Original Article

Robotic navigation-assisted percutaneous liver puncture: a pilot study

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Background: Liver cancer is often diagnosed at an advanced stage, rendering many cases unresectable and necessitating minimally invasive treatments such as ablation, for which accurate puncture is essential. Manual techniques are limited by steep learning curves, frequent needle adjustments, and increased radiation exposure. Robotic navigation-assisted puncture (RNAP) offers improved precision, efficiency, and safety, but its efficacy compared to that of manual puncture (MP) remains unclear. This study aimed to assess the safety and efficacy of RNAP in the treatment of liver tumors.

Methods: From October 2023 to February 2024, 65 patients with liver tumors underwent percutaneous puncture procedures (ablation, iodine-125 implantation, and biopsy) at department of interventional radiology. They were divided into two groups: the RNAP group (n=29) and the MP group (n=36). Two techniques were compared in terms of technical success (TS), clinical success (CS), puncture scoring (PS), number of computed tomography (CT) scans, total procedure time (TPT), puncture time (PT), irradiation dose (ID), and puncture-related complications.

Results: There were significant differences between patients in the RNAP group and those in the MP group in terms of PS (3.02±0.68 *vs.* 2.24±0.73; P=0.01), PT (8.86±1.91 *vs.* 13.44±3.66 min; P=0.01), number of CT scans (7.03±2.30 *vs.* 11.58±4.25; P=0.01), and ID (160.76±40.60 *vs.* 230.06±86.46 mGy·cm; P=0.01); meanwhile, TS (100% *vs.* 100%; P>0.99), CS (91.50% *vs.* 91.40%; P=0.81), TPT (33.22±7.80 *vs.* 32.13±5.50 min; P=0.52), and complications (10.30% *vs.* 5.56%; P=0.47) showed no differences.

Conclusions: RNAP is a useful tool for performing puncture procedures on liver tumors, which can decrease PT, CT scan times, and ID.

Keywords: Percutaneous puncture; liver tumors; robotic navigation; minimally invasive therapy

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Introduction

Liver cancer is the sixth most commonly diagnosed cancer and the third most common cause of cancer mortality worldwide (1). The standard treatment modalities for liver cancer are surgical resection and liver transplantation (2). However, more than 70% of liver cancers are considered unresectable at the time of diagnosis due to advanced stage, underlying liver disease, challenging tumor locations, or poor patient health (1,2). Recent advances in the management of hepatocellular carcinoma (HCC) have included significant progress in personalized therapeutic approaches via genotyping, imaging phenomics, and minimally invasive techniques such as radiofrequency ablation (RFA) and microwave ablation (MWA) (3,4). Percutaneous RFA and MWA are indicated for small (<2–3 cm) liver lesions regardless of their potential for surgical removal (5,6). These minimally invasive image-guided procedures have come to prominence due to their ability to reduce invasiveness, enhance precision, and improve patient outcomes (6,7). However, the accuracy of these puncture procedures remains a critical factor in their success (8).

Achieving precise puncture is essential for minimizing complications and ensuring effective treatment (9). Success in manual puncture (MP) procedures highly depends on experience, which involves making mental estimations of surface-to-target distance while accounting for accounting for needle angulations (8,9). In addition, MPs, with their steep learning curve, often lead to repeated needle adjustments and increased exposure of radiation to patient and attending intervention radiologists (9,10).

In recent years, several robotic navigational systems have been developed to address these challenges, offering an accurate, reproducible, time-efficient, and radiation-reduced solution for percutaneous puncture procedures. This navigation system provides real-time visualization of the needle's path, optimizing the trajectory and reducing the risk of tissue damage. This helps to flatten the learning curve for junior practitioners and improve the overall efficiency of the procedure (8-10). Furthermore, it improves ablation needle positioning and enhances local outcomes in minimally invasive procedures (10,11). Despite these advantages, a comprehensive evaluation of robotic navigation-assisted puncture (RNAP) versus traditional MP is necessary to determine their relative efficacy and safety.

This study aimed to assess the efficacy and safety of RNAP in liver tumor treatments, with a focus on puncture accuracy, procedure time, complication rates, and radiation exposure. We present this article in accordance with the STROBE reporting checklist (available at https://qims.amegroups.com/article/view/10.21037/qims-24-1584/rc).

Methods

Materials

The iSYS robotic system 1.3 (iSYS Medizintechnik GmbH, Kitzbuehel, Austria), a 64-row computed tomography (CT) scanner (Aquilion ONE TSX-305A, Canon Medical Systems, Otawara, Japan), an MWA system (ECO Medical Technology, Nanjing, China), a biopsy gun (Argon Medical Devices, Plano, TX, USA), and iodine-125 (Saide Co. Ltd., Tianjin, China) were used in this study.

The iSYS robotic needle guide system is designed for CT or cone-beam-guided interventions and features computer-assisted planning and execution. It includes a targeting control platform which is wired to a robotic positioning unit/arm, dedicated virtual navigation planning software, and a respiratory a gating signal system. After the initial CT scan, data are sent to the control station, and the planning software facilitates trajectory planning via Digital Imaging and Communications in Medicine (DICOM) images. The robotic arm features two degrees of freedom (DOF) for translational movements (40 mm × 40 mm workspace) and two DOF for angular movements (±32 degrees) of the needle allowing for flexible and precise movements (*Figure 1*).

Patients

The electronic data of 65 patients who underwent percutaneous puncture procedures [MWA, iodine-125 seed implantation (ISI), and biopsy] at The First Affiliated Hospital of Zhengzhou University, Department of Interventional Radiology between October 2023 to February 2024 were included in this retrospective study. The inclusion criteria were as follows: (I) age between 18 and 75 years; (II) a diagnosis confirmed by imaging or pathology; (III) a tumor diameter ≤3 cm; (IV) an Eastern Cooperative Oncology Group (ECOG) score ≤2; and (IV) a platelet (PLT) count $>60\times10^9$/L and a puncture time (PT) 21 s. Meanwhile, the exclusion criteria were as follows: (I) lack of malignant evidence on imaging; (II) tumor diameter >3 cm; (III) pulmonary function classification ≥3; (IV) insufficient cardiovascular, hepatic, or renal function for undergoing local and systemic treatments; and (V) ECOG score >2.

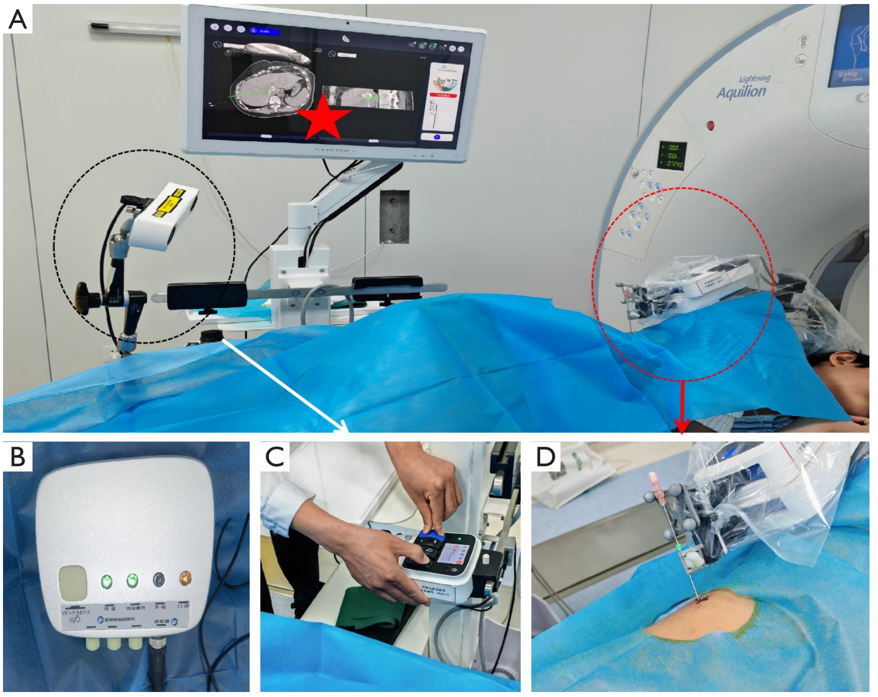

Figure 1 Robotic virtual navigation planning (iSYS1.3, Medzintechnik GmbH, Kitzbuehel, Austria). (A) Targeting control platform, camera, and screen indicated by a red circle, black circle, and red star, respectively. (B) Respiratory gating signal system to reduce puncture errors that can be caused by respiratory movements. (C) Targeting control platform. (D) Robotic arm. White arrow tail showing the position of targeting control platform position and the head during use in panel C; red arrow is connected to circle to to show a zoom into the working of robotic arm.

Larger tumors (>3 cm) were excluded due to higher risks of incomplete ablation, local recurrence, technical challenges, or complications, with the relevant guidelines (5,12,13) recommending RFA and MWA for smaller tumors to provide better outcomes. All patients were divided into two groups: the RNAP group (n=29) and the MP group (n=36). Due to the retrospective design of study, randomization was not possible. However, to avoid selection bias, the two groups were analyzed in terms of baseline factors of concern, which were found to be relatively comparable (*Table 1*).

This single-center retrospective study was approved by the Ethics Review Committee of The First Affiliated Hospital of Zhengzhou University (No. 2023-KY-478; September 15, 2023) and was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The requirement for informed consent was waived due to the retrospective nature of the study.

Procedure

Preoperative tests performed within a week before surgery included blood count, liver and renal function tests, coagulation function, electrolytes, electrocardiography (ECG), and abdominal enhanced CT. All procedures were performed by a team of two experienced interventional radiologists, one serving as the lead and the other assisting in each case. MWA was performed under intravenous anesthesia (0.5 μg/kg of dexmedetomidine and 10 mg of dezocine) with a minimal ablation margin of 5 mm, which was confirmed with intraoperative CT imaging, while the puncture biopsy and ISI were performed under local anesthesia (2% lidocaine) as described previously (11,14). The goal for minimal ablation margins was set at 5 mm and was evaluated intraoperatively using real-time multislice CT imaging to ensure adequate coverage of the target lesion.

The procedure for the RNAP group

The RNAP procedure began with the selection of an appropriate patient position based on tumor location, which was followed by local disinfection using iodophor and then draping with sterile sheets. A CT scan with a 1-mm slice

Table 1 Patient characteristics

Parameter	RNAP group (n=29)	MP group (n=36)	P value
Sex (male/female)	16/13	21/15	0.79
Age (years)	61.38±11.44	60.42±9.70	0.71
Body mass index (g/m^2)	25.50±3.40	25.31±3.23	0.83
ECOG score (0/1/2)	10/13/6	15/13/8	0.76
Tumor origin			0.55
Hepatocellular carcinoma	16 (55.17)	15 (41.67)	
Liver metastases	9 (31.03)	14 (38.89)	
Cholangiocarcinoma	4 (13.79)	7 (19.44)	
Max. tumor diameter (cm)	2.59±0.52	2.62±0.77	0.77
Distance from skin to tumor (cm)	5.05±2.62	4.93±2.56	0.57
Hepatitis status			0.51
HBV or HCV	20 (68.97)	22 (61.11)	
Non-HBV/HCV	9 (31.03)	14 (38.89)	
Target tumor location			0.94
Segment 8	8 (17.02)	11 (19.64)	
Segment 7	10 (21.28)	13 (23.21)	
Segment 5	12 (25.53)	10 (17.86)	
Segment 4	9 (19.15)	11 (19.64)	
Segment 2	5 (10.64)	8 (14.29)	
Segment 1	3 (6.38)	3 (5.36)	
Number of tumors in superior segments (IV, VII, VIII)	27/47	35/56	0.60
Number of tumors			0.43
1 tumor	15	25	
2 tumors	10	8	
3 tumors	4	5	
Procedure types for tumors (MWA/ISIB/biopsy)	30/12/5	38/12/6	0.24
Important laboratory data			
ALT (U/L)	42.72±10.30	41.05±7.26	0.44
AST (U/L)	41.92±6.12	42.57±4.29	0.61
TBIL (μmol/L)	29.23±4.72	28.78±4.30	0.68
Albumin (g/L)	43.96±4.75	44.69±4.38	0.52
Platelet (×10^9/L)	173.59±30.32	165.22±22.76	0.20
PT (s)	18.37±2.69	18.10±2.51	0.66

Data are presented as n, mean ± standard deviation, or n (%). RNAP, robotic navigation-assisted puncture; MP, manual puncture; ECOG, Eastern Cooperative Oncology Group; Max., maximum; HBV, hepatitis B virus; HCV, hepatitis C virus; MWA, microwave ablation; ISIB, iodine seed implantation brachytherapy; ALT, alanine aminotransferase; AST, aspartate aminotransferase; TBIL, total bilirubin; PT, prothrombin time.

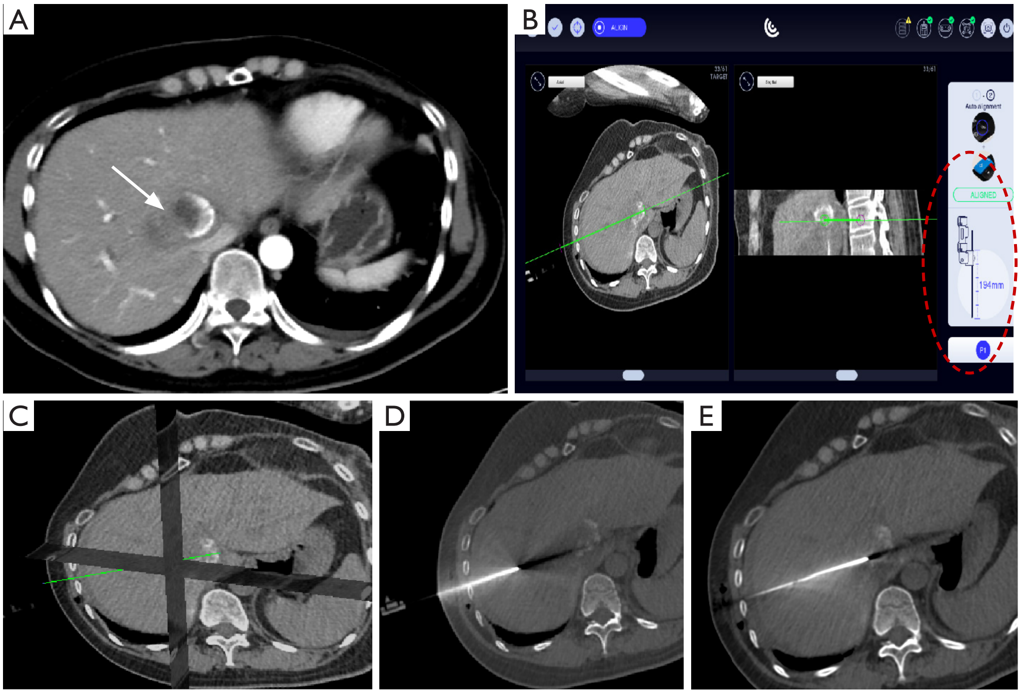

Figure 2 A 58-year-old female with liver metastasis from breast cancer. (A) Preoperative enhanced computed tomography showed a 3.1 cm × 4.2 cm lesion (arrow) in segment 8. (B) In the virtual navigation planning system, the puncture path was planned to avoid vital structures such as blood vessels. The red circle represents the depth of the puncture needle insertion. (C) A 3D image with the relationship between the puncture path (line) and the target lesion. (D,E) The target lesion was punctured 2 times.

thickness was then performed to locate the liver tumors, and the imaging data were transferred automatically to a virtual positioning system via a local network to generate a virtual 3D model of the liver and tumors. The system then aligned this virtual model with the patient's anatomy, ensuring accurate overlay with real-time imaging. This system also aided in the selection of the most reasonable puncture path that minimized the distance and avoided vital abdominal organs by via cross-sectional, coronal, and sagittal views (*Figure 2*). Upon confirmation of the puncture path, the virtual positioning system directed the orientation of the mounting arm of the puncture platform. Depending on the treatment strategy, various needles were employed: an 18 G needle for ISI, a 17 G needle for biopsy, and a 16 G needle for MWA. For the needle puncture, the robotic-assisted technique consisted of an automated approach: the robotic system precisely positioned and aligned the needle along the preplanned trajectory. Local anesthesia was manually administered along the aligned needle path before the automated needle puncture. Under the guidance of the robotic system, respiratory gating, and a patient breath-hold (10–15 s), the needle was passed to the target lesion, and multislice unenhanced CT was performed in all patients to ensure correct placement. After confirmation of successful needle positioning, appropriate treatment (MWA, biopsy, or ISI) was carried out according to pretreatment plans (*Figures 3,4*). Subsequently, all patients underwent a noncontrast multislice CT scan of the liver to detect early complications.

The procedure of the MP group

In the MP group, preoperative preparation and patient positioning were conducted similarly to those in the RNAP group. The procedure began with a 1-mm slice thickness CT scan to locate liver tumors, after which the interventional radiologist manually selected the needle entry point. The radiologist carefully planned the puncture path based on the tumor's location and proximity to critical structures, with experience and real-time imaging relied upon to minimize risks.

The needle was then manually advanced along the chosen path under CT guidance, with intraoperative scans verifying alignment at critical points. Once the needle reached the lesion, the selected treatment [MWA, biopsy, or iodine seed

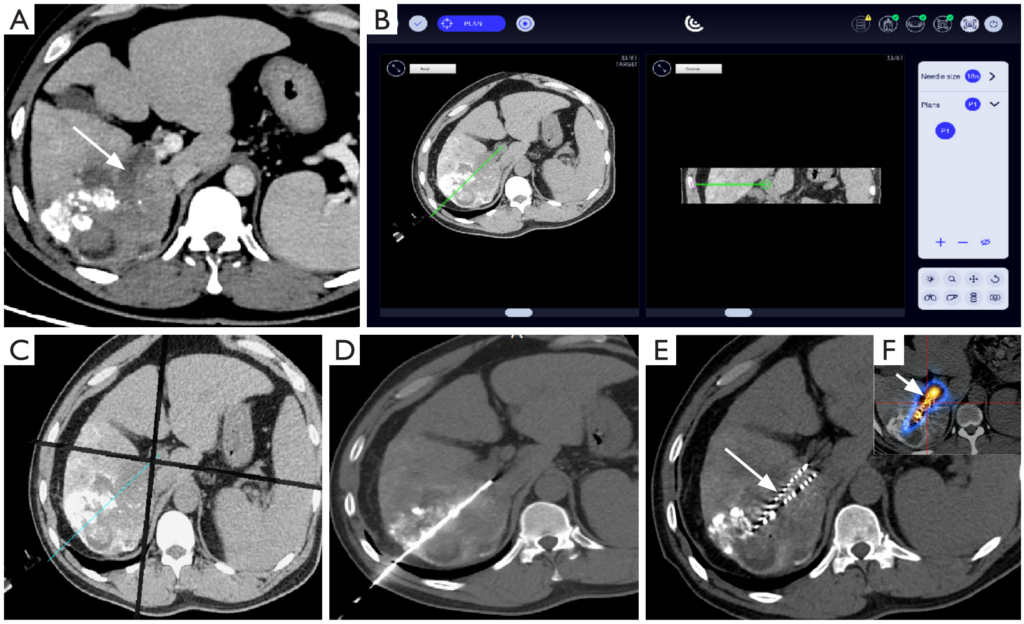

Figure 3 A 65-year-old male with hepatocellular carcinoma and portal vein tumor thrombus underwent transarterial chemoembolization which was poorly controlled. (A) Portal vein tumor thrombus (arrow). (B) The puncture path was designed at the robotic virtual navigation planning system. (C) A 3D image showing the relationship between the puncture path (line) and the target lesion. (D) The target lesion was punctured successfully. (E) Radioactive iodine-125 seeds (arrow) were implanted within the portal vein tumor thrombus. (F) Single-photon emission computed tomography showed a gamma ray (arrow) concentrated within the portal vein tumor thrombus. 3D, three-dimensional.

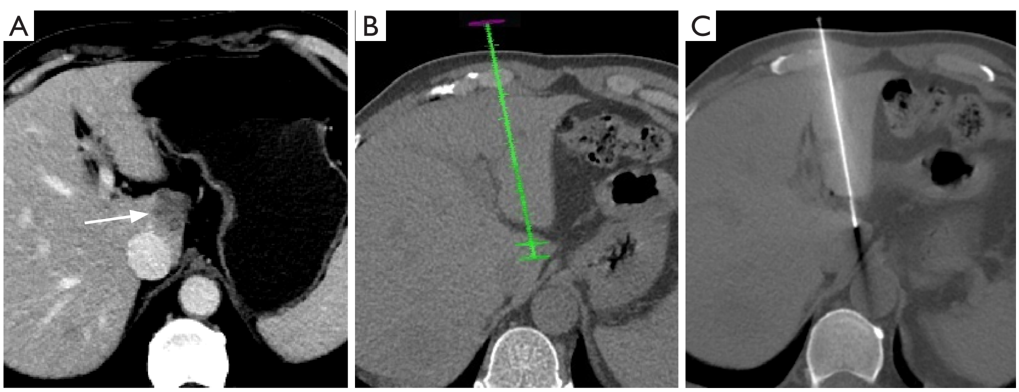

Figure 4 A 48-year-old male patient with liver tumor. (A) Preoperative computed tomography showed a liver tumor in segment 1 (1.9 cm × 1.4 cm dimension, arrow). (B) The puncture path was designed with the robotic virtual navigation planning system. (C) Biopsy was completed after successful puncture of the target lesion.

implantation brachytherapy (ISIB)] was performed. A final noncontrast CT scan was employed to confirm treatment completion and check for early complications.

Definition and endpoints

Needle repositioning was defined as the partial or complete withdrawal of the needle for adjustment of its position after the initial insertion in order to achieve correct placement. The puncture scoring (PS) standard was graded as needle repositions per lesion as follows: score 0, unsuccessful needle insertion; score 1, successful puncture requiring 3 needle repositions; score 2, successful puncture requiring 2 needle repositions; score

3, successful puncture requiring 1 needle repositions; and score 4, successful first puncture. Technical success (TS) was defined as the successful insertion and placement of the needle in the desired location for treatment or biopsy, as confirmed by real-time CT imaging. For MWA and ISI, clinical success (CS) was defined as a complete response of the treated tumors as indicated by the absence of viable tumor tissue on follow-up imaging assessed 2 months after treatment. For biopsy procedures, CS was defined as the successful retrieval of an adequate tissue sample, and the goal was to arrive at a definitive pathological diagnosis, which is critical for accurate treatment planning. CT scan times was defined as the number of CT scans performed throughout the whole procedure. The primary endpoints were PS, CT scan times, total procedure time (TPT), and PT. The secondary endpoints were irradiation dose (ID) and puncture-related complications. Complications were defined according to the Common Terminology Criteria for Adverse Events version 5.0, with grade 1 indicating mild complications and grade 5 indicating death. Grades 1–2 and 3–5 adverse events were defined as minor and major complications, respectively. The ID was recorded with a CT system.

Statistical analysis

Continuous variables are expressed as the median or as the mean ± standard deviation. For ordinal variables such as PS, the Mann-Whitney test was used to evaluate the differences between the groups. Continuous variables such as CT scan times and radiation doses were compared using the independent samples *t*-test. A P value of less than 0.05 was considered statistically significant. All statistical analyses were performed using SPSS 21.0 software (IBM Corp., Armonk, NY, USA).

Follow-up

Patients who underwent MWA and ISI placement were followed up, which included magnetic resonance imaging (MRI) with liver-specific contrast agent and a three-phase CT scan of the liver after 2 months. For determining CS, tumor response was analyzed by two experienced radiologists who were blinded to the study. Long-term follow-up was performed via MRI only, short-term follow-up was conducted in a standard manner. Patients who underwent liver biopsy were followed up after 1 week to determine the diagnostic yield.

Results

General information

A total of 65 patients (including 31 with HCC, 23 with liver metastases, and 11 with cholangiocarcinoma) were included in the study. The mean age was 61.38±11.44 years in the RNAP group and 60.42±9.70 years in the MP group (P=0.71). In the RNAP group, 30, 12, and 5 patients underwent MWA, ISI, and biopsy, respectively, while in the MP group, 38, 12, and 6 patients underwent MWA, ISI, and biopsy, respectively. The mean distance from the skin to the tumor was 5.05±2.62 and 4.93±2.56 cm (P=0.57) in the RNAP and MP group, respectively. The total number of tumors in the superior segments of the liver (IV, VII, and VIII) were 27/47 and 35/56 in RNAP and MP group, respectively. There were no clinical or statistical differences between the two groups, and they were comparable at baseline in terms of factors of concern related to tumor characteristics (*Table 1*).

Outcomes

The TS of both groups was 100%, and the mean PS was higher in the RNAP group than in the MA group [3.02±0.68 (range, 1–4) *vs.* 2.24±0.73 (range, 1–4); P=0.01]. The PT for the RNAP and MA groups was 8.86±1.91 and 13.44±3.66 min, respectively (P=0.01). The CT scan times and ID of RNAP and MA groups were 7.03±2.30 and 11.58±4.25, respectively, and 160.76±40.60 and 230.06±86.46 mGy·cm, respectively (P=0.01). Regarding the reduction in ID and PT, a significant reduction of 30% and 34% was noted in the RNAP group, respectively. No major complications were observed in either group. Grade 2 minor complications occurred in 10.30% of patients in the RNAP group (3/29; subcapsular hemorrhage: 1 patient; severe abdominal pain: 2 patients) and 5.56% of patients in the MA group (2/36; abdominal pain: 2 patients) (P=0.47). More detailed information is presented in *Tables 2,3*.

Follow-up

Follow-up revealed that 2 patients in the RNAP and 3 in the MP group had insufficient ablation volume; moreover, 1 patient in each group had no tumor response to ISI, and 1 patient in MP group was also considered to have inadequate sample volume for a diagnostic yield. The CS of the RNAP and MP groups was 91.50% and 91.07%, respectively (P=0.81).

Table 2 Outcomes of both groups

Parameter	RNAP group (n=29)	MP group (n=36)	P value
Technical success	47/47 (100.0)	56/56 (100.0)	NA
Clinical success	43/47 (91.5)	51/56 (91.07)	0.81
Total procedure time (min)	33.22±7.80	32.13±5.50	0.52
Puncture time (min)	8.86±1.91	13.44±3.66	0.01
CT scan times	7.03±2.30	11.58±4.25	0.01
Puncture scoring (4/3/2/1)	3.02±0.68	2.24±0.73	0.01
Needle repositions [1–3]	0.67±0.94	1.52±0.90	0.01
Irradiation dose (mGy·cm)	160.76±40.60	230.06±86.46	0.01
Hospital stays (days)	6.28±2.28	6.11±3.35	0.82
Complications			
Major complications	0/0 (0.0)	0/0 (0.0)	NA
Minor complications	3/29 (10.30)	2/36 (5.56)	0.47

Data are presented as n/N (%) or mean ± standard deviation. RNAP, robotic navigation-assisted puncture; MP, manual puncture; NA, not available; CT, computed tomography.

Table 3 Correlation of puncture score and tumor locations

Liver segment	RNAP group (n=29)				MP group (n=36)				P value
	Score 4	Score 3	Score 2	Score 1	Score 4	Score 3	Score 2	Score 1	
S8	6	2	0	0	1	3	7	1	0.01
S7	5	2	2	1	2	1	10	3	0.03
S5	7	3	2	0	1	4	5	0	0.17
S4	6	2	1	0	3	1	7	1	0.02
S2	4	1	0	0	2	4	2	0	0.48
S1	2	0	1	0	1	0	2	0	1.00
Total	30	10	6	1	10	13	33	5	–

Data are presented as n. RNAP, robotic navigation-assisted puncture; MP, manual puncture; S, segment.

Discussion

To the best of our knowledge, this study is the first to examine liver puncture conducted with the iSYS robotic system in human participants and to include a control group. In previous studies, the efficacy of this system was established via phantom studies and cadaveric studies (15-17); however, few studies have examined the use of robotic systems for liver puncture procedures in human participants (*Table 4*).

Based on our clinical experience, we formulated a grading system to assess the puncture score and comprehensively measure the efficacy of the procedure. The findings of our study show that the RNAP technique offers significant advantages over manual techniques in the puncture treatment of liver tumors. Specifically, our data demonstrate that this technique significantly improves puncture accuracy, as demonstrated by a higher PS in the RNAP group, indicating fewer needle repositionings compared to the MP group. This improvement, along with reductions in PT and ID, can be attributed to the enhanced precision and stability provided by the robotic navigation system. This

Table 4 Studies on CT-guided robotic puncture treatment for liver cancers

Year, first author, and study design	Group (n); RNAP *vs.* MP	Robotic puncture purpose	Robotic puncture device	Technical success	Mean duration comparison (min)	Mean radiation dose comparison	Adverse effect
2005, Patriciu A, PS (18)	25 patients; 14 *vs.* 11	RFA	AcuBot	NA	TPT*: 44 *vs.* 67	469 *vs.* 7,075 mrem	NA
2014, Abdullah BJ, RS (19)	11 patients; 17 *vs.* 30† lesions	RFA	ROBIO-EX	100%	NA	DLP: 956 *vs.* 1,703 mGy·cm	No any
2015, Mbalisike EC, PS (20)	70 patients; 30 *vs.* 40	MWA	MAXIO	100% *vs.* 100%	PT*: 2.9 *vs.* 1.5; TPT*: 22 *vs.* 25	DLP*: 190 *vs.* 193 mGy	4 *vs.* 0*, 2—major; 2—minor
2015, Abdullah BJ, RS (21)	20 patients; 40 *vs.* 30† lesions	RFA	MAXIO	100%	175 *vs.* 120	DLP: 1,383 mGy·cm	No any
2016, Beyer LP, RS (22)	46 patients; 34 *vs.* 30 tumors	MWA	MAXIO	100% *vs.* 100%	PT*: 18.3 *vs.* 27.7	DLP*: 2,216 *vs.* 2,881 mGy	0 *vs.* 1*, infected bilioma
2017, Beyer LP, RS (23)	35 patients; 40 lesions: 21 *vs.* 19	Irreversible electroporation	MAXIO	100% *vs.* 100%, 100% *vs.* 94%	PT*: 63 *vs.* 87.4	DLP*: 2,132 *vs.* 4,714 mGy·cm	No any
2020, Kumar R, PS (24)	25 patients; no MP	Biopsy	ROBIO-EX	100%	NA	NA	Transient pain and minor bleed
2020, Schaible J, RS (25)	192 patients; 249 *vs.* 199 tumors	MWA	MAXIO	NA	NA	NA	Grade IV 1 *vs.* 2; Grade V (death) 1 *vs.* 0
2021, Levy S, PS (26)	Centre 1 (n=32) & Centre 2 (n=21); no MP	Biopsy	XACT	100% *vs.* 100%	TPT*: 43.8 *vs.* 30.5	22 & 11.7 mSv	NA
2022, de Baère T, PS (12)	21 patients; 24 tumors; no MP	23 MWA & 1 RFA	EPIONE	83.3% for patients, 85.7% for tumors	TPT: 73	NA	No any

†, historical data; *, significant differences. CT, computed tomography; RNAP, robotic navigation-assisted puncture; MP, manual puncture; PS, prospective study; RFA, radio frequency ablation; NA, not available; TPT, total procedure time; RS, retrospective study; DLP, dose-length product; MWA, microwave ablation; PT, puncture time.

aids in overcoming the challenges and steep learning curve associated with MP procedures.

In our study, the mean PS was significantly higher in the RNAP group compared to the MP group, suggesting a more accurate puncture process. Analysis showed the needle repositions in RNAP were 46% lower than that in the MP group. Moreover, only 36% (n=17/47) of cases with score 1–3 required needle repositions in the RNAP group. These findings are similar to those in the literature: Abdullah *et al.* (19), Schaible *et al.* (25), and de Baère *et al.* (12) in their studies of ROBIO-EX, MAXIO, and EPIONE robotic systems reported needle readjustments in 35%, 37%, and 30% of percutaneous liver procedures, respectively. The mean number of repositions in our study improved from 1.52 in the MP group to 0.67 in the RNAP group. This is consistent with findings of similar studies mentioning the mean repositions ranging from 0.40 to 0.80 in robotic-assisted groups (18-20).

Radiation exposure is a major concern in interventional radiology, and minimizing this exposure is crucial for patient safety. The reduction in CT scan times and ID in the RNAP group is particularly important in lowering the cumulative radiation dose. This study shows that the use of robotic systems in different procedures contributes to the reduction in ID delivered to the patient ranging from 25% to 50% (12,21-23,26) and a PT from 27% to 58% (18,20,22) compared to manual procedures. This aligns with our study where we found a significant reduction in mean CT scan times from 11 to 7 in the RNAP and MP group, respectively. Similarly, a significant reduction in the

ID by 30% and reduction in PT by 34% was noted. Similar observations in robotic lung biopsies were reported by Bodard *et al.*, who found that robotic lung biopsies resulted in fewer needle adjustments with 35% faster procedures and 40% reduced radiation compared to manual techniques (13). The findings of Alexander *et al.* further supported these benefits and demonstrated comparable TS with robot-assisted precision in out-of-gantry needle navigation (27). These studies reinforce the broader application of robotic systems in enhancing procedural outcomes across different organs. Furthermore, we believe the reduction in PT observed in the RNAP group underscores the efficiency of robotic assistance, suggesting that while the overall procedure time may not differ significantly, the streamlined puncture process may enhance patient comfort during this critical phase.

The principal findings of our study are the notable disparities in PS analysis across the liver segments between the RNAP and MP groups. Segments occupying the superior segment of liver (IV, VII, and VIII) are considered the difficult-to-reach areas and challenging to navigate during puncture treatment and invasive surgeries (28,29). In our study, a significant difference ($P<0.05$) was seen in these segments between two groups (*Table 3*). We reported that 57% (n=27/47) and 63% (n=35/56) of our cohort had tumors deemed as challenging to target in the RNAP and MP group, respectively. Further analysis showed that only 15% (n=4/27) of these segments required more than 1 reposition in the RNAP group while 54% (n=19/35) required more than 1 reposition in the MP group. This highlights the efficacy of robotic navigation in challenging sites.

Despite these advantages, it is important to acknowledge that the TS and CS rates did not differ significantly between the RNAP and MP groups. This suggests that while RNAP improves procedural efficiency and safety, but the overall efficacy in terms of treatment outcomes remains comparable to that of manual techniques. This finding aligns with other studies that indicate that the primary benefits of robotic systems lie in procedural enhancements and maintaining clinical outcomes (12,13,18-27). The absence of major complications in both groups indicates that percutaneous liver puncture is safe, whether assisted by robotic navigation or performed manually by experienced practitioners. However, the minor complication rates were slightly lower in the RNAP group, suggesting a potential toward improved safety with robotic assistance. Furthermore, while RNAP offers clear benefits in accuracy and radiation reduction, its adoption involves significant upfront costs and specialized training for radiologists. However, these initial expenses may be offset by long-term gains in procedural efficiency, reduced complications, and shorter learning curves for less experienced operators.

Our study had several limitations which should be acknowledged. First, we employed a retrospective, single-center design with a limited number of procedures. Second, all procedures were performed by highly experienced interventional radiologist which may limit the generalizability of our findings. Finally, the accuracy of needle placement may depend on other factors such as needle angulation and subjective experiences with robots.

Nonetheless, we believe that we were able to demonstrate an excellent PS, with a marked reduction of procedure length and ID, along with a comparable CS rate.

Conclusions

RNAP is a useful tool for performing puncture procedures on liver tumors. Future prospective studies including a broader range of specialists with a varying level of experience and longer follow-ups to assess recurrence rate should validate the applicability of robot-guided puncture.

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Footnote

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