ORIGINAL ARTICLE

Vasculobiliary Complications Following Adult Right Lobe Split Liver Transplantation From the Perspective of Reconstruction Techniques

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Split liver transplantation (SLT) compensates for the organ shortage and provides an alternative solution for recipients disadvantaged by a smaller body size. Variations in the hepatic arterial anatomy and reconstructive techniques may lead to more technical complications, and we sought to analyze the incidence and risk factors of vasculobiliary complications with respect to reconstructive techniques. We identified 171 adult right lobe SLT procedures and 1412 whole liver transplantation (WLT) procedures between January 2000 and June 2012 and compared the results of these 2 groups. In the SLT group, arterial reconstruction techniques were classified into 4 subgroups (I-IV), and biliary reconstruction was classified into 2 groups [duct-to-duct (DD) anastomosis and Roux-en-Y hepaticojejunostomy (RH)]. Specific surgical complications were analyzed against reconstruction techniques. The overall incidence of vascular and biliary complications in the SLT group was greater than that in the WLT group ($P = 0.009$ and $P = 0.001$, respectively). There was no difference in hepatic artery thrombosis (HAT), but we saw a tendency toward early HAT in the presence of multiple hepatic arteries supplying the right lobe graft (group IV; 20%) in comparison with the other arterial reconstruction groups ($P = 0.052$). No difference was noticed in the overall incidence of biliary complications in either DD or RH recipients across 4 arterial reconstruction groups. When the arterial reconstruction involved a right hepatic artery (groups II and III) combined with a DD biliary anastomosis, there was a significant preponderance of biliary complications ($P = 0.04$ and $P = 0.01$, respectively). There was no survival difference between SLT and WLT grafts. In conclusion, the complications of SLT are directly related to arterial and biliary reconstruction techniques, and this classification helps to identify high-risk reconstructive techniques. ***Liver Transpl 21:63-71, 2015***. © **2014 AASLD.**

Received April 28, 2014; accepted September 29, 2014.

Split liver transplantation (SLT) is one of the major technical advancements in liver transplantation (LT). The success and technical innovation of SLT emanated from the feasibility, popularity, and better understanding of hepatic vascular and segmental anatomy with living donor LT. SLT is considered a technical counterpart in the cadaveric setting to living donor LT, and both of these options compensate for the donor organ shortage. Despite these innovations, the gap between patients added to the transplant waiting list and available donor organs for transplantation is widening.

Abbreviations: CHA, common hepatic artery; DD, duct-to-duct; HAT, hepatic artery thrombosis; LHA, left hepatic artery; LLS, left lateral segment; LT, liver transplantation; RH, Roux-en-Y hepaticojejunostomy; RHA, right hepatic artery; SLT, split liver transplantation; WLT, whole liver transplantation.

Potential conflict of interest: Nothing to report.

These data were presented at the 19th Annual International Congress of the International Liver Transplant Society; Sydney, Australia; June 2013.

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DOI 10.1002/lt.24015
View this article online at wileyonlinelibrary.com.
LIVER TRANSPLANTATION.DOI 10.1002/lt. *Published on behalf of the American Association for the Study of Liver Diseases*

By the mid-1990s, SLT was widely used in many centers, and it expands the donor pool by providing 2 unequally sized grafts: the left lateral lobe is an excellent choice for pediatric patients, who are disadvantaged by the lack of size-matched donors, and the extended right lobe graft (containing remaining hepatic segments I and IV-VIII) provides sufficient liver mass for an average-size adult recipient.[1] SLT is commonly performed as an ex-situ procedure, and in-situ splitting technique has been recently introduced. SLT requires the safe allocation and division of vasculobiliary structures to both grafts, and this is challenged by the presence of an abnormal vasculobiliary anatomy. Theoretically, it might be argued that split procedure potentially compromises the arterial supply and biliary microvasculature and leads to vasculobiliary complications.[2] Depending on the graft anatomy and implantation technique, several options for arterial and biliary reconstruction are possible for implantation.

Registry data from the United Network for Organ Sharing and other large series examining SLT confirm that SLT is safe and has comparable long-term outcomes.[3,4] However, increased vascular and biliary complications have been reported with SLT versus whole liver grafts. Some other smaller series have reported inferior outcomes with SLT,[5] but cautious interpretation of these data is necessary because the case load and expertise may have a bearing on these outcomes. Invariably, the outcomes of SLT are dependent on the technical success and adaptations of both the splitting and transplantation procedures.[6] The lack of systematic analysis of outcomes from a technical reconstruction point of view is an issue. It is important to recognize whether a particular reconstruction technique is more risky and could potentially jeopardize a right lobe graft in comparison with other techniques. This would probably necessitate exploring avenues for safe alternatives and other measures to minimize the graft loss. With this background, we report our experience with ex situ adult right lobe SLT and the incidence of posttransplant vascular and biliary complications from the perspective of vascular and biliary reconstructive techniques.

PATIENTS AND METHODS

All adult LT procedures performed at the Liver Unit of Queen Elizabeth Hospital (Birmingham, United Kingdom) between January 2000 and June 2012 were reviewed. SLT recipients were identified from a prospectively maintained database, and data were collated on technical aspects related to the split procedure and arterial and biliary reconstruction, donor and graft characteristics, and intraoperative details, including the cold ischemia time, transfusion requirements, and duration of surgery. These were compared with data for recipients who received a whole liver graft [whole liver transplantation (WLT)]. Recipient and donor demographics, recipient outcomes, patient and graft survival, and postoperative vasculobiliary complications were also reviewed. This study was approved by the institutional clinical audit department.

Split Procedure

Criteria for liver splitting in this unit included a donor age $<$ 40 years, weight $>$ 50 kg, liver function test results $<$ 2 to 3 times normal results or trend toward improving results, an intensive care stay $<$ 5 days, absence of sepsis, and use of low-dose vasopressors. Grafts without macroscopic steatosis and with favorable anatomy were considered for splitting. Detailed descriptions of the splitting technique have been provided previously.[7-10] The whole procedure was performed ex-vivo in a cold ice bath except for occasional cases in which the split procedure was performed in-situ. Bench cholangiography was used routinely to ascertain the biliary anatomy. Generally, the extended right lobe graft contained Couinaud segments I and IV to VIII; a variation of this rule was followed when an increased liver mass was required for the left side graft. The diameter of the main hepatic arterial branches (left and right) supplying the grafts were assessed during the split procedure, and the common hepatic artery (CHA)/celiac axis was allocated to the graft bearing the smaller hepatic arterial inflow. Contraindications for splitting included unusual vascular anomalies such as multiple accessory hepatic arteries. The arterial and portal anatomy was delineated by dissection of the hilum, and cholangiograms were reviewed before a commitment to the split procedure was made.

Transplant Procedure

The recipients for SLT were chosen according to the body weight and severity of liver disease of recipients on the transplant wait list and also on the basis of the technical complexity. Generally, patients with a body weight greater than 80 to 90 kg and very sick patients, including those with acute liver failure or late regrafts, were avoided with rare exceptions. The adult transplant procedure was standard and used the modified piggyback technique. The type of arterial reconstruction depended on the graft arterial anatomy as well as the arterial inflow/quality of the recipient native arteries. Several arterial reconstruction techniques were possible and depended on these factors, and these were categorized into 4 different types (Fig. 1). In brief, they included the donor CHA to the recipient CHA or aortic conduit (group I), the donor right hepatic artery (RHA) to the recipient CHA or aortic conduit (group II), the donor RHA with an interposition graft to the recipient CHA/aortic conduit (group III), and the presence of an accessory RHA (group IV). Replaced RHAs that were encountered were classified as described previously. In this classification, group I simulates the conventional reconstruction in WLT, whereas the primary difference between groups II and III is the interposition of an added vascular graft between the recipient inflow source and the graft arterial inflow, with the added vascular anastomosis present in group III.

Biliary Reconstruction

Biliary reconstruction was accomplished by duct-to-duct (DD) anastomosis or Roux-en-Y hepaticojejunostomy (RH).

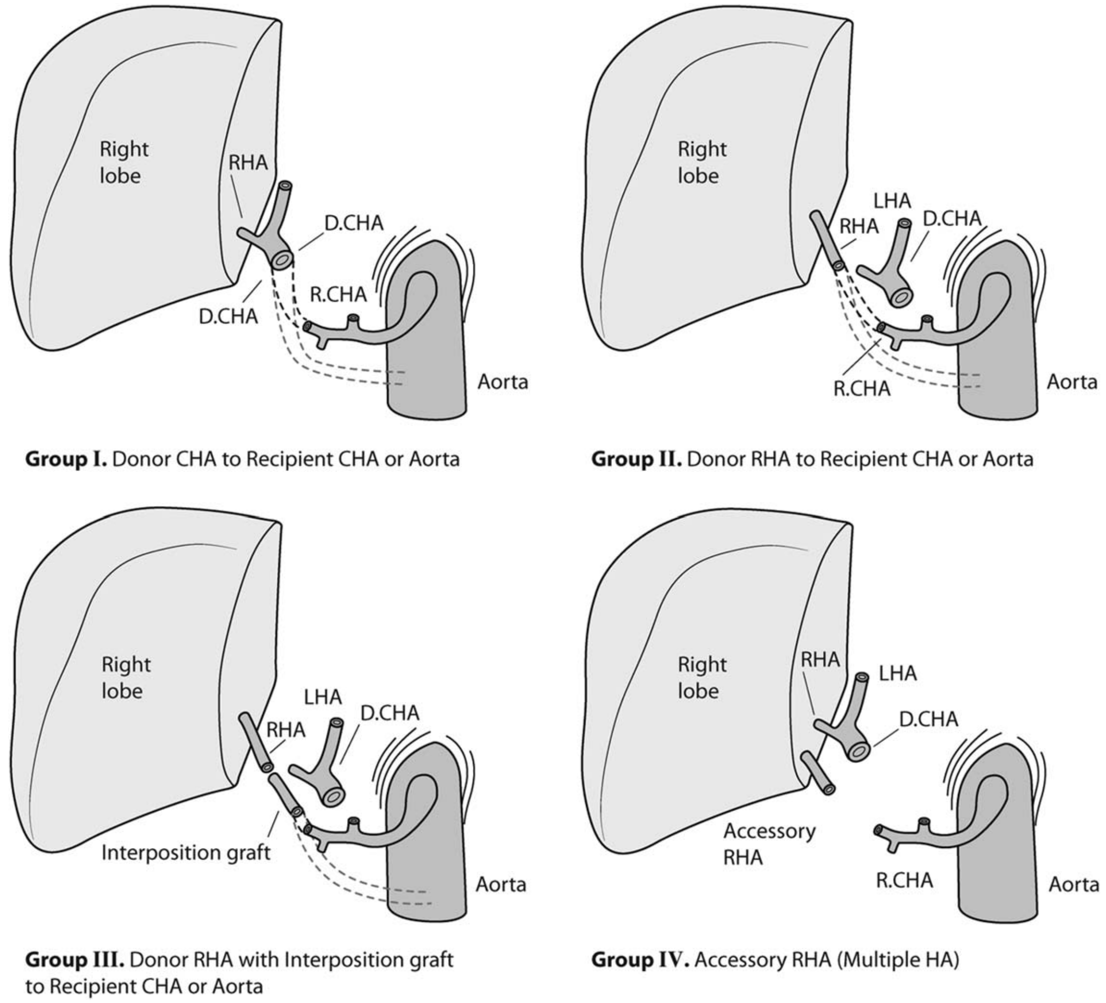

Figure 1. Different arterial reconstructive techniques in SLT with proposed classification. D indicates donor, and R indicates recipient; CHA - common hepatic artery, LHA - left hepatic artery, RHA - right hepatic artery.

Generally, a T-tube was used for free drainage in DD cases, and it was clamped after a T-tube cholangiogram demonstrating a sound anastomosis. A T-tube was also used as a safety valve in patients developing bile leaks. At the end of 3 months, this was removed after a further cholangiogram.

Vascular and Biliary Complications

A Doppler ultrasound examination to evaluate vascular patency was performed whenever the diagnosis of a vascular or biliary complication was suspected. In cases without any Doppler arterial flow, the hepatic artery patency was confirmed by computed tomographic angiography. Hepatic artery thrombosis (HAT) was defined as early HAT when it occurred within the first 21 days after transplantation. This definition was based on the recommendation of the Liver Advisory Group of the United Kingdom, permitting these patients to be relisted for superurgent retransplantation.

A biliary complication was defined as a bile leak or biliary stricture that required an intervention (surgical, radiological, or endoscopic).[11] Bile leaks were categorized by the site of the leak as nonanastomotic (liver cut surface) or anastomotic. A nonanastomotic stricture was defined as a diffuse intrahepatic stricture after LT in the presence of a patent hepatic artery.[12] The diagnostic or interventional procedures included percutaneous drainage, percutaneous transhepatic cholangiography, endoscopic retrograde cholangiopancreatography, and T-tube cholangiography.

Statistical Analysis

IBM SPSS Statistics 21.0 was used. Univariate analysis was performed for categorical variables, and Pearson's chi-square test or Fisher's exact test was used to identify independent predisposing factors for vascular or biliary complications. Continuous variables were analyzed with the 2-tailed unpaired *t*-test or Mann-Whitney U test. Survival curves were estimated with the Kaplan-Meier method and were compared with log-rank tests. $P < 0.05$ was considered significant.

TABLE 1. Donor, Recipient, and Operative Characteristics of SLT and WLT Groups

	Split (n = 171) (%)	Whole (n = 1412) (%)	Significance
Recipient			
Age in years (mean ± SD)	50 ± 13	51 ± 12	0.43
Age > 65 years [n (%)]	24 (14)	147 (10)	0.15
Sex: male [n (%)]	77 (45)	734 (52)	0.09
Presence of cirrhosis [n (%)]	168 (98)	1372 (97)	0.61
Model for End-Stage Liver Disease (mean ± SD)	13 ± 3.5	13 ± 4.1	0.62
Body mass index in kg/m^2 (man ± SD)	25 ± 0.4	27 ± 0.2	**0.001**
Comorbidities [n (%)]			
Diabetes mellitus	37 (22)	275 (19)	0.54
Cardiac disease	9 (5)	54 (4)	0.32
Smoking status	54 (32)	479 (34)	0.35
Cytomegalovirus status	104 (61)	841 (60)	0.81
Previous upper abdominal operations [n (%)]	16 (9)	145 (10)	0.79
Previous LT [n (%)]	8 (5)	118 (8)	0.10
Wait time on list: months [median (range)]	2.2 (0-18)	1.4 (0-19)	0.001
Simultaneous liver and kidney transplantation [n (%)]	2 (1)	20 (1)	0.86
Median follow-up in months [median (range)]	44.3 (0.2-160)	53.4 (0-161)	0.95
Donor			
Age in years (mean ± SD)	29 ± 10	46 ± 14	**0.001**
Age > 60 years [n (%)]	1 (1)*	281 (20)	**0.001**
Sex: male [n (%)]	110 (64)	748 (53)	0.52
Body mass index in kg/m^2 (mean ± SD)	25 ± 3	26 ± 4.7	0.23
Cytomegalovirus status [n (%)]	69 (40)	691 (49)	0.35
Donation after circulatory death (whole graft)	—	139 (10)	NA
Operative characteristics			
Superurgent transplant [n (%)]	5 (3)	123 (9)	**0.009**
Warm ischemia time in minutes (mean ± SD)	40 ± 9.7	42 ± 13	0.84
Cold ischemia time in minutes (mean ± SD)	578 ± 8	545 ± 10.5	0.07
Intraoperative blood transfusion in units (mean ± SD)			
Red blood cells	4 ± 1.2	5 ± 3.6	0.08
Fresh frozen plasma	8 ± 4	11 ± 2.3	**0.001**
Total blood products	20 ± 4.5	26.5 ± 6.6	**0.001**
Operative time: hours (mean ± SD)	5.4 ± 1.5	5.5 ± 1.4	0.14

NOTE: Values significant at $P < 0.05$ are bolded (Pearson's chi-square test, 2-tailed unpaired *t* test, and Mann-Whitney U test).
*The decision to split this graft was made in a critical situation in which both LLS and right split grafts from a previous donor developed primary nonfunction.

TABLE 2. Vascular and Biliary Reconstruction Techniques Used in SLT

Reconstruction Techniques	n (%)
Vascular reconstruction	
Group I: donor CHA to recipient CHA or aorta (conduit)	83 (49)
Group II: donor RHA to recipient CHA or aorta (conduit)	38 (22)
Group III: donor RHA with interposition graft	40 (23)
Group IV: accessory RHA (=multiple hepatic arteries)	10 (6)
Biliary reconstruction	
Direct end to end	97 (57)
Direct end to end over T-tube	75 (77)
Direct end to end without T-tube	22 (23)
RH	74 (43)

RESULTS

Donor, Recipient, and Operative Characteristics

In all, 1583 adult LT procedures were performed during the study period; among these, 171 (11%) were cadaveric adult right lobe SLT. The indications for transplantation in the study were equally distributed ($P = 0.38$) between SLT and WLT; the main indications were primary biliary cirrhosis (22%), primary sclerosing cholangitis (15%), and alcoholic cirrhosis (15%) in the SLT group and alcoholic cirrhosis (19%), hepatitis C cirrhosis (16%), and primary biliary cirrhosis (13%) in the WLT group. Retransplantation represented 5% and 8% of all indications in the SLT and WLT groups, respectively. The median follow-up was 52 months for the entire cohort. The donor and recipient characteristics and the operative details for these 2 groups are summarized in Table 1. The splitting procedure was ex vivo in 167 of 171 cases (98%). The right lobe

TABLE 3. Post-transplant Vasculobiliary Complications: Comparison Between SLT and WLT Groups

Vasculobiliary Complications	Split (n = 171)	Whole (n = 1412)	Significance
Overall vascular complications [n (%)]	32 (19)	161 (11)	**0.009**
HAT	18 (10)	101 (7)	0.12
Early HAT	7 (4)	28 (2)	0.09
Late HAT	11 (6)	73 (5)	0.47
Hepatic artery stenosis	1 (0.5)	20 (1)	0.71
Hepatic artery pseudoaneurysm	1 (0.5)	6 (0.5)	0.55
Portal vein thrombosis	4 (2)	12 (1)	0.08
Portal vein stenosis	2 (1)	10 (1)	0.37
Venous outflow obstruction	5 (3)	14 (1)	**0.02**
Overall biliary complications [n (%)]	43 (25)	188 (13)	**0.001**
Strictures			
Anastomotic	5 (3)	96 (7)	**0.047**
Nonanastomotic	4 (2)	38 (3)	0.81
Bile leak			
Anastomotic	4 (2)	54 (4)	0.40
Cut surface (split)	30 (18)		NA

NOTE: Values significant at $P < 0.05$ are bolded (Pearson's chi-square test).

grafts consisted of segments I and IV to VIII in 131 recipients (77%), segments IV to VIII in 29 recipients (17%), and segments I and V to VIII in 6 recipients (3%). Recipients of SLT had a smaller body weight (mean body mass index: 25 versus 27 kg/m^2; $P = 0.001$).

Fewer right lobe grafts were used in super-urgent transplants ($P = 0.001$). The SLT group also received fewer total blood products ($P = 0.001$) and less fresh frozen plasma ($P = 0.001$) than the WLT group, and this may reflect the selection of less complicated recipients for SLT. The cold ischemia time, warm ischemia time, and mean operative time were not significantly different between the SLT and WLT groups (Table 1).

Vascular and Biliary Reconstruction Options

The most common form of arterial reconstruction belonged to the proposed group I classification (the donor CHA directly anastomosed to the recipient CHA or aorta through a conduit) in 83 recipients (49%). In an equal proportion of cases, the donor RHA was used as the arterial inflow to the graft by direct anastomosis to the recipient CHA or aorta through a conduit (group II) in 38 (22%) recipients and with an interposition graft (group III) in 40 recipients (23%). Multiple hepatic arteries supplied the right lobe graft (group IV) in 10 recipients (Table 2). The proportions of aortic conduit usage in each group were similar. Overall, a variant hepatic arterial anatomy was encountered in 16 of 171 grafts (9%). A replaced RHA from the superior mesenteric artery was noticed in 6 cases placed in group II because in technical terms only 1 artery supplied the right lobe graft. In the remaining 10 cases, an accessory RHA originated from the superior mesenteric artery in addition to the RHA proper, and these patients constituted the multiple RHA group (group IV).

Biliary reconstruction was accomplished by DD anastomoses in 97 patients (57%) and by RH in 74 patients (43%). Most DD anastomoses were performed over a T-tube (Table 2). Biliary reconstruction by DD anastomosis and RH was equally distributed among the 4 arterial reconstructive technique groups.

Overall Vasculobiliary Complications among SLT and WLT Groups

Vascular Complications

The SLT group had more overall vascular complications than the WLT group (19% versus 11%, respectively; $P = 0.009$). The overall incidence of HAT was not significantly different between the 2 groups (10% versus 7%, respectively; $P = 0.12$). The incidence of early HAT was 4% and 2%, respectively ($P = 0.09$). The median time to the occurrence of HAT was 34 days (4-2460 days) and 81 days (1-3923 days), respectively ($P = 0.67$). Other vascular complications were also encountered equally between the SLT and WLT groups (Table 3) apart from venous outlet obstructions, which were significantly more frequent in the SLT group versus the WLT group (3% versus 1%, respectively; $P = 0.02$). The diagnosis of a venous outlet obstruction was made through hepatic venography and was confirmed by hepatic biopsy. Causes of venous outflow obstructions were inferior vena cava thrombosis (n = 2), hepatic vein thrombosis (n = 1), and piggyback syndrome (n = 2).

Biliary Complications

Forty-three (25%) of one hundred seventy-one SLT recipients had biliary complications, whereas only

TABLE 4. Post-transplant HAT in the SLT Group From the Perspective of the Arterial Reconstruction Technique

Arterial Reconstructive Technique (Total in Each Group)	Aortic Conduits in Each Group [n/N (%)]	HAT [n (%)]		
		Overall	Early HAT	Late HAT
I (n = 83)	4/83 (5)	7 (8)	3 (4)	4 (5)
II (n = 38)	2/38 (5)	5 (13)	2 (5)	3 (8)
III (n = 40)	2/40 (5)	3 (7)	0	3 (7)
IV (n = 10)	1/10 (10)	3 (30)	2 (20)	1 (10)
Significance (*P*) by Fisher's exact test	0.74	0.19	0.05	0.68

TABLE 5. Post-transplant Biliary Complications in the SLT Group From the Perspective of Vascular Reconstructive Techniques

Arterial Reconstructive Technique (Total in Each Group)	Biliary Reconstruction Technique [n (%)]		Biliary Complications [n (%)]			
			Overall Complications	According to Biliary Reconstruction		
	DD	RH		DD	RH	Significance
I (n = 83)	51 (61)	32 (39)	20 (24)	12 (23)	8 (25)	1
II (n = 38)	22 (58)	16 (42)	12 (32)	10 (45)	2 (12)	**0.04**
III (n = 40)	17 (42)	23 (57)	8 (20)	7 (41)	1 (4)	**0.01**
IV (n = 10)	7 (70)	3 (30)	3 (30)	2 (29)	1 (33)	1
Significance			0.63	0.23	0.13	

NOTE: Values significant at $P < 0.05$ are bolded (Fisher's exact test).

188 (13%) of the 1412 WLT recipients did ($P = 0.001$), and most of these were explained by cut-surface bile leaks (Table 3). The incidence of biliary complications was not different for donation after circulatory death and donation after brain death grafts within the WLT group (17% versus 16%, respectively; $P = 0.37$). Significantly fewer anastomotic strictures were reported in the SLT group versus the WLT group (3% versus 7%, respectively; $P = 0.047$); both the SLT group and the WLT group had equal incidences of nonanastomotic strictures (2% versus 3%, respectively; $P = 0.81$). With respect to the anastomotic leaks, no difference was detected between the SLT and WLT groups (2% versus 4%, respectively; $P = 0.40$; Table 3).

Vasculobiliary Complications in SLT From the Perspective of Arterial Reconstructive Techniques

Vascular Complications in SLT

The group IV arterial reconstructive technique had the highest incidence (30%) of overall HAT in comparison with the other groups, but this was not statistically significant ($P = 0.19$) (Table 4). The incidence of early HAT in this group was also comparably greater and nearly reaching statistical significance ($P = 0.05$). There was no significant difference in late HAT across the different arterial reconstruction techniques. The median time to the diagnosis of early HAT was 12 days (4-19 days), whereas this was 180 days (27-2461 days) for late HAT. The incidence of HAT in the replaced RHA was 3 of 6 (50%), with 2 early HAT cases and 1 late HAT case diagnosed.

Biliary Complications in SLT

The distribution of different biliary reconstruction techniques was equal across the 4 arterial reconstruction groups (Table 5). The overall incidence of biliary complications among these 4 arterial reconstruction groups was not statistically different ($P = 0.63$). Furthermore, there was no difference in the incidence of overall biliary complications within the DD ($P = 0.23$) and RH groups ($P = 0.13$). However, recipients who had DD anastomoses along with a type II or III arterial reconstruction (the donor RHA was used) had a higher incidence of biliary complications than those with RH biliary reconstruction with a similar arterial reconstruction [45% versus 12% ($P = 0.04$) and 41% versus 4% ($P = 0.01$), respectively; Table 5].

HAT was preceded by a bile leak in 6 recipients (early HAT, n = 2; late HAT, n = 4; $P = 0.13$), and leaks were diagnosed as anastomotic in 2 cases and

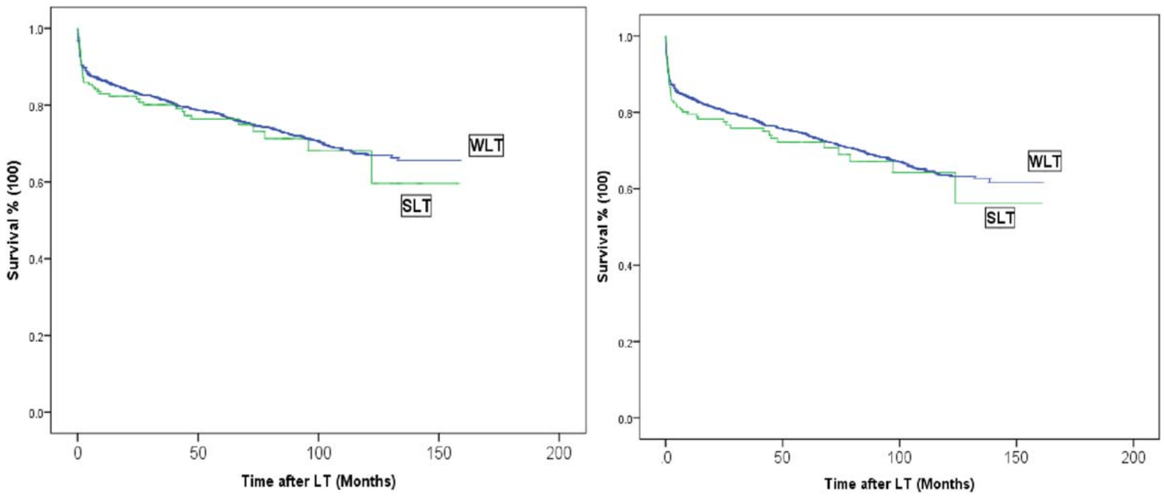

Figure 2. Graft survival (left) and overall survival (right) for the SLT and WLT groups.

nonanastomotic in 4 cases. The 2 early HAT cases were associated with anastomotic bile leaks. The vascular reconstruction techniques used for these 6 patients were group I (n = 3), group II (n = 2), and group III (n = 1).

DD recipients

The incidence of overall bile leaks was equally distributed ($P = 0.85$), with no significant difference in the incidence of anastomotic ($P = 0.99$) or cut-surface biliary leaks ($P = 0.82$) among the 4 arterial reconstructive technique groups. Group II had a higher incidence of overall biliary strictures (23%), and it was followed by group III (12%; $P = 0.02$). Five anastomotic strictures were diagnosed in group II, with no strictures detected in any of the remaining groups ($P = .001$). Three nonanastomotic strictures, 2 in group III (both ischemic-type biliary lesions, which may be related to profound ischemia in this group) and 1 in group I, were diagnosed ($P = 0.20$).

RH recipients

No difference was noted with respect to overall bile leaks ($P = 0.183$) or strictures ($P = 0.99$) among the 4 different arterial reconstruction groups. Only 1 patient was diagnosed with a stricture among the RH recipients, and this was a nonanastomotic stricture in group I.

Outcomes of Left Lateral Segment (LLS) Counterparts

In all, 144 counterpart LLSs (144/171 or 84%) were used in the pediatric LT program affiliated with our center; the overall vascular complication rates were 12% in this LLS group (18/144) and 19% in the right adult lobe graft group. The overall biliary complication rates were 13% (19/144) and 25%, respectively. The HAT incidence was less with LLS grafts at 5%, and this may be related to the policy of allocating the main hepatic artery preferentially to the LLS graft. The incidence of biliary anastomotic strictures was higher with LLS grafts at 5% versus 3% with right adult lobe grafts. There was no difference in nonanastomotic strictures (2% for both).

Survival Rates

There was no difference between graft or patient survival between the SLT and WLT groups. The 1-, 3-, and 5-year overall patient survival rates were 83%, 80%, and 76% for SLT patients and 86%, 81%, and 77% for WLT patients (0.58). Graft survival was 79% versus 83%, 76% versus 78%, and 72% versus 74% at 1, 3, and 5 years for SLT and WLT patients, respectively ($P = 0.45$; Fig. 2).

DISCUSSION

Despite many recent reports in the literature outlining the equal outcomes of graft and patient survival after SLT versus WLT,[13] technical aspects of vascular and biliary reconstruction techniques have not been analyzed in detail. This is the first such report to analyze different arterial and biliary reconstruction techniques in a systematic way against the technical outcomes. Early HAT and biliary strictures can be attributed to technical complications, and the splitting procedure may be directly or indirectly implicated. The findings of this study are, therefore, unique and may be used as benchmark guidance for different reconstruction strategies in liver splitting situations. Our findings indicate that multiple hepatic arteries supplying a right lobe graft probably carry a higher risk of early graft loss from HAT, although any form of arterial reconstruction using the RHA of the graft (groups II and III) combined with a direct biliary anastomosis may result in an increased incidence of biliary complications. An understanding of this might allow transplant surgeons to explore different options and prevent the aforementioned undesired complications that may culminate in graft loss.

Poor early results for both pediatric and adult LT with split grafts were attributed mainly to unfamiliarity with the procedure.[14,15] Results have improved since then with adequate hepatobiliary training, understanding of the vasculobiliary anatomy and its variations, and experience in liver resection, living donation, and vascular reconstruction techniques.[4,16] Despite this, split grafts are associated with a higher incidence of vascular complications, and rates of HAT as high as 17% have been reported.[17-19] Although these results may be caused by many factors, the technical details reported here may help to reduce such drastic results.

The 4 arterial reconstruction techniques incorporate documented risk factors for HAT in the literature along with the nature of the arterial remnant supplying the split right lobe graft. Naturally, the RHA is smaller in caliber than the CHA, so any reconstruction using an RHA graft may be considered a technical risk. The addition of an interposition graft further increases the risk by increasing the number of vascular reconstructions. Multiple blood vessels supplying the graft may be a risk of their own, and an increased number of reconstructions may also be needed for this group. Given these factors, we believe that any arterial reconstruction involving a right lobe graft and the recipient arterial inflow should fall into one of these categories, so the classification has the potential of reproducibility in future studies reporting outcomes.

One important finding in this study was the higher incidence of biliary strictures in the DD group when the arterial inflow to the graft included the RHA. Ischemia of the bile duct is an important factor contributing to the development of many biliary complications after LT,[20,21] including damage to the arterial blood supply for the bile ducts during the donor hepatectomy.[20] For some grafts, the RHA might not predominantly supply the common bile duct; this leaves open the possibility of duct ischemia caused by the split procedure being responsible for ischemic-type strictures.[20,22] RH biliary reconstruction may be protective, possibly through the acquisition of a blood supply to the bile duct through the Roux loop.

Not surprisingly, DD biliary reconstruction is preferred by many surgeons. In addition to the physiologic bilioenteric continuity, it provides easy access by endoscopy. Our results suggest that technical preferences may be modified if we take into account the arterial reconstructive technique. Studies of histological examinations of disrupted DD reconstruction have demonstrated a loss of 3:00 and 9:00 o'clock intramural arteries on the recipient side.[23] The increased risk of anastomotic strictures in group II and III vascular reconstructions probably denotes the devascularization of the microvascular arcade supplying the bile duct. Thus, in addition to proper selection of the arterial anastomotic method, preservation of periductal microcirculation in the recipient duct and careful hepatic artery reconstruction might be key factors for a successful DD anastomosis.

In conclusion, SLT demands a high level of technical expertise and experience. Through this analysis, we have postulated a classification of vascular reconstruction techniques that are predictive of arterial and biliary complications. These findings may be used for the future management of such grafts and in decision making for preventive strategies. The overall outcomes of SLT, however, are comparable to those of WLT, and attention to detail may further improve outcomes.

ACKNOWLEDGMENTS

The statistical expertise for this article was provided by James Hodson, medical statistician at the University of Birmingham, and we acknowledge his input.

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