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*Review article*

# Anatomical keys and pitfalls in living donor liver transplantation

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**Abstract** The surgery of living donor liver transplantation is more technically challenging than cadaveric whole liver transplantation and liver resection for the treatment of various pathological conditions. It requires a thorough understanding of the intra- and extra-hepatic anatomical relationships between the portal vein, hepatic artery, biliary tract, and hepatic vein, and also their respective contributions to liver physiology. Although a precise understanding of general anatomical principles is the key to correctly performing living donor liver transplantation procedures, anatomic anomalies are often present, and the means of detecting them and the surgical methods of coping with them represent technical challenges. In this monograph, we describe the anatomical keys and pitfalls of living donor liver transplantation surgery based on our own experience with more than 1800 hepatectomies, and 150 living donor liver transplantations. We also elaborate on techniques of selective intermittent vascular occlusion and their teleological and practical background.

**Key words** Living donor liver transplantation · Anatomy · Hepatic hilum · Hepatic vein · Selective intermittent occlusion

## Introduction

The surgery of living donor liver transplantation (LDLT) is more technically challenging than cadaveric whole liver transplantation, cadaveric split-liver transplantation, and liver resection for the treatment of various pathological conditions. Donor liver resection must be performed in a way that results in a well-vascularized graft, but it must be harvested in such a manner as not to disturb the normal passage of the hepatic artery, portal vein, hepatic vein, or biliary tract in the remaining donor liver.[1–3] Consequently, the portions of these vasculobiliary structures attached to the graft are very short and often composed of two or more tributaries, which necessitates multiple anastomoses or plastic procedures.[4–6] In addition to the portal vein and hepatic arterial supply, the hepatic vein tributaries, which have their own drainage area, unite the separate portal (and hepatic) areas and are interlaced with portal venous branches.[7] Thus, great attention must be paid to this anatomical arrangement, maintaining the delicate balance between the blood supply and venous drainage system of both the graft and the remaining donor liver.[3] Furthermore, the type of donor liver resection should be planned so that the size of the graft meets the minimum requirements of the recipient's metabolic demands, and at the same time the size of the remaining donor liver is not so small that it jeopardizes the donor's safety.[8–9] In this monograph, we elaborate on some important anatomical points in LDLT, mainly focusing on the hepatectomy in the donor.

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## Estimation of graft mass

The total liver volume has a relatively constant relationship to body weight and surface area (2%–2.7% of body weight[10–11]), although the ratios are larger in growing individuals than in adults.[12] In general, the left hemiliver comprises one-third of the total liver in humans.[8] On this basis, some workers have proposed that it might be feasible to estimate the maximal recipient body weight eligible for a left or right split hemiliver graft from cadaveric donors of known body weight.[13–14] However, the ratios of left and right hemiliver volume to total liver volume vary considerably among individuals, indicating that the size graft that will be obtained cannot be predicted preoperatively on the basis of the donor body weight alone.[8] Obviously, a volumetric imaging study, either by computed tomographic (CT) scan or magnetic

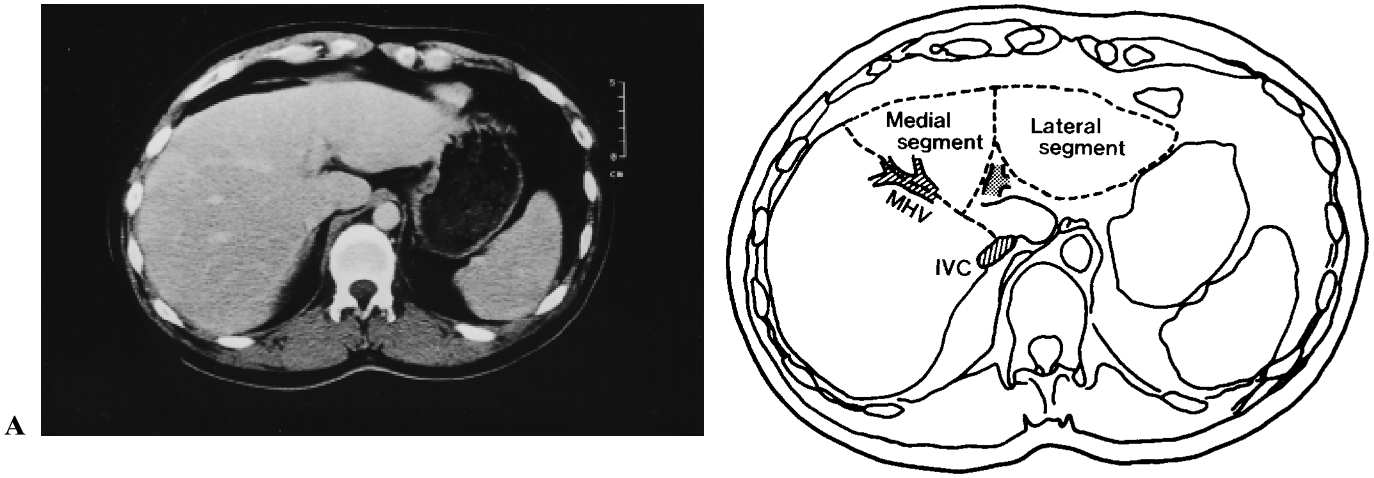


**Fig. 1.** **A** Abdominal compated tomographic (CT) scan and **B** schematic diagram of the scan for measurement of segmental liver volume. The umbilical portion of the left portal branch is used as the landmark for the borderline between the left lateral and medial segments. The border between the left medial and right anterior segments can be delineated by extrapolation of the line between the middle hepatic vein (*MHV*) and the left anterior aspect of the inferior vena cava (*IVC*). (From ref. 8, with permission)

resonance imaging, becomes an essential part of the donor workup[8,15] (Fig. 1A,B). For example, use of a right hemiliver graft is occasionally proposed for LDLT in adults, but in some individuals whose right hemiliver accounts for more than 70% of the total liver volume, this procedure leaves less than 30% of the liver behind. Such a situation is clearly unacceptable from the standpoint of donor safety. Conversely, if the left hemiliver occupies more than 35% of the entire liver of the donor candidate, use of the left hemiliver graft might be a suitable option, balancing both the recipient's and donor's safety, especially when the body size of the recipient is equal to or smaller than that of the donor. In summary, the type of donor hepatectomy for LDLT should be selected on the basis of both the segmental liver volume of the donor and the recipient's body size, to prevent liver failure in recipients and to assure the donor safety.

## Anatomy of the hepatic hilum

The main anatomic difficulties in LDLT lie in the division of the hilar structures outside the liver.[16–17] Although anatomic anomalies are common, and the means of detecting them and surgical methods of coping with them constitute the technical challenges of LDLT, a precise understanding of general anatomy is the key to correctly dividing these structures. We therefore first describe the general principles of hilar anatomy and then elaborate on the anatomical checkpoints of the portal vein, bile duct, and hepatic artery in the division of the hilar structures in relation to their anomalies.

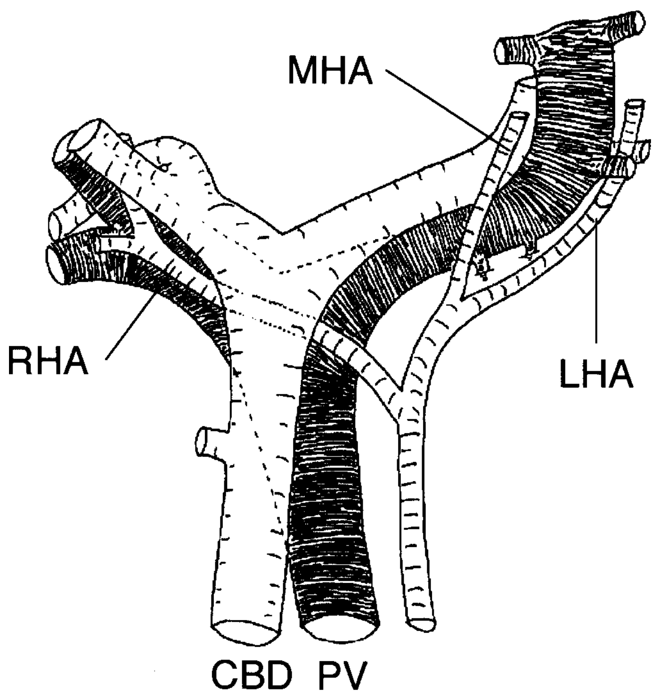


**Fig. 2.** Schematic presentation of the most common anatomy of the hilar structures. *CBD*; Common bile duct, *PV*; portal vien, *RHA*, right hepatic artery; *MHA*, middle hepatic artery; *LHA*, left hepatic artery

### *Basic anatomy of the hepatic hilum*

Figure 2 shows the most common anatomical variants of hilar structures. (1) The hepatic hilum (and the hepato-duodenal ligament) is, for the most part, composed of three layers: the portal vein in its most dorsal aspect, the hepatic artery in the middle, and the bile duct in its most ventral aspect. (2) The anatomy of the portal vein is generally very regular. Its bifurcation is located on the right side of the hepatic hilum. Its left branch consists of a transverse portion that runs from the bifurcation of the main portal vein to the ligamentum venosum, and an umbilical portion that runs upward in the umbilical fistula. (3) The bile duct normally follows an extrahepatic course very similar to that of the portal vein. Its bifurcation is located more cranially than that of the portal vein or hepatic artery. Immediately after bifurcating, its right and left branches run ventrally to portal vein, but they pass to the dorsal aspect of the right and left portal branches more cranially. Consequential anomalies of the bile duct are much more common than those of the portal vein. (4) The hepatic artery normally divides into a large right branch and a smaller left (and middle) branch more proximally in the hepatoduodenal ligament than the divisions of the bile duct or portal vein. As a result, both right and left branches have a relatively long extrahepatic course that differs from those of the portal vein and bile duct, especially in regard to the left and middle branch. The right hepatic artery is usually larger and passes behind the bile duct immediately after branding off the proper hepatic artery. The left and middle hepatic arteries travel along the left side of the hepatoduodenal ligament, with no relationship to the bile duct until the end of the transverse portion. The hepatic artery, like the bile duct, is subject to many anomalies that necessitate a variety of surgical modifications.

*Portal vein*

The transverse portion of the portal vein has a long extrahepatic course of several centimeters (Fig. 2), making it easier to obtain a longer extrahepatic portion of the portal vein in grafts from the left side than in right hemiliver grafts. Despite this, the portal vein branch attached to the graft is often insufficiently long, because the portal vein must be divided so as to leave an adequate length for closure without encroaching on the remaining liver portal vein of the donor. One key to obtaining sufficient length and mobility of the graft portal vein is to divide portal tributaries to the caudate lobe (segment I). Although some workers insist that this necessitates the resection of segment I,[17] it can be left intact with no adverse effect in the absence of afferent blood supply. Generally speaking, portal vein anomalies do not have any impact on donor hepatectomy. Some workers have reported that portal branches to segment IV originating from the right portal trunk are not uncommon, and have insisted that care be taken to preserve the viability of segment IV during donor hepatectomy;[2] however, this is obviously an erroneous statement based on a misinterpretation of the angiographic images. In a personal experience of more than 1800 hepatectomies (M.M.), no such anomalies have ever been encountered. The common anomaly that requires attention is trifurcation of the portal vein, i.e., individuals in whom the right portal vein is absent and there are separate veins origination from the main portal vein supplying the right paramedian and right lateral sectors (Fig. 3).[16] In individuals with trifurcation, the transverse portion is somewhat short, making complete division of portal tributaries to segment I even more important when harvesting a left-sided graft. The presence of a trifurcation means that the graft portal vein will consist of two branches when a right hemiliver graft is taken. There are two solutions: the first is venoplasty of the graft portal vein on the back table so that the anterior and posterior portal branches from a single lumen at the site of the anastomosis. The other is

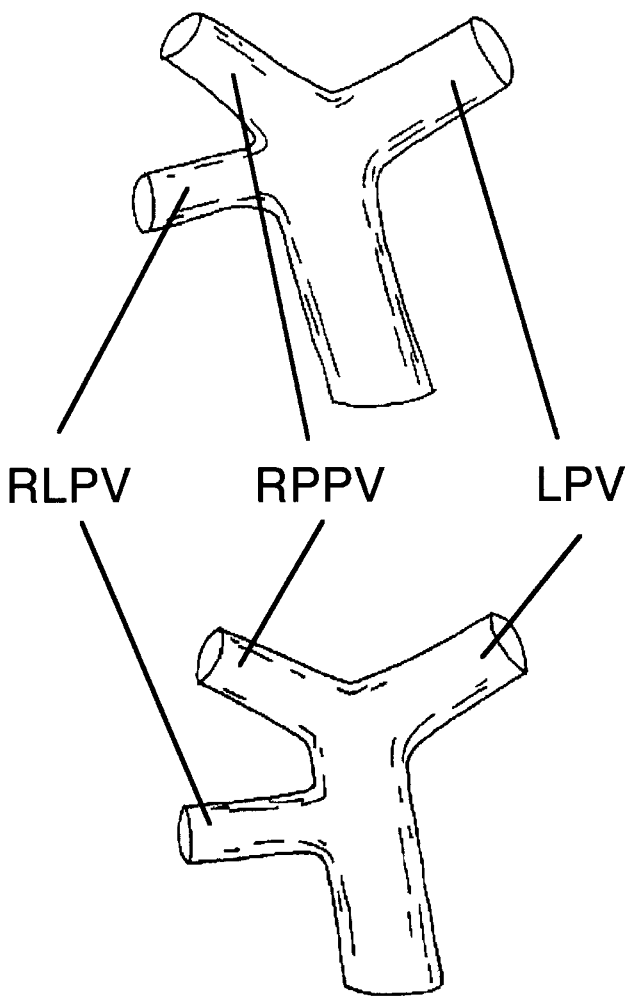


**Fig. 3.** The most common anomaly of the portal vein, i.e., trifurcation. *RPPV*, Right paramedian portal vein branch; *RLPV*, right lateral portal vein branch; *LPV*, left portal vein

to anastomoze these branches separately, and grafting the posterior branch to the recipient right portal vein and the graft anterior branch to the recipient left portal vein is the most natural means of achieving this.

*Bile ducts*

Although consequential anomalies of the bile ducts are much more common than those of the portal vein,[18,19] they rarely necessitate any special surgical modifications. In any event, intraoperative cholangiography is an essential intraoperative adjunct for visualizing the biliary anatomy and identifying the precise site of division.[1,20] After cholecystectomy is performed, liver transection in the donor is begun at the anterior edge of the liver and simultaneously advanced cranially and toward the hilar plate. Cholangiography is performed when the transection reaches two-thirds of the distance between the anterior edge and hilar plate. After the bile duct anatomy of the patient is identified, the presumed point of bile duct division is clamped with a Pean's forceps to confirm adequate residual length on the distal side of the bile duct, to avoid narrowing the common bile duct of the donor (Fig. 4B,E). The bile duct should be divided at this point (Fig. 4B,E). For the reason described under the heading "Basic anatomy of the hepatic hilum", early division of the bile duct during hepatic transection makes the procedure easier later. No attempt to obtain a single duct orifice in the graft should be made at the expense of normal bile flow in the donor. For example, when harvesting a left-sided graft from donors with a common anomaly in which the right lateral sectional duct branches directly from the left duct, the division of the bile duct becomes closer to this union (Fig. 4E). Accordingly, multiple short ducts to the graft are often encountered, and may result in an inadvertent suture or tie during the donor operation or bench surgery.[21] To prevent such complications, it is important to identify the orifice of the bile duct to each hepatic segment by inserting a surgical probe into each bile duct, occasionally using ultrasonography[22] (Fig. 5). In other words, the anomalies of order of union, such as whether or not the ducts from segments III and IV unite before receiving the branch from segment II, are of little consequence in LDLT. This issue has already been confirmed by our vast experience of extended hepatectomy for the treatment of hilar cholangiocarcinoma where the bilioenteric anastomosis at its peripheral site becomes necessary. Another point regarding bile duct anatomy that requires attention in LDLT is the arterial supply to the bile duct. The epicholedochal plexus receives its blood supply from three arterial branches (Fig. 6):[18,23] a branch of the posterior superior pancreatoduodenal artery, a branch of the right hepatic artery arising at the point where it passes behind the common bile duct, and a branch running caudally from the arteries of the hepatic hilum. Although these branches usually communicate with each other, division of any one of them may occasionally result in severe bile duct ischemia. In this regard, when collecting a right hemiliver graft, the right hepatic artery should be divided to the right of the common bile duct.[24] The arterial supply of the bile duct to the graft also requires some attention. In contrast to the left and middle hepatic artery, the right hepatic artery courses parallel to the right bile duct branch towards the liver on its dorsal aspect. Dissection of the dorsal aspect of the right bile duct branch should be avoided when harvesting right hemiliver grafts, in order not to devascularize this branch.

*Hepatic artery*

The hepatic artery, like the bile duct, is subject to many anomalies, but, in contrast to the bile duct, they require technical modifications. Consequently, the information provided by preoperative angiography is essential to surgical planning and donor safety. Variant hepatic arteries that are not peripheral hepatic branches of the celiac axis are referred to as "aberrant" hepatic arteries. These vessels may be "accessory", occurring in addition to the normal arterial supply, or "replaced", representing the primary arterial supply to the hemiliver, as described by Hiatt et al.[25] Although Michels'[26] autopsy series of 200 dissections, published in 1966, is regarded as defining the basic anatomic variations of hepatic arterial supply and as having served as the benchmark for later contributions in this area, the variations had already been precisely reported by Adachi in a series of 215 dissections almost a century ago[27] (Fig. 7). Hepatic arterial anatomy has been classified into six, ten, and five patterns by each of the three authors above, respectively.[25,26,27] Basically, these variations can be summarized as follows: (1) an aberrant left hepatic artery emanating from the left gastric artery; (2) an aberrant right hepatic artery originating from the superior mesenteric artery; and (3) the presence of these aberrant arteries as accessory, in addition to the original left (or original middle) hepatic artery, or in addition to the original right hepatic artery, or replaced. Division of the hepatic artery should be planned according to the anatomical pattern of the individual patient. For example, when an aberrant left hepatic artery arises from the left gastric artery, it must be identified in the lesser omentum and traced proximally to their origin from the celiac trunk (Fig. 8).[20] Meticulous division of all the stomach-related branches to their origin is the key to obtaining a long hepatic arterial branch in the graft. When a graft contains multiple hepatic arterial branches, there is controversy

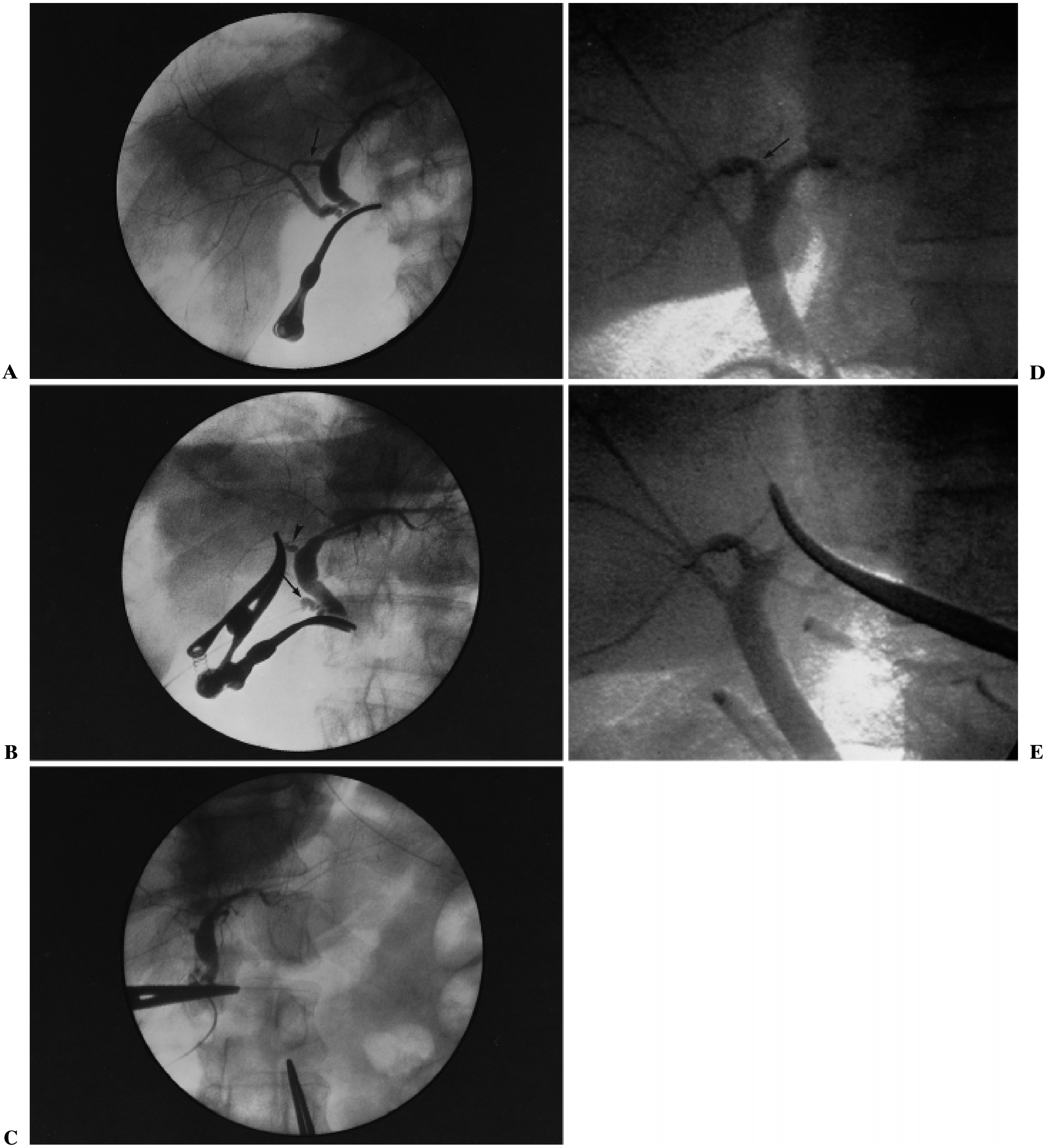


**Fig. 4A–E.** Intraoperative cholangiogram during right hepatectomy in a donor. **A** Because the bifurcation of the bile duct appearred to be located more inferiorly than usual, cholangiography was performed before the parenchymal transection. The branch to segment VII (*arrow*) arose from the left bile duct. **B** After the right hepatic duct was divided (*arrow*), the presumed point of division of the branch to segment VII was clamped with a bulldog clip (*arrowhead*). **C** Cholangiogram taken after graft harvesting. Normal biliary passage in the remaining donor liver was confirmed. **D** Intraoperative cholangiography of another donor who was undergoing left hepatectomy showed a branch to the right lateral sector arising directly from the left hepatic duct (*arrow*). **E** The presumed point of division of the left bile duct (left hemiliver graft) was clamped with a Pean's forceps. Note that the division of the bile duct is closer to this union

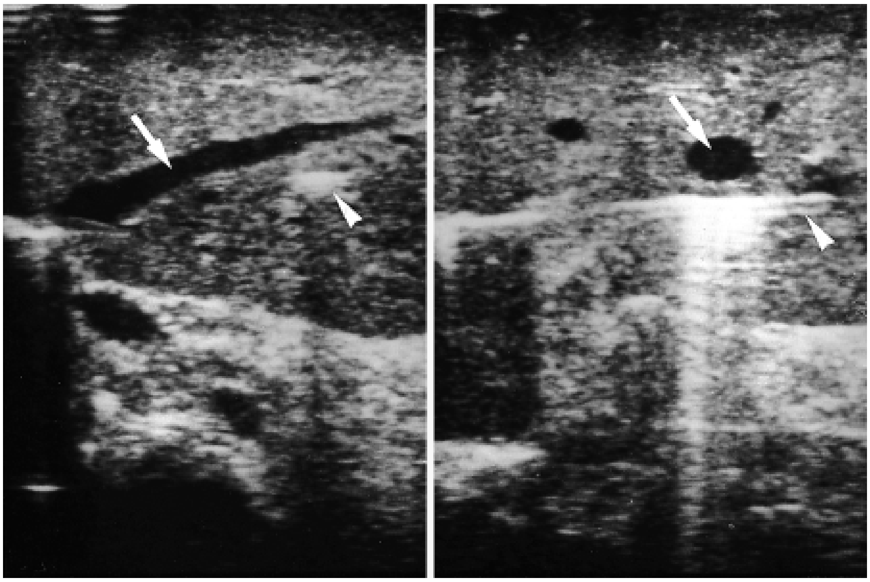

**Fig. 5.** A surgical probe (*arrowhead*) in the bile duct of the left lateral superior segment (segment II) was detected by ultrasonography. The *arrow* points to the left hepatic vein. (From ref. 22, with permission)

as to whether all of them should be reconstructed.[6,28] Some workers have hesitated to use such grafts because of their experience with technical failure;[29,30] the Kyoto group has proposed reconstruction of all arterial branches, claiming that they are basically end arteries.[28] However, when there are accessory hepatic arteries, they usually communicate with the original lobar arteries in the hepatic hilum, even though such collaterals are not demonstrated on angiograms,[31] and in the majority of cases, it is unnecessary to anastomose all the hepatic arteries supplying the graft.[6] Adequate arterial flow to the smaller non-anastomosed arterial branches through hilar communications can be confirmed at four steps in the LDLT procedure. First, it can be confirmed at the completion of donor hepatectomy by examining for pulsatile back-bleeding from the stumps of the branches when the smaller branches of hepatic artery are cut. Second, it can be confirmed at the time of graft perfusion on the back table, if perfusion fluid flushed through the largest artery flows out of the smaller arterial branches. Third, adequate arterial flow can be confirmed during the recipient operation, from the presence of pulsatile back-bleeding from the stump of the other graft arteries after reconstruction of the largest artery. And finally, by verifying pulsatile intrahepatic arterial flow in every segment of the graft by color Doppler ultrasonography. Reconstruction of a single arterial branch has another advantage in addition to its technical simplicity: the entire arterial blood supply of the graft passes through the single reconstructed artery. The blood volume and flow rate in the reconstructed artery, and consequently its size, will be greater, and this is thought to reduce the incidence of arterial thrombosis.[6]

## Hepatic veins

There are two key points in the anatomy of hepatic veins that need to be considered when performing LDLT. The first one is the anatomy of the junction of the hepatic veins with the inferior vena cava (IVC), which becomes an important issue in regard to outflow reconstruction of the graft. The second is the intrahepatic drainage territory of the individual hepatic veins and tributaries, because attention must be paid to maintaining the venous drainage system of both the graft and the residual liver during LDLT. These considerations will be discussed separately in this section.

### *Anatomy at the confluence of the hepatic veins*

Hepatic veins of the graft of sufficient length for reconstruction are not usually obtained during LDLT. And this anatomical limitation may lead to the serious problem of outflow block of the hepatic vein.[32,33] To date, several techniques of hepatic vein reconstruction have been reported in LDLT: anastomosis of hepatic veins to the IVC in an end-to-side fashion;[34,35] a wide end-to-side anastomosis in which the septum between the middle and left hepatic veins and the IVC wall of the recipient is incised to create a common wide orifice;[36] or a similar technique termed "triangular anastomosis";[37] and end-to-end anastomosis using hepatic veins of both donor and recipient. The end-to-end anastomosis technique has always been used in our institution, with a satisfactory outcome.[4,5,38] Thus, the anatomy is discussed mainly in relation to the technique of end-to-end anastomosis.

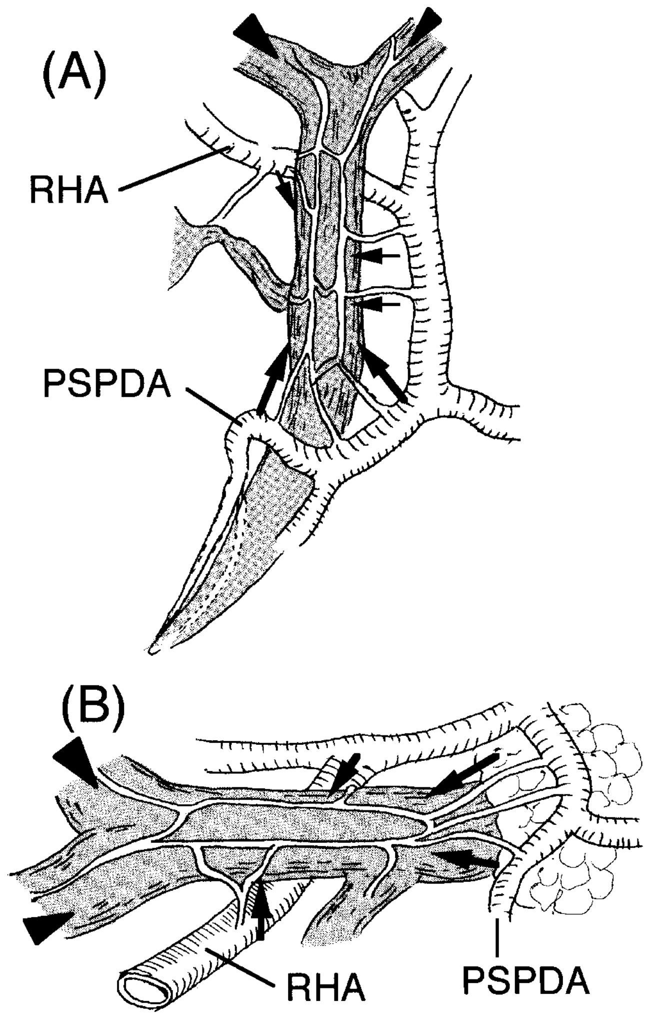


**Fig. 6A,B.** Epicholedochal plexus and its blood supply. **A** Ventral view; **B** lateral view. Arterial supply for the posterior superior pancreatico-duodenal artery (*PSPDA*; *thick arrows*), arterial supply from the right hepatic artery arising at the point where it passes posterior to the common bile duct (*thin arrows*), and arteries running caudally from the hepatic hilum (*arrowheads*)

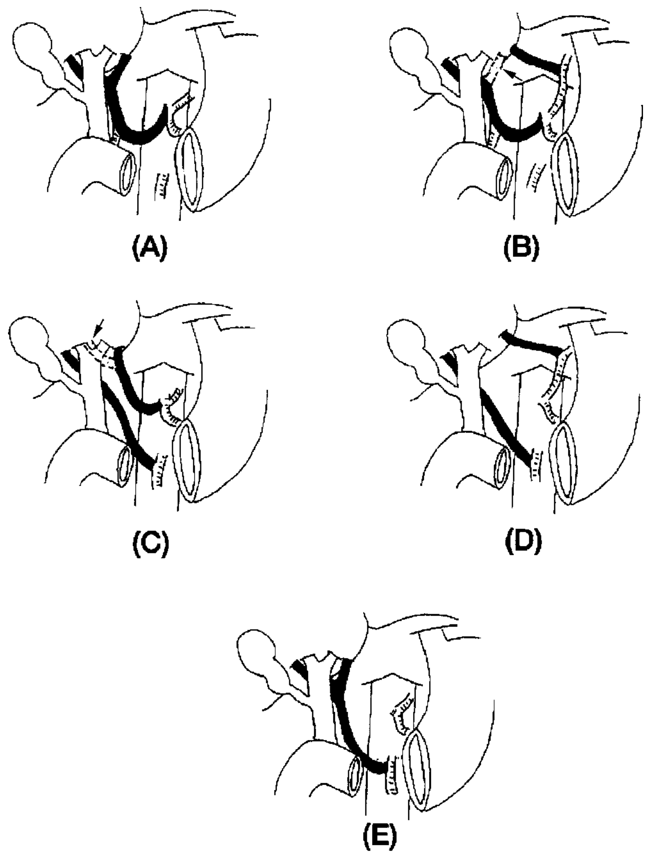


**Fig. 7A–E.** Hepatic arterial anatomy and its variants. The *arrows* indicate that the variant artery may be accessory (if the branch indicated by the dotted line is present) or replaced (if absent). **A** Normal; **B** replaced (accessory) left hepatic artery from the left gastric artery; **C** replaced (accessory) right hepatic artery from the superior mesenteric artery; **D** replaced (accessory) right and left hepatic artery; **E** common hepatic artery from the superior mesenteric artery

Of the three main hepatic veins, the extrahepatic portion of the right hepatic vein is anatomically separate and readily isolated from the middle and left hepatic veins (Fig. 9), whereas the extrahepatic portion of latter two veins usually forms a common trunk before joining the IVC.[39] Consequently, the right hepatic vein can be easily isolated extrahepatically,[40] whereas, division of the left hepatic vein, which becomes necessary when, for example, left lateral segmentectomy is performed in the donor, is carried out at the end of the liver parenchymal dissection by resecting the side wall of the common trunk and the middle hepatic vein.[1,3] Likewise, an extended right hemiliver graft using both right and middle hepatic veins requires division of the middle hepatic vein by dissecting the sidewall of the common trunk after the parenchymal dissection. Some transplant surgeons claim that intrahepatic division of the middle and left hepatic veins during the donor operation may lead to injury and narrowing of the remaining vein, subsequently ending in compromised outflow of the donor liver.[2] We maintain that this anxiety simply reflects their inexperience as liver surgeons. Division of these veins can be performed safely, if they are divided after complete dissection of the liver parenchyma around the common trunk. An ultrasonic dissector is a useful tool in dissecting around the trunk, because, compared with the forceps clamping maneuver, it dissects parenchyma of uniform thickness, making it easier to expose the common trunk. The suprahepatic IVC and extrahepatic segments of the major hepatic veins can be exposed during both donor and recipient operations by completely freeing the liver from its attachments and the retrohepatic IVC.[4] Freeing the liver from the

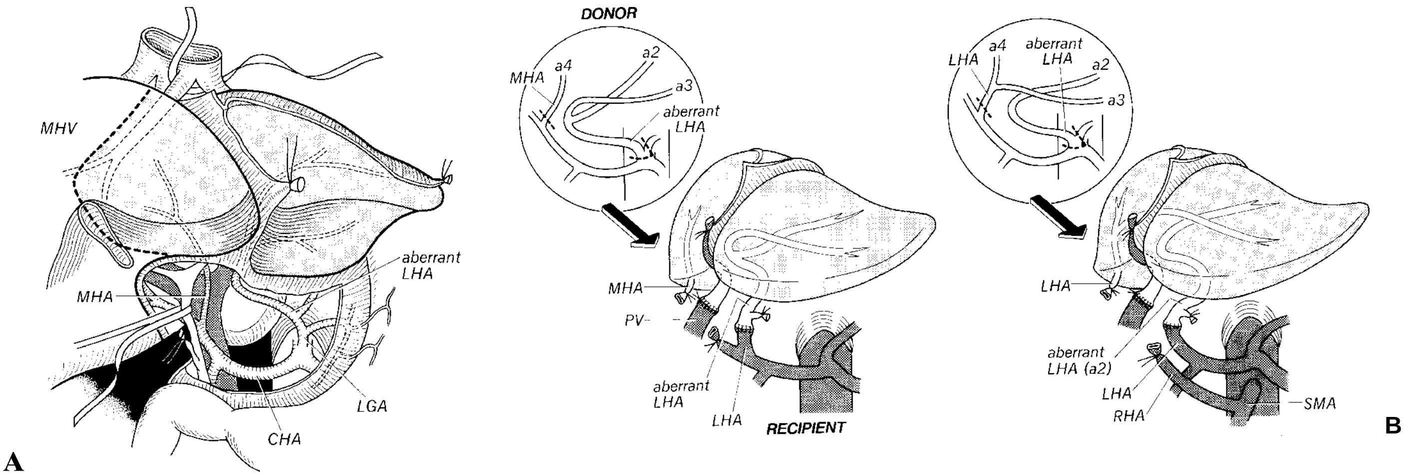


**Fig. 8A,B.** Modified surgical procedure in a living donor with aberrant left hepatic artery. **A** Hepatic hilar dissection to trace the aberrant left hepatic artery back to its celiac origin. The *shaded area* indicates the entire left liver to be harvested. *LGA*, Left gastric artery; *LHA*, left hepatic artery; *CHA*, common hepatic artery; *MHA*, middle hepatic artery; and *MHV*, middle hepatic vein. **B** Donor hepatic arterial variants and recipient arterial reconstruction. The *boldface dotted lines* indicate the site of cutting. The left-sided hepatic graft consists of the lateral segment (segments II and III) and the entire or partial medial segment (segment IV). Single arterialization is performed by using the aberrant left hepatic artery, whether it feeds the lateral segment (*left*) or just segment II (*right*). The recipient shown on the *right* had an aberrant right hepatic artery from the superior mesenteric artery. *LHA*, Left hepatic artery; *MHA*, middle hepatic artery; *RHA*, right hepatic artery; *a2*, *a3*, and *a4*, arterial branches to segments II, III, and IV, respectively; *SMA*, superior mesenteric artery; *PV*, portal vein. (Reprinted with permission from the American College of Surgeons[20])

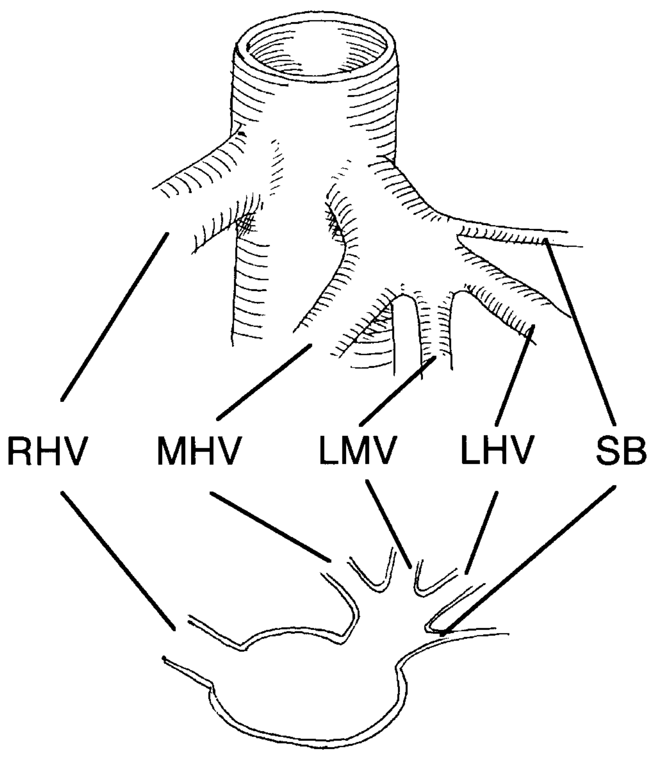


**Fig. 9.** Schematic presentation of the relationships between the right, the middle, and the left hepatic veins. *RHV*, Right hepatic vein; *MHV*, middle hepatic vein; *LHV*, left hepatic vein; *SB*, superficial branch of the left hepatic vein; *LMV*, left medial hepatic vein

retrohepatic IVC is completed by dividing the short hepatic veins and the IVC ligament, also called the "Makuuchi ligament" (Fig. 10).[40] When harvesting left-sided grafts without the caudate lobe, dividing the ligamentum venosum at its juncture with the left hepatic vein helps maintain sufficient length of the graft hepatic vein (Fig. 11). When collecting left hemiliver grafts with the caudate lobe, however, this ligament should not be divided, because small drainage veins from the caudate lobe often course within it.

Techniques of outflow Y-reconstruction by end-to-end anastomosis after venoplasty have been reported in detail by our team[1,4,5,38] (Fig. 12). We will elaborate on two important anatomical issues regarding this technique: the superficial branch of the hepatic vein, and the inferior diaphragmatic vein. Usually, a small- to medium-sized tributary enters the left hepatic vein near the common trunk with the middle hepatic vein and forms a common horizontal plane at its confluence in the majority of cases[4,5,38] (Fig. 12). This tributary drains the superficial area of the left lateral segment and is therefore called the superficial branch of the left hepatic vein. During venoplasty in the recipient, this tributary should be identified and linked to the major hepatic vein or veins, in order to obtain a long venous trunk with a large ostium. During the donor's operation, however, the superficial branch of left hepatic vein often does not form a common orifice with the left

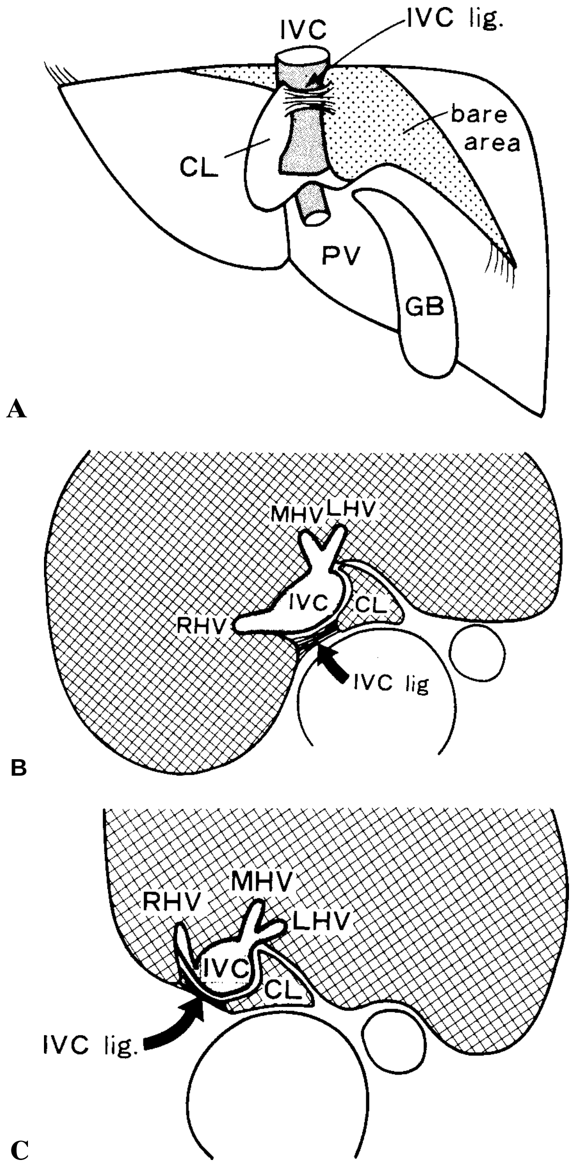


**Fig. 10A–C.** The inferior vena cava ligament (Makuuchi ligament). **A** Posterior aspect of the liver. The inferior vena cava ligament (*IVC lig.*) courses between the dorsal edge of the left caudate lobe and the right lobe. **B** Transverse view of the IVC lig. (*curved arrow*). **C** Schematic diagram of the IVC lig. during dissection of the liver from the IVC and elevation of the right robe. The right hepatic vein and the IVC are compressed to the left ventrally by an IVC lig. that is tightly attached to the dorsal wall of the IVC. *IVC*, Inferior vena cava; *PV*, portal vien; *GB*, gallbladder; *CL*, caudate lobe; *RHV*, right hepatic vein; *MHV*, middle hepatic vein; *LHV*, left hepatic vein. (From ref. 40, with permission)

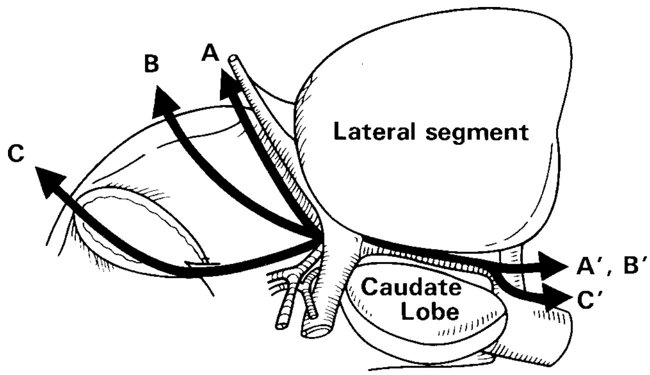


**Fig. 11.** Division of the ligamentum venosum at its junction with the left hepatic vein during left-sided donor hepatectomy. View from the left caudal aspect of three types of donor hepatectomy. *A-A′*, and *B-B′*, and *C-C′*, Transection lines for the left lateral segment graft, the extended left lateral segment graft, and the left hemiliver graft, respectively

hepatic vein, especially when the middle hepatic vein is left in the donor liver, e.g., when left lateral segment grafts are collected. In this situation, the superficial vein must be linked on the back table, either by the simple suture technique or the pantaloon technique to avoid formation of an area of graft congestion.[4,5,38] The right hepatic vein also has a tributary that drains the superficial area of the right lateral sector, i.e., the superficial branch of the right hepatic vein. The junction of this tributary with the right hepatic vein is located more distally than the junction between the superficial left hepatic vein and the left hepatic vein. This means that the venoplasty technique involving the superficial branch is usually not necessary for right hemiliver grafts when the right hepatic veins of both recipient and donor are anastomosed in an end-to-end manner. However, this tributary flows directly into the IVC in 4%–6% of individuals[39] (Fig. 13), and when a right hemiliver graft is taken from such donors, it is advisable to reconstruct the outflow of this tributary separately from that of the right hepatic vein to avoid partial congestion of the graft. Another key anatomical problem is the inferior phrenic veins. Both the right and left inferior phrenic veins flow into the right hepatic vein and the common trunk at their most cranial points, respectively. Therefore, the division of these veins and subsequent dissection of the more proximal connective tissue becomes an important procedure in fully exposing the right hepatic vein or the common trunk and facilitating extensive clamping of these veins for harvesting.[5] This procedure becomes particularly important for left-sided grafts, because the extrahepatic portion of the hepatic vein is shorter than in right hemiliver grafts.

### *Intrahepatic drainage territory of the individual hepatic veins*

Adequate venous outflow is necessary for optimal graft function. Limited outflow results in a variety of com-

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B
C

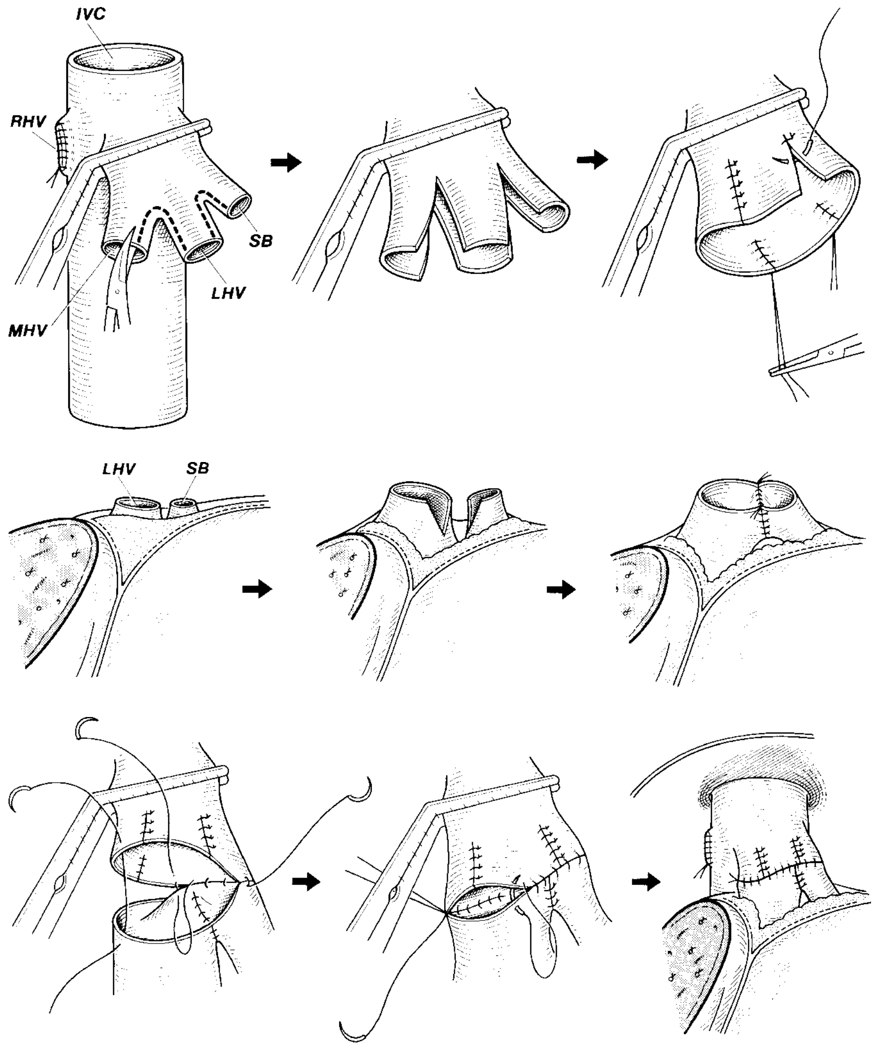



**Fig. 12A–C.** Techniques of outflow Y-reconstruction by end-to-end anastomosis in living donor liver transplantation (LDLT). **A** Recipient venoplasty of the middle and left hepatic veins to create a common trunk by splitting and suturing. **B** Graft venoplasty of the left hepatic vein to ensure a sufficient length by dissecting and joining. **C** Y-shaped end-to-end anastomosis between the recipient common trunk of the middle left hepatic veins and the graft left hepatic vein with continuous sutures. *MHV*, Middle hepatic vein; *LHV*, left hepatic vein; *SB*, superficial branch of the LHV; *RHV*, right hepatic vein; and *IVC*, inferior vena cava. (Reprinted with permission from the American College of Surgeons[4])

plications, ranging from mild graft dysfunction or ascites to rapidly progressive liver failure, depending on the degree of outflow block.[41,42] The anatomical relationships of the hepatic veins, including their drainage territories, dictates which veins are taken with the resected graft during LDLT. The principal drainage pattern is as follows (Fig. 14).[39] The right hepatic vein normally drains segments VI and VII and a portion of segment VIII, and occasionally it drains a small portion of segment V. The middle hepatic vein drains the major portion of segments V and VIII, and a large portion of segment IV. The left hepatic vein drains segments II and III, and a small portion of segment IV. In addition to these three major hepatic veins, there are numerous small venous branches that directly enter the retrohepatic IVC. These tributaries, called "accessory",[2] "dorsal",[39] or "short" hepatic veins[40] depending on the author, normally drain the caudate lobe and a small portion of segments VI and VII. The term "short hepatic vein" will be used in this monograph. Although this is the most common anatomical pattern, there are a great number of inter-individual differences in the drainage pattern of the liver, in terms of which of these veins or tributaries are the dominant drainage veins of the respective segments.[39] It is generally acknowledged that there is overlapping between these venous drainage territories, and that interruption of the tributaries of a single vein does not result in serious congestion of the graft or the remaining donor liver, probably because of the development of preexisting venous collaterals.[2,7,13,43,44] We should point out two pitfalls in this assumption. First, it is practically impossible to determine the degree of function of these venous collaterals prior to liver resection or graft implantation, and interruption of a single venous supply occasionally result in serious congestion of the corresponding liver territory.[45] Second, although congestion of the graft or the remaining liver, occurring in the

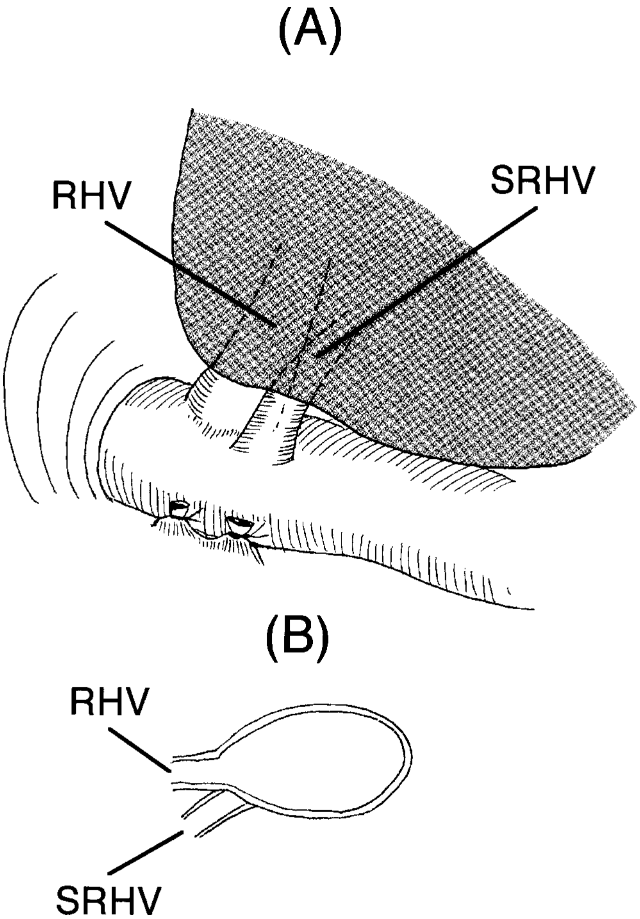



**Fig. 13A,B.** Schematic picture of the relationship between the right hepatic vein (*RHV*) and the superficial branch of the right hepatic vein directly draining to the IVC (*SRHV*). Note that the IVC ligament has already been divided and the right hemiliver is mobilized

absence of significant arterio-portal connections at the sinusoidal level, may be a rare phenomenon, portal veins usually substitute as draining veins, and the corresponding area is supplied with arterial blood alone when venous drainage is partially interrupted. Evidence for this phenomenon has been provided by the results of spiral CT[46] and intraoperative Doppler ultrasound sonography (findings obtained in our institution). This notion is also supported by the well known observation during wedge hepatic venography of portal vein visualization in a retrograde fashion. Obviously, this is not a desirable phenomenon in terms of adequate graft function, and it cannot be detected by simple inspection of the implanted graft. Taken together, these findings indicate that venous drainage is a potential problem during LDLT and that care should be taken to maintain all the major venous drainages of the graft whenever possible. This matter will be discussed case by case for each of the segmental grafts below.

When right hemiliver grafts are used, the right hepatic vein is usually reconstructed as the sole drainage vein of the graft.[2] In 20%–25% of the cases, however, one or two short hepatic veins are large enough to serve as major draining veins of segment VI and/or VII.[39] These veins are called the "middle right hepatic vein (MRHV)" and "inferior right hepatic vein (IRHV)" or "Makuuchi vein".[40] Therefore, it would be advisable to preserve the outflow from these veins by directly anastomosing them to the IVC in such cases.[2] The venous drainage of the right paramedian sector is another topic of debate in right hemiliver grafts, because the middle hepatic vein usually supplies the major part of this sector, especially segment VIII.[2,39] In

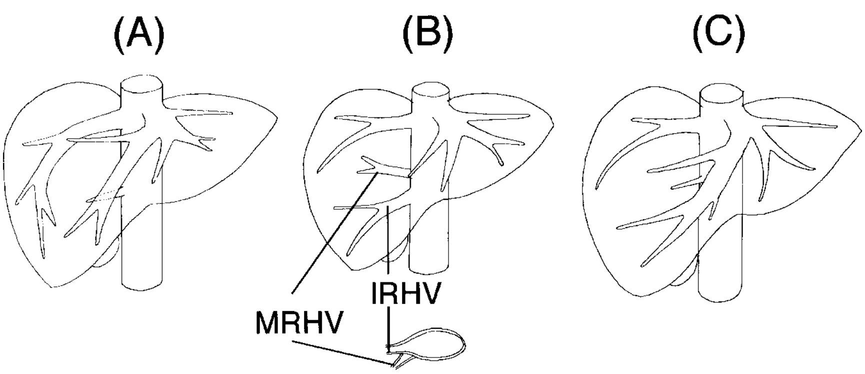



**Fig. 14A–C.** Various drainage patterns of the right hepatic vein. **A** In type I (32% to 39% of all cases) the right hepatic vein is large, and drains an extensive area of the right lateral sector and a part of the right paramedian sector. A small short hepatic vein drains a small area of the right lateral sector and is occasionally absent. **B** In type II (31% to 38% of all cases), the right hepatic vein is medium in size, and a thick short hepatic vein, having a diameter of 0.5 to 1.0cm, drains the right lateral sector concomitantly. They are called as middle and inferior right hepatic veins (*MRHV* and *IRHV*). **C** In type III (20% to 24% of all cases), the right hepatic vein is small and short, and drains superior part of the right lateral sector, while a large-sized middle hepatic vein and the thick short hepatic vein, having a maximal diameter of 1.8cm, drain the inferior part of the right lateral sector

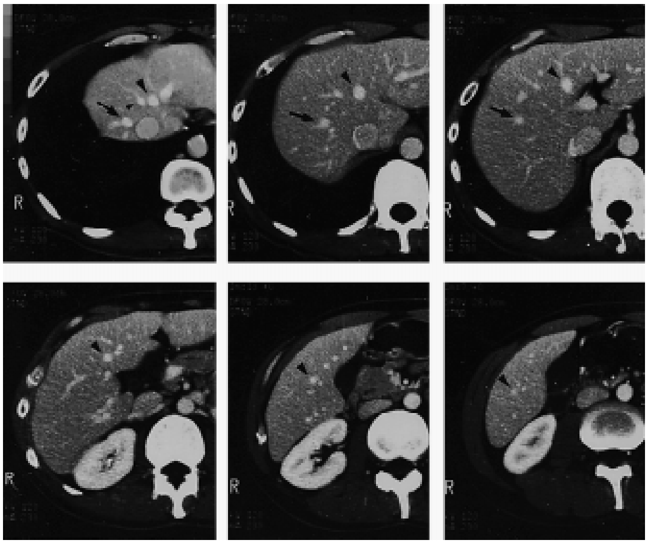


**Fig. 15.** Serial abdominal transverse CT scans showing a small right hepatic vein (*arrow*) and a thick middle hepatic vein (*MHV*; *large arrowheads*), which is traced to segment VI. A thick tributary (*small arrowheads*) draining segemnt VIII enters the MHV at its root. (From ref. 47, with permission)

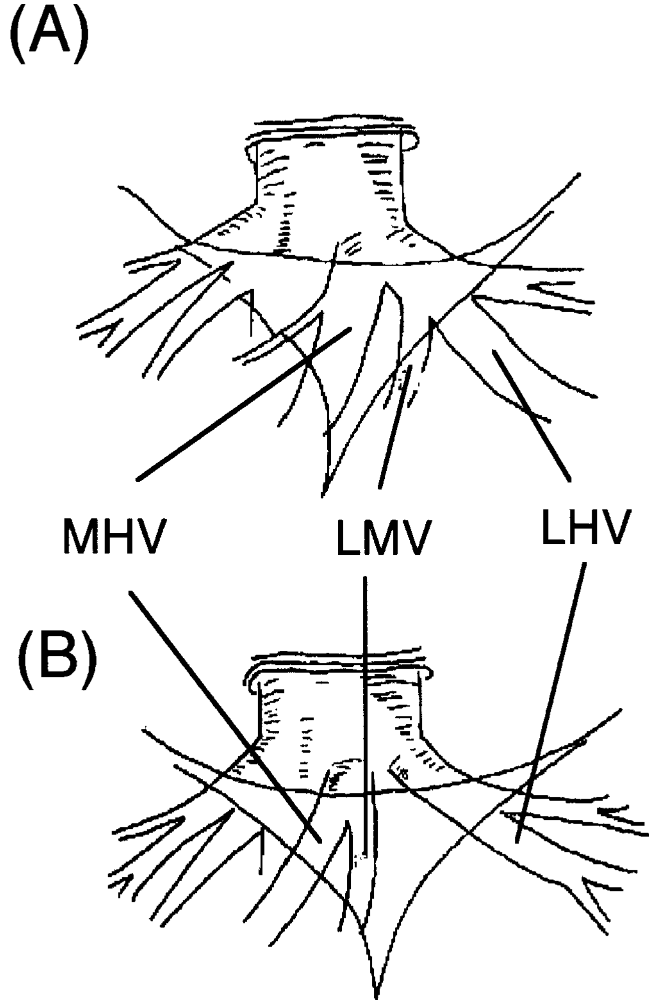
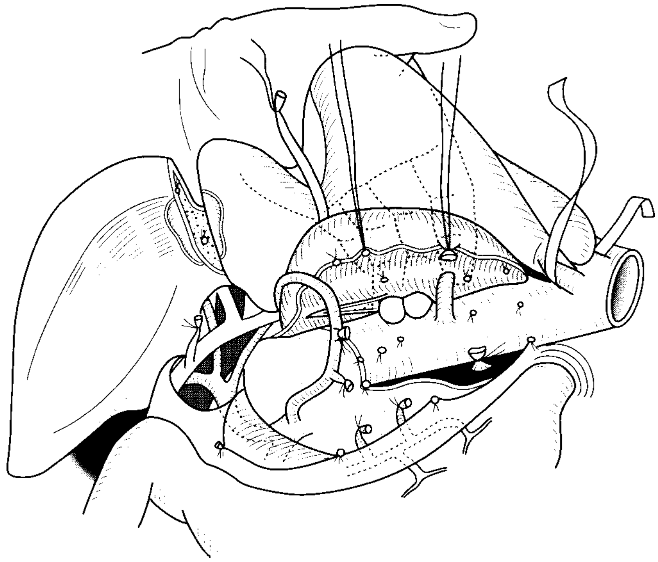



**Fig. 16A,B.** Two different patterns of ramification of the left medial hepatic vein (*LMV*). **A** LMV flows into the left hepatic vein (*LHV*); **B** LMV flows into the middle hepatic vein (*MHV*)

view of this, Lo et al.[24] proposed using extended right hemiliver grafts with both right and middle hepatic vein drainage. Although this procedure is an ideal option in terms of adequate graft drainage, it may result in impairment of the venous drainage of the remaining donor liver, because the middle hepatic vein drains a major portion of segment IV.[39] We maintain that the importance of preservation of the respective veins and tributaries depends on the drainage pattern in each donor. For example, if preoperative CT and ultrasound examination of the donor show that the right hepatic vein is relatively small and short, then the MRHV, IRHV, or the branches from middle hepatic vein become the major venous drainage of the right hemiliver. These veins or branches are usually identifiable by CT and ultrasound in such cases (Fig. 15) and should be preserved during graft implantation.[47] In this regard, precise evaluation of the venous drainage pattern in each donor by preoperative imaging studies is an essential part of LDLT.

When left-sided grafts are used, venous supply to segment IV requires attention when the middle hepatic vein is retained in the donor. This situation occurs when extended lateral segment grafts are used.[3] In most cases, the hepatic vein tributaries draining the left portion of segment IV (left medial vein) flow into the left hepatic vein close to its junction with the middle hepatic vein; however, they sometimes flow into the middle hepatic vein close to this junction[3] (Fig. 16). This branch should be included in the graft in order to secure an adequate outflow of segment IV. Intraoperative ultrasound (IOUS) is an indispensable adjunct to the correct performance of the inclusion of the left medial vein into the graft. When the left medial vein flows into the middle hepatic vein (Fig. 16B), venoplasty generally becomes necessary to create a common trunk as the drainage vein of the graft. When a whole hemiliver graft with both middle and left hepatic venous drainage is used, the venous outflow of the graft is very unlikely to become a problem, except for the drainage of the caudate lobe. When graft-recipient “borderline” size matching LDLT is performed, the caudate lobe is sometimes added, to increase graft size as much as possible (Fig. 17).[48,49] Although some portion of the drainage of this lobe may be via the left hepatic vein in most cases, it is recommended that the thickest short hepatic vein be reconstructed so that it functions as the major drainage vessel (Fig. 17).[49]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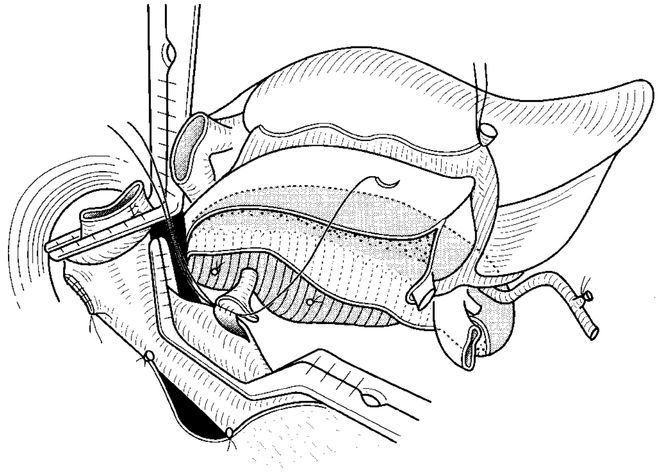
B

**Fig. 17A,B.** Techniques of left hemiliver graft with the caudate lobe. **A** Donor hepatectomy. The thickest hepatic vein of the caudate lobe (*shaded portion*) is preserved, and the aberrant left hepatic artery is dissected up to the celiac axis. **B** Recipient hepatic venous reconstruction. The caudate lobe hepatic vein with a caval cuff is anastomosed end-to-side to the IVC. (Reprinted with permission from the American College of Surgeons[49])

Regardless of which side of the liver is taken as the graft for LDLT, i.e., the right or the left hemiliver, inclusion of the middle hepatic vein in the graft results in good preservation of graft venous drainage. However, this is achieved at the expense of partial cessation of outflow in the remaining donor liver. Although this concern rarely becomes a clinical problem in the donor, it should be borne in mind that the use of the middle hepatic vein as the outflow of the graft may be a double-edged sword, from the standpoint of the donor.

## Addendum

It is debatable whether the inflow occlusion technique can be applied to donor hepatectomy during LDLT. Although this technique has been widely used in conventional liver resection to minimize blood loss during parenchymal dissection, many insist that it should be abandoned to avoid warm ischemia and resulting graft injury.[24] To the contrary, we have always used an intermittent selective inflow occlusion technique in donor operations for LDLT, with no serious consequences suggesting graft harvesting injury.[1] Although this is not truly an anatomical issue, we will discuss this matter in this section.

When using left lateral segment or extended left lateral segment grafts (case A), we carry out hepatic transection during selective occlusion of the middle hepatic artery, if present, and left portal vein (Fig. 18A). This technique produces complete ischemia in segment IV, while segments II and III are fed by the arterial flow during transection. When harvesting a whole left hemiliver graft (case B), transection is conducted during occlusion of the right portal vein and hepatic artery, a procedure resulting in right hemiliver ischemia (Fig. 18B). For right hemiliver grafts (case C) or right lateral sector grafts (case D), right portal vein and arterial branches to the right paramedian sector are occluded (Fig. 18C). In this procedure, the right paramedian sector becomes totally ischemic, while the right lateral sector is perfused by the arterial flow. There are three key points in these selective occlusion techniques that are different from classical inflow occlusion by the Pringle maneuver. First, the selective occlusion technique does not lead to the splanchnic congestion that accelerates liver ischemia/reperfusion injury, because visceral affluent is maintained during inflow occlusion via the unoccluded part of the liver. Second, in cases (A), (B), and (D), parenchymal transection is carried out within the completely ischemic part of the liver, but the liver segments that form the graft are normally perfused by arterial flow during the occlusion. In case (C), only part of the graft is subjected to temporary intermittent ischemia. Application of selective occlusion of portal flow is based on the following clinical observations. A marked increase in liver transaminase values is usually observed after acute cessation of hepatic arterial flow, such as in arterial thrombosis after liver transplantation[50] or transcatheter arterial embolization.[51] This finding indicates the

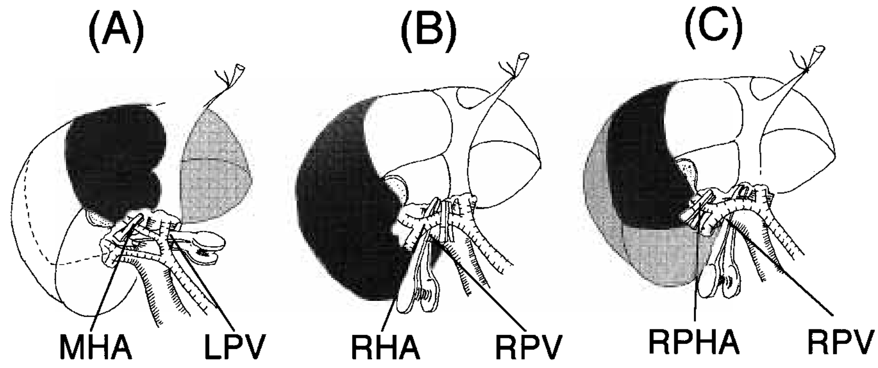


**Fig. 18A–C.** Selective vascular occlusion during donor hepatectomy. *Darkly shaded areas* represent the completely ischemic parts of the liver, while the *lightly shaded areas* signify the portions where the arterial flow is maintained. **A** Left lateral segment or extended left lateral segment graft. The middle hepatic artery and left portal vein are occluded with vascular clamps. **B** Left hemiliver graft. The right portal vein and the right hepatic artery are occluded. **C** Right hemiliver or right lateral sector graft. The right portal vein and right paramedian arterial branch are occluded. *LPV*, Left portal vein; *RHA*, right hepatic artery; MHA, middle hepatic artery; *RPV*, right portal vein; *RPHA*, right paramedian hepatic artery

occurrence of a necrotic reaction following hepatic arterial occlusion. Occlusion of the portal vein alone, however, does not result in such an injurious reaction in the liver, although, if permanent, it may induce hepatocyte apoptosis and resulting atrophy of the liver.[52,53]

In summary, certain technical barriers to LDLT exist, but all of them are surmountable if surgeons are fully cognizant of intra- and extra-hepatic anatomy and its variations. Thus, LDLT should be carried out by well trained liver surgeons who are accustomed to using intraoperative ultrasound, and not by transplant surgeons.

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