ORIGINAL RESEARCH

Study on the Application Effect of Three-dimensional Reconstruction Technology in Locating Small Pulmonary Nodules During VATS Surgery

Jialai Zhao, MM; Mingyue Qu, MD; Zigeng Xu, MM; Yiling Zhang, MM; Chenguang Ma, MM

ABSTRACT

Objective • To compare the positioning effect of three-dimensional reconstruction technology and Hook-wire puncture operation on small pulmonary nodules during video-assisted thoracoscopic surgery (VATS), and evaluate its effectiveness, efficiency, and safety.

Methods • The subjects of this study were 50 patients with small pulmonary nodules admitted to the Department of Cardiothoracic Surgery of Heilongjiang Provincial Hospital from January 2020 to December 2022, and all underwent thoracoscopic surgical resection. All study subjects met the inclusion criteria, grouping according to the intraoperative positioning method, the control group (n = 25) used Hook-wire puncture positioning, and the observation group (n = 25) used three-dimensional reconstruction technology. The positioning effect, pain level, and postoperative complications were compared between the two groups.

Results • The incidence rate of complications after puncture was 16.00% in the control group and 4.00% in the observation group, the complication rate in the observation group was significantly lower; the positioning success rate of the observation group was 96.00%, which was higher than that of the control group (92.00%). The operation time (32.25±6.08) min was lower than (38.50±7.12) min in the control group. The two groups had no statistical significance in the wedge resection success rate, VAS score, and complication rate ($P > .05$).

Conclusion • Three-dimensional reconstruction technology mainly makes preliminary judgments on the location, shape, size, and relationship between nodules and surrounding tissues based on preoperative CT scan images. It can select suitable scanning locations, map puncture paths, and anchor them in and around small lung nodules. The operation is simple, and the positioning success rate is high. The existence of three-dimensional reconstruction technology to position the guide wire can quickly shorten the time to detect lesions, shorten the time of VATS, reduce the occurrence of pulmonary infection in patients, and improve the prognosis. (*Altern Ther Health Med.* [E-pub ahead of print.])

Jialai Zhao, MM; **Mingyue Qu**, MD; **Zigeng Xu**, MM; **Yiling Zhang**, MM; **Chenguang Ma**, MM, Department of Cardiothoracic Surgery, Heilongjiang provincial hospital, Harbin, China.

Corresponding author: Jialai Zhao, MM
E-mail: DoctorZhaojialai@126.com

INTRODUCTION

According to statistics from the "Global Cancer Statistics Report 2020"[1] published by the "Journal of Clinicians' Cancer" under the American Cancer Society, lung cancer ranks second after breast cancer in terms of incidence (11.4%) but accounts for 18% of deaths and becomes the leading cause of death among cancer patients. In our country, lung cancer accounts for 17.9% of the incidence and 23.8% of the deaths, becoming the well-deserved "King of Cancers." Due to unremarkable early symptoms and insufficient attention to one's body, lung cancer patients in my country are often discovered in the middle and late stages. For lung cancer patients who have undergone clinical surgical treatment at different stages, the five-year survival rate of patients in the early stage is as high as 90%, and the five-year survival rate of stage I patients is more than 50%. However, as the cancer worsens, the five-year survival rate of patients gradually decreases. The five-year survival rate for stage IV patients is only 5%. Early detection and diagnosis of lung cancer are of great significance in reducing lung cancer deaths.

In terms of examination methods, imaging data in computed tomography (CT) images are an important basis for clinical judgment of lung cancer. Lung cancer appears as pulmonary nodules in lung CT. Finding nodules through detailed image data can help early diagnosis and timely surgery. Therefore, CT images have important research value in diagnosing pulmonary nodules. In the traditional method of benign and malignant classification, Jacob et al. [2] calculated based on more than a hundred features, such as nodule image shape, edge, texture, and nodule parenchyma degree, and obtained a priori probability for each feature through a Bayesian classifier finally, the features are sorted to classify the nodules. This method of classification has achieved good results. However, this method only calculates image features without adding the doctor's medical record information, and occasionally, the prediction results are far from the original labels. Gong Ping et al. [3] tried to introduce a large amount of pathological information and semantic information on pulmonary nodules to classify benign and malignant pulmonary nodules and achieved high classification accuracy. Since the prediction results are consistent with the clinical diagnosis results, this method has good general applicability.

At present, the clinical way to clearly define the nature of small nodules is the pathological diagnosis, which is the gold standard. The vigorous development of thoracic surgery has given rise to a new clinical idea and approach to diagnosing and treating small pulmonary nodules, which is video-assisted thoracoscopic surgery (VATS). It is minimally invasive, can reduce patients' pain, reduce postoperative complications, and speed up recovery, so it has been widely promoted in clinical practice. However, the ability of VATS to treat some small pulmonary nodules is still limited, the reason is that during operation, it is impossible to locate most small subpleural nodules with a depth of more than 5 mm or a diameter of less than 1 cm through finger palpation, vision, or endoscopic instrument gliding, prolonging the operation time, especially for pure ground-glass nodules (GGO) with soft texture, makes the operation more difficult.[4–6]

The most clinically used positioning method is Hook-wire positioning under CT guidance, which has high accuracy. The three-dimensional reconstruction and positioning technology converts the two-dimensional information of CT scans into three-dimensional visual data images. The role of multimedia and computers is prominent. It can be rotated, zoomed, and observed in three-dimensional space. It can display various imaging characteristics of small pulmonary nodules and is convenient for the clinical identification of benign and malignant pulmonary nodules.[7] It can also display the anatomy of the lungs, the location of pulmonary nodules, and their relationship with surrounding tissues in a three-dimensional and comprehensive manner at any angle before surgery.[8,9] It can detect the threshold of mutated blood vessels in advance, making it easier for the surgeon to reasonably plan the surgical path and formulate an individualized surgical plan; accurate positioning of small pulmonary nodules during surgery can also make the surgical margins precise and clear, reducing surgical risks.[10] and has the potential to improve surgical outcomes, reduce surgical time, and minimize complications. Therefore, this study aims to use three-dimensional reconstruction technology to provide data reference for the localization effect and application value of small pulmonary nodules in VATS and to identify the importance of surgical practice in the treatment of lung cancer and potentially improve patient outcomes.

METHODS AND MATERIALS

Basic information

This study aims to compare the effectiveness of three-dimensional reconstruction technology and Hook-wire puncture operation in localizing small pulmonary nodules during VATS, this was a retrospective cohort study. The subjects of this study were 50 patients with small pulmonary nodules who were admitted to the Department of Cardiothoracic Surgery of Heilongjiang Provincial Hospital from January 2020 to December 2022. According to the intraoperative positioning method, there were 15 males and 10 females in the control group, aged 33 to 65 years old, with an average age of (50. 2 ± 6.4) years; the diameter of the lesions ranged from 7 to 23 mm, with an average diameter of was (11. 5 ± 6.3) mm. Among the 25 cases in the observation group, there were 14 males and 11 females, aged 33 to 66 years old, with an average age of (51.5 ± 6.2) years; the diameter of the lesions ranged from 7 to 25 mm, with an average diameter of (13.0 ± 6. 2) mm.

Inclusion and exclusion criteria

Inclusion criteria: (a) The nodule is located in the outer zone of the lung, and the distance between the lesion and the visceral pleura is 5 to 40 mm; (b) The maximum diameter of the small pulmonary nodule does not exceed 20 mm, and there is no enlargement of the local lymph nodes; (c) Diagnosed as single peripheral pulmonary nodule by 64-slice enhanced CT scan before surgery; (d) There was a clear pathological diagnosis after surgery, and the stage was T1M0N0; (e) Know about this study and sign the informed consent form.

Exclusion criteria: (a) History of chest surgery or combined with obvious interstitial fibrosis, pulmonary hypertension, emphysema and other diseases; (b) The distance between the nodule and the visceral pleura is less than 5 mm; (c) Those whose lesions are close to the great pulmonary vessels or combined with pulmonary vascular lesions or central or multiple pulmonary nodules; (d) Those who have bleeding tendency or severe cardiopulmonary insufficiency; (e)Those who have contraindications for surgery.

Methods

The control group underwent CT-guided Hook-wire puncture positioning 2 hours before surgery, using a Dutch 256 spiral CT machine, and the conventional plain scan was used for positioning. Before positioning, the shape and size of the nodule, the relationship between the nodule and surrounding tissue, and the distance to the pleura should be clarified based on CT images. The position setting should be combined with the location of the nodule. Place the skin locator on the puncture area, scan the chest with a high-resolution CT thin-section, measure the planned puncture depth, and select the appropriate puncture angle. When positioning, use the trocar to gradually penetrate the parietal pleura along the planned puncture path. The needle path will be observed with a CT scan and adjusted reasonably based on the situation. Once the puncture needle reaches within 1cm of the periphery of the lesion or reaches the lesion, release the Hook-wire needle to anchor the lung tissue and withdraw the trocar. After positioning, observe whether the patient feels any discomfort, and the patient will be escorted to the operating room by specialized personnel for VATS. Use gentle movements during positioning, transfer, and anesthesia to protect the Hook-wire needle from falling out.

The observation team adopted three-dimensional reconstruction technology and used a Dutch 256 spiral CT machine to carry out enhanced scanning. After scanning, the original two-dimensional CT image data was obtained. And use ORS Visual 3D image processing software to convert into 3D data, and preprocess the chest CT images through scientific calculation methods. The 3D PDF Reader software is mainly used to open it, and 3D images are obtained based on this. The lesion's size, shape, and location can be displayed. Then, the relative positional relationship between the lesion, arteries, veins, and adjacent bronchi can be observed to identify the lung segment to which it belongs. The relative distance and position of surrounding landmark points, such as the highest point of bilateral dorsal segments, bilateral lung apex, or upper and lower pulmonary veins, should be clarified to locate small pulmonary nodules.

Then, control group and observation group of patients underwent VATS. The location should be selected based on the lung lobe where the tumor is located. Three-dimensional reconstructed images and CT images should be combined to determine the surgical method. Suppose the location of the nodule has a shallow vertical distance from the pleura, and the tumor location can be judged or predicted during the operation. In that case, a pulmonary wedge resection will be performed. If the location is deep, the Hook wire puncture needle is dehooked during the operation, or the three-dimensional reconstruction technology fails to predict, and it is difficult to judge the location of the nodule by sliding the instrument or visual observation. Segmentectomy needs to be performed based on the location of the nodule growth. Pathological examination will be carried out immediately after the set-on, and a decision will be made whether to carry out radical resection of lung cancer based on the results. If the result shows benign metastases or nodules, the operation will be completed while ensuring adequate surgical margins; if the result shows primary lung cancer, lobectomy combined with lymph node dissection will be performed.

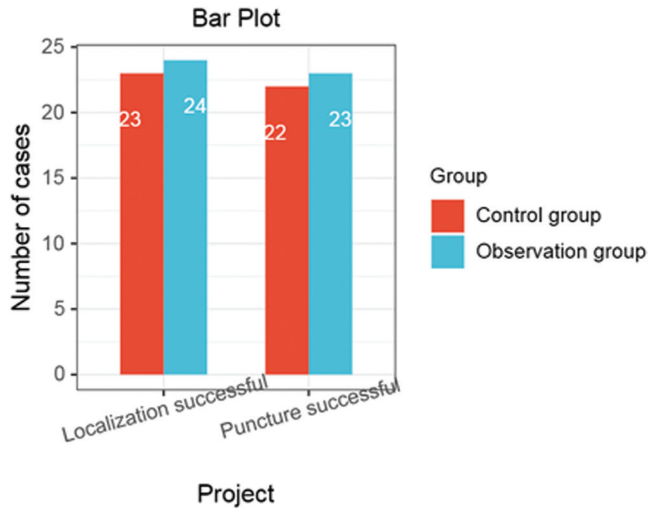
Observation indicators

(a) Nodule localization success rate and puncture success rate: Determine whether the nodule is located in the sub-pulmonary segment (such as the apical segment/dorsal segment, etc.), and at the same time, accurately display the relationship between the nodule and its surroundings, as well as the distance from the chest wall, which helps select the appropriate incision location. (b) Nodule wedge resection success rate: First, wedge resection of small pulmonary nodules was performed in the control group and observation group, and the specimens were taken out to calculate the success rate.

Table 1. Nodule localization and puncture success rate [n (%)]

Group	Localization successful	Puncture successful
Observation group (n=25)	24 (96.00)	23 (92.00)
Control group (n=25)	23 (92.00)	22 (88.00)
t	0.355	0.222
P value	.552	.637

Figure 1. Number of successful positioning and successful puncture cases in the two groups



There were small nodules inside, and the resection margin was more than 2 cm away from the lesion. (c) The visual analog scale (VAS) was used to evaluate the patient's pain level: the score ranged from 0 to 10. The higher the score, the more severe the pain. Once the score was above 1.2, it was determined to be pain caused by a puncture. (d) Postoperative observation indicators: operation time, blood loss, hospital stay, and total hospitalization costs. (e) Postoperative complications: lung infection, bleeding, and pneumothorax.

Statistical method

The data in this research were analyzed using SPSS 26.0 software, including counting and measuring data. The former is represented by "[n (%)]" and "χ^2" is used for categorical data. The latter is represented by "Mean ± Standard Deviation" and takes "t" to carry out the test for continuous data, if $P < .05$, it can be confirmed that the data difference is significant.

RESULT

Nodule localization and puncture success rate

Based on the preoperative three-dimensional reconstructed 3D image, the nodule can be accurately located in the sub-pulmonary segment (such as the apical segment/dorsal segment, etc.). At the same time, the relationship between the nodule and its surroundings and the distance from the chest wall can be accurately displayed. It is helpful to select the appropriate incision location to determine the success rate of nodule localization and puncture success rate. The results showed that the localization, and puncture success rate in the observation group was higher than that of the control group (Table 1, Figure 1), but the difference was not statistically significant ($P > .05$).

Table 2. Nodule wedge resection success rate and pain level

Group	Resection success rate (%)	VAS score (points)
Observation group (n=25)	24 (96.00)	3.10±1.20
Control group (n=25)	23 (92.00)	3.60±1.22
t	0.355	-1.461
P value	.552	.151

Figure 2. Violin plot of two sets of VAS scores

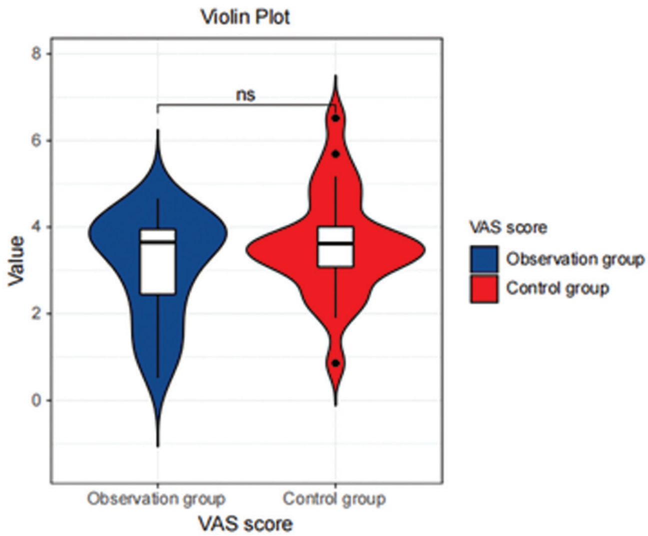


Table 3. Postoperative patient observation indicators (Mean ± Standard Deviation)

Group	Operation time (min)	Amount of bleeding (ml)	Length of stay (d)	Total hospitalization expenses (10 thousand)
Observation group (n=25)	32.25±6.08	36.08±7.21	8.30±1.20	4.23±0.40
Control group (n=25)	38.50±7.12	41.05±8.50	9.50±1.30	4.86±0.38
t	-3.338	-2.229	-3.391	-5.709
P value	.002	.030	.001	.000

Note: $P < .05$ indicates a statistical difference.

Figure 3. Violin plot of operation time and blood loss in the two groups

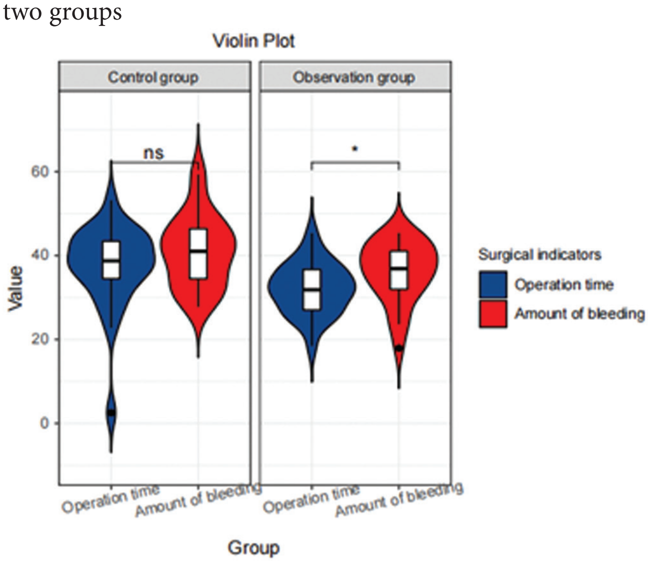


Figure 4. Violin plot of length of stay and total hospitalization costs between the two groups

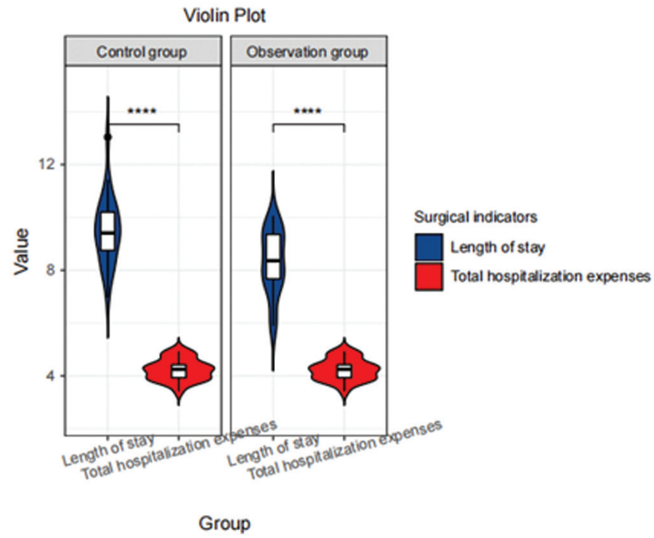


Table 4. Postoperative complications of patients [n (%)]

Group	Lung infection	Bleeding	Pneumothorax	Complication rate
Observation group (n=25)	0	1 (4.00)	0	1 (4.00)
Control group (n=25)	1 (4.00)	2 (8.00)	1 (4.00)	4 (16.00)
t	2.000			
P value	.157			

Nodule wedge resection success rate and pain level

The two groups had no statistically significant difference in wedge resection success rate and VAS score ($P > .05$). However, it can be seen from the results (Table 2, Figure 2) that the success rate of wedge resection in the observation group was higher than that in the control group, and the VAS score was lower, indicating that the pain level in the observation group was generally lower.

Comparison of surgical indicators

There were statistically significant differences in the operation time, blood loss, hospitalization time, and total hospitalization expenses between the observation and the control groupand control group (*P* all < .05) (Table 3). Moreover, compared with the control group, the operation time of the observation group was significantly shortened (32.25±6.08 vs. 38.50±7.12 minutes; $P = .002$); the blood loss in the observation group was significantly reduced (36.08±7.21vs. 41.05±8.50 ml; $P = .030$); the hospital stay in the observation group was shorter (8.30±1.20 vs. 9.50±1.30 d; $P = .001$); and total hospitalization expenses of the observation group were lower than those of the control group (Figures 3 and 4).

Comparison of surgical complication rates

The complication rate of the observation group was 4.00%, which was lower than that of the control group, which was 16.00%, and the difference was not statistically significant ($P > .05$) (Table 4).

DISCUSSION

Pulmonary nodules are divided into benign and malignant. Malignant lesions are early-stage primary lung cancer. Relevant studies have found that after effective treatment, the 5-year survival rate of early-stage lung cancer may be as high as 80% for first-stage lung cancer. Therefore, early diagnosis and treatment of malignant pulmonary nodules will significantly improve patient prognosis.[11,12] Imaging examination is an important method for diagnosing small pulmonary nodules, but ultrasound and magnetic resonance examination are easily interfered with by lung gas and have low sensitivity. X-ray examination has low sensitivity and a high misdiagnosis rate.[13] In recent years, as people's awareness of physical examination has increased, the detection rate of small pulmonary nodules has also increased yearly. However, based solely on imaging technology. The literature states that the density and size of pulmonary nodules are closely related to their malignancy. For example, the risk of malignant transformation of very small lesions, that is, the diameter is less than 5 mm, is less than 1%, and the risk of malignant transformation of tiny nodules, that is, the diameter is 5 to 10 mm, is 5% to 28%. The risk of malignant transformation for nodules with a diameter of more than 20 mm is 64% to 82%;[14–16] other literature states that solitary pulmonary nodules of 0.5 to 1cm have a 35% risk of malignancy.[17]

It has been clinically recognized that small pulmonary nodules have a high malignancy rate, tiny ground-glass nodules with fixed shapes requiring great attention. As lung cancer has become the leading cause of death from malignant tumors in my country, qualitative diagnosis and treatment of pulmonary nodules have been highly valued clinically. The key to improving prognosis is to explore new diagnostic methods to increase the early diagnosis rate and ensure the accuracy of lung cancer staging.[18] However, diagnosing small pulmonary nodules in the early clinical stages is extremely difficult, and imaging examinations lack specificity. The continuous development of thoracoscopy technology has reduced the difficulty of diagnosing and treating small pulmonary nodules to a certain extent.

The key to the success of thoracoscopic pulmonary nodule resection is preoperative positioning. In the past, positioning was done by injecting sclerosing agents and methylene blue under CT guidance. However, the operation was cumbersome, andome patients also had irritating cough symptoms and strong discomfort.[19] After the gradual development of VATS, Hookwire began to be used clinically to locate lung lesions. According to the data, the success rate is 100%, and the complications are reduced to 25%.[20] The use of this technology makes VATS easier and more intuitive. Because the lesions have loose density and are tiny, it is difficult to conduct pathological examination after surgery. Sometimes, it is even impossible to carry out a histological diagnosis because the lesions cannot be found, which affects the prognosis.[21,22] The existence of a Hook-wire positioning guide wire can quickly shorten the time to find the lesion shorten the time of VATS, which has a better effect on improving the prognosis. Three-dimensional reconstruction and positioning technology converts two-dimensional information from CT scans into three-dimensional visual data images, which can be rotated, zoomed, and observed in three-dimensional space. It can display the various imaging characteristics of small pulmonary nodules and facilitate the clinical identification of benign and malignant small pulmonary nodules, making it easier for the surgeon to plan the surgical path appropriately.

This study showed that among the 25 patients in the control group, 2 had bleeding, 1 had pulmonary infection, and 1 had pneumothorax after the puncture, with the overall incidence rate being 16.00%. Only one patient had bleeding complications during positioning using three-dimensional reconstruction techniques. The results show that this positioning technology is an invasive operation, and complications are inevitable, among which pain is the main symptom. Moreover, the three-dimensional reconstruction technology is a non-invasive positioning method with a low complication rate. This result is consistent with a previous study.[23] The results of this study also showed that the positioning success rate of the observation group was 96.00%, which was higher than that of the control group (92.00%). The operation time was (32.25±6.08) min, which was lower than that of the control group (38.50±7.12) min there were no statistically significant differences in the wedge resection success rate, VAS score, and complication rate between the two groups. It showed that three-dimensional reconstruction technology has great potential in improving the results of VATS surgery for small pulmonary nodules, reducing operation time and reducing the incidence of complications. This positioning method is confirmed to have acceptable accuracy and can be further promoted and applied in clinical practice.

Our study has several limitations that need to be addressed. Due to the small sample size of the current study and the lack of evidence-based translational research, additional evidence-based data are needed to combine evidence-based information with clinical reality to provide a more reliable basis for improving the clinical detection rate of patients. The long-term results of different positioning methods could be assessed in the future by increasing the sample size or including longitudinal studies to further confirm the safety and effectiveness of body surface localization during pulmonary nodule surgery. And to investigate the cost-effectiveness of three-dimensional reconstruction techniques compared with hook-and-wire procedures, or patient experience and quality of life outcomes after these procedures.

CONCLUSION

The three-dimensional reconstruction technology is mainly based on the preoperative CT scan image to make a preliminary judgment on nodule's location, shape, and size and relationship with the surrounding tissue. It can select the appropriate scanning position, draw up the puncture path, and anchor it in and around the small pulmonary nodule. The operation is simple, and the positioning success rate is high. Three-dimensional reconstruction technology has greater application value than traditional Hook-wire puncture surgery in terms of effect, complication rate, and operating efficiency. The existence of three-dimensional reconstruction technology positioning guide wire can quickly shorten the time to find lesions, shorten the time of VATS, reduce the occurrence of pulmonary infection in patients, and improve the prognosis. This study provides practical clinical implications for thoracic surgeons and the potential to standardize this technique in the surgical treatment of small pulmonary nodules and provides a compelling case for clinical workflow.

CONFLICTS OF INTEREST

The authors declared that they have no conflicts of interest regarding this work.

AUTHOR CONTRIBUTIONS

Jialai Zhao designed the study, Mingyue Qu wrote the manuscript, Zigeng Xu collected and analyzed data, Yiling Zhang and Chenguang Ma revised the manuscript.All authors read and approved the final submitted manuscript. Jialai Zhao and Mingyue Qu contributed equally to this article as co-first authors.

ACKNOWLEDGMENTS

This study was supported by the Heilongjiang Provincial Natural Science Foundation of China (No. YQ2019H023) and the Research Project of Health Commission Heilongjiang Province (No.2019-166).

DATA AVAILABILITY

The experimental data used to support the findings of this study are available from the corresponding author upon request.

REFERENCES

1. Sung H, Ferlay J, Siegel RL, et al. Global Cancer Statistics 2020: GLOBOCAN Estimates of Incidence and Mortality Worldwide for 36 Cancers in 185 Countries. *CA Cancer J Clin*. 2021;71(3):209-249. doi:10.3322/caac.21660
2. Jacobs C, van Rikxoort EM, Twellmann T, et al. Automatic detection of subsolid pulmonary nodules in thoracic computed tomography images. *Med Image Anal*. 2014;18(2):374-384. doi:10.1016/j.media.2013.12.001
3. Ping G, Yuhu C, Xuesong W. Classification of benign and malignant pulmonary nodules based on semantic attributes. *Electronic journal* 2476–2483 https://kns.cnki.net/kcms2/article/abstract?v=JhhVyKSVrEjO9iz0mppM0ppdS06wEL-ULEK0NTxSSD7jHAzbgPv433dJvGPS_4jLFO9ADpiI4Vivvtt4UaBcjwhmujm8Oji1kFCqY_h8b5iMeIBbkE-4AmIMplbU6kFCEBJr7NK2HhvKe0fWBUcqKw==&uniplatform=NZKPT&language=CHS (2015).
4. Zhang H, Li Y, Yimin N, He Z, Chen X. CT-guided hook-wire localization of malignant pulmonary nodules for video assisted thoracoscopic surgery. *J Cardiothorac Surg*. 2020;15(1):307. doi:10.1186/s13019-020-01279-9
5. Yan G, Cheng X, Wu S, Ge Y, Li S, Xuan Y. Clinical value and application of preoperative CT-guided hookwire localization of solitary pulmonary nodules for video-assisted thoracic surgery. *Technol Health Care*. 2022;30(S1):459-467. doi:10.3233/THC-THC228042
6. Yang Y, Qin C, Ma Y, Lu Z, Zhang Y, Li T. Application of computed tomography-guided hook-wire localization technique in thoracoscopic surgery for small pulmonary nodules (≤10 mm). *J Cardiothorac Surg*. 2023;18(1):99. doi:10.1186/s13019-023-02188-3
7. Tongxin L, Jing X, Runyuan W, et al. Application Research of Three-Dimensional Printing Technology and Three-Dimensional Computed Tomography in Segmentectomy. *Front Surg*. 2022;9:881076. doi:10.3389/fsurg.2022.881076
8. Kong Y, Xu H, Huang Y, Lv X, Ye X. Recent advances in nonsurgical treatment of pulmonary ground-glass nodules. *J Cancer Res Ther*. 2022;18(2):323-328. doi:10.4103/jcrt.jcrt_2030_21
9. Wang Z, Li Y, Yu J, Cai H, Wang Y. Combined indocyanine green and medical glue enables stable and precise position in animal studies: promising for fluorescence-guided pulmonary ground glass nodule resection. *Transl Lung Cancer Res*. 2023;12(9):1923-1934. doi:10.21037/tlcr-23-553
10. Vervoorn MT, Wulfse M, Mohamed Hoesein FAA, Stellingwerf M, van der Kaaij NP, de Heer LM. Application of three-dimensional computed tomography imaging and reconstructive techniques in lung surgery: A mini-review. *Front Surg*. 2022;9:1079857. doi:10.3389/fsurg.2022.1079857
11. Sekimura A, Funasaki A, Iwai S, Motono N, Usuda K, Uramoto H. Thoracoscopic small pulmonary nodule detection using computed tomography-guided cutaneous marking and pleural marking. *J Thorac Dis*. 2019;11(7):2745-2753. doi:10.21037/jtd.2019.06.68
12. Nardini, M. & Dunning, J. Pulmonary nodules precision localization techniques. *10.2217/fon-2019-0069* 16, 15–19 (2020).
13. Wang C, Gao A, Shi F, Hou X, Ni P, Ba D. Three-dimensional Reconstruction and Growth Factor Model for Rock Cracks under Uniaxial Cyclic Loading/Unloading by X-ray CT. *Geotech Test J*. 2019;42(1):117-135. doi:10.1520/GTJ20170407
14. Ren YY, Li YC, Wu HB, et al. [Combined use of thin-section CT and ^{18}F-FDG PET/CT for characterization of solitary pulmonary nodules]. *Nan Fang Yi Ke Da Xue Xue Bao*. 2017;37(3):283-289.
15. Li CR, Yu QL, Yang B, Zhang B, Liu Y. [Clinical value of holographic multimodal real-time three-dimensional navigation technology in the surgical location of pulmonary lesions]. *Zhonghua Yi Xue Za Zhi*. 2020;100(31):2452-2456.
16. Pan H, Zou N, Tian Y, et al. Short-term outcomes of robot-assisted versus video-assisted thoracoscopic surgery for non-small cell lung cancer patients with neoadjuvant immunochemotherapy: a single-center retrospective study. *Front Immunol*. 2023;14:1228451. doi:10.3389/fimmu.2023.1228451
17. Xu J, Si T, Zheng M, Guan J, Li Z, Xu Z. CT guided autologous blood localization of pulmonary ground glass nodules for video assisted thoracoscopic surgery compared to micro-coil localization. *J Cardiothorac Surg*. 2022;17(1):183. doi:10.1186/s13019-022-01934-3
18. Gallego-Herrero C, López-Díaz M, Coca-Robinot D, Cruz-Conde MC, Rasero-Ponferrada M. CT-guided hook-wire localization of pulmonary nodules in children prior to atypical resection by thoracoscopy: practical aspects. *Radiologia (Engl Ed)*. 2021;63(5):415-424. English Edition. doi:10.1016/j.rxeng.2021.06.001
19. Wang Y. Video-assisted thoracoscopic surgery for non-small-cell lung cancer is beneficial to elderly patients. *Int J Clin Exp Med*. 2015;8(8):13604-13609.
20. Su KW, Singhal S, Sarkaria IS. Intraoperative imaging and localization techniques for part-solid nodules. *JTCVS Tech*. 2021;10:468-472. doi:10.1016/j.xjtc.2021.10.028
21. Li H, Liu Y, Ling BC, Hu B. Efficacy of thoracoscopic anatomical segmentectomy for small pulmonary nodules. *World J Clin Cases*. 2020;8(11):2227-2234. doi:10.12998/wjcc.v8.i11.2227
22. Zuo T, Gao Z, Zhang T, Wen B, Chen B, Jiang P. Preoperative small pulmonary nodule localisation using hookwires or coils: strategy selection in adverse events. *J Cardiothorac Surg*. 2023;18(1):237. doi:10.1186/s13019-023-02301-6
23. Zhao L, Yang W, Hong R, Fei J. Application of three-dimensional reconstruction combined with dial positioning in small pulmonary nodules surgery. *J Cardiothorac Surg*. 2021;16(1):254. doi:10.1186/s13019-021-01642-4