Effect of arterial reconstruction using recipient's left hepatic artery on postoperative biliary complications in right lobe liver graft in living donor liver transplantation

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Background

Biliary complications are still considered the Achilles' heel of living donor liver transplantation (LDLT), with recorded complication rates for right lobe LDLT as high as 20–34%. Anatomically, it seems more appropriate to use the recipient's right hepatic artery (RHA) over the left hepatic artery (LHA) for arterial reconstruction in right lobe LDLT. The course of the recipient's RHA usually runs just behind the common hepatic duct and gives small nourishing branches to the biliary tree. Dissecting this tissue between the common hepatic duct and the RHA to increase the later flexibility can cause ischemia of the recipient's extrahepatic bile duct and cause further biliary complication, especially biliary anastomosis stricture (BAS). The aim of this study was to determine if the use of recipient's LHA as inflow in arterial reconstruction lowers the risk of postoperative biliary complication.

Patients and methods

A prospective cohort study was conducted at the Liver Transplantation Unit in Air Forces Specialized Hospital, Cairo, Egypt, between July 2020 and the end of April 2022. It included all patients who underwent LDLT with stentless duct-to-duct biliary reconstruction. They were divided into two group: group A included 40 recipients who had LHA for arterial reconstruction and group B (historical control) included 40 recipients who underwent LDLT using RHA for arterial reconstruction.

Results

A total of 80 patients were divided into two equal groups: group A, LHA reconstruction group, and group B, RHA reconstruction group. On stratifying the technique of biliary reconstruction used in both groups regarding the number of graft ducts and the way they were anastomosed to the recipient biliary tree, we found no significant difference regarding incidence on statistical analysis. The incidence of biliary leakage was higher in group A (22.5%) versus group B (15%). Moreover, the number of patients who experienced both leakage and BAS was also higher in group A (7.5 vs. 2.5%) but both did not achieve statistical significance. BAS alone showed no statistically significance difference regarding the incidence. On analyzing the factor influencing biliary leakage other than arterial reconstruction, such as number of graft ducts and the effect of biliary reconstruction technique in the context of minimal dissection of the CBD, all the patients who had biliary leakage in group B had two graft ducts, but there was no statistically significant difference when compared with group A. The same factors were studied for the BAS. There was no increase in incidence, and the difference was not statistically significant for both number of graft ducts and reconstruction techniques.

Conclusion

The use of either RHA or LHA in arterial reconstruction in right lobe LDLTs does not reduce the incidence of duct-to-duct biliary complications which is a multifactorial risk that needs to be approached systematically to reduce all risk factors such as number of graft ducts, ductoplasty, cold ischemia, and arterial reconstruction. In addition, further prospective multicenter studies are needed to definitively identify the multivariate risk factors and improve the outcome of these complications.

Keywords:
arterial reconstruction, biliary complications, living donor liver transplantation

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Introduction

Although short-term graft outcomes after living donor liver transplantation (LDLT) have improved significantly after refining the graft selection process and progress in surgical approaches [1], biliary complications are still considered the Achilles' heel of LDLT, with recorded complication rates for right lobe LDLT as high as 20–34% [2]. Biliary anastomosis stricture (BAS) is still one of the major factors that significantly affect the long-term morbidity, leads to poor quality of life, or even lead to graft loss [3].

Anatomically, it seems more appropriate to use the recipient's right hepatic artery (RHA) over the left hepatic artery (LHA) for arterial reconstruction in right lobe LDLT [4]. The course of the recipient's RHA usually runs just behind the common hepatic duct (CHD) and gives small nourishing branches to the biliary tree. So, it is recommended not to dissect the surrounding tissue around the CHD between it and the RHA during biliary reconstruction if duct-to-duct anastomosis to be performed. This compromises the recipient's RHA flexibility, making arterial reconstruction difficult [5].

Conversely, dissecting this tissue between the CHD and the RHA to increase the later flexibility can cause ischemia of the recipient's extrahepatic bile duct and cause further biliary complication especially BAS [6].

Many trials to decrease BAS after LDLT have been reported worldwide, including high hilar or en-bloc dissection technique in recipients, ductoplasty, and application of microsurgery and mucosal eversion techniques in biliary reconstruction [7,8].

The aim of this study was to determine if the use of recipient LHA as inflow in arterial reconstruction lowers the risk of postoperative biliary complication.

Patients and methods

A prospective cohort study was conducted at the Liver Transplantation Unit in Air Forces Specialized Hospital, Cairo, Egypt, between July 2020 and the end of April 2022. During this study, all patients underwent LDLT with stentless duct-to-duct biliary reconstruction and were divided into two group: group A included 40 recipients who had LHA for arterial reconstruction, and group B (historical control) included 40 recipients who underwent LDLT using the RHA for arterial reconstruction.

Informed consent was obtained from every recipient and donor after approval from the ethical committees of the institute as well as the approval of the supreme committee of organ transplant, MOH, Egypt.

All patients underwent evaluation and preparation for the surgery according to the center protocol. Donor's arterial anatomy was assessed using noninvasive contrast-enhanced computed tomography angiography, and biliary anatomy was assessed using MRCP.

All patients above 18 years old eligible for right lobe LDLT with duct-to-duct biliary reconstruction fulfilling the criteria of transplant according to the center protocol and approved by the transplant multidisciplinary committee were included.

Right liver graft (RLG) with three or more bile ducts were excluded due to the increased incidence of biliary complications in this group of patients, which may lead to conflict during interpretation of the outcomes. Moreover, recipients with previous hepatico-jejunostomy, left lobe graft, dual graft, age below 18 years even with RLG, and mortality in the same hospital stay were excluded.

Regarding arterial reconstruction, RLG with two or more RHAs or nonreconstructed accessory artery, in addition to extra-anatomical reconstruct (EAR) as using the splenic or left gastric artery or using CHA, were excluded.

In addition, recipients in whom LHA could not be used for arterial reconstruction due to improper length, integrity and blood flow, marked caliber discrepancy, low flow (low RI) after reconstruction, and portal vein thrombosis (PVT) necessitating extensive pedicle dissection during thrombectomy were excluded as well.

The recipients' age, sex, blood type, hepatopathy, diagnosis of hepatocellular carcinoma, model for end-stage liver disease score, Child–Pugh score, BMI, and graft to recipient weight ratio (GRWR) were abstracted. Intraoperative variables included the following: warm ischemia time, cold ischemia time and operative time, intraoperative blood loss, number of bile ducts and method of reconstruction, and intraoperative duplex reading. Postoperative outcomes included the following: postoperative duplex reading, morbidity (hepatic artery thrombosis and recurrent PVT), and biliary leak or stricture. The electronic medical records of the study sample were used to collect the data of the control retrospective group B, and there were no missing data.

All interventions were done by a team of surgeons with experience in hepatobiliary and liver transplant surgery. All authors are surgeons, and all contributed to the study. The last two authors are staff surgeons with special dedication to hepatobiliary surgery and liver transplantation, and have more than 18 years of experience. At least one of them was always present at the interventions. Arterial reconstruction was done by the same surgeon through the whole study.

Arterial reconstruction was performed by the transplant surgeon using magnification loop size 6.0 with microvascular surgical techniques using interrupted 8-0 polypropylene sutures. The HA velocity measurement after reconstruction was confirmed using Doppler ultrasonography. The biliary reconstruction was performed via stentless duct-to-duct anastomosis with knots outside the lumen with interrupted 6-0 polydioxanone sutures.

In group A, hepatoduodenal ligament was dissected as high as possible in the liver hilum. The LHA was dissected free and ligated at the level of the second order branch. On implantation, the LHA of the recipient was used for the anastomosis to the graft artery. The bundle including the extrahepatic biliary tree and the RHA was left en-bloc by dissecting on the plane just on the adventitia of the portal vein without jeopardizing the peribiliary vascular network besides transection of the hilar plate as high as possible with sharp cutting after ligation of the RHA at the level of the second braches.

However, in group B, the RHA of the recipient was ligated at the level of the second order branches. On implantation, the RHA was dissected down for a centimeter from the extrahepatic biliary tree to serve as the inflow artery, which was anastomosed to graft artery.

During the cold phase, multiple middle hepatic vein tributaries needed to be reconstructed using a recipient native PV graft taken during the recipient hepatectomy phase or synthetic PTFE grafts. After the establishment of hepatic venous and portal reconstruction followed by reperfusion of the graft, arterial reconstruction was performed as mentioned above. The arterial flow was measured after the completion of both portal and arterial reconstruction and reperfusion.

In the recipient surgery, biliary reconstruction was performed after establishment of the portal and arterial flows. Ductoplasty might be performed if the graft had two bile ducts less than 2-mm apart to set close together as common orifice using interrupted 6-0 polypropylene suture. Donor bile ducts less than 1 mm in diameter were routinely suture-ligated in the donor operation. If a second biliary anastomosis was needed, right and left branches of the CBD of the recipient were used.

All patients received postoperative anticoagulation with low-molecular-weight heparin (enoxaparin sodium, 40 mg once daily) and antiplatelet (aspirin 100 mg once daily).

An anastomotic biliary stricture was suspected once the patient was symptomatic including itching, fever, and icterus or when serum alkaline phosphatase levels and GGT were elevated, confirmed with MRCP finding as intrahepatic duct dilatation of 3 mm or more in the presence of considerable extrahepatic biliary narrowing.

Postoperative bile leakage was diagnosed once bile was detected from the wound or the drain or drained intra-abdominal collection with total bilirubin level in the fluid more than three times that in the serum.

All patients were followed up for at least 6 months, once weekly for the first 3 months, then once monthly for the following 3 months, and then every 3 months afterward. Patients were asked every visit postoperatively for abdominal ultrasound and duplex together with routine laboratory data and immunosuppressive drug level. Follow-up contrast-enhanced computed tomography with angiography was used only if necessary to confirm the patency of constructed HA, and as a part of the complete workup 12 months after LDLT, or based on the patient's condition.

Statistical analysis

Recorded data were analyzed using the Statistical Package for the Social Sciences, version 23.0 (SPSS Inc., Chicago, Illinois, USA). The quantitative data were presented as mean±SD and ranges. Data were explored for normality using Kolmogorov–Smirnov and Shapiro–Wilk test.

The following tests were done:

(1) Independent-samples *t* test of significance was used when comparing between two means and Mann–Whitney *U* test for two-group comparisons in nonparametric data.
(2) The comparison between groups with qualitative data was done using χ^2 test.
(3) Kaplan–Meier survival analysis is a descriptive procedure for examining the distribution of time-to-event variables.
(4) Log rank test was used to compare time-to-event variables by levels of a factor variable.
(5) The confidence interval was set to 95%, and the margin of error accepted was set to 5%. So, the *P* value was considered significant as follows:
(6) *P* value
    (a) *P* value less than or equal to 0.05 was considered significant.
    (b) *P* value less than or equal to 0.001 was considered as highly significant.
    (c) *P* value more than 0.05 was considered insignificant.

Results

As our center started LDLT program in 2015, we had sufficient data to analyze the risks and benefits of right to LHA reconstruction regarding biliary complications. Therefore, we designed this study accordingly. Between July 2020 and end of April 2022, we had performed 125 cases of LDLT grafts. We excluded 85 recipients due to the following: 48 pediatric cases, 6 cases of hepatico-jejunostomy, 10 cases with EAR, three cases of left lobe graft, a single case of dual liver graft, and 17 cases where the RHA was used due improper length, integrity, or blood flow of the LHA. All patients finished at least 6 months of follow-up.

Regarding the historical group B, we had chosen the latest 40 recipients so as to minimize the effect of the learning curve and its bias that could affect the interpretation of the results. Although our study only represents a small proportion of the total number of patients, it is still sufficient to have a satisfactory statistical analysis.

We aimed in our study to determine if the use of recipient's LHA, as inflow in arterial reconstruction, lowers the risk of postoperative biliary complication. We applied our study on 80 patients who were divided into two equal groups: group A LHA reconstruction group and group B RHA reconstruction group, where the occurrence of biliary complications were compared between group A and a historical cohort of patients group B, while controlling for patient characteristics.

The two groups were comparable in age, with mean±SD in each of group A and group B being 52.88 ± 11.97 and 52.18 ± 10.90, respectively (Table 1), as there was no statistically significant difference between the groups, with *P* value of 0.785.

Table 1 also showed comparable sex description. In group A, 33 (82.5%) were male patients and seven (17.5%) were female patients, whereas in group B, 37 (92.5%) patients and three (7.5%) patients were male and female, respectively; there was no statistically significant difference between the groups regarding sex, with *P* value of 0.176. There was no statistically significant difference between groups according to weight (kg), BMI, blood group, model for end-stage liver disease, and Child class and score, with *P* value more than 0.05.

Most patients had Hepatitis C Virus (HCV) in group A (45%) and in group B (45%), followed by Hepatocellular carcinoma (HCC), which was 40% in group A compared with 30% in group B, and then cryptogenic, with 22.5% in group A compared with 30.0% in group B. There was no statistically significant

Table 1 Comparison between group A (left hepatic artery reconstruction group) and group B (right hepatic artery reconstruction group) according to baseline characteristics

Baseline characteristics	Group A – LHA reconstruction group (*N*=40)	Group B – RHA reconstruction group (*N*=40)	Test value	*P* value
Age (years)				
Mean±SD	52.88 ± 11.97	52.18 ± 10.90	*t*=0.075	0.785
Range	26-72	21-70		
Sex [*n* (%)]				
Female	7 (17.5)	3 (7.5)	χ^2=1.829	0.176
Male	33 (82.5)	37 (92.5)		
Weight (kg)				
Mean±SD	80.49 ± 14.72	85.74 ± 14.50	*t*=2.581	0.112
Range	50.5–132	60–124		
BMI [wt/(ht)^2]				
Mean±SD	27.76 ± 4.00	29.08 ± 4.83	*t*=1.768	0.188
Range	21–37.7	20–45		
MELD				
Mean±SD	16.45 ± 6.42	14.63 ± 4.80	*U*=1.076	0.154
Range	6–32	6–29		
Child class [*n* (%)]				
A	9 (22.5)	8 (20.0)	χ^2:0.099	0.952
B	19 (47.5)	19 (47.5)		
C	12 (30.0)	13 (32.5)		
Child score				
Mean±SD	8.35 ± 2.15	8.58 ± 2.07	*t*=0.226	0.636
Range	5–13	5–13		

LHA, left hepatic artery; MELD, model for end-stage liver disease; RHA, right hepatic artery. t, independent sample *t* test; *U*, Mann–Whitney test; χ^2, χ^2 test. *P* value more than 0.05 nonsignificant.

difference between groups, with *P* value more than 0.05 (Table 2).

In addition, there was an even distribution of cases that underwent transarterial ablation [Trans arterial chemo embolization (TACE) or Trans arterial radio embolization (TARE)] in the two groups. There was a higher incidence of PVT in group B than A (22.5 vs. 15%) but with no statistical significance (*P*=0.390) (Table 3).

Table 2 Comparison between group A (left hepatic artery reconstruction group) and group B (right hepatic artery reconstruction group) according to hepatopathy

Hepatopathy	Group A – LHA reconstruction group (*N*=40) [*n* (%)]	Group B – RHA reconstruction group(*N*=40) [*n* (%)]	χ^2	*P* value
HCV	18 (45.0)	18 (45.0)	–	NA
HCC	16 (40.0)	12 (30.0)	0.879	0.348
Cryptogenic	9 (22.5)	12 (30.0)	1.067	0.302
HBV	4 (10.0)	5 (12.5)	0.125	0.723
NASH	3 (7.5)	3 (7.5)	0.157	0.692
AIH	5 (12.5)	1 (2.5)	2.883	0.090
Budd-Chiari syndrome	1 (2.5)	0	1.013	0.314
Wilson disease	0	1 (2.5)	1.013	0.314
Hyper-oxaluria	0	1 (2.5)	1.013	0.314

AIH, autoimmune hepatitis; HCC, hepatocellular carcinoma; HBV, hepatic B virus; HCV, hepatitis C virus; LHA, left hepatic artery; MELD, model for end-stage liver disease; NASH, nonalcoholic steatohepatitis; RHA, right hepatic artery. χ^2, χ^2 test. *P* value more than 0.05 nonsignificant.

Table 4 shows that according to operation in group A, mean GRWR was 1.07±0.23; mean cold ischemia time (min) was 52.03±33.05; mean operative time (h) was 9.19±1.80; and mean blood loss was 1502.50±787.23. However, in group B, mean GRWR was 1.03±0.26; mean cold ischemia time (min) was 50.68±39.85; mean operative time (h) was 8.99±1.82; and mean blood loss was 1467.50±794.33. There was no statistically significant difference regarding the operative data (*P*>0.05). The mean arterial RI in group A was 0.63±0.08 compared with 0.61±0.08 in group B. There was no statistically significant difference between groups, with *P* value of 0.127.

On stratifying the technique of biliary reconstruction used in both groups regarding the number of graft ducts and the way they were anastomosed to the recipient biliary tree, we found no statistically significant difference (*P*>0.05) (Table 5). The incidence of biliary

Table 3 Comparison between group A (left hepatic artery reconstruction group) and group B (right hepatic artery reconstruction group) according to preoperative portal vein thrombosis and transarterial ablation for hepatocellular carcinoma

	Group A – LHA reconstruction group (*N*=40) [*n* (%)]	Group B – RHA reconstruction group (*N*=40) [*n* (%)]	χ^2	*P* value
Preoperative PVT	6 (15.0)	9 (22.5)	0.738	0.390
TACE	5 (12.5)	5 (12.5)	0.000	1.000
TARE	2 (5.0)	2 (5.0)	0.000	1.000

LHA, left hepatic artery; PVT, portal vein thrombosis; RHA, right hepatic artery; TACE, transarterial chemoembolization; TARE, transarterial radioembolization. χ^2, χ^2 test *P* value more than 0.05 nonsignificant.

Table 4 Comparison between group A (left hepatic artery reconstruction group) and group B (right hepatic artery reconstruction group) according to operative data

Operative data	Group A – LHA reconstruction group (*N*=40)	Group B – RHA reconstruction group (*N*=40)	Test value	*P* value
GRWR				
Mean±SD	1.07±0.23	1.03±0.26	*t*=0.315	0.576
Range	0.6–1.7	0.57–1.7		
Cold ischemia time				
Mean±SD (min)	52.03±33.05	50.68±39.85	*U*=0.027	0.869
Range	0–130	1–190		
Operative time				
Mean±SD (h)	9.19±1.80	8.99±1.82	*t*=0.262	0.610
Range	5–13	6.5–16		
Blood loss				
Mean±SD (ml)	1502.50±787.23	1467.50±794.33	*U*=0.039	0.844
Range	500–4000	300–4000		
Arterial RI				
Mean±SD	0.63±0.08	0.61±0.08	*t*=1.376	0.127
Range	0.5–0.85	0.5–0.8		

GRWR, graft to recipient weight ratio; LHA, left hepatic artery; RHA, right hepatic artery. *t*, independent sample *t* test; *U*, Mann–Whitney test; χ^2, χ^2 test. *P* value more than 0.05 nonsignificant.

Table 5 Comparison between group A (left hepatic artery reconstruction group) and group B (right hepatic artery reconstruction group) according to number of graft ducts and biliary reconstruction

	Group A – LHA reconstruction group (*N*=40) [*n* (%)]	Group B – RHA reconstruction group (*N*=40) [*n* (%)]	χ^2	*P* value
No. of graft duct				
1	18 (45.0)	16 (40.0)	0.051	0.821
2	22 (55.0)	24 (60.0)		
Biliary reconstruction				
1×1	18 (45.0)	16 (40.0)	0.202	0.653
2×1	9 (22.5)	9 (22.5)	0.000	1.000
With ductoplasty	2/9 (22.2)	1/9 (11.1)	0.377	0.539
Without	7/9 (77.8)	8/9 (88.9)		
2×2	13 (27.5)	15 (37.5)	0.900	0.343

LHA, left hepatic artery; RHA, right hepatic artery χ^2, χ^2 test *P* value more than 0.05 nonsignificant.

Table 6 Comparison between group A (left hepatic artery reconstruction group) and group B (right hepatic artery reconstruction group) according to biliary postoperative outcome

Biliary postoperative outcome	Group A – LHA reconstruction group (*N*=40) [*n* (%)]	Group B – RHA reconstruction group (*N*=40) [*n* (%)]	χ^2	*P* value
Leak	9 (22.5)	6 (15)	0.729	0.393
BAS	10 (25)	9 (22.5)	0.068	0.794
Combined leak and BAS	3 (7.5)	1 (2.5)	1.039	0.308

BAS, biliary anastomosis stricture LHA, left hepatic artery; RHA, right hepatic artery. χ^2, χ^2 test *P* value more than 0.05 nonsignificant.

Table 7 Comparison between group A (left hepatic artery reconstruction group) and group B (right hepatic artery reconstruction group) according to biliary leakage

Biliary leak	Group A – LHA reconstruction (*N*=9) [*n* (%)]	Group B – RHA reconstruction (*N*=6) [*n* (%)]	Total (*N*=15) [*n* (%)]	χ^2	*P* value
Number of graft duct					
1	2 (22.2)	0	2 (13.3)	1.434	0.231
2	7 (77.8)	6 (100)	13 (86.7)		
Biliary reconstruction					
1×1	2 (22.2)	0	2 (13.3)	1.434	0.231
2×1	4 (44.4)	3 (50)	7 (46.7)	0.042	0.837
With ducto-plasty	1/4 (25.0)	1/3 (33.3)	2 (28.6)	0.050	0.824
Without	3/4 (75.0)	2/3 (66.7)	5 (71.4)		
2×2	3 (33.3)	3 (50)	6 (40.0)	0.391	0.532

LHA, left hepatic artery; RHA, right hepatic artery. *t*, independent sample *t* test; *U*, Mann–Whitney test; χ^2, χ^2 test. *P* value more than 0.05 nonsignificant.

leakage (Table 6) was higher in group A (22.5%) verss group B (15%), as well as the number of patients who experienced both leakage and BAS was also higher in group A (7.5 vs. 2.5%), but both the results did not achieve statistical significance (*P*=0.393 and 0.308, respectively). BAS alone showed no statistically significant difference regarding incidence (*P*=0.794).

On analyzing the factor influencing biliary leakage other than arterial reconstruction, such as number of graft ducts and the impact of biliary reconstruction technique in the context of minimal dissection of the CBD, Table 7 shows that all of the patients who had biliary leakage in group B had two graft ducts, but the results did not reach statistically significant difference (*P*=0.231). The same factors was studied for the BAS (Table 8). There was no increase in incidence and the difference was not statistically significant for both number of graft ducts and reconstruction techniques (*P*>0.05).

Discussion

This is one of the few prospective studies to evaluate the outcomes of the LHA to RHA arterial reconstruction for recipient LDLT where arterial reconstruction is more complicated and challenging than in the deceased donor LT. The etiology for the high incidence of biliary complications in LDLT is not well known, but may be related to the size and number of graft bile ducts, as well as the vascular supply of both donor and recipient bile ducts [9].

Table 8 Comparison between group A (left hepatic artery reconstruction group) and group B (right hepatic artery reconstruction group) according to biliary anastomosis stricture

BAS	Group A – LHA reconstruction (*N*=10) [*n* (%)]	Group B – RHA reconstruction (*N*=9) [*n* (%)]	Total (*N*=19) [*n* (%)]	χ^2	*P* value
Number of graft duct					
1	5 (50.0)	4 (44.4)	9 (47.4)	0.056	0.812
2	5 (50.0)	5 (55.6)	10 (52.6)		
Biliary reconstruction					
1×1	5 (50.0)	4 (44.4)	9 (47.4)	0.056	0.812
2×1	1 (10.0)	1 (11.1)	2 (10.5)	0.006	0.940
With ductoplasty	0/	0/1	0/2	0.000	1.000
Without	1/1 (100.0)	1/1 (100.0)	2/2 (100.0)		
2×2	4 (40.0)	4 (44.4)	8 (42.1)	0.036	0.850

BAS, biliary anastomosis stricture; LHA, left hepatic artery; RHA, right hepatic artery. *t*, independent sample *t* test; *U*, Mann–Whitney test; χ^2, χ^2 test. *P* value more than 0.05 nonsignificant.

As there is no deceased donor liver transplant program in Egypt and as we only practice LDLT, our center is highly concerned with the biliary outcome because it negatively affects the quality of life and long-term graft survival. We had previously studied the outcome of internal biliary stenting, and in this study; we studied the effect of using the LHA on arterial reconstruction on the biliary outcome.

The high hilar dissection technique during the recipient hepatectomy, previously described in LDLT series from Asia [10], was first reported by Lee *et al.* [11], who began to resect hilar structures en-bloc including all the components at the hilar intrahepatic level using scissors while clamping the hepatoduodenal ligament. This technique preserves the RHA and the common bile duct in continuity during the dissection, protecting the biliary vascular supply.

According to the design of our study, the primary intension during arterial reconstruction was to use LHA. We had 17 recipients in whom the decision was changed intraoperatively to RHA reconstruction. Unfortunately, the cause of conversion was not clarified in all cases. So, we chose to exclude them, trying to reduce the factors that may interfere with our results.

The same was done if EAR of the HA was needed. Uchiyama *et al.* [6] had the same concept during their study, as they reported the use of EAR was related to lower biliary stricture-free survival, while fortunately graft survival is not affected. However, Rhu *et al.* [12] found that EAR increased the incidence of bile leakage but it did not increase the risk of biliary stricture, graft failure, or overall survival in multivariable analyses.

It is well known that the longer cold ischemia time and the higher preservative fluid viscosity, the higher incidence of BAS due to the postreperfusion endothelial damage and the residual microclots in vascular beds, both resulting in impaired perfusion after reperfusion. In a study done by Park *et al.* [13], cold ischemic times were more than 71 min had a significant effect on the occurrence of BAS, whereas Chok *et al.* [14] reported that the mean cold ischemic times in the grafts with BAS was 120 min.

In an analysis done by Abu-Gazala *et al.* [2], high hilar dissection increased both hepatectomy time and anhepatic phase, increasing the risk of cold-ischemia time-related complications. This is in contrast to Lee *et al.* [11], who considered the 23 min mean increase in operative time is not significant to have clinically importance, and they recorded no apparent increase in biliary complications.

The cold ischemic time in our study was comparable in the two groups and much lower than that mentioned in the studies above (52.03 ± 33.05 and 50.68 ± 39.85 in groups A and B, respectively). This was first due to synchronization between the recipient and donor operation, not to harvest the graft until the recipient is ready for implantation. Second, the native PV graft used in reconstruction of V5 and V8 was prepared, lengthened, and taken in situ during the recipient operation, and the ductoplasty if needed was done just before biliary reconstruction. Therefore, the only work done on the back table was reconstruction for the accessory veins.

Ikegami *et al.* [15] reported that ductoplasty is a major cause of BAS because of the tension applied and scarring. The role of biliary anastomotic leakage on causing BAS due to the fibrogenic process around the biliary anastomosis was discussed frequently in the literature, and they related the improvement in biliary outcome to the minimal hilar dissection technique, which was useful in preventing biliary anastomotic leakage and consequently reduced the rate of BAS. In our study, we could not find a relation between ductoplasty and biliary complications. This is because the ductoplasty itself is not an appealing option in our practice (only three cases in the whole study).

During the previous study done by Ikegami *et al.* [15], univariate analysis did not find minimal hilar dissection as a risk factor for BAS but revealed that HA flow less than 50 ml/min and ductoplasty were the significant risk factors, and multivariate analysis confirmed that HA flow less than 50 ml/min was the only significant risk factor. This explained the 10% cumulative incidence of BAS in their study. In contrast, when applying the univariate analysis for the incidence of biliary anastomotic leakage, the only significant factor was the use of minimal hilar dissection, but unfortunately, multivariate regression analysis was not done.

In another multivariate analyses of risk factors done by Uchiyama *et al.* [6], RHA used as an inflow artery is an independent risk factor for BAS, and it leads to a higher incidence of septic complications. They also recorded occasional rereconstruction of the HA because of kinking at the anastomotic site, which appears after duct-to-duct biliary anastomosis. According to their study, this was due to the use of the anterior or posterior branches of RHA in arterial reconstruction to overcome the size discrepancy caused by the increase in the hepatic arterial flow in relation to decreased portal venous flow secondary to liver cirrhosis, which makes inflow arteries more redundant. We did not face such complications in our study because we always used the main RHA or LHA, and this enabled us to tailor the length of the artery, preventing redundancy and kink. The relation between the number of bile ducts and biliary anastomosis and the occurrence of biliary complications is controversial. Some studies have previously shown that the presence of more than one biliary anastomosis or multiple donor ducts is associated with increased risk for biliary complications [16].

In a recent study also done by Ikegami *et al.* [1] in which they evaluated eversion technique for biliary reconstruction in combination with minimal hilar dissection. significant increase in the efficacy of recipient surgery and decline in the incidence of BAS from 3 2.1 to 14.6% was recorded [13]. The same was concluded by Soejima *et al.* [10] regarding BAS when they applied high hilar dissection.

Moreover, Abu-Gazala *et al.* [2] concluded that en-bloc hilar dissection was associated with lower rates of biliary complications, particularly BAS. It worth mentioning that this outcome concluded by Abu-Gazala was influenced by the inferior results of using the cystic duct as an option for biliary reconstruction in his control group, and if these group of patients were excluded, the outcome was statistically insignificant in spite of higher rate of biliary complications in the conventional hilar dissection group even after.

During our study, we used to selectively ligate the second-order branches of the RHA as high as possible besides rimming the recipient's bile duct to the level where satisfying blood supply is noticed, and we did not consider the use of cystic duct for biliary reconstruction as an option. This may be the reason why the outcome between the two groups was not significant. On univariate analysis of the risk factors, only two duct-to-duct anastomosis without ductopasty showed an increased tendency for biliary leakage in both groups and can be considered a risk factor for both biliary leakage and BAS (86.7 and 52.6%, respectively), but statistical significance was not reached.

Limitations

Our study had several limitations. This is a single center study; therefore, the results may not be generalizable to other transplant centers. This is a retrospective study in a part where we had to compare the results to a historical group of patients. Another limitation is the small sample size that limited the power of the study and hinder the statistical capacity to do multivariate analysis.

Finally, we did not obtain or use information regarding HA blood flow, which is a major risk factor of biliary strictures in LT. Instead, we used Doppler ultrasonography intraoperatively immediately following vascular reconstruction and follow-up bedside Doppler ultrasonography daily on the first week. Unfortunately, patency by Doppler ultrasonography does not correlate accurately with proper blood flow, which may lead to BAS in the long term.

Conclusion

The use of either RHA or LHA in arterial reconstruction in right lobe LDLTs does not reduce the incidence of duct-to-duct biliary complications, which is a multifactorial risk that needs to be approached systematically to reduce all risk factors such as number of graft ducts, ductoplasty, cold ischemia, and as well as arterial reconstruction. In addition, further prospective multicenter studies are needed to definitively identify the multivariate risk factors and improve the outcome of these complications.

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Conflicts of interest

No conflict of interest.

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