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Clinical experiences with robotic computed tomography-guided interventions: A comparison with manual technique

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ABSTRACT

Background: Image-guided biopsies have become standard practice; however, challenges such as multiple punctures and re-attempts can complicate procedures. The introduction of robotic guidance systems, such as MAXIO offers a potential solution for improving planning and navigation. This study evaluated the efficacy of the MAXIO needle-guiding robotic device in computed tomography (CT)-guided interventions compared with conventional manual techniques. **Aims and Objectives:** This study aimed to evaluate the performance of the MAXIO robotic system for CT-guided biopsies at the Barnard Institute of Radiology and compare it with the conventional manual technique. **Materials and Methods:** A total of sixty patients who underwent CT-guided biopsies were retrospectively divided into two groups: Group A (manual procedure) and Group B (robot-assisted procedure). The MAXIO device was utilized in combination with a Siemens 32-slice CT scanner for robot-assisted biopsies. Key parameters analyzed between the two groups included the volume CT dose index, dose-length product (DLP), target location, target depth, target size, distance from the entry point, needle angulation, procedural time, number of punctures, complications, and re-biopsy rates. **Results:** Significant differences were found between the two groups in the number of punctures ($p = 0.002$), DLP ($p = 0.0001$), and degree of needle angulation ($p = 0.0002$), with the robotic technique demonstrating a better performance. Although the procedural time was reduced in the robotic group, this difference was not statistically significant ($p = 0.104$). Other assessed parameters, such as complications and rebiopsy rates, showed no significant differences. **Conclusion:** Robotic-assisted CT-guided procedures using the MAXIO system showed improved diagnostic accuracy and safety, with reductions in radiation dose, needle manipulations, and punctures, compared to conventional manual techniques.

Key words: Volume CT dose index; Dose-length product; Robot-assisted biopsy; Computed tomography-guided procedures; MAXIO; Radiation dose

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INTRODUCTION

Image-guided biopsies have been in vogue, particularly for organs such as the lungs and liver, and the mechanism employed is quite simple: the lesion is studied on axial computed tomography (CT) followed by freehand manual targeting by the clinician who then inserts the needle.[1] This usually requires more than one attempt and has many disadvantages. Multiple needle entries, repeated imaging with increased radiation exposure, collateral damage to surrounding tissues, and increased length and frequency of procedures cause distress to the patient. It is to circumvent

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this issue that needle-guiding robots that can pre-map needle paths and trajectories have been developed.[2] Though a wide range of products were in development, it is only a select few that have come out of research and development into the clinical phase, such as the commercially available MAXIO.[3] This technology can provide better spatial orientation before and during the procedure.

Multiple studies have shown that these interventional robots can potentially improve the accuracy of the site of needle placement, allow insertion in difficult, limited, and extended planes, reduce the associated learning curve and dependence on highly skilled practitioners alone, and also reduce the required radiation exposure and procedure time.[4] However, other studies have questioned its place in diagnosis and management today, considering the high complexity and cost as opposed to the supposed benefits. Comparative effectiveness research is more pertinent in resource-poor settings such as ours,[5] and hence, we attempted to study the effectiveness of MAXIO-guided biopsy versus conventional manual biopsies.

Aims and objectives

This study aimed to evaluate the performance of a robotic system for CT-guided biopsies in comparison to the conventional manual technique. The pre-defined objectives were to compare CT dose-related parameters such as dose length product (DLP) and volume computed tomography [CT] dose index (CTDIvol) for various procedures between the robotic and manual techniques and to compare CT procedure-related parameters to needle angulation, procedure time, number of punctures, complications, and re-biopsy rates between the robotic and manual techniques.

MATERIALS AND METHODS

A retrospective study was conducted on patients at Barnard Institute of Radiology for CT-guided procedures between September and October 2022.

Inclusion criteria

Patients referred for various CT procedures such as biopsies, pigtail drainage (moderate and large collections), and radiofrequency ablation after an initial CT magnetic resonance and positron emission tomography (PET) CT workup were included.

Exclusion criteria

- Patients with elevated international normalized ratio >1.5, decreased platelet count <50,000, and a deranged coagulation profile who were not in immediate need of the procedure
- Sick patients who become breathless on positioning. Patients who were unwilling to undergo the procedure and those who were not cooperative
- Patients who could not undergo a contrast study due to elevated renal parameters for lesions close to the main vessels.

Methods

A total of 60 patients who underwent CT-guided biopsies were retrospectively categorized into two groups: Group A (manual conventional procedure) and Group B (robot-assisted procedure), with 30 patients in each group.

All conventional biopsies were performed manually, with needle positioning and angulations retrospectively assessed. Initial pre-procedural planning for these biopsies was conducted using a Siemens 32-slice CT scanner under a dedicated biopsy protocol. The imaging parameters included KVP of 130, Mas averaging 80, slice thickness of 5 mm, and a reconstruction interval of 1.5 mm. The z-axis extension of the targeting scans was limited to include only the needle and the target lesion. A minimum of three scans was required to target the lesion, with additional scans and multiplanar reconstructions performed as needed for needle adjustments. All procedures were conducted under local anesthesia with 2% lidocaine. Once the needle tip was confirmed in position, biopsies were performed using a coaxial system and an automatic biopsy gun with a length of 18 cm and throws of 1 and 2 cm, depending on the

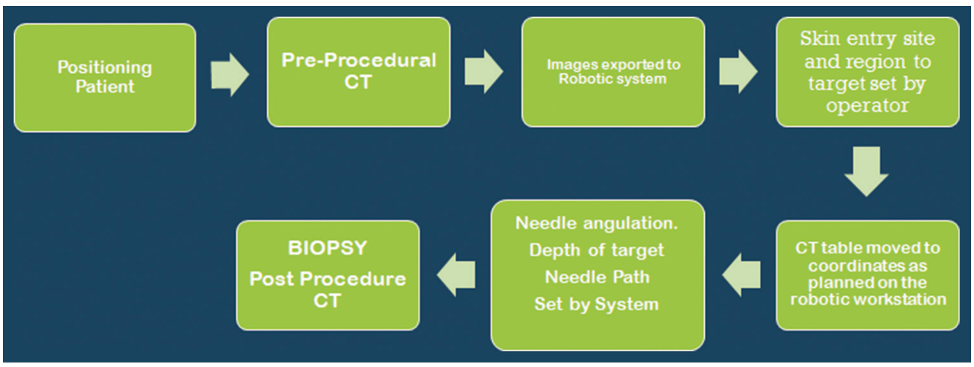

Figure 1: Workflow of the robotic system of biopsy

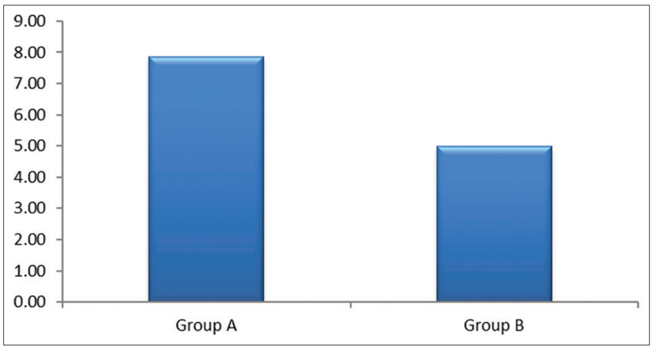

Figure 2: Comparison of angulations between both groups

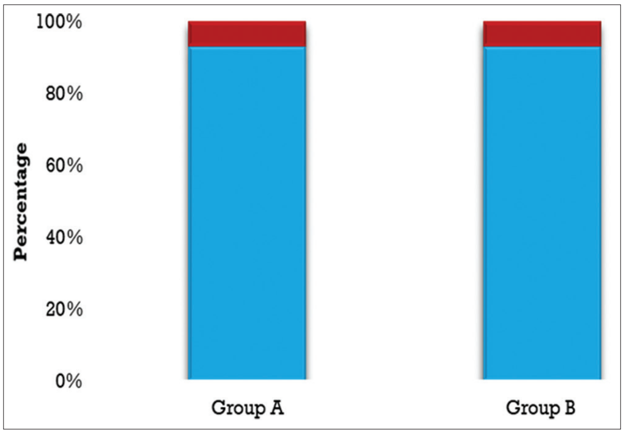

Figure 3: Comparison of complications between both groups

Figure 4: Patient being docked on computed tomography table with MAXIO robotic system

requirements. Post-biopsy CT imaging was conducted to evaluate the outcomes.

Robotic biopsy was performed using a MAXIO device and a Siemens 32-slice CT scanner. The procedure for robotic biopsy with MAXIO is depicted in Figure 1.

Statistical analysis

The collected data were analyzed using IBM SPSS Statistics for Windows, Version 23.0. (Armonk, NY: IBM Corp). To describe the data, descriptive statistics frequency analysis and percentage analysis were used for categorical variables, and the mean and standard deviation were used for continuous variables. To find a significant difference between the bivariate samples in the independent groups, the unpaired sample t-test was used. To determine the significance of categorical data, the Chi-square test was used.

RESULTS

A total of 60 patients who underwent CT-guided biopsies were retrospectively allocated to two groups: Group A (manual conventional procedure) and Group B (robot-assisted procedure), with 30 patients in each group.

There was a significantly reduced number of punctures (P=0.002) in the robotic MAXIO group (maximum 1 puncture) compared with the conventional manual biopsy group. There were no re-biopsies in the robotic group compared with the few in the manual group (Table 1).

There was also a reduced requirement for craniocaudal and mediolateral manipulations using the robotic system (average: 4°) compared to the conventional manual system (average: 7°) (P=0.0002) (Figure 2). There were also no complications observed in both the groups (Figure 3).

Our study revealed a decrease in the DLP and CT volumetric dose in patients under robotic guidance compared to the manual technique. The average DLP obtained in a manual technique was (255mGy×cm)

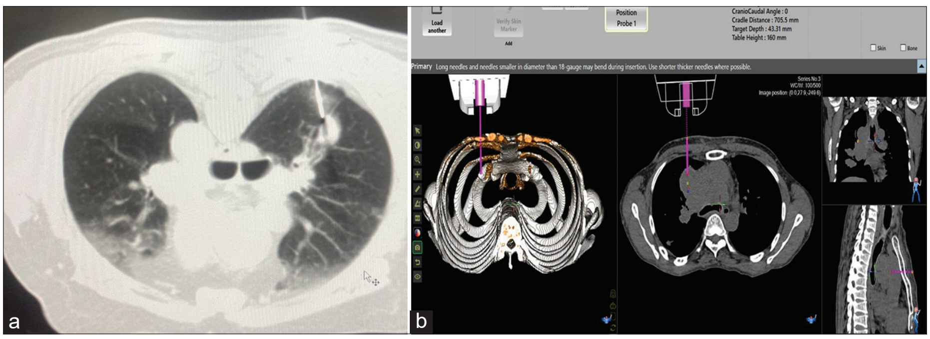

Figure 5: (a and b) Biopsy of a granulomatous lesion

compared to the robotic technique (138mGy×cm) (P=0.0001). A reduced procedure time and difference in CTDIvol were observed with robotic biopsy (16.97) compared to the manual technique (20.33), but this was not statistically significant (P=0.104) (Table 2).

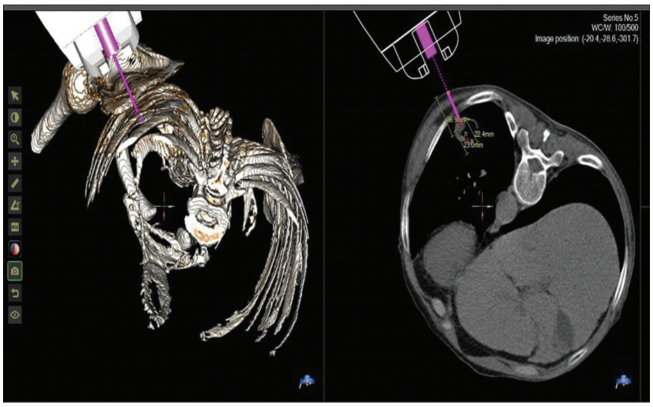

Figure 6: Squamous cell carcinoma diagnosed by robotic biopsy under computed tomography guidance

DISCUSSION

MAXIO, a USFDA 510(k) approved device, is a stereotactic device that is controlled by the clinician to assist in the planning and manual advancement of one or more instruments during CT-guided percutaneous procedures. The components include a stereotactic device and its accessories, software loaded on a computer, and a respiratory gating system. MAXIO® uses a single-use sterile disposable end effector, an instrument guide, and drapes.[3] The usual size is 850 mm×800 mm×1,350 mm (length×width×height) in the parked position and 850 mm×800 mm×1,800 mm when docked at the CT table side, with the robotic arm positioned over the CT Figure 4.[6]

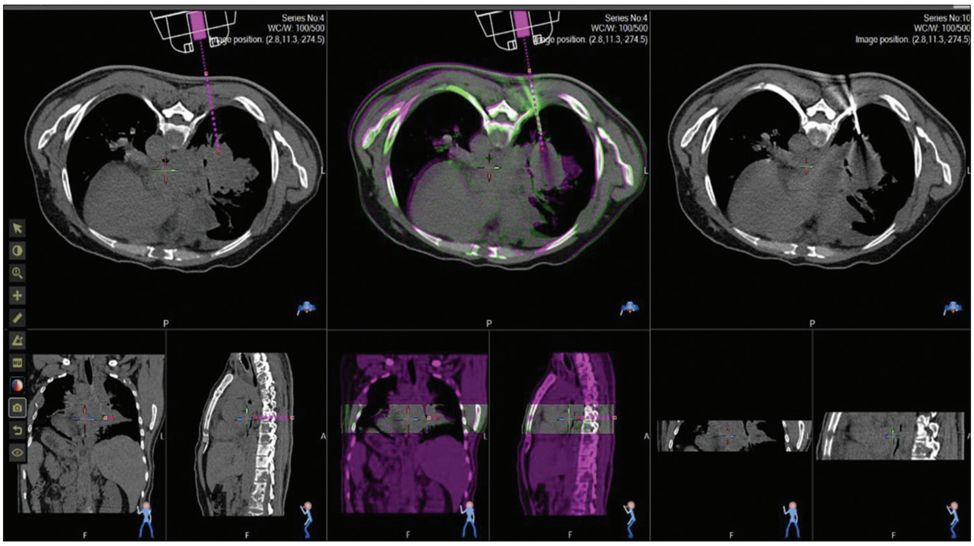

Figure 7: Hilar CA

Table 1: Comparison of punctures and re-biopsies between groups

Procedural related parameters	Group A (manual conventional) (%)	Group B (robot-assisted) (%)	P-value
Number of punctures			
1	16 (53.3)	27 (90)	0.002
2	14 (46.7)	3 (10)	
Re-biopsies			
Nil	29 (96.7)	30 (100)	1.000
Repeat	1 (3.3)	0 (0.0)	

Table 2: Comparison of DLP, procedure time and CTDI volume between groups

CT related dose parameters	Group A (manual conventional)	Group B (robot-assisted)	P-value
	Mean	Mean	
DLP	255.13	138.57	0.001
Procedure time	20.33	16.97	0.104
CTDI Volume	30.26	32.63	0.485

DLP: Dose-length product, CTDI: Computed tomography dose index

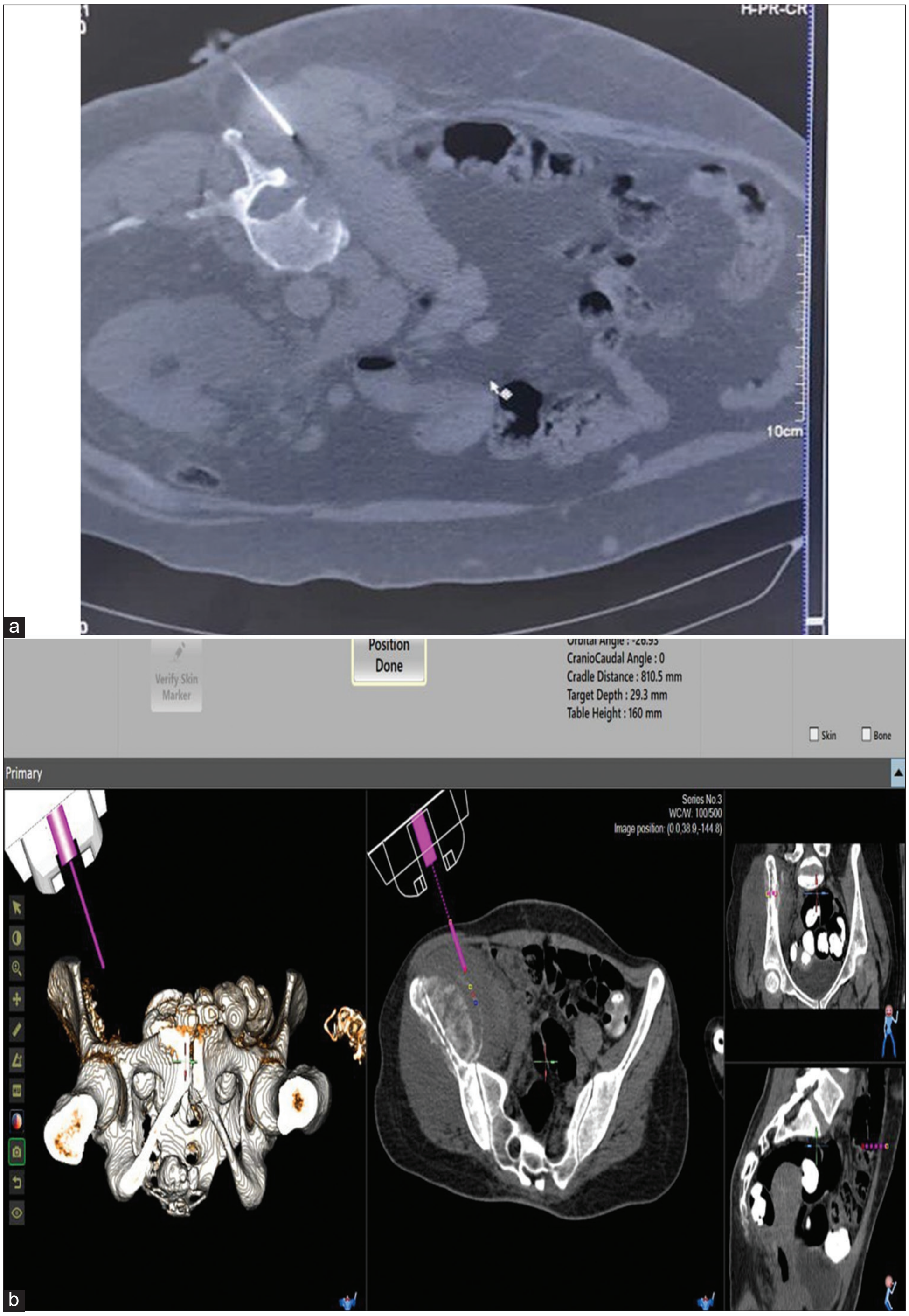

Figure 8: (a and b) Psoas and skeletal metastases with soft tissue from pulmonary malignancies, biopsied by computed tomography-guided robotic technique

Johnston et al., studied the results after installing MAXIO in a hospital in the UK. They noted that it was more efficacious for biopsies where a median path deviation and tip deviation of 1 mm were achievable, and only one instance of needle adjustment was noted. They noted that it had the potential for high accuracy in biopsies with reduced procedure time and shorter learning curve, but its role in ablation was still questionable, with no definitive results.[7]

Our study revealed a decrease in the DLP and CT volumetric dose in patients under robotic guidance compared to the manual technique. The average DLP obtained using the manual technique was 255mGy×cm compared with 138mGy×cm obtained using the robotic technique. Our findings are consistent with those reported by Solomon et al., also emphasized that this greatly reduces radiation exposure for those undergoing biopsies.[8,9]

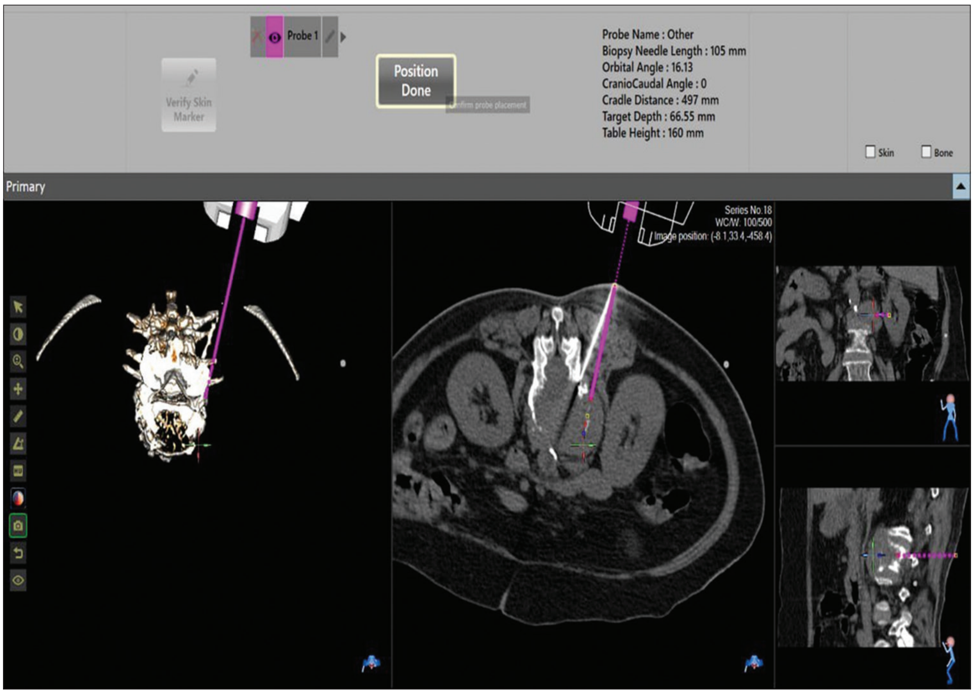

Figure 9: Lytic metastases

Figure 10: RFA of osteoid osteoma

The number of punctures and needle manipulation was significantly reduced in our study using the robotic system (Max 1 puncture, Avg: 4° mid-lateral angulation) compared with the manual technique. (average: 7° medial-lateral angulation), more so for pulmonary malignancies (Figures 5-8). Studies conducted by Koethe et al., also revealed better needle trajectories and placement using the robotic technique.[6] Anzidei et al., had similar results in their study, but the discordant feature was the presence of an increased rate of pneumothoraces in their study with the manual technique, which was barely minimal and similar for both techniques in our study.[10]

Various studies have demonstrated the ability of robotic biopsy techniques to accurately target lesions;[11] however, more research is needed at the clinical level. We also noticed reduced procedure times with robotic biopsies, a detailed echo by various other authors as well.

Kumar et al., studied the efficacy of PET/CT-guided robotic biopsy in the evaluation of hypermetabolic bone lesions and found that the procedure helped determine the treatment plan in 91.7% of 73 patients enrolled.[12] While CT-guided biopsy is an excellent tool for the evaluation of skeletal lesions, the lack of extra-osseous soft tissue, lytic, or benign lesions can reduce the diagnostic yield,[13] In such scenarios, the use of robotic instruments could greatly address navigational issues (Figure 9).

It could also play a role in the application of radiofrequency ablation to difficult sites (Figure 10). Patriciu et al., studied the role of robot-assisted RF ablation of hepatic tumors and noted better targeting, reduced procedure time, and radiation dose.[14] Recently, De Baère et al., studied a similar robotic device for RF ablation and reported positive results.[15]

Overall, robotic biopsy under CT guidance proved to be an excellent tool, allowing more precision in targeting, reducing radiation dose, procedure times, and learning curves, and reducing the need for multiple pricks and re-procedures. The diagnostic yields in our study and many others were encouraging. The cost factor may be a bottleneck, especially in limited economies, such as ours, and access to such technology may not be affordable for all patients. The major disadvantages of this equipment are that if a patient moves during any of the steps, repeat CT and planning are to be performed, thereby increasing the radiation dose and procedure time, as also suggested by Gupta et al.[16] Docking of the machine takes approximately 8–10 min. Due to the limited range of motion, lateral interventions are difficult to perform. Similar difficulties were reported by Schulz et al.[17]

Limitations of the study

Our study was limited by the sample size, and all biopsies were performed by a single radiologist. Furthermore, statistical in-depth analysis based on the anatomic characteristics of the target lesions (e.g., distance from the skin, target size) was not performed; hence, we cannot provide clustered data on system performance for the biopsy of smaller and hardly accessible lesions. There is a need for further research in this area to accurately document its advantages, pitfalls, and benefits.

CONCLUSION

This study demonstrates that the use of robot-assisted CT-guided procedures, specifically with the MAXIO device, showed significant advantages over conventional manual techniques. The robotic system led to a significant reduction in the number of needle punctures, radiation dose (DLP), and degree of needle angulation, all of which are critical factors for minimizing patient discomfort and procedural risks. Although the reduction in procedural time was not significant, the observed pattern indicated the efficiency of the robotic system. No significant differences were found in terms of complications or re-biopsy rates, indicating that robot-guided interventions maintain safety standards comparable to manual methods. These findings indicate that robotic guidance can improve clinical precision and outcomes in CT-guided biopsies. However, further research with larger sample sizes and consideration of economic factors is necessary to fully validate its broader clinical implementation, particularly in resource-limited settings.

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Authors Contribution:
AKA- Manuscript preparation, performed the procedure; **SK**- Study design, review manuscript; **GG-** Literature review, data collection, data analysis.

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