



Robot-Assisted Lung Biopsy: A Safer Approach to Lung Lesions

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Abstract

Purpose This article evaluates the feasibility, safety, and technical success of robot-assisted computed tomography (CT)-guided percutaneous lung biopsy.

Methods CT-guided lung biopsy was performed after clearance from the institutional ethical committee in 60 patients who were assigned to two groups, group A (robot-assisted biopsy) and group B (conventional CT-guided biopsy). The accuracy of needle placement, number of needle adjustments, radiation dose, procedure time, and complications were compared in both these groups.

Results In group A, the procedure duration was significantly shorter ($p = 0.001$), dose length product, lower ($p = 0.001$), accuracy of needle placement, superior ($p = 0.003$), and complication rates were lower ($p = 0.002$) compared with conventional CT guided biopsy.

Conclusion Robotic assistance during CT lung biopsy is associated with improved targeting of lesions with more diagnostic yield and less procedure duration, radiation exposure, and fewer complications compared with conventional CT lung biopsy.

Keywords

- ▶ CT-guided lung biopsy
- ▶ robotic biopsy
- ▶ lung cancer
- ▶ interventional radiology

Introduction

Computed tomography (CT)-guided percutaneous lung mass biopsy is a well-established and safe alternative to excisional biopsy. The overall success of CT-guided percutaneous biopsy in safely retrieving adequate tissue depends on adequate lesion visualization, accurate needle placement, and targeting of the lesion. The efficacy of this technique is often hampered by multiple factors, including respiratory/cardiac motion, difficult angulated access, limited space at the entry site, and changing target location under mechanical pressure in soft tissues.^{1–3} CT-guided biopsy can be performed manually using conventional CT or CT fluoroscopy. Recently, the introduction of robot assistance for CT-guided biopsies has

provided a tool that can overcome many of the limitations of conventional CT-guided biopsy. Replacement of the human component with the robot-based navigation system for needle placement (but not the planning) has been proposed in studies^{4–8} and performed in phantom models.^{9,10} The MAXIO (Perfint Healthcare Pvt. Ltd, Chennai, Tamil Nadu, India) robotic system facilitates percutaneous needle placement during CT-guided interventional procedures and has been successfully tested for CT-guided biopsy on phantoms and for radiofrequency ablation of liver lesions in humans. The aim of this study was to evaluate the feasibility, safety, and technical success of robot assistance in performing CT-guided percutaneous lung biopsies.

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Materials and Methods

Patient Population and Study Details

This study was a prospective observational hospital-based study performed between June 2021 and December 2021, after clearance from the institutional ethical committee. Sixty patients with previously diagnosed lung lesions suspicious of malignancy on chest CT, positron emission tomography-CT, or both were referred to our department for CT-guided biopsy. Among these patients, 48 were males and 12 females. The age ranged from 45 to 72 years (mean age 63 ± 4 years). The patients were assigned to group A (robot-assisted procedure) or group B (conventional procedure) as per patients requirement assessed by senior experienced radiologist. All enrolled patients gave their written informed consent to participate after being thoroughly informed of the benefits and potential risks of the procedure.

Preprocedure

All procedures were performed on a 32-multidetector CT scanner (Somatom Sensation 32, Siemens Medical Solutions). A standard inspiratory breath-hold scan of the chest (100 kV, 100 mAs, detector configuration 32×1 mm, slice thickness 1 mm, reconstruction interval 1 mm) was acquired in all cases prior to biopsy to confirm the presence and to assess the position of the target lesion. Patients were laid on a vacuum stabilization mattress and positioned to minimize the intrapleural path of the biopsy needle, as well as to avoid critical lung structures (vessels, bronchi, and fissures) during the biopsy. Local anesthesia was achieved by injecting 10 mL of 1% lidocaine along the projected path of the biopsy needle into the soft tissues, down to the epipleural space. In all cases an 18-G, 111-mm coaxial needle was used. CT scans were acquired with a low-dose interventional protocol (100 kV, 50 mAs, detector configuration 32×1 mm, slice thickness 1 mm, reconstruction interval 1 mm).

Conventional Biopsy Technique

All conventional biopsies were performed using the conventional helical CT technique to assess needle positioning and angulation. The z-axis extension of targeting scans was limited to include only the needle and the target lesion. A minimum of two scans (before the pleura and into the lesion) were required to target lesions adjacent to the chest wall and a minimum of three scans (before the pleura, midway to the lesion, into the lesion) was required for deeper lesions. Additional scans and multiplanar reconstructions were performed in real-time when necessary for needle adjustment. Once the needle tip was in position, a biopsy was performed.

Robot-Assisted Biopsy Technique

The robotic system was positioned and docked, and the arm and planning console were placed to the side of the CT bed (to the left or right, depending on the desired access). They were firmly attached to the ground through metal floor plates to provide stability. A preliminary inspiratory breath-hold CT of the chest was performed using a breath-hold respiratory belt coupled to a light sign mounted on a flexible arm, to monitor

the extent of chest movement and instruct patients to maintain and reproduce proper apnea. Images were then exported over a local area network to the MAXIO workstation for biopsy planning. The center of the target lesion and the entry point on the skin were determined by the operator, while the angulations of the needle, the depth of the target, and the needle path were automatically calculated by the workstation and displayed in real-time (**►Fig. 1**). Each parameter was readily modifiable by the operator to avoid critical structures, such as ribs, bronchi, and vessels. Once the plan was confirmed, the CT table was moved to the coordinates displayed on the workstation, and the robotic arm was activated and positioned for biopsy execution. A plastic holder with a disposable bush was placed at the end effector of the robotic arm to guide needle insertion. Subsequently, the needle was manually inserted through the chest wall directly into the lesion in a single pass, while the patient maintained a breath-hold to the same extent as that of the initial positioning CT scan, guided by the light sign coupled to the respiratory belt. After decoupling the needle from the end effector and retraction of the robotic arm, needle positioning was confirmed again with a CT scan (**►Figs. 2 and 3**) and adjustments were performed if required. Biopsy was then performed similar to the conventional approach.

Data Analysis

The two groups were matched for the age of the patients, size of the lesion, distance from the entry point, and location of the target lesion in the lung.

Technical success of the procedure was evaluated in both groups. The procedure was considered technically successful if the intended lesion was targeted and biopsy specimen acquired.

The following parameters were evaluated in the two groups. A difference was considered significant if the *p*-value was < 0.01 .

1. Procedure duration (from first planning CT to post-biopsy scan) and radiation dose were compared with the unpaired sample *t*-test.
2. Number of needle adjustments was compared with the unpaired sample *t*-test.
3. Planar and craniocaudal deviations of the needle tip from the planned target were calculated in millimeters and compared between the two groups with an unpaired sample *t*-test.
4. Qualitative diagnostic performance of the biopsy procedures was evaluated and compared with the Mann-Whitney test.
5. Complication rate in the two groups was evaluated and compared using Mann-Whitney *U* test.

Results

All biopsies were successfully performed under CT guidance in both groups. Lesions size ($p = 0.39$), distance from entry point ($p = 0.78$), and lesions location ($p = 0.41$) were similar in both the groups. Full results of the homogeneity assessment of the two groups are given in **►Table 1**.

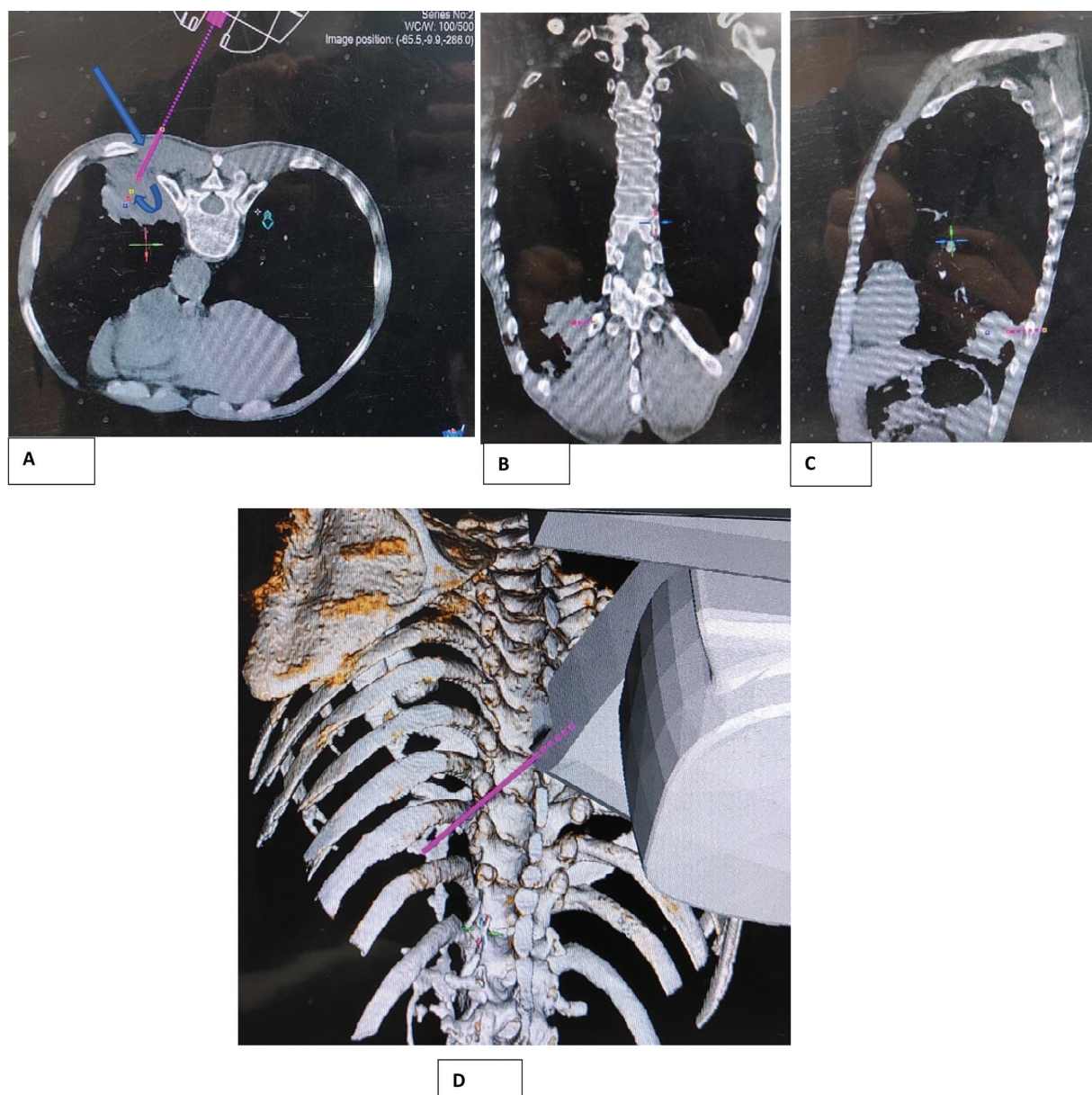


Fig. 1 Biopsy planning on the MAXIO workstation. Biopsy of target lesion located in the right lower lobe was planned. The entry point on the skin (A, arrow) and center of target lesion (A, curved arrow) are determined by the operator. The angulations and insertion path of the needle are automatically calculated by the workstation and displayed in real time. Coronal (B), sagittal (C), and volumetric rendering technique (VRT) images (D) help further in proper planning.

In group A, the procedure duration was significantly shorter ($p=0.001$), dose length product was lower ($p=0.001$), and occasional needle adjustments were required as compared with group B. Planar and craniocaudal deviations of the needle tip from the planned target were less common in group A as compared with group B ($p=0.003$). The diagnostic performance of CT-guided biopsies was similar in both the groups ($p=0.05$), with two patients in group A and three patients in group B requiring repeat biopsy due to inadequate quality of the biopsy sample. The rate of major complications (such as hemothorax, pneumothorax) was higher in group B as compared with group A ($p=0.002$) (►Table 2).

Discussion

CT-guided intervention is a well-established technique in the diagnosis and treatment of different pathologies including malignancies. The conventional technique for CT-guided interventional procedures can be performed using conventional CT or CT fluoroscopy. Even if the clinical performance of these conventional approaches is highly reliable in expert hands,^{11–14} conventional techniques require multiple needle adjustments depending on the experience of interventional radiologists, multiple intraprocedural scan acquisitions which prolong the procedure duration, as well as patient radiation exposure and the risk of complications. With an aim to reduce such operator

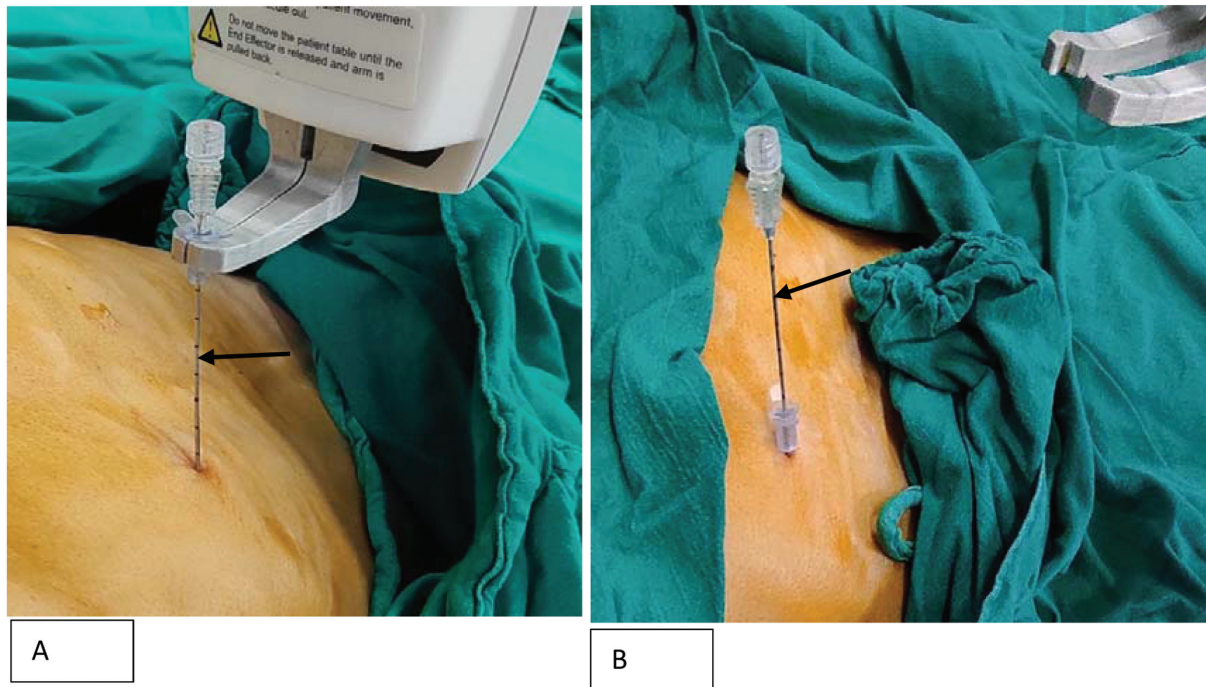


Fig. 2 Needle insertion through the chest wall directly into the lesion in a single pass (A, arrow). Needle in final position (B, arrow) after detachment from end effector and retraction of the robotic arm.

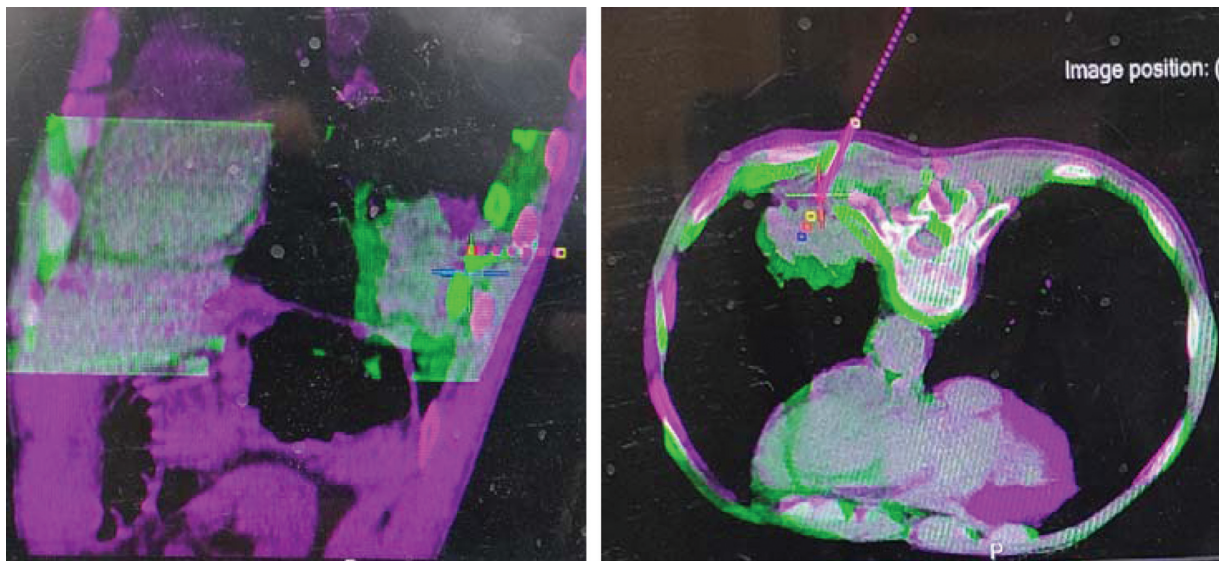


Fig. 3 Overlapping between the planned needle path (green line) and the actual needle position at the end of insertion. Robot-assisted biopsy allowed correct sampling of tumor tissue avoiding atelectasis. Final histological diagnosis was adenocarcinoma.

Table 1 Full results of the homogeneity assessment of the two groups

Parameters	Group A	Group B	p-Value
Lesion size (mm)	33 ± 11 (range 20–110 mm)	29.5 ± 6.5 (range 22–98 mm)	0.39
Distance from entry point (mm)	65 ± 6.5 (range 23–109)	67 ± 5.6 (range 25–110)	0.78
Lesion location	RUL (n = 3) LUL (n = 3) RML (n = 1) RLL (n = 13) LLL (n = 10)	RUL (n = 2) LUL (n = 2) RML (n = 1) RLL (n = 14) LLL (n = 11)	0.41

Abbreviations: LLL, left lower lobe; LUL, left upper lobe; RLL, right lower lobe; RML, right middle lobe; RUL, right upper lobe.

Table 2 Result of assessment of clinical and technical performance of two groups

Parameters	Group A	Group B	p-Value
Procedure duration (min)	30.1 ± 9.3 (range 15–40)	40.4 ± 11.2 (range 18–50)	0.001
DLP (mGy)	423 ± 111.7 (range 124–482)	624.2 ± 424.8 (range 313–680)	0.001
Number of needle adjustments	1.3 ± 1.1 (range 0–3)	4.9 ± 2.1 (range 2–9)	0.002
Deviation on the X and Y axis (mm)	2.5 ± 1.5 (x), 2.8 ± 1.6 (y) (range 2–8)	4.9 ± 2.1 (x), 5.4 ± 2.2 (range 4–13)	0.003
Final diagnosis	9 ADCA, 11 SCC, 4 SCLC, 4 metastasis, 2 benign	15 ADCA, 8 SCC, 4 SCLC, 2 metastasis, 1 benign	0.05
Complications (%)	2	9.2	0.002

Abbreviations: ADCA, adenocarcinoma; DLP, dose length product; SCC, squamous cell carcinoma; SCLC, small cell lung carcinoma.

dependence, various devices have been developed and tested from time to time in clinical practice, including the external laser¹⁵ or optical¹⁶ targeting systems that guide the needle path onto the skin surface, electromagnetic tracking with image fusion,¹⁷ and augmented reality system under infrared guidance that display a real-time simulation of needle movements.¹⁸ Although these techniques have tried to reduce operator dependence they have their own limitations and did not provide satisfying results. Robotic assistance is currently in use to improve the trajectory planning, targeting of desired lesions with an aim of increasing the accuracy of needle placement, and increased diagnostic yield with reducing complication rates and radiation exposure.¹⁹ While earlier robots required extensive installation and were often cumbersome to operate and time-consuming and economically disadvantageous,^{20,21} the recent robotic systems, such as the MAXIO robotic system, require minimal effort for installation and operation, reducing the complexity of the procedure. The goal of our study was to evaluate the technical success, radiation dose, and safety of this robotic system in planning and biopsy of lung lesions. Our study demonstrated that the robotic system facilitates CT-guided lung biopsies, with results that are substantially in line with previous reports on biopsies in phantoms,²² and with a preliminary clinical study conducted by Anzidei et al.²³ Our experience with this study shows that the use of the robotic system significantly increased the accuracy of needle placement and biopsy sampling and reduced procedure duration and radiation dose in comparison to the unassisted technique. The rate of complications was more with conventional technique as compared with robot-assisted biopsies which may be due to prolonged procedure time and increased number of needle adjustments within the lung parenchyma. Our study showed increased accuracy of needle placement with robotic assistance (< 3 mm off target) as compared with conventional unassisted CT-guided biopsy, this result is comparable to the study done by Ben-David et al.²⁴ Since our institution is a busy academic and teaching facility with multiple operators of variable experience performing these biopsies, this might be the reason for more accurate and safer needle placement with robot guidance. Our study has many limitations. First, a statistical subanalysis based on

the anatomic characteristics of the target lesions (size, distance to pleura, and position in lung) was not performed. Second, the effect of the lung parenchymal disease surrounding the target lesions on complications was not assessed.

Conclusion

Our study concluded that robot-guided lung biopsies are more successful in planning and safe targeting of lesions, with reduced procedure duration and radiation exposure, and decreased complications. Robotic system may reduce the dependence on the operator experience in performing CT-guided biopsies.

Declaration of Patient Consent

The authors certify that they have obtained all appropriate patient consent forms in the form, patients have given his/her/their consent for his/her/their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity can't be guaranteed.

Ethical approval

This study was approved by the Institutional Ethics Committee of Sher-i-Kashmir institute of Medical Sciences, under reference number #303/2022 of IEC-SKIMS. A written consent to participate in the study was taken from the patient or next of kin.

Conflict of Interest

None declared.

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