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Research Article

Comparison of setup errors of immobilization devices for thoracic radiotherapy☆

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A B S T R A C T

Performance of thoracic radiotherapy may be assisted by the use of thoracoabdominal flat immobilization devices (TAFIDs) and integrated cervicothoracic immobilization devices (ICTIDs). This study was performed to compare setup errors of TAFIDs and ICTIDs. Forty-four patients with lung cancer were retrospectively reviewed; 22 patients were immobilized with a TAFID and 22 with an ICTID. In total, 343 cone-beam computed tomography images of these patients were collected for radiotherapy setup. The 3-dimensional setup errors and the displacement of the acromioclavicular joint against the supraclavicular region were calculated. An independent-samples t-test and rank-sum test were used for statistical analyses. The translational setup errors of the TAFID group *vs* ICTID group in the left–right (LR), superior–inferior (SI), and anterior–posterior (AP) directions were 0.14 ± 0.17 *vs* 0.14 ± 0.16 cm ($p = 0.364$), 0.23 ± 0.26 *vs* 0.15 ± 0.15 cm ($p = 0.000$), and 0.16 ± 0.15 *vs* 0.12 ± 0.14 cm ($p = 0.049$), respectively. The relative displacement of the acromioclavicular joint against the supraclavicular joint in the LR, SI, and AP directions were 0.10 ± 0.12 *vs* 0.09 ± 0.10 cm ($p = 0.176$), 0.13 ± 0.13 *vs* 0.11 ± 0.12 cm ($p = 0.083$), and 0.17 ± 0.16 *vs* 0.12 ± 0.11 cm ($p = 0.001$), respectively. The overall displacement of the supraclavicular region was 0.28 ± 0.19 *vs* 0.23 ± 0.15 cm ($p < 0.001$). The recommended planning target volume margins in the LR, SI, and AP directions were 0.46 *vs* 0.74 cm, 0.51 *vs* 0.47 cm, and 0.49 *vs* 0.41 cm, respectively. For patients with lung cancer, using an ICTID can reduce setup errors in the SI direction and displacements of the acromioclavicular joint and supraclavicular region compared with a TAFID. Therefore, an ICTID is preferred for patients with lung cancer with supraclavicular target volume.

Introduction

Radiotherapy is the primary treatment for lung cancer.[1] Supraclavicular lymph node metastasis is not rare in patients with locally advanced lung cancer; it is present in 12% of patients at the time of their first diagnosis and in up to 37.5% of autopsy cases.[2] Previous studies have shown that local radiotherapy involving the supraclavicular area has a curative effect on patients with metastasis in this area.[3,4]

Ensuring high setup accuracy of this area during radiotherapy is critical. A thoracoabdominal flat immobilization device (TAFID) is suitable for radiotherapy in most patients with lung cancer[5] because the acromioclavicular joint mobility is large around this region. However, the repeatability of TAFIDs is far from satisfactory. An immobilization method for the head, neck, and shoulder is suitable for immobilization of tumors located in the supraclavicular region, but not for tumors located in the lower mediastinal region.

Previous studies have compared the pros and cons of the stereotactic body frame and thermal plastic body model for thoracic tumors, but these can only be used for radiotherapy of early-stage lung cancer. Patients with locally advanced lung cancer in which the target area involved the supraclavicular area underwent conventional radiotherapy segmentation. Moreover, the target area usually involved the mediastinum and more comprehensive thoracic area. Therefore, it is difficult to ensure overall positioning accuracy when using a TAFID for immobilization.

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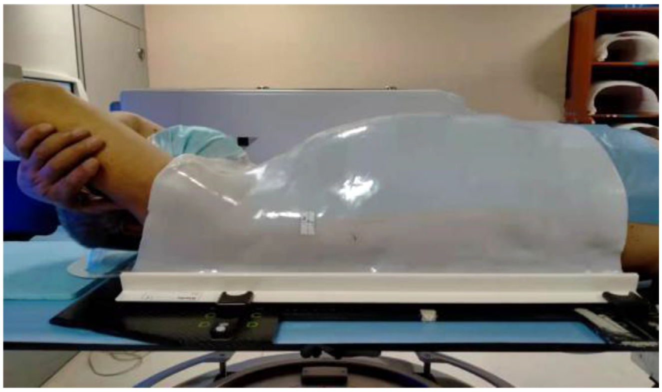

Fig. 1. TAFID group.

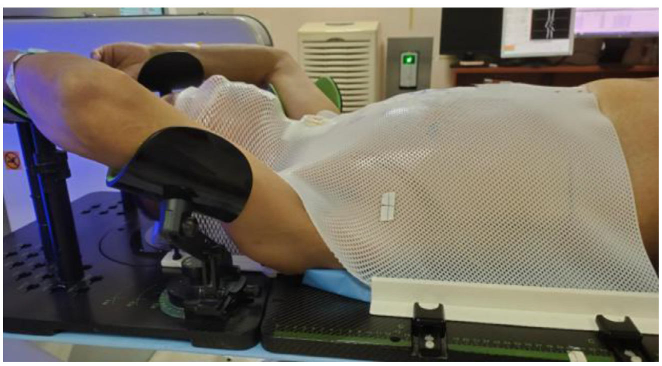

Fig. 2. ICTID group.

This report presents a novel method that takes both the lower mediastinal region and the supraclavicular region into account. Specifically, we retrospectively compared the overall setup error and setup stability around the supraclavicular area between an integrated cervicothoracic immobilization device (ICTID) and a TAFID.

Materials and Methods

Patients

We retrospectively reviewed patients with lung cancer who underwent thoracic radiotherapy in our center from November 2020 to April 2021. The inclusion criteria were as follows: (1) the treatment mode was volumetric modulated arc treatment, (2) the prescribed dose was 60 Gy (delivered in 30 fractions), (3) the target volume included the supraclavicular area, and (4) cone-beam computed tomography (CBCT) scanning was performed before and during radiotherapy. Patients with a Karnofsky performance scale score of <70 and those who underwent CBCT fewer than 5 times were excluded.[6]

Postural fixation and computed tomography simulated positioning

Patients in both immobilization method groups lay flat on the computed tomography (CT) bed for positioning in a calm state. In the TAFID group, the patient was told to hold his or her arms and elbows with both hands and place the arms in front of the forehead (left arm above right arm) (Fig. 1). In the ICTID group, the patient's arms were placed on an arm support device. The arms were abducted about 120 degrees, the wrists were relaxed and placed on wrist support devices, and both hands held the columns (Fig. 2). The head restraint model was selected according to the curvature of the patient's neck. CT positioning scanning was conducted under free breathing, and the treatment centerline was marked on the bilateral chest wall skin. The slice thickness was 5 mm, and the scanning area extended from 5 cm below the mastoid process to the sternal handle. The midline extended to the umbilicus.

Target volume delineation and plan design

The obtained CT simulated positioning images were then uploaded to a treatment planning system (Pinnacle version 9.10; Philips Healthcare, Amsterdam, Netherlands) for target volume delineation by the radiation oncologists. The treatment center was placed and the radiotherapy plan was designed according to ICRU Report 83.

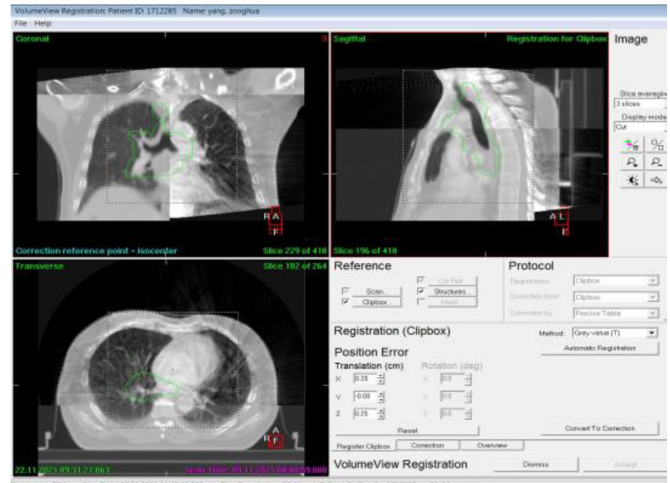

Fig. 3. Boundary in z direction of CBCT scan.

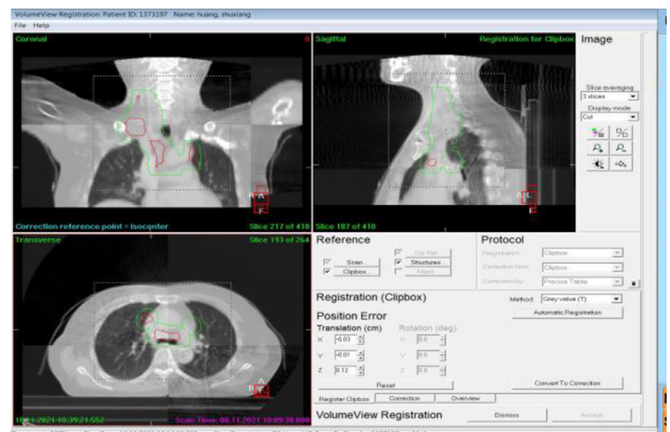

Fig. 4. Boundary in x direction of CBCT scan.

Image guidance and data acquisition

Before the beam delivery, the operator of the linear accelerator used the laser and the positioning line on the patient's body and body membrane for accurate patient setup, then performed CBCT scanning for online calibration. CBCT scanning was performed daily in the first week and then once a week for the remaining fractions. The upper boundary of the CBCT scan was determined at the cricoid cartilage and the lower boundary at 5 cm below the diaphragm (or 20 cm above and below the treatment center) (Fig. 3). According to the guideline recommendations, the scope of the registration frame was isotopically expanded by 2 cm from the planning target volume (PTV). In addition, because lung tumors are affected by many factors, such as respiration and the heartbeat, the treatment registration frame used in our center included the region 2 cm above the clavicle and 5 cm below the diaphragm. The anterior boundary included the subcutaneous soft tissue, and the posterior boundary included the vertebral column (Fig. 4). CBCT image registration was carried out using the soft tissue grayscale window. The target volume was used as the reference for manual fine adjustment. We recorded the setup errors of 6 degrees of freedom of translation error X (left–right, LR direction), Y (superior–inferior, SI direction), and Z (anterior–posterior, AP direction) and rotation error R_X (sagittal plane), R_Y (cross section), and R_Z (coronal plane).

The sternoclavicular joint displacements (X_{st}, Y_{st}, and Z_{st}) were obtained using the sternoclavicular joint and the posterior cervical spine as the region of interest (using the Elekta airborne XVI volume imaging system) with manual registration. The acromioclavicular joint was then manually registered to obtain the displacement of the acromioclavicular joint (X_{ac}, Y_{ac}, and Z_{ac}).

Table 1
Demographics of the patients in the 2 groups

	TAFID	ICTID	Z-stat	*p*-Value
Average age (range, y)	59 (40-75)	58.5 (46-71)	−0.294	0.769
Average height (range, m)	1.68 (1.57-1.82)	1.69 (1.58-1.80)	−0.400	0.689
Average weight (range, kg)	71.2 (52-102)	69 (54-93)	−0.012	0.991
BMI index			−0.845	0.398
<24	8	10		
≥24	14	12		
Gender			−1.423	0.155
Male	15	19		
Female	7	3		
KPS score			−1.339	0.181
80	18	14		
90	4	8		
Location of primary lesion			−0.895	0.371
Left lung	9	12		
Right lung	13	10		
Stage			−0.895	0.371
I	2	1		
II	1	0		
III	14	18		
IV	5	3		

BMI, body mass index; ICTID, integrated cervicothoracic immobilization device; KPS, Karnofsky performance scale; TAFID, thoracoabdominal flat immobilization device.

Table 2
Overall setup errors in the 2 groups

	TAFID ($\Sigma\pm\sigma$)	ICTID ($\Sigma\pm\sigma$)	T-stat	*p*-Value
T_X (cm)	0.14 ± 0.17	0.14 ± 0.16	0.910	0.364
T_Y (cm)	0.23 ± 0.26	0.15 ± 0.15	4.038	*0.000*
T_Z (cm)	0.16 ± 0.15	0.12 ± 0.14	−1.972	*0.049*
R_X (°)	0.81 ± 0.56	0.82 ± 0.49	−3.762	*0.000*
R_Y (°)	0.76 ± 0.67	0.74 ± 0.54	0.941	0.348
R_Z (°)	0.75 ± 0.51	0.70 ± 0.63	0.521	0.602

ICTID, integrated cervicothoracic immobilization device; TAFID, thoracoabdominal flat immobilization device.

Definition of PTV margin and displacement error

The PTV margin was calculated using the formula established by Perk et al.[7] to ensure that 90% of the CTV could be irradiated with at least 95% of the prescribed dose:

$$\text{PTV margin} = 2.5\Sigma + 0.7\sigma$$

where the systematic error Σ is the standard deviation of the average error of individual cases and σ is the random error (root mean square of the standard deviation of the individual case error).

Statistical analysis

For the overall target setup error, sternoclavicular joint setup error, acromioclavicular joint setup error, and motion of the sternoclavicular joint and acromioclavicular joint (the absolute value was used for comparison of the displacement), the 2 groups of data were compared by the t-test or rank sum test using SPSS 25.0 software (IBM Corp., Armonk, NY), with a significance level of 0.05. For calculation of the movement amplitude and spatial displacement of the upper and lower clavicle, we used the absolute value of the difference to indicate the position and movement range of the acromioclavicular joint.

$$\Delta X = |X_{st} - X_{ac}|$$
$$\Delta Y = |Y_{st} - Y_{ac}|$$
$$\Delta Z = |Z_{st} - Z_{ac}|$$

The 3-dimensional displacement of the acromioclavicular joint was calculated as follows:

$$D = \sqrt{\Delta X^2 + \Delta Y^2 + \Delta Z^2}$$

Results

General clinical features of patients setup error

As shown in Table 1, we analyzed 22 patients treated with a TAFID (175 sets of image data) and 22 patients treated with an ICTID (168 sets of image data). As shown in Table 2, the mean translation error in the SI direction and AP direction of the ICTID was significantly smaller than that of the TAFID ($p < 0.05$). The mean rotation error in the sagittal plane of the ICTID was significantly smaller than that of the TAFID ($p < 0.05$), but not in the cross-sectional and coronal planes.

Table 3
Three-dimensional translational displacement and rotation of the acromioclavicular joint

	TAFID	ICTID	Z-stat	*p*-Value
T_X (cm)	0.10 ± 0.12	0.09 ± 0.10	−1.355	0.176
T_Y (cm)	0.13 ± 0.13	0.11 ± 0.12	−1.736	0.083
T_Z (cm)	0.17 ± 0.16	0.12 ± 0.11	−3.221	*0.001*
R_X (°)	0.89 ± 0.71	0.83 ± 0.64	−0.123	0.902
R_Y (°)	0.75 ± 0.64	0.62 ± 0.53	−2.603	*0.009*
R_Z (°)	0.59 ± 0.54	0.63 ± 0.54	−2.296	*0.022*
D (cm)	0.28 ± 0.19	0.23 ± 0.15	−3.784	*<0.001*

D, 3-dimensional displacement of the acromioclavicular joint; ICTID, integrated cervicothoracic immobilization device; TAFID, thoracoabdominal flat immobilization device.

Table 4
Recommended planning target volume margins for the 2 groups

	Overall		Sternoclavicular area		Acromioclavicular area	
	TAFID	ICTID	TAFID	ICTID	TAFID	ICTID
LR (cm)	0.46	0.47	0.51	0.47	0.48	0.51
SI (cm)	0.74	0.49	0.75	0.56	0.81	0.51
AP (cm)	0.51	0.41	0.54	0.47	0.70	0.41

AP, anterior–posterior; ICTID, integrated cervicothoracic immobilization device; LR, left–right; SI, superior–inferior; TAFID, thoracoabdominal flat immobilization device.

Acromioclavicular joint movement amplitude and 3-dimensional spatial displacement

Table 3 listed the three-dimensional translational displacement and rotation of the acromioclavicular joint. All translation displacement amplitudes of the acromioclavicular joint immobilized with the TAFID were larger than those with the ICTID in the LR, SI, and AP directions. The rotation amplitudes in the sagittal plane and cross-sectional plane using the TAFID were also larger than those using the ICTID. Among them, the differences between the 2 groups in the AP direction, cross-sectional plane, and coronal plane were statistically significant ($p < 0.05$). Furthermore, the mean 3-dimensional spatial displacement was significantly larger in the TAFID group than in the ICTID group ($p < 0.05$). Table 4 listed recommended PTV margin of the two group, which indicated that the PTV margin could be reduced with ICTID.

Discussion

Radiotherapy technologies are rapidly evolving, leading to more accurate and faster treatments with fewer adverse effects.[8] One of the key factors in accuracy of radiotherapy delivery is the use of better immobilization. The success of radiotherapy depends on the accuracy of localization.[9] Some immobilization methods might affect the incidence of setup errors[10,11]; therefore, an adequate immobilization device is critical to help reduce setup errors. Nevertheless, relatively few studies have compared TAFIDs and ICTIDs for this purpose. The effects of different immobilization devices on the setup errors of the supraclavicular region in patients undergoing radiotherapy for lung cancer might vary, although no reports have yet addressed this. Our study was designed to investigate this question. The results showed that using an ICTID can reduce setup errors; therefore an ICTID is preferred for patients with lung cancer with supraclavicular target volume.

The ICTID has been mostly used for breast cancer radiotherapy; however, the recommended PTV margin for the treatment of lung cancer has been rarely reported. In this study, the setup error of the ICTID was systematically compared with that of the TAFID. The overall PTV margins required for the TAFID were 0.46, 0.74, and 0.51 cm in the LR, SI, and AP directions, respectively, which were in accordance with the values reported by Xu et al.[10] (0.36, 0.66, and 0.50 cm, respectively). In contrast, the overall PTV margins required for the ICTID were 0.47, 0.49, and 0.41 cm in the LR, SI, and AP directions, respectively. The values in the SI and AP directions were significantly smaller than those using the TAFID. The reason for needing a smaller SI margin is that the head restraint fixation of the ICTID has better repeatability in the SI direction. The reason for needing a smaller AP margin is that compared with the double-arm head-holding posture using the TAFID, the patient's arms have support devices and the abduction angle is large; meanwhile, the shoulder blades are retracted and the neck and back are more relaxed to fit the couch surface, overcoming the instability caused by a "shrug" or "shoulder drop." The setup repeatability of both arms is therefore better, improving the repeatability in the AP direction.

The rotation ranges of the acromioclavicular joint in 3 degrees of freedom and the 3-dimensional spatial displacements using the ICTID were significantly smaller than those using the TAFID. This was probably because using the ICTID increased the height and abduction range of the proximal arm and distal arm, improving the setup repeatability. Moreover, use of the headrest and facial membrane fixation reduced the error caused by head rotation. The difference in the setup error between the sternoclavicular joint and the acromioclavicular joint can intuitively show the relative movement of these 2 important joints. The statistical results of this study show that the average and standard deviation of 3-dimensional displacement of the acromioclavicular joint and its relative displacement to the sternoclavicular joint in all fractions was significantly larger when using the TAFID than when using the ICTID. This further verifies the advantages of the ICTID in controlling joint movement.

Two important issues should be noted with respect to practical application. First, in this study, the ICTID was combined with face-neck-shoulder membrane fixation, and because of the resultant increase in the number of fixed points, the operation time in the positioning and membrane-making stage may have been slightly longer than that in the TAFID group. However, there was no significant difference in the duration of treatment setup. Second, the abduction angle of the patients' arms was large and the setup position was high, necessitating close attention to the risk of upper limb collision with the machine.

This study has 2 main limitations. First, it was a retrospective study with a relatively small sample size, and the baseline characteristics of the 2 groups may have been unbalanced. Second, the influence of rotation error and internal body deformation on the translation results was not analyzed.

Conclusions

This study showed that for patients with locally advanced lung cancer with supraclavicular target, use of an ICTID can reduce setup errors in the SI direction and relative displacement of the acromioclavicular joint against the supraclavicular joint compared with a TAFID. An ICTID is therefore recommended for patients with lung cancer with supraclavicular target volume.

Authors' contributions

BW and BL conceived of the study design and analysis. FH, FL, WZ, and YZ wrote the programs and performed data measurement and analysis, and drafted the manuscript. TH, BY, TL, DC, QF, ZX, JL, NB, ZZ, XF, and WL coordinated the study and participated in discussions and preparation of the manuscript, and communications. All authors read and approved the final manuscript.

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Conflicts of Interest

No conflicts of interest.

References

1. Chinese Medical Association, Oncology Society of Chinese Medical Association, Chinese Medical Association Publishing House Chinese Medical Association guidelines for clinical diagnosis and treatment of lung cancer (2019 edition). *Zhonghua Zhong Liu Za Zhi* **42**:257–87; 2020. doi:10.3760/cma.j.cn112152-2020 0120-00049.
2. Hui, Z.; Han, W.; Sun, S.; *et al.* Comparation of set-up errors between two different body positions in precision radiotherapy for esophageal cancer. *Chin. J. Radiat. Oncol.* **23**:336–9; 2014.
3. Xu, H-R.; Sun, X-S.; Wang, X-H.; *et al.* Halcyon analyzed target margin in 142 patients with lung cancer treated by conventional segmentation therapy. *Basic Clin. Med.* **40**:1691–4; 2020.
4. Gu, H.W.; Sohn, M.J.; Lee, D.J.; *et al.* Clinical analysis of novalis stereotactic radiosurgery for brain metastases. *J. Korean Neurosurg. Soc.* **46**:245–51; 2009.
5. Sperduto, P.W.; Kased, N.; Roberge, D.; *et al.* Effect of tumor subtype on survival and the graded prognostic assessment for patients with breast cancer and brain metastases. *Int. J. Radiat. Oncol. Biol. Phys.* **82**:2111–17; 2012.
6. Dongryul, O.; Yong, C.A.; Hee, C.P.; *et al.* The prognostic impact of supraclavicular lymph node in N3-IIIB stage non–small-cell lung cancer patients treated with definitive concurrent chemo-radiotherapy. *Oncotarget* **8**; 2017.
7. Park, S.; Yoon, W.S.; Mi, H.J.; *et al.* Clinical impact of supraclavicular lymph node involvement of stage IIIC non–small-cell lung cancer patients. *Medicina (Kaunas, Lithuania)* **57**:301; 2021.
8. Vinod, S.K.; Hau, E. Radiotherapy treatment for lung cancer: Current status and future directions. *Respirology* **25**(Suppl 2):61–71; 2020.
9. Ueda, Y.; Teshima, T.; Cárdenes, H.; Das, I.J. Evaluation of initial setup errors of two immobilization devices for lung stereotactic body radiation therapy (SBRT). *J. Appl. Clin. Med. Phys.* **18**:62–8; 2017.
10. Li, R.; Han, B.; Meng, B.; *et al.* Clinical implementation of intrafraction cone beam computed tomography imaging during lung tumor stereotactic ablative radiation therapy. *Int J Radiat. Oncol. Biol. Phys.* **87**:917–23; 2013.
11. Sio, T.T.; Jensen, A.R.; Miller, R.C.; *et al.* Influence of patient's physiologic factors and immobilization choice with stereotactic body radiotherapy for upper lung tumors. *J. Appl. Clin. Med. Phys.* **15**:4931; 2014.