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Clinical application of an intraoperative three-dimensional imaging navigation system for computed tomography-guided thermal ablation of liver tumors

Da Fang[1], Peng Zhao[1], Bojun Liu[1], Yonghong Zhang[1], Jiasheng Zheng[1], Caixia Hu[1*]

[1] Center for Minimally Invasive Treatment of Liver Diseases and Tumors, Beijing You'an Hospital, Capital Medical University, Beijing, 100069, China

Abstract

Objective To explore the value of clinical application of a navigation system with three-dimensional (3D) imaging for thermal ablation of liver tumors.

Methods The study cohort comprised 60 patients who underwent computer tomography-(CT) guided thermal ablation (radiofrequency or microwave ablation) of liver tumors in our department from August 2021 to October 2022. A random envelope method was used to allocate the study patients randomly to two groups of 30 patients each: a navigation and a control group. An intraoperative 3D imaging navigation system with CT guidance was used in the navigation group, whereas traditional CT guidance was used in the control group. During the thermal ablation process, the number of puncture needle adjustments, time to target puncture, and number of CT scans were recorded and compare between the two groups.

Results The average number of punctures and needle adjustments was significantly lower in the navigation group (2.7 ± 1.1 mins) than in the control group (4.9 ± 3.7 mins). The average time taken to puncture the target was significantly shorter in the navigation group (11.3 ± 4.2 mins) than in the control group (15.5 ± 4.8 mins). There average number of CT scans was significantly smaller in the navigation group (4.5 ± 1.6) than in the control group (8.4 ± 4.5) (all $P<0.05$).

Conclusion Use of an intraoperative 3D imaging navigation system in thermal ablation of liver tumors can improve the accuracy of tumor thermal ablation puncture and reduce the number of punctures, number of CT scans, and average puncture time. Such systems can play an important role in the clinic.

Keywords: computed tomography guidance; intraoperative 3D imaging navigation system; liver tumors; thermal ablation

***Correspondence:**
Caixia Hu; Email: hucaixia1217@126.com.

Introduction

Liver cancer, a common condition, seriously threatens the life and health of Chinese people. Current treatment methods include surgical resection, liver transplantation, transcatheter arterial chemoembolization, ablation, and immune combination therapy. The aim of ablation therapy is to inactivate tumors in-situ while achieving maximal preservation of the relatively normal surrounding liver tissue. This procedure can also be curative for liver cancer. Its advantages include the ability to repeat the procedure, reliable efficacy, and low cost, making it increasingly valued in clinical practice, especially for patients with liver cancer that has only been diagnosed in the middle or late stages and is therefore ineligible for surgery. A tumor conformal ablation strategy can be used to determine the location and number of ablation needles needed for the volume of the target tumor, making the ablation area consistent with the tumor morphology, and consequently achieving good therapeutic effects, including prolongation of survival. In addition, multi-needle or single needle multi-point ablation strategies are often used during the ablation treatment process for liver tumors of a diameter greater than 3 cms. Needle placement is adjusted according to the shape of the tumor so that the ablation area completely covers the tumor contour with a 0.5–1 cm-wide ablation margin. IN contrast, surface localization marking methods are often used with traditional CT-guided puncture ablation. The lack of real-time visualization and dynamic guidance necessitates multiple CT scans during the procedure to adjust the needle direction and angle, confirm the puncture depth, and avoid important vessels on the puncture path. Performing multiple CT scans thus results in an increase in radiation dose to the patient, prolongation of surgery time, and more frequent complications of puncture. These considerations make precise ablation therapy for liver tumors in the clinic particularly important. In recent years, interventional navigation systems have become a research hotspot in the field of precise tumor ablation. In the present study, we used an intraoperative three-dimensional imaging navigation system in patients with liver tumors undergoing ablation, carefully conducted preoperative planning and intraoperative auxiliary navigation, and explored the value of clinical application of this navigation system as an aid to performing liver tumor ablation.

Data and Methods

Clinical data

The procedures followed in this study comply with ethical standards and have been approved by the Ethics Committee of Beijing You'an Hospital (Number: Jingyoulun Zi 2021205). All subjects have signed informed consent forms.

Sixty patients who underwent CT guided liver tumor thermal ablation (radiofrequency or microwave ablation) treatment in our department from August 2021 to October 2022 were selected for inclusion in this study. A random envelope method was used to allocate them into two groups of 30 patients: a navigation and a control group. An intraoperative CT-assisted three-dimensional imaging navigation system was used in the navigation group, whereas traditional CT guidance was used in the control group.

The inclusion criteria were: (i) age 18–70 years, either sex; (ii) primary liver cancer or liver metastases that meet the criteria for curative or palliative ablation of liver tumors; and (iii) the patient's general condition is good enough to tolerate CT guided thermal ablation therapy for abdominal tumors.

The exclusion criteria were:(i) presence of a pacemaker or other electromagnetic devices that could interfere with the navigation; (ii) presence of large metal im-

plant(s) that could cause electromagnetic interference to the navigation system; (iii) contraindications to CT scanning; (iv) pregnancy or lactation; (v) current participation in another clinical trial and not yet been enrolled in this one; and (vi) researchers have determined that the potential participant is not suitable for inclusion in this clinical trial.

The 60 enrolled patients comprised 51 men and nine women aged 35–73 years (average 56 years). Thermal ablation treatment was performed on 70 lesions, including 52 primary liver cancers and 18 liver metastases. The intrahepatic lesions were located in the left lobe of the liver in 20 cases and in the right lobe in 50. Radiofrequency ablation was performed on 21 patients, and microwave ablation on 39 patients.

There were no significant differences in sex, age, distribution of intrahepatic tumors, or ablation methods between the two groups of patients (Table 1).

Instruments and equipment

The intraoperative 3D imaging navigation system used (Yida Jixing Medical Technology, Suzhou, China) incorporates hardware systems that include a computer console, electromagnetic field emitter, electromagnetic positioning patch, and electromagnetic tracking adapter. The CT scanner used was a 16-slice spiral CT (Activon 16; Activion, Toshiba, Japan). The radiofrequency ablation therapy device used was a cold cycle radiofrequency ablation system (Tyco Cool trip RFA system; USA). The microwave ablation therapy device used was a Yigao Microwave ECO-100D (Nanjing Yigao Medical Technology).

Methods

Preoperative preparation

The risks and postoperative complications of thermal ablation were explained to the patient and their family members and an informed consent form was signed. The rest of the preparation was the same as for standard thermal ablation of liver tumors.

Intraoperative Navigation

There are four steps in the guided puncture positioning process for intraoperative CT-assisted three-dimensional (3D) imaging navigation systems: (i) The initial setup, in which an electromagnetic sensor is fixed on the surgical instrument and an electromagnetic tracking positioning mark is fixed on the patient's body surface. Once the electromagnetic tracking positioning system is in place, the initial CT scan is performed. (ii) Preoperative images are loaded and examined, the navigation system being used to select relevant patient examination data, read in the scanned CT data, and confirm the positioning mark for electromagnetic tracking. (iii) A 3D fully quantified electronic map is generated by performing interactive segmentation of organ or pipeline structures in the target tumor area. (iv) Preparation for navigation: the electromagnetic tracking and positioning system is activated, setting the surgical instrument port type and surgical instrument parameters, confirming the tracking signal strength and results of segmentation of the positioning markers, registering the preoperative image space with the patient's physical space, and calibration and adjustment are performed.

The specifics of the implementation process are as follows: the patient lies supine on an examination bed with the upper abdomen fully exposed. Data acquisition film is pasted on the skin overlying the target lesion and a preliminary CT scan covering the lesion and all data acquisition films performed. The original image data are then transmitted to the electromagnetic navigation system, which automatically reconstructs the original image for use during the puncture positioning process. The reconstructed image displays the target,

needle insertion point, and trajectory, and can also display the position of the electrode needle tip relative to the CT image and anatomical structures in real time. With the guidance of dynamic real-time monitoring, the depth and angle of the puncture are adjusted progressively until the electrode needle reaches the target lesion.

Conventional CT guidance was used for puncture positioning in the control group. The specifics of the implementation process were as follows: the patient lies supine on the examination bed with the upper abdomen fully exposed, positioning marks are attached to the skin overlying the target lesions, and repeated CT scans performed to determine the position, direction, angle, and depth of the needle and adjust the puncture path until the electrode needle reaches the target lesion.

Thermal Ablation Procedure

Another CT scan is performed to confirm that the thermal ablation electrode needle has reached the target lesion before proceeding with microwave ablation, generally with a power of 40–50 watts per site and duration of 5–8 mins, or radiofrequency ablation, which typically involves a power of 100–120 watts per site and duration of 10–15 mins. During the thermal ablation process, CT scanning is implemented to ensure that the ablation area completely covers the lesion together with a margin of 0.5–1 cm. After ablation of the lesion is completed, the needle path is also ablated during its withdrawal to prevent bleeding and implant metastasis. Finally the electrode needle is withdrawn completely to end the surgery. Electrocardiographic monitoring and comprehensive medical treatment are used postoperatively. To minimize physician-related variations in performing the procedure, all ablation was performed by the same physician in both groups of patients.

Data Collection

The following information was recorded for both the navigation and control groups: number of needle adjustments during puncture, interval between the patient's first CT scan and the electrode needle reaching the target lesion (puncture–target time), and number of CT scans. Enhanced CT scanning was performed immediately after completing the procedure to evaluate the ablation effect and determine the rate of complete ablation in both groups. Additionally, the occurrence and management of post-thermal ablation complications in both groups of patients were recorded.

Statistical analysis

SPSS 21.0 statistical software was used for statistical analysis. Student's *t*-test or the χ^2 test was used to compare the frequency of needle adjustment, puncture–target time, frequency of CT scans, and general data between the navigation and control groups. $P<0.05$ was considered to denote statistical significance.

Results

Liver tumor thermal ablation treatment: navigation group

An intraoperative 3D imaging navigation system was successfully used during the process of liver tumor thermal ablation in the 30 patients in the navigation group. In this group, the average number of needle adjustments was 2.7 ± 1.1, the average time to puncture the target was 11.3 ± 4.2 mins, and the average number of CT scans was 4.5 ± 1.6. One of these patients had minor bleeding under the liver capsule. No other complications occurred. After symptomatic treatment with hemostasis and fluid replacement, there was no active bleeding. Enhanced abdominal CT scans performed immediately post-procedure showed that all lesions in all patients had been completely ablated.

Liver tumor thermal ablation treatment: control group

All 30 patients in the control group completed liver tumor thermal ablation under conventional CT guidance. The average number of needle adjustments in this group was 4.9 ± 3.7, the average time to puncture the target was 15.5 ± 4.8 mins, and the average number of CT scans was 8.4 ± 4.5. Two of these patients had minor bleeding under the liver capsule that stopped with intravenous infusion of hemostatic drugs. Enhanced abdominal CT scans performed immediately post-procedure showed that all lesions in all patients were completely ablated.

The differences between the navigation and control groups in frequency of needle adjustment and CT were statistically significant (P<0.05), Table 2.

Discussion

Liver tumor ablation therapy

The aim of ablation therapy is to inactivate tumors in-situ while achieving maximal preservation of the relatively normal surrounding liver tissue. This procedure can also be curative for liver cancer. Its advantages include the ability to repeat the procedure, reliable efficacy, and low cost, making it increasingly valued in clinical practice, especially for patients with liver cancer that has only been diagnosed in the middle or late stages and is therefore ineligible for surgery. A tumor conformal ablation strategy can be used to determine the location and number of ablation needles needed for the volume of the target tumor, making the ablation area consistent with the tumor morphology, and consequently achieving good therapeutic effects, including prolongation of survival. In addition, multi-needle or single needle multi-point ablation strategies are often used during the ablation treatment process for liver tumors of a diameter greater than 3 cms. Needle placement is adjusted according to the shape of the tumor so that the ablation area completely covers the tumor contour with a 0.5–1 cm-wide ablation margin [2].

The ability to repeat image-guided liver tumor ablation, its reliable efficacy and low cost, and the fact that it is minimally invasive have resulted in this approach being increasingly valued in clinical practice as a treatment

Table 1. Comparison of the general information between the two study groups.

	Navigation group (n=30)	Control group (n=30)	T-value or χ^2-value	P
Gender (n,%)			0.131	0.718
male	26(50.98%)	25(49.02%)		
female	4(44.44%)	5(55.56%)		
Tumor location (n,%)			0.28	0.597
left lobe of liver	9（45%）	11（55%）		
right lobe of liver	26（52%）	24（48%）		
age	55.16 ± 1.82	56.08 ± 2.61	-1.584	0.119
Ablation method (n,%)			0.073	0.787
microwave ablation	20（51.28%）	19（48.72%）		
Radiofrequency Ablation	10（47.62%）	11（52.38%）		

Table 2. Comparison of the frequency of needle adjustment and time to puncture the target between the two types of guidance.

	Navigation group	Control group	T-value	P
Needle adjustment frequency	2.7±1.1	4.9±3.7	-3.12	0.003
Time taken to puncture the target (minutes)	11.3±4.2	15.5±4.8	-3.61	0.001
CT scan frequency	4.5±1.6	8.4±4.5	-4.47	<0.0001

for liver tumors. This is especially true for liver cancer patients who have presented with middle- or late-stage disease and are thus ineligible for surgery. A tumor conformal ablation strategy is used to determine the number and location of ablation needles required for the tumor volume and make the ablation area consistent with the tumor morphology, achieving good therapeutic effects in the clinic [3-5]. The main currently-used imaging guidance modalities are B-ultrasound and CT guidance, each of which has its own advantages. B-ultrasound, which produces two-dimensional images, can provide guide in real-time without radiation; however, its clarity is poor and it is easily affected by gas and bone. B-ultrasound is relatively unhelpful in guiding puncture if the liver tumor is located near the diaphragm or deep inside the liver, sometimes resulting in blind spots in ablation treatment [6]. CT guided images have high resolution and can clearly display the size, location, morphology, and relationship of lesions to surrounding tissues and are unaffected by gas and bone; however, they cannot provide guidance in real time. When performing liver tumor ablation after pre-puncture localization by CT, errors in the site of insertion of the puncture needle and localization of the target lesion can occur owing to preoperative psychological tension, excessively deep breathing, or perceived pain preventing regular respiration. The success of the puncture part of the procedure therefore largely depends on the operator's experience [7]. Furthermore, CT-guided puncture requires multiple CT scans during the needle insertion process, with the accompanying substantial irradiation. Additionally, blind puncture has a high risk of ectopic puncture, resulting in complications. Navigation technology assisted by CT guidance has therefore been increasingly valued in recent years [8-10].

Advantages of intelligent navigation during the ablation process

Intelligent navigation systems provide personalized, 3D, fully quantified electronic maps of organs, enabling incorporation of real-time interactive quantification technology into interventional surgery. These systems automatically locate and track the surgical target and thereby guide and monitor the entire process in real-time with 3D quantified images that display paths, distance, and angles from the tip of the puncture needle to the target lesion. They enable avoidance of important blood vessels and greatly improve puncture accuracy. These systems have unique advantages in minimally invasive interventional diagnosis and treatment of tumors. In our hospital, we have researched thermal ablation of liver tumors with the assistance of intelligent navigation systems and CT guidance, exploring the value of its clinical application in liver tumor ablation. We found that patients in the navigation group required fewer thermal ablation needle adjustments, shorter average time to puncture the target lesion, and fewer CT scans on average than those in the control group. Complete ablation was achieved in both groups of patients. Utilization of intelligent navigation systems can result in improvement in accuracy of punctures for tumor thermal ablation, reduction in the number of punctures and CT scans, and shorter average puncture times, making complete ablation treatment convenient, fast, and accurate. Both the navigation and control groups achieved complete ablation with a similar incidence of complications.

Conclusion

Intelligent navigation systems assisted by CT-guidance can accurately locate lesions, clearly display important organs and relationships between vascular systems and target lesions, and display puncture paths, distances, and angles, thereby reducing the incidence of puncture complications. They are effective auxiliary tools for CT-guided liver tumor thermal ablation and play an important role in clinical applications. However, there are some shortcomings in the practical application of

navigation systems, including their costliness, large footprint, and interference with respiration. Therefore, development of better means of implementing navigation systems in clinical practice still requires large-scale clinical research and creation of more functional products.

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Author contributions

Conceptualization, D.F.; methodology, D.F. and P.Z.; validation, D.F., P.Z. and B.L.; formal analysis, Y.Z. and J.Z.; resources, D.F. and C.H.. All authors had full access to all data in the study and had final responsibility for submitting it for publication. All authors read and approved the final version of the manuscript.

Conflicts of Interest

All authors declare that there are no conflicts of interest in this article.

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