Surgical Techniques in Adult and Paediatric Liver Transplantation

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Jan Lerut and Jean de Ville de Goyet

Overview

Liver transplantation is a complex undertaking. A "perfect" operation is of utmost importance because of the harbinger of a smooth postoperative recovery and evolution. To bring this surgery to a good end, not only extensive surgical skills but also experience are needed, the latter allowing in particular the liver transplant surgeon to resolve unexpected, sometimes very rare, intraoperative findings.

Although the technique has been perfected during the last two decades, an individualized approach to the recipient remains key for success. In *adult transplantation,* four conditions need particular attention: the severity of portal hypertension, the vascular status, the donor–recipient weight matching, and the nature of the liver disease. The particular technical aspects of retransplantation, sequential (or domino), and auxiliary partial liver grafting are also highlighted. In *paediatric transplantation,* the main challenges consist of adapting the graft to the small abdominal cavity using variant grafts such as left split or reduced livers and of dealing with anatomical variations such as hypoplastic or pre-duodenal portal vein, absent portal or inferior caval veins, and situs inversus.

This chapter discusses, using a similar template, the main generalities and particularities of both adult and pediatric liver transplantation.

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12.1 Introduction

The first attempts of canine liver transplantation (LT) covered one page short letter by Welch in 1955 in the "Transplantation Bulletin," a supplement of the Journal of Plastic and Reconstructive Surgery. At that time, a transplantation journal did even not exist! Later on, it was discovered that Staudacher from Milan had realized the first experiment in 1952. Starzl's large animal experience resulted in the "first LT in human" in March 1963. Refining surgical technique, organ preservation, and immunosuppression during two decades brought LT from an "unfinished" into a "finished" product [1]. Recipient (R) hepatectomy with removal of the retro-hepatic inferior vena cava (IVC), graft implantation using intraluminal suturing and use of active, heparin-coated, and veno-venous bypass (VVB) became the cornerstones of the procedure. At the end of the 80s, the IVC-preserving R-hepatectomy, described in 1968 by Calne, progressively became accepted as the standard procedure and led to the development of piggy-back (PB-LT) and cavo-caval implantation (CC-LT) techniques [2–6].

To overcome allograft shortage, several technical variants such as split, sequential (or domino) and auxiliary LT were developed [7–12]. Unfortunately, these techniques did not fulfill their promises because of logistic complexity, fear for technical complications, and, most of all, because of insufficient investment by the transplantation community. Technical knacks and pitfalls of all different adult and pediatric post-mortem LT (PM-LT) procedures are addressed in this chapter.

12.2 Adult Liver Transplantation

12.2.1 Surgical Technique: Generalities

Abdominal incision: The, unfortunately still frequently used, "Mercedes-type" incision should be replaced by the more, "abdominal wall friendly," J-shaped RUQ incision, even in the case of extreme hepatomegaly.

Abdominal drainage: Placement of one infra−and/or suprahepatic JP-drain remains of value to monitor early bleeding and biliary leakage and to decompress abdominal wall and abdomen in case of the (frequently present) massive ascites formation, reducing thereby eventual subsequent respiratory and parietal problems.

Hepatectomy: Early division of coronary and gastro-hepatic ligaments allows an easier access to the hepatoduodenal ligament (HDL) as a principle, recipient structure should be divided as high as possible in the HDL. Pinching the HDL between left thumb and fingers is useful to reduce bleeding. Supra- and infra-hepatic IVC encirclement needs to be done flush to its wall to avoid injury of the para- and retrocaval venous collaterals. The bare areas are not sewn in order to keep the available space for the allograft to the maximum.

Veno-venous bypass (VVB): In classical LT (CL-LT), VVB is used systematically or selectively after IVC test clamping. If poorly tolerated, meaning a persistent

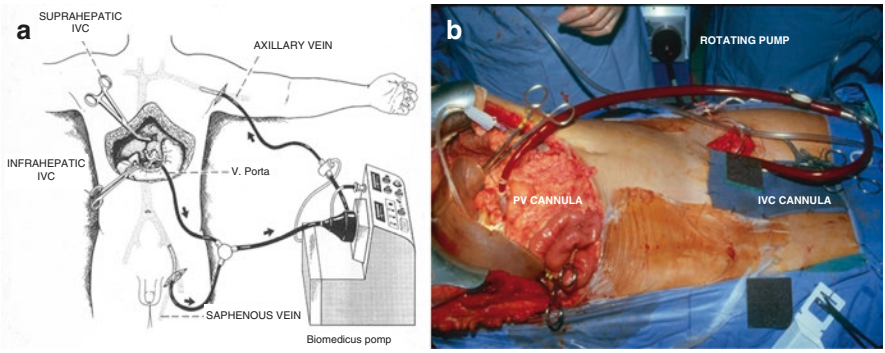

Fig. 12.1 Classical liver transplantation with resection of the inferior vena cava and use of veno-venous bypass: (**a**) scheme and (**b**) corresponding intraoperative view. The operative situs clearly shows the absence of intestinal congestion due to decompression of the splanchnic territory

decrease of mean arterial pressure and/or of cardiac index by more than 50%, VVB should be installed. The bypass decompresses and drains the splanchnic and lower IVC territories into the axillary or (even better) jugular veins (Fig. 12.1). All these veins can be accessed using ultrasound (US)-guided puncture. VVB is contraindicated only in the presence of septic conditions (intrahepatic or intra-abdominal abscess and biliary infection) and of peripheral tumor localization (danger for rupture). In cancer patients, VVB and blood salvage with leucocyte filtration can be used safely [13].

Anastomoses: Vascular anastomoses are done using Starzl's intraluminal suture technique using non-absorbable polypropylene (Prolene®, Ethicon Inc., Somerville, NJ, USA) 4–0 for the supra- and infra-hepatic IVC, 6–0 for portal vein (PV), and 6 to 8–0 for hepatic artery (HA) sutures. The biliary tract is sutured using 6–0 polypropylene or resorbable polydioxanone (PDS®, Ethicon Inc., Somerville, NJ, USA). Arterial and biliary anastomoses can be run or (partially) interrupted, using magnifying glasses or microscope. When suturing the IVC, the allograft is flushed with cold solution in order to evacuate air bubbles and potassium content.

The hepatic artery: There is no hepatic arterial abnormality that contra-indicates LT. Living donor (LDLT) experiences have shown that hepatic artery thrombosis is nearly always a surgical problem [14–16]. The anastomosis between the proper HA and the bifurcation of common hepatic and gastroduodenal arteries is the most used anastomotic site. Today, a compromised arterial tree is unfortunately seen more frequently due to the fact that more older and cancer patients presenting coeliac trunk stenosis, atheromatosis, and arteritis (caused by repeated chemo-embolization) are transplanted and that recurrent allograft disease makes re-LT more frequent [17–19]. Direct anastomoses with the recipient's gastroduodenal, left gastric, right gastro-epiploic, splenic, ileocolic, and inferior mesenteric arteries or indirect anastomosis using free arterial interposition grafts between allograft arterial tree and infrarenal abdominal aorta have all been described to solve the problem [20–22] (Fig. 12.2).

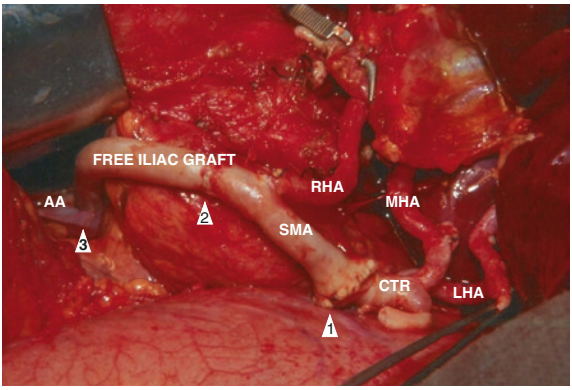

Fig. 12.2 Intraoperative view of a complex arterial reconstruction in case of triple arterial allograft supply and inaccessibility of direct arterial anastomosis. The superior mesenteric artery (SMA) (giving rise to a right hepatic artery (RHA)) and the coeliac trunk (CTR) (giving rise to middle and left hepatic arteries) (MHA-LHA) have been joined to make a common orifice (arrowhead 1). Next, the SMA has been connected to a free iliac graft (arrowhead 2), which is anastomosed to the infrarenal abdominal aorta (AA) (arrowhead 3)

The portal vein: PV stenosis is avoided using the growth factor or the "two-clamp" method. In the former, the running suture is tied at a distance from the PV; in the latter, the recipient PV clamp is opened against a closed donor PV clamp; both tricks allow maximal expansion of the suture line [23]. The management of large *spontaneous portosystemic shunt* remains a matter of debate. Routine ligation of large shunts, whenever feasible, has been shown to improve outcome [24].

Transjugular intrahepatic portosystemic shunt (TIPSS), used frequently during pre-LT work-up, may lead to specific TIPSS-related modifications needing technical adaptations. In some cases, it may be safer to include residual TIPSS material in the venous suture lines [25].

Splanchnic venous thrombosis, a part of the natural evolution of chronic liver diseases, was initially seen as an obstacle to perform LT. Precise preoperative imaging of acquired or congenital splanchnic venous and/or portosystemic shunt anatomy, timing of donor and recipient surgeries to keep cold and warm ischemia times to a minimum, and deciding on the method of PV reconstruction *before* starting the allograft implantation are essential to be successful. The technique depends on extent of thrombus and quality of vessel wall [25–28]. The presence of thrombophlebitic changes should be approached very carefully. The thrombosed PV is transected flush to the liver parenchyma, the dissection done till the spleno-mesenteric confluence, and the thrombus progressively freed by using the (carotid endarterectomy) eversion technique, while the left index finger of the surgeon occludes the spleno-mesenteric confluence from behind (Fig. 12.3a). This technique allows transplanting safely most recipients even when presenting an extended thrombosis. If impossible, a pre- or retropancreatic, venous interposition graft between donor PV and superior mesenteric vein (SMV) or left renal vein (renoportal ansatomosis)

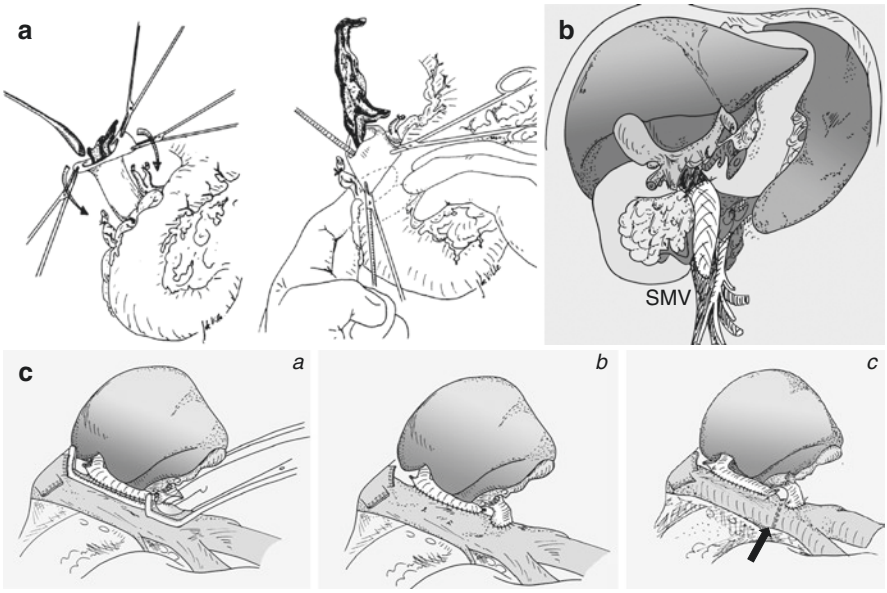

Fig. 12.3 Technical adaptations in case of splanchnic venous thrombosis: (**a**): eversion thrombectomy; (**b**) free iliac venous "jump graft" between the donor portal vein and the superior mesenteric vein (SMV); (**c**) Modified cavoportal hemi-transposition technique in three simple steps: (*a*) latero-lateral cavo-caval continuous anastomosis; (*b*) portocaval end-to-side anastomosis and (*c*) transversal stapling of the vena cava (arrow). The last maneuver eliminates the existence of blind sacks and so the formation of possible clots by directing all "systemic and splanchnic venous blood" to the liver graft

can be used [29, 30] (Fig. 12.3b). Sometimes, it is possible to connect the D-PV to the choledochal left gastric, hepatoduodenal, bile duct, gastro-epiploic, and ileocolonic varices. Intraoperative venography is useful to identify these varices [27, 29, 30]. The cavoportal hemi-transposition can be a very useful option in case of porto-spleno-mesenteric venous thrombosis in order to avoid the much more invasive combined liver-intestinal transplantation [31, 32]. A personal modification of this technique is represented in Fig. 12.3c. PV arterialization, reported with various successes in these challenging situations, can be lifesaving but does not allow to obtain good long-term outcome [31].

Surgical porto- or mesocaval shunts are left intact until the end of the hepatectomy as they may serve as "partial VVB" throughout the procedure. A distal spleno-renal shunt can eventually be left intact. If electromagnetic flow measurement (EFM) reveals inadequate portal perfusion, the shunt must be closed, the safest approach being the ligation of the left renal vein at its ending into the IVC. If too dangerous, shunt closure can be done using intra- or peri-operative interventional radiology [27].

Arterial and portal flows need to be assessed by EFM and Doppler US. If unsatisfactory, the haemodynamic constellation or anastomotic technique needs to be questioned immediately. Proximal ligation of the splenic artery and/or interruption

of spontaneous or surgical portosystemic shunts, both conditions leading to steal phenomena, and section of the arcuate ligament to free the coeliac trunk frequently enable to obtain an adequate vascularization [33, 34]. Simultaneous reperfusion of both PV and HA, aiming at reducing ischaemic biliary damage and attenuating reperfusion syndrome, has been rarely reported. Its real benefit has not been proven [35–37].

The biliary tract: Biliary problems still remain the "Achilles' heel" of LT. The incidence is still around 20% [38–40]. Especially, non-anastomotic biliary lesions [or ischaemic-type biliary tract lesions (ITBL)] often result, despite repeated radiologic and/or endoscopic interventions, in re-LT because of refractory sepsis and/or secondary biliary cirrhosis [39–41]. Adequate rinsing of bile ducts at procurement, shortening of ischaemic times, and more deliberate use of machine perfusion are all of help to reduce their incidence [42–44]. End-to-end or side-to-side duct-to-duct reconstruction should be done whenever possible because having several advantages: (a) simplicity, (b) avoidance of biliary tract bacterial pollution (a condition linked to intrahepatic biliary stricturing), and (c) easier (endoscopic) access for both diagnosis and treatment. If the R-bile duct is absent (because atretic or resected) or abnormal (because of portal cavernoma and sclerosing cholangitis), Roux-Y hepatico-jejunostomy (RYHJ) is necessary. If not possible, as a consequence of digestive disease (inflammatory bowel disease) or surgery (extensive bowel resection or colectomy), choledochoduodenostomy represents a valid alternative [45]. In the case of primary sclerosing cholangitis, duct-to-duct should be favoured if the R-duct is healthy. RYHJ has indeed been shown to be linked to a much higher incidence of ITBL [46].

The use of T-tube or stent remains controversial although there is again a trend to favour biliary stenting due to the frequent use of extended criteria and cardiac death donors [47, 48]. If used, the exit site should be at least 0.5 cm from the suture line in order to avoid ischaemic damage [38]. Different Asiatic teams introduced in LDLT microsurgical and telescopic anastomotic techniques as well as use of nonabsorbable polypropylene suture to reduce the fibrotic process during suture healing [49–51]. Extending these experiences to the field of PM-LT is worthwhile to consider.

12.2.2 Surgical Technique: Individualization is Key

In order to be successful, LT surgery needs to be individualized to the recipient and his/her underlying disease. Four conditions need particular attention: a) the severity of portal hypertension, b) the vascular status, c) the donor–recipient (D/R) weight matching, and d) the nature of the liver disease.

A. Portal hypertension is absent in non-cirrhogenic metabolic diseases and acute liver failure and mild or absent in primary and secondary hepatobiliary cancers. In these situations, IVC clamping is frequently poorly tolerated, and IVC sparing LT technique should here be preferred; if technically not possible VVB should be installed.

In the case of liver congestion due to vascular diseases (Budd–Chiari syndrome, Rendu–Osler–Weber disease) and cardiac disease (familial amyloidotic polyneuropathy [FAP]) or in case of severe portal hypertension (frequent in alcoholic and cholestatic cirrhosis), early de-arterialization makes the hepatectomy easier. Temporary (right) portosystemic shunting from the very beginning of the procedure may be useful to reduce portal pressure and thus bleeding [52].

B. Modified vascular status may render LT hazardous. Congenital (due to hypoplastic, anomalous or absent PV or IVC) or acquired (due to splanchnic venous thrombosis, arteritis following locoregional cancer treatment, and surgical portosystemic shunting) vascular anomalies, status after upper abdominal surgery, and previous LT require optimal timing of D and R surgeries in order to reduce to a minimum ischaemia times. Harvesting arterial and venous vascular grafts in the donor is important because frequently needed to solve complex intraoperative situations. In the case of Budd–Chiari syndrome or inappropriate positioning of TIPSS, a transdiaphragmatic approach to the suprahepatic IVC may be warranted.

C. Donor–recipient weight matching is an underestimated feature in LT. Too large grafts make the implantation difficult, too small grafts lead to liver insufficiency or small-for-size syndrome [53, 54]. D/R pairing should respect a 20% weight difference in favour of the recipient. In the case of hepatomegaly (encountered in cholestatic liver and polycystic liver disease or tumours such as haemangioendothelioma), this rule does not apply. Transplantating small grafts, defined as a graft to body weight ratio of ≤ 0.5, should be abandoned because responsible for major cholestasis, coagulation disturbances and ascites formation [51, 53]. Too large grafts frequently cause a compartment syndrome resulting in ischaemic necrosis of the graft and severe respiratory or wound problems. A silastic mesh closure maybe a temporary solution to the problem [54, 55].

D. Malignant diseases should be approached using a minimal mobilization of the liver and a "no-touch" technique to avoid tumour dissemination or rupture. Organs adhering to a tumour (diaphragm, adrenal gland, duodenum and colon) need to be removed en bloc with the tumour. Conversely, close contact of a tumour with the IVC exceptionally requires vascular resection as invasion is very rare in the absence of clinical symptoms [56].

12.2.3 Surgical Techniques: IVC Resecting Versus IVC Sparing LT

A. Classical liver transplantation (CL-LT) implies removal of the retro-hepatic IVC with the diseased liver and use of VVB [1] (Fig. 12.4a). Once all Glissonean structures are divided, the IVC is clamped above the liver using a large, curved clamp and below the liver using a straight, angulated clamp. The hepatic veins (HV) are cut flush to the liver parenchyma, and the different septa between them are divided to create a large anastomotic cuff. Implantation time is prolonged as two IVC anastomoses are needed. After reperfusion, the VVB is removed once the R-haemodynamic condition is stabilized.

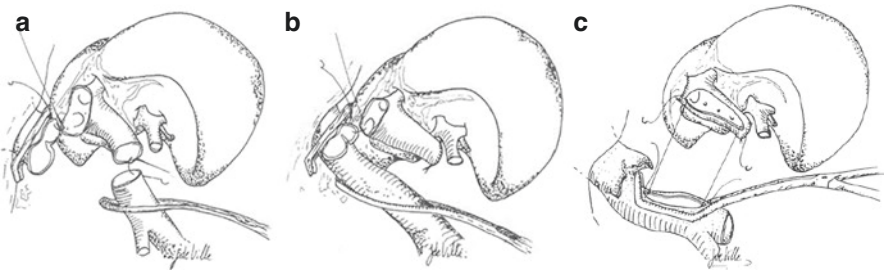

Fig. 12.4 Liver allograft implantation techniques: (**a**) classical technique with inferior vena cava resection needing two caval anastomoses; (**b**) piggy-back technique needing only one suprahepatic caval anastomosis; and (**c**) latero-lateral cavo-caval implantation offering one large anastomosis. To perform this anastomosis safely, a specifically designed clamp has been developed

B. Piggy-back IVC sparing liver transplantation (PB-LT). The diseased liver is disconnected from the retro-hepatic IVC (this maneuver is described below in detail) and the orifices of LHV and MHV are joined [2–4] (Fig. 12.4b). In the case of good D/R weight matching, the diameters of suprahepatic donor IVC and recipient L-MHV cuff usually fit. This cuff may need to be enlarged by incising the R-IVC in an upward and right direction, leaving the stapled RHV intact. The different orientations of the L-MHV cuff (horizontal) and the RHV (vertical) indeed imply that interconnecting both orifices needs an (almost) IVC occlusion to perform the caval anastomosis. The main advantage of the IVC sparing technique, namely avoiding total IVC clamping, is thereby lost. PB-LT requires only one caval anastomosis. The lower IVC cuff is shortened (described below).

C. Cavo-caval IVC sparing liver transplantation (CC-LT). This technique is described more extensively because used more and more frequently [5, 6] (Fig. 12.4c). The high transection of bile duct and HA and skeletonization of the PV to the level of the pancreaticoduodenal vein allow easier rotation of the right liver lobe to the left upper quadrant and to better expose right and anterior sides of the R-IVC. The division of the retrocaval (Makuuchi) ligament is the key element in the *flush* dissection of the R-IVC, especially when the prominent part of the caudate lobe encircles the R-IVC. All smaller Spieghelian veins and right accessory vein(s) are ligated from below upward (Fig. 12.5). In this way, the RHV is easily encircled and transected using the endovascular stapler (United States Surgical Corporation, Norwalk, Connecticut, USA). The R-IVC usually does not need to be encircled nor clamped at the level of the diaphragm. Encircling is safer in cases of huge hepatomegaly or re-LT. Precise stapler application close to the parenchyma permits safe and tight transection of the HV without narrowing the R-IVC. This vascular closure also avoids bleeding from the parenchymal side when extensively mobilizing the liver. The transection of RHV allows the liver to be rolled off further from the R-IVC and aids in the safe isolation of the MHV and LHV. At the end of this dissection, the R-liver remains attached only to the PV and the L-MHV cuff. This constellation allows to finalize retroperitoneal haemostasis

Fig. 12.5 Recipient vena cava sparing hepatectomy technique. The native liver is rolled off the inferior vena cava, and all Spieghelian and accessory veins are ligated from below upward. The stapling of the right hepatic vein makes this approach easy and safe

(using argon beam coagulation and suture ligation) before completion of the hepatectomy. PV section and MHV-LHV cuff stapler transection can be done almost simultaneously. Autotransfusion is achieved in case of benign liver disease by compressing the organ just before transection of the HV cuff. The prepared allograft can be implanted immediately following liver removal, shortening thereby markedly the anhepatic phase. During back-table preparation, the retro-hepatic IVC of the allograft needs careful preparation. The lower cava cuff is shortened up to the level just below the first major vein draining segment I, and the upper cava cuff is shortened flush to the hepatic veins. Both IVC ends are closed with running sutures. The papillary (or Spieghel) process is mobilized and a 6 cm (or three fingers) long cavotomy made on the left posterior side of the donor IVC (D-IVC); this incision encompasses the orifices of the major HVs in order to optimize venous drainage and permit later eventual procedures such as transjugular biopsy, hepatic vein stenting or TIPSS placement. The D-liver is implanted using *one large* anastomosis between left posterior D-IVC wall of and anterior R-IVC wall under partial clamping of R-IVC. A specially designed Satinsky-Lerut vena cava clamp allows to do this safely (Ulrich AG, St Gallen, Ch). The anastomosis can be done from the left or right side using running sutures (Fig. 12.4c). The lateral cava clamp is opened when finishing the anterior part of the PV anastomosis in order to allow retrograde, sanguinous, flushing of the allograft and restore complete caval venous return to the heart just before completion of the PV anastomosis. If D/R weights are matched, implantation can be done within 30 min. VVB is exceptionally needed in CC-LT. This CC-LT technique is also very useful in right split LT as the right lobe falls down in the right upper hepatic fossa and gives a superb exposure to both donor and recipient IVCs (Fig. 12.6).

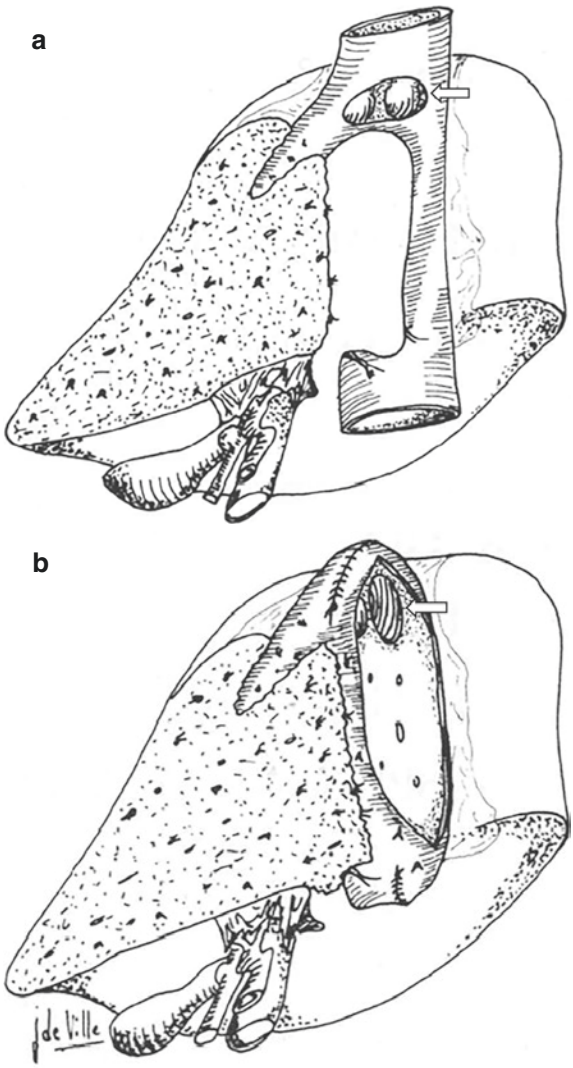

Fig. 12.6 Back-table preparation of a right split liver graft in case of recipient vena cava sparing hepatectomy: (**a**) the orifice of the excised left hepatic vein [arrow] (for the left lateral liver graft) is closed horizontally and (**b**) a long cavotomy is made at the posterior side of the vena cava, encompassing the orifices of the major veins [arrow]

D. Rapid IVC sparing recipient hepatectomy techniques.

K.W.Lee's "rapid high hilar dissection hepatectomy" is based on the extensive Seoul National University Hospital LDLT experience [57]. Partial freeing of the R-IVC from the liver is followed by RHV and L-MHV-cuff encircling and total HDL tourniquet occlusion. While pinching the HDL with the left-hand fingers, the hilar plate is bluntly dissected and all Glissonian pedicles are cut intrahepatically. After rapid completion of the perihepatic, dissection, the liver is lifted up and the RHV and the MHV-LHV cuff are clamped and transected. The PV is afterward isolated within the HDL and clamped separately. The HA branches are isolated from the remaining (still clamped) structures and clamped with microsurgical clips. After selection of the adequate bile duct for duct-to-duct anastomosis, all bleeding vessels are sutured.

Zheng's "clamping IVC first, no touch R-IVC sparing hepatectomy" aims at reducing blood loss as well as cancer recurrence [58, 59]. After "en masse" ligation of the HDL structures, two large, curved, vascular clamps are applied vertically without any dissection, above and below the liver in such a way that they encompass all three HVs and touch each other retro-hepatically. The occluded IVC allows, after rapid and blunt severing of the coronary ligaments, to rotate the liver to the left and to clamp and ligate all accessory hepatic and Spieghelian veins.

Both techniques allow to take out the liver within 30 min.

IVC sparing hepatectomy techniques have been proven to be possible free of anatomical consideration and regardless of the R-condition. These techniques have several advantages compared with the CL-LT with IVC resection: a) precise dissection during hepatectomy, based on the principles of anatomical surgery and surgical anatomy, reduces the need for blood product and fluid use; b) avoidance of injuring para- and retrocaval venous collaterals, diaphragm, and phrenic nerve reduces bleeding and respiratory and thoracic problems; c) preservation of R-IVC flow, vital for the different abdominal and thoracic organs avoids splanchnic and renal venous congestion and promotes hemodynamic stability, adequate venous return and filling during the anhepatic phase; d) elimination of VVB avoids (life-threatening) complications such as air or blood clot embolism, lymphatic fistula, wound infection and nerve injury and e) reduced need for transfusion, artificial ventilation, expensive pump material and technicians lowers the cost of the procedure [1, 3, 5, 6].

12.2.4 Particular Technical Aspects of Transplantation in Adults

12.2.4.1 Re-Transplantation (re-LT)

In the case of early as well as late re-LT, the anastomotic cuff(s) of the previous allograft should be preserved [1, 6]. In IVC sparing LT, the failed graft can be removed without interfering with IVC flow by lifting up the liver and applying the large IVC clamp just beneath the previous end-to-end or latero-lateral anastomosis [5]. In the case of re-LT following previous CL-LT with IVC replacement, the previous allograft-IVC can also be preserved because planes between allograft parenchyma and anterior IVC side as well as the one between the HVs and IVC have not been approached previously [60] (Fig. 12.7a). Sometimes, it may be impossible to identify after previous CL-LT the IVC; in such cases, r*etrograde* hepatectomy (this means removal of the liver from above downward), which can be done using the same, above-described, principles (Fig. 12.7b). Sometimes, it may be necessary to isolate the IVC in the thorax through a vertical, pericardium sparing, cut of the diaphragm [61].

12.2.4.2 Sequential or Domino Transplantation (DLT)

In 1984, sequential or DLT was introduced by Furtado in Coimbra [8]. This technique is based on the knowledge that some non-cirrhogenic, liver-based, metabolic diseases such as FAP (or ATTRv), maple syrup disease, hyper) homocyteinemia, methylmalonic acidemia and hypercholesterolemia are slowly transmitted to a minority (up to 10%) of recipients who do not have these inherited treats [8, 62]. Primary hyper-oxalosis is a contraindication to DLT as the recipient rapidly develops end-stage renal insufficiency.

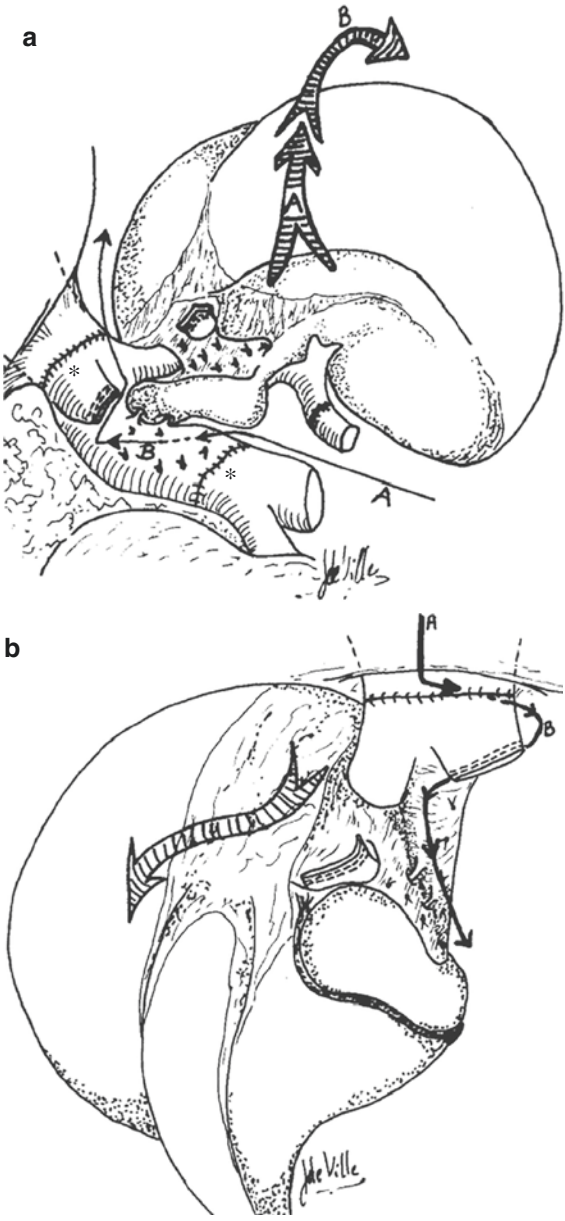

Fig. 12.7 Recipient vena cava sparing hepatectomy technique in case of re-transplantation after classical transplantation: (**a**) the liver is rolled off from the "previous" donor inferior vena cava [* previous vena cava suture lines]; (**b**) in case of inaccessibility, a left approach and retrograde hepatectomy may be necessary with stapling of the trunk of middle and left hepatic veins

This procedure, merely used in elderly and/ or oncologic recipients, allows, starting with one "metabolic liver" to transplant two or even three (in case this graft is split) recipients. In order to not compromise the "domino liver donor" nor the implantation of the graft, a modified IVC sparing hepatectomy technique without use of VVB has been developed (Fig. 12.8). In order to lengthen maximally the

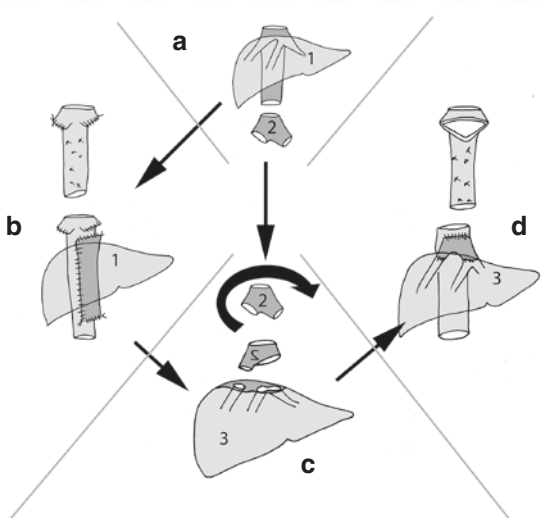

Fig. 12.8 Sequential or domino liver transplantation technique. (**a**) The liver (1) is retrieved from a post-mortem donor together with the iliaco-caval bifurcation (2) of the same donor as a free vascular graft; (**b**) In the first (FAP-) recipient, the native vena cava is preserved; the native (or domino) liver (3) is explanted the hepatic veins being cut flush to the liver parenchyma. Depending on their anatomical variation, left and median hepatic veins are either together or separated. The post-mortem allograft (1) is implanted using a large latero-lateral cavo-cavoplasty; (**c**): On the back table, the iliaco-caval homograft is swapped over 180° (2). The iliac part of this graft is sutured to the right hepatic vein; the caval part to the joined middle and left hepatic veins of the domino liver (3). In some cases, left and middle hepatic veins have to be joined using venous patches to obtain again one ostium; (**d**): In the second recipient, the vena cava has been preserved and the domino liver (3), extended by the venous homograft (2), is anastomosed in a piggy-back manner onto the cuff of left and middle hepatic veins. The RHV is usually closed with the vascular stapler; in some cases it may be necessary to interconnect all three hepatic vein ostia to obtain a good venous allograft outflow

venous hepatic cuff of the "domino liver donor," the phrenic veins are suture-ligated and all three HVs are transected flush to the liver parenchyma. The HA is divided at the bifurcation of gastroduodenal and common hepatic arteries, the PV one cm below its bifurcation, and the bile duct just above the level of the cystic duct. On the back table, the liver is flushed and the orifices of RHV and cuff of MHV and LHV are anastomosed to a free iliaco-caval or reno-caval vein graft (ideally) from the same PM donor in order to create a new venous outflow tract (Fig. 12.8). When turned around for 180°, the diameter of the left common iliac vein, divided one cm below its confluence with the IVC, exactly fits the diameter of the RHV, and the diameter of the L-MHV cuff fits the lower part of the IVC (Fig. 12.9). If MHV and LHV are too far from each other, they need to be joined using venous patches. Such newly constructed "suprahepatic cuff" fits exactly the joined orifices of the R's L-MHV cuff; trimming is necessary to avoid kinking and outflow obstruction. When scheduling a DLT, one should be assured of the absence of an advanced fibrosis ("cardiac liver") which can be encountered in around 20%

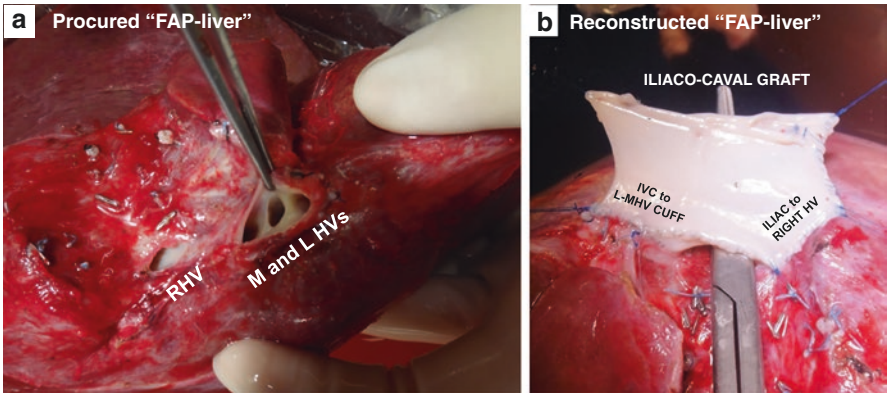

Fig. 12.9 Intraoperative view of (**a**) procured "FAP-liver" with the hepatic veins cut flush to the liver parenchyma and (**b**) backside of the reconstructed "FAP-graft." The IVC orifice exactly fits the diameter of left and middle hepatic vein (L-MHV) cuff and the orifice of the iliac vein exactly the right hepatic vein (RHV) one

of mutations leading to the development of a restrictive cardiomyopathy. This procedure has also been reported in the context of LDLT.

12.2.4.3 Auxiliary Partial Liver Grafting (APOLT)

Auxiliary partial LT (APOLT) was developed to treat acute liver failure and inherited, liver-based, metabolic diseases (Crigler-Najjar, ornithine transcarbamylase deficiency citrullinemia, propionic academia, hypercholesterolemia, and haemophilia) [63, 64]. This concept has also been applied in transplanting hyperimmunized renal patients, the partial liver graft serving as a successful absorber of harmful antibodies, reported in about 80% of patients [65]. In the case of acute liver failure, the selection of the recipient has to consider the presence of advanced fibrosis as this condition will interfere with the regeneration process of the residual, native liver [11, 12, 66]. In this situation the main interest of APOLT is related to the withdrawal of the immunosuppressive treatment once the native liver part has overcome the acute liver damage. If so the partial liver graft can be (immunologically) abandoned and even removed.

Several logistical limits and technical difficulties question the interest of this procedure in children and especially infants. The procedure is difficult to use in small infants to whom oversized grafts are usually allocated; obtaining an adequate balance between portal flows of the native and the grafted livers may therefore be difficult to obtain [64, 67]. Moreover, assessment of the postoperative function and liver tests, which may stay relatively low despite ongoing (also immunologic) damage to the graft, can be difficult. For all these reasons, APOLT remained anecdotal in the pediatric setting. Recently more experience with this type of graft has allowed to improve the results of APOLT [67].

Key Points

- Successful LT needs a good strategic plan taking thereby into consideration frailty and underlying disease of the recipient, degree of portal hypertension, presence of modified vascular status and donor–recipient weight match.
- The transplantation procedure starts with the organ procurement. Donor and recipient operations must be timed well in order to shorten ischaemia times especially in case of preexisting splanchnic venous modifications, previous right upper quadrant surgery and re-transplantation.
- Arterial and venous vessels should be harvested appropriately as they frequently act as lifesavers when complex vascular situations are encountered.
- The inferior vena cava preserving hepatectomy should become the preferred technique of LT.
- Before starting the allograft implantation, one should be assured of the method of portal revascularization.
- More and more recipients present with a compromised arterial status due to their advanced age or underlying oncologic disease. All different extra-anatomical arterial reconstructions should be part of the armory of the transplant surgeon.
- Biliary problems remain the Achilles' heel of the procedure especially in the era of cardiac death and extended criteria donors. Machine perfusion might be of help to reduce the incidence.
- Split liver transplantation needs to be developed more aggressively to enlarge the allograft pool. The implementation of partial auxiliary and sequential liver transplantation techniques have also to be seen in this context.
- Implementation of several technical refinements developed in living donor LT should be considered in post-mortem LT.

12.3 Pediatric Liver Transplantation

12.3.1 Introduction

The epidemiology of liver diseases in the paediatric age range is characterized by a dominant prevalence in young infants, which is associated with a higher demand for transplantation in the youngest ones. For that reason and also because significant growth retardation is associated with their condition, many candidates for LT are less than 12 kg and less than 2 years of age. In a context of severe shortage of size-matched liver donors, this situation of high demand and low offer led to prolongation of waiting times, often associated with clinical deterioration, high pre-transplant death rates and increased post-transplant morbidity and mortality. To face this situation, pediatric transplant surgeons developed techniques for preparing "technically variant" liver grafts, using the liver from larger donors for transplantation in the

small recipients. Initially, the strategy aimed at reducing the mass of the liver, by resecting a part of or the totality of the right liver. These grafts were called "reduced," "partial," or "cut-down" liver grafts. This strategy allowed a rapid growth of pediatric transplant programs in the 90s as well as mushrooming of new centers [68–74]. With the evolution of technical skills, the preparation of the left lateral segment (segments II–III) consisted at some point of an extended right hepatectomy. This experience paved the way to the division of the liver into two halves (right and left "hemi-livers") each preserving their dedicated vasculo-biliary support; the "split graft" concept was born. Because the splitting technique maximizes the organ offer by providing two grafts, it became progressively the worldwide, gold standard allowing to prepare small (left) grafts for small candidates and larger (right) grafts for small adult recipients. This concept of liver division was "extended" to right or left, living donor hepatectomy. The latter techniques not only allowed a rapid development of both adult and pediatric LT in countries where organ donation was absent or scarce, but it also became the most important source of liver grafts for small recipients worldwide. Large and expert pediatric centers nowadays combine all these techniques in order to timely transplant children, resolving so the imbalance between organ demand and offer in pediatric LT [75–80].

12.3.2 Selection of Donors

A. Age: The consensus is to not use donors less than 3 months (because of liver immaturity and small-diameter vessels are risk factors for early graft dysfunction and thrombosis) or more than 45 years ("quality-positive" selection and ethical considerations) of age, although some teams accept donors up to 60 years of age especially in urgent conditions.

B. Weight: Conceptually, "any weight" liver donor can nowadays be downsized to what is adequate for the recipient by using one of the described technical variants. There are, however, some clinical, logistical, and practical limitations due to the fact that large donor livers are proposed for splitting and preparation of a left lateral segment, and that pediatric small-donor livers are used full size. As these graft types are mostly allocated to recipients <30 kg, the intermediate age/weight group (30 to 60 kg) often experiences prolonged waiting times. For the latter group, tailored solutions for equitable allocation, which may possibly vary between countries and allocation systems, should be designed.

C. Donor characteristics: Adding a variant procedure to the graft at procurement (in situ split) or at back-table work (ex situ split or reduction) may be associated with a reduction of the transplanted parenchymal mass, an increase of ischaemic time, or a potential damage to the graft. Optimal donor selection and timing of donor and recipient procedures are therefore warranted when variant techniques are used to prepare a graft. The following criteria have been proposed: donor haemodynamic stability (no recent significant hypotension or cardiac arrest), with low or mild inotropic support, normal or slight alteration of liver tests (< 2× nrl) and normal macroscopic aspect at procurement (no steatosis nor fibrosis) [81, 82].

D. ABO compatibility or identity is recommended. Incompatibility is accepted for infants aged <18 months because they present with low natural anti-A/B isoagglutinin titers (>1/64). This advantage allows to significantly expand the potential donor pool for this age group [83].

12.3.3 Surgical Techniques for Liver Procurement and Graft Preparation

12.3.3.1 Standard Liver Procurement in Post-mortem Donors

En bloc procurement and aortic-only perfusion are recommended to reduce the risk of trauma to the vessels and the time of surgical preparation in the donor. A variety of venous and arterial grafts must be procured from the donor; vascular reconstructions are indeed frequently necessary in infants and in split LT. When necessary, vascular reconstructions will preferably be done during back-table work.

12.3.3.2 Splitting Livers from Post-mortem Donors

Liver division can be performed either in or ex situ, using similar techniques [72, 74, 75]. In situ division can be performed in a haemodynamic stable donor without the risk of compromising the other organs; it offers the possibility of shipping both grafts to two different recipient hospitals at the end of the procurement. Moreover, insurance of optimal haemostasis of the cut surfaces and reduction of ischaemic time to a minimum makes in situ liver splitting the best split strategy [84, 85]. Although similar outcomes have been reported after ex situ splitting, the latter approach is logistically and surgically more demanding and is associated with higher blood loss at reperfusion. The only advantage of the ex situ procedure is the fact that it gives an opportunity to the surgeons to assess in detail the vascular and biliary anatomy, either by surgical dissection or by contrast imaging [86–88].

The division of a liver can be done in various ways, cutting along different division lines (Cantlie's or umbilical scissure lines or through segment IV) [89–91] (Fig. 12.10). Although this flexibility allows to produce a wide range of graft types with variable weights, this approach is used only in the living donor setting and in expert centers. Conversely, most centers perform the liver division in post-mortem donors along the umbilical scissure line as a standard. This approach provides a large right split graft (segments V–VIII and I), usually inadequate for or not allocated to children (except teenagers), and a small left lateral segment graft (segments II and III) weighing around 300 g and typically transplanted in an infant or a child <25 kg of weight.

12.3.3.3 Procurement from Living Donors

The techniques for division of the liver in a living donor exactly mimic the ones used for preparing a split graft from a PM donor, with the exception that only the left biliary and vascular structures are procured with the graft, whereas all biliovascular supply to the right liver remains protected [70–72]. Typically, the paediatric recipient is a small child, and the living donor is a close relative (most frequently

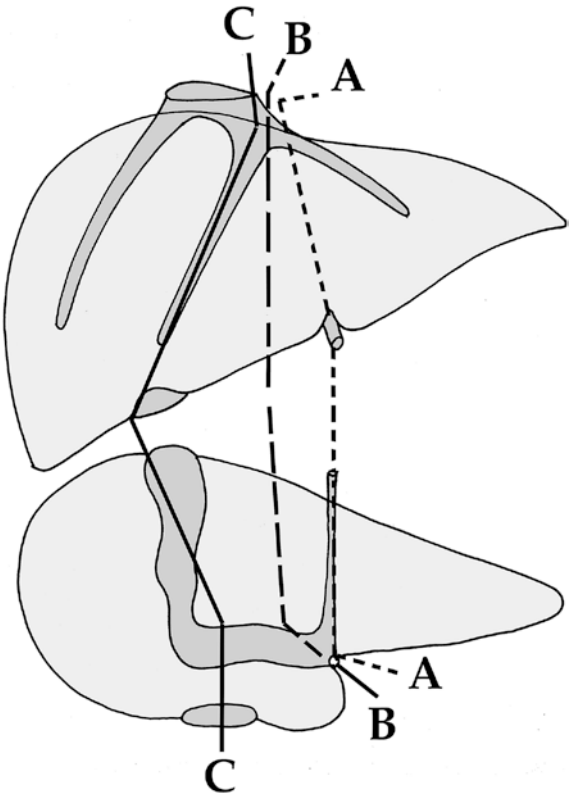

Fig. 12.10 Major techniques for parenchymal division (liver splitting): (**a**) along the umbilical scissure; (**b**) through segment IV; (**c**) or along the main scissure of the liver (Cantlie's line) with the median hepatic vein being kept with the right or left graft, or even longitudinally split

father or mother). In this setting, the left liver lobe (or left lateral segment corresponding to segments II–III) is procured.

The parenchymal division line may be modified in order to provide more parenchymal mass to the recipient. If the recipient is >25 kg, a larger graft can be procured by shifting the line of division to the right passing through segment IV or following the MHV; by doing so, larger grafts fitting larger recipients (20 to 40 kg) are obtained (Fig. 12.10). In rare situations, based on a case-by-case discussion and selection, the whole left liver (segments I–IV with the MHV) or the right liver (segments V–VIII) can be procured for older children and teenagers (40 to 70 kg).

Cholangiography during the procurement from living donors is recommended in order to identify the anatomy of the biliary system and to decide on the optimal transection plane of the bile duct without harming the donor.

12.3.3.4 Reduction Techniques

Reduction techniques have mostly been used in the late 80s and early 90s [92–94]. They consisted usually of ex situ performed, partial or full right hepatectomy; by doing so, the liver hilum is not dissected and all main structures are left with the graft. The development of the splitting strategy limited the application of this procedure to liver grafts presenting either a trauma or harbouring a right-sided,

anomaly or a benign tumor, the transplant surgeon prefers to eliminate. Accessorily, reduced-sized liver grafts can also be used for ensuring an adequate, size-matched graft to a recipient presenting such a life-threatening condition that waiting for the allocation of another lifesaving graft is a "no-option."

12.3.4 Particular Technical Aspects of Transplantation in Children

12.3.4.1 Dealing with Anatomical Variations

Portal Vein Abnormalities

Hypoplastic portal vein, *defined as a vein with a* diameter less than 5 mm, is a frequent finding in biliary atresia patients. Direct anastomosis of the donor PV to such hypoplastic PV is associated with a high risk of postoperative thrombosis [95–100]. Various approaches have been proposed to guarantee a satisfactory flow at reperfusion in this situation namely revascularization from the spleno-mesenteric junction or from the SMV with interposition of a venous graft or direct anastomosis after longitudinal plasty of the portal venous trunk from the spleno-mesenteric confluence up to the portal vein bifurcation (Fig. 12.11). This option provides the best results; the portoplasty is also used in the setting of LDLT. In these cases, the inferior mesenteric vein of the donor can be used as a venous patch for the longitudinal plasty.

Pre-duodenal portal vein is another rare condition in patients with biliary atresia and polysplenia syndrome [101–103]. The vein is always hypoplastic and presents with unusual branching. When passing the duodenal area, it enters the root of the mesentery and divides into multiple veins due to the absence of a true spleno-mesenteric junction. The pre-duodenal position exposes to lesioning or dividing the vein when the surgeon approaches the liver hilum. By presenting the vein in front of the duodenum down to the mesenteric branching, exposure and preparation for the portal reconstruction become easy; here also the longitudinal plasty of the vein is very helpful.

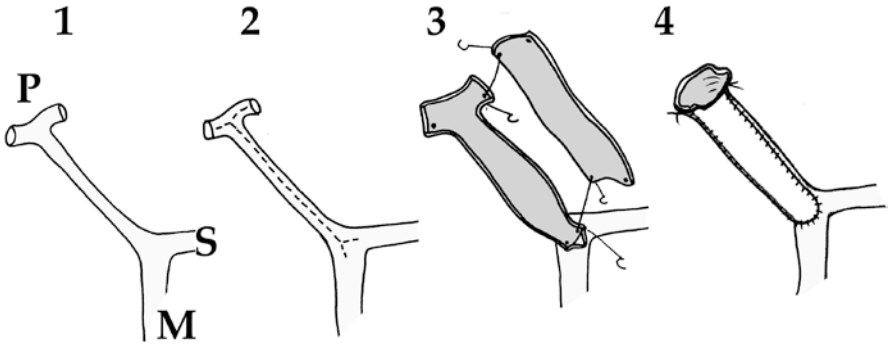

Fig. 12.11 Longitudinal plasty of an hypoplastic portal vein (1). The portal trunk is preserved from its bifurcation (P) to the Spleno(S)-Mesenteric(M) confluence. After splitting the whole portal trunk (2), a venous homograft from the same donor is sutured on the whole length of the portal trunk (3) allowing so a 100% expansion of the original split diameter (4)

Absent portal vein. This malformation of the portal system is exceptional and is associated with a variant drainage of the splanchnic vein through one (or multiple) congenital portosystemic shunts. It can be found in children with biliary atresia and polysplenia syndrome or with Abernethy malformation [104, 105]. The anomaly must be diagnosed and assessed before transplantation (Angio-CT and/or angiography) as adequate reconstruction of the portal system at LT is only possible when understanding exactly the variant splanchnic anatomy and the location of the associated congenital portosystemic shunt. Good planning is also important in relation to the closure of the portosystemic shunt, a maneuver mandatory to avoid portal flow steal and/or thrombosis [106].

Situs Inversus

Transplantation of a full-size liver in a patient with situs inversus may be difficult because the right lobe takes a median position in the abdomen [106–108]. This situation exposes to either compression of the graft or of retroperitoneal structures at closure of the abdomen. It also increases the risk of vascular kink and thrombosis and compromises abdominal closure. Using a reduced liver graft or a left split, liver graft is helpful in such case.

Absent Inferior Vena Cava

Patients with polysplenia syndrome can also present with the absence of retrohepatic portion of the vena cava (that continues into the azygos network) [101, 108]. Although some authors have proposed to reconstruct the absent vena cava by interposing a venous graft from the renal veins up to the diaphragmatic vena cava, the absence of the vein does not interfere with transplantation. The cuffs of the hepatic veins can be simply joined and creating a large enough ostium for anastomosing the hepatic vein of the graft [102].

12.3.4.2 Selected Particular Technical Aspects of Liver Graft Implantation

Implantation of Variant Grafts (Left Split or Reduced Grafts)

When the graft consists of the left liver or lobe, the main vascular and biliary structures of the graft (the hilum) are located at the right side of the graft (Fig. 12.12). Even if the graft is positioned medially in the abdomen at the end of the transplant procedure, the reconstruction of the vessels and of the biliary continuity must take into account this shift to the right and possibly adapt the technique to ensure a sufficient length for the reconstruction. The latter aspect is important when a split graft is procured with short vascular pedicles (as typically present in LDLT). Although not difficult to achieve in most cases, the modality of the biliary and vascular reconstructions must be anticipated ahead of the hepatectomy and the graft implantation in order to be adequate. The surgeon must consider (not) to keep the whole length of the native PV and to do a longitudinal plasty of the vein if hypoplastic; all branches of the extra-hepatic arteries should be sectioned as distally as possible in order to allow direct reconstruction on the right or left HA using microsurgical techniques.

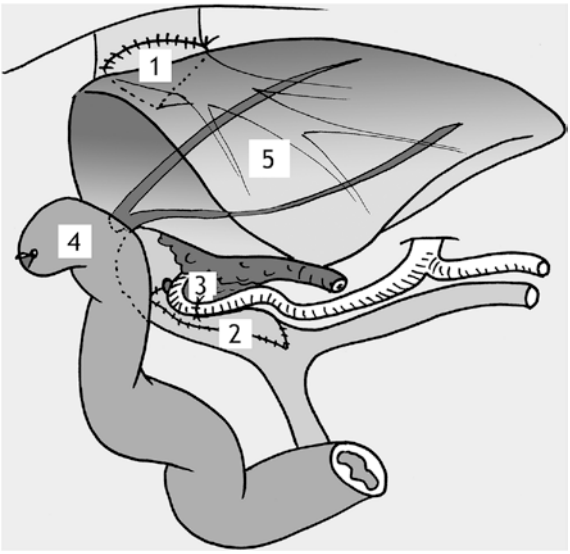

Fig. 12.12 The five key steps for transplantation of a left liver lobe (left lateral segment graft) from either a post-mortem or a living donor: (1) Large triangular-shaped piggy-back implantation onto the vena cava (using the ostia of all three recipient hepatic veins); (2): The whole portal trunk of the recipient is retained until its bifurcation, and the vein is refashioned in the case of hypoplasia (diameter < 5 mm), with an end-to-end porto-portal anastomosis; (3): End-to-end microsurgical arterial anastomosis, between the donor left hepatic artery and a distal site on the recipient hepatic arterial system; (4): Bilio-jejunal drainage with straight positioning of the Roux-en-Y jejunal loop; (5): Medial positioning of the graft followed by US Doppler check of the vascularization at end of operation, before closing the abdomen

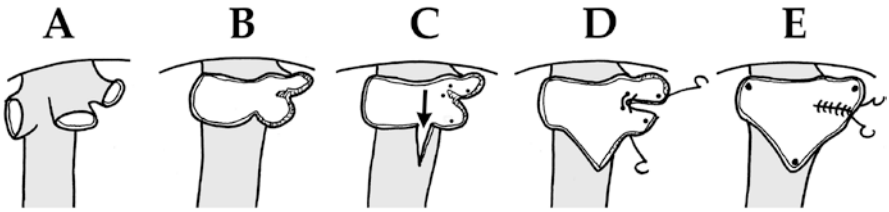

Fig. 12.13 Plasty of the hepatic vein ostia in order to obtain a large, equilateral, triangle for graft implantation. The three ostia of the hepatic veins (**a**) are joined to form a single large ostium (**b**); after vertical lateral split of the vena cava (**c**) and suturing of the left and median ostia (**d**), an ideal triangle (**e**) will be obtained

Hepatic Vein Reconstruction

Piggy-back-type implantation to the hepatic vein ostia is the gold standard in children and can be used for any type of grafts, including full-size liver grafts [7, 109–111]. Attention should be given to use a single large recipient ostium made of all three native hepatic veins, and reshaping it in a large triangle with a division of the anterior aspect of the vena cava if necessary (Fig. 12.13). In the case of left split graft, the donor left hepatic vein also is enlarged by splitting it's posterior aspect.

Biliary Reconstruction

Because most candidates are young and have small weights and because biliary atresia represents the largest recipient group, the biliary reconstruction is usually done using a RYHJ. When the loop must be brought up to the far right of the liver fossa and toward the diaphragm, typically necessary when a left split graft is implanted, a simpler positioning of the RY-loop can be obtained by putting the intestine along the liver cut surface with the tip oriented to the right diaphragm. This gesture is helpful when the loop is short.

Prosthetic Abdominal Wall Closure

Many infants and low-weight recipients are transplanted using a left split graft. Although this graft type is the smallest standard graft, it's mass (mostly representing around 300 g) outweighs the theoretical mass corresponding to the child physionomy, and it's size is larger than what fits into the abdominal cavity. In such conditions, primary closure of the abdomen is associated with a risk of abdominal compartment syndrome, ischaemic graft damage due to low perfusion, vascular thrombosis, ventilation difficulties and even liver infarction [92, 112–114]. Further reduction of the mass of the graft using the hyper-reduction technique or the preparation of a mono-segmental can solve this problem [115–117]. Another means to circumvent this issue consists of increasing the capacity of the abdominal cavity with a prosthetic closure of the muscular wall and a mobilization of skin flaps in order to allow a primary skin closure over the prosthesis. This strategy is helpful to limit the risk for infection or ascites leakage [113].

Key Points

- The current technical armory from the full-size liver to the mono-segmental graft nowadays allows the paediatric transplant surgeon to tailor the size of the liver graft to what is the minimal mass necessary for the recipient and to what is the maximum volume matching the recipient's liver fossa and abdomen, and to avoid small-for-size and large-for-size problems.
- Donor selection must take into account that variant techniques, especially splitting livers, may impose an added trauma and ischaemic time to the graft, as well as some bleeding and haemodynamic instability at reperfusion. For these reasons, donor selection criteria must be thighter in these situations.
- All recipient anatomical variations can nowadays be faced successfully with adequate techniques; attention must be given to prioritize simple strategies and technical approaches that ensure high flow reconstructions (triangular anastomosis and plasty of native veins where appropriate).
- In the situation of continuing shortage of optimal post-mortem donors, living-related donation of the left lateral segment, to be seen as a complementary strategy allowing expert teams to offer transplantation to all small weight candidates, seems to be the best way forward.

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