Partial liver transplantation—living donor liver transplantation and split liver transplantation

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Abstract

In the last two decades, liver transplantation (LTx) has become the treatment of choice for several liver diseases including hepatocellular carcinoma in selected cases. Improvements in surgical and anesthesiological procedures have increased patient survival after LTx, resulting in excellent 1-year survival rates. The rate-limiting factor to further increase the number of LTx is the extreme shortage of suitable organs with the consequence that pediatric and adult patients are dying on the waiting list. At present, mortality reported for pediatric and adult patients on the waiting list is 10 to 20%. Living-donor liver transplantation and split liver transplantation are measurements to reduce the severe lack of cadaveric grafts by expanding the donor pool. Major centers around the world now routinely perform partial LTx in infants and adults with survival success equivalent to that after full-size liver transplantation.

Keywords: liver transplantation; living-donor liver transplantation; partial-organ liver transplantation; split-liver transplantation

Introduction

Full size liver transplantation (LTx) has been performed since 1963 [1] and has evolved as the treatment of choice for patients with end-stage liver disease, acute irreversible liver failure and hepatic malignancies in selected cases [2–4]. Improvements in surgical techniques, anaesthetic protocols, and the introduction of new immunosuppressive regimens have increased patient survival after LTx, resulting in a 5-year survival rate of more than 90% in experienced transplant centers [5–8]. Because donor liver shortage has been the rate-limiting step in the expansion of hepatic transplantation, several innovative techniques have been developed to enlarge the relatively constant pool of organs. Although liver replacement in children account for only 10 to 15% of all liver transplants performed, the number of full-size cadaveric grafts size-matched for this population is inadequate. Because of the natural history of their liver disease, the vast majority of children are very young at the time of transplantation. In the Western world, the number of pediatric candidates exceeds the number of small-sized pediatric donors of similar weight allowing full-size LTx to be performed. To maximize donor organ use in children and small adults, three procedures have been developed to reduce pretransplant mortality in small patients: Reduced size liver transplantation first described by Bismuth and Houssin in 1984 [9], Living-related donor liver transplantation (LDLT) first successfully carried out by Strong in 1989 [10] and Split liver transplantation (SLT) which increased the total number of donor organs. The first ex situ SLT was performed by Pichlmayr et al. in 1988 [11]. They split one donor liver into two grafts which were used for transplantation for two recipients. This innovative technique served the fundamental principle of dividing a whole donor liver in parts with each a vascular pedicle, venous outflow and bile duct. Broelsch et al. reported initial series of 30 SLTs in 21 children and 5 adults [12]. In these early reports using the ex vivo technique, results were poor with only 67% of children and 20% of adults surviving, with a high rate of complications and a retransplant rate of 35%. In the mid-90s, several centers achieved better results after SLT comparable with those after full size liver transplantation [13–16]. Graft and patient survival rates became equivalent with cadaveric full size transplantation. Although wide-ranging investigations such as intraoperative ultrasound, angiography, computed tomography, and magnetic resonance imaging are used routinely to delineate the hepatic vascular and
biliary anatomy [17,18], not all anomalies can be demonstrated with certainty by these investigations. Therefore, the transplant surgeons should have a profound knowledge of normal liver anatomy and should recognize the presence and implications of anatomical variations. This review will focus on the current status of partial LTx techniques covering LDLT and SLT.

Anatomic principles

The Couinaud classification divides the liver into 8 independent segments each of which has its own vascular inflow, outflow, and biliary drainage [19]. Because of this division into self-contained units, theoretically, each can be resected or transplanted without damaging the remaining ones. For the liver to remain viable, resections must proceed along the vessels that define the peripheries of these segments. In general, this means resection lines parallel the hepatic veins while preserving the portal veins, bile ducts, and hepatic arteries that provide vascular inflow and biliary drainage through the center of the segment. Currently, segments 4 through 8 (right lobe) are most commonly used for adults and liver segments 2 and 3 (left lateral segment) or segments 2, 3, and 4 (left lobe) for paediatric recipients [20] (Figure 1).

Liver volume

The basic assumption for success of a LDLT or a SLT is the realization of adequate liver parenchyma for both the recipient and the donor [21,22]. Total liver volume is reported to have a relatively constant relation to body weight, ranging between 2–2.7% in healthy subjects [23]. Indeed, a large deviation of the real liver volume was observed and a differentiated calculation of the left and the right hepatic lobe was not successful. The Urata formula is most commonly used in Asia to calculate the recipient’s standard liver volume. In European countries, liver volume is generally calculated with the graft-recipient body weight ratio (GRWR). The minimum graft volume for successful liver transplantation is controversial, and in living donors the GRWR is desired to be 1% or more [24,25], however, successful results have even been reported with grafts having a GRWR less than 0.7% [26,27]. Liver remnant volume of approximately 30% of the total liver volume is sufficient for the donor to survive, provided that the liver parenchyma is normal without evidence of fatty infiltration or fibrosis [28]. A small graft may result in malfunction and may not sustain adequate metabolic function in the recipient (small for size syndrome). A large graft is associated with the risk of graft compression and poor perfusion (large for size syndrome). Therefore, accuracy of total and segmental liver volumes is important to avoid donor-recipient volume mismatch [29]. The Couinaud classification, developed in the early 1960s, is well established as a general model, but clinical studies have demonstrated that the shape and localization of these segments do not always match the real situation [19,30,31]. Today, liver volumetry is generally performed by computer-assisted models of contrast enhanced spiral CT as data source. The use of computer-based liver operation-planning systems for surgical procedures improves preoperative evaluation [32–34]. It allows accurate liver-segmentation to visualize liver segments, vessel trees, liver volumes to be resected or critical residual organ volumes, either for preoperative planning and intraoperative visualization. Therefore, it is helpful to use these systems before surgery to select the best strategy for optimal donor and recipient safety. Volume calculations using conventional and helical CT are reported to be relatively accurate [24,35–37]. It is widely assumed that the mean specific gravity of healthy liver tissue is 1.00 g/ml so that preoperatively calculated volumes of the entire living donor’s liver and both of its lobes are approximately equal to their respective weights [38,39].

Selection of donors

Of paramount importance for the success of SLT and LDLT is donor and recipient selection. The SLT
achieves liver transplantation in two recipients from a single cadaver liver, usually a right lobe implanted into an adult recipient, and left lobe or left lateral segment transplanted into a child. With the current technique, it is quite reliable to split a donor liver into a left lateral lobe (segment 2, 3) and a right extended lobe (segment 1, 4–8) for one child and one adult recipient. Nevertheless, the increasing disparity between adult donor supply and demand has stimulated interest in extension of split liver techniques to include two adults. Splitting a graft into a full left lobe (segment 2–4 or segment 1–4) or a full right lobe (segment 1, 4–8 or segment 4–8) suitable for two adult recipients has been reported [40,41]. LDLT and SLT accounted for less than 10% of all liver transplantations performed in the United States in 2004 [42]. In some countries however, LDLT is the only available source for transplantation [43,44]. As a result, the Japanese have aggressively pursued living donation for all indications in both pediatric and adult patients. Accurate donor assessment by the procurement team is important because SLT outcomes are affected by vascular and biliary anatomy as well as parenchyma quality and quantity [45]. Procedures used to evaluate donors include standard history and physical examination, routine laboratory tests, radiographic studies and liver biopsies in selected cases. Aside from basic requirements for donor livers, the following factors are of major importance: donor age (<50 years, >10 years), donor stay at the ICU <5 days, hypernatremia <170 mmol/l and a hemodynamic stable donor. Intraoperatively an eligible liver should have a soft consistence (fat <20%), a sharp edge and no evidence of hepatic hypoperfusion [46–48].

Pre-operative evaluation of donor’s liver function

The indocyanine green (ICG) retention test, namely, retention of ICG at 15 min following the injection of 0.5 mg/kg, is the most widely used clearance test. It depends on hepatic blood flow and on the functional capacity of the liver. ICG is a synthetic dye that has been used for many years to measure hepatic blood flow and as a test of liver function [49]. It was also used as a guide for selecting the type of resection to be performed [50]. The monoethylglycinexylidide (MEGX) test, which depends on cytochrome p450 activity, is a quantitative liver function test, related to the severity of liver disease [51]. A value of <25 ng/ml predicts safe hepatic resection [52]. It is a useful test but is less accurate than ICG. The galactose elimination capacity (GEC) is used to determine the cytosolic metabolic capacity of the liver based on galactokinase activity [53]. Its usefulness is currently under investigation.

Selection of recipients

In general, recipients selected for LDLT or SLT had to meet the standard requirements for listing for cadaveric liver transplantation. Splitting liver into two grafts for adults has been largely developed under the background of the increasing disparity between adult donor supply and demand. The evaluation and the management of patients were the same as for cadaveric transplantation [54]. For lightweight adult patients (body weight <50 kg), it is often difficult to find an adequate donor organ. Especially patients with Primary Biliary Cirrhosis (PBC) and Primary Sclerosing Cholangitis (PSC) are often growth-retained and need a small graft. For these patients a SLT is an excellent option. The PSC patients, however, have increased an increased risk to develop biliary duct cancer and the PBC patients suffer from an impaired quality of life. These patients can be transplanted using a split liver graft. Additionally this procedure can be performed in an elective situation. Patients with a Hepatocellular carcinoma (HCC) are in unpredictable danger of tumor dissemination and incurability. Liver transplantation may be the best curative treatment for HCC. It removes the tumor with the widest margin and cures the underlying cirrhosis that is responsible for both postoperative hepatic decompensation and tumor recurrence after partial hepatectomy. Using the Milan [2] or the extended [55] criteria which limit transplantation to patients with a solitary tumor less than 5 cm (6.5 cm) in diameter or 2 to 3 tumor nodules no larger than 3 cm, a 4-year survival rate of 75% can be achieved. However, there is a second problem for these highly selected patients, namely tumor progression and drop out as well as death during the waiting period. Recent advances in adult LDLT produce a dramatic change in the role of transplantation surgery. Although the results suggest that this may become the dominant strategy for patients with early irresectable HCC, there are serious limitations in such a concept above all the risk for the living donor. At present, LDLT for HCC with extended indications is a debatable procedure and cannot be generally recommended due to the poor 5 year survival of the recipients. Normally, patients with haemodynamic instability, obesity, multiple upper gastrointestinal surgeries, and severe debilitation are usually excluded from partial liver transplantation.

Preoperative evaluation of recipient’s liver function

The Child—Turcotte-Pugh score [56,57] is still the most widely used tool to estimate the severity of liver disease and to predict survival in these patients but has provided inconsistent prediction of mortality after hepatic resection. Various laboratory data and imaging techniques have been used to complement the Child-Pugh score to predict liver failure after hepatectomy and assess functional hepatic reserve [58]. The Model for End Stage Liver Disease (MELD) score is considered a good short-term predictor of death in cirrhotic patients but does not give any information on the functional liver cell mass, which is probably the most important factor for patient survival.
Living-related donor liver transplantation (LDLT)

LDLT was first performed in children, because organ shortage of organ donors was particularly acute in the pediatric patient population. Raia et al. and Broelsch et al. resected left lateral segments from living adults for transplantation in children [59,60]. LDLT is different from all other types of surgery because it subjects a healthy individual to a major operation that he or she does not need. LDLT provides several important advantages to the recipient. The transplantation can be scheduled electively, before the patient develops life-threatening complications of end-stage liver disease. Other advantages include short ischemic time and a healthy graft with normal liver function. The liver rapidly regenerates in both donors and recipients, and normal liver volume is almost completely restored within 8–12 weeks [61]. There are some ethical issues with LDLT because the donor has no direct benefit. LDLT is becoming an accepted therapeutic option for end-stage liver disease in pediatric or small adult patients. This surgery is safe when performed in experienced centers, but complications and even death can occur in both the healthy donor and diseased recipient. Since the first operation, LDLT has been very successful with patient and graft survival rates at more than 90% after 1 year [62,63].

Donor surgery

The living donor undergoes the removal of either the left lateral segment, which represents between 15 and 20% of the total liver mass, or the full left lobe, which represents 30 to 35% according to the weight of the potential recipient or the full right lobe, which represents >50% of total liver volume. After evaluating the quality and the size of the liver, the procedure begins with hilar dissection. Left lobectomy is started by dissection of the left hepatic artery, followed by left portal vein and left hepatic vein. After these steps, the left lateral segment (segments 2 and 3) bile duct is transected followed by the parenchymal transection, which is generally performed using Cavitron Ultrasonic Surgical Aspirator (CUSA; Valleylab, Boulder, CO, USA) and without clamping the portal vein and the hepatic artery. The left and the middle hepatic veins are usually preserved with the graft, and the donor right lobe is drained through the right hepatic vein and the retrohepatic veins. Right lobectomy is performed by resection along the Cantlie line after cholecystectomy. After removal, the grafts are immediately flushed with cold preservation solution and prepared for implantation. In the case of right lobe grafts, venous reconstruction of segments 5 and 8 hepatic veins (if larger than 5 mm) is performed on the back-table using interposition vein grafts. Some centers explant the middle hepatic vein with a right lobe graft.

Recipient surgery

Removal of the native liver is the first step of liver transplantation. The grafts are generally implanted in a piggy-back fashion. The hepatic vein anastomosis can be performed with two different techniques. In left lateral segment grafts, the left hepatic vein can be attached to the common orifice of the recipient hepatic veins, or it can be anastomosed to the caval opening with triangulation of the recipient vena cava. Portal vein reconstruction is performed in an end-to-end fashion. After liver reperfusion, the hepatic artery anastomosis is performed between graft hepatic artery and the recipient right, left or proper hepatic artery depending on the alignment and size match. In most cases, the bile duct anastomosis is performed by Roux-Y-hepatico-jejunostomy in children, but in adults an end-to-end anastomosis of the bile ducts is preferred.

Split liver transplantation

The first report of in situ liver splitting was published by Rogiers et al in 1995 [64]. In 1996 the same group reported an experience with 14 split grafts that resulted in 6-month patient and graft survival rates of 92.8 and 85.5%, respectively [65]. The experience in SLT as well as LDLT accumulated over the last years clearly indicates that the most reliable basis in deciding whether or not to split is the judgement of an experienced transplant surgeon. Two techniques have been used for SLT, ex situ, splitting the liver on the bench after removal from the cadaver, and in situ, (in vivo), division of the liver in the donor before procurement. In situ SLT is a modification of the ex situ technique and was firstly introduced by Rogiers et al. in 1995 [64]. This technique eliminates the prolonged bench surgery procedure, decreases the ischemic damage to the graft and the incidence of bile leakage, and facilitates complete haemostasis of the cut surface. However, the in situ technique has some disadvantages. It is a time-consuming technique, needs the coordination with other harvesting surgeons for lungs and heart and in presence of complicated anatomical variations of vessels and bile ducts it is easier to carry out cholangiography or angiography in the hepatic graft ex situ as compared to the in situ situation. The increased blood loss and volume replacement during in situ splitting has prompted concerns that the quality of thoracic organs may be affected [66]. In situ SLT results have initially shown superiority over the ex situ technique with increased patient and graft survival rates and lower incidence of complications [65,67,68]. The ex situ technique potentially lead to an increased rate of primary dysfunction and nonfunction due to a prolonged cold ischemia time [69,70]. Nowadays, many groups with sufficient experience in SLT have returned to the ex situ or bench splitting technique, with the transplant outcomes of ex situ being equivalent to those of in situ. The King’s College group has adopted ex situ procedure in
Table 1. Review of SLT series

<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>N</th>
<th>Technique</th>
<th>1y-patient survival (%)</th>
<th>1y-graft survival (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emond [12]</td>
<td>1990</td>
<td>18</td>
<td>Ex situ</td>
<td>67</td>
<td>50</td>
</tr>
<tr>
<td>De Ville [56]</td>
<td>1995</td>
<td>98</td>
<td>Ex situ</td>
<td>68</td>
<td>62</td>
</tr>
<tr>
<td>Rela [43]</td>
<td>1998</td>
<td>41</td>
<td>Ex situ</td>
<td>90</td>
<td>88</td>
</tr>
<tr>
<td>Broering [67]</td>
<td>2001</td>
<td>49</td>
<td>mixed</td>
<td>82</td>
<td>76</td>
</tr>
<tr>
<td>Ghobrial [51]</td>
<td>2000</td>
<td>110</td>
<td>In situ</td>
<td>79</td>
<td>86.1</td>
</tr>
<tr>
<td>Spada [17]</td>
<td>2000</td>
<td>39</td>
<td>In situ</td>
<td>84</td>
<td>76</td>
</tr>
<tr>
<td>Yersiz [49]</td>
<td>2003</td>
<td>92</td>
<td>In situ</td>
<td>78 (3y)</td>
<td>68 (3y)</td>
</tr>
<tr>
<td>Cardillo [68]</td>
<td>2006</td>
<td>323</td>
<td>In situ</td>
<td>79.4 (3y)</td>
<td>72.2 (3y)</td>
</tr>
</tbody>
</table>

pediatric patients with 1- and 3-year survival rates of 93.5% 88.1% and graft survival rates of 89.7 and 86.1%, respectively [5]. Survival rates for adult recipients after a 12-months follow-up were both 95% [71]. Some centers have obtained excellent results, with 1-year patient and graft survival rates of 100 and 80% respectively [68]. An overview of published SLT series is shown in Table 1.

Ex situ split technique

Grafts are generally prepared and split at the recipient transplant center in ice cold preservation solution. Dissection of the portal triad is performed to separate the branches of the hepatic artery, portal vein, and right and left bile ducts. A metal cannula is normally used to probe the hepatic artery and bile duct gently to facilitate detection of aberrant anatomy. The key to successful splitting is to share vascular and biliary structures between the two sides without injury. 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. SLT is initiated with division of the venous ligament to expose the hepatic vein-caval junction. The left hepatic vein is isolated and encircled with a vessel loop. After exposing the left hepatic artery and identifying the segment 4 artery, the left hepatic artery is transected distally. The left portal vein is isolated and transected as well with ligating the branches supplying segment 4. Afterwards the liver parenchyma is split step by step from downward to upward and the various tiny vessels and bile ducts handled with ligation or metal clips followed by transecting the left hepatic vein. Finally, the bile duct is transected and preservation solution is injected via the portal vein, hepatic artery and bile duct to check for leaks at the surface of the split liver.

In situ split technique (Segments 2 and 3)

The left side of the hepatic triangular ligament is dissected first to identify the left branch of the hepatic artery. Throughout this dissection, attention is paid to the arterial branch to segment 4, which is preserved whenever possible. Next the portal vein is dissected to the bifurcation, followed by dissection of the parenchyma just to the right of the falciform ligament. Extrahepatic isolation of the left hepatic vein is accomplished with care to ensure that the middle hepatic venous drainage of segments 4, 5 and 8 is not obstructed. After completion of the dissection, two liver grafts are procured, each with a preserved vascular pedicle and venous drainage. At the end of the procedure, the artery, portal vein branch, and left hepatic vein are clamped and transected. When this dissection is completed, two liver grafts (right: segments 1 and 4–8; left lateral: segments 2 and 3) are separated, each with its own vascular pedicles and venous drainage, segment 1 is then usually resected. At this time, the donor liver is perfused in situ with preservation solution.

Full split

The increasing disparity between adult donor supply and demand has stimulated interest in extension of split techniques to supply two adults. Left lobe grafts (segments 1–4) that include the caudate lobe may be used for adults weighing as much as 65 kg or more in selected cases [40]. The right hepatic artery, the right portal vein and the right hepatic vein are encircled with a vessel loop followed by a right sided clamping to create a demarcation line for parenchymal division. Upon completion of parenchymal division, the right hepatic artery, right portal vein, and right hepatic vein are maintained for cold organ perfusion. When the full right hepatic graft is used, the middle hepatic vein branches draining segment 5 and 8 as well as the accessory hepatic veins ≥5 mm in diameter should be anastomosed either to the vena cava directly or through utilization of a venous conduit [72].

Cava split

To prevent serious venous congestion of the right graft, one group designed a split-cava technique in liver splitting for two adult patients [73] by longitudinal transection of the inferior vena cava. This results in 2 grafts, each with a large venous patch including the main hepatic vein and additional smaller veins. These patches are very easy to anastomose using the cavocavostomy technique.

Implantation

Left lateral graft

Left lateral grafts (segments 2 and 3) are generally transplanted into a child or a small adult using a piggyback technique with retention of the recipient vena cava. The left hepatic vein is anastomosed to the suprahepatic vena cava of the patient. Portal vein reconstruction must be individualized to the recipient’s anatomy. Hepatic artery reconstruction in ex vivo split
glafts varies, depending on whether the common hepatic/portal trunk is retained with the graft. In this setting, anastomosis is either to the hepatic artery of the recipient or to the aorta. A major technical problem is caused by reconstruction of the biliary tree. The left graft biliary tract reconstruction is generally a Roux-en-Y left hepaticojejunostomy, with the caveat that in up to 25% of cases there are 2 or more separate ducts to segments 2 and 3. Occasionally a duct-to-duct biliary anastomosis is possible if a normal common bile duct exists.

Right graft

The right trisegmental liver graft is implanted in the same manner as a full-size organ [74]. Generally the biliary reconstruction is performed via a choledochocholedochostomy or via Roux-en-Y hepaticojejunostomy.

Discussion

Today, the discrepancy between organ supply and recipient demand has never been greater. As a result of the current organ shortage, novel strategies are being explored to expand the pool of hepatic allografts including the use of marginal donors [74a,75], living donors, split cadaveric livers and the use of donors. Based on the experience of Tanaka et al., the full size graft-to-recipient body weight ratio should be 0.8% or greater to achieve graft and patient survival of 90% [22,24,76]. Transsection in the midplane divides the liver into the anatomic right lobe (65–70% of the whole liver) and the left lobe (30–35% of the whole liver). The left lateral segments from an adult are always of sufficient size for children of less than 2 years of age. For the right lobe graft, the ideal graft-to-recipient body weight ratio should be 1.5 to 2.0%. Weight alone is not a suitable guide because steatosis, particularly when greater than 30%, increases the risk of graft dysfunction and primary nonfunction. Fatty infiltration of 30% or more should therefore preclude using a liver for splitting because of the inability to predict function from the partial graft. Age of more than 50 years was initially used to define marginal donors, but in full-size liver transplantation this risk factor has been regarded as less important than fatty infiltration in particular. Recipients with advanced liver disease, particularly those with severe portal hypertension, seem to need larger and/or better-functioning grafts to avoid small-for-size syndrome [77] which is characterized clinically by the appearance of cholestasis, prolonged coagulopathy, portal hypertension, ascites, and in severe cases, gastrointestinal bleeding. Impaired venous inflow or even more critical, impaired venous outflow may significantly reduce graft function [77,78]. Biliary complications are reported to occur in 10–30% of full-size transplants and as many as 35% of partial transplants [79]. This high rate is not only related to surgical experience, but especially to the anatomical variations of the biliary tree and ischemic damage of the graft bile ducts [79,80].

Living donor liver transplantation

LDLT in both pediatric and adult recipients has been well established in major Asian transplant centers as a primary type of LTx or as a complement to the markedly limited supply of cadaveric grafts in other countries. Because organ transplantation from deceased donors is not practiced due to religious reasons in these countries, LTx from living donors is the only alternative. LDLT has emerged as an important option for many patients, particularly small pediatric patients and those adults that are at disadvantage by the current deceased donor allocation system. LDLT can now be performed with a reasonably high rate of success attributable to judicious patient selection, careful preoperative evaluation, excellent anesthetic management, experienced surgeons and prompt detection and treatment of complications.

Today, many patients become unsuitable for transplantation as a result of multi-organ failure or infectious complications. If a cadaveric liver is not available, LDLT provides an opportunity to transplant patients before the onset of sepsis, renal failure, or other complications that preclude transplantation. In addition, patients with small HCC who are likely to be curable by LTx and patients with primary sclerosing cholangitis at increased risk for cholangiocarcinoma are excellent candidates for LDLT. With the development of LDLT, there has been a decrease in the pretransplant mortality for children [41,48,71,72]. It has been suggested that LDLT offers an immunological advantage to the recipient partly due to the small size of the graft, partly due to the haplodeficiency between the donor and the recipient in blood related donations [79,81] but many studies do not support these hypotheses.

Split liver transplantation

Several European countries, faced with an increasing waiting list and death rate due to the lack of donor organs, pursued the split liver option. Splitting one donor liver into a left lateral and a right extended graft for one pediatric and one adult recipient is technically demanding, requires a high level of surgical expertise and has shown comparable results to full size transplantation and is therefore an established procedure in the standard repertoire of LTx [13–16,82]. In 1995, the results of a collective experience of 50 donor livers providing 100 grafts during a 5-year period from the European Split Liver Registry demonstrated no significant difference when compared to conventional full-size LTx during the same period [83]. Ghobrial et al. confirmed these results after comparing 110 consecutive SLTs in 55 adults and 55 paediatric recipients showing that patient survival of SLT was
not significantly different from full-size LTx [84]. Similar results were reported by Broering et al. [68]. The Hamburg group recently reported that transplantation of the right extended lobe deriving from left lateral splitting of deceased donor livers is followed by the same long-term patient and graft survival, which is known from full size LTxs. There were no differences in the complication rates even in long-term outcome [85].

Although the progress of SLT, the complexity of the whole procedure allows for a series of complications which might occur postoperatively, including bleeding, bile leakage, and infection of the transected liver surface; disparity of graft size, complications of the hepatic artery and the bile duct caused by complex reconstructions, and outflow problems related to the hepatic veins. Vascular and biliary complications account for a considerable proportion of technical complications, especially with the use of partial grafts. Biliary complications are reported with an incidence of 18–27% in the current literature [86]. Potential problems associated with ex situ splitting include prolonged cold ischemia time, poorer definition of the biliary tree, less precise hemostatic control and poorer overall results for right-sided grafts compared to those obtained by in situ splitting [87]. In situ splitting increases organ retrieval time by approximately 2 h [88]. The Pittsburgh group found no overall difference in 1-year patient and graft survival between in situ and ex situ split transplants in their center and concluded that either form of split transplantation resulted in acceptable results [67]. More recent studies, particularly after in situ splitting, have reported lower biliary complication rates of <10% [5,89].

SLT applied to pediatric recipients yield excellent outcomes with significant decreases in pediatric waiting times and morbidity. SLT has been demonstrated to reduce the waiting time by approximately one-third in children [90]. Furthermore, the outcome of children transplanted with split-liver graft is similar to the outcome reported for pediatric recipients of LDLT [91–93]. SLT represents a significant source of pediatric liver grafts without compromising the adult donor pool, and the right lobe graft should be used in good risk patients with grafts from optimal donors. The 6-month graft survival in patients who receive a split liver is similar to that in patients who receive a full-size liver according to the data of the European LTx Registry in both adult and in pediatric recipients. That is reflected in the increased SLT activity in central Europe between 1993 (1.2% SLT of all LTx) and 1999 (10.4% SLT of all LTx) [94]. The advantage of SLT over LDLT is that it expands the existing donor pool without placing otherwise healthy people at risk of complications from the donation procedure.

In the case of reduced size LTx and SLT, some reports have mentioned technical difficulties in dealing with the small size of the graft vessels and the associated deterioration in outcomes, such as biliary complication and HAT, compared with those for full-size LTx [12,95]. Postoperative problems, such as bile leaks, surface bleeding and vascular complications, have been significant in SLT and LDLT, especially in early series. Even today, biliary complications still occur in 20–25% of SLT [16,96] and 15–30% of LDLT [81,97,98]. More recent studies, however, particularly after in situ splitting, have reported lower biliary complication rates of <10% [88,89]. This high rate is not only related to surgical experience, but especially to the anatomical variations of the biliary tree [22,80]. Biliary complications can broadly be categorized as a result from either vascular insufficiency or technical difficulties [99]. The relationship between prolonged ischemia time and an increased incidence of arterial thrombosis and biliary complications is well established [100,101]. Overall, the many large series and reviews of pediatric [102,103] and adult [104,105] recipients of live donor grafts report favourable results, often better than those observed with cadaver organs. Donors and recipients need to be chosen carefully and responsibly. The entire evolution of live donor LTx has been based on two principles: donor safety, and ensuring an adequately sized graft for the recipient. The perioperative morbidity of the living related liver donor including all minor complications is stated to be 10–25% [20,106]. In the European experience, the donor morality is shown to be 0.3–0.9% [107].

Summary

LDLT and SLT has become an increasingly common approach to liver transplantation and currently accounts for approximately 5% of all liver transplantations. Children with diseases eligible for LTxs should be seen in a transplantation center early in the course of their disease. Grafts from younger donors have a favourable impact on survival. Postoperative problems, such as bile leaks, surface bleeding and vascular complications, have been significant in SLT and LDLT in earlier series. Even today, biliary complications still occur in 20–25% of SLT, and 15–30% of LDLT. Vascular and biliary complications may lead to loss of valuable grafts and cause significant morbidity and mortality. It is hoped that increasing experience, center effects, coupled with refinement of technique and a sound knowledge and application of anatomy, modern diagnostic tools such as the 3-dimensional visualization of the liver will lead to an improved outcome for patients undergoing partial liver transplantation. The most pressing challenge is the ongoing shortage of donor organs. The use of reduced-sized, split grafts, and live-donor livers has reduced the size but not eliminated the problem. SLT is an important option for expanding the cadaveric liver donor pool and has the potential to provide grafts to the majority of listed pediatric patients and to substantially decrease the adult waiting time. Donor-to-recipient size mismatch was an additional limitation to LTxs in children until the development of partial liver transplantation techniques. Although these techniques have significantly reduced waiting list mortality in children, they
do not completely address the major problem of limited organ availability.

Conflict of interest statement. None declared.

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