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Original Article

Retrospective Evaluation of Safety of Using a Semi-automatic Robotic System for Transthoracic Biopsy of Lung Mass Under Positron Emission Tomography-computed Tomography Guidance

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ABSTRACT

OBJECTIVE: Lung cancer poses unique challenges due to heterogeneity in tumor and metastatic cellular composition. The use of ^{18}F-fluorodeoxy glucose positron emission tomography-computed tomography (^{18}F-FDG PET-CT) integrates functional and anatomical imaging. This study assessed the safety and diagnostic yield of PET-CT–guided transthoracic needle biopsy for intrathoracic mass lesions using a semi-automatic robotic system.

MATERIAL AND METHODS: Forty consecutive patients underwent whole-body PET-CT imaging following which they underwent transthoracic biopsy, using a semi-automatic robotic biopsy system (Maxio™ III; Perfint Healthcare Pvt Ltd., Chennai, Tamil Nadu, India), consisting of docking system, digital screen and a stereotactic arm. Clinicodemographic profile, PET-CT and biopsy findings, histopathology reports, and complications were retrieved from patient records.

RESULTS: The mean age of the patients was 57.08±12.39 years, and the mean maximum standardized uptake value was 16.71±8.61. PET-CT revealed a unilateral lung mass in 92.5% (n = 37) and bilateral lesions in 7.5% (n = 3) of patients. Heterogeneous ^{18}F-FDG uptake was noted in 97.5% (n = 39). The average target lesion distance was 40±12.7 mm. At least four biopsy cores were obtained in all patients except one. Core length was 2 cm in 90% of cases. The most common complication was local pain, followed by pneumothorax in 12.5% (n = 5). Tissue was adequate for analysis in all cases. None of the patients had to undergo repeat PET-CT or biopsy. The diagnostic yield was 100%, with malignancy in 82.5% (n = 33), acute inflammation in 10% (n = 4), and tuberculosis in 7.5% (n = 3). 50% (n = 20) underwent next-generation sequencing for targeted mutation testing.

CONCLUSION: Semiautomatic robotic assistance can be a safe option for diagnosing intrathoracic mass lesions, with an acceptable diagnostic yield.

KEYWORDS: Lung cancer, lung biopsy, positron emission tomography, robotic biopsy, thoracic imaging

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INTRODUCTION

Lung cancer is the second most common cancer, accounting for 11.4% of all cancers and 18% of the 1.7 million cancer-related deaths. The five-year survival still varies between 10-20% due to delayed presentation.[1] A suspicious nodule once detected radiologically, obtaining an adequate tissue sample is vital for immunohistochemical analysis and for detecting gene mutation of cancer.[2] Computed tomography (CT)-guided transthoracic needle biopsy (TTNB) is reliable, with diagnostic accuracy varying between 70-93%.[3] However, TTNB may yield non-diagnostic results when lung masses are associated with fibrosis, atelectasis, necrosis, or obstructive pneumonia, which is not uncommon.[4] ^{18}F-fluorodeoxy glucose positron emission tomography (^{18}F-FDG PET)-CT serves as an important imaging modality for diagnosis and treatment planning in patients with lung cancer. It is essential for staging and response evaluation at follow-up.[5,6] ^{18}F-FDG PET-CT can detect viable tumor cells within a mass that contain nonmalignant areas like necrosis, fibrosis and collapsed lung due to differential uptake of ^{18}F-FDG thereby improving diagnostic yield.[7] Additionally, PET-CT–guided TTNB aids in acquiring better quality samples for further immunohistochemistry and genomic studies.[8,9]

The successful experience of use of semi-automatic robotic system is mainly from liver biopsies and experience of using it in lung is limited to a few studies[10,11] and case reports.[12] There is a dearth of data on the real-life safety and diagnostic yield of such a procedure for lung masses. This is a retrospective evaluation of our initial experience using semi-automatic robot-guided biopsy of lung masses.

MATERIAL AND METHODS

This retrospective study was conducted in the departments of Pulmonary, Critical Care and Sleep Medicine and Nuclear Medicine, All India Institute of Medical Sciences (AIIMS), Raipur, India from October 2022 to May 2024. The study was approved by the Institute Ethics Committee of AIIMS Raipur vide letter no: OW/RC/AIIMS-RPR/2022/1028 dated 4th February 2022 and conducted as per recommendations of amended declaration of Helsinki. Informed written consent was obtained from all patients undergoing biopsy. Inclusion criteria: patients aged more than eighteen years and willing to undergo a biopsy procedure were included in the study. Exclusion criteria were: patients aged less than eighteen years, hemodynamic instability, inability to lie down, coagulopathy, and active hemoptysis.

Main Points

- Diagnosis of intrathoracic mass lesions can be challenging, particularly for lesions located deep inside the thorax or with internal necrosis.
- Positron emission tomography-computed tomography can improve tumor sampling by targeting ^{18}F-fluorodeoxy glucose-avid areas of the tumor, thereby improving diagnostic yield and potentially reducing complications.
- Semi-automatic robotic systems can improve tumor sampling by guiding to the preferred area within the tumor and safety by avoiding surrounding by vascular structures and has the potential to improve diagnostic yield.

^{18}F-FDG PET-CT Imaging Technique

All PET-CT scans were conducted using a GE DISCOVERY MIDR PET-CT scanner (GE Healthcare, Milwaukee, Wisconsin, USA). The scans were performed after six hours of fasting. Prior to the scan, fasting blood glucose was checked; if the levels were below 150 mg/dL, ^{18}F-FDG was injected. The scans were performed 45–60 min after injection. Images were acquired from the vertex to the thigh in 7 to 8 bed positions, with an acquisition time of 1 to 2 minutes per bed position. PET images were reconstructed using iterative methods. Patients were taken for biopsy when slots became available on the same day. The resulting images were then transferred to the semiautomatic robotic biopsy system.

Biopsy Procedure

We followed the CIRSE Guidelines on Percutaneous Needle Biopsy, incorporating PET-CT guidance for optimal targeting.[13] Biopsy was performed by a team of nuclear physician and pulmonologist using a semi-automatic robotic biopsy system under ^{18}F-FDG PET-CT guidance.[14]

Semiautomatic Robotic Biopsy System (Maxio™ III; Perfint Healthcare Pvt Ltd, Chennai, Tamil Nadu, India)

The system features a docking system that can be adjusted on either side of the patient bed, a digital screen for 2D and 3D visualization of the lesion and planning the biopsy. It also includes a stereotactic arm with the ability to move in 5 degrees of freedom along axes X, Y, Z, A, and B, providing sub-millimeter and sub-degree accuracy. The arm is equipped with a needle holder, a stabilizer, and a gripper with specifically sized bushes to hold a coaxial needle. Figure 1 describes the biopsy system used.

Positioning and Planning Before the Procedure

After establishing the biopsy plan, the patient was immobilized in a vacuum-assisted immobilizer on the PET-CT table. A thoracic ^{18}F-FDG PET-CT (120 kVp, 40 mA, 1.25 mm section thickness, 1 mm section interval) was reconstructed for biopsy planning. This imaging decisively identified the target point within the lung mass with the highest ^{18}F-FDG avidity and the skin entry point. Other key aspects such as needle trajectory, lesion depth, and angulations were determined using the automated robotic-arm system. The interventionist assessed the planned trajectory in relation to nearby organs. Once the robotic system was actuated, the stereotactic arm automatically positioned itself according to the planned coordinates on the console.

Coaxial Needle Placement

The site of entry was cleaned and draped. 7–10 mL of lidocaine 1% was infiltrated into the skin and the target area. A suitable bush and bush-adaptor assembly was then mounted in the end effector of the robotic arm. This was done to firmly hold and guide the needle along the planned trajectory. An 18-gauge ×20-cm coaxial core biopsy system (Bard Mission; BD) was

Figure 1. ^{18}F-FDG PET-CT–guided coaxial core needle biopsy using a robotic stereotactic navigation platform. A) Robotic arm–based guidance system (Perfint MAXIO) integrated with the PET-CT gantry, docked on the right side of the gantry with the patient positioned supine. B) Laser cross-hair projection onto the marked skin entry site over the chest wall, localising the planned puncture point. C) Navigation workstation display with a three-dimensional skeletal reconstruction, fused axial PET-CT images of the hypermetabolic left lung mass target, and trajectory parameters (needle length, orbital and craniocaudal angles, target depth, table height) for reproducible metabolically guided sampling

^{18}F-FDG: ^{18}F-fluorodeoxy glucose, PET-CT: positron emission tomography-computed tomography

manually introduced through the bush and advanced through the skin (entry site) to reach the target site. After the bush and adaptor were detached from the robotic arm, the coaxial needle placement was confirmed by a regional computed tomogram (120 kVp; 40 mA; section thickness, 1.25 mm; interval, 1 mm), and multiple specimen cores were obtained using the biopsy system. We tried to obtain a maximum of four tissue cores from all patients through a single puncture site. The samples were collected in both formalin and 0.9% normal saline. Haemostasis was achieved by slowly pulling out the needle during expiration, followed by manual compression. After the procedure, a chest CT scan was performed to assess for any post-procedural complications, such as bleeding or pneumothorax. Figure 2 shows the procedural images of the biopsy. After the procedure, participants were observed for a day in the day-care ward. Pain was assessed using the visual analogue scale (VAS).

Statistical Analysis

As there are no robust data on the diagnostic yield of using a semi-automatic robotic system for lung mass biopsies with PET-CT guidance, this pilot study included 40 consecutive patients at the time of this analysis. Demographic characteristics, clinical history, PET-CT findings, details of the procedure, histopathological findings, and complications were retrieved from these patients' records. The data were entered into Microsoft Excel 2023 and analyzed using the IBM SPSS version 20.0 (IBM Corp, Armonk, USA). The quantitative variables were expressed as means and standard deviations (SD). Categorical data were expressed as percentages.

RESULTS

All 40 patients were included in the analysis. The mean ± SD age was 57.08±12.39 years. Thirty-one patients (77.5%) were male. Thirty patients (75%) were symptomatic for more than two months. The most common symptom reported was cough (87.5%, n = 35), followed by dyspnea (47.5%, n = 19). The mean ± SD maximum standardized uptake value was 16.71±8.61. Table 1 shows the dimensions of lung lesions on PET-CT. Three (7.5%) patients had mass lesions abutting the diaphragm; 2 (5%) patients each had mass lesions abutting the pericardium and the aorta; and 1 (2.5%) had a mass lesion near the pulmonary trunk. The mean ± SD target distance from the lesion was 40±12.7 millimeters (mm). Four biopsy cores were obtained in all patients except one, in whom three cores were obtained due to excessive bleeding. The core length was 2 centimeters (cm) in 36 (90%) patients. Complications observed in the study were minor local site pain (100%), median [interquartile range (IQR)] VAS score was 1 (1–2), excessive cough (15%), pneumothorax in 5 patients (12.5%). One patient had excessive local biopsy site bleeding, which was managed with local pressure bandage application. All complications were successfully managed conservatively. The diagnostic yield of the procedure was 100%. The most common diagnosis was malignancy (82.2%, n = 33), followed by acute inflammatory lesions in 4 patients (10%). Three (7.5%) patients were diagnosed with tuberculosis. Patients with acute inflammatory lesions and those with tuberculosis were followed up after treatment and were found to have radiological resolution. Table 2 shows the diagnostic outcomes of the biopsies performed in the study.

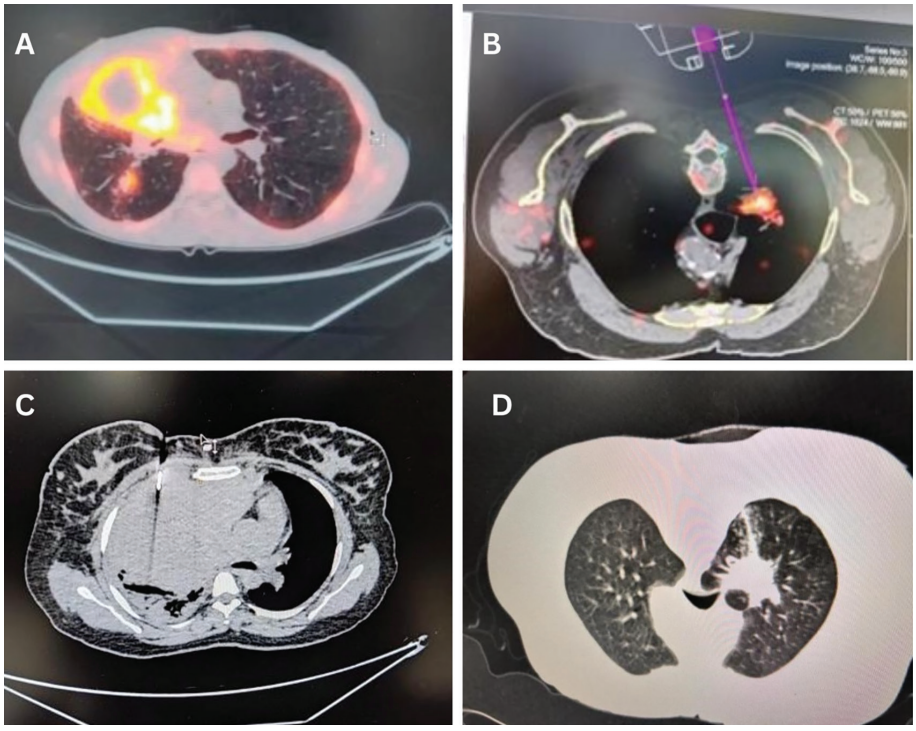

Figure 2. PET-CT–guided coaxial core needle biopsy of lung lesion. A) Axial fused PET-CT image shows a heterogeneously hypermetabolic right lung mass with a photopenic, necrotic core and intense peripheral ^{18}F-FDG uptake, which represents the metabolically viable component selected for sampling. B) Fused axial PET-CT with the planned magenta trajectory directed toward a focal ^{18}F-FDG-avid left lung nodule; the target lesion is indicated, illustrating metabolically guided targeting. C) Axial CT soft-tissue window confirming coaxial core needle placement within the lung mass, with the needle tip indicated prior to tissue acquisition. D) Axial CT lung window depicting the post-procedural bleeding along biopsy tract within the lung parenchyma

PET-CT: positron emission tomography-computed tomography, ^{18}F-FDG: ^{18}F-fluorodeoxy glucose

Table 1. Features of lung masses in PET-CT scan (n = 40)

Variable	
SUV_{max} (mean ± SD)	16.71±8.61
AP diameter in cm (mean ± SD)	5.20±2.53
Transverse diameter in cm (mean ± SD)	4.80±2.46
Cranio-caudal diameter in cm (mean ± SD)	6.79±4.11
	n (%)
Unilateral lung mass	37 (92.5%)
Bilateral lung mass/nodules	3 (7.5%)
Heterogeneous ^{18}F-FDG enhancement	39 (97.5%)

PET-CT: positron emission tomography-computed tomography, SUV_{max}: maximum standardized uptake value, SD: standard deviation, AP: anteroposterior, cm: centimeters, ^{18}F-FDG: ^{18}F-fluorodeoxy glucose

Table 2. Diagnosis established via PET-CT–guided lung mass biopsy (n = 40)

Diagnosis	**n (%)**
Lung adenocarcinoma	20 (50%)
Inflammatory lesion	4 (10%)
Lung squamous cell carcinoma	3 (7.5%)
Metastatic adenocarcinoma from GI system	3 (7.5%)
Tuberculosis	3 (7.5%)
Lung adenosquamous carcinoma	2 (5%)
Small cell cancer lung	2 (5%)
Metastasis from breast cancer	1 (2.5%)
Metastasis from FCT	1 (2.5%)
Neuroendocrine tumor	1 (2.5%)

PET-CT: positron emission tomography-computed tomography, GI: gastrointestinal, FCT: follicular carcinoma of the thyroid

DISCUSSION

Early detection of primary tumors greatly improves the chances of successful intervention and better outcomes. Tumor sampling is the cornerstone for diagnosing lung cancer and for guiding treatment through molecular and genetic testing. Various biopsy techniques, such as fiberoptic bronchoscopy, endobronchial ultrasound-guided biopsy, navigation bronchoscopy, and percutaneous biopsy, are currently in use.[15] Percutaneous lung biopsy, a minimally invasive procedure, is performed under ultrasonography, CT, and PET guidance to ensure accurate lesion targeting. But ultrasound and CT is unable to differential viable tumor from necrosis to a large extent, while CT-guided biopsy carries the drawback of increased radiation exposure and a false-negative rate of up to 10-24%.[16,17] Technological advancements such as laser targeting, augmented reality, and interventional robotic systems have been introduced to improve yield.[18,19] PET-CT-guided biopsies are particularly useful, as increased ^{18}F-FDG uptake is seen in metabolically active tumor cells within a mass lesion, enabling precise targeting and successful biopsy procedures, thus overcoming the limitations

of CT-guided biopsies.[7,16,17] In India, limited studies have been conducted on the use of robotic biopsy systems for lung lesions. Results of our study demonstrated a diagnostic yield of 100%, and the most common diagnosis was lung adenocarcinoma (50% of patients). As per our institutional protocol, all samples of adenocarcinoma were tested for targeted mutations by next-generation sequencing, and the samples were adequate for mutation testing. The results of our study are in line with previous studies and highlight the advantages of PET-CT guidance in obtaining biopsies from peripheral thoracic lesions.

A study conducted by Cerci et al.[7] and Guralnik et al.[8] found that PET-CT–guided TTNB was superior than other conventional methods, including CT–guided TTNB, since fewer repeat procedures were required using PET-CT– guided biopsy, with improved diagnostic yield. Radhakrishnan et al.[20] performed robotic-assisted PET-CT–guided biopsy for thoracic lesions on 25 patients with a diagnostic yield of 100%, similar to our study suggesting that PET-CT–guided TTNB effectively improves success rate of obtaining biopsy from peripheral thoracic lesions.

In the present study, pneumothorax occurred in 12.5% of cases; this incidence is comparable to previous studies of CT–guided TTNB, which reported an incidence of 5-25%.[21] Nath et al.[22] in their study reported pneumothorax and hemothorax each in 4% (n = 1) patients. The VAS score for pain was 1 (IQR: 1–2) following biopsy. All these findings highlight the results of previous studies indicating that PET-CT–guided TTNB is a safe technique for obtaining biopsy from peripheral thoracic lesions and do not carry any additional risk when compared to CT–guided TTNB.[9]

The diagnostic yield of PET-CT-guided TTNB in the current study surpassed that of previously reported traditional CT-guided TTNB, reinforcing the importance of PET-CT in identifying appropriate target lesions for obtaining biopsies from peripheral thoracic lesions. However, this finding should be interpreted with caution due to the pilot nature of the study and its small sample size. Piacentino et al.[9] in their study found that TTNB obtained under PET-CT guidance improved the sample adequacy for performing molecular studies for targeted therapies similar to our study. While the current study demonstrates the safety of PET-CT–guided TTNB, there are certain limitations that should be acknowledged. The sample size (n = 40) is relatively small, and the generalizability of the results to a larger population needs to be further explored. Additionally, a head-to-head comparison with CT-guided biopsy in the same patient cohort would have provided stronger evidence supporting the superiority of PET-CT-guided biopsy. Further research is needed to weigh the benefit of early and better diagnostic yield with high cost involved in PET-CT–guided TTNB on lung cancer management.

CONCLUSION

This study demonstrates that PET-CT-guided TTNB is a safe technique for sampling intrathoracic mass lesions, with good diagnostic yield and a similar safety profile even in tumors with internal necrosis. Future large-scale studies can further validate these results and explore additional clinical applications of PET-CT in interventional pulmonology.

Ethics

Ethics Committee Approval: The study was approved by the Institute Ethics Committee of AIIMS Raipur vide letter no: OW/RC/AIIMS-RPR/2022/1028 dated 4th February 2022 and conducted as per recommendations of amended declaration of Helsinki.

Informed Consent: Informed written consent was obtained from all patients undergoing biopsy.

Footnotes

Authorship Contributions

Surgical and Medical Practices: M.R., R.G., R.K., P.P., Concept: M.R., R.G., A.K.B., P.K.D., R.V., Design: M.R., R.G., R.K., P.P., P.K.D., R.V., Data Collection or Processing: M.R., R.G., R.K., P.P., P.K.D., R.V., Analysis or Interpretation: M.R., R.G., P.P., A.K.B., P.K.D., R.V., Literature Search: M.R., R.G., R.K., P.P., A.K.B., P.K.D., R.V., Writing: M.R., R.G., R.K., P.P., A.K.B., P.K.D., R.V.

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