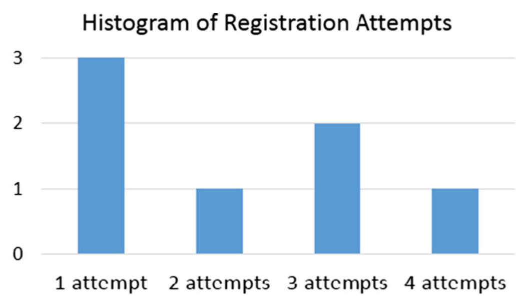
qualitatively rate the registration accuracy with (sufficiently accurate, less accurate, inaccurate) from which we could count the number of registration attempts to reach “accurate” results. As shown in Fig. 2a, the first registration attempt yielded accurate results in three cases, while in other four cases it took no more than four attempts to reach sufficient accuracy.



(a)

Step	Initialization	US Sweep	Computation	Overall
Time (sec)	76 ± 23	27 ± 6	13 ± 4	116 ± 25

(b)

Fig. 2 a Histogram of the registration attempts in seven cases. **b** Table of the times needed for the various steps of the registration

Conclusions

To the best of our knowledge, this is the first report on real-time intraoperative US-to-CT registration using a navigated 2D ultrasound under clinical conditions. In addition, surgeons can use this approach on their own without further need for technical assistance. To this end, the proposed method requires only one landmark selection by the surgeon to initialize the registration process. This ensures registration accuracy in the region of interest and accelerates the numerical computation. We integrated the proposed method into a commercially available navigation system and validated extensively in real open liver surgeries. The obtained accuracy is 6 ± 2 mm, which is smaller than the 10 mm safety margin suggested by the R0 resection and radio-frequency/microwave ablation guideline. This indicates that the proposed registration method could potentially provide sufficient accuracy during surgical navigation in open liver surgery. Despite the variations in US imaging properties due to varying tissue properties and as a result of the present pathologies, no more than four individual registration attempts were needed to achieve sufficient registration accuracy. Moreover, efficacy measurements show that the overall operation time of the registration module is within 2 min, which is not disruptive to the existing surgical workflow.

Future work will focus on exploring the sensitivity of the registration algorithm to the input conditions such as different ROI selection and US vessel segmentation. Moreover, we will investigate a more anatomically meaningful user interaction to shorten the initialization process even more.

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Feasibility evaluation of an image-guidance system for laparoscopic liver ablation procedures

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Keywords Image-guided surgery · Laparoscopy · Liver ablation · Multi-center evaluation

Purpose

During laparoscopy, a two-dimensional (2D) video camera is introduced into the patient’s abdomen, providing visual information regarding the operative field. Despite its evident benefits, a laparoscopic approach suffers from several drawbacks, such as reduced haptic and visual feedback. These aspects weaken the spatial understanding and perception, thus resulting in a need of extensive training for the surgeon. These drawbacks become even more relevant during tumor ablation when tumors might not be visible with common imaging modalities, due to chemotherapy shrinkage and lack of haptic feedback.

To address the aforementioned limitations, one direction is to use the image-guided system (IGS). Common IGS systems map the tracked surgical instruments as well as the patient model into a common coordinate system in a virtual scene. This virtual scene allows the surgeon to anticipate the position of underlying anatomical structures (e.g. tumors, vessel) when approaching with a surgical instrument, thus offering both haptic and visual feedback.

Despite the potential benefits of IGS for laparoscopic liver procedures, its use in a clinical environment is still limited, with few examples of its clinical use in the operating room. This scarcity relegates the benefits of IGS on a theoretical level and an evaluation of the feasibility for laparoscopic guided liver procedures is, to date, missing. In addition, the efficacy of IGS for laparoscopic liver procedures is unclear because there is no focus its specific use for particular laparoscopic surgical procedures (e.g. resection, ablation).

Within this work we present a multi-center study of an IGS for laparoscopic procedures aimed at defining a setup and workflow in a clinical context. The feasibility of the IGS was evaluated in 23 laparoscopic liver ablation procedures with a retrospective analysis performed to measure the accuracy, efficacy and clinical outcome.

Methods

A clinical study was conducted in a multi-centric setting (Danderyd hospital Stockholm, Sweden University hospital Bern, Switzerland), aiming to investigate feasibility of the laparoscopic guidance approach. 23 laparoscopic liver ablation procedures were performed between April 2103 and October 2014 in which fiducial registration error, time for registration, number of lesions and landmark positions were recorded for retrospective analysis.

For image guidance, an optical-based IGS for open liver procedures (CAScination AG, Switzerland) was adapted with laparoscopic instruments tracking capabilities. To this end, removable passive markers were attached onto the laparoscopic instruments. Additionally, a virtual 3D model of the liver was reconstructed from multi-phase and contrast enhanced CT or MRI scans via MeVis Distant Services, showing relevant structures such as tumour and vessels. Intraoperatively, the system was positioned in the anaesthesiologist area with the optical tracking system facing over the patient's abdomen and the monitors covered with sterile drape, allowing the surgeon to easily interact with the system (Fig. 1). Subsequently, sterile passive markers are attached to the distal end of a laparoscopic pointer and ablation applicator, which is then automatically calibrated with a multi-calibration unit. Locally rigid patient-to-image registration was performed by mapping four landmarks from the patient liver to the preoperative model (Fig. 2, left) during jet-flow ventilation to keep respiratory movements at minimum.

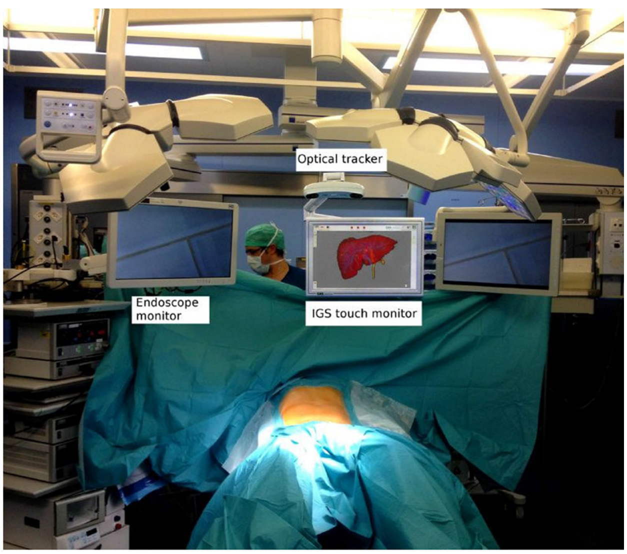

Fig. 1 System setup in the operating room

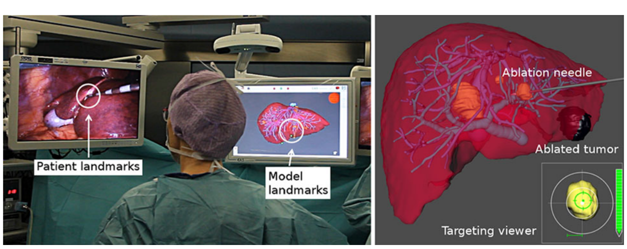

Fig. 2 *Left* registration process. *Right* ablation view from the IGS

Once the registration is performed, the position of the tracked instrument and the preoperative model are shown in a common coordinate system allowing for instrument guidance. The guidance information consists of a 3D virtual environment where a virtual representation of the tracked instruments is displayed in real-time together with the registered preoperative model. Additionally, a cross-hair viewer and a depth-bar, depict the distance from the tip of the tracked microwave applicator to a designated target. Internal 3D anatomical structures (e.g. tumors) can be defined as targets and thereafter become active within the targeting guidance application. Once ablated, the anatomical structure can be marked and become inactive (Fig. 2, right)

Results

Using the navigation system, a total of 130 lesions were targeted with the aid of the IGS in the 23 patients (6.5 lesions per patient on average, average lesion diameter = 23.6 mm). The obtained fiducial registration error for all 23 cases was recorded to be 8.6 ± 1.8 mm. Registration required 3 attempts (median) and 10 min (average).

Conclusions

We reported the use of an IGS for laparoscopic liver ablation procedures in a clinical scenario. The obtained accuracy is smaller than the 10 mm safety margin suggested by the RF/WMA ablation guideline [1]. We clearly acknowledge that the rigid landmark based registration is of preliminary nature while at the same time we work on the integration of our previously developed ultrasound registration approach for utilization in a laparoscopic setting. To this end, this study served for collection of valuable information about time and accuracy requirements as well as a deeper understand of workflow requirement. Our work suggests that the proposed laparoscopic IGS could potentially provide for sufficient accuracy during laparoscopic ablation procedures. It remains particularly useful in more complex cases with high number of lesions, or in presence of vanishing lesions, which cannot be easily targeted with non-navigated approaches. The dedicated functionalities of trajectory planning and tumor marking allow the surgeon to track and monitor the ablated lesions which is particularly useful in cases of multiple ablations. The average operation time of proposed workflow is 10 min, therefore does not significantly disrupt the surgical procedure. This allows the surgeon to perform multiple registrations per case, which provides the possibility to improve the navigation accuracy and reliability, as well as to compensate organ motion or deformation.

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Compact gravity compensation mechanism using spring in minimally invasive surgery robot

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Keywords Gravity compensation mechanism · Minimally invasive surgery · Robot surgery · Spring gravity compensation

Purpose

In the field of minimally invasive surgery robot (MIS robot), Back-drivable and Non-back drivable transmission has been a controversial discussion for many years. Both back-drivable and non-back-drivable transmissions have their advantages and disadvantages when different design goals are taken into account. Back-