Review Article

Technical aspects and surgical complications of laparoscopic liver resection

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Abstract: Laparoscopic liver resection (Lap LR) is widely used to perform various types of LR and has replaced open surgery in many cases. As far as the technique is concerned, Lap LR is more difficult than open LR. The difficulty score (DS) was developed as a tool for evaluating the technical complexity of Lap LR and has been validated in several studies. In this review, we validated the DS in our case series and used it to compare our series with those described in a previous report. Improvements in blood flow control methods have also played an important role in the expansion of the indications for Lap LR. We reviewed the development of the inflow blood control methods used during LR. Biliary stricture is the most significant complication after Lap LR. Unfortunately, heat injuries are unavoidable when a radiofrequency (RF) surgical device is used to achieve hemostasis. We reviewed the methods used to dissect the liver parenchyma and treat biliary stricture in one of our cases. Although Lap LR is less invasive than open LR, clinicians should monitor patients for biliary stricture, as it is a severe complication that requires multidisciplinary planning and management.

Keywords: Laparoscopic liver resection (Lap LR); difficulty score (DS); inflow blood control; radiofrequency surgical device (RF surgical device); biliary stricture

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Introduction

Liver resection (LR) is one of the curative strategies for various liver tumors, including primary malignant tumors, metastatic liver tumors, and some benign tumors. Laparoscopic LR (Lap LR) was first reported in 1991 (1). The indications for Lap LR are expanding, and the feasibility of performing major hepatectomy using a laparoscopic procedure has been proven at expert institutions (2,3). The main clinical benefits of Lap LR compared with open surgery are that it is less invasive, causes less pain, and results in a fast recovery after surgery (4). On the other hand, the demerits of Lap LR include its technical difficulty, the safety of such surgery, the longer operation time, and increased operating theater costs. One of the aims of this review is to discuss the technical aspects of Lap LR, including the difficulty score (DS) and intraoperative blood flow control.

Although Lap LR results in fewer postoperative complications than open surgery, biliary duct complications require careful attention. As the surgeon cannot hold the liver parenchyma with their left hand to control hemostasis during Lap LR procedures, parenchymal ablation is necessary to achieve hemostasis. Various ablation devices have been developed for use during surgery. They can be used to seal blood vessels (by denaturing the chemical structure of collagen fibers) during surgery, and bile ducts

Table 1 Difficulty score system for pure laparoscopic liver resection proposed by Ban and Tanabe

Variables	Score
Tumor location	
S2	2
S3	1
S4	3
S5	3
S6	2
S7	5
S8	5
Total	A
Extent of liver resection	
Hr0	0
Hr-LLR	2
Hr-S	3
Hr-1, 2	4
Total	B
Tumor size	
<3 cm	0
>3 cm	1
Total	C
Proximity to major vessels	
No	0
Yes	1
Total	C
Liver function	
Child-Pugh A	0
Child-Pugh B	1
Total	C

Difficulty score (DS) = A + B + C (range: 1–12). DS: 1–3, low grade; 4–6, intermediate grade; and 7–10, high grade. S, segment; Hr, hepatic resection; LLR, left lateral sectionectomy.

can be sealed via a similar mechanism. However, unexpected biliary complications can occur because the ablated area is hard to estimate during surgery. We encountered a case in which biliary stricture occurred as a late surgical complication of Lap LR, and endoscopic intervention was required in this case. The second aim of this review is to caution against the use of ablating devices adjacent to the major Glissonian pedicle.

DS

The difficulty of LR is determined by the type of operation and the degree of central obesity (5). A complexity score and a classification of LR, which were based on expertise from all over the world, were proposed for open LR (6). Twelve procedures were rated and divided into three grades, low, medium, and high complexity. The "A Body Shape Index" (ABSI), which is based on waist circumference (WC), adjusted for height and weight, represents body habitus (7). Unlike body mass index, the ABSI distinguishes between peripheral and central fat (which can affect clinical outcomes after Lap LR) (5). Although the ABSI was shown to be a substantial risk factor for premature mortality in the general population (7), the ABSI and the difficulty of LR are also associated with the conversion risk (5). Interestingly, the ABSI was only correlated with the operation time in the high difficulty group (5). The DS for Lap LR is summarized in *Table 1* (8). This score takes into account the location of the resection site, the surgical procedure, tumor size, the of the resection site distance from major blood vessels, and liver function (8). The score is calculated based on mathematical equations. It has been validated in a retrospective study involving 78 patients who underwent Lap LR, and the DS was found to be correlated with the operation time and intraoperative blood loss (the mean values were 256 min and 168 mL, respectively) (9). Another validation study also obtained similar results (10), but it did not detect a relationship between the DS and the operation time. Although the DS does not take body habitus into account, it can be used for both technical evaluations at single institutions and comparisons of surgical outcomes among multiple institutions.

Evaluation of the DS in our case series

The cases of 88 consecutive patients who underwent pure Lap LR at our institution between July 2010 and December 2016 were retrospectively evaluated. The patients' clinical data are shown in *Table 2*. The mean operation time was 257.8 min, and the median amount of intraoperative blood loss was 20 mL. The mean DS was 3.7. The results of a linear regression analysis of the relationships between the DS and the operation time or intraoperative blood loss are

Table 2 Clinical data of patients who underwent pure laparoscopic liver resection

Variables	Median or mean	IQR or SD	Kolmogorov-Smirnov test
Age (years)	67.0	61–72	0.017
Sex (male: female)	40:48		
Albumin (g/dL)	3.9	3.3–4.1	0.001
Bilirubin (mg/dL)	0.7	0.5–1.0	0.003
PT (%)	89.2	12.5	0.897
ICG-R15 (%)	10.0	6.5–16.45	0.002
Platelets (/10^4 mm^2)	15.9	10.6–20.0	0.001
Tumor size (cm)	2.7	1.7	0.115
Tumor numbers	1	0–1	0.001
Hr (0:1:2)	79:7:2		
Op time (min)	257.8	117.8	0.813
Intraoperative blood loss (mL)	20	0–112	0.001
Difficulty score (points)	3.7	2.1	0.184

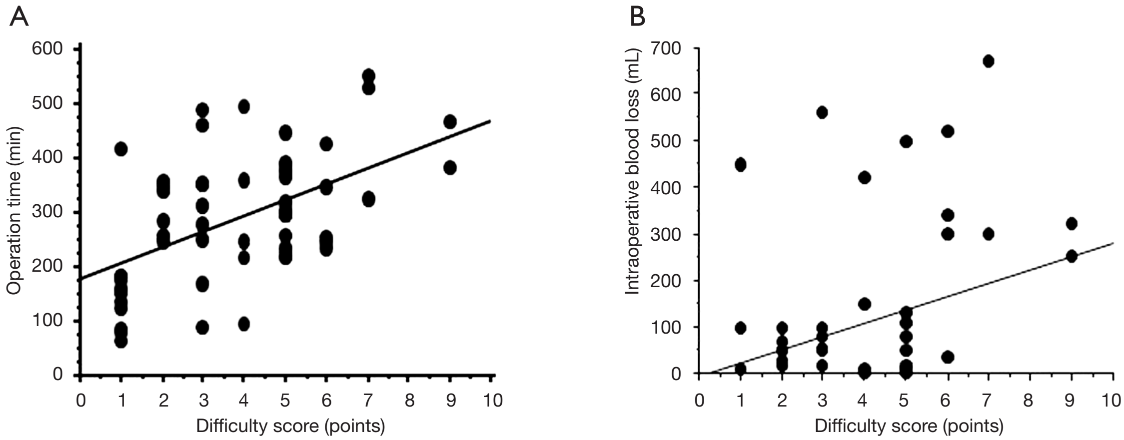
IQR, interquartile range; SD, standard deviation; PT, prothrombin time; ICG-R15, indocyanine green retention at 15 min; Hr 0, partial resection; Hr 1, mono-segmentectomy; Hr 2, bi-segmentectomy.

shown in *Figure 1*. The DS was found to be correlated with the operation time (R=0.526, P<0.0001) and the amount of intraoperative blood loss (R=0.364, P=0.0045). The regression coefficients for these relationships indicate that the operation time and amount of intraoperative blood loss increase by 30 min and 30 mL, respectively, for every DS point. Furthermore, the utility of the DS for predicting an operation time of 300 min or intraoperative bleeding of 300 mL was assessed based on receiver operating curve (ROC) analysis (*Figures 2A,B*). The area under the ROC curve for these parameters was 0.686 and 0.800, respectively (*Figure 2C*). The optimal DS cut-off values for predicting these outcomes were evaluated using a dot-blot diagram (*Figure 3*) and was found to be 5 DS points in both cases. Using this cut-off value, the DS exhibited sensitivity and specificity values of 53.8% and 66.7%, respectively, for predicting an operation time of ≥300 min. On the other hand, it displayed sensitivity and specificity values of 63.6% and 91.7%, respectively, for predicting intraoperative blood loss of ≥300 mL. Therefore, the DS could be useful for predicting the risk of a long operation and increased intraoperative blood loss. Patients with DS of ≥5 points could be at high risk of requiring an operation lasting at least 300 min and/or involving at least 300 mL of intraoperative blood loss. These roles may be applied in our institute solely, but self-evaluation should be considered at each institution. It might be possible to compare the clinical outcomes of different institutions by matching patients using the DS.

In fact, a comparison of our experience and the cases described in the study by Im *et al.* is shown in *Table 3*. While higher DS were recorded in Im's study, the mean operation time was shorter, and the mean amount of intraoperative blood loss was greater than in our cases. It would not be appropriate to perform simple comparisons between the clinical outcomes of the two studies as they exhibited different DS, which might have been due to variations in the patients' backgrounds. The abovementioned findings could imply that different surgical policies are in operation at the two institutions; i.e., that our surgical team regard intraoperative bleeding as the most important factor but Im's team regard the operation time as the most important factor. Therefore, the DS could also aid comparisons of the clinical outcomes of Lap LR among different circumstances.

Blood flow control (*Table 4*)

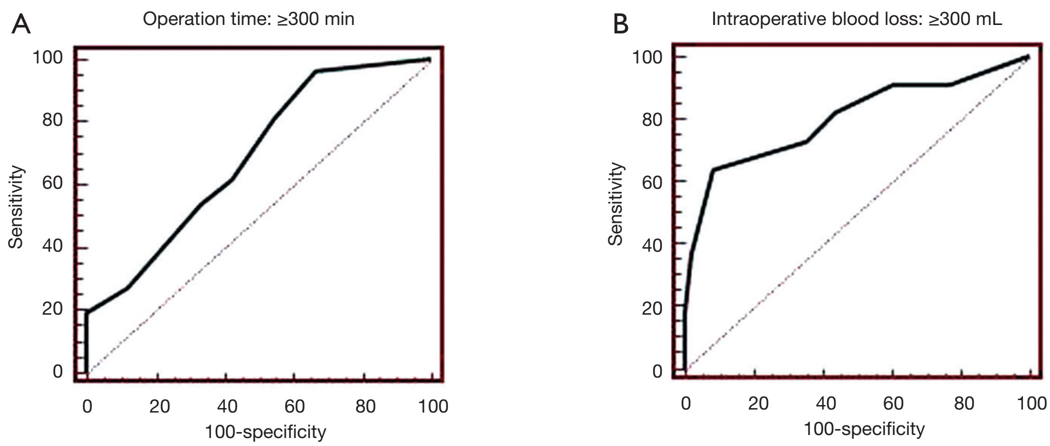
Various blood flow control methods have been invented, such as inflow and outflow control methods, for both open and Lap LR. In this review, we focus on inflow control methods. In open surgery, Pringle described the total



C

Difficulty score	Operation time	Intraoperative blood loss
Linear equation	Y =178.725+29.083X	Y =−6.371+28.89X
R	0.526	0.364
P	<0.0001	0.0045

Figure 1 Linear regression analysis of the relationships between the difficulty score and the operation time (A) or intraoperative blood loss (B). Summary of the statistical results including linear equations, correlation coefficients (R), and P values (C).



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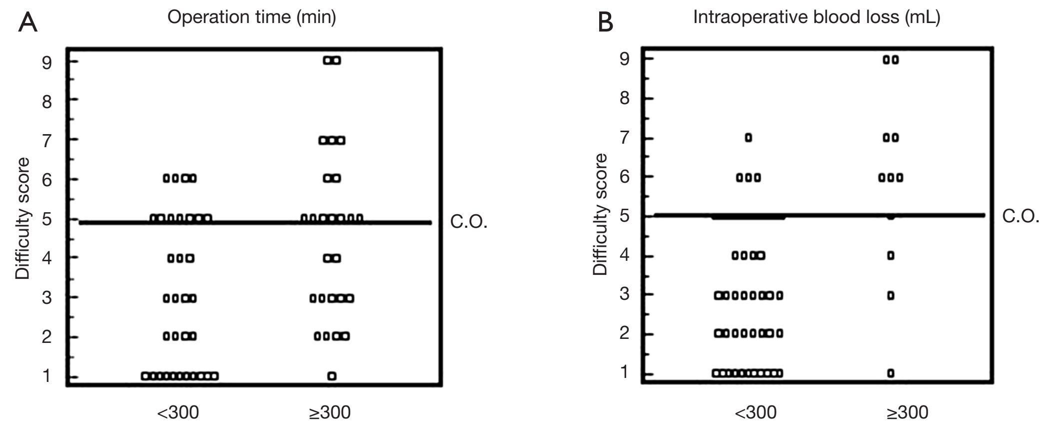
Difficulty score	Operation time	Intraoperative blood loss
Area under the ROC (AUC)	0.686	0.800
Standard error	0.0708	0.0845
95% confidence interval	0.552 to 0.801	0.676 to 0.893
Z statistic	2.633	3.554
Significance level (P-value; area=0.5)	0.0085	0.0004

Figure 2 Receiver operating curve (ROC) analysis of the utility of the difficulty score for predicting an operation time of ≥300 min (A) or intraoperative blood loss of ≥300 mL (B). Summary of the statistical results including the area under the ROC (C).



C

Cut-off level =5.0 points	Operation time	Intraoperative blood loss
Sensitivity	53.8%	63.6%
Specificity	66.7%	91.7%

Figure 3 Interactive dot diagram of the operation time versus the difficulty score (A). Interactive dot diagram of intraoperative blood loss versus the difficulty score (B). The sensitivity and specificity of the difficulty score for predicting the abovementioned parameters at a cut-off level of 5.0 (C).

Table 3 Comparison of clinical outcomes between our cases and those in Im's study

Variables	Median or mean	IQR or SD
Our experience		
DS	3.7	2.1
Op time	257.8	117.8
Intraoperative blood loss	20	0–112
Im *et al.*		
DS	4.7	3–6*
Op time	160	152–200*
Intraoperative blood loss	300	64–300*

*, range. DS, difficulty score; Op, operation; IQR, interquartile range; SD, standard deviation.

clamping of the hepatoduodenal ligament in a traumatic case in 1908 (11). Makuuchi *et al.* reported a hemihepatic vascular occlusion technique for reducing the risk of organ congestion and hepatic ischemia (12). Furthermore, Shimamura *et al.* achieved selective vascular control of the segmental branches using a balloon catheter during LR (13). In Lap LR, various blood flow control techniques have been reported.

Table 4 Representative blood flow control methods employed during open and laparoscopic liver resection

Years	Authors	Strategy
1908	Pringle	Pringle maneuver
1987	Makuuchi	Hemihepatic vascular occlusion
1986	Shimamura	Selective vascular control of segmental branches
2000	Cherqui	Intracorporeal hepatic inflow control
2008	Belli	Surround the hepatoduodenal ligament using the Endo Retract Maxi
2009	Cho	Extracorporeal hepatic inflow control using a short tube
2012	Rotellar	Extracorporeal hepatic inflow control using a long tube
2015	Mizuguchi	Extracorporeal hepatic inflow control using a long tube (patents submitted in Japan and the US in 2010 and 2011, respectively)

An intracorporeal method was described by Cherqui *et al.* in 2000 (14). However, difficult cases in which it was not possible to obtain good blood flow control were sometimes encountered, as it can be hard to squeeze the tourniquet

Table 5 Representative liver parenchymal dissection methods

Techniques and surgical devices	Year	First author
Finger fracture technique (digitoclasy)	1960	Lin
Kelly (clamp crushing)	1974	Lin
Ultrasonic dissector (CUSA, Tyco Healthcare, Mansfield, MA, USA)	1992	Hodgson
Hydro-Jet (Erbe, Tubingen, Germany)	1993	Baer
Harmonic scalpel (Ultracision, Ethicon Endo-surgery, Cincinnati, OH, USA)	2000	Gertsch
Dissecting sealer (Tissuelink, Dover, NH, USA)	2005	Arita
Radiofrequency generator (RFALR)*	2005	Haghighi

*, RFALR can be performed with the Habib and LigaSure devices (Medtronic, Minneapolis, MN, USA). RFALR, radiofrequency-assisted liver resection.

sufficiently using laparoscopic devices. Extracorporeal hepatic inflow control methods were subsequently reported. Cho *et al.* reported an extracorporeal method involving the use of a short tube in 2009 (15). Belli *et al.* (16) stated that they described this technique earlier than Cho *et al.*; however, Belli *et al.*'s method advantage involved surrounding the hepatoduodenal ligament with the Endo Retract Maxi. We also came up with a similar extracorporeal inflow control method at a similar time. Our idea was based on the use of a long tube, which was placed at the bottom of the surgical field. This made it possible to secure the surgical working space. We prepared to protect our idea and submitted patents regarding our extracorporeal method on Oct 5, 2010, in Japan and on Oct 5, 2011, in the US. Eventually, Rotellar *et al.* reported a similar idea; i.e., they used a long tube during the extracorporeal Pringle maneuver, in 2012 (17). Our paper was delayed and was not published until 2015 (18) due to the long process involved in getting patent rights in Japan and the US. Our clamping device is commercially available as the vClump™ (Kono Seisakusho: Crownjun, Tokyo, Japan). We could not name it the vClamp™ due to commercial rights issues in Japan.

Biliary stricture after Lap LR

Lap LR is less invasive than open surgery. Surgical energy devices, such as radiofrequency (RF)-based energy devices and bipolar ultrasound coagulators, play an important role in obtaining good hemostasis and as well as in Lap LR itself. *Table 5* shows representative liver parenchymal dissection methods (19). In the classic method, which was in use at the end of the last century, the liver parenchyma is dissected manually and mechanically (the upper section in *Table 5*), and most vessels and bile ducts are ligated. On the other hand, sealing devices based on ultrasound oscillation, monopolar ablation, bipolar ablation, or RF ablation, are employed in modern methods (the lower section in *Table 5*). Among these methods for dissecting the liver parenchyma, RF ablation has been found to result in high bile duct injury-associated morbidity rates. Janssen *et al.* also reported that 4 out of 122 patients suffered biliary stricture and required multiple endoscopic procedures (20). The clinical symptoms of the bile duct stricture in these cases occurred late (from 1 to 4 months after surgery). A randomized controlled trial of the RF and clamp crushing methods showed that both techniques produced similar clinical outcomes, but the bile duct injury-related morbidity rate was significantly higher in the RF group than in the clamp crushing group. In the latter study, one out of 24 patients in the RF group suffered biliary stenosis (21). Clinicians should be aware that bile duct stricture can occur as a severe late complication after Lap LR.

A representative case of post Lap LR biliary stricture is shown in *Figure 4*. A 70-year-old male had hepatocellular carcinoma (diameter: 3 cm) in segment 4a of the liver. The affected segment and the tumor were removed via a pure laparoscopic approach without any complications (*Figure 4B*). However, bile leakage was seen from the stump of B4 because the internal pressure in the affected region had increased due to bile duct stricture in B2 + B3. First, external drains were placed in the bile cavity (*Figure 5A*). Then, endoscopic retrograde biliary drainage of B2 was performed (*Figure 5B*). Subsequently, bile duct stricture developed in the B3 branch. Percutaneous drainage of B3 was carried out, and B3 was recanalized through the B4 stump using the rendezvous technique (*Figure 5C*), which was similar to the technique reported by Deviere (22). Eventually, internal drainage of bile ducts B2 and B3 was performed (*Figure 5D*). The successful treatment of biliary morbidities requires organized planning and care from a multidisciplinary team. Although Lap LR is less invasive, biliary complications can arise as significant morbidities. It is better to consult a tertiary center before considering the surgical approach in cases in which biliary stricture occurs after Lap LR.

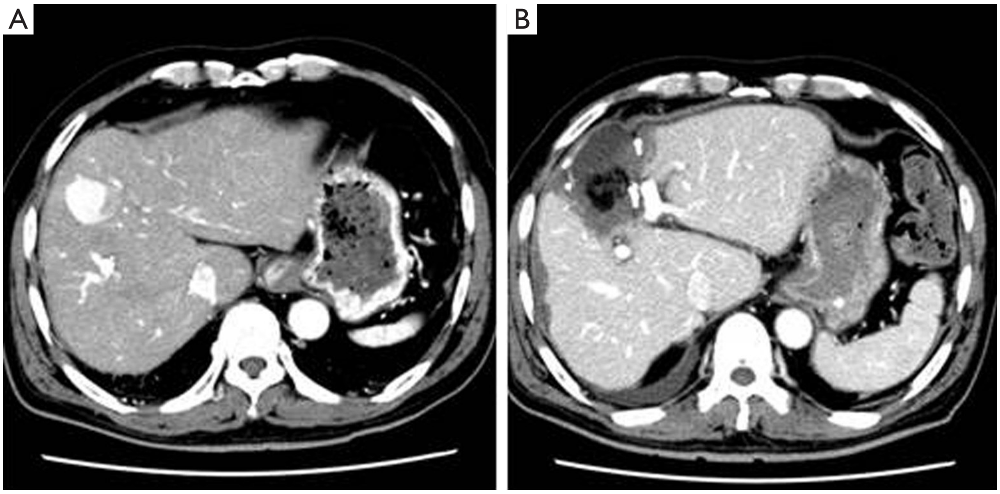


Figure 4 Pre- (A) and postoperative (B) images of a 70-year-old male with hepatocellular carcinoma (diameter: 3 cm) in segment 4a of the liver.

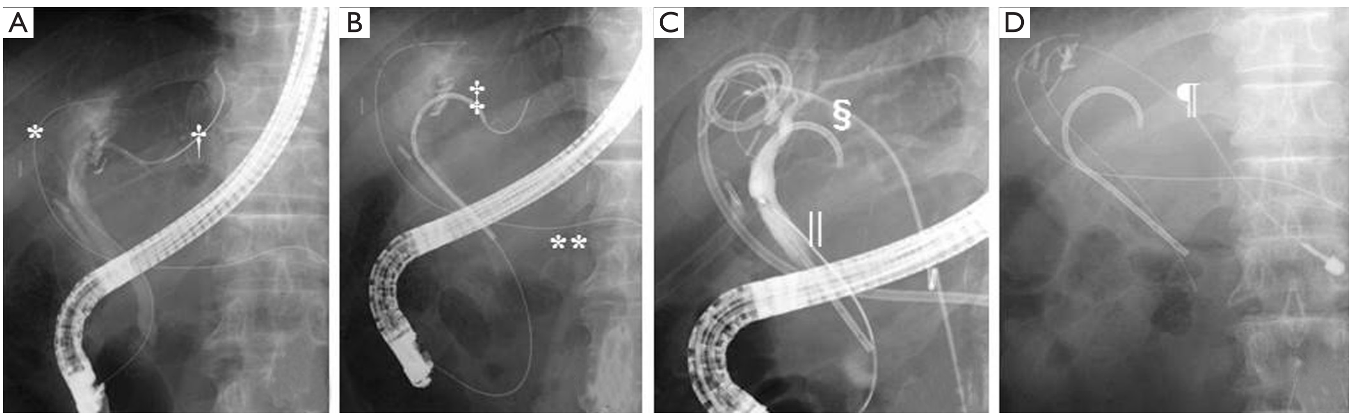


Figure 5 Management of biliary stricture after laparoscopic liver resection due to a heat injury caused by a radiofrequency surgical device. The management of the biliary stricture involved four steps. Step 1: percutaneous bile cavity drainage and internal bile duct drainage of B2 were performed (A). Step 2: the stent tube in B2 was replaced (B). Step 3: a bridge was formed between the B3 branch and the common bile duct using the rendezvous technique (C). Step 4: internal bile drainage of B2 and B3 were completed independently (D). Asterisk (*), percutaneous extra-bile cavity drainage; single dagger (†), the wire inserted into the B2 bile duct via endoscopic retrograde cholangiopancreatography-based cannulation; double dagger (‡), the endoscopic retrograde bile duct drainage stent tube in B2; the section sign (§), percutaneous extra-bile cavity drainage through the B3 bile branch; double sticks (||), the biopsy forceps used for the rendezvous technique; paragraph sign (¶), the external-internal bridge connecting the B3 branch, the bile cavity, and the common bile duct.

Conclusions

We have reviewed the utility of the DS for evaluating the technical difficulty of Lap LR using our case series. The development of inflow blood control methods was also reviewed. Furthermore, we have highlighted that bile duct stricture can arise as a significant complication after Lap LR and is associated with RF-based heat injuries. Consultation with a tertiary center and multidisciplinary planning should be considered in cases involving post-LAP LR biliary stricture.

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Footnote

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