Abstract: Since radiofrequency ablation (RFA) therapy for liver tumor was established, it became a standard percutaneous therapy. However, after the first ablation microbubbles sometimes obstruct a clear observation of the tumor under ultrasound guidance, and despite multiple RFA, a part of the tumor may remain viable. To solve this problem we developed a computer-guided navigation system for an accurate electrode insertion. We used POLARIS™ (Northern Digital Inc., Ontario, Canada) as the active optical tracking system. The POLARIS™ allows us to determine the real time 3D positions of active markers. With this system we could determine the location and the direction of the RFA electrode and the distance from the tip of the electrode to the target, which were displayed on the PC monitor. We also investigated the accuracy of this system as a preliminary test for its clinical application. The primary error between the real and the theoretical target was 2.88 mm. The first insertion error was 5.78 ± 1.97 mm and the second insertion error was 8.01 ± 1.01 mm. While some hardware improvements and more technical experience are needed for its clinical applications, this computer-guided navigation system will be of great help for an accurate electrode insertion, especially in case of unresectable liver tumors subjected to RFA.

Key Words: radiofrequency ablation, liver tumor, computer-guided navigation, optical tracking system

Introduction

The use of ultrasonography (US) has improved the detection of small hepatocellular carcinomas (HCC) and it has facilitated the treatment of HCC by percutaneous injection under US guidance. The main local therapy for HCC is still surgical resection1), but due to concomitant liver cirrhosis or the presence of multiple nodules, HCC is unresectable in many cases. Therefore percutaneous therapy is a key therapy for HCC.

Percutaneous ethanol injection (PEI) was developed in 19832), and it has been performed worldwide...
ever since. However, part of the tumor occasionally remains intact because of an uneven distribution of ethanol. To achieve an accurate coagulation effect percutaneous microwave coagulation therapy (PMCT) was then developed\(^3\). But the size of coagulation area after one microwave exposure is small and thus it is necessary to insert the needle several times.

Radiofrequency ablation (RFA) for HCC has been employed since 1989\(^4\). With RFA one achieves a higher percentage of complete necrosis than with PEI and a larger coagulation area than with PMCT. Therefore it has become a standard percutaneous therapy for HCC\(^5\). Although RFA is superior to PEI or PMCT, the necessity of accurate insertion to achieve complete necrosis of the tumor is the same as for the other procedures. The coagulation area after one exposure of RFA is 3 cm in diameter. In the case of a large HCC (i.e. over 2.5 cm), RFA must be repeated twice or three times. Usually, RFA is performed under US guidance. But the microbubbles generated by the first RFA sometimes interfere with a clear observation of the whole tumor at the time of the second RFA. Between December 1995 and August 2001 we treated in 38 consecutive patients with 79 HCC nodules by RFA\(^6,7\). The local recurrence rate was 25% for the \(\geq 3\) cm in diameter group, and 6.3% for the \(< 3\) cm in diameter group (unpublished data). For a more accurate insertion we have developed a computer-guided navigation system.

Materials and methods

Optical tracking system

We used POLARIS\(^\text{TM}\) (Northern Digital Inc., Ontario, Canada) as the active optical tracking system. With this system one can determine the real time six degrees of freedom of tool by measuring the 3D positions of active markers. The POLARIS consists of light-emitting diodes (LED) markers, a position sensor, a tool interface unit and a personal computer (DynaBook 2710, Toshiba Co., Tokyo, Japan) (Fig. 1). The LED markers were mounted to the RFA electrode grip (Model 30, RITA Medical System, Mountain View, CA, USA) (Fig. 2).

Fig. 1. Photograph of the optical tracking system "POLARIS\(^\text{TM}\)". From the left (clockwise), the personal computer, the position sensor, the tool interface unit and the RFA electrode with the mounted light-emitting diodes (LED) markers.

Fig. 2. Photograph of the RFA electrode with the mounted LED markers.
Software

To visualize the tracking data from the system The Visualization Toolkit Version 3.2 (Kitware Inc., Clifton Park, NY) was used. Statistical analysis was performed using StatView statistical software (version 5.0, SAS Institute Inc., Cary, NC).

Primary error evaluation

An acrylic cubic case with a target at its center was used as the phantom of this experiment (Fig. 3). The RFA electrode was inserted directly to the real target. The distances on the PC display from the tip of the electrode to the theoretical target were measured.

Evaluation of the insertion error

The images of the phantom and target were taken into the interface software in advance. The phantom was filled up with agar-agar. The RFA electrode was inserted toward the target under PC guidance. When the tip of the electrode reached the target on the PC display, the distance from the tip of the electrode to the target was measured (first insertion). Then an imaginary target was set at random at 10 mm from the first target mimicking the second insertion and the error of second insertion was measured as already described.

Results

We could track the location of the LED marker with the position sensor and personal computer connected to the tool interface unit processed the tracking data. The location and the direction of the RFA electrode were clearly displayed on the monitor as well as the distance from the tip of the electrode to the target (Fig. 4a, b). During this study no hardware and software troubles occurred.

The primary error between the real and the theoretical target was 2.88 mm.

The first insertion error was 5.78 ± 1.97 mm and the second insertion error was 8.01 ± 1.01 mm (Table I). There was not a statistically difference between them (p = 0.063). These errors seemed to be caused by two main factors. The first was the difficulty to determine the direction of the insertion. The

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<td>Second insertion</td>
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Table I. Errors of the system. Values of the insertion errors indicate mean SD ± (n=5)

Fig. 3. Photograph of the acrylic cubic phantom of 100 x 100 x 100 mm. The top of the column is the center of this phantom.
display of the electrode on the PC was not prompt. However, this is only up to the PC speed, and it can be improved by using a more rapid PC. The second was that the electrode was not settled firmly during the insertion. Agar-agar was very soft and the electrode was not fixed. In clinical practice this problem can be easily solved.

Discussion

Imaging techniques such as computed tomography (CT) and magnetic resonance image (MRI) can provide 3D virtual reality images of the tumors\(^8,9\). Recent advances of computers and optical devices have allowed the development of image-guided surgery, especially in the field of neurosurgery\(^10\) and sinus surgery\(^11,12\). Neurosurgery and sinus surgery require minimum invasive techniques. The indication of an optimal access route to the precise location of a tumor that is not visible from the surface is very important to remove it without injuries of healthy tissues. 3D images of a liver tumor are very useful for pre-operative planning. However, intraoperative 3D image guidance is not widely employed in liver surgery because of the use of intraoperative US\(^13\). The location of a tumor and its relationship with vessels can be observed more clearly with intraoperative US than with extracorporeal US. Sometimes one cannot detect the part or the whole tumor using extracorporeal US. Besides, in the case of RFA, after the first ablation, glittering microbubbles on the US image obstruct the clear observation of the tumor. A computer-guided navigation system provides clear information for RFA electrode insertion in spite of the presence of microbubbles.

In this study we investigated the accuracy of this system as a preliminary test for clinical application. The primary error between the real and the theoretical target was 2.88 mm. Bending of the electrode was assumed to be the cause of this error, because the electrode was too flexible and bent easily. If it bent, the distance from LED markers to the tip would be shortened. In fact, the Polaris system itself has been reported to jitter only 0.053 mm\(^14\). Use of a stiffer electrode will reduce this error. Insertion errors were 5.78 mm and 8.01 mm. These errors seemed to be critical depending on the size of the tumor.
Improvement of the system, especially regarding the computer, and more technical experience are required for a more accurate insertion.

We used an acrylic cubic phantom to simplify the transfer of the image data and its position in navigation system to the PC. The registration of patient's abdominal position is an important issue. Some markers have to be put on the patient's skin prior to preoperative CT or MRI scan. Besides, an accurate respiratory control is required.

Conclusions

We have investigated the possibility of using a computer-guided navigation system for RFA electrode insertion. Some hardware improvements and more technical experience are needed before its clinical use. We believe a computer-guided navigation system will be of great help for an accurate electrode insertion in the case of patients with an unresectable liver tumor to be subjected to RFA.

References


正確な RFA ニードル穿刺のための
ナビゲーションシステムの開発

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要　旨：肝腫瘍に対する RFA 療法において、腫瘍が大きい場合などで複数回の穿刺が必要な場合があり、その際 1 回目の照射の際に発生する気泡により、超音波では腫瘍の観察が不十分となり、焼け残しが生じる可能性がある。この問題に対し、我々はコンピューターガイド下ナビゲーションシステムを開発した。これにより、RFA 電極先端の位置と方向、目標との関係をモニター上に描出し得た。システムの初期誤差（現実の位置と理論上の位置との差）は 2.88 mm であり、実際に目標に穿刺した際の誤差は 5.78 ± 1.97 mm であった。