Surgical experience in splitting donor liver into left lateral and right extended lobes

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AIM: To outline the surgical experience with donor liver splitting in split liver transplantation.

METHODS: From March 1 to September 1 in 2004, 10 donor livers were split ex situ into a left lateral lobe (segments II and III) and a right extended lobe (segments I, IV–VIII) in Medical School of Hannover, and thereafter split liver transplantation was performed successfully in 19 cases. The average age, weight and ICU staying period of the donors were 32.7 years (15–51 years), 64.5 kg (45–75 kg) and 2.4 d (1–8 d) respectively.

RESULTS: The average weight of the whole graft and the left lateral lobe was 1 322.6 g (956–1 665 g) and 281.8 g (45–75 kg) respectively. The average graft to recipient weight ratio (GRWR) of the bile duct variation in one case.

MATERIALS AND METHODS

INTRODUCTION

Orthotopic liver transplantation (OLT) has been widely accepted as an effective treatment for end-stage liver diseases. The advent of new immunosuppressive agents and refinement of the surgical techniques have accounted for remarkable progress in the years since the first OLT was performed in 1963. Thousands of patients who would have died otherwise have been saved by the improved results of organ transplantation. However, the past two decades have also witnessed an exceptional increase in the number of patients awaiting liver transplantation, and the ever-growing great disparity between demand and supply of donor organs has become the major limiting factor for further expansion of liver transplantation. Hence, a death rate on the waiting of 10–15% would even be underestimated. Historically, the situation has been worse for children because of the difficulty of finding size-matched donor organs. However, the development of a reduced-size liver transplant technique has provided a first step to alleviate this problem. Although such technique does not increase the number of grafts available, it shifts available organs from adult to pediatric recipient. Obviously, split liver transplantation, first successfully performed in the Medical School of Hannover, is becoming an efficient approach to expand the donor pool for both adults and children.

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Key words: Split; Donor liver; Anatomic variation
Ten pediatric patients, three boys and seven girls, received left lateral lobe liver transplantation. The average age and weight of the pediatric recipients were 48.1 mo (5-82 mo) and 14.3 kg (6.9-23.8 kg) respectively. Indications included seven cases of congenital biliary atresia (one child receiving liver re-transplantation due to chronic rejection after the first transplant), two cases of progressive familial intrahepatic cholestasis and one case of acute liver failure. Nine adult or adolescent patients, five males and four females, received right extended lobe liver transplantation. The average age and weight of the adult recipients were 30.7 years (10-49 years) and 64.1 kg (39.9-88.5 kg) respectively. Indications included four cases of postnecrotic cirrhosis, two cases of primary sclerosing cholangitis, one case of Wilson’s disease, one case of autosomal recessive polycystic kidney deficiency and one case of acute liver necrosis caused by ligation of the hepatic artery due to rupture of the hepatic arterial aneurysm. Two patients were emergency cases, one due to postnecrotic cirrhosis and the other due to acute liver necrosis (Tables 1 and 2).

The key to successful liver division is to share vascular and biliary structures between the two sides but without handicapping either, and preferably to provide either graft with single first order arterial and biliary elements. Normally, the inferior vena cava, the common bile duct, and the main trunk of the portal vein as well as the hepatic artery are preserved for the right extended graft. We emphasize on performing dissection of the hepatic hilum only from the left side and always keeping the right side untouched, the steps of ex situ splitting the donor liver into a left lateral lobe and a right extended lobe were described briefly as follows: (1) completing the conventional bench hepatic graft preparation and resecting the gallbladder, briefly checking the portal vein, the hepatic artery, the bile duct, and the hepatic vein; (2) exposing the left hepatic artery and identifying the segment IV artery, and then transecting the left hepatic artery distally to the origin of segment IV artery; (3) isolating and transecting the left portal vein, and ligating the branches supplying segment IV originating from left portal vein; (4) splitting the liver parenchyma step by step along with umbilical scissure from downward to upward, and the various tiny vessels and bile ducts handled with ligation or metal clips; (5) exposing the left hepatic vein when dividing close to suprahepatic inferior vena cava, and then transecting the left hepatic vein leaving a suitable stump; (6) finally transecting the bile duct connecting the two parts of donor liver; and (7) injecting cold preservation solution via portal vein, hepatic artery as well as bile duct to check for leaks. None of these 10 cases of donor livers was applied cholangiography or angiography in the process of splitting.

**RESULTS**

All the 10 donor livers were split successfully into a left lateral lobe (segments II and III) and a right extended lobe (segments I, IV-VIII), and subsequently split liver transplantation was performed in 19 cases. The average weight of the whole graft before splitting was 1 322.6 g (956-1 665 g), and the average weight of the left lateral lobe and the right extended lobe after splitting was 281.8 g (198-373 g) and 1 075.8 g (726-1 299 g) respectively. The average ratio of left lateral lobe to total graft was 0.215

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**Table 1 Basic data of donors**

| Age/Sex | Height (cm)/weight (kg) | ICU (d) | AST (IU/L) | Crea (mg/dL) | Na (mmol/L) | BIL (mg/dL) | Whole graft weight (g) |
|---------|------------------------|---------|------------|--------------|-------------|------------|-----------------------|
| 1       | 15/M                   | 168/70  | 1          | 22           | 1.20        | 152        | 1.60                  | 1 290                  |
| 2       | 35/M                   | 185/50  | 3          | 14           | 1.10        | 152        | 0.63                  | 1 580                  |
| 3       | 46/F                   | 176/70  | 2          | 16           | 0.80        | 153        | 0.09                  | 1 296                  |
| 4       | 43/F                   | 175/70  | 2          | 122          | 1.25        | 158        | 0.48                  | 1 435                  |
| 5       | 37/F                   | 170/75  | 8          | 77           | 1.22        | 137        | 0.28                  | 1 665                  |
| 6       | 51/F                   | 160/45  | 2          | 28           | 0.40        | 156        | 0.70                  | 1 000                  |
| 7       | 40/F                   | 170/65  | 2          | 23           | 0.59        | 138        | 0.10                  | 1 299                  |
| 8       | 15/F                   | 175/65  | 1          | 94           | 1.01        | 153        | 1.56                  | 1 225                  |
| 9       | 27/F                   | 175/75  | 2          | 30           | 0.70        | 155        | 0.88                  | 956                    |
| 10      | 18/F                   | 165/60  | 1          | 105          | 0.80        | 144        | 0.71                  | 1 570                  |

**Table 2 Basic data of recipients receiving left lateral lobe and right extended lobe liver transplantation**

| Age (m) / sex | Weight (kg) | Graft weight (g) | GRWR (%) | Age (yr) / sex | Weight (kg) | Graft weight (g) | GRWR (%) |
|---------------|-------------|-----------------|----------|---------------|-------------|-----------------|----------|
| Patients receiving left lateral lobe | | | | Patients receiving right extended lobe | | | |
| 1             | 74/F        | 18.6            | 242      | 1.30          | 46/M        | 80.0            | 1 048    | 1.31                  |
| 2             | 50/F        | 15.0            | 281      | 1.87          | 42/F        | 88.5            | 1 299    | 1.47                  |
| 3             | 72/F        | 15.7            | 318      | 2.03          | 49/M        | 70.5            | 978      | 1.39                  |
| 4             | 78/F        | 21.9            | 275      | 1.26          | 17/M        | 60.5            | 1 160    | 1.92                  |
| 5             | 5/M         | 6.9             | 373      | 5.41          | 49/F        | 63.0            | 1 292    | 2.05                  |
| 6             | 20/F        | 10.0            | 274      | 2.74          | -           | -               | -        | -                     |
| 7             | 11/F        | 7.1             | 268      | 3.72          | 14/F        | 64.6            | 941      | 1.46                  |
| 8             | 8/M         | 7.8             | 270      | 3.46          | 26/M        | 55.0            | 955      | 1.73                  |
| 9             | 82/M        | 16.2            | 198      | 1.22          | 10/M        | 39.9            | 758      | 1.90                  |
| 10            | 81/F        | 23.8            | 319      | 1.34          | 25/F        | 54.5            | 1 251    | 2.30                  |

The right extended lobe from case 6 was sent to the other center.
The average GRWR of the left lateral lobe and the right extended lobe reached 2.44% (1.22-5.41%) and 1.73% (1.31-2.30%) respectively. The average weight ratio of donor to pediatric recipient was 5.47 (2.52-10.87). The average time required to split the donor liver was 105 min (85-135 min).

A total number of five anatomic variations occurred in the process of graft splitting. The left hepatic vein variation occurred in two cases, where the segment II hepatic vein, the segment III hepatic vein and the middle hepatic vein draining separately into inferior vena cava appeared to be a trifurcation at the junction. In order to obtain a sufficiently long left hepatic vein, some part of the lateral wall of the middle hepatic vein and suprahepatic inferior vena cava was sacrificed, the defect was repaired with part of donor common iliac vein (Figures 1 and 2). Two donor organs had anatomical variations of the left hepatic artery. In one case with the segment IV artery arising very distal from the left hepatic artery, only 3 mm of the common trunk of segments II and III arteries could be obtained after painstakingly dissecting the liver parenchyma of the left lateral lobe. There was one case where the replaced left hepatic artery originated from the left gastric artery (Figure 3). Although partial blood supply of the segment II liver from the segment IV artery could be identified, the diameter of this branch was less than 2 mm with quite good backflow under perfusion, consequently no reconstruction was required. Finally there was the anatomical bile duct variation. In this case the union of segments II and III bile ducts was right to the umbilical fissure resulting in two separate openings of bile duct on the cutting surface of left lateral lobe. Fortunately in this case the distance between the two bile duct openings was quite close and in the shape of a figure ‘8’, therefore, one opening could be achieved by plastic reconstruction (Figure 4).

**DISCUSSION**

Pichlmayr et al.[6], reported the first clinical attempt of split liver transplantation in 1988, and 1 year later Bismuth et al.[7], described two patients with fulminant hepatic failure, each receiving a split graft. In 1990, Broelsch et al.[8], presented the first series of 30 split liver transplantations in 21 children and 5 adults. In this early experience, patient survival was inferior to that reported in series of cadaveric whole-size orthotopic liver transplants. Despite skepticism as to the lasting role of split liver transplantation, several European centers, faced with an increasing waiting list of death rate due to the scarcity of donor organs, pursued the split liver options. In 1995, the results of a collective experience of 50 donor livers, providing 100 grafts during a 5-year period form the European Split Liver Registry[9] demonstrated no significant difference when compared to conventional whole-sized OLT during the same period.

With the present improved surgical techniques, it is commonly acceptable to split the donor liver into two transplantable grafts, one for a pediatric and the other for an adult recipient. A series comprising 110 consecutive split liver transplantations in 55 adults and 55 pediatric recipients showed that patient survival of split liver transplantation...
was not significantly different from whole-organ OLT[10]. Similar results are also reported by Broering et al.[11]. Such view is strongly evidenced by more and more current clinical data[12-19]. Our experience with more than 150 cases of split liver transplantation since 1988 has confirmed these results. Between 1993 and 1999, split liver transplantation activities increased in central Europe from 1.2% to 10.4%[10]. Currently, split liver transplantations make up more than 20% of all liver transplantations performed at the Medical School of Hannover. With the refinement of surgical skill, split liver transplantation could even be applied in the cases of retransplantation and emergency.

What kind of donor liver is suitable for splitting calls for thorough consideration and evaluation whenever an organ donor is available. Besides meeting the basic prerequisites regarding the donor livers, the following factors are worth to be considered based on our experience and opinions from other authors[10,11,17]: (1) a donor age below 50 years and above 10 years; (2) hemodynamic stability, if in use of vasopressor, maintaining good blood pressure at least; (3) the preferable donor ICU stay less than 5 d; and (4) no status of hypernatremia, a serum sodium concentration of <170 mmol/L or even better <150 mmol/L. Although donor parameters are critical when selecting livers for a splitting procedure, the experience accumulated over the years clearly indicates that the most reliable basis for the decision on splitting is the judgment of an experienced transplant surgeon. Microscopic examination should become a kind of supplement to macroscopic observation. It is pivotal to scrutinize whether the donor liver has a soft consistency, a sharp edge and is well perfused. One has to appreciate the frank remark of Busuttil on criteria for splittable donor livers[16]: “I think that the ultimate exclusion criterion is when you go and look at the liver, if the liver does not look good, you do not split it.”

With the current technique, it is quite reliable to split a donor liver into a left lateral lobe (segments II and III) and a right extended lobe (segments I, IV-VIII) for one child recipient and one adult recipient. Our results confirmed that the right extended liver lobe would account for about 80% of the standard volume in humans, and can be allocated that the right extended liver lobe would account for about 80% of the standard volume in humans, and can be allocated that the right extended liver lobe would account for about 80% of the standard volume in humans. Currently, split liver transplantations are handled in the process of splitting. Considering that the left liver lobe is more constant regarding anatomical variations, it can be said that the more one stays on the left, the fewer anatomical variants one is confronted with.

In most of cases, the left hepatic vein joins the middle hepatic vein, thus forming the common trunk entering the antero-left surface of the inferior vena cava[20]. Instead of joining the segment II hepatic vein to form the left hepatic vein, the segment III hepatic vein seldom joins the middle hepatic vein individually with the probability for about 5-10%. The diameter of the extrahepatic portion of the left hepatic vein is around 10 mm, and the smaller diameter less than 7 mm is sufficient to suspect such circumstance. In the present study, left hepatic vein variation occurred in two cases, the segments II and III draining of hepatic veins appeared with the middle hepatic vein as a trifurcation. Under certain circumstances, the dividing line needs to be moved slightly to the right slightly in order to guarantee one venous drainage from the graft of left lateral lobe. The defect of middle hepatic vein and inferior vena cava could be repaired by the common iliac vein from the donor.

Intrahepatic portal venous variations can be seen in approximately 20% of the population[21]. However, unless the rare absence of a portal vein bifurcation with only 0.9% possibility, will it become the contradiction of graft splitting. In the majority of cases the portal vein inflow to segment IV is accomplished by the left umbilical section of the left portal vein. However, those branches originating from umbilical section will inevitably be transected. Fortunately, in most cases the additional portal vein branches to segment IV arising from the portal vein bifurcation and the right portal vein could be expected. By preserving these veins and moving the transection line to the left, partial portal vein supply to segment IV can be achieved.

Variations of the hepatic artery are comparatively frequent[22]. Only 50-70% of livers present with “normal” anatomy[23,24]. If the left main hepatic artery originates from the left gastric artery (10-15%) both the length and the diameter of this artery would be adequate for the Anastomosis in the recipient. Such a situation occurred in one case. Although one branch from the segment IV artery supplying segment II could be identified, no reconstruction was required with small diameter and good backflow under perfusion. Since in most cases the portal vein supply to segment IV has to be sacrificed in the process of splitting, arterial supply will largely determine survival of this segment, and therefore, every effort should be made to preserve the segment IV artery. In most cases the segment IV artery originates from the left hepatic artery, and its origin should have some distance to the union of segments II and III arteries. The segment IV artery rarely arises far distal from the left hepatic artery, and the three arteries of segments II, III, and IV might form a trifurcation at their origins. A similar situation occurred in one of our cases when with painstaking efforts only a length of 3 mm of the common trunk of segments II and III arteries could be obtained at last. In case the segment IV artery has to be cut down, it is suggested to anastomose it with the stump of the left hepatic artery on the backtable.

Close attention should also be paid to variations of bile ducts. During the initial period of left lateral split liver transplantation, many groups isolated the main left hepatic
duct next to the main bile duct bifurcation when harvesting the left lateral lobe, in order to create a nice bile duct stump for anastomosis. However, this technique seems to be associated with a high rate of biliary complications on both grafts for the following reasons. First, leaving the long stump of bile duct with the left lateral graft might result in ischemic necrosis due to damaging the parabiliary vascular plexus in the isolation of the left hepatic duct. Second, a high incidence of damage to the segments I and IV bile duct of the right extended graft might occur with such a method. Therefore, we kept the connective tissue surrounding bile ducts untouched, and only used a metal probe or Arrow catheter to identify the trend of bile duct, and transected bile duct as the last step of the whole splitting procedure. Although in 15% of donor livers the union of segments II and III bile ducts is located right to the umbilical fissure, which means two separate openings of bile duct appear on the cutting surface of the left lateral graft, we would still rather keep the transecting line curving a little to the left in order to retain an undamaged segment IV bile duct. If the distance between two separate bile duct openings is quite close, they might be merged into one through plastic reconstruction.

Undoubtedly, split liver transplantation has become a well-established approach to extend the donor pool for both pediatric and adult patients. Careful donor and recipient selection, good knowledge of the liver anatomy, excellent surgical skills and meticulous postoperative management all contribute to the success of each case of split liver transplantation.

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