CHAPTER 13
Surgical Aspects of Liver Transplantation

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Key points

• The abdominal organs are primarily perfused through the aorta, although dual perfusion (arterial and portal venous) is used for the liver graft in most cases.
• The splitting procedure converts even a perfect quality graft into a marginal graft and therefore marginal donor liver grafts are not offered for split grafts.
• Split liver grafts offer considerable benefits to the paediatric population awaiting liver transplants in countries where deceased donor liver transplant activity is predominant.
• Anatomical variations in blood supply may render a graft not suitable for splitting because vessel allocation to each graft would compromise viability and successful function.
• The liver transplantation operation can be broadly divided into three successive phases: the explant phase is overlapped by the anhepatic phase until the blood supply to the new liver graft is commenced (reperfusion phase).

Abdominal organ procurement from donors following brain death (DBD)

In every case of multi-organ procurement an essential checklist should include the revision of patient notes, medical history, laboratory data and consent for organ donation. Respect for the human body is important and organ procurement surgeons and team members should act in a professional manner during the entire organ procurement process. The patient’s identity has to be checked before initiating the operation and a good
rapport with theatre staff and the anaesthetist is essential. A discussion about prophylactic antibiotics and heparinisation, etc. needs to be held with all of the teams involved.

**Laparotomy and assessment**

The preferred incision is a long midline incision made from the pre-tracheal notch to the symphysis pubis. This gives sufficient access to all organs in the thorax and abdomen. Some advocate a cruciate incision but this does not have any added advantage apart from possibly in extremely obese donors. The easiest and safest place to enter the peritoneal cavity is just above the umbilicus. The falciform ligament is divided between ties, and the falciform ligament is mobilised across the top surface of the liver, leaving at least 10 mm of the falciform ligament on the surface of the liver (Video 1: Multi-organ retrieval: skin incision).

An abdominal retractor is placed and a systemic peritoneal survey is carried out. The liver is assessed for colour, sharpness of margins and consistency; an assessment of the size of the liver may not be possible at this stage. The dome of the right lobe, superior surface of left lobe and then the underside (inferior aspects) of the liver should be palpated. The surgeon may encounter mass lesions that have been missed during the initial donor assessment. The surgeon should also examine the proximal small bowel and progress to the distal part of the colon including the rectum. The pelvic organs, especially in the female, should also be examined. Palpation of kidneys will not be possible in the majority of cases until they are removed from the body. The gastro-colic ligament is divided along its length to assess the quality of the pancreas. Generally this step is performed towards the end of the warm phase dissection, and is explained elsewhere. Any abnormalities at this stage are reported back to the relevant implanting surgeons and any relevant fluids are sent for microbiological assessment. If a lesion is detected it may be possible to arrange rapid histopathological assessment (occasionally in the donor hospital) and so a biopsy is taken. If processing is not possible locally then the specimen is sent with the respective organs.

**Initial warm phase dissection aimed at preparation for cannulation**

The warm phase dissection is aimed at access for cannulation, facilitating organ perfusion and mobilisation of organs, and the vascular anatomy is delineated, making the dissection during the cold phase quicker and organs therefore less prone to procurement-related injury. The abdominal organs are primarily perfused through the aorta, although dual perfusion (arterial and portal venous) is used for the liver graft in most cases. Vascular access to the aorta and inferior vena cava is facilitated by posterior
mobilisation and medial rotation of the right colon along with the duodenum, the so-called Cattell-Braasch manoeuvre.

**Cattell-Braasch manoeuvre**
The right colon is mobilised from the white line (of Toldt) towards the midline (Video 2: Multi-organ retrieval: mobilising the right colon). Deviation from the correct tissue plane is likely to cause damage to the ureter or right kidney. The mobilisation is continued superiorly to include the hepatic flexure, then inferiorly, progressing toward the midline over the anterior surface of the inferior vena cava, until the left renal vein (LRV) is visualised. The LRV is the upper limit of this dissection. The last part of this mobilisation includes the full posterior mobilisation of the duodenum along with the colon (Cattell-Braasch manoeuvre).

The inferior vena cava (IVC) should be visible along its length from its origin at the pelvic brim to the subhepatic region apart from overlying loose connective tissue. The IVC is carefully mobilised at a point just above the confluence of the iliac veins and a tie is passed round the IVC (Video 3: Multi-organ retrieval: exposing the IVC). Ligating the IVC in the abdomen during cold perfusion allows proximal division which enables the abdominal vasculature to be vented and prevents back bleeding flow from the lower half of the body, maintaining a cold operating field.

**Aortic control**
The aorta is cannulated via the right common iliac artery; this has the added advantage of avoiding injury to aberrant lower pole renal arteries originating from the aorta and minimises under-perfusion of the kidney supplied by these vessels. Direct cannulation of the aorta is an alternative approach. The ureters are identified as they cross the common iliac artery bifurcation. Ureteric damage, especially in the obese donor, is common. Dissection around the common iliac artery (CIA) close to its origin from the aorta helps avoid ureteric injury. This approach also preserves the maximum length of the iliac arteries to use as vascular grafts.

The peritoneum over the right iliac artery is divided and the peri-adventitial connective tissue is dissected. The circumference of the CIA is dissected using a blunt technique, taking care to avoid damage to the common iliac vein (CIV) which is abutting the posterior wall of the CIA. The CIV is situated slightly towards the right side of the CIA, therefore dissection is carried out from right to left. Once the artery is dissected, two ties are passed around the vessel and held on clips separately (Video 4: Multi-organ retrieval: dissecting the common iliac artery). A gap of at least 10 mm is needed between the two ties to secure the cannula. The left CIA should be ligated during perfusion to prevent unnecessary left lower limb perfusion. The left CIA has a straighter and deeper course from its origin.
from the aorta. This is approached from the right side of the vessel to prevent injury to the left CIV and a single ligature is passed. To cannulate the aorta directly, the aorta is palpated at the pelvic brim and the peritoneum overlying is dissected. Two ligatures need to be passed around the aorta, one for distal occlusion and the other for securing the cannula. Injury to the middle sacral artery needs to be avoided during aortic control. Once preparation for aortic cannulation is complete, even in the rare event of patient instability a crash cannulation is possible.

**Superior mesenteric vein control**

The aim of superior mesenteric vein (SMV) control is to provide portal perfusion when dual perfusion is required. If the pancreas is to be procured for transplantation, SMV cannulation may cause congestion of the pancreas graft and is therefore best avoided. There are four places where the SMV/portal vein can be cannulated to establish portal perfusion.

1. **Via the SMV.** This is performed at the root of the mesentery. The transverse colon is retracted superiorly and the small bowel loops along with root of the mesentery are retracted inferiorly. The peritoneum over the valley between the transverse mesocolon and the small bowel mesentery is incised horizontally. Careful blunt dissection on the right side of the superior mesenteric artery (SMA) pulsation exposes the SMV. In a thin patient this approach is easier, while the technique is more difficult in an obese donor.

2. **Via the inferior mesenteric vein (IMV) at the ligament of Treitz.** The IMV is small in diameter and cannulation may be difficult with a standard size cannula used for portal perfusion. It is also possible for the tip of the cannula to lie at the splenic vein and as a result perfusion fluid may not be directed to the liver.

3. **Supraduodenal cannulation** can be carried out when the pancreas is being retrieved. This is best achieved towards the end of the warm dissection or during the cold phase itself and will be explained below.

4. **Infraduodenal approach.** In extremely difficult cases and when the pancreas graft is not being procured this manoeuvre can be tried. At the end of the Cattell-Braasch manoeuvre a full anterior mobilisation of the duodenum is carried out. The SMV is approached at the neck of the pancreas in the supracolic compartment.

**Identifying the superior mesenteric artery**

The root of the mesentery is retracted superiorly and the aorta palpated just above the left renal vein. The SMA pulsation should be felt at the upper border of the left renal vein. There is a significant amount of perivascular lymphatic and nerve tissue encasing the SMA. This area is carefully dissected with diathermy, followed by gentle blunt dissection around the
origin of the SMA to allow passage of a sloop (Video 5: Multi-organ retrieval: dissecting the SMA).

A sternotomy is generally carried out at this point either by the cardiothoracic team or the abdominal team. Hilar dissection of the liver is not attempted until the thorax is opened as lack of exposure may cause inadvertent injury.

**Hepatoduodenal ligament and aorta**
The left lobe of the liver is mobilised by dividing the left triangular ligament and the liver retracted superiorly to expose the hepatoduodenal ligament. The gallbladder is opened at the fundus and the bile is aspirated. The common bile duct is identified along the free edge of the gastroduodenal ligament; it is dissected and ligated just above the duodenum. The distal bile duct is divided, and the gallbladder is flushed with warm normal saline until clear effluent comes out from the cut end of the bile duct (Video 6: Multi-organ retrieval: 05:54-07:18).

The following are important where simultaneous liver and pancreas organ retrieval are to take place:

1. Dissecting 5 mm proximal to the upper border of the duodenum will prevent damage to the pancreas head.
2. Identifying the gastroduodenal artery (GDA) to the left of the bile duct and carefully dissecting to demonstrate the junction between GDA and common hepatic artery (CHA). The GDA should be dissected towards the pancreas but not into the pancreas head.
3. The CHA is dissected towards the coeliac trunk, while gently retracting the pancreas inferiorly with a damp swab, taking care not to dissect into the pancreas.
4. At the junction between the CHA and splenic artery (SA) dissection continues approximately 5 mm along the splenic artery.

**Supraduodenal cannulation of the portal vein**
The portal vein is approached from the right side of the partially dissected hepatoduodenal ligament. The portal vein will be identified beneath the bile duct by its colour, and when the connective tissue layer beneath the bile duct is incised the portal vein will be exposed. The portal vein is held with forceps and dissected anteriorly and posteriorly until the vein is free from connective tissue. A tie is passed around the portal vein.

Occasionally this approach to the portal vein can be obstructed by the presence of an accessory or replaced right hepatic artery (ARHA/RRHA). If this is the case the supraduodenal approach to cannulation should be abandoned. The portal vein is not ligated during the warm phase dissection as it is cannulated only when the cold perfusion through the aorta is commenced. If this technique for portal vein cannulation is used, the portal
vein is completely divided above the pancreas head during the cold phase to allow free venting of the pancreas and to minimise pancreatic oedema.

### Preparing the supracoeliac aorta for the cross-clamp

There are two techniques to access the aorta above the coeliac trunk. The right crura of the diaphragm can be divided directly over the aorta and after feeling for the aortic pulsation the thick muscular band directly over the aorta is divided with diathermy. The aorta is then dissected and slooped. This technique may be challenging in the obese donor. Alternatively, once the splenic artery has been slooped, the coeliac trunk can be further dissected and the arcuate ligament will be identified as the aorta emerges from the right crura. The arcuate ligament is divided until the aorta and the origin of the coeliac trunk are revealed (Video 7: Multi-organ retrieval: exposing the aorta). The only occasion this technique may become challenging is in the presence of an accessory left hepatic artery (ALHA) as the operative window is limited.

### Final steps of the warm phase dissection

The gastro-colic ligament is divided between clamps, revealing wide exposure of the lesser sac reaching as far as the splenic hilum. This allows assessment of the pancreas along its length anteriorly (Video 8: Multi-organ retrieval: exposing the lesser sac).

The most frequent place for liver graft injury during organ procurement is inferiorly in the region of segments V/VI where the parietal peritoneum reflects over the liver. These peritoneal attachments are divided before beginning the cold phase dissection. Intravenous heparin 300 U/kg body weight of the donor or a total of 30 000 U is administered 5 minutes before the cross-clamp.

### Application of the cross-clamp

The left CIA is ligated followed by ligation of the distal tie around the right CIA and an anterior arteriotomy is made in the right CIA proximal to the tie. The aortic perfusion cannula is passed through the arteriotomy into the aorta and secured with the proximal tie previously placed around the right CIA (Video 9: Multi-organ retrieval: cannulation).

The SMV is now cannulated (if appropriate) by tying distally, making a proximal venotomy and securing the cannula with the second tie. An aortic clamp is placed across the aorta and mechanical ventilation is ceased. The IVC is ligated and divided proximal to the tie and a suction catheter is placed within the lumen. The IVC is also divided within the pericardial sac as it enters the right atrium. The liver is surrounded with slush or ice and the same is placed in both paracolic gutters for topical cooling of the kidneys (Video 10: Multi-organ retrieval: 11:56-12:30).
Cold phase dissection (Video 11: Multi-organ retrieval: cold phase dissection)

Liver graft procurement

The gastroduodenal artery (GDA) is divided approximately 5 mm distal to its origin, leaving the proximal (hepatic) end untied (Video 12: Multi-organ retrieval: 12:52-13:15). The portal vein is divided 5–10 mm above the duodenum and all of the lymphatics in the hepatoduodenal ligament are divided. The common hepatic artery (CHA) is dissected towards the splenic artery (SA) and the SA is divided approximately 5 mm distal to its origin from the coeliac trunk (Video 13: Multi-organ retrieval: 13:30-13:49). The coeliac axis is taken with a patch of aorta, preserving all vessels in continuity. A finger is then placed in the suprahepatic IVC from above and the transection of the IVC at this point is completed. The diaphragm is then divided to mobilise the liver, and the IVC just above the entry of the left renal vein is also divided. The liver graft procurement is completed by dividing the remaining attachments of the right lobe and right hemi-diaphragm using the finger in the IVC to lift the liver.

Pancreas graft procurement

The anterior mobilisation (Kocherisation) of the duodenum is completed. The stomach is divided with a stapling device just distal to the pylorus and all of the short gastric vessels are divided. The transverse mesocolon is divided close to the colon as far as the splenic flexure and the lienocolic ligament is divided. The colon is retracted inferiorly and the jejunum retracted superiorly. The first jejunal loop is divided with a stapling device. The root of the mesentery including the vessels is also divided with a stapling device away from the lower border of the pancreas to avoid injury. The posterior surface of the pancreas is mobilised commencing near the spleen and using the spleen as a handle. The posterior peritoneal fold of the spleen and the lienorenal ligament inferiorly are divided. The dissection is continued in a plane posterior to the pancreatic capsule towards the midline. The dissection line passes through the left adrenal gland. Dissection continues until the aorta is reached and the SMA root is divided with a small aortic patch; care is taken not to damage the renal arteries which arise close to the SMA.

Variant hepatic artery anatomy

The incidence of atypical hepatic arterial anatomy is high. In the presence of an ARHA/RRHA the liver graft has priority over the pancreas graft. If the ARHA/RRHA traverses posterior to the head of the pancreas and is encased in peripancreatic tissue this does not preclude pancreas graft procurement. The artery can be safely dissected back to the SMA without pancreatic damage. The origin of the SMA is left with the liver graft and
the SMA just distal to the aberrant branch is divided and left with the pancreas graft (Video 14: Multi-organ retrieval: 15:40-17:00). Occasionally the ARHA/RRHA traverses through the pancreatic head (intraglandular) in which case pancreas organ procurement is impossible without significant pancreatic damage.

**Kidneys**
The left renal vein is divided with a small IVC patch and dissected across the midline to the left and over the aorta. The anterior wall of aorta is then opened along the midline from the level of the SMA to the iliac bifurcation. The site and number of renal arteries are identified and the posterior wall of the aorta in the midline is divided along its length. The aorta is divided distally at the origin of the iliac arteries.

The kidney is mobilised from the retroperitoneum, protecting the arterial and venous patches. The kidney is held in one hand and both sides of the ureter are dissected to the pelvis, preserving all the soft tissue around the ureter. The ureter is divided at the level of the pelvis and the opposite kidney is procured in a similar manner.

**Blood vessels for vascular grafts**
Following solid organ procurement, extra blood vessels are obtained from the same donor for potential jump grafts, conduits or interposition grafts during organ implantation. One set of iliac vein and artery accompany the pancreas graft with the remaining vessels accompanying the liver.

**Closure**
All the blood and fluid is sucked out from the body cavities and all mobilised and unused organs are replaced in the body cavity. The skin and subcutaneous tissue are closed without incorporating the rectus sheath using a continuous suture.

**Ex-situ liver graft splitting: Technique to obtain left lateral segment and extended right lobe grafts**

**Graft splitting criteria**
Liver graft splitting ex-situ is performed on the back bench in an ice bath and may take up to 3 hours. This time is added to the cold ischaemia of the graft. Despite best efforts to keep the graft under ice during this procedure, a degree of warming is inevitable. The splitting procedure converts even a perfect quality graft into a marginal graft and therefore marginal donor liver grafts are not offered for split grafts. The criteria for accepting
liver grafts for splitting are generally determined by the requirements, experience and the need for split grafts and may vary geographically. Split liver grafts offer considerable benefits to the paediatric population awaiting liver transplants in countries where deceased donor liver transplant activity is predominant. In the United Kingdom, the current accepted split criteria include donors below 40 years with favourable anatomy, no steatosis, normal or normalising liver functions and short ICU stays. Donor age is not considered an absolute contraindication and successful outcomes can be achieved using liver grafts from older donors.

**Graft assessment and anatomical considerations**
The liver graft is assessed on the back bench while immersed in an ice bath. The graft size, dimensions of the left lateral segment (LLS), estimated weight, degree of steatosis, and quality of perfusion along with any injury to the graft during organ procurement are noted. The success of split grafts depends on safe vascular division including the hilar structures and hepatic outflow. Occasionally anatomical variations in blood supply may render a graft not suitable for splitting because vessel allocation to each graft would compromise viability and successful function. Bile duct and parenchymal division is less complicated and only rarely may lead to an unsuccessful outcome.

**Hepatic artery considerations**
Arterial anatomy of the liver graft is the first priority, and aberrant arterial anatomy is common. Accessory or replaced, left and/or right hepatic arteries make the split procedure more complicated. Finding of totally replaced left and right hepatic arteries is rare but is considered as a natural vascular split. The size of the individual vessels is also taken into account before proceeding with the split.

**Portal vein considerations**
It is rare for portal vein anatomy to preclude a liver graft being split. The segment IV portal blood supply is usually sacrificed during the procedure. This makes a variable portion of segment IV ischaemic and the natural outcome of a right lobe graft which includes this segment is for segment IV to liquefy or atrophy. This rarely has a serious impact on the outcome of the affected graft. Trifurcation of the portal vein is a rare presentation and is not a contraindication for splitting.

**Hepatic vein considerations**
Hepatic vein anatomy is normal in most cases. The left hepatic vein (LHV) usually provides the venous drainage from segments II and III; the middle and right hepatic veins (MHV and RHV) and the donor inferior vena cava
are included with the right graft. The bridge between the LHV and the MHV is the transection plane. The fissural vein may enter the IVC to the left or right of the bridge. Occasionally there is a trifurcation because the segmental veins (of segments II and III) enter separately.

**Bile duct considerations**

Bile duct anatomy is assessed by on-table cholangiography. An understanding of the segmental biliary drainage from the LLS in relation to the intended transection plane is important. A surgical clip is placed at the lower border of the hilar plate close to the falciform ligament to serve as a guide to the plane of division of the hilar plate. A second surgical clip is placed near the apex of the gallbladder fossa, which marks the right edge of the hilar plate and helps identify the segmental bile ducts of the right graft. The cystic duct is ligated and a cholangiogram catheter is placed in the distal end of the common bile duct (Video 15: Preparation of the split liver: preparation of biliary tree). The liver graft is placed on an X-ray plate or, using a C-arm, an on-table cholangiogram is obtained. The cholangiogram is reviewed to understand the anatomy of the segmental bile ducts of the LLS and are assessed in relation to the surgical clips. The transection plane can be moved to the left or right by a few millimetres if required. Obtaining a single duct may not be possible if the segment II and III ducts drain to the right side of the biliary system separately; however, this is not a contraindication to splitting.

**Split procedure: Technical aspects**

The liver graft is turned with the postero-inferior surface of the graft facing upwards and the hepatic artery with the aortic patch is held with tissue forceps and gently stretched along its axis. The entire hepatic artery is assessed starting from the splenic artery patch toward the gastroduodenal artery; during the bench procedure the artery is dissected beyond the origin of the gastroduodenal artery towards the hilum. The common hepatic artery is traced to the hilum and the origin of the left and right hepatic branches are identified. Only the left hepatic artery is dissected free from the perivascular tissue beyond the bifurcation (Video 16: Preparation of the split liver: preparing to split the artery). Dissection is carried out to the right side of the left hepatic artery towards the hilum of the liver. Segment IV hepatic artery branches may be encountered: their size, place of origin etc. are assessed. If major segmental branches arise from the left hepatic artery to the right lobe of the liver then this might contraindicate a safe vascular division and therefore liver split.

The portal vein is cleared of all of the surrounding soft tissue up to the portal vein bifurcation. Small segmental branches to the caudate lobe arise from the portal vein at the hilar plate and these should be ligated before
division (Video 17: Preparation of the split liver: preparing to split the portal vein). This dissection continues along the length of the left portal vein (LPV) until the intended transection plane of the parenchyma near the falciform ligament is reached. Care is taken not to damage the hilar plate as this could result in bile leakage and stricturing of the bile duct. At the end of this procedure the segment of LPV is of sufficient length for the implanting surgeon. The LPV is divided a few millimetres distal to the bifurcation. The defect in the main portal vein is closed with a running suture (5/0 Prolene) in a horizontal manner.

If segmental branches of the right hepatic artery cross the triangle between the left and right bile ducts then this may be a contraindication to liver splitting, depending on the site of origin and the calibre of the vessels. These segmental branches provide sole or additional arterial supply to the segment II/III of the left lateral segment, and sacrificing these may be detrimental to the LLS graft. The common hepatic artery is usually allocated to the LLS on the basis that it is generally safe to reconstruct the RHA with an interposition vascular graft. As mentioned in the previous paragraph, the surgeon may encounter a segment IV hepatic artery branch originating from the LHA to the segment IV of the liver, which has to be sacrificed. The natural course of the segment IV is ischaemia/liquification or involution due to the compromised portal blood supply, which is inevitable in a left lateral/extended right lobe split technique, hence sacrificing the segment IV hepatic artery branch originating from LHA does not aggravate this outcome. If the soft tissue triangle mentioned above is free of any of these arterial branches, it is safe to proceed with the splitting procedure.

The venous bridge between the LHV and the MHV is divided. A deep division is more likely in cases when segmental veins have separate openings in the inferior vena cava. The approach is from outside the liver while holding open the upper vena cava with surgical clips. The bridge of tissue between the LHV and the MHV is probed with a mosquito forceps and is gently guided in the space in an anterior-posterior direction until this emerges from the opposite side. The left hepatic vein is divided from the top and continued to the mosquito forceps lying just beneath the venous bridge (Video 18: Preparation of the split liver: dividing the hepatic veins). The defect in the vena cava is closed with a running non-absorbable suture in a horizontal manner. If the defect is large and simple closure would narrow the MHV outflow, a venous patch can be used for reconstruction.

**Division of the hilar plate**

Gentle probing of the bile duct may help understand the segmental bile duct anatomy and to confirm the cholangiogram findings. A fine mosquito forceps or a small pair of scissors is passed under the hilar plate through...
the hepatic parenchyma until it emerges from the opposite edge (Video 19: Preparation of the split liver: dividing the portal plate). The hilar plate is then divided with a knife. The bile duct will be visible within the hilar plate and the left hepatic duct. The cut edge of the hilar plate remaining on the right graft is sutured with a fine monofilament suture.

**Parenchymal transection** (Video 20: Preparation of the split liver: dividing the liver parenchyma)

The success of each split graft relies on meticulous parenchymal transection. The transection plane is marked with an incision in the hepatic capsule joining the cut edges of the hilar plate. A nylon tape is passed under the marked line for transection to ‘hang’ the liver. The vascular structures meant for each graft are placed on either side to prevent inadvertent vascular injury. The liver remains immersed in the ice bath and the parenchymal transection is performed. A straight cut surface is the expected final outcome which results in a smaller cut surface and therefore less bleeding on reperfusion, with a reduced chance of damage to the other structures. There are several techniques useful for hepatic transection. The Kelly clamp technique is quick and it is easy to identify the biliary and vascular radicals crossing the transection plane; bipolar diathermy is also useful and probably gives better haemostasis, or an energy device may be used. Whatever technique is employed, the portal venous and biliary radicals supplying segment IV need to be identified and ligated. These portal branches are abundant more posteriorly and close to the hilum.

The cut surfaces of each graft are checked for major leaks on the bench by perfusion of the portal vein using cold organ preservation solution. Temporary occlusion of the hepatic venous outflow is often helpful (Video 21: Preparation of the split liver: 25:08-25:30). Any leak points are sutured with fine monofilament non-absorbable sutures. A cannula is inserted down the LHV and then the MHV for each graft to check if any of the hepatic venous radicals are leaking; these are secured in the same manner. The individual grafts are now weighed and packed for transport.

**Orthotopic liver transplantation**

The liver transplantation operation can be broadly divided into three successive phases: the explant phase is overlapped by the anhepatic phase until the blood supply to the new liver graft is commenced (reperfusion phase). The primary goals during the explant and anhepatic phases are to minimise blood loss and to maintain the haemodynamic stability of the recipient. The reperfusion phase can be challenging because of the altered haemodynamics and the reperfusion syndrome.
Surgical technique

The incision

The chosen surgical incision should allow wide access to the right upper quadrant. Individual surgeons will have their own favoured incision but the decision may vary according to the patient’s build and the costal angle and size of the diseased liver. The bilateral subcostal incision will give wide access to the left upper quadrant but can make access to the upper vena cava more difficult. This incision can be extended in the midline up towards the xiphisternum (the ‘Mercedes’ incision), either as a full-thickness extension or by dividing the linea alba and leaving the skin intact. A right subcostal incision placed 2–3 cm below the right costal margin and continuing up to the xiphisternum is a smaller incision favoured by some surgeons, but careful patient selection and experience is required in using this incision (Video 22: Transplanting the split liver: skin incision). The alternative is a ‘J-shaped’ incision which includes a horizontal right subcostal incision which originated from a point in the midline above the umbilicus and then has a midline extension to the xiphisternum. In patients with portal hypertension there are often cutaneous varices that require careful haemostasis. The chosen incision is deepened through the rectus sheath and oblique abdominal musculature to gain entry to the peritoneal cavity. In the midline the falciform ligament often contains varices or a recanalised umbilical vein, and is divided between clamps and ligated (Video 23: Transplanting the split liver: falciform cutting). The peritoneum is opened on the right of the midline as at this point the falciform ligament fans out and opening at this point avoids damage to either varices or other intra-abdominal structures. The abdominal wall retractors are then placed under the costal margin. Several different types of retractor are used for this purpose, depending on the surgeon’s preference and availability.

Dissection of the hepatic hilum

The liver is retracted superiorly using a fixed blade retractor (often attached to the main abdominal wall retractor). The duodenum is retracted inferiorly and the hilar structures are divided close to the liver, retaining a good length of the recipient structures in the hepatoduodenal ligament. The cystic duct and the cystic artery are ligated and divided, followed by the common hepatic duct or common bile duct (Video 24: Transplanting the whole liver: dissecting the porta hepatitis). The hepatic artery is divided between ties, often as separate left and right hepatic artery branches (Video 25: Transplanting the split liver: dissecting the porta hepatitis). The portal vein is exposed; if the portal vein is not thrombosed the delicate soft tissue around the portal vein divides easily. If there has been longstanding portal vein thrombosis it may appear sclerotic and the connective
tissue surrounding the portal vein may be adherent, making dissection more difficult. The portal vein is dissected and cleared from the hilum to the head of the pancreas. The left and right branches are defined in the hilum and proximally pancreatic-duodenal veins may be seen to enter the portal vein. These branches may need ligation and division to allow maximum length of the portal vein and prevent inadvertent damage. A portal vein clamp is applied proximally and to ensure ongoing correct orientation it is usually applied in the 3–9 o’clock position. The portal vein is suture ligated in the hepatic hilum and divided at this point.

**Temporary porto-caval shunt**

A temporary porto-caval shunt is not mandatory but has a number of advantages (Video 26: Transplanting the whole liver: portacaval shunt). It:
- allows early ligation of the portal vein, which facilitates liver shrinkage and makes the subsequent hepatectomy more straightforward;
- avoids venous congestion of the small and large bowel;
- maintains the haemodynamics of the recipient by ensuring adequate venous return;
- reduces the pressure in the portal system and therefore reduces bleeding.

Some surgeons favour selective porto-caval shunt, others prefer to shunt in all patients except very early regrafts, while other surgeons rarely use the technique at all. There is no evidence from randomised controlled trials to support the use of a shunt.

The infrahepatic vena cava is prepared by clearing the overlying adventitial tissue. The cleared area is then clamped with a side-biting clamp and a longitudinal venotomy is made to match the diameter of the portal vein. A 4/0 Prolene suture is used to create an end-to-side porto-caval anastomosis, ensuring correct orientation of the portal vein. The 9 o’clock corner to the inferior end of the venotomy and the 3 o’clock to the superior end are usually successful. A stay suture in the right lateral wall of the venotomy helps maintain the venotomy open. In an obese male recipient the shunt has to be performed in a deep body cavity and may be technically challenging (Figure 13.1).

**Mobilisation of the liver**

The gastrohepatic ligament is divided using diathermy with ligation of large varices and any accessory left hepatic artery. The left lateral segment of the liver is mobilised by dividing left coronary and triangular ligaments. A swab is placed under the left lateral segment to prevent injury to the stomach and spleen. Posterior mobilisation of the liver can be either from the left side to the right side or vice versa (Video 27: Transplanting the split liver: mobilising the liver). If working from left to right the mobilisa-
Figure 13.1 Portacaval shunt parts 1 and 2.
Donation and Allocation

tion is commenced inferiorly by freeing the caudate lobe from the vena cava. The short hepatic veins (segment I veins) are ligated close to the vena cava and the proximal end is clipped with vascular clips before division. Larger-calibre vessels are secured with a suture. The caudate lobe is slowly mobilised off the vena cava; occasionally the caudate lobe may need dividing where it wraps around the vena cava posteriorly and this is best achieved using a laparoscopic staple that staples and divides. The left and middle hepatic vein trunk is dissected and divided using the same stapling device and the liver is rolled to the patient’s right, ligating and dividing the segment I veins as encountered. The right hepatic vein is also dissected and divided using the same stapler (Video 28: Transplanting the split liver: dividing the hepatic veins). Attempts should be made to divide the left/middle hepatic vein trunk transversely and the right hepatic vein longitudinally to leave a small gap between the two staple lines for the subsequent cavo-cavostomy. The right lobe of the liver is mobilised with diathermy, freeing the right triangular ligament and dividing the right hepatocaval ligament with the same stapler. The liver is then removed from the recipient. Haemostasis of the operative field is achieved prior to the implantation of the liver graft. The bare area of the diaphragm and the retroperitoneum often has several bleeding points and can be plicated with a running suture if necessary.

Implantation of the liver graft

Several techniques for reconstruction of the hepatic outflow have been described: (1) modified piggyback; (2) classical piggyback; (3) caval replacement.

The caval replacement technique requires total venous occlusion of the inferior vena cava and may not be suitable in high-risk patients unless veno-venous bypass is available.

Once the liver graft is removed from the ice bath the cold ischaemia time ends and the warm ischaemia time begins.

Modified piggyback technique (Video 29: Transplanting the split liver: modified piggyback anastomosis) (Video 30: Transplanting the whole liver: modified piggyback anastomosis)

A stay suture is placed between the staple lines on the left/middle hepatic vein and the right hepatic vein, a Duvall tissue forceps is applied to the wall of the vena cava below the suture and both are lifted anteriorly. A large Satinsky clamp is applied to the vena cava encompassing the stay suture and Duvall forceps and partially occluding the inferior vena caval return. A longitudinal cavotomy is made in this segment of the inferior vena cava; the cavotomy should reach to the level of the hepatic vein orifices superiorly and is several centimetres in length. A cavotomy is
made in the posterior surface of the inferior vena cava of the liver graft; the length should match the recipient cavotomy or be a little shorter. A stay suture is placed in the left side wall of the recipient vena cava about halfway along the length of the cavotomy. The inferior vena cava of the liver graft is closed at both ends using 3/0 Prolene sutures. Two double-ended 4/0 Prolene sutures are used to align the cavotomy of the graft and the recipient at the 12 o’clock and 6 o’clock positions. The cavoplasty is performed as a side-to-side anastomosis starting at the superior corner; the right lateral wall is sutured from within the vena cava with a continuous suture using the double-ended 4/0 Prolene suture. Care is needed in the superior corner as additional sutures inserted after reperfusion can narrow the hepatic venous outflow (Figure 13.2). Once the suture line has come round the lower corner the anastomosis is completed on the left side of the vena cava by swapping to the other end of the suture inserted superiorly and suturing from superiorly to inferiorly on the left side of the

![Figure 13.2 Modified piggyback anastomosis.](image-url)

Donor Cava
Recipient Cava
vena cava. This suture is carried out from outside the wall of the vena cava and the two ends are then tied together. The lower and side stay sutures are removed.

**Classical piggyback technique**

If the classical piggyback technique is used then the left and middle hepatic vein common trunk of the recipient is clamped with a Satinsky clamp during the explant without using a stapling device (Video 31: Transplanting using classic piggyback technique). This orifice may be widened slightly to the right side. The upper vena cava orifice of the donor liver graft is left open and anastomosed end-to-side to the trunk of the middle and left hepatic vein of the recipient (Video 32: Transplanting using classic piggyback technique: liver implantation). The lower vena cava of the donor is either ligated or closed with a running suture and no posterior cavotomy is made. This anastomosis is performed with 3/0 Prolene suture.

**Caval replacement technique**

Technically this is the simplest technique, especially if the recipient is on veno-venous bypass. This technique requires clamping and removal of the retrohepatic portion of the recipient vena cava and can save time during the liver explant because the caudate lobe is not mobilised off the vena cava (Figure 13.3). Any savings in surgical time are however negated by the time required to set up veno-venous bypass. The liver graft is positioned in the space created by removing the recipient vena cava. Two double-ended 3/0 Prolene stay sutures are inserted in both recipient and donor vena cava at 3 o’clock and 9 o’clock. The back wall of the vena cava is sutured by retracting the liver graft inferiorly and suturing from inside the vena cava 3 o’clock to 9 o’clock. The anastomosis is completed by swapping back to the other end of the suture at 3 o’clock and completing the anterior wall (this time from outside) and tying the two ends together. The lower vena cava anastomosis is performed using a similar technique with a 4/0 Prolene suture (Figure 13.4).

**Portal vein anastomosis**

The porto-caval shunt is ligated with a 2/0 ligature and suture reinforced with 4/0 Prolene and the portal vein is clamped maintaining the 3 o’clock and 9 o’clock orientation. The shunt is then divided. The graft portal vein and recipient portal veins are aligned and their lengths are shortened to prevent kinking after the anastomosis. The right lobe of the liver is lifted anteriorly by placing cold swabs beneath. A double-ended 5/0 Prolene suture is inserted in both the 3 o’clock and 9 o’clock corners to oppose the ends. The back wall of the anastomosis is performed from the left side of the vein towards the operating surgeon, from inside the vein, in a continuous suture. Once the right corner has been reached, the suture
is swapped for the other end and the anterior wall is continued from outside the vein (Video 33: Transplanting the split liver: portal vein anastomosis) (Video 34: Transplanting the whole liver: portal vein anastomosis) (Video 35: Transplanting using classic piggyback technique: portal vein anastomosis). Thin bites of the portal vein are taken to avoid strictures and narrowing of the anastomosis, and the alignment of the veins is important to avoid rotation.

Before the final sutures are placed in the portal vein anastomosis the graft should be flushed with 5% dextrose, 0.9% saline or 4.5% human albumin solution to elute the excess potassium that has leached into the graft (Video 36: Transplanting using classic piggyback technique: liver washout). A perfusion cannula is inserted into the graft portal vein through the unfinished anastomosis and the effluent is vented through the donor vena cava through a separate opening made in the lower end. One litre of the preferred solution is used to flush the graft; however, if the graft

Figure 13.3 Classical caval replacement part 1.
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weight is greater than 2 kg then more should be used. The perfusion cannula is removed and the portal vein anastomosis is completed, a growth factor equal to 0.5–1.0 times the diameter of the portal vein is left in the suture to minimise the risk of strictures at the anastomosis.

Reperfusion
The vena cava clamp is removed and haemostasis is carried out. The portal vein clamp is removed. The haemodynamic changes and the ECG pattern should be observed during the reperfusion and any evidence of the reperfusion syndrome or hyperkalaemic ECG changes may require temporary re-clamping of the portal vein with finger compression to allow sufficient time for the anaesthetist to deal with these (Video 37: Transplanting the split liver: reperfusion) (Video 38: Transplanting the whole liver: reperfusion) (Video 39: Transplanting using classic piggyback technique: liver reperfusion).

Arterial reconstruction
The recipient common hepatic artery is dissected free from all perivascular tissue to just beyond the gastroduodenal artery (GDA). The recipient GDA
is ligated distally and the CHA is clamped with a small vascular clamp. A patch is created at the site of the GDA bifurcation. Provided that the donor hepatic artery has conventional anatomy, a patch is created at the bifurcation of the donor coeliac axis into the CHA and splenic artery (Figure 13.5). The two patches are anastomosed end to end with 7/0 Prolene (Video 40: Transplanting the split liver: arterial anastomosis) (Video 41: Transplanting the whole liver: arterial anastomosis) (Video 42: Transplanting using classic piggyback technique: arterial anastomosis). Once the anastomosis is complete a small ‘bulldog’ clamp is placed on the donor hepatic artery distal to the donor GDA and the arterial clamp is removed. This ensures any thrombus is flushed out and allows an assessment of blood flow. The ‘bulldog’ clamp is removed and the donor GDA is either clamped (to be ligated later) or ligated with a 2/0 ligature.

In the presence of multiple donor hepatic arteries, several possible options for reconstruction exist. The commonest scenarios are explained below (Figure 13.6).

1. **ARHA/RRHA is provided with the donor SMA and a full-length CHA.**
   The donor CHA with a splenic artery patch is anastomosed to the distal cut end of the SMA and the proximal end of the donor SMA is anastomosed to the recipient CHA/GDA patch.

2. **ARHA/RRHA is provided cut above the pancreas and/or damaged and without the SMA.** The ARHA/RRHA is reconstructed onto the donor GDA stump or the donor splenic artery and the donor coeliac trunk is anastomosed to the recipient CHA/GDA patch.

3. **Three hepatic arteries.** The ARHA/RRHA is anastomosed as above and the donor coeliac trunk is anastomosed to the recipient CHA/GDA patch (Figure 13.7).

   If the recipient CHA does not provide sufficient inflow due to stenosis, thrombosis or failed reconstruction, an aortic conduit is inserted. The conduit is anastomosed to the recipient infrarenal aorta immediately below the origin of the SMA. The ligament of Treitz is mobilised, the aorta is exposed, and the peritoneum over the infrarenal aorta is opened. The aorta is mobilised and encircled and a side-biting clamp is applied. A vertical arteriotomy is made and a punch is used to trim the edges. A suitable length of donor iliac artery is chosen, preferably from the same donor, and an end-to-side anastomosis is made with a continuous running 4/0 Prolene suture. The conduit is tunnelled behind the stomach, in front of the pancreas and through the transverse mesocolon to lie at the hepatic hilum. The conduit is then anastomosed end-to-end with the donor hepatic artery.

**Biliary anastomosis**

The biliary anastomosis is usually an end-to-end anastomosis between the donor common bile duct and recipient common hepatic duct. If the liver
Figure 13.5 Standard arterial anatomy.
Figure 13.6 Accessory left hepatic artery and accessory right hepatic artery.

In the presence of accessory/replaced right hepatic artery, the proximal end of the SMA is reconstructed on to the splenic artery patch.

Figure 13.7 Reconstruction options for hepatic artery.
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Figure 13.8 Roux-en-Y hepatico-jejunostomy.

The donor bile duct is freshened and any choledochal vessels running alongside the bile duct are controlled with fine sutures. Diathermy is not used to control this bleeding as it may cause ischaemia of the bile duct. The recipient bile duct is also freshened and any bleeding controlled in a similar manner. It may be possible to incorporate the cystic duct stump of the
donor bile duct into the anastomosis if this helps to rectify a duct size discrepancy. The anastomosis is performed using a double-ended continuous 5/0 PDS suture (Figure 13.9) commencing at the 3 o’clock corner and carrying out the anastomosis in a similar manner to the vascular anastomoses above (Video 44: Transplanting the whole liver: bile duct anastomosis).

**Figure 13.9** Bile duct anastomosis.

**Closure**

A final check on haemostasis is carried out and it may be necessary to use haemostatic aids in the retroperitoneal areas or the cut surface of a split liver. A large tube drain is placed in the subhepatic space and a ‘time-zero’ needle biopsy of the liver is performed. The muscle layer is closed using a mass technique with a loop 1-PDS and skin staples are the preferred means of skin closure.
Further reading


