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ORTHOTOPIC LIVER TRANSPLANTATION

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# ORTHOTOPIC LIVER TRANSPLANTATION

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## INTRODUCTION

During the past 30 years orthotopic liver transplantation (OLTx) has become a highly successful form of therapy<sup>2,5,20,24,30,31,36</sup> and at the time of writing it is being performed at more than 100 institutions in the US, and a similar number in Europe. This is testimony to the great advances achieved in this field since the 1960s and 1970s, when there were essentially only two places actively engaged in liver transplantation<sup>3,20</sup>.

Essential to its success have been the technical refinements introduced during the last decades<sup>24,32</sup>, which have allowed many surgeons around the world to be able to do the procedure safely. However, this is still perhaps the most complex operation in use today, and a good technique is crucial to a satisfactory outcome. Unlike kidney, pancreas and intestinal transplantation, OLTx lacks a back-up system, such as dialysis, ventricular assist device, insulin or total parenteral nutrition. Thus, the smallest mistake in the surgical management of the patient may prove fatal.

In this chapter we will describe the surgical technique of OLTx, as it is currently carried out at the Pittsburgh Transplantation Institute, and which is essentially the one developed at the University of Colorado in Denver<sup>20,36</sup>. It is not within our scope to discuss the various aspects of the donor operation, but we cannot overemphasize the fact that a successful OLTx is completely dependent on a well harvested and pre-

served organ. Effective techniques for multiorgan procurement, and the practical aspects of donor management, have been reviewed elsewhere<sup>12,20,28,37</sup>.

We will first describe the standard recipient operation, dividing it into five main stages: the hepatectomy and venovenous bypass, the preimplantation hemostasis and design of the vascular cuffs, the graft implantation and reperfusion, the post-implantation hemostasis, and the biliary reconstruction. We will then review some of the most useful modifications of the standard procedure.

## STANDARD RECIPIENT OPERATION

### Hepatectomy and Venovenous Bypass

Performing a total hepatectomy in a patient with cirrhosis or severe portal hypertension is a stressful experience, one that requires a seasoned surgeon and two or three assistants, who should also be thoroughly familiar with the procedure. The assistants have specific tasks. The first assistant aids in tying, suctioning, and helps during the anastomoses. The second assistant, probably the most important, maintains the exposure. The third assistant is mainly involved during the last phase of the hepatectomy and the performance of the vascular anastomoses, and his role is to expose the hilar structures by holding back the liver. If this assistant is not available, a properly applied "universal retractor" can be used.

In preparation for the operation, the patient should be placed in the supine position with both arms extended outward. Since the operation may last from 5 to 24 hours, the operating table should be well-padded, and a pillow should be

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**Figure 6.218.** *Orthotopic liver transplantation I. A:* Preparation of the surgical field. The skin is painted with antiseptic solution from the neck to the thighs. Both axillae and groins should be exposed. A retractor, two electrocauteries, two suction systems, and one Argon beam coagulator are in place.



**Figure 6.218.** *Orthotopic liver transplantation I. B:* The usual surgical approach is through a bilateral subcostal incision, with an upper midline extension.

placed under the legs to facilitate venous return. Also, egg crate foam pads should be placed to specifically protect elbows, heels and coccyx. Two arterial lines (right femoral and either radial), two volume lines, a Swan-Ganz catheter, and a Foley catheter are then placed. The skin is painted with antiseptic solution from the neck to the upper thirds of the thighs, including groins and both axillae. As shown in Fig. 6.218A, a

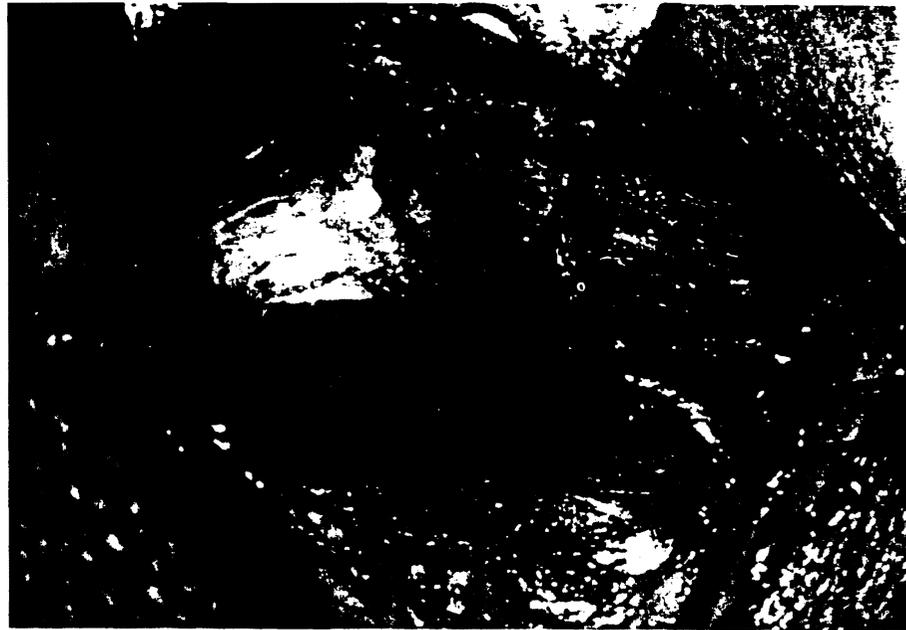
retractor is placed for later exposure, and 2 suction systems, two electrocauteries, and an Argon beam coagulator are prepared. A bilateral subcostal incision, with an upper midline extension is the usual approach (Fig. 6.218B). However, the exact location of the incision depends on the presence of previous scars and on the size and configuration of the liver. Before entering the abdominal cavity the greater saphenous and axil-

lary veins are dissected out, through the appropriate incisions (Fig. 6.219 A,B) to be used at a later stage to establish venovenous bypass. These dissections are usually carried out on the left side, although in retransplantation the untouched right side is often used. The greater saphenous vein is dissected up to the confluence

with the femoral vein (Fig. 6.219A). Extreme care is taken to avoid injury to the brachial plexus, which surrounds the axillary vein (Fig. 6.219B).

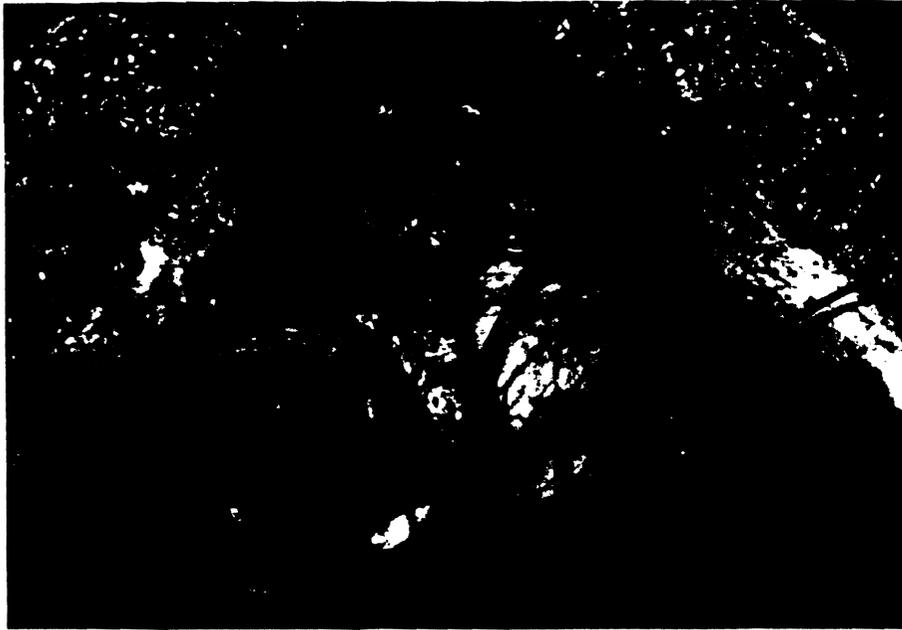
The abdominal wall incision is performed using electrocautery, and all the enlarged collateral veins which are present in advanced cirrho-

**Figure 6.219.** *Orthotopic liver transplantation II.* A: The left long saphenous vein is dissected out to its junction with the femoral vein (arrow).



**Figure 6.219.** *Orthotopic liver transplantation II.* B: The left axillary vein is dissected out and encircled. Extreme care is taken not to injure the brachial plexus (arrow).





**Figure 6.220.** *Orthotopic liver transplantation III.*  
A: The xiphoid process is excised with heavy scissors and electrocautery to achieve better access to the hepatic veins and the subphrenic vena cava. The falciform ligament is divided between silk ties to control the collaterals present here.



**Figure 6.220.** *Orthotopic liver transplantation III.*  
B: Before placing the wound retractor the peritoneum is sutured to the fascia of the rectus muscles, for hemostasis and prevention of adhesions.

sis, are divided between silk sutures. These varices of the abdominal wall and the abdominal cavity should always be carefully identified and controlled to prevent unpleasant, or even lethal, hemorrhage during the preliminary dissection.

The xiphoid process is excised with heavy scissors and electrocautery (Fig. 6.220A), to obtain better access to the hepatic veins and

suprahepatic vena cava. The falciform ligament is then divided between heavy silk sutures (Fig. 6.220A) to control the collateral present there. Before placing the wound retractor, the peritoneum is sutured to the fascia of the rectus muscles (Fig. 6.220B). This is done to control the bleeding and also to prevent strong adhesions between the upper abdominal wall and the new liver,

which can make for a difficult dissection in case of a re-operation. As soon as the upper surface of the liver is free from the diaphragm, the wound retractor is placed in order to retract the rib margins upwards and backwards (Fig. 6.220B). The retractors used at our institution are either the Rochard or the Iron Intern<sup>R</sup> (Fig. 6.221 a,b). The

quality of the exposure achievable with these instruments is usually so good that thoracic extensions of the incision<sup>21, 22</sup> are almost never needed. Once the possible adhesions between the intestinal serosa and the gallbladder (or the gallbladder fossa in the case of previous cholecystectomy) and the lower surface of the liver

**Figure 6.221.** *Orthotopic liver transplantation IV. A:* The Iron Intern<sup>®</sup> retractor used in liver transplantation. The rib margins are retracted upwards and backwards.

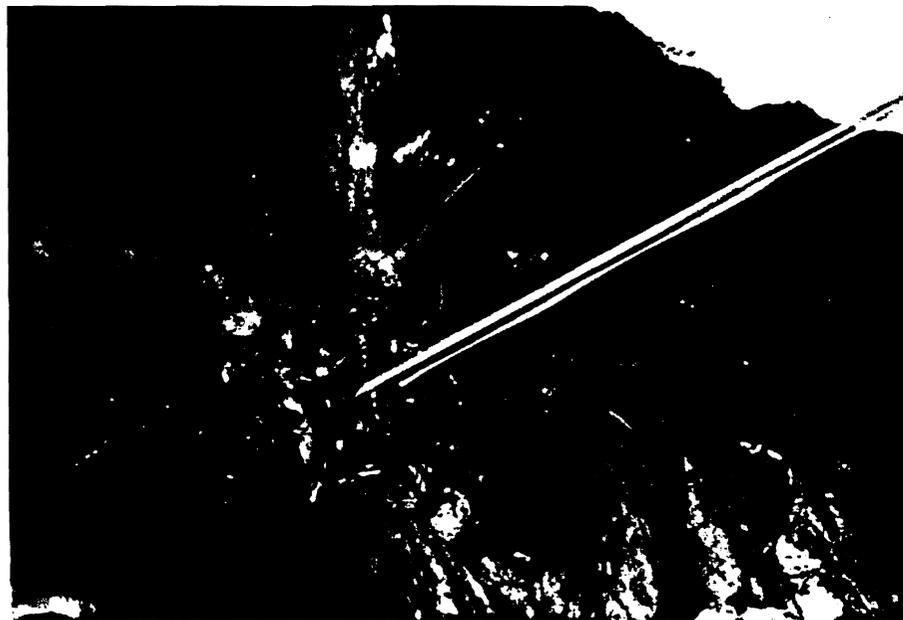


**Figure 6.221.** *Orthotopic liver transplantation IV. B:* An attachment of the Iron Intern<sup>®</sup> can be used to lift up the liver and expose the hilum, while the second assistant maintains the exposure by keeping traction on the stomach, duodenum and transverse colon.





**Figure 6.222.** *Orthotopic liver transplantation V. A.* The hilum is encircled, allowing an accurate examination of the hilar structures. The posterior wall of the portal vein is palpated to rule out a portal thrombosis. The lesser omental sac is opened and the caudate lobe (arrow) is exposed. The gallbladder is retracted upward (double arrow).



**Figure 6.222.** *Orthotopic liver transplantation V. B.* The hepatic artery, here encircled by a vessel loop, is exposed after dissecting, and dividing between silk ties the peritoneal covering of the hepatoduodenal ligament. The arrow indicates the bile duct.

are free, the diseased organ can be lifted up exposing the hilum (Fig. 6.221). This can be done with the help of an assistant, or with the use of a specific attachment of the Iron Intern<sup>R</sup> retractor (Fig. 6.221). The second assistant is critical in maintaining the exposure by keeping traction on the stomach, duodenum and transverse colon (Fig. 6.221B).

Although the technique of the recipient hepa-

tectomy has been standardized over the past 30 years<sup>2, 21, 22, 32, 36</sup>, it is almost impossible to find two identical anatomical situations in two different recipients. Thus, once the abdominal cavity has been entered, a plan of action should be prepared. If possible, the dissection of the hilar structures (bile duct, hepatic artery, portal vein) should be performed first, so that the hepatic artery can be divided and venovenous bypass

**Figure 6.223.** *Orthotopic liver transplantation VI.* The single arrow shows the divided hepatic artery, while the double arrow shows the divided bile duct (the silk of this tie has been divided with one long and one short arm, to facilitate later identification of the duct). The portal vein (triple arrow) is completely skeletonized.



established, in that way achieving early liver devascularization. This will translate into a significant reduction of blood loss.

At the beginning of the hilar dissection an attempt should be made to encircle the hilar structures (Fig. 6.222A) by passing the forefinger behind the hilum and opening the lesser sac. This manoeuvre allows a careful palpation of the posterior wall of the portal vein, to rule out a portal vein thrombosis. It is also possible then to carry out *en masse* clamping of the portal triad, the so-called *Pringle manoeuvre*<sup>21</sup> if the individual structures cannot be safely dissected free. Furthermore, the posterior palpation of the portal vein will alert the surgeon to the presence of an aberrant right hepatic artery, which has an incidence of about 10%<sup>41</sup>. The dissection is started by dividing the peritoneum covering the hepatoduodenal ligament. This tissue contains many venous collaterals, as a result of portal hypertension, and should be divided between silk ties to minimize blood loss (Fig. 6.222B). The hepatic artery should be identified (Fig. 6.223) and divided first, since this will significantly decrease the subsequent blood loss. The bile duct is then also divided between ties, and we usually cut the silk leaving one arm long and the other short (Fig. 6.223). This allows for a quick identification of the bile duct stump during graft implantation.

After completing these steps, the portal vein can be identified and dissected out by dividing all the areolar tissue surrounding it (Fig. 6.223).

At this point, before preparing the patient for venovenous bypass, it is useful to dissect the entire length of the recipient hepatic artery that will be necessary for later arterial reconstruction. To achieve this an imaginary line is drawn between the divided hepatic artery and the superior margin of the pancreas, across the group of lymph nodes anterior to the common hepatic artery (Fig. 6.224A). Then this group of lymph nodes is dissected out and partially or totally removed, thus allowing for exposure of the gastroduodenal artery and of one cm of the common hepatic artery, proximal to the gastroduodenal artery (Fig. 6.224B).

If the hemostasis is good at this point, some further dissection can be carried out. The peritoneum covering the infrahepatic vena cava is divided between silk ties and opened to expose the vessel (Fig. 6.225A). There is usually a large collateral from the caudate lobe that has to be divided between silk ties before encircling the infrahepatic vena cava (Fig. 6.225B). The gastrohepatic ligament is then divided, keeping in mind the possibility of an aberrant left hepatic artery arising from the left gastric artery, which has an incidence of about 13%<sup>41</sup> (Fig. 6.226A). The dis-



**Figure 6.224.** *Orthotopic liver transplantation VII.*  
A: An imaginary line (dotted line) is drawn between the vascular clamp holding the divided hepatic artery and the superior margin of the pancreas, across of the group of lymph nodes anterior to the common hepatic artery. This will allow the identification and dissection of the segment of the hepatic artery necessary for later arterial reconstruction.



**Figure 6.224.** *Orthotopic liver transplantation VII.*  
B: The group of lymph nodes anterior to the common hepatic artery is partially or totally removed, thus allowing the exposure of the gastroduodenal artery (arrows) and of one cm of the common hepatic artery proximal to the gastroduodenal artery.

section is extended so as to include the left triangular ligament and the initial segment of the right triangular ligament (Fig. 6.226B).

We and other teams have shown that clinical liver transplantation usually can be performed by experts without venovenous bypass. However, the learning curve to reach the necessary level of performance is a steep one that cannot be justi-

fied for new teams or those without superb technical capability. It is not safe to proceed beyond the foregoing stage of the dissection without the aid of venovenous bypass. Moreover, if the bleeding from venous collaterals has been significant, the bypass should be installed even earlier, as soon the portal vein is first identified.

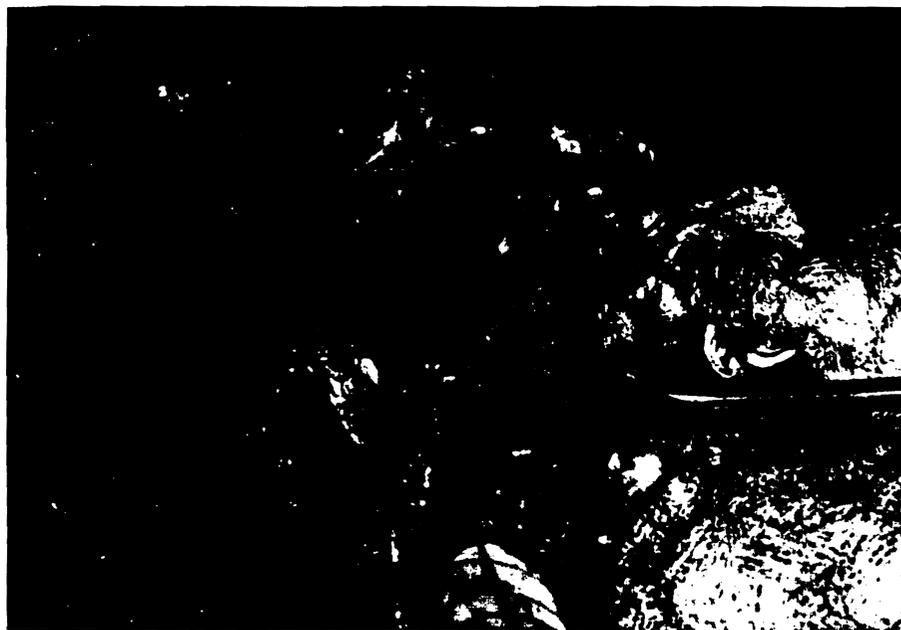
Venovenous bypass, as it is presently used,

was introduced into clinical practice by the Pittsburgh group, in January 1983<sup>18, 21, 22, 31</sup>. The need to decompress the portal system and the lower vena cava, after crossclamping of these vessels, was immediately recognized in the dog model in 1958, necessitating development of a passive bypass for the operation in dogs<sup>35</sup>. However, the application of this technique has

resulted in several instances of lethal pulmonary emboli that originated in the bypass. In addition, it was learned that the presence of portocaval venous collaterals, stimulated by the liver disease, has made venovenous bypass less important in the cirrhotic patient than in the laboratory animal. Consequently, a bypass was not used between 1967 and 1982.

**Figure 6.225.** *Orthotopic liver transplantation VIII.*

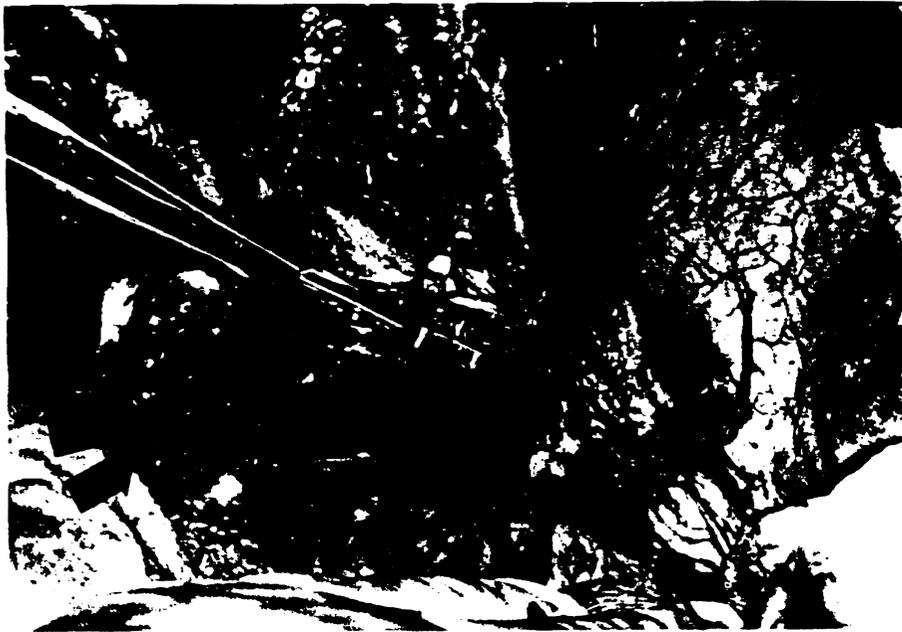
A: If the hemostasis is completed, before preparing the patient for venovenous bypass the infrahepatic vena cava (arrow) can be exposed by dividing between silk ties the peritoneum covering it. The portal vein is gently retracted by a vein retractor, while the sponge is covering the intestine.



**Figure 6.225.** *Orthotopic liver transplantation VIII.*

B: To encircle the infrahepatic vena cava it is usually necessary to divide between silk ties a large collateral (arrow) from the caudate lobe. From left to right it is possible to see the infrahepatic vena cava, the portal vein, and the hepatic artery entirely isolated and encircled by vessel loops.





**Figure 6.226.** *Orthotopic liver transplantation IX. A:* Division of the gastrohepatic ligament. The arrow shows a divided and tied aberrant left hepatic artery. The thick arrows indicate the portal vein.



**Figure 6.226.** *Orthotopic liver transplantation IX. B:* The initial segment of the right triangular ligament is divided between silk ties, again to minimize blood loss. The arrows indicate the previously divided falciform ligament.

Although the consequent hemodynamic problems of the anhepatic phase are less severe in the sick patient than in the healthy laboratory animal, they were for many years a part of a physiologically turbulent and critical period of the human recipient operation and convalescence. Clamping of the splanchnic and systemic venous systems results in a highly variable sequestration of blood volume, the consequences of which

may range from trivial to grave. At the grave end of the spectrum there are diffuse intestinal edema, worsened portal hypertension, and increased pressure in the renal veins; and these changes increase the risk of postoperative renal failure and bleeding from the thin-walled venous collaterals and raw surfaces of the surgical field. Surmounting this acute intraoperative crisis requires volume preloading, which may easily

result in pulmonary edema after the reperfusion of the graft and decompression of the stagnant venous pools. Also, the high potassium and acid load returned to the systemic circulation by this stagnant blood can result in significant hemodynamic instability and cardiac arrest<sup>11</sup>. The development of a pump-driven venovenous bypass has allowed us to maintain physiological

stability, and contributed to a significant reduction of morbidity and mortality<sup>17</sup>. It has also made possible the training of many surgeons, since the hemodynamic instability related to the hepatectomy initially confined this operation to the hands of a few virtuoso surgeons in the United States and Europe. The fascinating details surrounding the development of the venove-

**Figure 6.227. Orthotopic liver transplantation X. A:** Venous outflow cannulae for the venovenous bypass, used during the hepatectomy and the anhepatic phase. The longest and larger cannula (9 mm diameter Gott shunt) will be inserted into the portal vein, while the other (7 mm diameter Gott shunt) will be inserted into the greater saphenous vein, and advanced into the femoral vein.



**Figure 6.227. Orthotopic liver transplantation X. B:** The thick arrows indicate the portal (double arrow) and femoral bypass lines, which are the outflow cannulae. The thin arrow indicates the axillary (7 mm Gott shunt) cannula, which returns blood to the systemic circulation.



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**Figure 6.228.** *Orthotopic liver transplantation XI.*  
 A: Usually the axillary vein is cannulated first. Here a 7 mm Gott shunt primed with heparinized saline solution is placed in the left axillary vein and secured with a Rummel clamp and umbilical tape.



**Figure 6.228.** *Orthotopic liver transplantation XI.*  
 B: A 7 mm Gott shunt is inserted in the left femoral vein through the left greater saphenous vein.

nous bypass are reported elsewhere<sup>22, 23, 27</sup>.

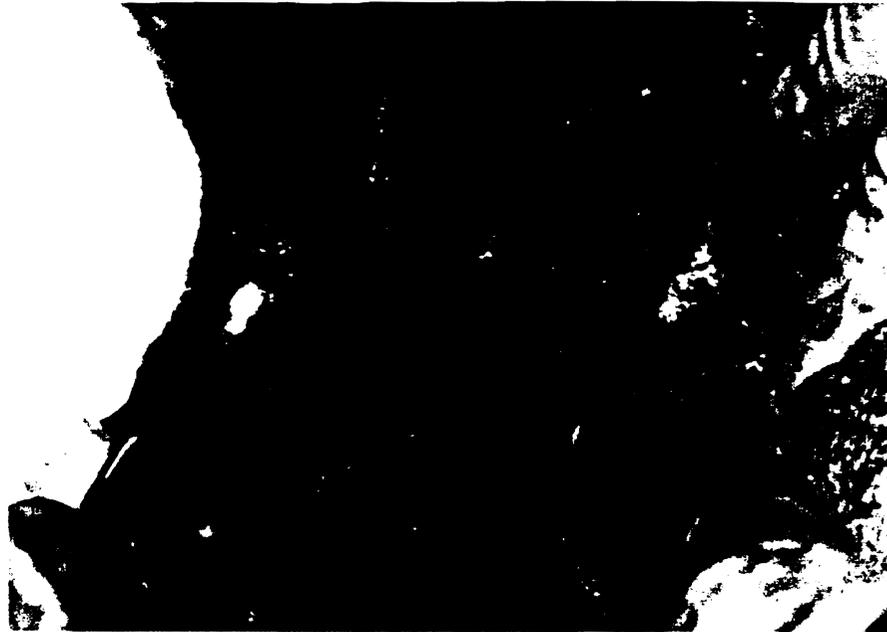
The bypass consists of a pump and 3 venous cannulae. The pump is managed by a technician, while the venous cannulae are placed and connected by the surgeon. The cannulae used are Gott shunts, which are available in 7 mm and 9 mm diameters. In adults, a 9-mm Gott shunt is usually used to cannulate the portal vein, where-

as a 7-mm shunt is used to cannulate the greater saphenous vein (the 2 outflow vessels) (Fig. 6.227A). These two outflow cannulae are connected to the pump, and the blood is driven back into the systemic circulation through another 7-mm shunt placed into the axillary vein (Fig. 6.227B). Small chest tubes may be used in place of Gott shunts when the veins are small, as in

children. Average flows in adults vary from one to six liters/min. This technique is also easy to use in children weighing more than 15 kg<sup>s</sup>, and in this population flows of 500-700 ml/min or more are acceptable. The success of the venovenous bypass is dependent on a perfect inflow; therefore the cannula in the axillary vein should be as large as the vein will allow. The axillary and

greater saphenous vein cannulae are secured with Rummel clamps and umbilical tapes to avoid accidental dislodgement and fatal air embolism (Fig. 6.228 A,B). The portal vein is now dissected bluntly with a Küttner swab to prepare it for cannulation (Fig. 6.229A). The portal vein is ligated as high as possible in the hilum (separate ligation of the 2 major branches is preferable, if

**Figure 6.229.** *Orthotopic liver transplantation XII.*  
A: Before the actual cannulation for the venovenous bypass, the portal vein is bluntly dissected with a Küttner swab. The thick arrow indicates the portal vein, the double thin arrows show the hepatic artery, and the single thin arrow shows the gastroduodenal artery. The vessel loop is around the infrahepatic vena cava.



**Figure 6.229.** *Orthotopic liver transplantation XII.*  
B: A 9 mm diameter Gott shunt primed with heparinized saline solution is placed in the portal vein and secured by an umbilical tape tie.





**Figure 6.230.** *Orthotopic liver transplantation XIII.* A: As soon as the right hepatic vein and the suprahepatic vena cava have been visualized, the surgeon can create, with the left forefinger (thick arrow), a tunnel behind the suprahepatic vena cava. This will be used to pass a vascular clamp and obtain control of the suprahepatic vena cava. The double arrow shows the liver being retracted by the right hand of the surgeon. The thin arrow shows the left diaphragmatic vein. The second assistant (white glove) is retracting the stomach.



**Figure 6.230.** *Orthotopic liver transplantation XIII.* B: After clamping the infrahepatic vena cava (black arrow) and the suprahepatic vena cava (white thick arrow) the liver can be elevated into the wound and excised. The thin white arrow shows the right adrenal vein divided between silk ties.

possible) and then transected and cannulated. The cannula is secured in place by an umbilical tape tie (Fig. 6.229B). All three cannulae are flushed with heparinized saline solution (1,000 IU/liter) and connected. The bypass is then started by the pump technician. Children of very small size tolerate venous occlusion better than adults, and venovenous bypass usually is not

attempted unless instability is demonstrated with test cross clamping.

The division of the portal vein provides a better exposure of the infrahepatic vena cava which, if not done before, should now be encircled and clamped. What remains of the right triangular ligament is subsequently divided, and the suprahepatic vena cava can be identified from

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the right. Particular attention should be given to the identification of the right hepatic vein, since in the shrunken cirrhotic liver it can be rotated to the point that it almost assumes a posterior position. As soon as the right hepatic vein and the suprahepatic vena cava have been visualized, the surgeon can pass his left forefinger behind the suprahepatic vena cava (Fig. 6.230A) creating a tunnel that will accept a large vascular clamp.

The infrahepatic vena cava is usually clamped first, followed by the suprahepatic vena cava. This particular sequence is largely a matter of preference, except in special situations such as with intrahepatic abscesses or gangrene of the liver. Here it is important to clamp first the suprahepatic vena cava to prevent necrotic tissue and toxins, including potassium, from reaching the right atrium during manipulation of the

**Figure 6.231.** *Orthotopic liver transplantation XIV.*  
A: The recipient's cirrhotic liver is excised.



**Figure 6.231.** *Orthotopic liver transplantation XIV.*  
B: The new donor liver is placed in the field by the second assistant, and the implantation is started with the end-to-end anastomosis of the suprahepatic vena cava. The right and left corner stitches have already been placed on the recipient suprahepatic caval cuff. The white arrows show the clamp placed on the infrahepatic vena caval cuff, while the black arrow shows the vascular clamp on the large suprahepatic caval cuff.





**Figure 6.232.** *Orthotopic liver transplantation XV.*  
**A:** Suprahepatic vena cava anastomosis. The posterior wall has been completed. This anastomosis is performed with a running suture of 3-0 polypropylene. Two corner stitches are placed initially. The left one is tied down and is used for the actual anastomosis. The stitch placed in this case at the mid-point of the anterior wall of the recipient vena cava is to improve the exposure. The vascular clamp is occluding the recipient suprahepatic vena cava.



**Figure 6.232.** *Orthotopic liver transplantation XV.*  
**B:** Infrahepatic vena cava anastomosis. The posterior wall has been completed. The hand of the third assistant is holding the caudate lobe of the donor liver to improve the exposure. This anastomosis is performed with a running suture of 4-0 polypropylene. The vascular clamp is occluding the recipient infrahepatic vena cava, above the renal veins.

liver. Usually, the right adrenal vein is the only posterior tributary of the vena cava behind the liver and, if possible, it should be identified and divided between ties. If this is accomplished at this stage, the surgeon can pass a finger behind the vena cava from the diaphragm to the renal veins without meeting any obstacles<sup>21</sup>. The liver can now be elevated into the wound, allowing

good visualization of the supra- and infrahepatic segments of the inferior vena cava (Fig. 6.230B), and the excision of the organ can be completed (Fig. 6.231A), leaving almost the entire retrohepatic vena cava in place<sup>39</sup>. This will protect the retroperitoneal structures, especially the right adrenal gland, from possible injury, and allow a safer fashioning of adequate caval cuffs.

### Pre-implantation Hemostasis and Vascular Cuffs Design

Once the liver is removed the retrohepatic vena cava is divided, leaving two long infra- and suprahepatic vena caval stumps. The bleeding in the so-called bare area, the raw surface created during the hepatectomy, is often significant, and sur-

gical hemostasis is always required before proceeding with the implantation of the new liver. This area is usually oversewn and reperitonealized with running 2-0 polypropylene<sup>33</sup>. However, before running this continuous suture it is important that individual bleeding vessels be identified and ligated individually. Occasionally, the bleeding is relatively minor, and superficial coagula-

**Figure 6.233.** *Orthotopic liver transplantation XVI.*

**A:** Hepatic artery anastomosis. The vascular clamp is occluding the recipient common hepatic artery, one cm proximal to the take-off of the gastroduodenal branch. The single black arrow shows the large patch obtained by opening the gastroduodenal bifurcation. The double black arrow indicates the donor aortic Carrel patch of the donor celiac trunk. The white arrow shows the recipient portal vein still cannulated for the venovenous bypass



**Figure 6.233.** *Orthotopic liver transplantation XVI.*

**B:** Hepatic artery anastomosis. In this case, the arterial anastomosis was done before the portal anastomosis and the liver will be perfused with both arterial and portal blood. The double black arrows show the start of the arterial anastomosis, with the placement of the corner stitches. The triple black arrows show the donor portal vein, still with the cannula for the cold perfusion in place. The white arrow shows the recipient portal vein, with the cannula for the venovenous bypass.





**Figure 6.234.** *Orthotopic liver transplantation XVII.* The hepatic artery (triple white arrows) anastomosis has been completed before the portal anastomosis. The portal anastomosis is started by placing two 6-0 polypropylene corner stitches (thick white arrow). The bile duct (black arrow) is held with a suture. The hand of the third assistant is maintaining the exposure of the hepatic hilum.

tion with electrocautery and argon beam coagulator is enough to achieve a dry field.

After reaching a satisfactory hemostasis of the bare area the infrahepatic and suprahepatic caval cuffs should be fashioned. The infrahepatic vena cava cuff is tested by placing a second vascular clamp proximal to the edge and releasing the previously placed clamp. This way any bleeding points from this segment of the vessel can be identified and sutured. The careful search for severed branches near to the planned anastomosis is very important to prevent bleeding after reperfusion, since it is much easier to deal with these leaks at this time, when the absence of the liver ensures a superb exposure. To fashion the suprahepatic caval cuff, the orifices that remain from the division of the recipient suprahepatic veins and the retrohepatic vena cava should be interconnected. In this way, by dividing the septa between the suprahepatic veins and the cava, a large tunnel-shaped single lumen can be obtained. The redundant caval tissue around the circumference of the upper caval cuff should then be removed to avoid an excessively long vessel that can kink later.

#### **Graft Implantation and Reperfusion**

Before taking the donor liver out of the ice container, two 3-0 polypropylene sutures are placed

as right and left corner stitches on the recipient suprahepatic caval cuff. After this, the donor liver is brought into the wound for implantation (Fig. 6.231B). The vascular anastomoses are performed in the following order: suprahepatic vena cava, infrahepatic vena cava, and portal vein. After the portal vein anastomosis is completed, the vascular clamps are removed and the liver is reperfused. Then the arterial anastomosis is carried out. Sometimes, the arterial anastomosis can be performed immediately after the two caval anastomoses, leaving the portal anastomosis as the last to be completed, as in the case illustrated in this Chapter (6.232A-B, 6.233A-B, 6.234). In this way, the liver is perfused simultaneously with both arterial and portal flows.

The suprahepatic caval anastomosis is performed by 3-0 polypropylene running suture. As mentioned before, a suture is placed at each corner of the recipient and donor vessels (Fig. 6.231B). The left corner suture is tied, while the right corner suture is anchored with an atraumatic clamp and placed under gentle tension. A third suture (usually 4-0 silk) can be placed on the mid-point of the anterior caval edge to improve the exposure (Fig. 6.232A). This stitch will be removed before completion of the anastomosis. Another suture (5-0 or 6-0 polypropylene) can also be placed at the mid-point of the posterior wall, and removed before proceeding

to the anterior caval wall. Traction on this stitch will evert the edge of the caval wall and facilitate endothelium-to-endothelium approximation<sup>26</sup>. The left corner stitch is first brought inside the lumen of the caval cuff, on the recipient side. Then the needle is passed inside-out and outside-in at the left corner of the posterior wall of the

donor suprahepatic caval stump. The needle is brought out approximately three mm from the line of incision, and then brought in approximately one mm from the edge. A mirror manoeuvre is then carried out on the recipient cuff. The full thickness of the wall should be included with this technique bringing out the formation of

**Figure 6.235.** *Orthotopic liver transplantation XVIII.*

**A:** Choledocho-choledochostomy. Two 4-0 silk stay sutures are placed on the corners of both donor and recipient duct, after they have been appropriately trimmed (small white arrows). A biliary probe (triangular arrow), which was brought out through a small stab wound in the recipient duct, is now used to drive a 2-0 silk suture (thick white arrow) into the common bile duct. The portal anastomosis (double black arrows), and the reconstructed hepatic artery (thin white arrow and blue vessel loop) are clearly visible.



**Figure 6.235.** *Orthotopic liver transplantation XVIII.*

**B:** The long limb of the T-tube (single triangular arrow) is pulled through the stab wound in the recipient duct, with the help of the silk suture (double triangular arrows). Again, the portal anastomosis (double black arrows), and the hepatic artery (thin white arrow and blue vessel loop) are clearly visible.





**Figure 6.236.** *Orthotopic liver transplantation XIX.* A: choledocho-choledocho-stomy. Initially, the two posterior polydioxanone stitches are placed and tied outside (triangular white arrow). The proximal short limb of the T-tube will be now inserted in the donor duct, after removal of the silk stitch used to retract it. The two white arrows indicate the reconstructed hepatic artery (a blue vessel loop is around it). The liver is retracted with the metallic hand of the Iron Intern® retractor. The two hands of the second assistant are controlling the intestine, maintaining a good exposure of the surgical field.



**Figure 6.236.** *Orthotopic liver transplantation XIX.* B: A standard cholecystectomy is performed after the biliary duct reconstruction.

intraluminal shoulders, on both vessels to be joined. By gentle traction on the running suture, and the posterior mid-point stitch, a mound of protruding tissue presents to the surgeon, which make the placement of subsequent sutures easier. When the right corner is reached the needle is brought outside, and the anterior wall in then run for about one third of its length. Then the

other needle of the left corner stitch is used to complete the remaining two thirds of the anterior wall, again with an everting technique. In this way the tie of the running suture will be on the anterior wall instead of on the corner.

This suprahepatic caval anastomosis should be done expeditiously but with good technique, since placement of other posterior hemostatic

stitches is very difficult after graft reperfusion, and carries a high risk of stricture. The help of the second assistant is critical, since he or she should elevate the recipient caval cuff by holding with the right hand the vascular clamp placed on it, while applying a gentle torque. At the same time the second assistant should line-up the

donor and recipient caval cuffs by holding the liver with the left hand.

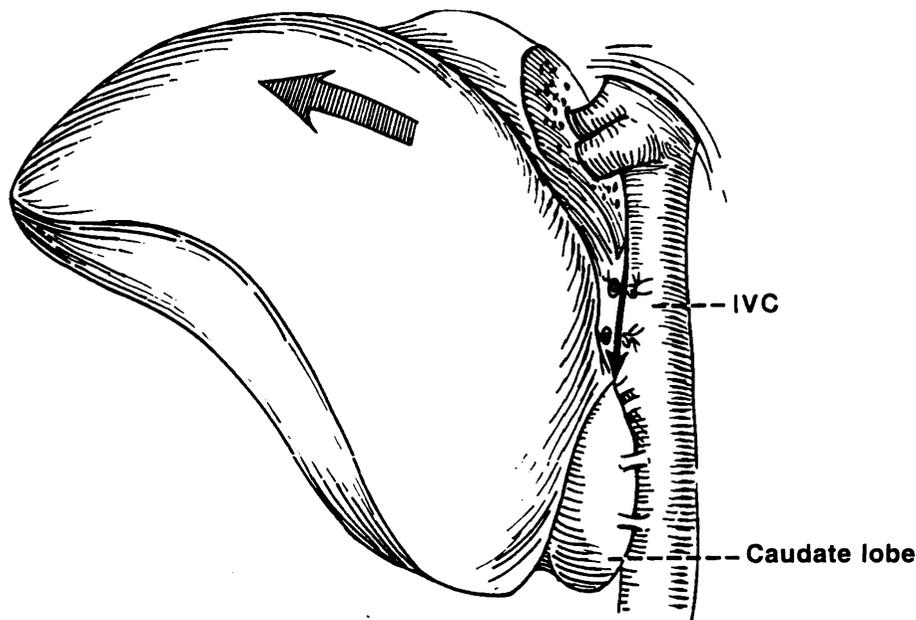
The same vascular technique is used for the infrahepatic vena caval anastomosis. Attention should be paid to the length of the infrahepatic caval cuffs, and they should be tailored appropriately in order to avoid a kinked anastomosis.

**Figure 6.237. Orthotopic liver transplantation XX.** A: The liver is moved upward and medially to examine the infrahepatic caval anastomosis (curved arrow) and the bare area (triple arrows). The black areas on the liver parenchyma and on the bare area are the result of some superficial hemostasis achieved with the Argon beam coagulator. The black arrow shows the hepatic artery crossed anteriorly by the T-tube.

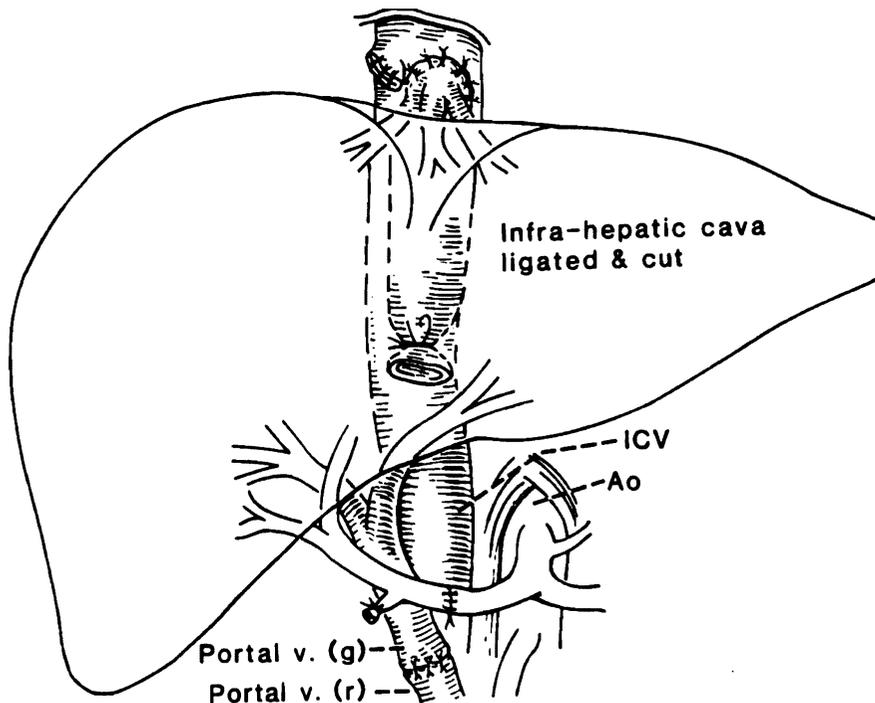


**Figure 6.237. Orthotopic liver transplantation XX.** B: The liver transplant is completed. Good looking bile draining out of the T-tube (arrow), along with a dry field are the most reassuring facts for the operating surgeon.





**Figure 6.238.** *The piggyback technique.* A: Steps in preparation of the recipient vena cava for the piggyback technique. The left lobe is rotated and the small hepatic veins entering the retrohepatic vena cava are ligated and divided. The middle and left suprahepatic veins are exposed and dissected free (From Tzakis, A., Todo, S., Starzl, T.E.: Orthotopic liver transplantation with preservation of the inferior vena cava. *Ann. Surg.* 210 (1989), 649, used by permission).



**Figure 6.238.** *The piggyback technique.* B: Transplantation of a liver piggyback onto an inferior vena cava which is preserved throughout its length. Note that the suprahepatic vena cava of the allograft is anastomosed to the anterior wall of the recipient vena cava. The infrahepatic vena cava of the allograft is sutured or ligated, leaving a blind sac into which numerous hepatic veins empty. g: graft, r: recipient, IVC: recipient inferior vena cava, Ao: aorta. (from Tzakis, A., Todo, S., Starzl, T.E.: Orthotopic liver transplantation with preservation of the inferior vena cava. *Ann. Surg.* 210 [1989], 649, used by permission).

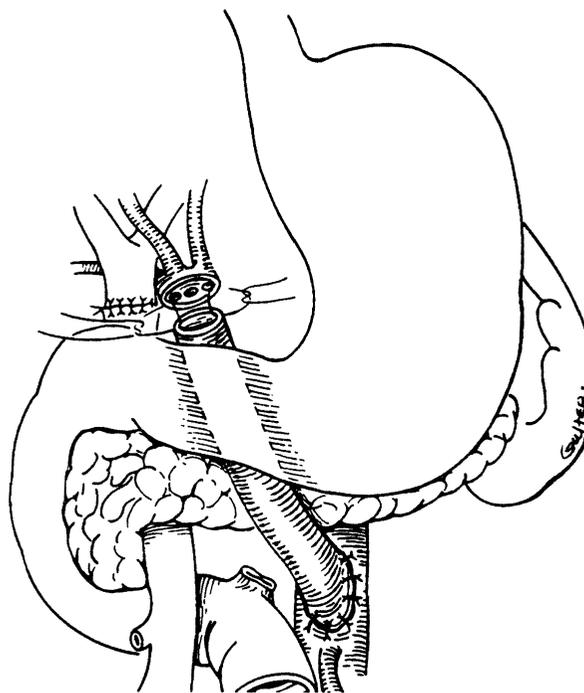
Redoing this anastomosis after reperfusion is a much more difficult undertaking. If available, the third assistant will retract the caudate lobe with the fingers of the left hand shaped as a V (Fig. 6.232B). Once the posterior wall is completed, the liver is flushed through the portal vein (Fig. 6.233B) with 400-600 ml of 4°C Ringer lactate solution. This is done in order to wash out any air

previously entrapped in the organ, as well as the potassium coming from the preservation solution and the hepatocytes<sup>10</sup>. After revascularization this electrolyte imbalance can cause serious acidosis and hyperkalemia<sup>11, 47</sup>, and if not prevented lead to myocardial dysfunction and cardiac arrest<sup>1, 11</sup>.

After completion of the infrahepatic vena caval anastomosis the portal vein anastomosis is

usually performed. However, if at this point the surgeon estimates that all four vascular anastomoses can be easily completed within 60 minutes the arterial anastomosis can be carried out first. This will then be followed, as in the case herein illustrated (Figg. 6.233A-B, 6.234, 6.235A), by the portal anastomosis, and the liver will be perfused simultaneously with portal and arterial blood (Fig. 6.235A). The recipient artery has been already dissected during the hepatectomy (Fig. 6.224A-B) to expose the gastroduodenal artery and one cm of the common hepatic artery proximal to the take-off of the gastroduodenal artery. The donor hepatic artery is usually procured in continuity with the celiac axis and a patch of abdominal aorta (Fig. 6.233A). It is mandatory, before starting the anastomosis, to assess the length of the donor artery. If necessary, a segment of the donor artery should be sacrificed to avoid later kinking and possible thrombosis. The bifurcation of the donor splenic artery, or the take-off of the donor gastroduodenal artery, can be opened to fashion an adequate anastomotic patch. An end-to-end anastomosis is performed using a running suture (Figg. 6.233A-B, 6.234), usually leaving "growth factor"<sup>34</sup> by tying the suture at a variable distance from the vessel wall. After clamping, the excessive polypropylene suture recedes back into the vessel wall, and redistributes itself throughout the the circumference of the suture line. This technique is very effective in preventing anastomotic strictures and is routinely used for the portal and arterial anastomoses. The resulting anastomotic bleeding is small, and most of the time all that is needed is a single extra stitch, close to the knot of the running suture, to prevent distraction of the vessel lips at this point.

As mentioned before, an aberrant right hepatic artery originating from the superior mesenteric artery is present in about 10% of the procured livers<sup>41</sup>. In these cases, the anomaly should be corrected before implanting the liver. To obtain a single-donor arterial conduit two techniques can be used<sup>6, 15, 21, 41</sup>. The aortic incision can be made so as to include in one single large Carrel patch both superior mesenteric artery and celiac trunk orifices. The two orifices are then "folded-over" and anastomosed. Then, an end-to-end anastomosis of the distal superior mesenteric artery to the recipient common hepatic artery is



**Figure 6.239.** Venous jump graft in case of portal vein thrombosis. The donor iliac vein is anastomosed to the recipient superior mesenteric vein and placed in a tunnel created through the transverse mesocolon, anterior to the pancreas and behind the pylorus. The graft is anastomosed in the subhepatic area onto the donor portal vein (From Tzakis, A., Todo, S., Stieber, A., Starzl, Th.E.: Venous jump grafts for liver transplantation in patients with portal vein thrombosis. *Transplantation* 48 [1989], 530, used by permission).

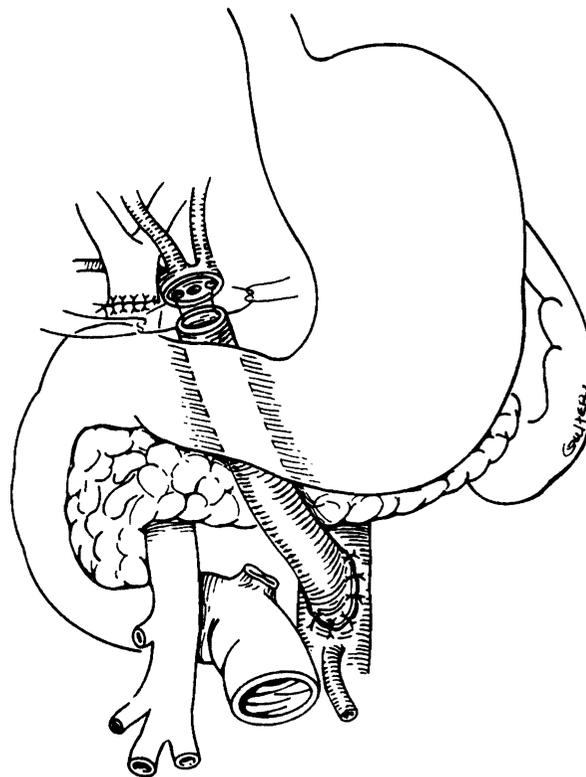
performed. Alternatively, the aberrant right hepatic artery can be anastomosed end-to-end to the stump of the splenic artery (on the celiac trunk). The latter is the technique we use more often because it seems to be easier. However, attention should be paid to the design of the vessels before the right hepatic and common hepatic artery anastomoses, to prevent any hemodynamically significant rotation later. If the arterial anastomosis is done first the recipient vessel is left clamped, and the surgeon proceeds to the portal anastomosis. Before starting this anastomosis, the portal bypass is discontinued by clamping and removing the portal cannula, leaving only the cavo-caval bypass and reducing the flow sig-

nificantly. However, a flow of 1,000 ml/min is considered safe and the bypass is usually maintained until the liver is reperfused.

The length of the donor and recipient portal vein is a critical issue when performing the end-to-end portal anastomosis. The most common mistake is to leave these vessels too long, resulting in a kink. A very helpful manoeuvre is to place 2 or 3 folded laparotomy pads over the dome of the liver. This pushes the hilum caudally and medially, into a position that is closer to the anatomical situation when the retractors are removed and the abdomen is closed. We trim as little as possible the recipient portal vein, trying to preserve most of its length in case the patient needs a retransplantation at a later date. The anastomosis is done using a 6-0 polypropylene suture, and the same everting technique described for the caval anastomosis (Fig. 6.234). The portal vein should have a very generous "growth factor", approximately as long as the vessel's diameter. A few minutes before completing the anastomosis the anesthesiologist should be notified, so that any electrolyte abnormality can be addressed before reperfusion. The portal clamp is removed first, followed by the infrahepatic and suprahepatic vascular clamps, and the liver is reperfused. If the arterial anastomosis was done before the portal vein, the artery is unclamped simultaneously with the portal vein. The surgeon should then quickly look for major bleeding sources from the anastomoses, as well as from the dissected surfaces, and ensure a reasonable hemostasis with interrupted sutures. Immediately after this, the arterial anastomosis is performed, to restore its blood flow as soon as possible.

### Post-implantation Hemostasis

After reperfusion is completed, with both portal and arterial flow, the remaining by-pass cannulae are removed from the greater saphenous and axillary veins. The greater saphenous vein is simply ligated, while the axillary vein is repaired with 7-0 polypropylene. Before proceeding with the biliary tract reconstruction, complete hemostasis should be achieved. It is much more difficult, if not impossible, to obtain good exposure of the hilar structures and to mobilize the liver in



**Figure 6.240.** Arterial graft conduit in liver transplantation: the anterior route. The donor iliac graft is anastomosed end-to-side onto the infra-renal aorta. The graft is brought into the subhepatic region through a tunnel in the transverse mesocolon, anterior to the pancreas, and beneath the pylorus. (From Tzakis, A., Todo, S., Starzl, Th.E.: The anterior route for arterial graft conduits in liver transplantation. *Transplant Int.* 2 [1989], 121, used by permission).

search of bleeding sources once the biliary tract reconstruction is completed. In a few cases very little effort is needed to achieve complete hemostasis. However, on most occasions this phase requires one to several hours of meticulous work. A good system is to sequentially examine all the anastomoses and dissection areas in a clockwise fashion. The surgeon starts by examining the anterior surface of the suprahepatic caval anastomosis, then moves to the area of the divided recipient gastrohepatic ligament. Then two Küttner swabs are used to retract the caudate lobe laterally, to inspect the retrohepatic area and the posterior wall of the suprahepatic caval anastomosis. The hilar structures are then examined, followed by the infrahepatic vena

cava and the areas of intestinal serosa dissected from the recipient liver. The graft is then retracted cephalad and medially, to examine the bare area and the posterior surface of the liver itself (Fig. 6.237A). This round needs to be repeated several times placing stitches on all the bleeding sources, until the operation field is completely dry.

### Biliary Reconstruction

Since the early days of liver transplantation, the favored technique for the biliary reconstruction has been end-to-end choledocho-choledochostomy over a T-tube<sup>21</sup>. The basic aim of this type of reconstruction, as well as the far less popular cholecysto-choledochostomy<sup>4, 46</sup>, is to preserve the function of the sphincter of Oddi for the prevention of subsequent cholangitis. Another benefit is the availability of the T-tube to monitor bile production and perform cholangiography, if necessary. However, a duct-to-duct reconstruction is often not feasible, especially in those conditions associated with a pathologic recipient common bile duct, such as in biliary atresia, primary sclerosing cholangitis, distal common bile strictures, Caroli's disease, biliary tract malignancy, or in the case of a major discrepancy between the donor and recipient ducts. When a direct reconstruction is not possible, or is contraindicated, the donor common duct can be anastomosed to a defunctioned Roux-en-Y limb of jejunum, with equally good results<sup>7, 24, 31</sup>.

Whichever method is used, one of the basic principles to follow during this step of the operation is to carefully evaluate the blood supply to the distal portion of the donor common duct, which normally receives its principal arterialization from retroduodenal sources<sup>13, 14</sup>, and now solely depends on arteries in the central hilum. Another issue that requires specific attention is the donor cystic duct, which may give rise to a mucocele if obstructed at both ends, and cause biliary obstruction by extrinsic mass effect on the donor common hepatic duct<sup>9</sup>. This can easily happen when the cystic duct enters the common duct at a low level, resulting in a double lumen at the site of transection. The best technique to avoid mucocele formation is to completely excise the cystic duct. Alternatively, it can either

be included in the anastomotic ring or completely excluded, leaving its distal portion open.

In a choledocho-choledochostomy the donor and recipient ducts are first trimmed to the appropriate length. The 3 o'clock and 9 o'clock vessels that accompany the duct<sup>13</sup> are usually ligated with 7-0 polypropylene just proximal to the cut edge, and two 4-0 silk stay sutures are then placed on the corners of each duct (Fig. 6.235A-B). A biliary probe is introduced into the recipient duct for 1-2 cm and pushed through a small stab wound made with a No.15 blade (electrocautery should be absolutely avoided to prevent tissue damage and possible subsequent biliary leak). After the probe has been pushed through the wall of the recipient duct a 2-0 silk tie is placed on its end, and the probe is pulled back (Fig. 6.235A). This 2-0 silk tie is cut off from the probe and stitched to the end of the long limb of the T-tube, using a french-eye needle. The T-tube is then pulled through the stab wound in the recipient duct, with the help of the silk tie (Fig. 6.235B). The two short ends of the T-tube are cut to such a length that will allow the proximal segment to cross the anastomosis line into the donor duct, but not to reach the hepatic duct bifurcation. They can also be cut longitudinally, to form a gutter. The anastomosis is performed using a monofilament suture, usually 5-0 polydioxanone, and it is started by placing two posterior sutures that are immediately tied (Fig. 6.236A). All sutures are placed such that the knot will lay outside. After placing the proximal limb of the T-tube inside of the donor duct, a mid-anterior suture is placed and tagged, but not tied. All subsequent interrupted sutures are placed in succession, moving on both sides to the anterior wall. They are individually tagged, and tied at the end. Or, alternatively, a running suture can be used. At the end of the biliary anastomosis, when it is clear that there is no need for it, the gallbladder is removed (Fig. 6.236B). After completion, the anastomosis is tested for possible leaks, first by covering it with saline and injecting air into the long limb of the T-tube, and finally by an intraoperative T-tube cholangiogram.

In the case of a choledocho-jejunostomy, the donor duct is trimmed and prepared in the same way as for the choledocho-choledochostomy (Fig. 6.235A). As soon as the donor duct is ready, a 40-cm Roux-en-Y loop of jejunum is fashioned,

using either stapling devices or manual suturing. A small opening is made with the electrocautery on the antimesenteric border of the Roux-en-Y limb, 3-4 cm proximal to its closed end. This small opening is then anastomosed to the donor duct using 5-0 polydioxanone. The anastomosis is started by placing two posterior stitches that are immediately tied. Then, a 3-4 cm Silastic® stent, with several openings made along its length, is stitched to the Roux-en-Y side of the anastomosis, using 6-0 chromic catgut. This stent is tied loosely, so it can be moved during the placement of the anastomotic sutures. A mid-anterior anastomotic suture is placed, tagged and not tied. All subsequent interrupted sutures are placed in succession, moving on both sides toward the anterior wall. The anastomosis is then completed with the same technique used for the choledocho-choledochostomy. Here also, a running technique can be used. The choledochojejunostomy could be checked using a cholangiography catheter placed inside the cystic duct, if the latter joins the hepatic duct above the level of the anastomosis. However, an intraoperative cholangiogram is not routinely performed at our institution.

Whichever technique is used, the biliary reconstruction is a critical part of the operation, and should not be left in hands less experienced than the ones that do the hepatectomy and the graft implantation. The success of the entire operation depends on an adequate biliary drainage. Biliary tract complications are always very dangerous, and the mortality associated with some of them is extremely high (50% in biliary leaks after choledochojejunostomy)<sup>7</sup>.

### Conclusion of the Operation

After performing the biliary tract reconstruction, the hemostasis is checked once more and all the anastomoses are examined (Fig. 6.237A), before placing 3 closed suction drains that are brought out through separate stab incisions on the abdominal wall. One drain is placed behind the right lobe of the liver, one behind the biliary anastomosis and the last one behind the left lobe of the liver. In this phase of the operation, the most reassuring facts for the surgeon are a dry

operating field and bile draining out of the T-tube (Fig. 6.237B). Finally, the abdomen is closed in layers and the skin margins approximated with staples.

## MODIFICATIONS OF THE STANDARD PROCEDURE

### Modified Hepatectomy

As mentioned at the beginning of this chapter, the hepatectomy can be extremely difficult, and sometimes the presence of adhesions from previous surgery make the standard technique unsuitable. If the hilum cannot be directly approached, the suprahepatic vena cava should be isolated first, and the liver mobilized from cephalad to caudad approaching the hilum posteriorly, where it is usually relatively free of adhesions.

Another technique that is extremely useful is the hepatectomy with preservation of the inferior vena cava. This method, called the piggyback operation, was first reported by *Calne*<sup>2</sup> and popularized by *Tzakis*<sup>45</sup>. This technique cannot be used in liver malignancies, where the resection margins should be as wide as possible, and should be avoided in case of very small cirrhotic livers. However, the technique has special value if a liver from a substantially smaller donor is to be used, because it is easier to adjust disparities in length and size of the donor and recipient vessels. This was the case in our two recent baboon-to-human liver xenotransplantations<sup>25, 38</sup>. Also, smaller raw surfaces are created with the piggyback dissection, thus making subsequent hemostasis easier. In small children, where venovenous by-pass is not used, a combination of piggyback technique and a temporary portocaval shunt<sup>44</sup> minimizes the physiologic disturbances of the anhepatic period. Finally, the fact that there are only 3 vascular anastomoses to do will always allow the donor liver to be reperfused simultaneously with portal and arterial blood.

In the piggyback technique, after completion of the hilar dissection the liver is rotated to dissect the individual hepatic veins. The small hepatic veins are ligated and divided while the three suprahepatic veins are crossclamped (Fig. 6.238A).

### Modified Graft Implantation

The piggyback technique of liver implantation is similar to the standard one, except for the out-flow anastomosis which is made to the anterior surface of the recipient vena cava, on a large common funnel fashioned by opening and interconnecting two (middle and left, Fig. 6.238B) or all three of the main suprahepatic veins. The lower end of the donor inferior vena cava is either ligated or sutured (Fig. 6.238B).

When the recipient portal vein is thrombosed, or significantly smaller in diameter than the donor portal vein, the anastomosis can be performed onto the confluence of the splenic and superior mesenteric veins. If the donor portal vein is not long enough to reach the confluence in the recipient, a free interposition graft from donor iliac vein<sup>29</sup>, can be used to bridge the gap<sup>16</sup>. If the portal thrombosis extends below the confluence, and the superior mesenteric vein is the only available vessel, a jump graft between this vessel and donor portal vein is the only possible technical solution<sup>19, 40, 43</sup>. In this situation, a segment of the superior mesenteric vein to the right of the superior mesenteric artery is skeletonized below the transverse mesocolon, at the root of the small bowel mesentery (Fig. 6.239). A clamp is placed on this segment of the superior mesenteric vein, and the angled distal end of the donor iliac vein graft is anastomosed to it. The proximal end is passed through an opening in the transverse mesocolon, either to the right or left of the middle colic vessels. The graft is then placed anterior to the pancreas and behind the pylorus, in a tunnel bluntly made in the avascular plane between the anterior surface of the pancreas and the posterior wall of the pylorus. Then, the graft is brought into the subhepatic area, where it will be used to perfuse the portal vein of the donor liver. Obviously, if the recipient portal vein is thrombosed, a portal by-pass is not used, and only a femoro-axillary by-pass will be established during the hepatectomy and the anhepatic phase.

When a direct arterial reconstruction is not feasible, or the arterial flow is unsatisfactory, a so-called arterial conduit can be used<sup>15, 21, 35, 41, 42</sup>. Many routes have been used in the past to bring the donor iliac graft, anastomosed to the

recipient infrarenal aorta, into the subhepatic area. Currently, the preferred route is to pass the graft from the recipient aorta through an opening in the transverse mesocolon, behind the pylorus (Fig. 6.240). In this way, the entire arterial conduit can be examined for hemostasis, and the risks associated with a blindly fashioned retropancreatic tunnel are avoided. The arterial graft can also be placed in parallel with a venous jump graft from the superior mesenteric vein, if the anatomical situation of the recipient requires both grafts.

The various vascular graft techniques described in this last section enable today's liver transplant surgeons to accomplish a liver transplantation with minimal hilar dissection. With these approaches the technical contraindications to liver transplantation are very few.

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