Computed Tomography and Ultrasound-Guided Robotic Assistance in Percutaneous Puncture in Abdominal Phantom and Porcine Liver Models

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Abstract

Aim: Percutaneous puncture is a pivotal technique in diagnosing and treating hepatic lesions; however, traditional manual puncture methods rely heavily on the expertise of medical practitioners. This study aimed to evaluate the feasibility, safety, and efficacy of percutaneous needle placement through the innovative utilization of computed tomography-ultrasound fusion-guided robotic assistance in abdominal phantom and porcine liver models.

Methods: The abdominal phantom and eight Bama miniature pigs were selected as experimental subjects. Two puncture methods (handheld and robot-assisted puncture) were administered to each simulated tumor with an 18-gauge biopsy needle.

Results: The Euclidean distance between the needle tip and the predetermined target point of robotassisted puncture was 3.30 ± 1.48 mm in the pig model and 2.15 ± 0.82 mm in the phantom model. The planning time required for the physician to perform robot-assisted needle insertion was 8.25 ± 2.59 min. All pigs exhibited stable conditions without any complications following the puncture.

Conclusions: Robot-assisted needle insertion in percutaneous puncture was accurate and safe in the pig liver model, highlighting its feasibility and potential clinical application.

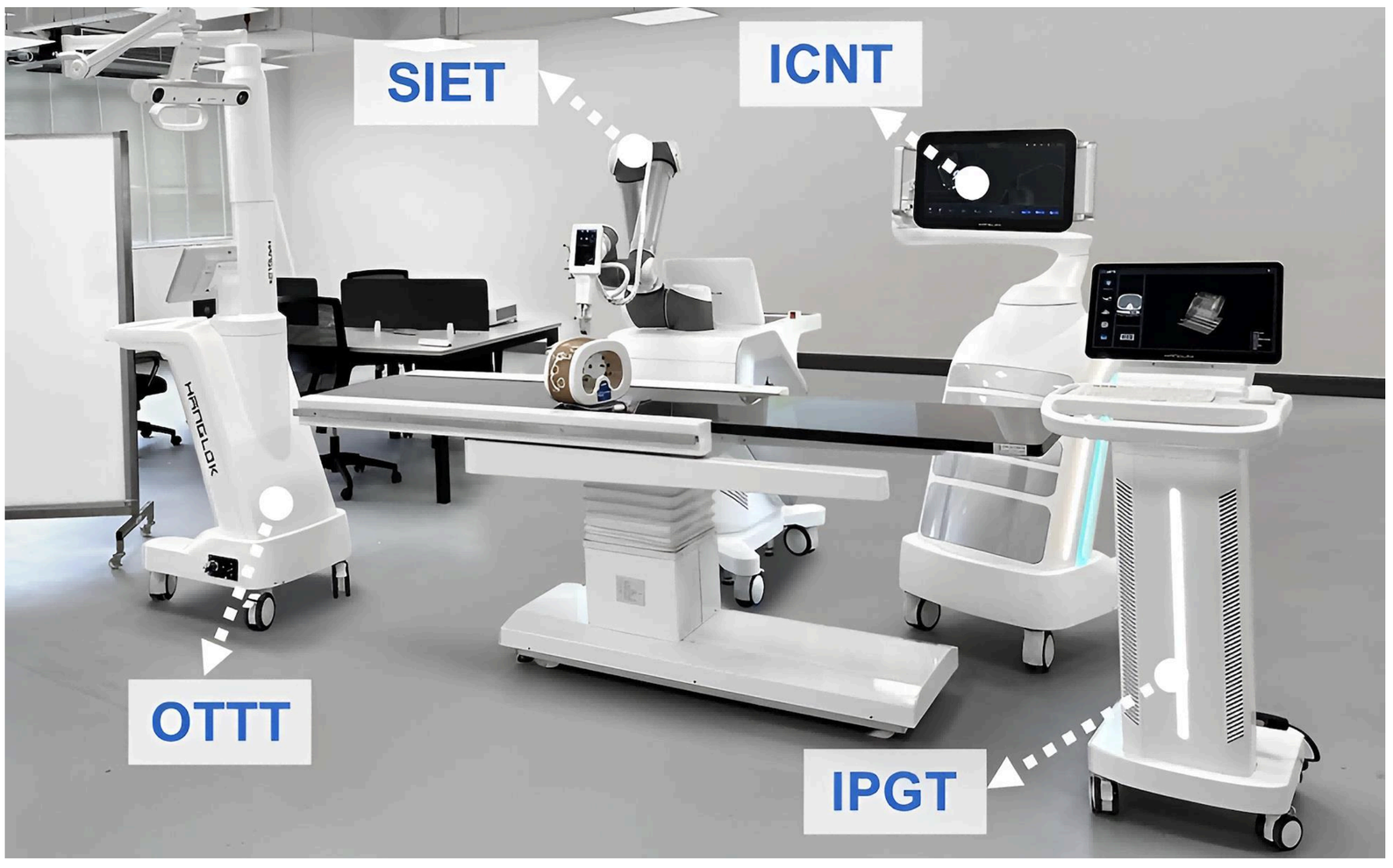

Fig. 1 Robot Overall Schematic: OTTT, Optical-based Tool-Tracking Trolley; OTTT, Optical-based Tool-Tracking Trolley; ICNT, Immersive Control and Navigation Trolley; and IPTG, Interventional Planning Generation Trolley.

Method

Eight Bama miniature pigs were used in this study. The punctures were performed during continuous free breathing. When using the robot-assisted positioning function, the physician can view the CT–US fusion image on the display at the end of the robot arm, adjust the puncture path according to the actual situation, and complete the puncture (Fig. 2). The CT images obtained after needle insertion are shown in Fig. 3a. By utilizing the reconstruction function of the DICOM Viewer, a 3D reconstruction model of the image was generated, providing a more intuitive visualization of the relationship between needle insertion and the simulated tumor position (Fig. 3b).

Fig. 2 A trained physician using the robotic device to assist in puncture procedures.

Parameter	Insertion Mode	Number	Mean	Median	Min; Max	P-value
Euclidean Distance(mm)	Robot	16	2.15 ± 0.82	1.99	0.99; 3.76	<0.001
	Free Hand	16	5.32 ± 2.26	1.5	2.59; 10.92	
Cranio-Caudal Error(mm)	Robot	16	0.16 ± 0.36	0.21	0.00; 1.00	0.018
	Free Hand	16	2.27 ± 2.69	2.25	0.00; 10.50	
Ventro-Dorsal Error(mm)	Robot	16	1.12 ± 0.74	1.03	0.00; 2.79	0.003
	Free Hand	16	2.63 ± 1.59	2.27	0.00; 4.50	
Left-Right Error(mm)	Robot	16	1.61 ± 0.89	1.4	0.00; 3.49	0.022
	Free Hand	16	2.72 ± 1.57	3.11	0.00; 6.00	
Skin-to-target distance(mm)	Robot	16	84.5 ± 10.10	86.84	54.25; 104.60	0.059
	Free Hand	16	74.06 ± 18.54	68.05	58.00; 103.40	

Table. 1 Experimental results of robot-assisted punctures vs handheld punctures.

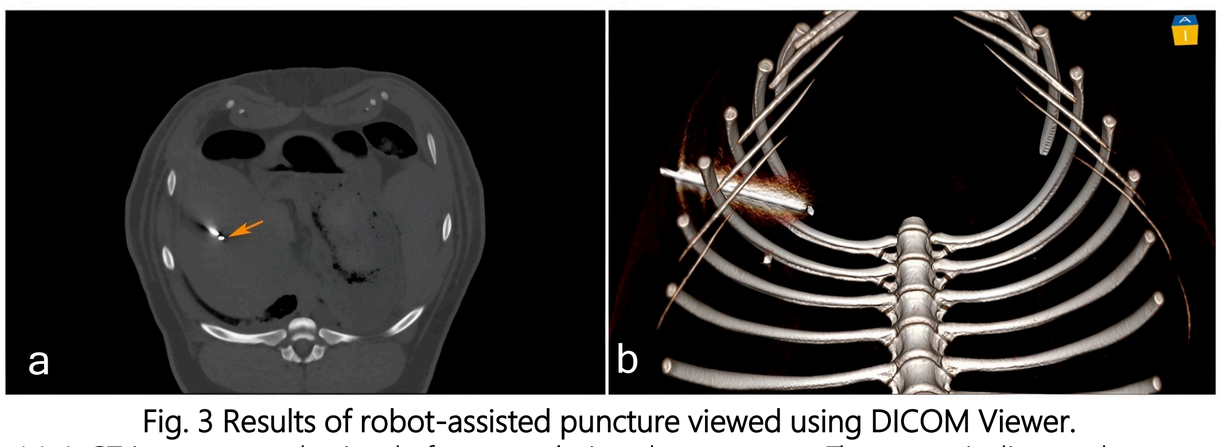

Fig. 3 Results of robot-assisted puncture viewed using DICOM Viewer.
(a) A CT image was obtained after completing the puncture. The arrow indicates the simulated tumor target in the liver.
(b) A 3D model was reconstructed using DICOM Viewer after completing the puncture.

Result and Conclusion

The Euclidean distance between the needle tip and the predetermined target point was 5.32 ± 2.26 mm for the handheld puncture and 2.15 ± 0.82 mm for the robot-assisted puncture. The difference in accuracy between the handheld and robot-assisted punctures was significant ($P < 0.001$).

Robotic-assisted puncture needle insertion using the CT–US fusion-guided technique demonstrated feasibility, safety, and accuracy in both phantom and animal models.

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