Surgical technique

A new visualization technique for laparoscopic ultrasonography

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Background. Using laparoscopic ultrasonography (LUS) is challenging for both novice and experienced ultrasonographers. The major difficulty surgeons experience is understanding the orientation of the ultrasonography image. The purpose of this study was to assess whether providing surgeons with orientation information improves their ability to interpret LUS images.

Methods. We performed a LUS examination on a 25-kg pig and simultaneously digitized video from the laparoscopic camera, the LUS, and a novel orientation system. From the video recordings, 12 different clips of intra-abdominal anatomy were prepared. Twenty surgeons (18 staff, 2 fellows) volunteered to participate in an experimental crossover study. Test subjects reviewed the LUS clips along with the laparoscopic video images and the orientation display. Controls reviewed the LUS clips with only the laparoscopic video images. Diagnostic accuracy was compared by using the odds ratio.

Results. For all vessels, the orientation display improved the odds ratio for correctly identifying structures from 3.7 to 8.9 (P = .02). For arteries, the orientation display improved the odds ratio from 2.4 to 9.6 (P = .01). For veins, the orientation display improved the odds ratio from 4.4 to 13.6 (P = .04).

Conclusions. Providing orientation information significantly improves a surgeon’s ability to interpret LUS images. (Surgery 2004;136:84-92.)

Over the last 5 years, several important applications for laparoscopic ultrasonography (LUS) have emerged. LUS has been shown to be the most sensitive method for detection of hepatic metastases, improving the staging of both hepatic and pancreatic malignancies. It is also a rapid means of assessing the common bile duct for stones during laparoscopic cholecystectomy. Despite these advances, the adoption of LUS in clinical practice has been slow. While several factors account for the reluctance, one of the major obstacles facing those learning to use LUS is difficulty in interpreting LUS images. Surgeons are accustomed to ultrasonography images that are oriented in either transverse or sagittal planes, whereas LUS images usually are obtained in nonconventional planes.

Learning to use LUS is challenging because the standard orientation techniques used by transabdominal ultrasonographers are difficult to apply with laparoscopic instruments. Both novice and experienced ultrasonographers who are learning to use LUS struggle with orienting the oblique images. With transabdominal ultrasonography (US), orienting an image is often accomplished by using conventional imaging planes (eg, sagittal, transverse). When conventional planes are not possible, the technique for orienting an oblique image is to first image a landmark in a known plane and then to move...
the transducer to the region of interest. With this technique, ultrasonographers can be confident they know the area being imaged because they understand where they started and how they moved the transducer. Both these orientation techniques are difficult to apply with LUS.

The visualization problem with LUS has been described by some authors as a port placement problem. Laparoscopic ultrasonographers can get approximate sagittal planes by performing an examination through a dedicated right lower quadrant port and approximate transverse planes by performing an examination through a dedicated left upper quadrant port. It is generally straightforward to orient these images. The drawback of this approach, though, is that it requires 2 ports which may not be well positioned for any other role. Ideally, a comprehensive examination could be done through a single port placed for surgical rather than diagnostic considerations.

In this paper, we briefly describe a system we developed for orienting LUS images. We then report how we assessed the utility of the system by using a porcine model. We hypothesized that this new visualization technique could provide important spatial cues that would make interpreting LUS images more intuitive.

**MATERIAL AND METHODS**

**Navigation system.** We developed a system for performing LUS that can be used to orient oblique images. Figure 1 illustrates how the technique works. As the operators perform their examinations they are provided with a display that shows them how the plane of the ultrasonography is oriented relative to the patient’s arterial and skeletal anatomy. The purpose of the system is to provide operators with important spatial cues so they can perform a comprehensive examination with few constraints on positioning the laparoscopic port.

The key component of this visualization technique is that it shows how the ultrasonography plane interacts with the aorta. The aorta makes an excellent point of reference because it runs throughout the entire abdomen and has a characteristic three-dimensional shape that can be quickly
identified. Also, it is relatively fixed and non-deformable; therefore, it can be aligned with the ultrasonography. Unlike most intraperitoneal structures, the retroperitoneal aorta is tethered to the spine so that its physiologic motion is limited to a few millimeters. The aorta is resistant to deformation because of high intraluminal pressure. Both of these features are important for aligning three-dimensional images.

The navigation system consists of 5 components: a laparoscopic transducer (Leopard; BK Medical, Wilmington, Mass), a surgical pointing device, a tracking device (miniBIRD; Ascension Technology, Burlington, Vt), a laptop computer, and a video monitor. Both the laparoscopic transducer and the surgical pointing device are tracked with the use of 5-mm electromagnetic sensors. Figure 2 shows the tracking sensor mounted on the side of the laparoscopic transducer.

The software for the system was written as a module for 3D Slicer, a medical visualization package developed by the Brigham and Women’s Hospital in collaboration with the Massachusetts Institute of Technology. In general, the software reads the orientation data from the tracking device, computes the orientation of the ultrasonography plane model, and renders the ultrasonography plane model relative to models of the aorta and ribs. The three-dimensional models are generated with the use of the Visualization Toolkit. The aorta and ribs were generated from a preoperative computed tomography (CT) scan with the use of 3D Slicer. The models of the laparoscopic transducer and the B scan plane were constructed based on their geometry.

Before using the system for orientation, the operator needs to align the models with the actual objects. This is accomplished by identifying the tips of 4 specific ribs in the preoperative CT with the use of 3D Slicer and identifying the same 4 ribs in the operating room with the use of the tracked surgical pointer. Figure 3 shows how the ribs are identified from the CT. Once the alignment is complete, the operator can view the orientation display to see how the tracked LUS plane moves relative to the aorta and the ribs. Figure 4 shows 2 examples of the display in use.

Image acquisition. To assess the utility of the system, a LUS examination was performed on a 25-kg pig. The animal research protocol was approved by the Harvard Medical Area animal care committee. First, the animal was anesthetized (induction: telazol 4.4 mg/kg, xylazine 2.2 mg/kg, atropine 0.05 mg/kg; maintenance: isoflurane 1%-4%) and underwent a contrast-enhanced CT. The anesthetized animal was placed in the CT scanner in the same supine position it would have been placed on the operating table for a laparoscopic procedure. During scanning, the animal was ventilated with oxygen at a low tidal volume to minimize breathing motion artifact. The CT volume was obtained with a multidetector row CT scanner (Somatoform Plus4; Siemens Medical Systems, Iselin, NJ). The helical scan extended from the xiphoid sternum to 2 cm below the lowest thoracic ribs. After a 20-gauge catheter was placed in the auricular vein, a 50-mL bolus of nonionic contrast agent (Ultravist; Berlex laboratories, Wayne, NJ) was injected at 3 mL/s by using a power injector. The scanning parameters were scan delay of 4 seconds, 120 kVp, 52 mA, 1.25 mm collimation, table speed 30 mm/s. The CT volume (512 × 512 pixels, 2-mm-thick slices) was then transferred to the laptop computer and the models of arterial and skeletal anatomy were generated with the use of the 3D Slicer medical visualization software.

On a subsequent day, the same animal was again anesthetized (induction: telazol 4.4 mg/kg, xylazine 2.2 mg/kg, atropine 0.05 mg/kg; maintenance: isoflurane 1%-4%). We then performed laparoscopy and LUS examinations. A 10-mm access port for the laparoscopic camera was placed in the lower midline, and the abdomen was insufflated with CO₂ to a pressure of 15 mm Hg. An 18-mm access port was placed for the tracked LUS in 3 locations: the left upper quadrant and both lower quadrants. The animal and the three-dimensional models were aligned by using the tip
of the 3rd and 5th lowest ribs. A comprehensive LUS examination of the liver, biliary tree, and pancreas was then performed through all 3 ports. The video signal from the LUS, laparoscopic camera, and orientation display were all recorded simultaneously by using 3 digital video recorders. The recorders were synchronized intermittently during the examinations by using a string of distinct audio pulses.

After the examination, the 3 digital video recordings were reviewed on a personal computer with the use of video-editing software (Premiere; Adobe Systems, San Jose, Calif). From the recordings, 17 different sets of video clips of intra-abdominal anatomy were prepared. The selection criteria for each set of clips were that vessels were clearly present in the ultrasonography video and that the shaft of the laparoscopic transducer could be clearly seen in the laparoscopic video. Two experienced laparoscopic ultrasonographers reviewed the clips and established by consensus whether any of 9 specific vessels were present in a given clip. The vessels included the celiac axis, hepatic artery, splenic artery, superior mesenteric artery, hepatic vein, splenic vein, portal or superior mesenteric vein, inferior vena cava, and renal vein.

**Study design.** Twenty surgeons (18 staff, 2 fellows) volunteered to participate in a crossover study. None of the test subjects was from an institution involved in the development of the visualization technique. Four of the subjects were experienced laparoscopic ultrasonographers (>100 cases). The remainder had little to no experience. Figure 5 illustrates the study design. Experimental subjects reviewed the LUS clips along with the laparoscopic video images and the orientation display. The controls reviewed the LUS clips with only the laparoscopic video images. Each surgeon was an experimental subject for 6 clips and a control for 6 clips. The review of a particular LUS clip with the orientation display was alternated between surgeons.

The video review software used in this study was created with the use of the Tcl/Tk language (ActiveState, Vancouver, BC). Figure 6 is a screen shot of the video review software. Five clips were used for software training. Once the surgeons were comfortable with the review software and the

**Fig 3.** Four ribs were used to align the models from CT in the operating room so they could be viewed in the proper orientation.
In the testing process, they reviewed 12 test clips. For each clip, they specified whether any of 9 vessels were present. The software recorded their responses and the amount of time they reviewed each test clip.

**Data analysis.** Diagnostic accuracy with and without the orientation display was assessed by using the odds ratios (OR) according to the following formula:

\[
\text{OR} = \frac{\text{Number of vessels identified with display}}{\text{Number of vessels identified without display}}
\]
The diagnostic accuracy was analyzed according to vessel type (artery or vein) and whether the tip of the LUS probe could be seen in the laparoscopic video. All data were analyzed with the use of the SPSS statistical package (SPSS Inc, Chicago, Ill). The Mantel-Haenszel test was used to compare the odds ratios; the Mann-Whitney \( U \) test, a nonparametric equivalent to the \( t \) test, was used to compare the time to review data.

### RESULTS

Tables I and II show the effect the orientation display had on accuracy. For all vessels, the orientation display improved the odds ratio for correctly identifying structures from 3.7 to 8.9 \((P = .02)\). For arteries, the orientation display improved the odds ratio from 2.4 to 9.6 \((P = .01)\). For veins, the orientation display improved the odds ratio from 4.4 to 13.6 \((P = .04)\).

Table III shows the effect that visibility of the LUS tip had on whether the orientation display was
helpful. There was no significant improvement in the diagnostic accuracy with the orientation display if the tip of the probe was visible in the laparoscopic video clip (5.7 vs 6.6; \(P = \text{NS}\)). However, if the tip of the probe was not visible in the laparoscopic video clip (eg, imaging the retroperitoneum), the orientation display improved the odds ratio from 2.3 to 12.4 (\(P = .01\)). The presence of the LUS tip by itself though did not affect accuracy (4.4 vs 3.8; \(P = \text{NS}\)).

The mean time it took subjects to interpret a clip was longer when they were presented with the orientation display (68 vs 98 s; \(P < .01\)).

**DISCUSSION**

We described a novel system that tracks a laparoscopic transducer and displays the plane of the ultrasonography image relative to a three-dimensional model of the aorta and the ribs. The prototype was designed to test the hypothesis that surgeons could interpret LUS images better if they understood the orientation of the ultrasonography plane. Our surgical team found this technique to be helpful in other projects we have undertaken.\(^{14}\) However, objectively assessing the utility of the system in the operating room setting is difficult. In the current study, we digitally recorded a LUS examination on a pig and used the video to assess whether having orientation information was helpful in interpreting LUS images.

The orientation display dramatically improved the surgeons’ ability to accurately identify vascular structures. This result confirms our hypothesis that providing surgeons with orientation information would be beneficial. Since the orientation display uses the aorta as the main visual reference, one interesting question was whether the orientation display helped surgeons with only arteries or with both arteries and veins. The analysis shows that the system was helpful for both types of vessels. This result implies that surgeons could effectively use the spatial information provided by the orientation display to orient the anatomic information provided by the ultrasonography display.

The orientation information was particularly helpful when the tip of the LUS was not present...
in the laparoscopy view. This result reinforces the point that the visualization technique can provide orientation clues when the laparoscopic view is inadequate. Clinically, disorientation is quite common when surgeons use only the laparoscopic camera to gauge where the LUS image is. It is at these times that orientation display will be most helpful.

While the orientation display was helpful to surgeons in interpreting the LUS images, it increased the time spent in evaluating images. This is an expected finding given that the surgeons had another source of information to synthesize. Interestingly, it took roughly 60 seconds to review 2 clips (ie, LUS and laparoscopy) and roughly 90 seconds to review all 3 clips. We did not ask the subjects if they spent the same amount of time reviewing each component of the clips.

The system in its current form is a prototype designed to test whether this visualization technique is helpful. Several issues need to be addressed before a similar system could be used in a clinical evaluation. First, the diameter of the tracked probe needs to be reduced so it can pass through a standard 10-mm or 12-mm laparoscopic access port. Another important clinical consideration would be to remove the requirement for a preoperative CT. Many patients who have a gastrointestinal malignancy will undergo a staging CT. However, there remains a group of patients with benign disease who could benefit from LUS, but will not have had a contrast-enhanced CT. Avoiding CT in this group of patients would reduce the risks inherent in radiation exposure and contrast administration. It is possible that transabdominal ultrasonography could be used as an alternative for generating models of the aorta.23

It is foreseeable that a clinical orientation system could be used in a number of different ways. Some surgeons may never be interested in performing LUS themselves. They may choose instead to have radiologists come to the operating room to perform the examination when it is clinically indicated. In this situation, the system could be helpful by showing the surgeon what is being imaged even though they are not performing the examination themselves. Some surgeons may wish to use the system to help learn how to perform LUS. This system could effectively be used as an aid to overcome the steep learning curve. As surgeons gain experience, they may find they no longer require the orientation feedback after they are comfortable with the oblique images that are common with LUS. The last group of surgeons who may find the system helpful are the experts who are comfortable with the examination but appreciate having a navigation aid to confirm what they have determined by using conventional orientation techniques. An analogy would be the experienced sailor who carries a global positional system receiver when they sail.

We have developed a novel system that tracks a laparoscopic transducer and displays the plane of the ultrasonography image relative to a three-dimensional model of the aorta. We showed that using this system improves surgeons’ ability to interpret LUS images. In the future, the practice of surgery will increasingly rely on imaging, such as LUS, to guide procedures on solid organs and stage malignancy, and to assess the results of therapy at “second look” operations. Guidance systems such as the one described in this paper will have an important role in helping surgeons transition to these less-invasive techniques.

### Table III. Effect of presence of LUS tip on diagnostic accuracy*

<table>
<thead>
<tr>
<th>Laparoscope tip</th>
<th>Orientation</th>
<th>Observed</th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>No vessel</td>
<td>Vessel</td>
<td>Total</td>
</tr>
<tr>
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<td></td>
<td>252</td>
<td>137</td>
<td>389</td>
</tr>
<tr>
<td>Not visible</td>
<td>No display</td>
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<td>46</td>
<td>82</td>
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<tr>
<td></td>
<td>Predicted</td>
<td>288</td>
<td>183</td>
<td>471</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Display</td>
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<td>109</td>
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<td>312</td>
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<td>383</td>
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<td>Predicted</td>
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<td>184</td>
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<td>Display</td>
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<tr>
<td>Visible</td>
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</tbody>
</table>

*Controlling for the presence of the LUS tip in the laparoscopic video showed that the orientation display was primarily helpful when the LUS tip was not visible. When the tip was not visible, there were more true positive and true negatives as well as fewer false positive and false negatives.
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REFERENCES