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ORIGINAL ARTICLE

Evaluation of an online navigation system for laparoscopic interventions in a perfused *ex vivo* artificial tumor model of the liver

PHILIPP HILDEBRAND[1], VOLKER MARTENS[2], ACHIM SCHWEIKARD[2], STEFAN SCHLICHTING[1], ARMIN BESIREVIC[1], MARKUS KLEEMANN[1], UWE ROBLICK[1], LUTZ MIROW[1], C. BÜRK[1] & HANS-PETER BRUCH[1]

[1]*Department of Surgery and* [2]*Institute for Robotics and Cognitive Systems, University of Schleswig-Holstein, Luebeck, Germany*

Abstract
Background. Laparoscopic radiofrequency ablation (RFA) is a safe and effective method for tumor destruction in patients with unresectable liver tumors. However, accurate probe placement using laparoscopic ultrasound guidance is required to achieve complete tumor ablation. After evaluation of an ultrasound navigation system for transcutaneous and open RFA, we now intend to tranfer this technique to laparoscopic liver surgery. This study aimed to evaluate an electromagnetic navigation system for laparoscopic interventions using a perfusable *ex vivo* artificial tumor model. *Materials and methods.* First a special adapter was developed to attach the ultrasound and electromagnetic tracking-based navigation system to a laparoscopic ultrasound probe. The laparoscopic online navigation system was studied in a laparoscopic artificial tumor model using perfused porcine livers. Artificial tumors were created by injection of a mixture of 3% agarose, 3% cellulose, and 7% glycerol, creating hyperechoic lesions in ultrasound. *Results.* This study showed that laparoscopic ultrasound-guided navigation is technically feasible. Even in cases of angulation of the ultrasound probe no disturbances of the navigation system could be detected. Artificial tumors were clearly visible on laparoscopic ultrasound and not felt during placement of the RFA probe. Anatomic landmarks and simulated 'tumors' in the liver could be reached safely. *Discussion.* Laparoscopic RFA requires advanced laparoscopic ultrasound skills for accurate placement of the RFA probe. The use of an ultrasound-based, laparoscopic online navigation system offers the possibility of out-of-plane needle placement and could increase the safety and accuracy of punctures. The perfused artificial tumor model presented a realistic model for the evaluation of this new technique.

Key Words: *Radiofrequency ablation, artificial tumor model, laparoscopic ultrasound, navigation, liver*

Introduction

Surgical resection is the only potentially curative treatment for patients with primary or secondary hepatic malignancies. However, only 5–15% of all patients with hepatocellular carcinoma (HCC) and 20–25% of all patients with liver metastases are suitable for curative resection at the time of diagnosis [1–4]. Correspondingly interventional therapies for effective tumor destruction of unresectable liver tumors have received considerable interest. In recent years radiofrequency ablation (RFA) has become the most commonly used and perhaps most promising modality for tumor ablation. RFA can be used transcutaneously or intraoperatively via laparotomy or laparoscopy.

Laparoscopic RFA offers a combination of minimal invasiveness with optimal diagnosis. However, accurate placement of the RFA probe is the prerequisite to guarantee complete tumor destruction [5]. Advanced laparoscopic ultrasound skills are the basis for accurate probe placement. Hands-on practice is necessary to improve intraoperative ultrasound techniques and a learning curve has to be overcome [6,7]. After evaluation of an ultrasound navigation system for transcutaneous and open RFA, we now intend to tranfer this technique to laparoscopic liver surgery. An ultrasound-based laparoscopic online navigation

Correspondence: Dr med. Philipp Hildebrand, University of Schleswig-Holstein, Campus Lübeck, Department of Surgery, Ratzeburger Allee 160, D-23538 Lübeck, Germany. Tel: +49 451 7076883. Fax: +49 451 7076883. E-mail: philipphildebrand@yahoo.com

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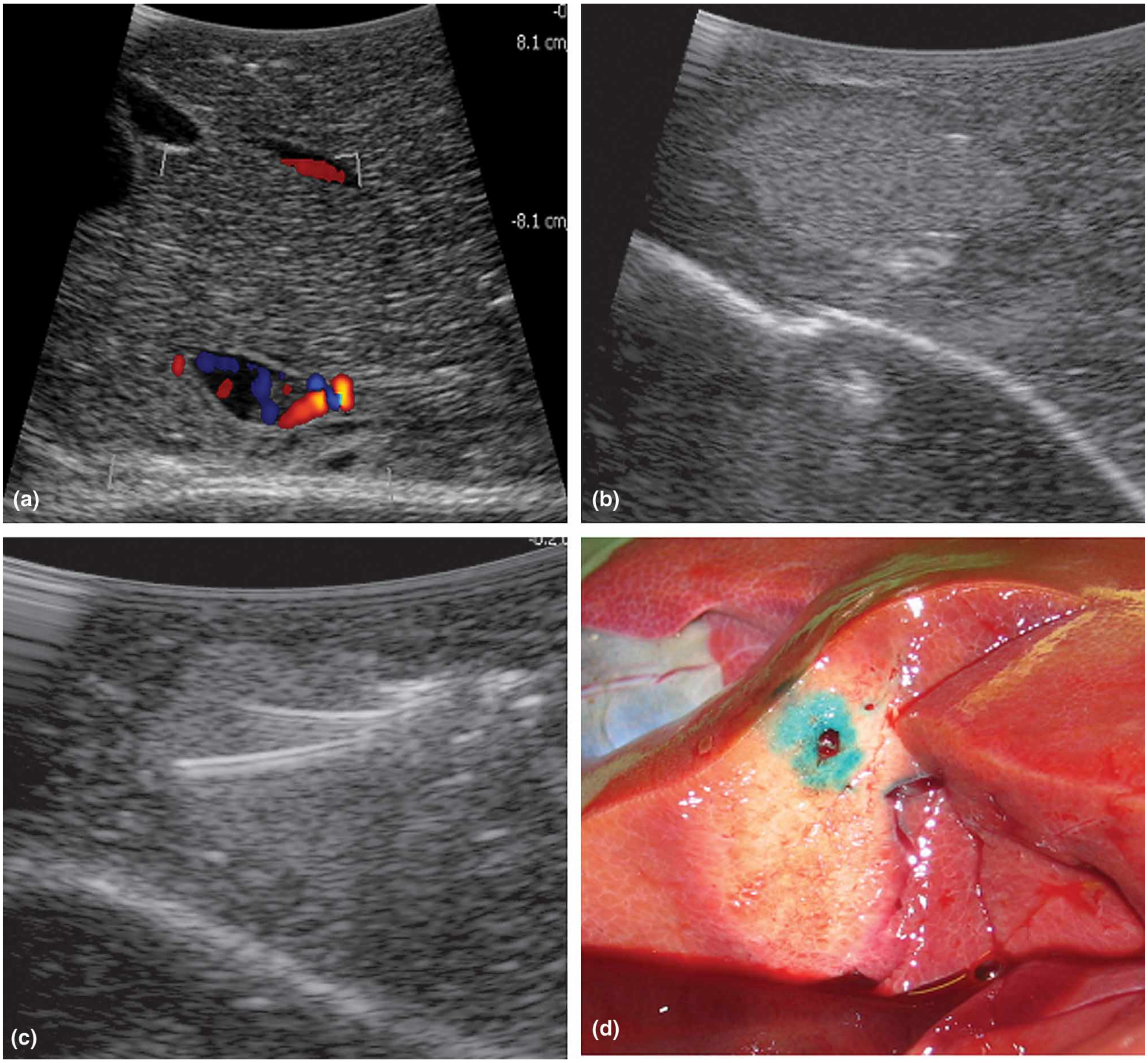

Figure 1. Ultrasound view with color duplex signals (a), hyperechoic artificial tumor (b), and placement of the RFA probe (c). Macroscopic section of a tumor mimic ablation (d).

system that allows out-of-plane needle placement combines the flexibility of free-hand puncture and the accuracy of a canal for puncture, which could significantly increase the safety of punctures. This study aimed to evaluate an electromagnetic navigation system for laparoscopic interventions using a perfusable *ex vivo* artificial tumor model.

Materials and methods

Organ perfusion and artificial tumors

After explantation of the liver from freshly slaughtered animals the organ was prepared by separating the portal vein and the vena cava. The portal vein was attached to an elastic tube that enabled connection to a perfusion pump. The porcine liver was rinsed with a cooled heparinized solution (20 000 units in 2 L of HTK solution), comparable to the procedure used in organ transplantation. Artificial tumors were created by injection of a mixture of 3% agarose, 3% cellulose, 7% glycerol, and 0.05% methylene blue, as introduced by Scott et al., creating hyperechoic lesions in ultrasound [8]. A heparinized HTK/porcine blood mixture was used as perfusion medium. Continuous perfusion of the porcine liver was guaranteed by connection of a pump system to the portal vein and the vena cava inferior, creating a closed circulation. Evaluation of navigated laparoscopic RFA was performed using a laparoscopic box-trainer.

Navigation system

Laparoscopic ultrasound was performed using an SSD-3500 system from ALOKA. For electromagnetic tracking, NDI's AURORA system with two 5° of freedom sensors was used. These sensors give the

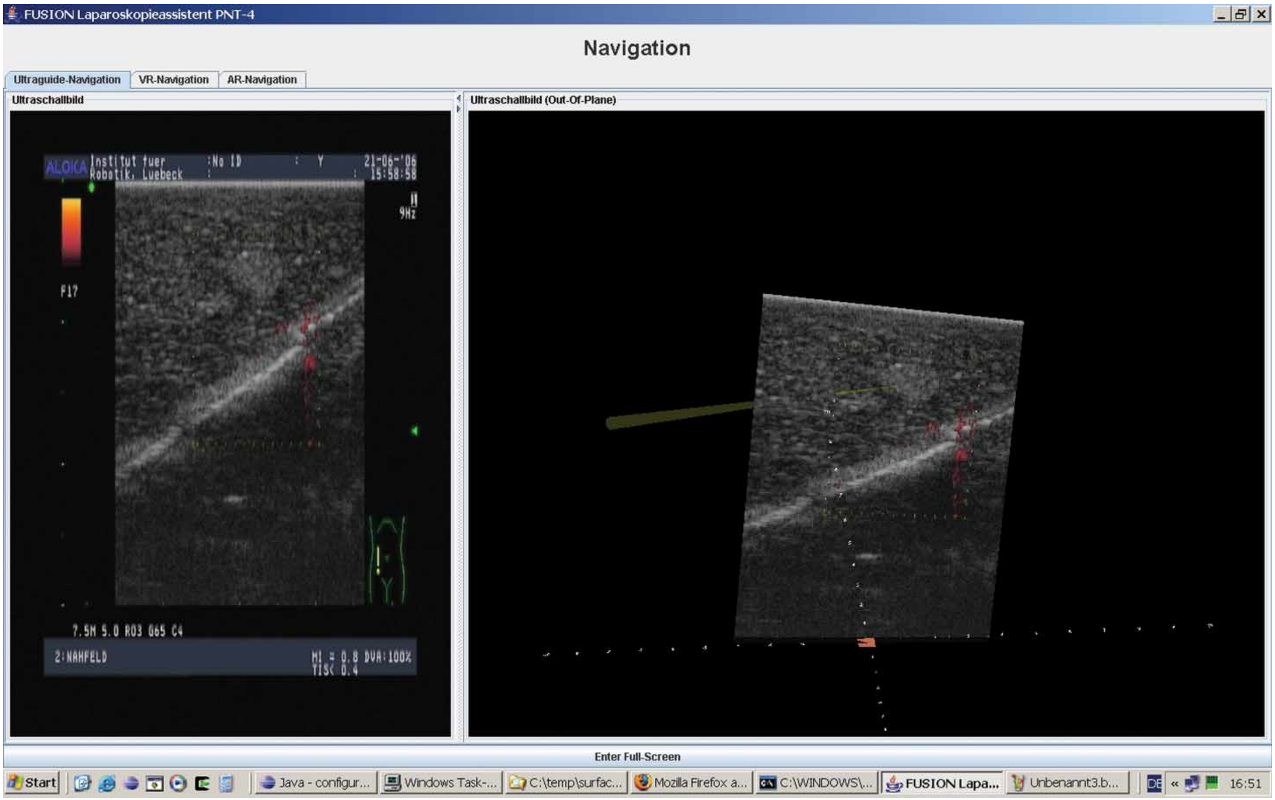

Figure 2. Screenshot of the navigation system with the out-of-plane view on the right side. The virtual instrument points directly at the localized tumor.

complete pose except the rotation around their principal axis (roll). Therefore, image acquisition was done without rotating the ultrasound transducer.

One of the sensors was attached to a laparoscopic ultrasound probe, the other was held in a thin rigid tube simulating any kind of rigid laparoscopic instrument.

In addition, CT scans of the perfused artificial tumor model were made to evaluate the accuracy of the electromagnetic tracking system's measurements in comparison to the navigated ultrasound slices.

Results

The perfusion of the organ through the portal vein showed positive ultrasound signals in the color duplex extending all the way into surface vessels, indicating a sufficient circulation of the perfusion medium (Figure 1a). The artificial tumor mixture produced hyperechoic lesions with no accoustic shadowing in the laparoscopic ultrasound (Figure 1b, c) and artificial tumors shown to be solid after the liver was sectioned (Figure 1d).

The navigation system displayed the ultrasound image and a simple model of the navigated instrument in two views (Figure 2). The left side shows the pure ultrasound image. On the right side, the instrument and the ultrasound image are displayed in a 3D virtual reality view, visualizing the measured poses relative to each other. This kind of view is known as the 'out-of-plane' view.

Having localized the artificial tumor in the ultrasound image, we were able to point with the other instrument directly at the tumor only with help of the navigation system.

We reconstructed a 3D CT volume from single CT slices. A cut through this volume shows the perfused vessels (Figure 3). We tried to build a 3D volume from the ultrasound slices to test the accuracy of the electromagnetic tracking system's measurements. Because of limitations of the tracking system and volume changes caused by pressing the ultrasound transducer on the liver, the reconstruction of the ultrasound slices showed unacceptable distortions, revealing the weaknesses of the sensors currently used.

Discussion

Interventional therapies for effective tumor destruction of unresectable liver metastases have found considerable interest. In recent years, RFA has become the most commonly used and perhaps most promising modality for tumor ablation. The laparoscopic approach, originally described by Siperstein et al. in 1997, offers a minimally invasive procedure in combination with the advantages of an open procedure [9]. Furthermore, laparoscopic RFA can be performed with the same exactness and effectiveness as the open approach in well selected patients [5,10]. Despite carrying a higher level of access trauma, laparoscopic RFA shows no significantly increased

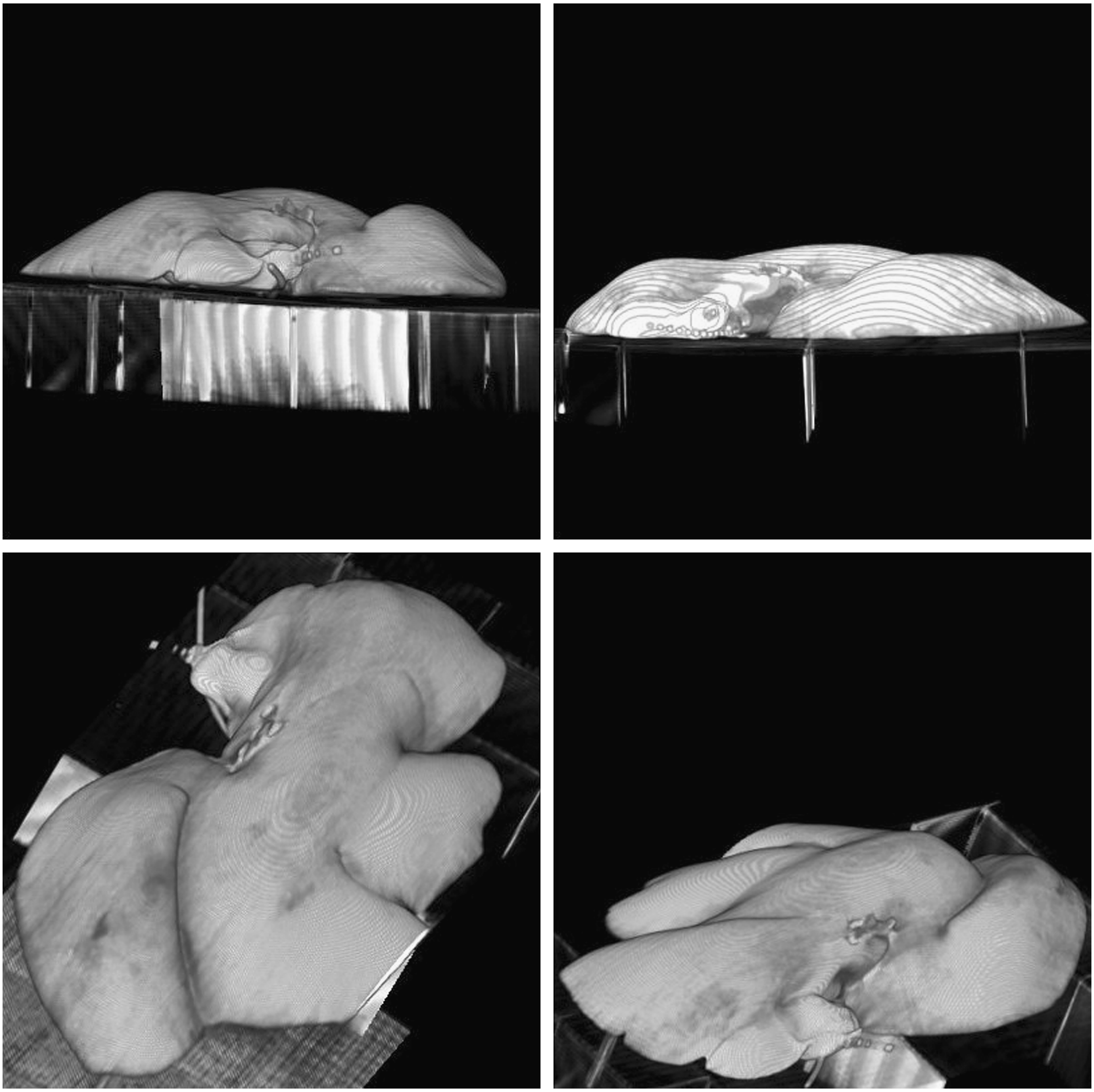

Figure 3. Four views of the liver's CT volume reconstructed from the single CT slices.

morbidity or mortality rates in comparison to percutaneous probe application, which means a safe and gentle treatment for the patient [5,11]. However, the basis of a successful laparoscopic RFA procedure is accurate placement of the RFA probe using ultrasound guidance [10]. Advanced laparoscopic ultrasound skills are required for accurate probe placement. Unfortunately, the skills required for ultrasound guidance for laparoscopic RFA are difficult to acquire. Furthermore, there are technical limitations to the laparoscopic approach based on the laparoscopic needle placement. Ultrasound-guided interventions like RFA are presently performed as free-hand type procedures or using an ultrasound probe with a canal for puncture. In contrast to transcutaneous free-hand puncture, laparoscopic free-hand puncture is limited because of the capnoperitoneum and the consecutive fixation of the needle at two different points. Correction of the puncture angle after penetration of the liver capsule is hardly possible. The use of a laparoscopic ultrasound probe with a canal for puncture can solve this problem and improve the accuracy of puncture. However, with a stiff needle the necessary angulation to reach right lateral and cranial liver metastases is limited. Therefore we present a new ultrasound-guided navigation tool for laparoscopic interventions. This tool offers a new technique for interventional liver therapy. The major advantage is the possibility of out-of-plane needle placement and the combination of flexibility of free-hand type procedures with the accuracy of a biopsy transducer. This improves the safety and accuracy of punctures and may lead to an improvement in quality of the intervention. Our preliminary results show the feasibility of this technique in the field of laparoscopic RFA. The perfused artificial tumor model offers a safe, easy, effective, and economic method for the evaluation of the laparoscopic navigation tool. The artificial blood flow offered by the perfusion model is strong enough to help in finding vessels automatically. The artificial tumors were shown to be ideal targets for navigated laparoscopic ultrasound.

In summary, the perfused artificial tumor model used in this study provides realistic conditions for the evaluation of the navigation tool and the practice of navigated interventions. Limitations based on laparoscopic needle application could be solved by an ultrasound-based laparoscopic navigation system.

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