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LDALTs, 18 cases were split-type RHD (Nakamura II, III, and IV type). Among these 18 cases, 13 patients underwent the conventional surgical technique and bile duct reconstruction during our early study period (Jun 2006 to May 2008) whereas ve patients underwent our innovative procedure of donor bile duct dissection and reconstruction between June 2008 and December 2012. e later ve patients had been chosen for emergent LDALT because of the progressive deterioration of the situation and the unavailability of an alternative live donor in an emergency. e main parameters related to the severity of the ve patients are shown in Table 1.

D ' ' s t ' a v a uat '

e procedures involved in donor selection and evaluation conformed to the guidelines of the Regulation of Human Organ Transplantation of China and was approved by our Hospital Ethics Committee. All donors were adults aged 19-55 years with knowledge of civil rights. e evaluation was only carried out a er the donor expressed a willingness to donate and learned about the advantages and risks of the operation, especially the need for donor biliary reconstruction. Written informed consent was obtained from all donors before surgery.

No.	Gender	Age	Pathogenesis	Serum creatinine (εmol/L)	Total bilirubin (εmol/L)	GTT		

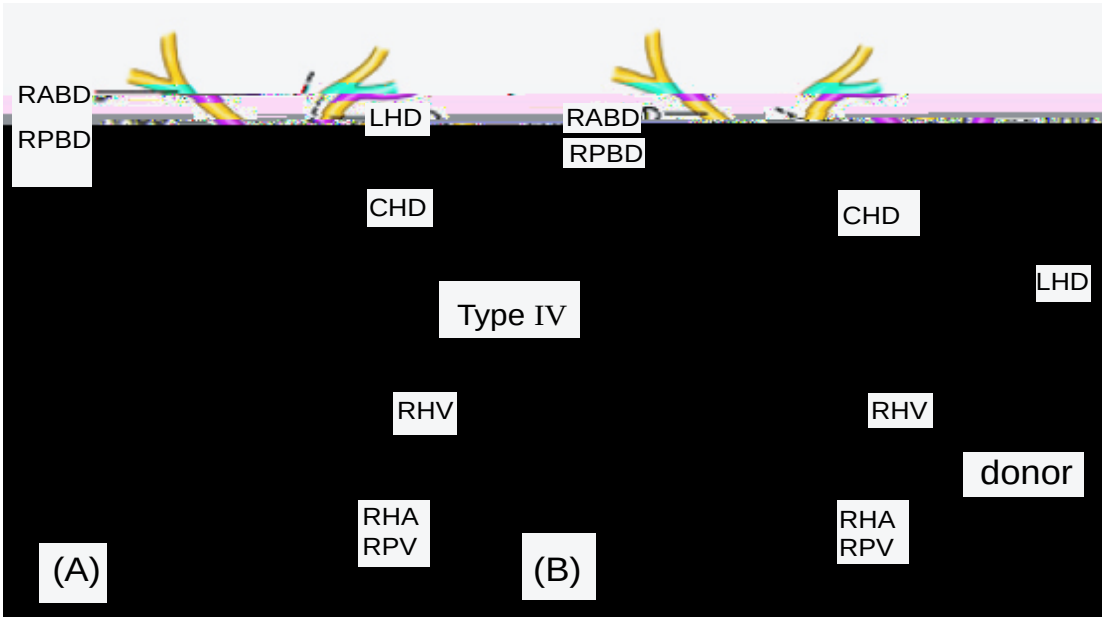

Figure 2: Two surgical division for Nakamura type IV bile duct variant. (A) There are two biliary oriýces on the graft and they are far away from each other leading to the difýculty with reconstruction. (B) Reconstruction using a short common trunk of CHD is shown. Donor LHD and CHD underwent end-to-end anastomosis; the right anterior and right posterior bile ducts of the graft openings in the common trunk of CHD, the CHD and the recipient CHD underwent duct-to-duct anastomosis (if the recipient bile duct is large enough, it may be more reasonable to open the left side wall of the common trunk longitudinally for anastomosis).

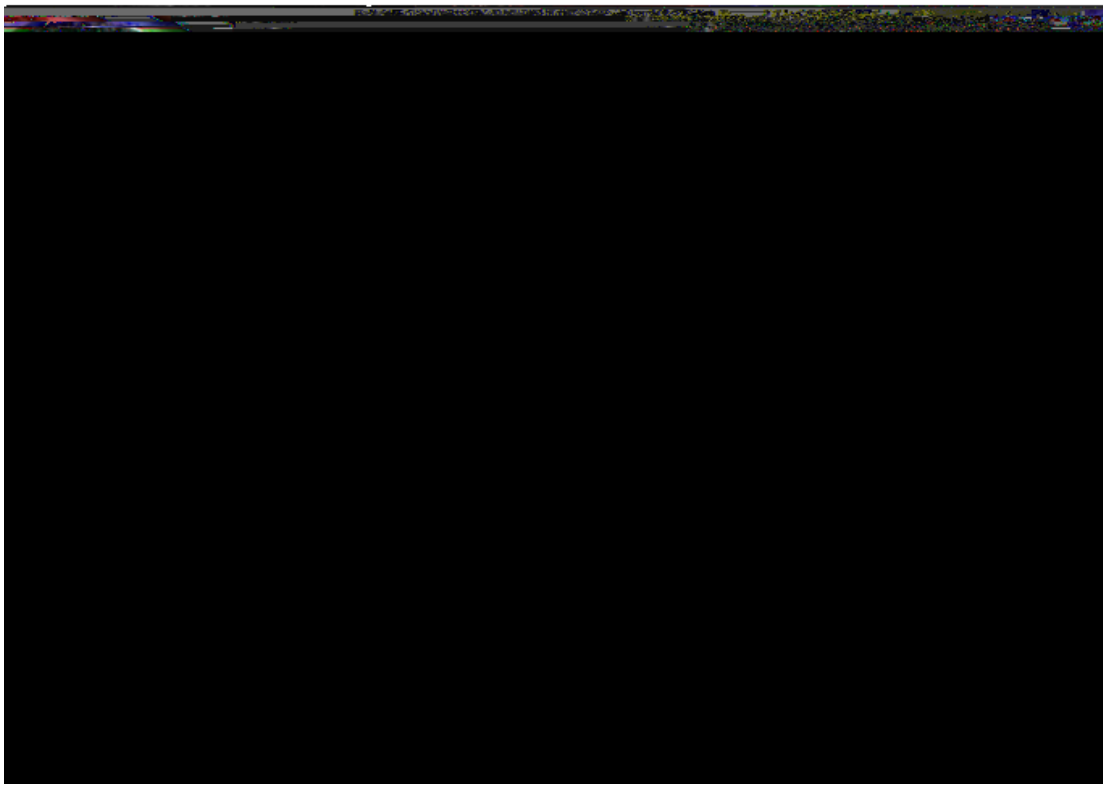

Figure 4: Division of donor variant bile duct and reconstruction of recipient /donor bile ducts. (A) The right posterior bile duct opening in the LHD was found in the preoperative MR imaging. (B) The LHD (yellow arrow) and the CHD (green arrow) after division of donor bile ducts. (C) Fine end-to-end anastomosis of donor bile duct using 6/0 PDS-II and Prolene sutures with interrupted suture, without support drainage. (D) Two top and bottom oriýces (green arrows) are shown i.e., the common trunk of the CHD of procured donor liver when it was rinsed. (E) Recim s right and left bile duct oriýces need to be modiýed. (F,G) End-to-end anastomosis of recim and graft CHD. (H) Completion of the posterior wall anastomosis with the diameter of the bile duct about 0.8 cm. (I) MRCP results of a donor are shown at 49 months postoperatively. The LHD is patent, without dilation of intrahepatic bile duct.

R s ts

B t a at typ , b t fi s a b a p at s

As shown in Table 3, of the 75 cases of right lobe LDALTs, 18 cases were of split-type of RHD (Nakamura II, III, IV types). Among 13 early stage cases, 10 showed two or more ori ces of the right bile duct, three showed trigeminal-type of right anterior, right posterior and LHD and one ori ce was formed by resecting the right side wall of the converging part of the bile duct. In these 13 recipients, the incidence of biliary complications was 53.8% (7/13). Among ve later stage cases, four cases were of right posterior bile duct (one or two branches) con uence into LHD (Nakamura IV type) and one case was of "trigeminal-type". Using our innovative method for the reconstruction of the recipient bile duct, no postoperative biliary abnormality was detected in donors or recipients by MRCP a er 47-53 months of follow-up (Figures 4 and 5), and the di erence between the two methods was found to be signi cant ($P<0.05$). Also, no biliary complications of donors were observed in the two groups.

C a s s a p ts t sts

In donors, transaminase recovered rapidly and returned to normal a er 10 days. Bilirubin reached peak levels in three to four days and γ-glutamyltransferase returned to normal in about one month. As shown in Table S1, there was no signi cant di erence found between early stage donors in whom the conventional method was used and later stage donors in whom the innovative method was applied.

With regard to recipients, in the novel method group, bilirubin returned to normal within one week, and transaminase and γ-glutamyltransferase returned to normal in one month a er the liver transplant surgery. On the other hand, in the conventional method group, bilirubin and transaminase levels were found to be higher than those of controls due to the higher incidence of biliary complications (Table S2).

D s ss

LDALT, as compared with cadaver liver transplantation, has the main advantages of a shorter ischemia time, a higher gra quality and relatively fewer liver transplantation complications. However, the biliary complications are still very common. For example, the incidences of biliary leakage and stricture are 4.7-18.2% and 8.3-31.7%, respectively [9]. ere is 55.8-73.6% variation rate in the right bile duct [10,11]. Also, the distance between the resection line of the donor RHD and the convergence is only several micrometers, and the probability of having multiple ori ces on the right liver can be as high as 39.1-60.4% [12-14]. Moreover, the variant secondary grade bile ducts are tenuous and small. Undoubtedly, these variations increase the di culty in ductoplasty and reconstruction and are also the high risk factors for biliary complications [2,3]. In addition, in the case of right anterior, right posterior and le hepatic ducts converging into a "trigeminal type" duct in donors, the transection plane deviate to the LHD to obtain a single biliary ori ce can sometimes signi cantly increase the incidence of biliary leakage and stricture in donors [4].

Current surgical approaches for multiple bile duct ori ces are as follows: (i) When two or multiple branches are in close proximity, they can be formed into one single ori ce and then reconstructed [4,8,10], but a er ductoplasty, the incidence of postoperative biliary leakage can be as high as 50% [2]. (ii) When two or multiple branches are far away from each ori ce, the gra ori ces can be anastomosed to the recipient's LHD and RHD, or anastomosed to the recipient's CHD and cystic duct [4,15,16]. As the diameters of multiple bile ducts are far smaller than those of a single ori ce, and also because of the artery communicating arcade of the hilar bile duct is damaged in varying degrees during surgical procedures, the blood supply of the bile duct will probably be a ected [17,18]. erefore, the incidences of bile duct necrosis and biliary leakage are high when following the anastomotic procedure of two biliary openings to the recipient's LHD and RHD separately. e cystic duct has a spiral valve and a small diameter and is usually not suitable for reconstruction. (iii) If it is di cult to perform multiple bile ducts duct-to-duct anastomosis, then one bile duct end-to-end anastomosis and a cholangiojejunostomy are performed; alternatively, two or more cholangiojejunostomies are performed in multiple bile ducts patients [12,13]. However, cholangiojejunostomy involves certain disadvantages. First, the loss of Oddi's sphincter leads to the loss of prevention function of intestinal uid re ux which may lead to ascending cholangitis. Second, cholangiojejunostomy involves intestine operations and, therefore, it

sutures without support drainage. e gra CHD and recipient CHD was duct-to-duct anastomosed for recipient biliary reconstruction. Of note, this approach ensures a single, larger caliber of the duct-to-duct anastomosis and less likelihood of stenosis. Importantly, liver function recovered stably and the bile duct patency was con rmed by MRCP or ultrasound during 47-53 months of follow-up.

One of the major concerns about the use of this new approach is the reconstruction of donor bile duct and some critical queries need to be addressed. First, can the defect between LHD and CHD (1.6-2.2 cm; Table 2) be anastomosed and reconstructed? Second, will the incidence of postoperative bile leakage and duct stricture increase? In our practice, we nd that transecting a certain length of converging portion of bile duct poses no tension in the bile duct anastomosis. is is due to increased mobility of the hepatoduodenal ligament a er resection of the right hemiliver. Moreover, without the traction from the RHD, the angle between the LHD and CHD is larger leading to the direct anastomosis and reconstruction without the need to free and loosen bile duct. Importantly, however, it is prohibited to isolate liver in the le hepatic hilum and CHD to protect the blood supply of the LHD during the right lobectomy. e reconstruction of bile duct requires an accurate anastomosis technique in which 6/0 PDS-II is used in the posterior wall, 6/0 Prolene suture is used in the anterior wall duct-to-duct interrupted sutures and keeping prompt margins and su cient distance between needles avoids bile leakage and biliary ischemia due to too tight sutures. No biliary drainage tube is required in this procedure.

Another major concern about the use of this new approach is that if the increased donor risk will be worthwhile to have this change. We summarized as follows: (i) All our patients belong to critical illness, the median MELD scores was 34.38 (Table 1), three of ve patients were in a delirious situation, the mortality rate will be very high if an e ective treatment was not performed. (ii) e multiple biliary ori ces on the right gra increase the di culty in ductoplasty and reconstruction and are also the high risk factors for biliary complications. e higher biliary complication rates are a marker for a lower posttransplant life quality, health-care spending, gra failure, and an increased risk of death. (iii) All donors were the closest relatives of recipients, such as husband-wife, parents-daughter or son, etc. If there is a ash of hope, they all used full e orts to strive for the last choice of the patients' survival. Moreover, all the donors positively expressed a willingness to donate and learned about the advantages and risks of the operation, especially the need for donor biliary reconstruction. (iv) e approach provides an e ective alternative option for treatment of this critical illness during LDLT when an alternative donor is unavailable. However, it is noteworthy that the reconstruction of donor bile duct needs highly specialized surgical skills and an extensive experience with bile duct anastomosis, otherwise, the occurrence of postoperative biliary complications may still be a problem to deal with. erefore, this method can only be carried out at a hepatobiliary surgery center where surgeons have extensive biliary surgery experience and the access to advanced surgical facilities, which guarantee the risk of donor, is controllable.

C ' us ' s

Our initial experience suggest that, in the urgent condition of LDALT when an alternative live donor is unavailable, a surgical innovation by cutting part of CHD trunks including variant RHD in complicated donor bile duct variant may facilitate in biliary reconstruction and reduce long-term biliary complications. However, although the advantages of recipient biliary reconstruction observed