or without a flattening filter. The study was comprised of 6 male patients and 4 female patients. Three patients were treated with deep inspiration breath hold (DIBH) and 7 were free breathing (FB). The DIBH technique was accomplished by employing the Active Breathing Coordinator 3 (ABC3), which is capable of being integrated with the treatment beam but requires manual beam control with the XVI imaging software. Eight patients had right-sided lesions and 2 had left-sided lesions (Table 1).

Single treatment arc lung SABR patients were excluded from this study.

Ethical consideration

Ethical approval was obtained for this departmental imaging data audit from our local quality assurance committee.

IGRT process

The IGRT process for a lung SABR patient at our center consists of a pre-correction 3D CBCT (for DIBH) or 4-dimensional CBCT (for FB) to account for the respiratory motion of the lesion. The patient position is corrected with a 0-mm and 0° correction tolerance from these images, followed immediately by a post-correction 3-dimensional (3D) CBCT with 2-mm and 2° tolerances. After the delivery of the first VMAT arc, a mid-treatment 3D CBCT is taken with a 2-mm and 2° correction tolerance. At the completion of treatment delivery (ie, after the second VMAT arc), a post-treatment 3D CBCT is acquired.

Here, we retrospectively reviewed average motion imaging data from a full arc IFI technique and a MT CBCT. They were evaluated after the completion of the first arc, once the CBCT was reconstructed. This data was tabulated and subsequently compared to evaluate any similarities or differences. This comparison allowed for a

Table 1 Patient characteristics

Patient no.	Gender	Motion management	Site	Prescription
1	M	FB	RUL	24 Gy/3#
2	F	FB	RLL	50 Gy/5#
3	M	FB	RUL	50 Gy/5#
4	F	DIBH	RUL	50 Gy/5#
5	F	FB	RUL	50 Gy/5#
6	M	DIBH	RML	50 Gy/5#
7	M	FB	LUL	48 Gy/4#
8	M	FB	RUL	50 Gy/5#
9	F	FB	RUL	48 Gy/4#
10	M	DIBH	LUL	48 Gy/4#

Abbreviations: DIBH = deep inspiration breath hold; FB = free breathing; LUL = left upper lobe; RUL = Right upper lobe; RML = right middle lobe. M = Male, F = Female

comprehensive assessment of the performance and reliability of the IFI technique in relation to the established MT CBCT method.

IFI CBCT acquisition

The IFI preset used was set up for a full 360°arc with a 1024 × 1024 image resolution, acquired using the XVI software. Two presets were created to mimic typical full arc lung SABR treatments in clockwise (CW) and counterclockwise (CCW) directions. Full arc IFI images were still acquired for patients who were planned with partial arcs, by manually acquiring the Kilovoltage (KV) projections beyond treatment beam angular ranges, using the gantry move assist (GMA) feature in Mosaiq.

Statistical analysis

Bland-Altman (BA) plots (Fig. 1a-b) were used to assess the agreement between translational ($T_{X,}$ $T_{Y,}$ T_Z) and rotational ($R_{X,}$ $R_{Y,}$ R_Z) position errors. The difference between the positional error of an IFI and MT CBCT ($\Delta T_{x,y,z}$, $\Delta R_{x,y,z}$) is plotted against the mean positional error of each patient across all treatment fractions.

Image quality comparison

The IFI and MT CBCT images were also compared for their visual image quality by the same staff performing the IGRT as a secondary analysis based on their SABR experience. Comments were recorded in a free text column (Fig. 2a-b).

Results

In this study, 82 image comparisons (41 IFI and 41 MT CBCT) were analyzed. The average displacement for T_x was 0.03 cm, T_y was 0.05 cm, Tz was 0.04 cm, R_x was 0.22 cm, R_y was 0.46 cm, and R_z was 0.16 cm.

BA statistics (Fig. 1a-b) for T_x had a bias of -1.22×10^{-3}, with an upper limit of agreement (UOA) of 0.07, and a lower limit of agreement (LOA) of −0.07. For T_y the bias was 0.01 (UOA: 0.18; LOA: −0.16), T_z bias was 2.6×10^{-3} (UOA: 0.10; LOA: −0.09), R_x bias was 0.09 (UOA: 0.82; LOA: −0.64), R_y bias was −0.04 (UOA: 1.08; LOA: −1.16) and R_z was −0.03 (UOA: 0.45; LOA: −0.51).

The inter-class correlation (ICC) coefficient (Table 2) for T_x was 0.89 (95% CI, 0.80-0.94), T_y was 0.69 (95% CI, 0.49-0.82), T_z was 0.89 (95% CI, 0.82-0.95) in the translational planes, and R_x was 0.79 (95% CI, 0.65-0.88), R_y was 0.79 (95% CI, 0.65-0.88), and R_z was 0.91 (95% CI, 0.84-0.95) in rotational planes.

Image quality comments included "good" for 2 comparisons and "excellent" for 39 comparisons.

Discussion

Improving treatment efficiency for SABR patients is crucial to the accurate delivery of treatment and improving patient experience by potentially reducing the overall treatment time. This review was conducted to assess the consistency of positional errors captured by an IFI, with a MT CBCT for 10 lung SABR patients. The aim was a departmental change in practice to replace the MT CBCT with an IFI, to streamline the treatment workflow, and further enhance efficiency within the department. The treatment time saved due to this process change is

(a)

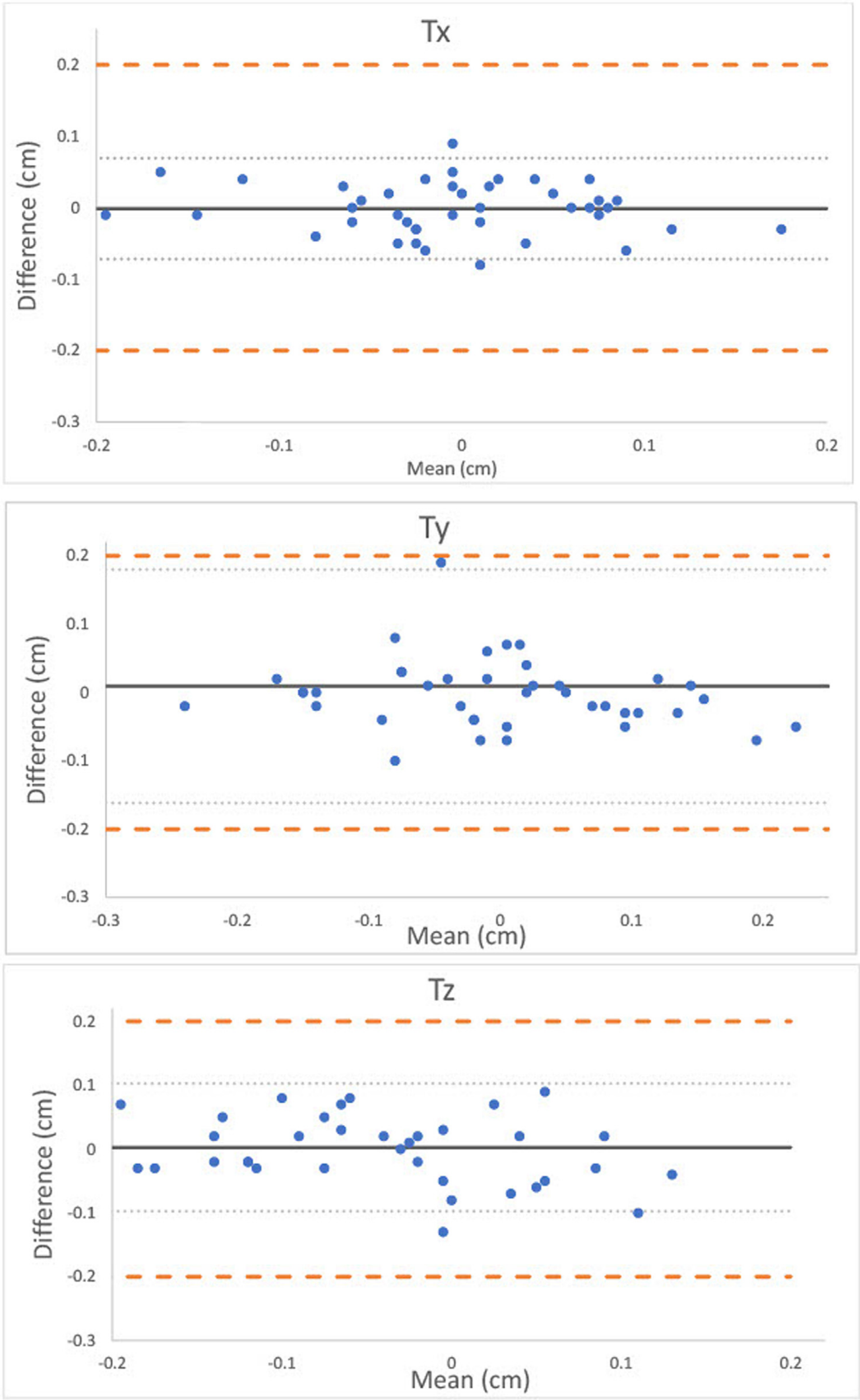


Figure 1 Bland-Altman plots — (a) The absolute difference between the translational positional error of an IFI and MT CBCT ($\Delta T_{x,y,z}$) is plotted against the mean positional error of each patient across all treatment fractions in the lt/rt (X), sup/inf (Y) and ant/post (Z) planes. The dashed line indicates +/-2 mm action threshold tolerances and the dotted line indicates the upper and lower limits of agreement. (b) The absolute difference between the rotational positional error of an IFI and MT CBCT ($\Delta R_{x,y,z}$) is plotted against the mean positional error of each patient across all treatment fractions in the lt/rt (X), sup/inf (Y) and ant/post (Z) planes. The dashed line indicates +/-2 mm degree threshold tolerances and the dotted line indicates the upper and lower limits of agreement.

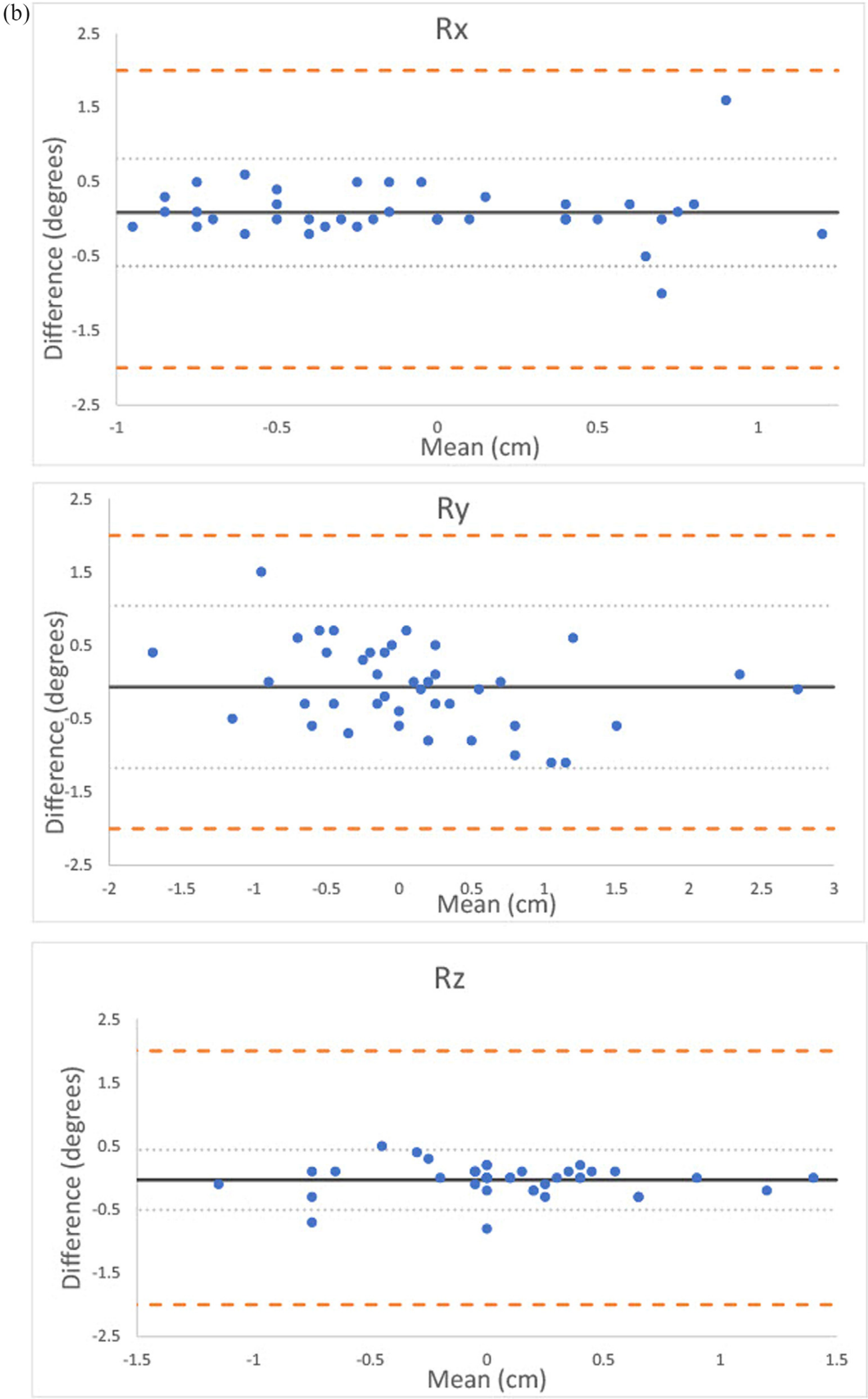


Figure 1 **Continued.**

estimated to be by at least 2 minutes per fraction, the time it takes to acquire a standard MT CBCT.

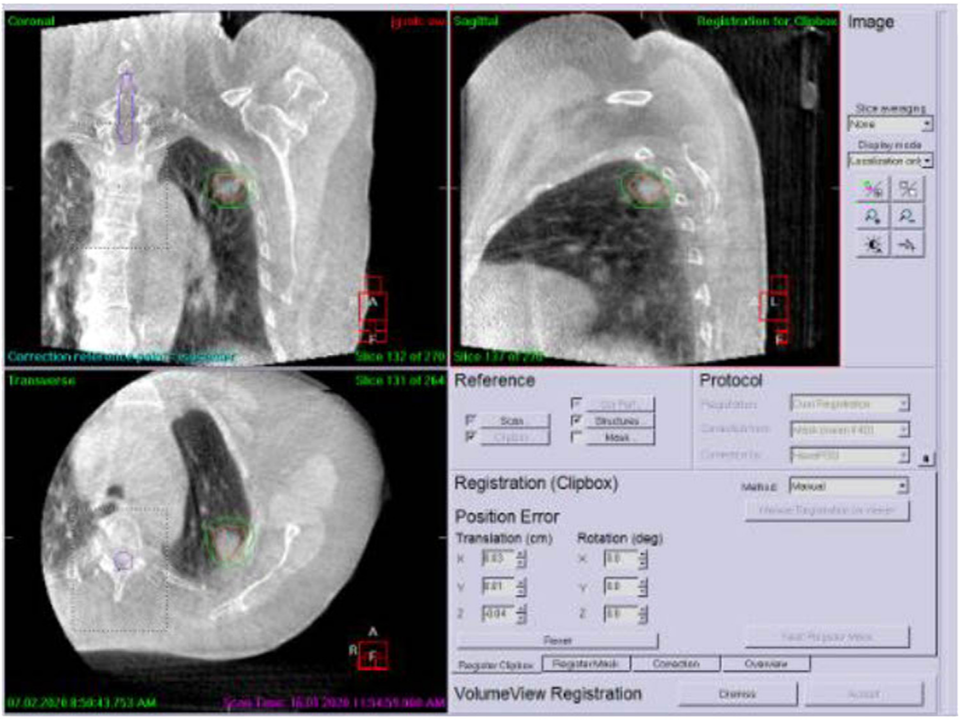
The BA plots in Fig. 1 demonstrate agreement for the $\Delta T_{X,\ Y,\ Z}$ and $\Delta R_{X,\ Y,\ Z,}$ with 95% of the values falling within the upper (mean + 2 SD) and lower (mean − 2 SD) limits of this range. The magnitude of the 2 images were below < 1 mm and <1° for most of the comparisons, which is well below any clinically significant value that would be of concern, considering our standard post correction IGRT tolerances for lung SABR are 2 mm/2° (colored lines in Fig. 1a-b).

The ICC coefficient demonstrates excellent correlation for the $\Delta T_{X,\ Z}$, $\Delta R_{X,\ Y,\ Z}$ directions, and good correlation in the $\Delta T_{Y,}$ direction, potentially due to an outlier in the data for patient number 5. This patient was treated FB with an irregular tumor shape and large tumor motion, which could contribute to the variability in the values of the 2 images, and therefore the overall reduced correlation in the superior/inferior (T_Y) direction. Clinically, these small differences in the values would be similar to those observed as a result of interobserver variability when image matching daily on treatment, and therefore acceptable.

A potential concern with an IFI is related to the negative effect of MV scatter from the treatment arc on the quality of the image.[8] Previous literature has reported on methods to apply correction factors to eliminate the effect of MV scatter on these intrafraction images.[4] However, an MV scatter correction is applied by the Elekta XVI imaging system used for this study. During our analyses, the IFI was found to have a visual quality like a MT CBCT. In fact, in certain instances, given the higher pixel resolution of the IFI compared with the MT CBCT, distinguishing true tumor edges was easier due to a sharper appearance of the lesion (Fig. 2a-b).

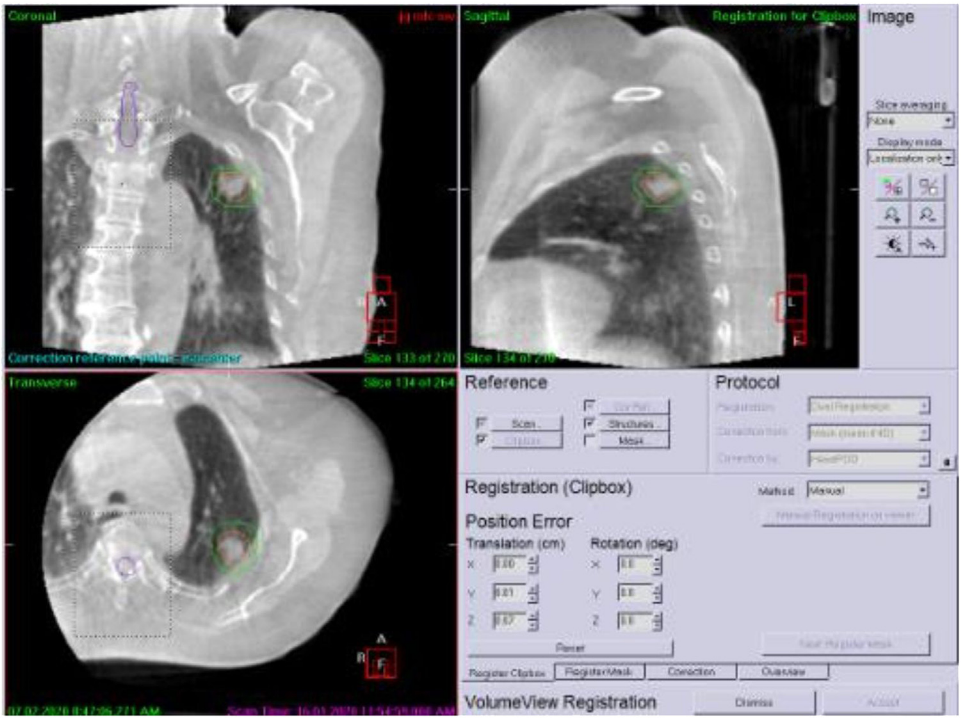
Additionally, we enhanced the image resolution of our IF images by increasing the projection size to 1024 × 1024 pixels, compared with the standard 512 × 512 pixels used for our regular cone beam images. This could have contributed to the sharper appearance of the IFI. Furthermore, the success of IFI for treatments in the chest region has been reported in literature previously. For example, in a study from Stanford Cancer Institute in California,[4] the authors concluded that for high contrast anatomic features such as a lung tumor, contamination from MV scatter had negligible effect.

Although the current patient cohort was considered adequate for the purposes of our department's retrospective data analysis, increasing the size of the cohort would enhance the validity of the study. The sample size of 10 for this study, is consistent with other studies on IGRT found in the literature.[9,10] Additionally, this study only considered IFI for lung SABR patients. The effectiveness and image quality of IFI on other SABR sites are still to be explored.



(a)

Figure 2 (a) A lung SABR CBCT acquired through IFI during the dose delivery of the first treatment arc and (b) a lung SABR MT-CBCT image acquired between the first and second treatment arc.



(b)

Figure 2 **Continued.**

Table 2 Inter-class correlation (ICC) between an IFI and a midtreatment CBCT, showing CI and statistical significance (*P* value)

Image correction axis	ICC	95% CI (Lower bound-upper bound)	*P* value
Tx	0.89	(0.80-0.94)	<.001
Ty	0.69	(0.49-0.82)	<.001
Tz	0.89	(0.82-0.95)	<.001
Rx	0.79	(0.65-0.88)	<.001
Ry	0.79	(0.65-0.88)	<.001
Rz	0.91	(0.84-0.95)	<.001

Conclusion

The findings of this review demonstrated a promising correlation between the magnitudes of patient position error of an IFI and a MT CBCT. This data can be used as the basis to support the replacement of the MT CBCT with an IFI for lung SABR patients in future, although further validation with a larger cohort of participants is recommended.

Disclosures

The authors declare that they have no known competing financial or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.adro.2023.101397.

References

1. Kim J, Keum KC, Lee H, Hong C-S, Park K, Kim JS. Image quality of 4D in-treatment CBCT acquired during lung SBRT using FFF Beam: A phantom study - radiation oncology. *BioMed Central*. 2020;15:224.
2. Li R, Han B, Meng B, et al. Clinical implementation of intrafraction cone beam computed tomography imaging during lung tumor stereotactic ablative radiation therapy. *Intl J Radiat Oncol Biol Phys*. 2013;87:917-923.
3. Beasley M, Brown S, McNair H, et al. The Advanced Radiotherapy Network (ART-net) UK lung stereotactic ablative radiotherapy survey: National provision and a focus on image guidance. *Br J Radiol*. 2019;92:20180988.
4. Ling C, Zhang P, Etmektzoglou T, et al. Acquisition of MV-scatter-free kilovoltage CBCT images during RapidArcTM or Vmat. *Radiother Oncol*. 2011;100:145-149.

5. McBain CA, Henry AM, Sykes J, et al. X-ray volumetric imaging in image-guided radiotherapy: The new standard in on-treatment imaging. *Int J Radiat Oncol Biol Phys*. 2006;64:625-634.
6. Nakagawa K, Haga A, Shiraishi K, et al. First clinical cone-beam CT imaging during volumetric modulated arc therapy. *Radiother Oncol*. 2009;90:422-423.
7. Nakagawa K, Yamashita H, Shiraishi K, et al. Verification of in-treatment tumor position using kilovoltage cone-beam computed tomography: A preliminary study. *Int J Radiat Oncol Biol Phys*. 2007;69:970-973.
8. Friend G, O'Connor P, Charles P. The effect of megavoltage field size on intrafraction cone-beam CT image quality. *Phys Eng Sci Med*. 2020;43:711-717.
9. Stroom J, Vieira S, Mateus D, et al. On the robustness of VMAT-SABR treatment plans against isocentre positioning uncertainties. *Radiat Oncol*. 2014;9:196.
10. Goff PH, Harrison LB, Furhang E, et al. 2d KV orthogonal imaging with fiducial markers is more precise for daily image guided alignments than soft-tissue cone beam computed tomography for prostate radiation therapy. *Adv Radiat Oncol*. 2017;2:420-428.