EUS with CT improves efficiency and structure identification over conventional EUS

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Background: EUS is complicated because of the subtleties of US interpretation, small fields of observation, and uncertainty of probe position and orientation.

Objective: Improved EUS performance is sought by providing contextual information to support US probe positioning and identification of features in US images. Our aims were to demonstrate the feasibility of the image registered gastroscopic US (IRGUS) system in a porcine model and to compare the effectiveness and the efficiency of IRGUS with traditional EUS.

Design: Animal feasibility study.

Interventions: The IRGUS system uses preprocedure CT and miniature US probe trackers to create real-time synthetic displays of the position of the probe tip and a matched slice of CT data for comparison with the US image. Participants used EUS and IRGUS systems in a porcine model to evaluate the speed and accuracy of structure identification.

Main Outcome Measurements: The performance and utility of IRGUS were determined by the number of correctly identified structures in a timed trial, kinematic variables, and a structured survey.

Results: IRGUS was twice as effective as EUS in localizing and identifying individual structures. In timed trials, IRGUS users identified over 25% more structures than EUS users. Improvement in examination efficiency and accuracy of feature identification was statistically significant, and 90% of the users preferred IRGUS to EUS for these tasks.

Conclusions: IRGUS appears feasible and may be superior to conventional EUS in efficiency and accuracy of probe positioning and in image interpretation. IRGUS has the potential to shorten the EUS learning curve and to broaden the adoption of EUS techniques by gastroenterologists. (Gastrointest Endosc 2007;65:866-70.)

EUS has been shown to be beneficial in the diagnosis and staging of abdominal and thoracic disease,[1] as well as in biopsy guidance[2,3] and interventional procedures.[4,5] EUS offers imaging advantages by achieving close proximity to target organs, thus producing high contrast and resolution. However, the traditional challenges of all US imaging techniques (variable contrast, dependence on boundary-layer reflections, and occlusion by sonically opaque structures) are compounded in EUS by small fields of view, uncertainty in probe position and orientation, and difficulty in establishing target contact or a clear viewing window. These limitations result in a long learning curve and necessitate formal EUS fellowship training, thus limiting the adoption of EUS by practicing gastroenterologists. The image registered gastroscopic US (IRGUS) system is a real-time guidance system[6-8] that uses 2 synthetic displays driven by the position of the US probe to overcome these technical hurdles. One display is a 3-dimensional (3D) anatomic model that tracks scope position; the second display is an oblique CT slice in the exact plane and location of the EUS image. These displays provide contextual information that complements and reinforces both the positioning of the EUS transducer and the identification of features in the US image.

The aims of this study were to demonstrate the feasibility of the IRGUS system in a porcine model and to compare the effectiveness and efficiency of the IRGUS system with traditional EUS in the identification of standard abdominal targets.

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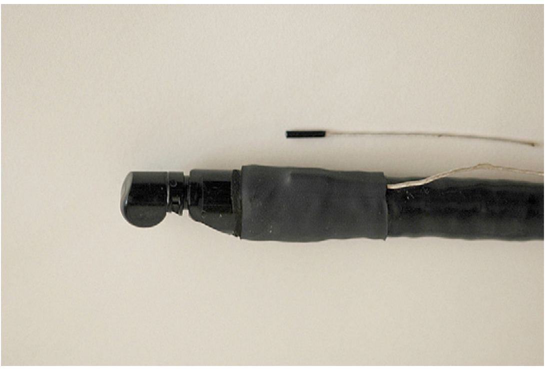

Figure 1. Position sensor placed next to endoscope tip to show relative size. The sensor is glued to the endoscope tip and covered with shrink-wrap tubing.

Capsule Summary

What is already known on this topic

- Effective use of EUS is complicated by the subtleties of interpretation, small fields of observation, and uncertainty of probe position and orientation, but performance could be improved by contextual information to support the probe positioning.

What this study adds to our knowledge

- In an animal feasibility study, the IRGUS system, a real-time guidance system, was twice as effective as EUS in localizing and identifying individual structures, with IRGUS users identifying 25% more structures than standard EUS users.

MATERIALS AND METHODS

The IRGUS system provides the clinician with contemporaneous real-time displays that show the probe orientation within the preoperative volumetric CT or the magnetic resonance image. For these studies, the volumetric data were collected by using a Siemens Sensation 64 (slice) CT system (Siemens Medical Systems, Erlangen, Germany). Two synthetic images were then created, as shown in Figure 1: (1) 3D models of reference anatomy and (2) a single oblique planar slice that matches the plane sampled by the US transducer. The synthetic images have no perceptible lag when the probe is moved.

The IRGUS system uses established techniques for the visualization of the probe position and image registration, but implements them in real-time by using recent advances in miniaturized position-tracking technology (microBIRD; Ascension Technology Corp, Burlington, Vt) (Fig. 2). The tracking sensors are small (0.3 mm diameter, 1.8 mm length) and have been tested to meet International Electrotechnical Commission (IEC) 60601-01 standards. Such a sensor was attached to the tip of a curvilinear echoendoscope (Olympus EU-C60; Olympus America Inc, Center Valley, Pa) and was covered with medical-grade heat-shrink tubing for sterilization by conventional techniques. The sensor provides specific localization of the echoendoscope tip within the model but does not differentiate between anterior and posterior orientation and can be placed anywhere on the tip of the US probe. All components (tracker system, interfaces, personal computer with displays) are commercially available, with a total cost well under $10,000, depending on the size of the displays, and the software is written in the open-source 3D Slicer[9] environment.

To evaluate the utility of the IRGUS system, a sample of expert (n = 5) and novice (n = 5) users were asked to identify 8 key anatomic landmarks in 5 minutes by using both traditional EUS systems and the IRGUS system (Table 1) in live anesthetized pigs. The standard EUS system used was the Olympus curvilinear array endoscopic US system with the GF-UCT160-OL5 probe and the EU-C60 processor (Olympus America). Novices were gastroenterologists with significant experience in endoscopy but less than 6 months of EUS training; these included private practice physicians and advanced endoscopy fellows. Experts were endosonographers from U.S. and European academic institutions with influential publications and international reputations in the field. The experts, although renowned in EUS skill, had only limited experience in the porcine model. All participants first used standard EUS, and in a later session the same day, but not back-to-back, they used the IRGUS system. All examinations were performed in the same study animal. Participants were asked to identify 8 structures, including the following: portal vein, right kidney, right lobe of liver, inferior vena cava, superior mesenteric artery, pancreas tail, spleen, and left kidney. In an effort to standardize the procedure, all examinations were started with the echoendoscope in the duodenal bulb, and participants were read the list of structures before starting. Participants were encouraged to follow the specified order; however, if a structure was identified out of turn, it was counted and not penalized. Structures could also be skipped and returned to later without penalty, and answers could be altered as the examination progressed and were considered final only at the conclusion of the procedure. An instructor asked study participants to identify each structure as they progressed through the examination, and each answer that was provided was evaluated by a scoring panel. The participants were not informed about the accuracy of their answers until both procedures had been completed and scored. The multidisciplinary scoring panel consisted of an expert endosonographer with experience in the animal model and simultaneous access to both systems, a software engineer, and 2 experts in CT and US interpretation. Examinations were also recorded and reviewed after each case as needed.

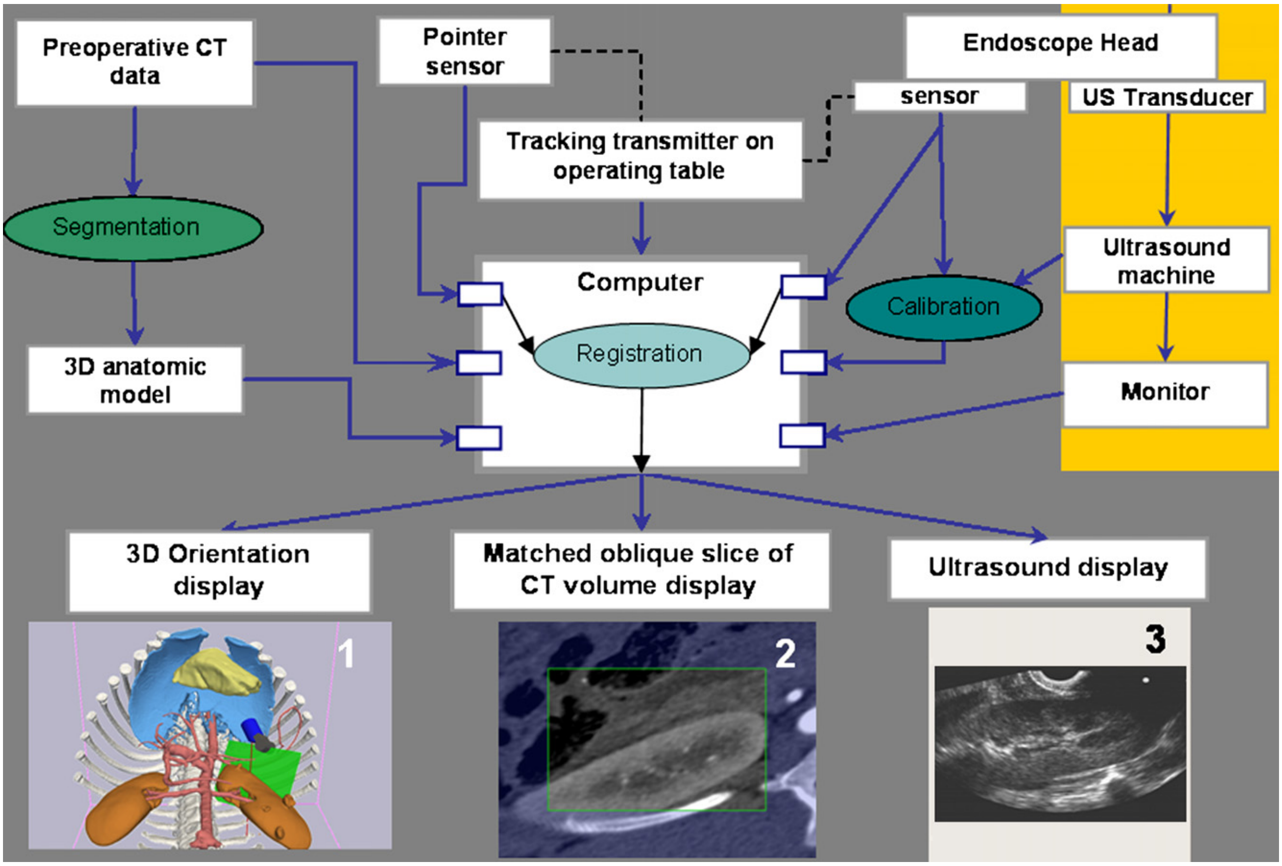

Figure 2. Display 1 shows the position of the tip of an endoscopic probe in the stomach relative to the ribs and the major vessels extracted from a preprocedure CT image of the subject. The *oblique green slab* shows the acquisition plane of the US transducer head. The *red line* in the plane is the nominal track of the biopsy needle. **Display 2** shows the plane of the volumetric CT data that corresponds to the observed US image (ie, matches the *green oblique plane* in **Display 1**). **Display 3** shows the unmodified image made by the US system. The operator uses **Display 1** for overall orientation and identification of key landmarks, and then uses **Displays 2** and **3** to identify features in the US image and to build confidence in the interpretation.

The data are reported as the ratios: (sum of answers provided)/(sum of questions asked) and (sum of correct answers)/(sum of answers provided). In other words, these numbers represent the probability of a person using EUS or IRGUS to provide an answer (label a target) and the probability of this answer being the correct one (accuracy). The position and the orientation of the probe were measured continuously during the procedures. These data were then used to calculate a set of kinematic metrics[10] to correlate with performance. These included smoothness of motion, path length, and instrument rotation. At the conclusion of the hands-on trials, the subjects completed a structured questionnaire designed to evaluate the ease of use of the interface.[11]

RESULTS

In the 5-minute timed trial, both novice and expert endosonographers were able to locate and identify roughly twice as many abdominal organs and landmarks when using IRGUS compared with conventional EUS (Table 1). Novice structure identification improved uniformly, except in respect to the right kidney, for which there was no improvement, with 40% of users correctly identifying the structure with both EUS and IRGUS. The most significant improvements for experts were in identifying the porcine pancreatic tail and the right lobe of the liver; however, there was substantial improvement in identification of all structures. With IRGUS, users were also more accurate in structure identification (Table 2). For novices, the mean score with EUS was 0.29 versus 0.51 with IRGUS ($P = .02$). For experts, the score was 0.71 versus 0.80 (EUS vs IRGUS, respectively; $P = .03$). In the EUS timed trial, a novice had a 46% probability to label a requested target by using EUS, with a 64% accuracy (64 times of 100, this answer is correct). In contrast when using IRGUS, the probability of labeling a target increased to 58%, with 100% accuracy ($P = .01$). The experts had a 71% probability to label a requested target when using EUS, with 86% accuracy. In contrast when using IRGUS, this probability increased to 91%, with 100% accuracy ($P = .004$). The

TABLE 1. IRGUS is superior to EUS in the localization and identification of anatomic structures

	% Improvement in identification with IRGUS	
Structure	**Novice**	**Experts**
Portal vein	100	100
IVC	100	151
Right kidney	0	100
SMA	100	151
Pancreas tail	100	303
Spleen	100	151
Left kidney	100	151
Right lobe of liver	51.5	303

IVC, Inferior vena cava; *SMA*, superior mesenteric artery.

TABLE 2. EUS vs IRGUS of the percentage of structures that were identified by study participants

	Answers provided by study participants	
	% Total	**% Correct**
Novices		
EUS	46	64
IRGUS	58	100
Experts		
EUS	71	86
IRGUS	91	100

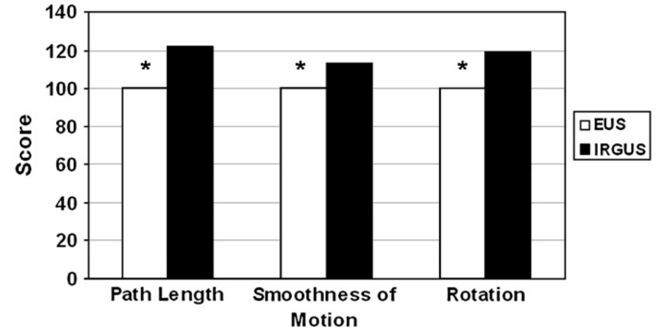

Figure 3. Comparative scores for various kinematic factors for EUS and IRGUS, showing that the kinematics of IRGUS users was favorable for the parameters measured. The *asterisk* denotes that the difference between the 2 groups is statistically significant at the level of $P < .05$.

difference between novices using IRGUS and experts using simple EUS was not statistically significant ($P = .32$), which indicates that IRGUS closes the performance gap between experts and novices.

The kinematic evaluation for the IRGUS versus EUS systems showed overall improvement in efficiency of examination with IRGUS, with score improvements that ranged from 17% to 27% (Fig. 3). All users reported that the displays of (1) global position and orientation and (2) CT-US slice comparison (Fig. 1) were naturally intuitive and greatly facilitated target identification and probe positioning. All IRGUS users also reported that the tracker system gave additional confidence in image interpretation (Table 3).

DISCUSSION

EUS is an effective tool for diagnosis, cancer staging, and tissue acquisition in the abdomen and the thorax. Technical challenges, however, have resulted in a long learning curve and limited adoption by practicing gastroenterologists. The IRGUS combination of global orientation in a sparse 3D model and direct comparison with an oblique CT image corresponding to the US image provides an effective environment to assist in probe positioning and image interpretation that is easily learned. In the current study, IRGUS operators identified anatomic features and navigated in the body more confidently than with conventional EUS. Compared with EUS, IRGUS provided more efficient scope movement and enabled users to more easily identify and distinguish between structures, such as the right and left lobes of the liver.

The performance of both novices and experts improved with IRGUS in terms of structure identification and kinematics. It is also important to note that IRGUS appears to close the performance gap between these groups, because the performance of novices with IRGUS overlaps with that of experts without these orientation aids. This finding may have been affected, in part, by the EUS expert's relative unfamiliarity with porcine anatomy. The location of key porcine structures relative to each other varies considerably from human beings, and other structures (eg, the spleen) appear very different from the human equivalent. This could have impacted the 5-minute timed trial. Nevertheless, gastroenterologists are typically more comfortable reading CTs than interpreting US images, and this finding suggests the possibility that IRGUS could shorten the traditional EUS learning curve.

Several technical and design limitations must be addressed. A potential technical limitation was the registration error of the synthesized oblique CT image to the US image planes of approximately 3 mm. IRGUS capability does not depend on absolute image registration accuracy, and this was found to be more than sufficient for the guidance task, because most targets of interest are considerably larger, and slight misregistrations did not appear to hamper the use of the system. These experiments were conducted in an animal model, with the animal breathing

TABLE 3. All participants rated IRGUS as superior to EUS in a questionnaire

		Score, mean
Rate overall experience with IRGUS		91.6
0	Poor	
100	Excellent	
Compare IRGUS with conventional EUS		94.4
0	IRGUS offers absolutely no advantage over conventional EUS	
100	IRGUS is absolutely superior to conventional EUS	

slowly but freely. Initially, it was anticipated that the motion of organs induced by respiration would compromise the utility of the comparison of the preoperative CT image with the real-time US images. However, this was not the case; very little relative motion between the CT oblique image and the US image was observed. Important design limitations of this study include the small number of subjects and the lack of randomization for determining which system was used first. Not informing the participants about the correctness of their answers until after the final session, the delay between the first and second examination, and the consistent nature of findings among users only partially attenuate these concerns. It is difficult to explain the sizable and consistent improvement seen among novices after only 1 examination, without attributing some of the improvement to the IRGUS system. Nevertheless, it is certainly possible that part of the overall improvement seen with the IRGUS system was because of the experience of the prior examination, and this limits the strength of the comparison and our ability to clearly differentiate between contributory factors. This study does, however, establish the feasibility of the system, and we plan to address randomization issues in future comparative trials.

IRGUS appears feasible and may be superior to conventional EUS in efficiency and accuracy of probe positioning and in image interpretation; however, these comparisons are limited in the current feasibility study. When considering these results, as well as the intuitive interface and the ease of implementation, it is anticipated that such systems could find utility in many diagnostic and therapeutic procedures, and may lead to the development of new procedures and additional indications. These preliminary results also indicate that IRGUS technology may shorten the EUS learning curve and could broaden the adoption of EUS techniques by practicing gastroenterologists.

DISCLOSURE

None of the authors have commercial associations that might be a conflict of interest in relation to this article.

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