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Clinical Performance of Robotic-Assisted CT and PET/CT-Guided Biopsy Across Multiple Organs: A Multicenter Observational Study

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ABSTRACT

Background: Percutaneous image-guided biopsy is widely used for tissue diagnosis in oncology and interventional radiology Conventional freehand biopsy is highly operator-dependent and may require repeated needle repositioning, increasing procedure duration, radiation exposure, and complication risk. Robotic-assisted navigation systems such as MAXIO have been developed to improve targeting precision and workflow efficiency in CT and PET/CT-guided interventions.

Objective: To evaluate targeting accuracy, radiation exposure, workflow efficiency, and diagnostic success of robotic-assisted CT/PET-CT-guided biopsy across multiple anatomical targets.

Methods: This observational study included 50 robotic-assisted biopsy procedures performed across multiple hospitals in India between April 2026 and June 2026. Procedures included lung (n=15), prostate (n=15), liver (n=10), and abdominal lesions (n=10). Outcomes assessed were targeting accuracy (mm), radiation dose (DLP, mGy·cm), needle manipulation count, procedure duration (minutes), and diagnostic success rate.

Results: A total of 50 procedures were analyzed. Mean targeting accuracy was 1.31 ± 1.16 mm. Mean procedural radiation dose was 186.16 ± 35.89 mGy·cm. Mean needle manipulation count was 0.38 ± 0.60. Mean procedure duration was 19.94 ± 2.54 minutes. Diagnostic success was achieved in 47 of 50 cases (94%). Organ-wise analysis demonstrated high performance across all target regions, with diagnostic success ranging from 90 to 100%.

Conclusion: Robotic-assisted CT/PET-CT-guided biopsy demonstrated promising targeting accuracy, low needle manipulation, efficient workflow, and high diagnostic yield across multiple organ systems. These findings suggest robotic assistance as a promising adjunct for improving procedural consistency in image-guided interventions.

Keywords: CT-guided biopsy, PET/CT-guided biopsy, Needle navigation, Interventional radiology, Nuclear medicine, Targeting accuracy

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INTRODUCTION

Percutaneous image-guided biopsy has become an essential diagnostic tool in modern interventional radiology and oncology.[1-3] It enables minimally invasive tissue sampling from suspicious lesions while avoiding open surgical procedures.

Despite its widespread use, freehand biopsy remains technically demanding, especially for[2-7]

- Deep-seated lesions
- Sub-centimeter lesions
- Respiratory motion-affected targets

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Figure 1: *MAXIO robotic system for treatment planning and image-guided percutaneous needle placement.*

- Difficult anatomical trajectories

Accurate needle placement is critical for diagnostic success while minimizing complications such as [2-7]

- Pneumothorax
- Hemorrhage
- Organ injury
- Inadequate tissue sampling

Robotic-assisted navigation systems have emerged as a promising technological advancement to address these challenges.[1-4]

Conventional freehand CT-guided biopsy remains highly dependent on operator skill and anatomical accessibility. [2-7]Deep-seated lesions, moving targets affected by respiration, and narrow needle corridors often require repeated needle repositioning and multiple confirmation scans. These challenges may increase radiation exposure, prolong procedure time, and elevate complication risk.[2-7] Robotic guidance systems aim to address these limitations by improving trajectory planning, alignment precision, and procedural reproducibility.[1-4]

The robotic guidance system (MAXIO) shown in (Figure 1) used in this study assists CT and PET/CT-guided interventions by enabling

- Pre-procedure trajectory planning
- Robotic alignment
- Needle path stabilization
- Improved targeting accuracy

These systems are increasingly used in [1,2,8–15]

- Biopsy
- Tumor ablation
- PET-guided prostate biopsy
- Pain palliation
- Complex multi-needle procedures

Although robotic guidance has demonstrated promise in interventional oncology, real-world clinical performance data across multiple organs remain limited.[1-7]

This study evaluates the clinical performance of robotic-assisted biopsy using MAXIO across four major organ categories.

OBJECTIVES

Primary Objective

To evaluate the clinical performance of robotic-assisted biopsy using MAXIO.

Secondary Objectives

To assess

- Targeting accuracy
- Procedural radiation exposure
- Needle manipulation count
- Procedure duratio
- Diagnostic success rate

MATERIALS AND METHODS

Study Design

This was an observational study analyzing consecutive robotic-assisted biopsy procedures performed between April 2026 and June 2026. Data were collected from participating centers in India using standardized procedural records. Only cases with complete imaging, procedural, and histopathology records were included to minimize selection bias.

This exploratory multicenter observational study included all consecutive eligible robotic-assisted biopsy procedures. Formal sample size calculation was not performed because the

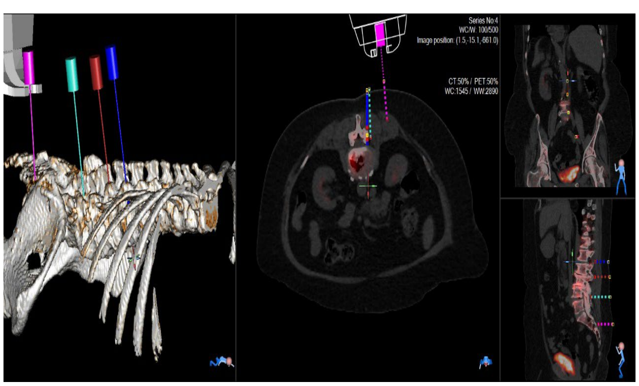

Figure 2: *Multi-needle trajectory planning in MAXIO for pain management targeting multiple spinal levels (L1–L2, L2–L3, and L4).*

Figure 3: Clinical setup showing MAXIO robotic alignment with the planned trajectory during a biopsy procedure.

Table 1: Distribution of Biopsy Cases by Organ System (n = 50)

Organ	Cases
Lung	15
Prostate	15
Liver	10
Abdomen	10

Table 2: Overall Clinical Outcomes (n = 50)

Parameter	*Mean ± SD*	*Median*	*Range*
Accuracy (mm)	1.31 ± 1.16	1	0–4.00
Radiation Dose (mGy·cm)	186.16 ± 35.89	187	133–262
Needle Manipulation	0.38 ± 0.60	0	0–2
Procedure Duration (min)	19.94 ± 2.54	19.5	15–25
Diagnostic success (%)	47/50 (94%)	—	—

study was designed as a pilot real-world clinical performance evaluation.

Study Centres

Biopsy procedures were performed at multiple centres in India using MAXIO.

Inclusion Criteria

- Patients undergoing robotic-assisted biopsy using MAXIO
- CT-guided or PET-CT-guided procedures
- Complete procedural records available
- Histopathology results available

Exclusion Criteria

- Incomplete procedure documentation
- Inadequate imaging records
- Procedures converted to manual workflow

PROCEDURE WORKFLOW

Each biopsy followed the standard robotic-assisted workflow

- Patient positioning
- Planning CT/PET-CT acquisition
- Target selection and trajectory planning
- Robotic alignment
- Needle insertion
- Confirmation scan
- Tissue sampling

The clinical setup used during robotic-assisted biopsy is shown in Figure 3.

STUDY POPULATION

Total cases

50

Outcome Measures

Accuracy

- Measured as the deviation between the planned target point and actual needle tip location.

Unit: mm

Formula: Targeting Error = Distance between planned target and actual needle tip

Radiation Dose

Measured using total procedural CT Dose Length Product.
Unit: mGy·cm

For PET-CT guided cases, only CT component radiation related to procedural workflow was considered.

Needle Manipulation Count

Defined as the number of needle repositioning attempts after first insertion.

Procedure Duration

Measured from: Initial planning scan → final needle confirmation

Unit

Minutes

Diagnostic Success

Defined as successful acquisition of adequate tissue sample for pathological diagnosis.

Reported as

Success / Failure

STATISTICAL ANALYSIS

Statistical analysis was performed using Microsoft Excel 2021 (Data Analysis ToolPak enabled). Continuous variables were expressed as mean ± standard deviation (SD), median, and range. Categorical variables were expressed as frequencies and percentages.

One-way analysis of variance (ANOVA) was used to compare continuous outcome variables across the four organ groups (lung, prostate, liver, and abdomen), including targeting accuracy, radiation dose, needle manipulation count, and procedure duration. A p-value of <0.05 was considered statistically significant. One-way ANOVA findings are summarized in Table 4.

Table 3: Organ-wise clinical performance

Organ	*Accuracy*	*Radiation dose*	*Needle manipulation*	*Procedure duration*	*Diagnostic success*
Lung (n=15)	1.84 ± 1.28	159.20 ± 29.64	0.53 ± 0.64	20.13 ± 3.14	15/15 (100%)
Prostate (n=15)	0.64 ± 0.76	185.47 ± 37.09	0.20 ± 0.41	18.93 ± 1.79	14/15 (93.3%)
Liver (n=10)	1.67 ± 1.09	208.60 ± 24.90	0.60 ± 0.70	21.40 ± 3.13	9/10 (90%)
Abdomen (n=10)	1.17 ± 0.96	214.80 ± 20.76	0.30 ± 0.48	19.90 ± 1.37	9/10 (90%)

Table 4: One-Way ANOVA Comparison of Clinical Outcome Measures Across Organ Groups

Parameter	*F-value*	*p-value*
Targeting Accuracy	3.81	0.016
Radiation Dose	8.96	<0.001
Needle Manipulation	1.42	0.248
Procedure Duration	1.98	0.131

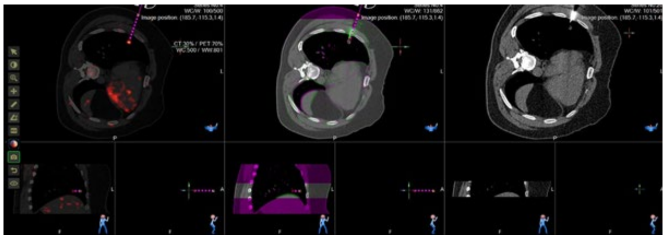

Figure 5: PET-CT guided prostate biopsy showing target selection, robotic trajectory planning, and confirmation scan of needle placement.

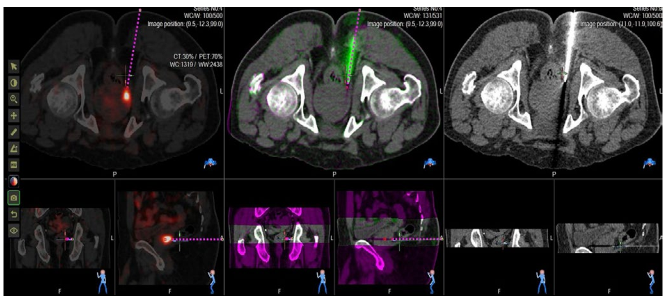

Figure 4: Apical lung lesion biopsy planned and confirmed using MAXIO robotic guidance.

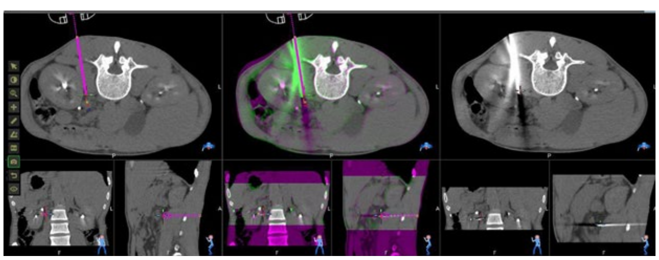

Figure 6: Robotic-assisted CT-guided biopsy of a para-aortic lesion demonstrating trajectory planning and needle confirmation.

RESULTS

A total of 50 robotic-assisted biopsy procedures were analyzed. Overall clinical outcomes are summarized in Table 2, and organ-wise outcomes are summarized in Table 3.

- Overall Results (n = 50)
- Organ-wise analysis

ANOVA results

ANOVA demonstrated statistically significant differences in targeting accuracy among organ groups ($F = 3.81$, $p = 0.016$) and radiation dose ($F = 8.96$, $p < 0.001$). However, differences in needle manipulation count ($F = 1.42$, $p = 0.248$) and procedure duration ($F = 1.98$, $p = 0.131$) were not statistically significant.

Safety Outcomes

No major procedure-related complications were observed in the study population. No emergency intervention or procedure-related hospital admission was required.

DISCUSSION

The study demonstrated

- High targeting accuracy (1.31 ± 1.16 mm)
- Low needle manipulation (0.38 ± 0.60)
- Predictable procedure duration (19.94 ± 2.54 min)
- High diagnostic success (94%)

The observed targeting accuracy is consistent with previous robotic-guided intervention studies reporting targeting deviations within 1–3 mm, supporting the precision advantage of robotic systems over conventional freehand approaches.

Lung biopsies showed relatively higher targeting error (1.84 ± 1.28 mm), likely due to respiratory motion and lesion displacement during breathing. Despite this, diagnostic success remained 100%, demonstrating the effectiveness of robotic guidance in managing moving thoracic targets.[5-7-13] An example of robotic-assisted planning for an apical lung lesion is shown in Figure 4

Prostate biopsies under PET/CT guidance benefited significantly from robotic trajectory planning, particularly in metabolically active lesions with difficult access pathways. The high diagnostic success observed aligns with previously published PET/CT-guided robotic biopsy studies from PGIMER.[8-10] Figure 5 illustrates PET/CT-guided robotic-assisted prostate biopsy planning and confirmation.

Liver and abdminal lesions showed comparatively higher radiation dose, likely due to increased target depth, surrounding critical anatomy, and the need for additional confirmation scans. However, robotic planning minimized repeated manual corrections and maintained procedural efficiency.[1-3-4-11] Figure 6 shows robotic-assisted CT-guided biopsy of a para-aortic lesion.

These findings support prior literature suggesting robotic navigation improves procedural reproducibility, workflow standardization, and targeting consistency across diverse anatomical targets.[1-5,11-13]

LIMITATIONS

This study has several limitations

- Retrospective observational design
- Limited sample size
- No manual freehand control group: This limits direct assessment of the incremental benefit of robotic guidance.
- Multicenter operator variability
- Potential investigator bias due to manufacturer affiliation
- No long-term follow-up or complication grading

- Future large-scale prospective comparative studies are recommended.

CONCLUSION

Robotic-assisted CT and PET/CT-guided biopsy using MAXIO demonstrated excellent clinical performance across multiple organ systems.

The systems achieved

- High targeting accuracy
- Low needle manipulation
- Efficient procedural workflow
- High diagnostic success

Robotic guidance represents a promising advancement in interventional radiology and nuclear medicine, particularly for complex, deep-seated, and anatomically challenging lesions.

Ethics approval

This retrospective observational study used fully anonymized procedural and clinical outcome data collected from participating centers. No direct patient intervention was performed as part of the study, and no identifiable patient information was accessed or reported.

Formal institutional ethics committee approval was waived because the study involved retrospective anonymized data analysis without patient interaction. All procedures included in this study were performed as part of routine clinical care and complied with institutional clinical protocols and the ethical principles of the Declaration of Helsinki.

Consent for publication

All patient-related images and clinical data were anonymized prior to analysis and publication. Consent for publication was obtained where applicable.

Availability of Data and Materials

The datasets generated and analyzed during the current study are available from the study investigators upon reasonable request after publication.

Competing Interests

Some investigators involved in this study are employees of the manufacturer of the robotic guidance system evaluated in this study. The remaining authors declare no competing financial interests.

To minimize potential bias, clinical outcomes and histopathology endpoints were independently validated by collaborating clinicians from participating centers.

FUNDING

No external funding was received for this study.

AUTHORS' CONTRIBUTIONS

The study was conceived and designed by the core investigation team. Data collection and validation were performed collaboratively across participating centers. The primary analysis team conducted statistical analysis and manuscript drafting. Clinical collaborators reviewed procedural outcomes and validated the scientific interpretation. All authors reviewed and approved the final manuscript.

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