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Evolution of Image-Guided Liver Surgery: Transition from Open to Laparoscopic Procedures

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Abstract

Indications for liver surgery to treat primary and secondary hepatic malignancies are broadening. Utilizing data from B-mode or 2-dimensional intraoperative ultrasound, it is often challenging to replicate the findings from preoperative CT or MRI scans. Additional data from more recently developed image-guidance technology, which registers preoperative axial imaging to a 3-dimensional real-time model, may be used to improve operative planning, locate difficult to find hepatic tumors, and guide ablations. Laparoscopic liver procedures are often more challenging than their open counterparts. Image-guidance technology can assist in overcoming some of the obstacles to minimally invasive liver procedures by enhancing ultrasound findings and ablation guidance. This manuscript describes a protocol that evaluated an open image-guidance system, and a subsequent protocol that directly compared, for validation, a laparoscopic with an open image-guidance system. Both protocols were limited to ablations within the liver. The laparoscopic image-guidance system successfully creates a 3-D model at both 7 and 14 mm Hg that is similar to the open 3-D model. Ultimately, improving intraoperative image guidance can help expand the ability to perform both laparoscopic and open liver surgeries.

Keywords

image-guided surgery; liver surgery; minimally invasive

Introduction

Liver resections are increasingly performed to treat hepatic malignancies. As surgeons continue to push the limits of surgical interventions, maintaining quality is a major clinical concern, given the large number of patients affected.[1-3] Hepatic resections and ablations can be challenging due to the complex 3-dimensional (3-D) anatomy of the liver. Preoperative computed tomography (CT) and/or magnetic resonance imaging (MRI) scans are used in combination with intraoperative ultrasound (iUS) to assist with hepatic surgical interventions. The 2-dimensional (2-D) images supplied by ultrasound, however, are of limited use in orienting the surgeon to anatomic relationships within fibrotic/cirrhotic livers, steatotic livers (often associated with preoperative chemotherapy), or where tumors are otherwise difficult to visualize with ultrasound.

These obstacles can be addressed with image-guided surgery (IGS).[4-6] IGS uses preoperative medical images that are registered with intraoperative landmarks to provide a 3-D image of the liver to assist with surgical resections and ablations. IGS allows for the interactive use of medical images during a surgical procedure. It involves three steps: 1) processing the preoperative CT or MRI images, 2) acquiring data that pertains to the geometry of the organ of interest, and 3) matching (registering) the intraoperative data with the preoperative CT or MRI images. A commercially available system (Explorer™ Liver, Pathfinder Technologies, Inc., Nashville, TN) has been developed and FDA-cleared for use in open hepatic procedures.

One of the largest obstacles in image-guided liver surgery is registration: the process of linking real-time liver positioning with the 3-D model. The Explorer™ Liver device initially employed an active optical tracking system (Optotrak Certus, Northern Digital, Inc., Waterloo, Ontario) containing infrared light emitting diodes that were attached to the hub of surgical instruments along with a laser range scanner (LRS) to identify the location of the instrument hub for intraoperative surface acquisition. The newest generation of the Explorer™ Liver device utilizes passive instrument tracking (Polaris Spectra / Polaris Vicra, Northern Digital, Inc.) in which infrared light is reflected from photoreflective hemispheres attached to tracked surgical instruments. While IGS technology has shown potential for providing navigational assistance during open hepatic procedures, the transition of IGS technology into the realm of minimally invasive hepatic procedures would be a valuable addition to the armamentarium of liver surgeons in order to increase the feasibility and safety of this approach.[7]

The present article summarizes the results of two separate clinical protocols to evaluate the FDA-cleared Explorer™ Liver IGS device for open procedures. In addition, the second protocol includes a clinical evaluation of the experimental Explorer™ Minimally Invasive Liver (MIL) device that is intended for use during laparoscopic ablation procedures.

Methods

Two protocols were used to evaluate the IGS. The first protocol included 32 adults who underwent a laparotomy and open liver resection from 7/9/08 to 6/25/10. This protocol evaluated the accuracy with open surgery of two methods of liver registration and the ability of the IGS model to predict a resection line. The second **protocol enrolled 32 patients in a study** to evaluate the ability to perform registrations for laparoscopic IGS, which included for validation a direct comparison with registration from an open laparotomy, from 8/20/10 to 5/18/11 (**Figure 1**). These two protocols were approved by the institutional review board at Memorial Sloan-Kettering Cancer Center. All patients underwent preoperative triple phase CT or MRI to assess the liver disease. All image sets were required to have an in-plane pixel spacing of no more than 1 mm. The slice thickness of the image sets was no more than 2.5 mm for the non-contrast and venous phase image sets, and no more than 1.5 mm for the arterial phase set. The vessels in each of the phases were required to measure at least 30 Hounsfield Units (HU) more than the liver parenchyma. For the second or laparoscopic protocol, patients were enrolled that were undergoing a laparoscopic staging prior to an open resection for any diagnoses of liver pathology with the intention of conversion to an open laparotomy.

In both protocols, before the procedure, the surgical team used surgical planning software provided by the sponsor to segment the liver based on views from the preoperative imaging. From the segmented images, a 3-D surface model of the liver was generated (**Figure 2**) using the Scout™ Liver (Pathfinder Technologies, Nashville, TN) preoperative planning software package. Tumors were identified on the preoperative scan by the user, and their

locations were inserted into the 3-D model by the Pathfinder computer system. For the laparoscopic protocol, prior to intraoperative data acquisition using the prototype Explorer™ MIL system, laparoscopic staging was performed to determine the extent of disease and the resectability of the disease. Once the surgeon acquired sufficient staging information, the laparoscopic acquisition of liver surface and feature data proceeded. If the disease was determined to be unresectable, only laparoscopic liver surface and feature data were acquired.

For **both** protocols, either during laparoscopic surgery or at laparotomy, after mobilizing the falciform ligament and exposing the anterior liver surface during staging, the liver surface and anatomical features were acquired by manually swabbing the regions of interest using an optically tracked stylus. The salient anatomical features included in this study were the falciform ligament, round ligament, and the inferior ridges along segment III and along segments IV, V, and VI. (**Figure 3a**).[8] **For the second (laparoscopic) protocol**, the surface and feature data digitizations were acquired under conditions of standard insufflation pressure (14 mm Hg) **and reduced insufflation (7 mm Hg)** and during apneic periods initiated at end expiration. After intraoperative liver surface and feature acquisition were performed with the tracked probe, the physical-to-image space registration was performed via the previously described algorithm used in the Explorer™ Liver device (**Figure 3b**).[8] The surface data that was gathered was retrospectively compared with the preoperative imaging data to ascertain the robustness of the proposed registration method as well as the accuracy of the registration with respect to surface targets.

In the **laparoscopic** protocol, for patients determined to be resectable, conversion to standard laparotomy was performed immediately following the laparoscopic registrations. Prior to organ resection, the physical surface of the liver and salient anatomic features were acquired as standard in open hepatic IGS **registration method**. In the cases where the first generation Explorer™ Liver device was used, tracked LRS hardware was used for surface acquisition while the salient anatomical features were acquired via manual digitization using an optically tracked probe.

The intraoperative surface digitizations acquired with the LRS device or manual swabbing within the Explorer™ Liver (first protocol, with laparotomy only) and Explorer™ MIL (second or “laparoscopic protocol”) devices were compared with the preoperative liver models in a manner similar to that performed by Cash et al. [6] where two types of error calculations were performed. These error calculations compare anatomic points on the preoperative 3-D image with the same anatomic points on the 3-D image that is created in the operating room after registering the liver. The first error, the surface residual error, was calculated by comparing the thousands of points captured on the surface of the liver before and after registration. The second error calculation, the feature error, compared the pre- and post-registration location of each of the four salient features (falciform ligament; inferior ridge along segment III; inferior ridge along segments IV, V, and VI; and round ligament) that was used for liver registration. The individual feature error measurements were then combined to compute the mean feature error. For example, the location of the round ligament in the 3-D model was compared pre- and post-registration. If after registration the round ligament was 5 mm to the right of where it was on the pre-registration scan, the individual feature error is then 5 mm. Of the two error measurements, the mean feature error provides a superior metric for quantifying registration accuracy due to the fact that a low surface residual error could result from a highly inaccurate registration. The closest point distance was used to determine differences between points and salient features on the pre- and post-registration 3-D image. This distance is defined as the mean of the closest distances calculated between a point located on the preoperative liver surface and the intraoperative model after registration has been performed.

Statistics

To compare registrations performed with the laser and manual probe or at different levels of pneumoperitoneum, the non-parametric Wilcoxon rank sum test was used for statistical analysis. Statistical comparisons were performed between the overall surface residual and mean feature errors calculated for both generations of the Explorer™ Liver device. Additionally, the Mann-Whitney rank sum test was used to perform a comparison between the overall surface residual and mean feature errors computed for the Explorer™ MIL device (under 14 mm Hg insufflation pressure), with the residual and feature errors calculated for both generations of the Explorer™ Liver open IGS device. Finally, a statistical comparison was performed for surface residual and feature error measurements calculated for registrations acquired with the Explorer™ MIL device under conditions of 7 mm Hg and 14 mm Hg insufflation pressures.

Results

This study was performed over the course of two separate, non-simultaneous protocols. The first protocol was the clinical evaluation in 32 patients of the utility of the FDA-cleared Explorer™ Liver device in intraoperative acquisition of liver registrations and subsequent liver mapping. The second protocol was the clinical evaluation in 32 patients of preoperative and intraoperative parameters comparing registrations obtained during laparoscopy and laparotomy. Additionally, the planned line of resection was also acquired intraoperatively for a subset of the patients (N = 9) enrolled in the first protocol of this study in order to provide an additional means of assessing registration accuracy. The demographics of the patients included in both protocols of this study are listed in **Table 1**.

During the open surface acquisitions, both a LRS and a manually-tracked probe were used. The development of the manually-tracked probe was important, as it is required for laparoscopic surface acquisitions. Before testing it in a laparoscopic protocol, with multiple new variables, the manually-tracked probe was first studied during registrations performed at laparotomy. It was found that with the LRS the closest point distance was a mean of 2.8 mm with a maximum value of 13.4 mm. With the probe, the closest point mean was 4.9 mm with a maximum value of 12.1 mm. In addition to the use of the overall surface residual error to quantify registration accuracy, an analysis of the individual feature errors was also performed. A summary of the error measurements used to quantify the accuracy of registration for the two generations of the Explorer™ Liver device is shown in **Table 2**. The results of the statistical comparison between the surface residual errors calculated for the LRS-based and probe-based registrations indicate a statistically significant difference between the measurements ($P < 0.001$). However, the statistical comparison of the mean feature error measurements indicates that there is no statistically significant difference between LRS-based and probe-based registrations within the Explorer™ Liver device. It should be noted that while there is a statistically significant difference between the surface residual errors, the absolute magnitude of the difference between the probe-based and LRS-based surface residual errors is on the order of 1.4 mm, which may not be clinically relevant.

In the first protocol, the preoperative resection plane was predicted for nine patients using the preoperative Scout™ Liver planning software. This was then compared to the resection contour obtained **at laparotomy** to provide an additional measure of registration accuracy. The contour errors were calculated by computing the closest point distance between the intraoperatively digitized resection contour and the preoperatively planned resection plane. The mean error measurement was 6.5 ± 3.7 mm (**Table 3a**). For reference, the margin of normal tissue seen with the tumor was evaluated on the intraoperative 3-D model and the postoperative pathologic report. Results showed that the software predicted a mean margin of 7.6 ± 7.2 mm compared to the pathologic margin of 12.3 ± 10.5 mm (**Table 3b**).

During the laparoscopic portion of this study, surface and salient feature data were obtained to compute registrations within the Explorer™ MIL device at both 14 mm Hg and 7 mm Hg. Laparoscopic registrations took approximately 2.9 minutes per patient and open registrations took approximately 1.3 minutes per patient. This comparison was selected to determine the impact of elevated peritoneal pressures on the registration accuracy. A visualization of a qualitative evaluation of the registration accuracy of the Explorer™ MIL device is shown in **Figure 4**. A summary of the error measurements made for the registrations performed laparoscopically is shown in **Table 4**. A statistical comparison of the surface residual errors between the registrations performed at 7 mm Hg and 14 mm Hg insufflation pressures indicates that there is no statistically significant difference between the measurements ($P = 0.220$). Additionally, there is no statistically significant difference between the mean feature errors for the laparoscopic registrations performed at the two insufflation pressures ($P = 0.835$).

Finally, a statistical comparison with the Mann-Whitney rank sum test between the surface residual data for the laparoscopic registrations performed at 14 mm Hg insufflation pressure (shown in **Table 4**) and the LRS- and probe-based registrations **performed during laparotomy** (shown in **Table 2**) with the Explorer™ Liver device indicates statistically significant differences ($P < 0.001$ and $P = 0.002$, respectively). The mean feature error comparison indicates that there is no statistically significant difference between the 14 mm Hg insufflation laparoscopic registrations and either the open probe-based ($P = 0.521$) or open LRS-based registrations ($P = 0.888$).

As with the comparison of the LRS- and probe-based residual errors, the absolute magnitude of the differences between the residual errors is small (i.e. the difference in error between laparoscopic and open probe-based registrations is approximately 1.5 mm and the difference between the laparoscopic and open LRS-based registrations is approximately 2.9 mm). The difference in surface residual error between the manual and LRS registrations is expected due to the impact of lower noise in the surface acquisitions.

Discussion

In general, surgeons currently rely on iUS to provide image guidance for the resection and ablation of liver tumors. Local recurrence rates, especially for large tumors, can be high.[9] Over the past ten years, an image-guided liver surgery system, for use in open procedures, has been developed by engineers and clinicians at Vanderbilt University and Washington University in St. Louis.[4-6, 8, 10-12] The primary goal of this research was to provide the ability for surgeons to utilize high-resolution preoperative image data interactively within the surgical setting to improve patient outcomes for open resection and ablation. We have previously demonstrated that tracked iUS can be utilized to assist in providing a 3-D liver image.[13] Development of minimally invasive IGS systems has been difficult due to the inability to use direct visual techniques such as laser mapping to register the liver. Thus, the development of a probe-based registration system is required to bridge the gap between open and laparoscopic IGS.

The LRS device is capable of rapidly acquiring high resolution surface data in a non-contact fashion and has been validated for use in open hepatic IGS by Cash et al.[4] However, the LRS device is limited by its cumbersome nature as well as the difficulty in maintaining tracking line of sight of the instruments due to positioning constraints of the large Certus camera. The newest generation of the Explorer™ Liver device, used in the second protocol described in this manuscript, utilizes passive instrument tracking (Polaris Spectra / Polaris Vicra, Northern Digital, Inc.). The passive tracking systems use smaller cameras with more flexibility regarding camera placement that mitigates many of the line-of-sight issues

experienced with the active system. Additionally, passively tracked instrumentation is wireless, making the device much less cumbersome to set up and use in the surgical environment. The newest generation of the Explorer™ Liver device has thus replaced the use of the LRS for surface acquisition with the manual surface acquisition method.[11]

Hepatic tumors are localized using a combination of preoperative imaging studies (triple phase CT and/or MRI) and iUS. Advances in preoperative imaging (CT and MRI) have greatly outpaced advances in intraoperative image guidance with iUS. Intraoperative ultrasound imaging, however, can provide valuable information regarding tumor location, but the images are 2-D, and this modality is of limited value once the resection begins. Preoperative CT or MRI scans provide high-resolution, 3-D views of the tumor and surrounding anatomy. The ideal instrument would provide high-resolution images of the relevant anatomy that are continuously updated during the course of the resection. By providing the surgeon continuous feedback regarding the position of the hepatic transection line with respect to the tumor and adjacent major vasculature, the likelihood of an incomplete resection or inadvertent injury to adjacent liver segments should be minimized.

Computing physical-to-image space registration in liver surgery, which is required for any IGS system, presents a unique challenge due to the lack of rigid anatomy surrounding the liver, the need for liver mobilization, and the patient positioning that facilitates liver exposure. Image guidance is often used in neurosurgery because the brain can be fixed in space.[14, 15] This fixation, however, cannot be duplicated in the liver. Image guidance in liver surgery has lagged behind neurosurgical applications because of this difficulty. With respect to precision, however, liver surgery is more forgiving than neurosurgery, a difference that may be advantageous in developing clinically useful liver IGS systems. Additionally, it is difficult to utilize anatomical fiducial points (e.g. portal vein bifurcation) to compute an accurate point-based registration due to localization errors.[16-18] The salient feature registration (SFR) algorithm was developed to address this need.[8] The SFR algorithm makes use of anatomical features that can be localized in both the intraoperative presentation and the preoperative image data. The accuracy of the preoperative 3-D liver model is evident in the small (<2 mm) difference in the preoperative projected plane and the actual plane on the intraoperative image. Similarly, the 6 mm difference in the tumor margin, from comparison of the preoperative margin and the postoperative pathology report, is clinically small when taking into account that the resection line can change due to the deformation of the liver after it is resected. In addition, this difference likely represents the difference between drawing an optimal resection plane on a 3-D model and creating this resection line in vivo with pedicles and hepatic veins causing small deviations from the planned resection. While a deviation of 6 mm is not adequate for image guidance in organs like the brain, the device likely offers adequate accuracy for hepatic image guidance. With ablations that the device will be used with in future protocols, microwave and radiofrequency devices should be able to overcome a 6 mm deviation between the probe location in the 3-D image and in vivo.

The analysis of the surface data acquired by both generations of the Explorer™ Liver system, and the prototype Explorer™ MIL device indicates that all of the devices perform in a comparable quantitative fashion. The absolute error measurements suggest that these devices are of suitable accuracy for use during hepatic procedures. The small difference in the surface residual errors between the two surface data acquisition devices is expected, given that the LRS device acquires surface data in a non-contact fashion and is less prone to noise in the collection of surface data than is a manual acquisition. Thus, the mean feature error metric provides a more reliable quantification of the true accuracy of the registration than does the surface residual error. This study showed that the LRS-based, probe-based, and laparoscopic registrations are all quantitatively comparable with respect to the mean

feature error, which is the most reliable error metric to quantify registration accuracy given the data set acquired.

Demonstrating that laparoscopic registrations can be performed with clinically acceptable accuracy is important, as the loss of tactile information and limited organ visualization that accompany minimally invasive surgery represent major concerns regarding the oncologic efficacy of laparoscopic resections and ablations. Development of an IGS device that provides a 3-D adjunct to laparoscopic iUS for improving the efficiency of tumor localization during these procedures would help overcome one of the last major technical barriers in the field of minimally invasive hepatic procedures. The primary hurdle to overcome in the translation of our open IGS system into the laparoscopic environment is the performance of image-to-physical space registration. Data in this study show that a tracked stylus placed through a laparoscopic port to acquire the organ surface and features under laparoscopic visualization can accurately capture salient liver features. In addition, there does not appear to be any meaningful deformation associated with the presence of pneumoperitoneum.

Improving intraoperative image guidance can help expand the ability to perform both laparoscopic and open surgical resections and ablations. Prior to using these systems clinically, the ability to register the real-time position of the liver with the 3-D image created from preoperative CT or MRI scans is vital. This study demonstrates that both laparoscopic and open hepatic registrations are accurate. Using this foundation, the IGS system can be applied to guiding ablations within the liver in both laparoscopic and open cases. The IGS system has been used outside of clinical trials in several cases where identification of hepatic tumors visualized on CT or MRI is challenging in the operating room with iUS. In addition, an early CT or MRI with pre treatment tumors can be imported into the IGS system so that the original location of tumors, prior to response, is clear on the intraoperative model. While these cases are still too few from which to determine the benefit of the device, the IGS system has allowed ablation or resection in a scenario where that would not have occurred without the system.

Conclusion

This study shows the evolution of an open hepatic IGS system (Explorer™ Liver) with the development of an analogous device for use in laparoscopic procedures (Explorer™ MIL) through the lens of data acquired from two separate clinical trials. The primary driver of the evolution of the Explorer™ Liver device was clinician feedback provided from the first protocol or clinical trial; the resulting second generation of the system is a more streamlined device that provides similar quantitative performance to the original system. The initial validation study of the Explorer™ MIL device indicates that the system is capable of performing registrations in the laparoscopic environment that are of comparable quantitative quality to that provided in open IGS.

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Figure 1.
Flowchart of two image-guided liver surgery protocols.

Figure 2.

Screen capture of the user interface for the Scout™ Liver preoperative surgical planning software (left). The resection planning interface highlighting the tumor margin “heat map” is also shown (right). Once the resection plan has been finalized, the resection margin and volumetric calculations, including total liver volume and functional liver remnant volume, can be performed for evaluation by the clinician.

Figure 3.

- a. Salient anatomical features used for surface registration in open hepatic IGS. The standard liver (far left) features are the groove along the falciform ligament [red], the round ligament (at junction of red, green, and blue lines), the inferior ridge along segment III [blue] and the inferior ridge along segments IV, V, and VI [green]. (IGS= image-guided surgery)
- b. The laparoscopic surface acquisition points used to compute the physical-to-image space registration are demonstrated in yellow. The graphical user interface (GUI) in the larger, left panel allows the surgeon to visualize the alignment of the preoperative image surface with the intraoperatively swabbed surface.

Figure 4.

Visualization of the qualitative registration evaluation performed by the clinician while using the Explorer™ MIL device during laparoscopic staging. There is a strong agreement between the guidance system display (right) and the true location of the probe as visualized via the laparoscope (left).

Table 1

Patient demographics and general information for the protocols evaluating the open Explorer™ Liver and laparoscopic Explorer™ Minimally Invasive Liver (MIL) devices. (IGS= image-guided surgery; LRS= laser range scanner; MI= minimally invasive)

	Open Hepatic IGS Evaluation	Laparoscopic Hepatic IGS Evaluation
Total Patients	32	32
<i>Sex</i>		
Male	20	22
Age (years)	53±13	64±12
<i>Preoperative Imaging</i>		
CT	29	23
MRI	3	9
<i>Pathology</i>		
Metastatic Colorectal Carcinoma	20	13
Hepatocellular Carcinoma	1	4
Cholangiocarcinoma/Gallbladder Carcinoma	6	12
Other	5	3
<i>IGS Surface Acquisitions</i>		
Open LRS	23	1
Open Probe	9	26
MI Probe	N/A	32
<i>Mean Surface Points Acquired</i>		
Open LRS	6258±2073	8211±N/A
Open Probe	3713±4101	1663±516
MI Probe	N/A	2768±911

Table 2

Surface error calculations for open LRS- and probe-based surface acquisitions. The maximum error values are shown in parentheses. The surface residual and feature errors were calculated using a method similar to that described by Cash et al.[6]

Error Measure (mm)	Open-LRS (N = 24)	Open-Probe (N = 34)
Surface Residual	4.1±1.4 (8.2)	5.5±1.2 (8.3) *
<i>Falciform Feature</i>	5.2±2.8 (10.5)	5.5±3.7 (20.3)
<i>Left Ridge Feature</i>	6.1±6.1 (30.6)	5.3±2.0 (10.4)
<i>Right Ridge Feature</i>	5.6±3.4 (15.3)	5.7±2.0 (11.9)
<i>Round Ligament</i>	5.7±4.3 (17.2)	5.3±3.5 (14.7)
Mean Feature	5.7±3.8 (18.4)	5.4±2.1 (12.9)

* p<0.001. (LRS= laser range scanner)

Table 3a

Summary of the errors between the planned resection plane on the preoperative model and the intraoperative resection contour digitization for nine clinical cases. The error measurement was calculated by computing the Euclidean distance between each intraoperative resection contour point and the preoperatively planned resection plane.

CASE	Resection Plane	Error Measurement (mm)
6	Left Lobe (Segments II, III, IV)	7.5±5.0
8	Extended Right Lobe (Segments IV, V, VI, VII, VIII)	3.6±2.3
10	Right Lobe (Segments V, VI, VII, VIII)	4.9±3.6
12	Left Lobe (Segments II, III, IV)	3.2±3.5
15	Left Lobe (Segments II, III, IV)	11.5±6.8
16	Right Lobe (Segments V, VI, VII, VIII)	5.4±3.3
17	Left Lobe (Segments II, III, IV)	3.0±1.4
20	Left Lobe (Segments II, III, IV)	6.3±5.1
23	Left Lobe (Segments II, III)	13.2±2.2
MEAN		6.5±3.7

Table 3b

A comparison of the open surgery tumor margins provided by the pathology reports with those indicated by the Scout™ Liver preoperative planning software.

Resection Type	Pathology (mm)	Software (mm)	Difference (mm)
Left Hepatectomy (N = 4)	16.5±15.9	9.8±15.1	6.7±8.2
Left Lobectomy (N = 8)	19.8±8.8	10.9±6.0	10.4±10.0
Right Hepatectomy (N = 5)	14.9±9.8	8.0±7.6	7.1±8.1
Extended Right Lobectomy (N = 3)	1.8±0.8	2.4±2.5	1.9±0.6
Right Partial Hepatectomy (N = 4)	12.5±7.1	6.7±4.8	5.8±4.9
Non-anatomical Wedge (N = 7)	3.9±4.3	5.3±3.8	4.2±2.8
Total (N = 31)	12.3±10.5	7.6±7.2	6.6±7.1

Table 4

Comparison of residual and feature errors obtained laparoscopically with the pneumoperitoneum at 7 mm Hg and 14 mm Hg. Errors are reported both in terms of the overall surface error as well as the individual anatomical feature errors.

Error Measure (mm)	Lap - 7 mm Hg (N = 32)	Lap - 14 mm Hg (N = 32)
Surface Residual	6.2±2.6 (18.9)	7.0±2.8 (20.1)
<i>Falciform Feature</i>	5.7±1.7 (12.3)	5.9±2.2 (10.9)
<i>Left Ridge Feature</i>	4.9±2.0 (10.7)	5.1±1.8 (8.4)
<i>Right Ridge Feature</i>	4.9±1.9 (9.2)	4.4±1.7 (9.0)
<i>Round Ligament</i>	4.5±2.5 (10.8)	4.3±2.3 (11.0)
Mean Feature	5.0±1.6 (8.6)	4.9±1.3 (9.3)