Pure Laparoscopic Versus Open Right Hepatectomy in Live Liver Donors

A Propensity Score-matched Analysis

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Objective: The aim of the study was to present the safety and feasibility of pure laparoscopic donor right hepatectomy (PLDRH) in comparison with those of conventional donor right hepatectomy.

Summary Background Data: Although the use of PLDRH is gradually spreading worldwide, its outcomes, including the long-term outcomes in both donors and recipients, have not yet been evaluated in a large comparative study.

Methods: We retrospectively reviewed the medical records of 894 donors who underwent living donor liver transplantation between January 2010 and September 2018 at Seoul National University Hospital. We performed 1:1 propensity score matching between the PLDRH and conventional donor right hepatectomy groups. Subsequently, 198 donor-recipient pairs were included in each group.

Results: The total operation time ($P < 0.001$), time to remove the liver ($P < 0.001$), and warm ischemic time ($P < 0.001$) were longer in the PLDRH group. None of the donors required intraoperative transfusion or experienced any irreversible disabilities or mortalities. The length of postoperative hospital stay was significantly shorter in the PLDRH group ($P < 0.001$). The rate of complications in donors was similar between the 2 groups. Although other complication rates in recipients were, however, similar, the rates of early ($P = 0.019$) and late ($P < 0.001$) biliary complications in recipients were higher in the PLDRH group. There was no significant difference in overall survival and graft survival between the 2 groups.

Conclusions: PLDRH is feasible when performed at an experienced living donor liver transplantation center. Further studies on long-term recipient outcomes including biliary complications are needed to confirm the safety.

Keywords: donor hepatectomy, laparoscopy, liver live donor, liver transplantation, right hepatectomy, surgery complications

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Living donor organ transplantation is somewhat different from other surgeries in that it must take into account the concerns of both recipients and donors. Minimally invasive surgery has been introduced in living donor liver transplantation (LDLT) to address the donors' cosmetic and functional concerns. After the first report of laparoscopic donor left lateral sectionectomy in 2002,[1] laparoscopic donor hepatectomy has spread worldwide, and the types of grafts used in these procedures have diversified to full left and right lobe.[2–12] Laparoscopic donor left lateral sectionectomy is now considered a standard practice like the conventional open approach by international consensus.[10–12] Full left and right hepatectomies, which are, however, technically more challenging, need additional studies, including assessments of their long-term outcomes. Their outcomes have not yet been evaluated in a large comparative study.

In November 2015, we started the pure laparoscopic donor hepatectomy program at Seoul National University Hospital in Seoul, Korea. Recently, and at present, about 85% to 90% of donor hepatectomies, mainly right hepatectomies, are performed using the pure laparoscopic technique without any selection criteria. By June 2019, we had performed more than 300 pure laparoscopic donor right hepatectomy (PLDRH) procedures. With the data from these cases and follow-up periods of more than 1 year, we aimed to present the safety and feasibility of PLDRH in comparison with those of conventional donor right hepatectomy (CDRH). To our knowledge, this is the largest comparative study including the long-term outcomes of both donors and recipients.

PATIENTS AND METHODS

The medical records of 894 donors who underwent LDLT between January 2010 and September 2018 at Seoul National University Hospital were reviewed. Among these 894 donors, those who underwent hepatectomy other than right hepatectomy, laparoscopic-assisted hepatectomy, and CDRH after November 2015 were excluded. After the accumulation of experience from cases and standardization of the procedure, the pure laparoscopic approach was used without any selection criteria, from March 2016. To minimize selection bias, donors who underwent PLDRH between November 2015 and February 2016 were additionally excluded. The institutional review board of Seoul National University Hospital approved this study (IRB no. 1806-083-951). The requirement for informed consent was waived because of the retrospective nature of the study.

Donor Selection and Procedures

Our general donor selection protocol has been reported previously.[13–16] Multidisciplinary evaluation was conducted preoperatively for all donors and their recipients. No absolute contraindications for PLDRH were considered since March 2016.[8,17] After March 2016, conventional donor open right hepatectomy was performed only when the 3D laparoscopic system or indocyanine green (ICG) near-infrared fluorescence camera system was not available at the day of operation or the donor or their families chose the open technique after being informed that the standard procedure is CDRH and PLDRH was a novel technique. We explicitly stated that the risk for the PLDRH had not been evaluated thoroughly due to the low volume of cases, and anatomical variations may increase

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the risk of complications. The present study involved PLDRH donors who underwent surgery after March 2016 to minimize selection bias.

The CDRH and PLDRH techniques used at our center have been described in detail.[8,9,13–23] An inverted L incision, of which transverse incision down to the lateral end of right rectus abdominis muscle, is considered the standard method of CDRH at our center. An upper midline or transverse incision, 10 to 15 cm long, was used in one-third of the CDRH donors according to the condition of individual donors to improve cosmetic and functional results. A 10 to 12 cm suprapubic incision, which can be hidden by undergarments, was used to retrieve the graft in PLDRH donors.

Both CDRH and PLDRH are based on the liver hanging maneuver, demarcation, and transection of the exact midplane of the liver, and optimal bile duct division. Since March 2016, which was when we stopped applying selection criteria for PLDRH, the ICG near-infrared fluorescence camera began to be used in earnest for demarcating the exact midplane of the liver and identifying the optimal bile duct division point together with preoperative magnetic resonance cholangiopancreatography (MRCP).[8,9,19,21,23] The 3D flexible scope was used for PLDRH as its 3-dimensional vision provided better depth perception, and its flexibility allowed easy manipulation in a small space, which is especially necessary for liver mobilization.[8,17,20] No Pringle maneuver was used in both CDRH and PLDRH.

Statistical Analysis

Results were expressed as means ± standard deviation or as number and percentage values. Continuous variables were compared using Student *t* tests, whereas categorical variables were compared using the χ^2 test or Fisher exact test, as appropriate. Patient and graft survival rates were calculated using the Kaplan-Meier method and compared by the log-rank test. All *P* values were 2-sided, and values less than 0.05 were considered statistically significant. We also performed 1:1 case matching using a propensity score incorporating 9 factors: donor sex, donor age, donor body mass index (BMI), graft including middle hepatic vein, recipient sex, recipient age, recipient BMI, model for end-stage liver disease score, and ABO incompatibility. Nearest-neighbor matching without replacement within a caliper was used. The caliper width was 0.2 standard deviations of the logit-transformed propensity score. The absolute standardized differences method was used to diagnose the balance after matching and all were checked to be less than 0.25. All statistical analyses were performed using SPSS software (version 23; SPSS Inc., Chicago, IL).

RESULTS

Between January 2010 and September 2018, 894 donors underwent right hepatectomy for LDLT at Seoul National University Hospital. Donors who underwent hepatectomy other than right hepatectomy, laparoscopic-assisted hepatectomy, and CDRH after November 2015 were excluded, yielding 505 donors who underwent CDRH and 213 who underwent PLDRH. To correct selection biases and confounding factors, propensity score matching was performed at a 1:1 ratio. After matching, 198 donors were included in each group. Table 1 summarizes the baseline characteristics of the overall cohort and matched cases. Before matching, the proportion of female donors, donor BMI, proportion of grafts including the middle hepatic vein, recipient BMI, proportion of ABO incompatibility, and recipient age were higher while model for end-stage liver disease score was lower in the PLDRH group. After matching, there were no significant intergroup differences in relation to the 9 factors encompassing donors' and corresponding recipients' baseline characteristics.

The operative outcomes for donors are summarized in Table 2. The operative time (270.8 vs 289.9 min; $P < 0.001$), time to remove the liver (166.2 vs 211.4 min; $P < 0.001$), and the warm ischemia time (3.7 vs 12.3 min; $P < 0.001$), defined as the time of starting the right hepatic artery ligation to the time to removal of the liver, were significantly longer in the PLDRH group. The Δhemoglobin (Hb)%, calculated as ΔHb % = [(preoperative Hb − postoperative lowest Hb)/preoperative Hb] × 100, was significantly lower in the PLDRH group (21.3% vs 16.6%; $P < 0.001$). The postoperative peak total bilirubin (3.7 vs 4.2 mg/dL; $P = 0.012$) level, aspartate aminotransferase (AST) level (167.8 vs 222.0 IU/L; $P < 0.001$), alanine aminotransferase (ALT) level (174.6 vs 231.1 IU/L; $P < 0.001$), Δbilirubin%, calculated as Δbilirubin% = [(postoperative peak bilirubin − preoperative bilirubin)/preoperative bilirubin] × 100 (413.0% vs 672.8%; $P < 0.001$), ΔAST%, calculated as ΔAST% = [(postoperative peak AST − preoperative AST)/preoperative AST] × 100 (783.8% vs 1136.9%; $P < 0.001$), and ΔALT%, calculated as ΔALT% = [(postoperative peak ALT − preoperative ALT)/preoperative ALT] × 100 (912.7% vs 1358.1%; $P < 0.001$), were significantly higher in the PLDRH group. The duration of hospitalization was significantly shorter in the PLDRH group (8.6 vs 7.5 days; $P < 0.001$). There were fewer grade I complications (6.1% vs 1.0%; $P = 0.007$) based on the Clavien-Dindo classification[24] in the PLDRH groups, but there was no statistically significant intergroup difference in the rate of complication greater than grade II. None of the donors

TABLE 1. Baseline Characteristics of Liver Donors Before and After Propensity Score Matching

	Before PSM				After PSM			
Variables	**CDRH (N = 505)**	**PLDRH (N = 213)**	***P***	**SD**	**CDRH (N = 198)**	**PLDRH (N = 198)**	***P***	**SD**
Donor sex, male: female	335 : 170	123 : 90	0.029	−0.17	120 : 78	119 : 79	0.918	−0.01
Donor age, mean ± SD, yr	33.3 ± 11.3	33.2 ± 10.7	0.884	−0.01	34.1 ± 11.2	33.1 ± 10.6	0.362	−0.09
Donor BMI, mean ± SD, kg/m^2	23.0 ± 3.1	23.7 ± 3.3	0.013	0.20	23.9 ± 3.2	23.7 ± 3.4	0.591	−0.05
Graft including middle hepatic vein, n (%)	13 (2.6)	16 (7.5)	0.002	0.19	10 (5.1)	11 (5.6)	0.823	0.02
Recipient sex, male: female	376: 129	156: 57	0.734	0.03	144: 54	146: 52	0.820	−0.02
Recipient age, mean ± SD, yr	52.6 ± 10.7	54.9 ± 10.9	0.010	0.21	54.5 ± 9.3	54.5 ± 11.1	0.965	−0.004
Recipient BMI, mean ± SD, kg/m^2	23.2 ± 3.4	23.8 ± 3.4	0.018	0.19	23.7 ± 3.3	23.7 ± 3.3	0.993	−0.001
MELD, mean ± SD	16.3 ± 7.8	14.9 ± 6.1	0.009	−0.23	14.8 ± 6.6	15.2 ± 6.2	0.533	0.07
ABO incompatibility, n (%)	18 (3.6)	29 (13.6)	<0.001	0.29	13 (6.6)	17 (4.3)	0.447	0.06

MELD indicates model for end-stage liver disease; PSM, propensity score matching; SD, standardized difference.

TABLE 2. Operative Outcomes of Liver Donors Undergoing Conventional Donor Right Hepatectomy and Pure Laparoscopic Donor Right Hepatectomy

Variables	CDRH (N = 198)	PLDRH (N = 198)	*P*
Operative time, mean ± SD, min	270.8 ± 50.3	289.9 ± 54.9	<0.001
Time to remove liver, mean ± SD, min	166.2 ± 40.2	211.4 ± 49.6	<0.001
Warm ischemic time, mean ± SD, min	3.7 ± 2.7	12.3 ± 5.7	<0.001
GRWR, mean ± SD	1.1 ± 0.4	1.1 ± 0.3	0.940
Multiple bile duct openings, n (%)*	90 (45.5)	108 (54.5)	0.096
Graft weight, mean ± SD, g	743.3 ± 142.5	714.2 ± 146.7	0.052
Estimated blood loss, mean ± SD, mL	335.4 ± 226.1	306.1 ± 213.1	0.192
Intraoperative transfusion, n (%)	0	0	NS
Postoperative blood tests, mean ± SD			
Hb, g/dL			
Lowest	11.5 ± 1.5	11.8 ± 1.4	0.147
Delta	21.3 ± 7.4	16.6 ± 7.4	<0.001
Total bilirubin, mg/dL			
Peak	3.7 ± 2.1	4.2 ± 1.9	0.012
Delta	413.0 ± 333.2	672.8 ± 387.3	<0.001
AST, IU/L			
Peak	167.8 ± 59.3	222.0 ± 81.0	<0.001
Delta	783.8 ± 316.5	1136.9 ± 492.9	<0.001
ALT, IU/L			
Peak	174.6 ± 72.5	231.1 ± 86.3	<0.001
Delta	912.7 ± 506.3	1358.1 ± 785.6	<0.001
Hospital stay, mean ± SD, days	8.6 ± 2.0	7.5 ± 2.4	<0.001
Postoperative complications, n (%)	21 (10.6)	12 (6.1)	0.102
Grade I	12 (6.1)	2 (1.0)	0.007
Transient neutropenia	0	1 (0.5)	1.000
Wound problem	6 (3.0)	1 (0.5)	0.122
Transient bile leakage	1 (0.5)	0	1.000
Intra-abdominal fluid collection	2 (1.0)	0	0.499
Pleural effusion	2 (1.0)	0	0.499
Ileus	2 (1.0)	0	0.499
Grade II	4 (2.0)	5 (2.5)	1.000
Pulmonary thromboembolism	0	1 (0.5)	1.000
Urinary tract infection	0	1 (0.5)	1.000
Bile leakage	1 (0.5)	1 (0.5)	1.000
Portal vein partial thrombus	0	1 (0.5)	1.000
Intra-abdominal fluid collection requiring antibiotics	2 (1.0)	1 (0.5)	1.000
Pneumonia	1 (0.5)	0	1.000
Grade IIIa	4 (2.0)	3 (1.5)	1.000
Portal vein thrombus requiring thrombectomy and stent insertion	0	1 (0.5)	1.000
Biliary problem requiring endoscopic stenting and/or percutaneous drainage	2 (1.0)	2 (1.0)	1.000
Liver abscess requiring percutaneous drainage	1 (0.5)	0	1.000
Pleural effusion requiring percutaneous drainage	0	1 (0.5)	1.000
Intra-abdominal fluid collection requiring percutaneous drainage	1 (0.5)	0	1.000
Grade IIIb	1 (0.5)	2 (1)	1.000
Biliary problem requiring surgery	0	1 (0.5)	1.000
Bleeding requiring surgery	0	1 (0.5)	1.000
Ileus requiring surgery	1 (0.5)	0	1.000

*More specific results of bile duct are described in Table 5.
GRWR indicates graft-to-recipient weight ratio; Hb, hemoglobin; SD, standardized difference.

required intraoperative transfusion or experienced any irreversible disabilities or mortalities.

The operative outcomes of the recipients are summarized in Table 3. The duration of hospital stay and the rate of early major complications, defined as complications more than grade III occurring within 30 days after LDLT were similar between the 2 groups. Specifically, the rate of early biliary complications was, however, significantly higher in the PLDRH group. (4.0% vs 10.1%; $P = 0.019$). Biliary problem was defined as biliary leakage or stricture, which required endoscopic stenting and/or percutaneous drainage or surgery. Although not statistically significant, the PLDRH group tended to show a higher rate of late major complications defined as complication more than grade III occurring later than 30 days after LDLT. Specifically, the rate of late biliary complications requiring intervention or surgery was significantly much higher in the PLDRH group (21.2% vs 39.4%; $P < 0.001$). The details of early and late major biliary complications in the recipients are described in Table 4.

Considering the higher rate of biliary complications, the detailed results for the bile duct are described in Table 5. The percentage of expected multiple bile duct openings from preoperative MRCP was similar between the CDRH and PLDRH groups (24.7% vs 25.8%; $P = 0.771$). Trifurcation of the bile duct was

TABLE 3. Postoperative Outcomes of Conventional Donor Right Hepatectomy and Pure Laparoscopic Donor Right Hepatectomy Recipients

Variables	CDRH (N = 198)	PLDRH (N = 198)	*P*
Hospital stay, mean ± SD, days	21.6 ± 42.6	20.6 ± 15.4	0.754
Early major complications, n (%)	38 (19.2)	50 (25.3)	0.147
Intra-abdominal bleeding	9 (4.5)	9 (4.5)	1.000
Intra-abdominal fluid collection	7 (3.5)	8 (4.0)	0.792
Wound problem	2 (1.0)	3 (1.5)	1.000
Hepatic artery problem	4 (2.0)	3 (1.5)	1.000
Portal vein problem	4 (2.0)	5 (2.5)	1.000
Hepatic vein problem	2 (1.0)	2 (1.0)	1.000
Biliary problem*	8 (4.0)	20 (10.1)	0.019
Cardiac problem	2 (1.0)	1 (0.5)	1.000
Pulmonary problem	5 (2.5)	5 (2.5)	1.000
Gastrointestinal problem	2 (1.0)	1 (0.5)	1.000
Lymphatic problem	1 (0.5)	0	1.000
Primary nonfunction	1 (0.5)	0	1.000
Bone problem	0	1 (0.5)	1.000
Sepsis	0	3 (1.5)	0.248
Late major complications, n (%)	72 (36.4)	91 (46.0)	0.052
Intra-abdominal bleeding	2 (1.0)	2 (1.0)	1.000
Biliary problem*	42 (21.2)	78 (39.4)	<0.001
Hepatic artery problem	1 (0.5)	1 (0.5)	1.000
Intra-abdominal fluid collection	8 (4.0)	6 (3.0)	0.586
Wound problem	8 (4.0)	2 (1.0)	0.055
Hepatic vein problem	1 (0.5)	3 (1.5)	0.623
Portal vein problem	2 (1.0)	5 (2.5)	0.449
Gastrointestinal problem	6 (3.0)	6 (3.0)	1.000
Pulmonary problem	3 (1.5)	6 (3.0)	0.503
Bone problem	7 (3.5)	1 (0.5)	0.068
Varicose vein	1 (0.5)	0	1.000
Cardiac problem	3 (1.5)	3 (1.5)	1.000
Kidney problem	3 (1.5)	0	0.248
Sepsis	1 (0.5)	2 (1.0)	1.000
Neurology problem	4 (2.0)	2 (1.0)	0.685

*Details of early and late major biliary complications in the recipients are described in Table 4.

SD indicates standardized difference.

TABLE 4. Details of Early and Late Major Biliary Complications in the Recipients

Variables	CDRH (N = 198)	PLDRH (N = 198)	*P*
Early major biliary complications, n (%)	8 (4.0)	20 (10.1)	0.019
Types of biliary complication			
Biliary leakage	5 (2.5)	13 (6.6)	0.054
Biliary stricture	4 (2.0)	7 (3.5)	0.359
Treatments required			
PCD	1 (0.5)	3 (1.5)	0.623
ERCP	2 (1.0)	5 (2.5)	0.449
PTBD	0	2 (1.0)	0.499
PCD and ERCP	2 (1.0)	5 (2.5)	0.449
PCD and PTBD	0	1 (0.5)	1.000
ERCP and PTBD	2 (1.0)	2 (1.0)	1.000
PCD, ERCP, and PTBD	0	1 (0.5)	1.000
Reoperation	0	1 (0.5)	1.000
PCD and reoperation	1 (0.5)	0	1.000
Late major biliary complications, n (%)	42 (21.2)	78 (39.4)	<0.001
Types of biliary complication			
Biliary leakage	4 (2.0)	12 (6.1)	0.041
Biliary stricture	39 (19.7)	66 (33.3)	0.002
Treatments required			
PCD	2 (1.0)	1 (0.5)	1.000
ERCP	16 (8.1)	19 (9.6)	0.595
PTBD	3 (1.5)	7 (3.5)	0.200
PCD and ERCP	0	4 (2.0)	0.123
PCD and PTBD	1 (0.5)	4 (2.0)	0.372
ERCP and PTBD	19 (9.6)	36 (18.2)	0.014
PCD, ERCP, and PTBD	1 (0.5)	5 (2.5)	0.215
PCD, ERCP, and reoperation	0	1 (0.5)	1.000
ERCP, PTBD, and reoperation	0	1 (0.5)	1.000

ERCP indicates endoscopic retrograde cholangiopancreatography; PCD, percutaneous drainage; PTBD, percutaneous transhepatic biliary drainage.

recorded as multiple while a short right bile duct stump was recorded as single. Although the probability of multiple bile duct openings at the graft appears to be higher in the PLDRH group, there was no statistically significant difference between the 2 groups (45.5% vs 54.5%; $P = 0.096$). A double-barrel bile duct opening was regarded as multiple bile duct openings. The probability of separate bile duct openings (27.8% vs 33.3%; $P = 0.271$) and the ratio of multiple bile duct anastomosis (13.6% vs 11.6%; $P = 0.507$) were similar between the 2 groups. The probability of obtaining multiple bile duct openings in donors whose preoperative MRCP, however, showed a single bile duct opening was significantly higher in the PLDRH group (28.6% vs 41.3%; $P = 0.032$). The duct-to-duct anastomosis was routinely performed unless the quality of the recipient bile duct was too poor for reconstruction. The rate of hepaticojejunostomy was similar between the 2 groups.

There was no significant difference between the 2 groups in overall recipient and graft survival (Fig. 1).

DISCUSSION

Since the first report of pure laparoscopic donor hepatectomy as left lateral sectionectomy in 2002[1] and PLDRH in 2013,[25] more

TABLE 5. Results of Bile Duct in Liver Donors Undergoing Conventional Donor Right Hepatectomy and Pure Laparoscopic Donor Right Hepatectomy

Variables	CDRH (N = 198)	PLDRH (N = 198)	*P*
Expected multiple bile duct openings from MRCP, n (%)	49 (24.7)*	51 (25.8)†	0.771
Multiple bile duct openings, n (%)	90 (45.5)‡	108 (54.5)	0.096
Separate bile duct openings, n (%)	55 (27.8)‡	66 (33.3)	0.271
Multiple bile duct anastomosis, n (%)	27 (13.6)‡	23 (11.6)	0.507
Expected single bile duct opening from MRCP but intraoperative multiple bile duct openings n (%)	42/147 (28.6)	59/143 (41.3)	0.032
Hepaticojejunostomy, n (%)	9 (4.6)	7 (3.5)	0.345

*Two patients with missing data.

†Four patients with missing data.

‡Three patients with missing data.

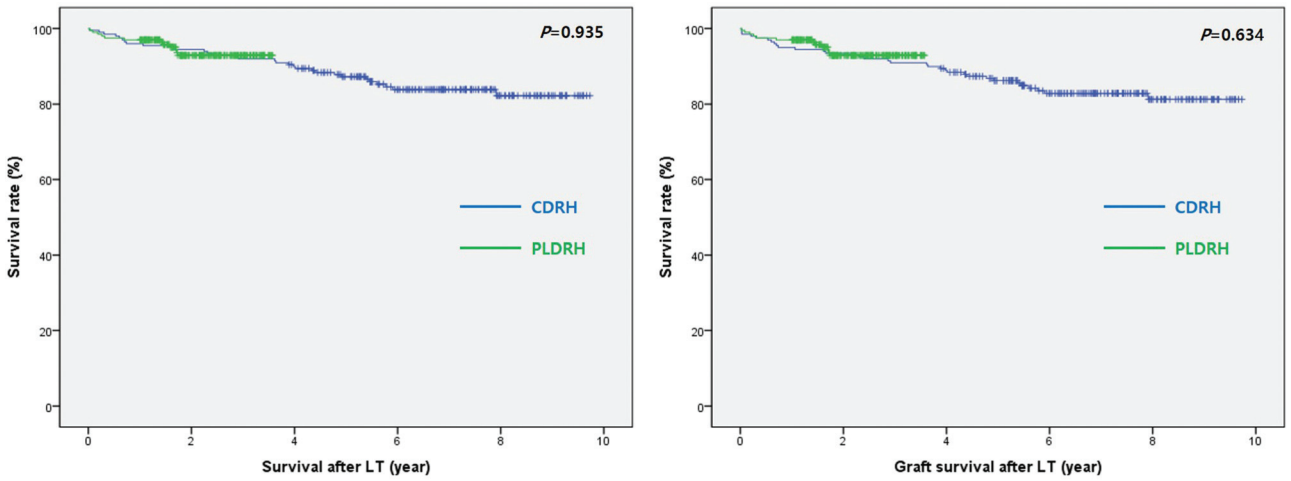

FIGURE 1. Kaplan-Meier curve of (A) overall survival and (B) graft survival. LT indicates liver transplantation.

surgeons are adopting PLDRH worldwide.[7–9,17,19–23,26–32] The feasibility and safety of this novel procedure have, however, not been fully evaluated due to the small case numbers and relatively short follow-up periods. Our center has performed more than 2000 cases of LDLT, of which 300 were performed using PLDRH. We designed this comparative study using propensity score matching to verify the feasibility and safety of PLDRH in comparison with CDRH, including the long-term outcomes of both donors and recipients on the basis of maximal evidence since a randomized control study cannot be conducted in the current situation. All the donors and recipients were followed up for at least more than 1 year.

The operative time, time to remove the liver, and warm ischemic time were significantly longer, which are well documented in several reports, including our previous reports.[8,9,33,34] There is a significant learning curve for this novel procedure, and the operative time can be decreased gradually as the center's experience accumulates.[8,9,32] The present study included PLDRH donors who underwent the operation 4 months after the procedure was first performed at our center. Donors who underwent PLDRH in the very early period were not included since PDLRH does require a longer operative duration than CDRH even after the initial learning curve. The mean operative time of PLDRH in this study was 289.9 minutes, which is relatively shorter than the times reported from other centers.[30] Warm ischemic time is critical and directly causes hepatocellular and biliary injury, and affects overall graft function.[35–38] In the pure laparoscopic approach, the warm ischemic time is longer since additional time is needed for instrument exchanges and because pneumoperitoneum has to be maintained to allow adequate exposure for laparoscopy. Steps have been taken to mitigate this prolonged time with maneuvers before ligating the inflow. For example, the specimen is bagged early, the incision through which the graft is delivered is prepared, and all attachments to the liver other than the inflow and outflow are divided. Despite these efforts, the warm ischemic time was still prolonged, as evident in our study. Although there was no significant intergroup difference in recipient outcomes, including overall survival and graft survival, except biliary complication, the long-term effects of longer warm ischemic time are yet to be determined.

The peak bilirubin and Δbilirubin%, peak AST and ΔAST%, and peak ALT and ΔALT% of the donor were all higher in the PLDRH group than in the CDRH group. Other than the possible direct effect of carbon dioxide pneumoperitoneum in causing liver injury,[39,40] this could also be partly explained by laparoscopic liver manipulation. Pure laparoscopic liver manipulation including perihepatic dissection and mobilization, and its limited tactile feedback, may have also contributed to the elevated results in liver function tests. Because a pure laparoscopic technique uses laparoscopic instruments, which inevitably have a small action point at the end, much force is applied to the specific focal area to manipulate the liver. Our previous study showed significantly reduced peak AST levels during the recent period in comparison with the initial period.[17] This method of mobilizing the liver was changed from pressing or pulling the liver directly to lifting and holding the liver using the remnant end of the right triangular ligament. Higher liver function results, however, did not lead to worse outcomes in the donor. Rather, the duration of hospital stay in the PLDRH group was significantly shorter with a similar complication rate in comparison with that in the CDRH group. Shorter duration of hospital stay despite higher postoperative peak bilirubin, AST, and ALT can be explained by several factors. First, the rates of grade I complications were significantly lower in the PLDRH group, whereas the rates of complications more than grade I were similar. Second, according to a recent meta-analysis comparing laparoscopy-assisted right hepatectomy with conventional open right hepatectomy in donor, laparoscopy-assisted group needed less pain control.[41] Less pain can lead to early discharge. Third, it is well documented in our previous report that although peak AST and ALT were higher in the PLDRH group, the level of AST and ALT were similar on the day of discharge, reflecting the effective recovery of liver function in the PLDRH group.[8]

Biliary complications were higher in the PLDRH group as compared to the CDRH group after propensity score matching. Biliary complications can result in long-term morbidity for the recipient in the form of biliary strictures, biliary leaks, and recurrent cholangitis. These patients may require repeated invasive procedures such as percutaneous transhepatic biliary drainage and ballooning/stenting, endoscopic procedures, and insertion of percutaneous drains. All these will lead to a reduction in the quality of life, recurrent admissions to the hospital, increased healthcare costs, and potentially eventual graft failure. The causes of these biliary complications are likely to be multifactorial, contributed by the longer warm ischemic time of the graft and increase in the likelihood of multiple bile duct openings.

As expected, because our center has no special selection criteria, the ratio of expected multiple bile duct openings from preoperative MRCP was similar between the CDRH and PLDRH

groups. Although not statistically significant, the PLDRH group, however, tended to show a higher proportion of multiple bile duct openings at the graft in comparison with the CDRH group. Moreover, there were significantly more donors who were expected to show a single bile duct opening at the graft from preoperative MRCP but eventually showed multiple bile duct openings at the graft. This finding was also evident in our previous study.[8] After encountering 1 donor with biliary leakage after intracorporeal suturing during PLDRH in the initial period, our center routinely uses a double clipping method with metal clips at the division of the hepatic ducts leaving behind a short stump under ICG imaging guidance, coupled with continuous referencing of the preoperative MRCP. This double-clipping method, however, inevitably occupies some space and the line of bile duct transection migrates slightly more to the graft side in comparison with CDRH. As the margins are often very fine and measured in millimeters, slight adjustment of the bile duct transection line toward the graft side may result in multiple bile duct openings since the length of the common channel of the right bile duct is usually around 1 cm or shorter.[42]

To validate the higher rate of biliary complications in the PLDRH group donors with bile duct anatomical variations, a subgroup analysis was performed. Expected multiple bile duct openings from preoperative MRCP ($P = 0.315$), multiple bile duct openings at the graft ($P = 0.527$), and multiple bile duct anastomosis ($P = 0.854$) did not increase the rate of biliary complications in the recipient. More specifically, 1, 2, or 3 bile duct openings at the graft did not defer in terms of biliary complication (30.3% vs 35.0% vs 22.2%; $P = 0.405$). The expected short common channel of the right bile duct in MRCP, which is defined as <5 mm, also did not increase bile duct complications ($P = 0.260$). According to the subgroup analysis, there was no significant relationship between the bile duct anatomical variations in the donor who underwent PLDRH and the results of biliary complications in the recipient.

The nature of laparoscopic surgery can contribute to an increase in biliary complications. The surgeon is more likely to use energy-sealing devices in closer proximity to the bile ducts in laparoscopic surgery. This transference of thermal energy can potentially cause damage to the endothelium and seal the microvasculature surrounding the bile ducts, resulting in ischemic injury. The use of ICG imaging to delineate the biliary anatomy intraoperatively before transection can play an important role. To obtain satisfactory images of the common hepatic duct bifurcation, the investing tissue surrounding it needs to be dissected clean since ICG can penetrate only approximately 5 to 10 mm into the tissue.[19,43] This additional dissection to clearly visualize the bile duct can result in the devascularization of the bile ducts, causing ischemic injury. Thus, caution should be exercised when using energy sealing devices around the hilar structures and dissection should be minimized around the bile duct should to reduce biliary complications.

Since June 2019, we have started to adopt duct-to-duct anastomosis with external biliary drainage (EBD) routinely in the case of graft bile ducts sized less than 5 mm. The main purpose of EBD is to prevent early bile leakage by decompressing the bile duct tree. It can also be helpful to reduce late bile duct complications since early bile leakage is related to late biliary stricture.[44] According to the results obtained from our preliminary 25 cases of EBD, there were no early major bile duct complications, and there were 4 cases (16.0%) of late major bile duct complications, which are markedly lower than those observed in the present study.

Anatomical variations of the portal vein were not a contraindication. There was no difference in early and late portal vein complication rates between the 2 groups. Special caution should be paid not to induce any stricture or twisting at the remnant left portal vein while providing a sufficient right portal stump at the graft since stapling may cause these problems. Stapling the remnant portal vein vertically rather than horizontally or obliquely is an important technical point. Because a bilateral stapler inevitably occupies space, the length of the right portal vein at the graft can be short. Thus, in many cases, the problem of a short portal vein is solved at the back-table or recipient operation. The surgical team's experience in performing back-table and recipient operations is especially important while performing PLDRH. One solution that can be employed during the donor operation can be temporary clipping, intracorporeal suturing, and clip removal (SNUH technique),[22] which can provide a similar length of right portal vein at the graft with CDRH by eliminating stapler line or clips. This technique is also useful in anatomic variations in the portal vein.

This study has several limitations. First, this was a single-center retrospective study, and our results may not be generalizable to other centers. The retrospective design may have resulted in under-reporting of complications. Second, despite adjustments through propensity score matching, unobserved components may have affected the results. This study has, however, sufficient value, because pure laparoscopic donor hepatectomy programs including PLDRH are spreading worldwide, and few centers have reported their experience of PLDRH with adequate sample sizes and long-term follow-up data for both donors and recipients. To the best of our knowledge, the present study used the largest number of PLDRH and CDRH cases and compared them under propensity score matching. Furthermore, by providing real-world data, including long-term follow-up for both donors and recipients, the findings could reveal the problems and potential scope for improvements in PLDRH.

In conclusion, the results of the present study indicated that PLDRH is a feasible option in experienced LDLT centers. Further studies should, however, be performed to confirm the safety of the recipients, especially with regard to the bile duct, and to propose a more secure and effective protocol for donor and recipient operations.

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