

Original

Practical and Cost-Effective Use of Open-Surgery-Type Ultrasound Probes in Laparoscopic Hepatectomy: A Single-Center Experience with over 150 Cases

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Background: Laparoscopic hepatectomy (Lap-H) is increasingly being performed in Japan, but the high cost and handling complexity of laparoscopic ultrasonographic (US) probes remain a barrier to its wider adoption. Intraoperative ultrasonography is essential for safe liver resection; however, specialized laparoscopic probes are expensive, have a limited field of view, and are difficult to manipulate.

Methods: To overcome these limitations, we developed a practical technique using an open-surgery-type microconvex US probe in Lap-H. The probe is inserted via an umbilical incision using a Lap Protector mini™ and EZ Access™, and probe manipulation is achieved through a cord-based control system. We applied this method in over 150 Lap-H cases before the introduction of a dedicated laparoscopic US system.

Results: This technique enabled the acquisition of axial and sagittal images with a wide and deep field of view, enhancing anatomical orientation and lesion visualization. There were no complications such as air leaks or equipment failure. The method allowed for the use of contrast-enhanced ultrasound and minimized interference with the operative field.

Conclusions: The use of open-surgery-type US probes in Lap-H offers a cost-effective, safe, and practical alternative to expensive laparoscopic US systems. This innovation may lower the barrier for institutions initiating Lap-H programs and promote the broader adoption of high-quality intraoperative ultrasonography in minimally invasive liver surgery.

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Introduction

In Japan, there has been a dramatic increase in the use of laparoscopic hepatectomy (Lap-H) since the national insurance system began to cover the procedure in April 2010, initially for partial and left lateral sectionectomies. In April 2016, insurance approval was expanded to cover nearly all liver resections, assigning higher reimburse-

ment points for laparoscopic surgery than for open surgery and encouraging the widespread adoption of Lap-H¹. Unlike in Western countries where Lap-H is centralized, Lap-H in Japan is widely performed in many institutions². However, Lap-H still accounts for only about 30% of all liver resections performed in Japan³.

In both open and laparoscopic approaches, intraopera-

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Table 1 Summary and statistical comparison between the Open Probe and Laparoscopic Probe groups

	Open Probe (n=151)	Laparoscopic Probe (n=61)	p
Duration	Oct 2015–Jan 2021	Feb 2021–Oct 2022	
Age, y	68.5 (34–88)	72 (36–86)	0.197
Gender			0.614
Male	110	42	
Female	41	19	
Diagnosis			
Hepatocellular carcinoma	65	26	
Liver metastasis	68	30	
Intrahepatic bile duct cancer	11	2	
Hemangioma	5	-	
Hepatitis	2	-	
Liver abscess	-	1	
Liver cyst	-	1	
Focul nodular hyperplasia	-	1	
Surgical method			0.154
Low-difficulty hepatectomy	110	51	
High-difficulty hepatectomy	41	10	
Operation duration, min	316 (85–780)	313 (174–674)	0.771
Bleeding volume, mL	80 (0–3,200)	57 (0–2,000)	0.617
Post-operative hospitalization, d	9 (4–70)	8 (5–34)	0.004
Clavien Dindo IIIa	17	4	0.446
Mortality	0	0	

tive ultrasonography (IOUS) is a critical tool for safe and accurate liver resection. Laparoscopic IOUS probes are typically rod-shaped, inserted through ports, and have flexible tips, making their manipulation complex and making them prone to dislocation. Moreover, IOUS probes produce sagittal rather than axial imaging, which makes anatomical interpretation more difficult, and they have a narrow field of view that limits deep observation.

Additionally, specialized laparoscopic IOUS probes are costly, presenting a barrier to institutions wishing to newly implement Lap-H. For new purchases, the list price of an ultrasound probe is around 4 million yen (approximately USD 25,800), with high-grade models costing approximately 6 million yen (approximately USD 38,700). Although there are variations in the procurement price, the hurdle for new purchases remains extremely high in Japan.

To address these issues with specialized laparoscopic IOUS probes, our institution adopted an innovative method of Lap-H using an open-surgery-type microconvex probe inserted via an umbilical wound using a Lap Protector mini™ and an EZ access™ system. This paper reports our experience using this novel method in over 150 Lap-H cases.

Patients and Methods

Between October 2015 and October 2022, a total of 212 Lap-H were performed at the Nippon Medical School Chiba Hokusoh Hospital. In January 2021, the institution acquired a laparoscopic surgery-type ultrasound probe, which was used for procedures conducted thereafter. The patient cohort was divided into two groups: the Open Probe group (n = 151), which underwent surgery using an open surgery-type ultrasound probe, and the Laparoscopic Probe group (n = 61), which underwent surgery using laparoscopic a surgery-type ultrasound probe. The Open Probe and Laparoscopic Probe groups were comparable in age, sex, disease distribution (hepatocellular carcinoma, liver metastasis, cholangiocarcinoma, hemangioma, hepatitis, and so on), and proportion of high-difficulty resections (Table 1). Comparative analyses between the two groups were conducted regarding age, sex, operative time, intraoperative blood loss, proportion of high-difficulty procedures, incidence of complications classified as Clavien-Dindo grade IIIa or higher, and length of postoperative hospital stay.

Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics software. Differences in mean values between groups were assessed using the Student's *t*-test. Associa-

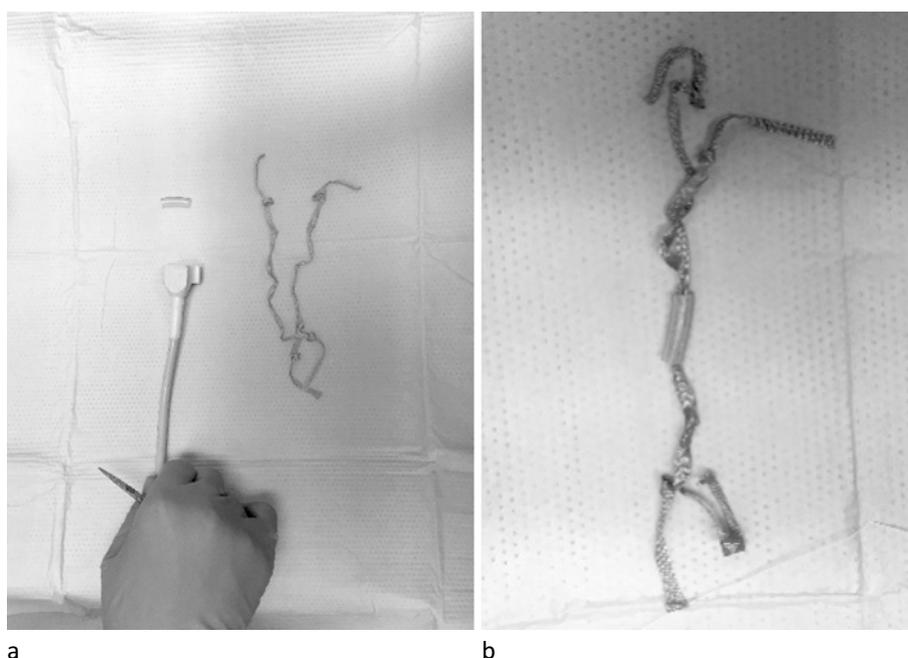


Figure 1 Photographs showing the equipment needed for ultrasonographic examination in our Lap-H technique
 (a) Microconvex open-surgery-type ultrasonographic probe, caudal segment of a 15 Fr BLAKE drain trimmed to approximately 2 cm, and two polyester vascular tapes each trimmed to approximately 20 cm. (b) A 15 Fr BLAKE drain (trimmed) with two polyester vascular tapes passed through it.

tions between categorical variables were evaluated using cross-tabulation analyses, with chi-square tests applied where appropriate.

Surgical Technique

Preparation (Figure 1)

The required items included a microconvex open-surgery-type ultrasonographic probe (UST-9132T or UST-9146T, Hitachi Aloka), a 15 Fr BLAKE™ drain cut to approximately 2 cm, two polyester vascular tapes (each approximately 20 cm long), and 1-0 silk suture.

The drain was threaded with vascular tapes and attached longitudinally to the back of the probe. The tapes were tied around the cord side and crossed over the probe to fix it securely. Size 1-0 silk suture was used to tie the tapes at the probe tip and prevent detachment (Figure 2). This preparation took approximately 5 minutes.

Statistical analysis

Comparisons between the two groups were performed using Student's *t*-test for continuous variables and the chi-square test for categorical variables. Recurrence-free survival and overall survival were estimated using the Kaplan–Meier method, and differences between the two

groups were assessed with the log-rank test. A *p*-value of <0.05 was considered statistically significant. All statistical analyses were performed using EZR (Saitama Medical Center, Jichi Medical University Saitama Medical Center), which is a graphical user interface for R.

Ethical Considerations

This study was conducted in accordance with the principles of the Declaration of Helsinki (as revised in 2013). The protocol was approved by the institutional ethics committee of Nippon Medical School Chiba Hokusoh Hospital (approval number: 2018-650). The hospital's device management office authorized the probe modification and use prior to its clinical application. For retrospective data collection, the requirement for informed consent was waived by the ethics committee due to the anonymized nature of the data and minimal risk to participants.

Results

Application

A 3-cm umbilical incision was created for specimen extraction. The probe assembly was inserted through the wound, and the Lap Protector mini™ and EZ access™ were attached (Figure 3). Pneumoperitoneum was main-

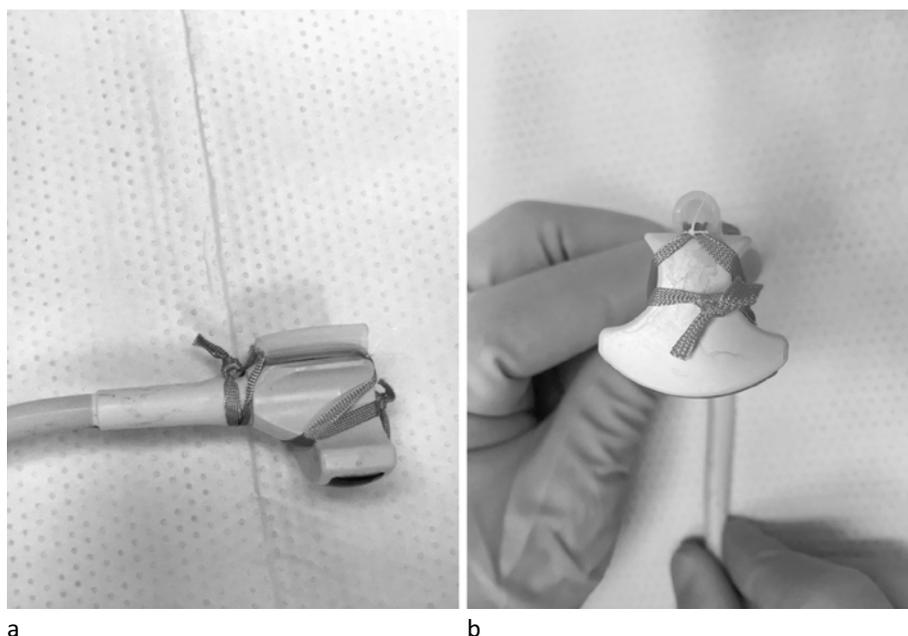


Figure 2 Photograph of the open-surgery-type ultrasonographic probe modified for laparoscopic use (a) Lateral and (b) frontal view.

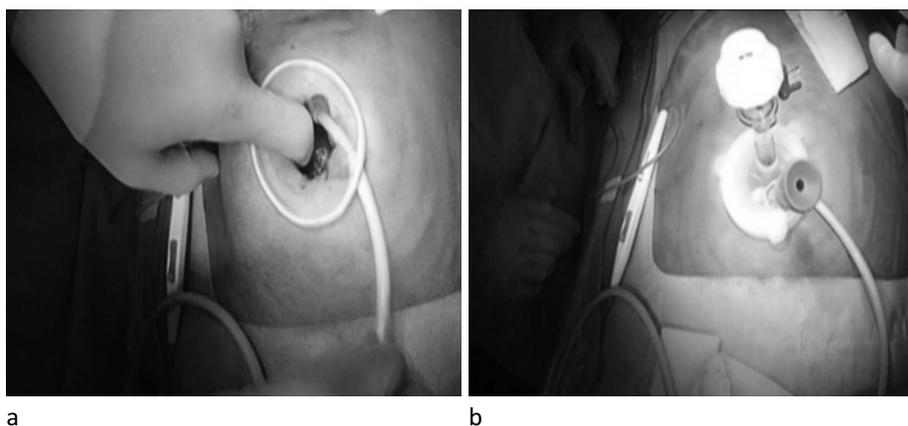


Figure 3 Insertion through the umbilical incision (a) Application of the Lap Protector mini™ following insertion of the ultrasound probe into the abdominal cavity. (b) Attachment of the EZ Access™ system.

tained without causing subcutaneous emphysema. The probe was manipulated by adjusting the external cord, enabling axial rotation and movement (**Figure 4**). When not in use, the probe was retracted to the abdominal wall, minimizing interference with the surgical field.

During IOUS, the probe was advanced to the target area and its tip was manipulated with graspers or by inserting instruments into the drain lumen. The probe was used to create axial imaging, similar to CT or MRI, which facilitated anatomical orientation. The convex-type probe offered a wide and deep field of view, aiding in the identification of lesions and vascular relationships. Addition-

ally, altering the holding angle or pulling the cord enabled the attainment of sagittal views.

During the study period, 212 consecutive Lap-H were performed and analyzed. From October 2015 to January 2021 an open-surgery-type IOUS probe was used in 151 patients (Open Probe group), whereas from February 2021 to October 2022 a laparoscopic-surgery-type IOUS probe was introduced and applied in 61 patients (Laparoscopic Probe group).

Patient demographics and indications were comparable between the two groups. The median age was 68.5 years (range 34–88) in the Open Probe group and 72 years (36–

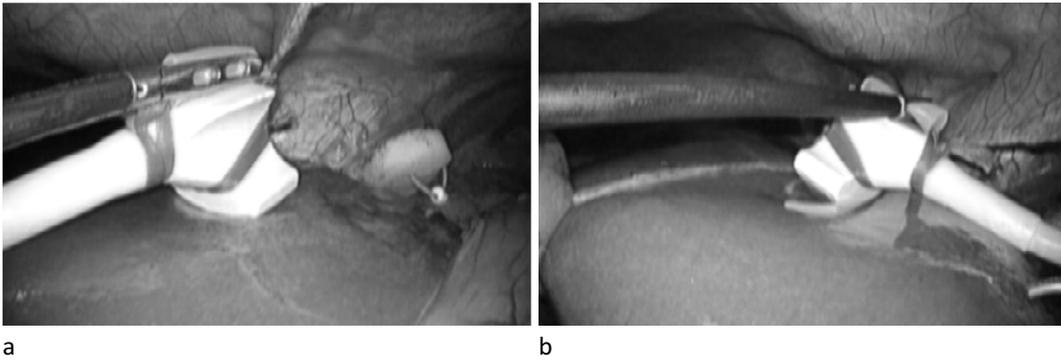


Figure 4 Insertion through the umbilical incision (a) Axial and (b) sagittal scanning views.



Figure 5 Injection of dye into the liver parenchyma using 23 G needle for the tattooing technique

86) in the Laparoscopic Probe group ($p = 0.197$). Male-to-female ratios did not differ significantly (110/41 vs. 42/19, $p = 0.614$). The principal indications were hepatocellular carcinoma (43%), colorectal liver metastasis (45%), intra-hepatic cholangiocarcinoma (7%), hemangioma (3%), and hepatolithiasis (2%); there was no inter-group difference in diagnostic distribution.

Procedural complexity was similar: high-difficulty resections, as defined by the Japanese Society of Hepato-Biliary-Pancreatic Surgery, accounted for 27.2% (41/151) in the Open Probe group and 16.4% (10/61) in the Laparoscopic Probe group ($p = 0.154$).

Operative outcomes were unchanged after the introduction of the dedicated laparoscopic probe. Median operative time was 316 min (85–780) with the open probe and 313 min (174–674) with the laparoscopic probe ($p = 0.771$). Estimated blood loss likewise remained low in both groups (80 mL [0–3,200] vs. 57 mL [0–2,000], $p = 0.617$).

Postoperative course improved after adoption of the laparoscopic probe. The median length of postoperative

hospitalization was reduced from 9 days (4–70) to 8 days (5–34) ($p = 0.004$). The incidence of Clavien–Dindo grade \geq IIIa complications fell numerically from 11.3% (17/151) to 6.6% (4/61) but did not reach statistical significance ($p = 0.446$) (**Table 1**). The complications in the Open Probe group included bile leakage requiring drainage (8 cases), abdominal abscess requiring percutaneous drainage (3 cases), postoperative bleeding requiring embolization (1 case), and pneumonia or respiratory failure requiring mechanical ventilation (5 cases); no cases of liver failure were observed. In the Laparoscopic Probe group, three patients had bile leakage requiring drainage, and one had an abdominal abscess requiring drainage. There was no peri-operative mortality in either group.

No significant differences were observed between the two groups in disease-free survival ($p = 0.597$) or overall survival ($p = 0.874$) (**Figure 5**).

Taken together, conversion to a purpose-built laparoscopic IOUS probe maintained operative safety and efficiency while significantly shortening postoperative hospitalization. This technique caused no complications such as air leaks or equipment damage.

Discussion

The use of Lap-H in Japan has rapidly increased since 2016 due to favorable insurance incentives. However, the use of laparoscopy in hepatectomy remains limited compared with laparoscopic procedures in gastric or colorectal surgery^{4,5}. IOUS is essential in hepatectomy, regardless of the surgical approach, and the high costs of laparoscopic IOUS probes remain a barrier to the broader adoption of Lap-H.

In open surgery, IOUS using microconvex probes has been refined into a gold-standard tool⁶. These microconvex probes emit radial waves and produce axial images, aligning well with preoperative imaging and anatomical

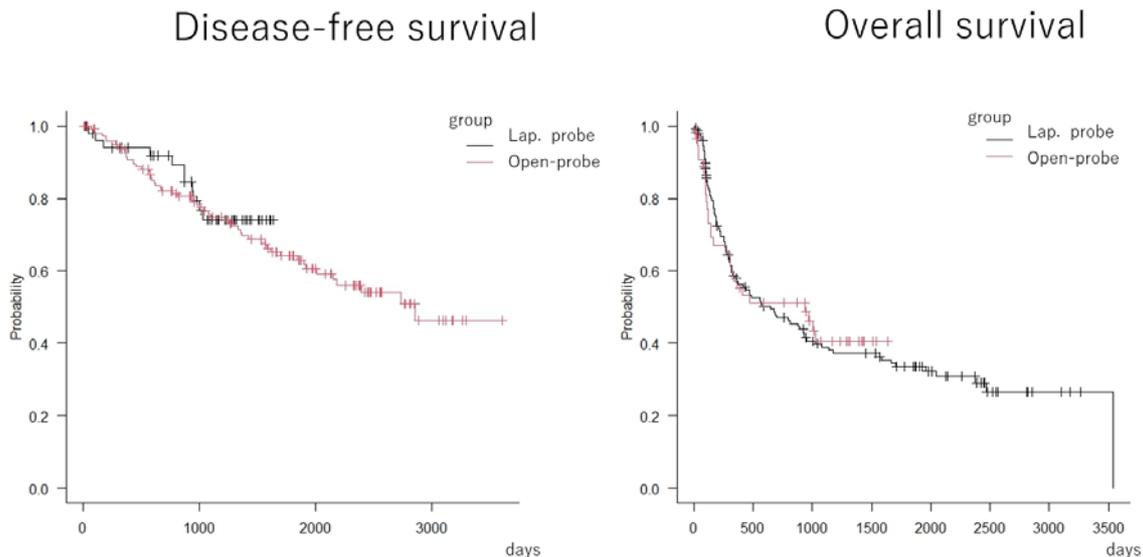


Figure 6 Disease-free survival and overall survival of the Open Probe group and the Laparoscopic Probe group

understanding. In contrast, laparoscopic linear probes often yield sagittal images and are more difficult to handle.

For the Open Probe and Laparoscopic Probe groups, no significant differences in operative time or intraoperative blood loss—two variables that could plausibly be influenced by the probe employed, underscoring the utility and safety of the open-surgery-type ultrasound probe were observed. Likewise, the proportion of high-difficulty procedures was comparable in both groups, suggesting that this probe can be used without impediment even in technically demanding cases. The fact that the Clavien–Dindo grade \geq IIIa complications observed in both groups were not attributable to the intraoperative US probe, and that their frequency did not differ between the groups, suggests that this method can be safely used during Lap-H (**Table 1**).

Conversely, the initially significant reduction in postoperative length of stay in the Laparoscopic Probe group was considered to reflect greater surgical proficiency and growing institutional confidence in the safety of Lap-H, which fostered an early-discharge policy. When postoperative length of stay was re-examined in two strictly contemporaneous subsets—61 patients treated with the Open probe between July 2019 and February 2021 and the 61 patients in the Laparoscopic Probe group—no significant difference emerged ($p = 0.119$).

Our method allowed the use of standard open-surgery-type probes in Lap-H with the following benefits:

1. No need to purchase expensive laparoscopic IOUS probes.

2. Acquisition of axial images similar to open surgery.
3. No need to change ports during IOUS.
4. Enables contrast-enhanced ultrasonographic examination in hard-to-visualize cases.
5. The umbilical port can be used for specimen retrieval.
6. Adaptable and can be used with other access devices or retractors.

The disadvantages of our method include the need for preoperative probe preparation and possible requirement for additional dissection due to the probe thickness.

Despite initial concerns about gas leakage or subcutaneous emphysema, these complications were not observed in over 150 cases of Lap-H. Our technique supports cost-effective and high-quality Lap-H, which is particularly helpful in cases with metastasis requiring enhanced ultrasound. Our method also aligns with recent advancements in intraoperative guidance, such as real-time ultrasound navigation⁷ and tattooing techniques⁸ (**Figure 6**), which improve the precision of partial liver resection.

Lap-H offers superior outcomes to open hepatectomy regarding blood loss, postoperative complications, liver function, and recovery⁹. Although robotic hepatectomy was recently covered by insurance in Japan (2022), the widespread adoption of this approach will take time due to the associated costs¹⁰. This cohort did not include any robotic cases. Although small probes for robotic use are now available, they are associated with additional costs; therefore, the present method may offer a useful alternative. Our method may serve as a bridge to robotic he-

patectomy by promoting safer and more accessible Lap-H.

Conclusion

The use of open-surgery-type ultrasonographic probes in Lap-H provides a practical, economical alternative to specialized laparoscopic systems. This technique not only facilitates high-quality IOUS but also lowers the barrier for institutions initiating Lap-H programs, contributing to the broader adoption of Lap-H and improved surgical outcomes.

Author Contributions: Yoichi Kawano conceived the study. Yoichi Kawano, Yukio Ohshiro, Yuto Aoki, Takashi Ono, Akira Hamaguchi, and Toshiyuki Irie acquired the clinical data. Yoichi Kawano, Tetsuya Shimizu, Akihisa Matsuda, Junji Ueda, and Takahiro Murokawa performed the surgical procedures and patient management. Yoichi Kawano conducted the statistical analysis. Akira Matsushita, Masato Yoshioka, Nobuhiko Taniai, and Hiroshi Yoshida supervised the project and revised the manuscript. All authors reviewed and approved the final manuscript.

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