ABDOMINAL ORGAN RETRIEVAL AND TRANSPLANTATION BENCH SURGERY

Edited by Gabriel C. Oniscu • John L. Forsythe • John Fung

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Foreword

I am delighted to see a book concentrating on the techniques and associated problems of organ retrieval and donor management, and especially the inclusion of techniques of bench surgery. This book starts with the logistics of organ retrieval and then moves through donor management (including the diagnosis of brainstem death), multiorgan retrieval and organ preservation. The various techniques of bench surgery related to the kidney, the liver and especially splitting of the liver both *in situ* and *ex situ* are very well described. The increased activity in pancreas transplantation and intestinal transplantation warrants detailed descriptions of techniques of retrieval and the relevant bench surgery, and these topics are well covered. Finally, there is a chapter on retrieval of organs from children and the associated bench surgery which often presents greater technical difficulties.

This book is a very welcome addition to the transplantation literature and fills a much needed gap. It should be essential reading for all transplantation units and especially for transplantation surgical trainees.

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Preface

Over the last 50 years, transplantation has been at the forefront of innovation in medicine. Advances in surgical techniques, immunosuppression and a holistic care of the transplant recipient have ensured the continued success of life-saving and life-enhancing transplantation. However, none of this would have been possible without the donors' gift of life and the efforts and dedication of the teams that ensure successful organ recovery.

Organ retrieval is the bedrock of transplantation. New techniques, such as multivisceral retrieval and *in-situ* and *ex-situ* liver splitting, have been developed in an effort to expand the donor pool and reach more patients. Bench surgery, an understated element of the transplantation pathway, has seen innovative changes to deal with more and more complex anatomical situations in an effort to provide more organs for transplantation. Deceased circulatory failure donation has seen a resurgence in the last few years, fueled in part by significant advances in organ preservation.

In many ways, abdominal organ retrieval is on the brink of a revolutionary change, with advances such as regional normothermic perfusion and warm pulsatile preservation paving the way.

In this context, this book provides a timely review of the current status of organ retrieval and bench surgery techniques in a step-wise approach and introduces novel practices, to illustrate the changing landscape in the field.

Conceived as a practical guide for retrieving surgeons of all levels of experience, the book follows the journey of the donated organs from retrieval to preparation for implantation, and as such will help all transplant professionals to understand the management of potential donors, be familiar with standard retrieval techniques, understand anatomical variations and learn effective ways of dealing with them. Each step of the surgical procedures is illustrated with high quality intraoperative pictures and diagrams, whilst decision algorithms are provided for difficult clinical scenarios. A novel aspect is the provision of evidence-based information, which is clearly identified in the text. Practical tips and learning points are highlighted throughout the text, in yellow and green boxes respectively, and each chapter finishes with an 'in a nutshell' summary.

We hope that the format of this book will provide an easy reference point to those involved in every aspect of abdominal organ retrieval and bench surgery and, as such, will promote excellence in this challenging area of transplantation surgery.

Gabriel C. Oniscu
John L. Forsythe

About the Companion Website

This book is accompanied by a companion website:

www.wiley.com/go/oniscu/abdominal

The website features video clips to accompany four chapters:

- Multiorgan retrieval
- Kidney bench surgery
- Liver bench surgery
- Pancreas bench surgery

1 Organ Retrieval Logistics

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Introduction

There are very few countries where organ donation is not covered by the provisions of law or is expressly prohibited. However, healthcare infrastructure or cultural and religious traditions have prevented widespread adoption of the practice in many societies. Substantial differences exist in donation rates even amongst countries of similar socio-economic status, sharing a similar cultural and religious heritage and similar legislative framework. Such differences testify to the important role of logistics in the success of organ transplantation.

Organ transplantation involves two surgical procedures: the retrieval of an organ from a donor and implantation of the organ to a recipient.

This chapter specifically deals with logistical issues surrounding organ retrieval. The details of the surgical procedures required to retrieve organs are covered in subsequent chapters of the book. The logistical issues discussed refer to organ retrieval from deceased donors only.

Diagnosis of death – DBD and DCD donation

It is acknowledged worldwide that the irreversible loss of the capacity for consciousness combined with the irreversible loss of the capacity to breathe equates to death. Irreversible loss of brainstem functions produces this state. Therefore demonstration that the functions of the brainstem have irreversibly ceased allows diagnosis of death.

On the background of this principle, different legal definitions of death have evolved in different countries.

Donation after brain death (DBD)

In the UK demonstration of the absence of all the functions of the brainstem by clinical tests is adequate for the diagnosis of brainstem death (BSD) to be made, providing that severe metabolic disturbance and potential effect of drugs and hypothermia have been excluded and a cause has been established. Other countries require additional criteria such as demonstration of lack of electrical activity in EEG or demonstration of the absence of blood flow to the brain by imaging. Criteria used to diagnose BSD in children are the same as those in adults, but it should be noted that the diagnosis of BSD in infants under the age of 2 months is not appropriate or possible.

In order to test for BSD, the patient must be in an unresponsive coma, having sustained 'irreversible' brain damage of known aetiology.

Potential reversible circulatory metabolic and endocrine disturbances must have been ruled out as the cause of continuation of unconsciousness:

- Drugs: sedative, muscle relaxants
- Hypothermia < 35°C
- Circulatory, metabolic, endocrine disturbance

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In DBD donors, circulation and the oxygenation of peripheral tissues are maintained after death. This allows better preservation of function in the organs to be retrieved and transplanted. The range of organs suitable for transplantation is greater in DBD donation and in general the outcome of transplantation using DBD donor organs is better.

BSD testing:

- Absence of pupillary response to light (occulomotor III cranial nerve)
- Absence of corneal reflexes (trigeminal V cranial nerve)
- Absence of caloric responses
- No motor response in the distribution of the cranial nerves (trigeminal V sensory supply to upper face and facial VII cranial nerves)
- No cough or gag reflex (glossopharyngeal IX and vagus X cranial nerves)
- Testing for apnoea

Death following cessation of cardiorespiratory function – DCD donation

Death can also be diagnosed by an appropriately qualified individual, by confirming irreversible cessation of cardiac, respiratory and neurological activity. In practice the irreversibility of the loss of neurological function is inferred from the length of time that breathing and circulation has been absent.

The cessation of cardiac activity can be determined by the absence of pulses and heart sounds. In the hospital setting, demonstration of asystole on ECG or the absence of blood flow in direct arterial pressure monitoring may also supplement the diagnosis. After 5 minutes of continued absence of circulation and absence of breathing, the absence of pupillary or corneal reflex is tested to confirm cessation of neurological function also. This category of deceased organ donation (previously also referred to as non-heart beating donors – NHBD) is called donation after cardiac death or donation after circulatory death (DCD).

Organ donors in this category are patients who have often sustained catastrophic irrecoverable brain injury and in whom further treatment has been considered futile.

Any decision about futility of further treatment and whether or not active treatment should be withdrawn must be made only in the interest of the patient and with no regard to any consideration of potential organ donation.

When the doctors caring for the patient have made the decision that further treatment is futile, the timing of the withdrawal of treatment can be coordinated, to allow for organ retrieval to take place after circulatory death is diagnosed.

In the early days of organ transplantation, prior to the establishment of criteria to diagnose BSD, this type of donation was the only means to provide organs for transplantation from deceased donors. In the last 10 years there has been a revival of the concept and the practice of DCD. DCD donors provide a variable but increasing proportion of the deceased donor organs transplanted. Specific considerations about retrieval of organs from DCD donors and transplantation of such organs are dealt with in the relevant chapters of this book.

It should be noted that the practice of donation after circulatory death is expressly forbidden by law in certain countries, notably in Germany.

Evolution of organ donation and the legal framework governing organ donation

Historically, even after donation after brain death became accepted practice, the responsibility for retrieving organs from deceased donors rested with the surgical teams of individual transplant units. The multiorgan retrieval procedure involved separate teams from kidney, liver, pancreas and cardiothoracic transplant units to travel to and assemble at the donor hospital.

As organ transplantation became established practice and activity levels increased, it became evident that better coordination of organ retrieval from multiorgan donors and regulation of the allocation of organs for transplantation were required. The differences in statute and social–cultural norms in different countries naturally resulted in varying forms of regulation of organ donation. Broadly speaking the laws dealing with authority for organ retrieval can be divided into two categories:

Table 1.1 Donor legislation in various countries.

Presumed consent (opt out)		Informed consent (opt in)	
Argentina	Italy	Australia	Lithuania
Austria	Latvia	Brazil	Netherlands
Belgium	Luxembourg	Canada	New Zealand
Bulgaria	Norway	Chile	Romania
Costa Rica	Panama	Denmark	Switzerland
Croatia	Poland	Germany	UK
Czech Republic	Portugal	Ireland	USA
Estonia	Singapore	Japan	Venezuela
Finland	Slovak Republic		
France	Slovenia		
Greece	Spain		
Hungary	Sweden		
Israel			

1 opting out systems where it is assumed that the deceased had no objection to donation unless such objection had been expressly registered prior to death, and

2 opting in systems where prior consent is not assumed and some indication or evidence is required that donation was the wish of the deceased or donation requires consent from relatives.

The legal requirements for donation vary across the globe (Table 1.1) [1,2]. In some countries, an opt-in law, which requires informed consent from the relatives prior to proceeding to donation, is in place. Most European countries have adopted the opt-out or presumed consent law, whereby organs are removed from every identified donor unless they have expressed their wishes against donation ('hard form' opt out) or after inquiring from the relatives whether they were aware of such wishes ('soft form' opt out).

There is some evidence that the introduction of a decentralized organ procurement system has led to an increase in the number of organ donors [3,4]. It is yet unclear whether replacing an 'informed consent' with 'presumed consent' legislation has a similar effect on organ donation rates, but some studies [5,6] suggest that a significant increase was noted in countries where the change in legislation was adopted.

Organ retrieval teams and organ transplantation units

Many countries worldwide have gradually moved to a varying degree of separation of the multiorgan retrieval process from the process of organ transplantation. Whilst the details of organ retrieval services vary around the world, there is broad agreement about the principles and standards that apply to successful retrieval of organs from deceased donors.

The key to successful organ retrieval is cooperation between the three essential components, namely donor coordinators, the organ retrieval team and the transplant units.

Donor coordinators

Donor coordinators may be affiliated to transplant centres or be part of an independent organization. Transplant coordinators who remain affiliated to transplant units and serve a dual role as donor and recipient coordinators may fulfill each role equally effectively and this model may arguably have some benefits. However, in terms of one of the most important outcome measures, namely maximizing the potential from deceased donation, international experience and the balance of evidence suggests that dedicated donor coordinators based in potential donor hospitals is a superior model [7].

A wide network of donor coordinators based in local hospitals is the key component of a successful organ donation programme.

In some of the countries with the highest deceased donation rates such as Spain, Portugal and Italy, there are donor coordinators based in every hospital in the country. They play an important role in raising and maintaining the awareness of donation and provide education and support to staff of potential donor hospitals. In the case of DBD donation, donor coordinators will often help approach the donor family, take part in the process of consent or authorization for donation, provide help with donor management in the critical care unit and support the donor family during the process of donation. When required, donor coordinators will also liaise with legal authorities to facilitate donation and ensure that potentially surmountable legal obstacles do not prevent donation

Figure 1.1 The equipment required by a single multiorgan abdominal retrieval team.

of organs. Donor coordinators will then inform organ retrieval teams and coordinate the retrieval process.

The responsibility for transporting teams to donor hospitals and organs to their destinations may rest with the donor coordinator, or the transplant units themselves, or be shared. The increased regionalization of the donation services, together with a standardized approach to the travel arrangements, is expected to improve the quality and safety of the travel services for the donor team [8,9].

Donor coordinators also share the responsibility for appropriate documentation of donor details and the submission of information to the National Transplant Database as well as individual transplant units.

The paperwork that is currently completed throughout the donor process in the UK includes:

- Authorization for Solid Organ and Tissue Donation
- Patient Assessment Form
- GP Fax – will be sent retrospectively if donation outwith GP surgery hours
- EOS form (Core Donor Data Form)
- Donor Management Audit paperwork
- If the heart is being used for valves – separate documentation pertaining to Tissue Services will be completed (this also applies to islets)
- UK Transplant Registry – Proceeding and Non-Proceeding Donors after Cardiac Death Information
- UK Transplant Registry – Organ Retrieval Information for attending Specialist Nurse – Organ Donation
- End of process documentation for the donor patient hospital notes

Donor coordinator roles:

- Promote and facilitate the entire donation process
- Provide support and appropriate information to families regarding organ and tissue donation.
- Ensure that donation proceeds in line with national legislation, policies and procedures.
- Obtain all relevant information enabling transplant centres to assess the suitability of potential donors.
- Assist in the optimization of organs for transplant through appropriate donor management.
- Maximize the placement of organs for transplant
- Train donation services team members
- Collect data for the organ donation related audits
- Facilitate and support education of healthcare professionals and the general public

Organ retrieval teams

The organ retrieval teams vary in their size, composition and funding. Most teams will be formed of staff of transplant centres, who should be available 24 hours a day without other commitments in their own centres during the time on-call for retrieval. Cardiothoracic organ retrievals are almost always performed by teams from cardiothoracic transplant centres (lead surgeon +/– assistant, scrub nurse and perfusionist). For retrieval of all other organs, ideally a single abdominal organ retrieval team should be available. The team should include a lead surgeon, assistant surgeon, scrub nurse and operating theatre practitioner.

Organ retrieval often happens in small hospitals unaccustomed to the surgical procedure and where some of the specialist equipment required may not be available. The presence of a single retrieval team, rather than individual organ teams (e.g. a liver team, a kidney team, a pancreas team) streamlines the process and ensures a uniform approach to the abdominal retrieval, which is an important factor, particularly when operating in different environments.

Ideally the retrieval team should be self-sufficient and not require any support from the donor hospital other than an operating theatre and a local member of staff. In practice, for DBD donors, most retrieval teams also require a donor hospital anesthetist to be present during the retrieval procedure. There is some evidence that the inclusion of a dedicated transplant anesthetist in the retrieval team allows a greater degree of flexibility at the local hospital (as the team will only require access to an operating theatre) and improves the quality of the organ donor management preretrieval.

All retrieval teams should be self-sufficient. Ideally a dedicated transplant anesthetist should be part of the retrieval team to facilitate organ donation management.

There should be policies in place for training and certification for the members of the retrieval team and for effective audit of the teams' activity and outcomes.

The key responsibility, by far the most important responsibility and an absolute imperative for the lead surgeon of the retrieval team is correct identification of the potential donor in the operating theatre prior to the retrieval operation. The lead surgeon assisted by the donor coordinator must also check that diagnosis of death has been made appropriately and documented correctly, and the consent or authorization for donation has been obtained and documented. Preoperative checks (see Figure 4.1) should also ensure that all other necessary information about the donor (e.g. blood group, virology status, relevant medical history, results of other blood tests) is available. If there are both cardiothoracic and abdominal teams present, a brief discussion about the conduct of the surgical procedure and the sequence of events should take place between the teams before the operation.

The surgeons of the retrieval team should document any unexpected finding or abnormality, should document donor instability or suboptimal organ perfusion and should provide a brief description of the surgical procedure for the hospital records of the donor.

The retrieval team jointly with the donor coordinator are also responsible for documentation of the timing of the key events (such as withdrawal of support, time of asystole, time of declaration of death and the start of perfusion for DCD donors or the time of cross-clamp, start of cold perfusion, time of placement of organs in ice for DBD donors) and the correct labeling of all organs and accompanying blood and tissue samples.

Key checks to be performed by the lead surgeon:

- Identity of the donor
- Brainstem death tests performed and documented appropriately
- Consent for organ donation
- Blood group
- Virology status, medical history and other blood tests

Responsibilities of the retrieval team:

- Documentation of key retrieval events
- Completion of appropriate documentation
- Completion of procedure summary in medical notes
- Correct labeling of the organs and blood and tissue samples

Transplant units

The recipient centre where the implantation of organs takes place must have a point of contact available at all times. A senior transplant surgeon should be available to discuss donor details and the retrieval operation with the donor coordinator and the retrieval team.

Transplant centres should maintain a record of all offers of deceased donor organs accepted or rejected. The transplant centres have the ultimate responsibility for the suitability of the organs to be transplanted. This requires checking of donor and recipient blood group, donor virology status, other blood tests and medical history, the critical times during the retrieval procedure and physical inspection of the organ to be transplanted when it arrives in the recipient centre. Any damage or abnormality such as a suspected tumour noted by the transplanting surgeons must be reported to the National Transplant Organization without delay, since this may have implications for potential recipients of other organs from the same donor.

Post Operative Theatre Checklist for SN-OD (optional)

	Yes	No
Has the operation / procedure summary been completed by lead surgeon in medical records?		

	Yes	No
Organ specific forms completed?		
Organ specific forms with organ?		
Blood group form with organ?		
Organs packed?		
Have the specimens been labelled correctly (including patient's name)?		
Proceeding/non-proceeding DCD form with organ?		

	Yes	No	N/A
Have security tag numbers been documented?			
Left kidney tag # _____			
Right kidney tag # _____			
Pancreas tag # _____			
Heart for valves # _____			
Corneas tag # _____			

	Yes	No	N/A
Has transport been arranged?			
Tissue donation paperwork / bloods			

		Yes	No
Last offices	Family keepsakes		
	Family requests		

Details: _____

_____

	Yes	No
Local policies available:		

Name:	
Signature:	

Figure 1.2 Postoperative checklist to ensure appropriate documentation is completed following organ retrieval procedures. (SN-OD, Specialist Nurse for Organ Donation.)

Donor surgeons and coordinators should be able to discuss any donor-related issues with the recipient centres at all times.

The transplant centres have the responsibility to organize the transport for the organs that they have accepted. They should liaise with the donor coordinators to establish the optimal time for the dispatch of organs, without undue delays that could increase the length of the cold ischemic time.

Patient selection for transplantation and allocation of deceased donor organs for transplantation

Patient selection

Refinement of surgical techniques and immunosuppressive therapy as well as improvements in the detection and management of comorbidity and complications of organ transplantation have resulted in widening of the indications for transplantation. Organ transplantation therefore has become a victim of its own success, with a worsening shortfall in the availability of organs for transplantation compared with the number of patients registered for transplantation.

Policies used for the selection of patients for transplantation vary depending on the type of organ transplant under consideration and the local circumstances, primarily pertaining to the degree of donor organ shortage. It is beyond the scope of this chapter to examine patient selection policies and the evidence base for such policies in detail. It is sufficient to mention here that each organ transplantation organization needs to consider the appropriate balance between the conflicting requirements of utility and duty of care to individual patients and reach an agreement on uniformly applied criteria for patient selection. An example of the dilemmas faced with patient selection would be eligibility for liver transplantation for hepatocellular carcinoma (HCC). Offering transplantation to patients with advanced HCC, however small the cure rate may be, may still be the best treatment option for the patients with the cancer. However, restricting transplantation to those whose cancers are not advanced beyond certain limits (such as the Milan criteria) may represent a better balance between utility and benefit.

Allocation of deceased donor organs for transplantation

Allocation of deceased donor organs to potential recipients is an even greater challenge than determining the suitability of patients for transplantation. All methods of allocation attempt to strike an appropriate balance between the conflicting demands of utility, duty of care to individual patients, justice and benefit.

In general, models of allocation of deceased donor organs for kidney transplantation take account of factors associated with improved outcome, such as HLA matching, in addition to elements of fairness or justice, such as waiting time. The need or desire to give priority to certain groups such as children or other disadvantaged recipients on the waiting list, such as those with anti-HLA sensitization or certain blood groups, are also considered in kidney allocation models. In most countries complex allocation formulas based on the considerations mentioned above are used to allocate deceased donor kidneys to individual patients on national or regional waiting lists. Clearly other criteria such as social status, ability to pay, gender and ethnic origin have no role in allocation decisions.

The difficulties are compounded further for transplantation of other solid organs such as heart, lung or liver, where the potential recipients often have a short life expectancy on the waiting list; hence the conflict between utility and benefit comes into sharper focus.

Again, a detailed discussion about the pros and cons of different allocation policies is beyond the scope of this chapter, but it seems important to remember that deceased donor organs are scarce and extremely valuable resources. Therefore rules governing the selection of patients for transplantation and allocation of the organs must be carefully considered, must be transparent and must command the support of the public as well as the healthcare professionals.

We must also remember that patient selection and organ allocation are only two aspects of a range of logistical challenges, all of which play an important role in the success of the endeavor of organ transplantation. A thorough understanding of these challenges and continuous efforts to address them is the duty of every transplant professional.

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2 Strategies in Preservation of Abdominal Organs

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Introduction

Due to the use of new immunosuppressive regimens, standardization of surgical techniques and better post-operative management, results in organ transplantation have improved significantly in the past decade. Unfortunately, the donor organ shortage has persisted and, as a consequence, living donation has increased, particularly in kidney transplantation. The majority of donor organs, however, are obtained from deceased donors either after brain death (DBD) or after cessation of circulation and cardiac death (DCD). As donor resources are scarce, many transplant centres have started to accept organs from older deceased donors (extended criteria donors: ECD). Furthermore, the current neurosurgical and intensive care therapy in patients with cerebral injury is more aggressive and will attempt early intervention when necessary. As a result, in some patients with irreversible cerebral injury the state of brain death does not occur. When further treatment is futile and organ donation is allowed in these potential donors, support is withdrawn and they become donors after cessation of circulation and cardiac arrest (DCD) [1,2]. Many of these deceased donors, including unstable standard criteria donors, ECDs and DCDs, are 'high risk donors' with a lower donor organ yield compared to standard criteria donors (SCDs). This different 'quality' is reflected by increased rates of primary nonfunction (PNF), delayed graft function (DGF) and post-transplant complications including a reduction of graft survival.

Thus, more than ever, the strategies of bridging from donor to recipient with optimal preservation conditions are key to an adequate early function and good survival in the recipient.

Removal of an organ following a period of donor management after brain death or after cessation of circulation and cardiac death causes a cascade of injuries that result in deterioration of function and eventually may lead to the death of the organ. Most organs tolerate only 1–2 hours of warm ischemic injury without any perfusion, before metabolic changes become so prominent that normothermic reperfusion with blood cannot resuscitate the organ and restore adequate function. Hypothermia allows prolonged preservation of donor organs with the possibility of recovery of function [3]. Maximum cold storage times differ between organs and recovery will also depend on other (risk) factors that play a role in this process, such as donor age, warm ischemia, immunogenicity and preservation solution or method.

The preferred preservation method for most organs in the past decades has been static cold storage (SCS): a flush-out with cold solution followed by submerging the organ in a cold (0–4°C) preservation solution, packaging it in sterile bags and placing it on melting ice in an insulated container (Figure 2.1a).

Most abdominal and also cardiac-thoracic organs can be preserved effectively from 4 hours (heart) to 30 hours (kidney).

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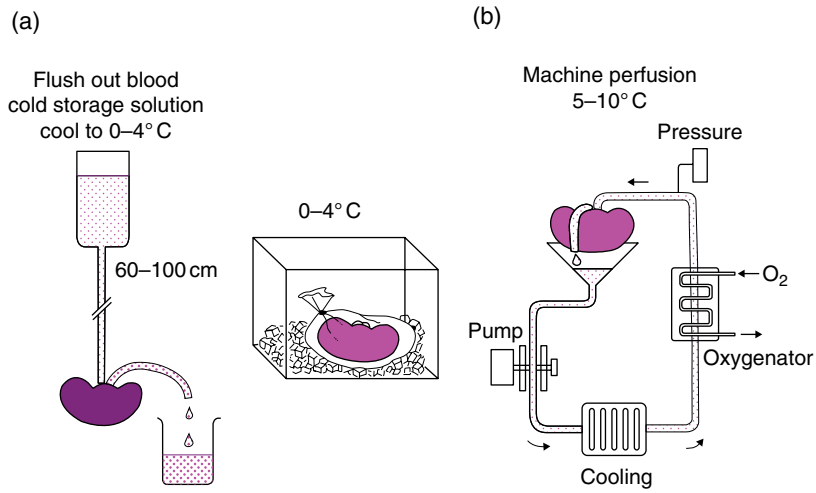

Figure 2.1 Blood is flushed out until the organ is homogeneously pale. Next the kidney is either submerged in preservation solution and statically cold stored on melting ice (a) or placed on a machine for continuous pulsatile cold perfusion (b).

An alternative method that was used in the early days of kidney transplantation is continuous hypothermic machine perfusion (HMP). With this method, kidneys are continuously perfused in a pulsatile mode with a special cold solution containing a colloid at 5°C (Figure 2.1b).

Despite its success, most centres abandoned this preservation strategy as transportation of large machines was cumbersome and SCS was equivalent and cheaper.

In recent years the viability of donor organs has changed significantly. Whilst in the early days the majority of donor organs were retrieved from young brain-dead donors who suffered cerebral trauma due to road accidents, most organs are nowadays obtained from elderly patients with irreversible injury due to cerebral hemorrhage (Figure 2.2).

In addition to being older and in a definitely less 'healthy' condition, current organ donors have had several hemodynamically unstable periods during brain death (unstable DBD) or after cessation of circulation and cardiac death (DCD) [4,5].

It has been well documented that age and type of donor significantly affect the function and outcome after kidney transplantation (Figure 2.3).

Due to this definite change in 'quality', it has become obvious that for many organs, SCS is not sufficient any more to sustain viability to allow immediate function. Therefore HMP has been revisited to evaluate its capability of better conditioning the donor organs. HMP also challenged the long maintained axiom that hypothermia was the best option to bridge from donor to recipient. With more modern and miniaturized technology we now have opportunities to apply normothermic reperfusion to donor organs *in situ* and *ex situ*, which could reduce injury, facilitate repair and restore function.

A touch of preservation history

The preservation of organs was developed in the 1960s by Belzer and colleagues at the University of California at San Fransisco. In those days donation and transplantation of kidneys was only possible when organ retrieval and subsequent recipient operation could be performed at the same time and in the same hospital in adjacent operating theatres. The retrieved organ was rinsed with saline or Ringer's lactate solution at room temperature to remove the blood, and the kidney was then brought to the next-door theatre to be implanted without any further delay. Obviously this situation constituted a significantly limiting factor to promote deceased donation and matching between donor and recipient.

To imitate normal physiology and allow transportation, Belzer designed a machine using a roller pump

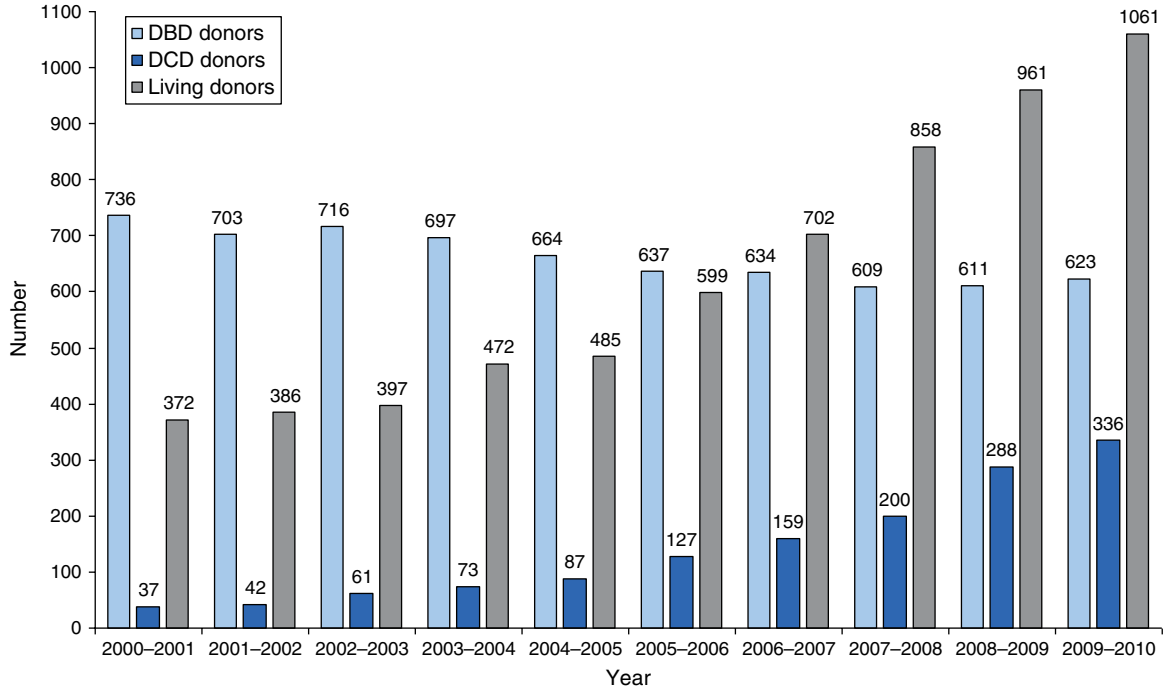

Figure 2.2 Number of living and deceased donations for transplantation including donations after brain death (DBD) and donations after cardiovasculatory death (DCD) per year in the UK. (Source NHSBT-ODT report 2010, http://www.organdonation.nhs.uk/statistics/transplant_activity_report/archive_activity_reports/pdf/ukt/activity_report_2010_11.pdf)

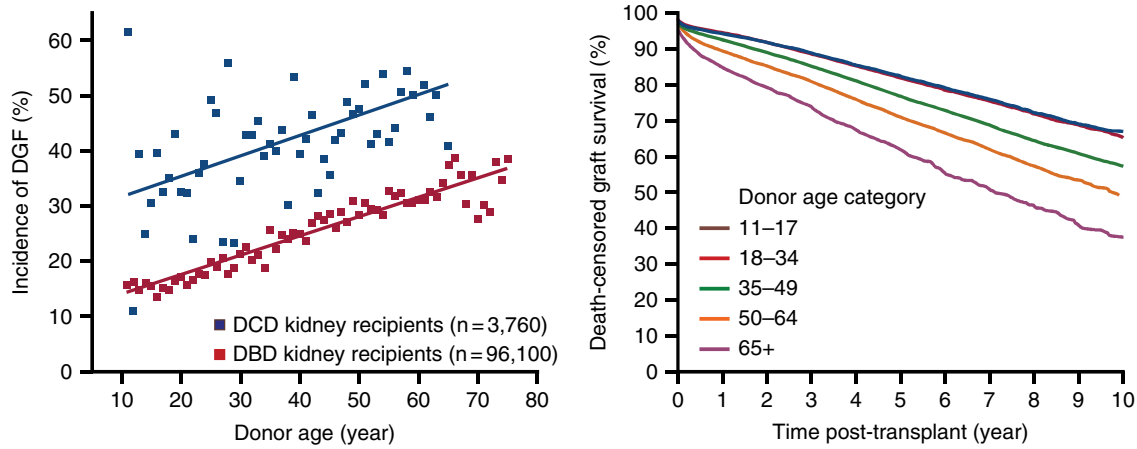

Figure 2.3 Effect of older donor age on incidence of delayed graft function (DGF) including donation after brain death (DBD) and after cardiovasculatory death (DCD) (left) and effect on death-censored graft survival per donor age category (right). (Moers et al.; source OPTN database [5])

that could perfuse both kidneys from a donor in two separate cassettes in a pulsatile mode, with a specially developed preservation solution [6]. To delay decay and allow restoration of function he used hypothermic conditions and a solution based on human cryoprecipitated plasma. The continuous and pulsatile flow of the renal artery with systolic and diastolic pressures of 50 and 20 mmHg respectively was able to effectively perfuse

the entire kidney and resulted in optimal tissue penetration with preservation solution. As transmission of diseases remained a potential hazard, the human plasma was first replaced with synthetic albumin and later with the dialysed colloid hydroxyethyl starch (HES) [7].

In the same era, Collins and colleagues successfully developed a simple solution that allowed satisfactory preservation of kidneys using SCS in Collins' C2 solution without the need for continuous MP [8]. Soon after being used to preserve the kidney, SCS became the preferred choice for liver, heart, lung, pancreas and finally intestine. Due to its simplicity, SCS has remained the most prominent form of preservation to date.

Donor related organ injury

To better understand the preservation-related damage, including ischemia and reperfusion injury, it is important to realize that the majority of donor organs are retrieved from deceased donors with a distinct medical history and not from carefully selected living donors with a healthy background [9,10,11]. To date, most deceased donors have suffered from cerebral injury due to trauma, hemorrhage or anoxia. Some donors will progress to brainstem death (DBD) while others will have irreversible injury but not reach that stage and may become donors following withdrawal of support (DCD Maastricht category III or controlled DCD). Other donors may have suffered from a cardiac arrest and despite all efforts resuscitation remains unsuccessful, leading to donation (DCD Maastricht category II or uncontrolled DCD).

Cerebral injury induces a significant systemic pro-inflammatory and pro-coagulatory response and affects organ function prior to organ retrieval.

Cerebral injury and certainly brain death, especially in combination with warm and/or cold ischemia, are associated with inferior outcome after transplantation of kidneys, livers and lungs [12,13,14]. In contrast to DBD and category III DCD, category II DCD donors have had no exposure to this systemic inflammatory response syndrome, a fact that could be beneficial and explain the surprisingly good graft survival results despite long warm ischemia times.

Current initiatives are directed to respond immediately and reduce this inflammatory response in order to prevent injury to the graft-to-be as well as lower immunogenicity.

The addition of cold ischemia during preservation after either cerebral injury or warm ischemia is certainly not beneficial. Prolonged static cold ischemia will derange cell metabolism and functional integrity of the donor organ. This will result in a high likelihood of delayed graft function or even primary nonfunction.

One of the aims of adequate preservation strategies is to maintain viability and allow rapid restoration of function after reperfusion with minimal impact on graft survival.

Some basic principles in organ preservation

Induction of hypothermia

Hypothermia is still a key factor in preservation in order to maintain viability and allow recovery of the donor organ after reperfusion at the time of transplantation. Reduction of temperature effectively reduces cellular metabolic rate and the activity of catabolic enzymes. Currently, best cold storage results are obtained at 0–4°C.

Prevention of oedema

Hypothermia is accompanied by a number of unwanted side effects encountered during preservation [15]. One of these is interstitial and cellular oedema which will induce cell death if not prevented. Thus, agents have to be added to preservation solutions to minimize oedema and support local electrolyte and ionic balances as best as possible.

Prevention of acidosis

Another side effect is hypoxia-induced acidosis which requires adequate buffering and pH regulation.

Neutralize the formation of reactive oxygen species

During preservation, reactive oxygen species (ROS) will form and can lead to significant oxygen free radical injury at the time of normothermic reperfusion.

Addition of antioxidants to the preservation solutions may neutralize the detrimental effect of these agents.

Hypothermia is still a key factor

Hypothermia (0–4 °C) is still a key factor for successful preservation. Slowing down the metabolism when no perfusion and oxygenation are present enhances the recoverability of donor organs. As early as the 1960s, it was discovered that cooling the liver, kidney or small bowel significantly increased the likelihood of success after transplantation. Hypothermia will not arrest cell metabolism but will reduce it to a level that is sufficient for the function and survival of essential cell organelles and membrane stability.

Approximately 10% of the metabolic activity at 37°C is maintained at 4°C.

Obviously 'warm perfusion' is better than 'cold preservation'. However, only in very recent years, due to better insight and miniaturized modern technology, it has been possible to simulate normothermic physiology under *ex-vivo* conditions.

After all, cooling will allow a certain period of short preservation, as shown by Calne in the 1970s in kidney transplantation [16]. In an experimental setting, pure hypothermia at 5°C was able to sustain viability and allow transplantation in a dog model. These findings illustrate the presence of a 'temperature effect'. To obtain longer cold ischemia times, the quality of preservation is determined by the compounds used in the preservation solution: the so-called 'solution effect'.

One of the most important factors to reduce preservation injury is prevention of interstitial and cellular oedema in the cold.

Interstitial and cellular oedema

During hypothermic conditions interstitial and cellular oedema will develop. Without an intravascular colloid to counteract it, a fluid shift from the intravascular space towards the interstitial compartment between the cells will take place. In addition, during hypoxia and hypothermia, the activity of ATP-dependent Na^+-K^+ pumps in the cellular membrane slows down, resulting in a lower membrane potential (Figure 2.4).

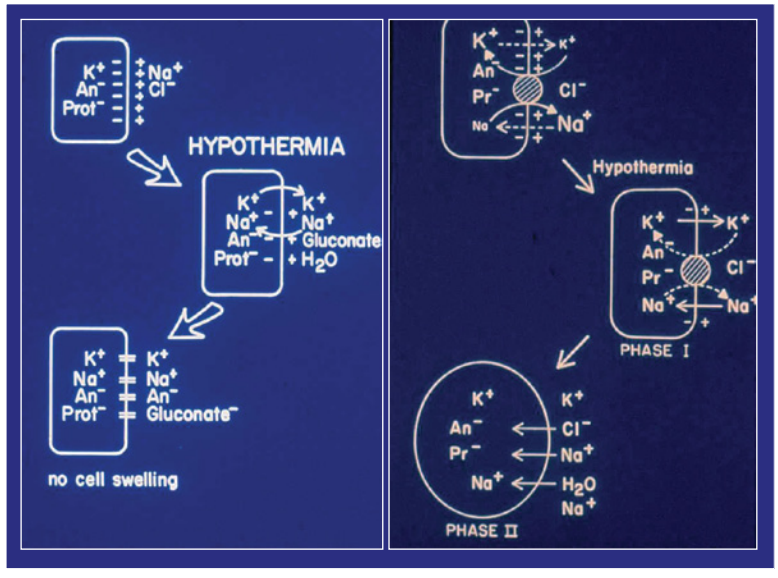

Figure 2.4 Balance of intra- and extracellular milieu with intact 'Donnan equilibrium' and functioning Na^+-K^+ pumps (left) versus disturbed equilibrium under hypothermic conditions with influx of Na^+ and water resulting in cell swelling (right). The change of this 'Donnan equilibrium' allows influx of Na^+ in the negatively charged cytosol with passive diffusion of water creating cellular oedema. To counterbalance this effect and minimize oedema, it is important to add an impermeant or colloid on the outside of the cell membrane.

Effective impermeants are:
- saccharides such as (in order of increasing molecular weight) glucose, mannitol, sucrose and raffinose
- anions such as citrate, gluconate and lactobionate.

After flush-out and equilibration of the tissue with preservation solution, the impermeant(s) will remain in the interstitium and reduce cellular oedema. Colloids are macromolecular agents that should remain intravascularly and create an osmotic force which prevents diffusion of water into the interstitial spaces [17,18].

Examples of colloids are albumin, dextran, hydroxyethyl starch (HES) and polyethylenglycol (PEG).

Cellular acidosis

An important condition for long-term cold preservation is the prevention of cellular acidosis. Therefore the addition of a strong pH buffer to the preservation solution is crucial. Despite hypothermia, anaerobic metabolism continues, albeit at a very low rate. This causes an increase in concentration of intracellular lactate and hydrogen, resulting in acidosis. Minimal acidosis up to a pH of 6.9 or 7.0 provides protection due to the inhibition of fructokinase enzyme and thus reduction of glycolysis and lactate formation. Serious acidosis causes lysosomal instability and activation of lysosomal hydrolases, eventually leading to cell death [19].

Buffers frequently used in preservation solutions are phosphate and histidine.

Formation of oxygen free radicals

Oxygen free radicals are short-lived molecules that interact with other molecules causing serious damage to lipids, nucleic acids and proteins. Previously the idea was that oxygen free radical damage occurred only at the time of normothermic reperfusion in the transplanted organ. More recently, however, it has been demonstrated that ROS are also formed during hypothermic preservation, inducing injury to the tissues and affecting recovery after retrieval and preservation. To reduce the detrimental effect of ROS some preservation solutions contain scavengers to neutralize radical formation [20,21].

Effective compounds used are the antioxidants glutathione, mannitol and tryptophane and the agent allopurinol.

Preservation solutions

To provide effective preservation, the solution has to contain:
- macromolecular agents or impermeants to counteract oedema
- an adequate pH-buffer to prevent acidosis
- a balanced electrolyte composition of Na^+ and K^+
- antioxidants to neutralize ROS.

In the past decades a number of original and look-alike solutions have been developed. Many solutions have been tested in small and/or large animal experiments. Only a small number of solutions have been evaluated in sufficiently powered randomized clinical trials. This fact probably did not matter so much when organs were retrieved from younger and 'healthier' donors having suffered a road traffic accident.

Nowadays, with more older and 'high risk donors', the solution-effect has become rather crucial and organs require better protection from warm and cold ischemic injury. In fact, it is questionable whether SCS should remain the standard for all types of organ donors.

Whilst sufficient for SCD, in ECD and DCD other preservation strategies such as continuous cold or even (temporary) warm perfusion could be the better alternative. Table 2.1 gives a list of current and recent SCS solutions including the effective components.

The static cold storage method of organ preservation

Since the introduction of **Collins' C2 solution** in 1969, a number of attempts have been made to improve simple cold storage (CS) by changing components in

Table 2.1 Cold storage preservation solutions.

		Celsior	EC	HOC	HTK	IGL-1	UW	Belzer MPS
Colloids (mM)	HES	—	—	—	—	—	0.25	0.25
	PEG	—	—	—	—	0.03	—	—
Impermeants (mM)	Citrate*	—	—	80	—	—	—	—
	Gluconate	—	—	—	—	—	—	85
	Glucose	—	195	—	—	—	—	10
	Histidine*	30	—	—	198	—	—	—
	Lactobionate*	80	—	—	—	100	100	—
	Mannitol*	60	—	185	38	—	—	30
	Raffinose	—	—	—	—	30	30	—
	Ribose		—	—	—	—	—	5
Buffers (mM)	HEPES	—	—	—	—	—	—	10
	K_2HPO_4	—	15	—	—	—	—	—
	KH_2PO_4	—	43	—	—	25	25	25
	$NaHCO_3$	—	10	10	—	—	—	—
Electrolytes (mM)	Calcium	0.25	—	—	0.0015	—	—	0.5
	Chloride	42	15	—	32	20	20	1
	Magnesium	13	—	40	4	5	5	5
	Potassium	15	115	84	9	25	120	25
	Sodium	100	10	84	15	120	30	100
ROS scavengers (mM)	Allopurinol	—	—	—	—	1	1	—
	Glutathione	3	—	—	—	3	3	—
	Tryptophan	—	—	—	2	—	—	—
Nutrients (mM)	Adenine		—	—	—	—	—	5
	Adenosine	—	—	—	—	5	5	—
	Glutamate	20	—	—	—	—	—	—
	Ketoglutarate	—	—	—	1	—	—	—
Osmolality (mOsm)		255	406	400	310	320	320	300

*Citrate, histidine and lactobionate also act as buffers. Histidine, lactobionate and mannitol also act as ROS scavengers.

EC: Euro-Collins; HEPES: 4-(2-hydroxyethyl)-1-piperazineethanesulfonic acid; HES: hydroxyethyl starch; HOC: hyperosmolar citrate; HTK: histidine–tryptophan–ketoglutarate; IGL-1: Institut-George Lopez-1 solution; MPS: machine perfusion solution; PEG: polyethylene glycol; UW: University of Wisconsin solution.

CS solutions, particularly for kidney and liver but also for other organs. A first minor modification of C2 solution leaving out Mg was **Euro-Collins (EC) solution** which was adopted in the early 1970s by the international organ sharing organization Eurotransplant as its main CS solution for all organs [22]. Next, Ross and Marshall in Australia developed a very interesting and well-tested solution in many experimental models: the **hyperosmolar citrate (HOC) solution**. Due to strong Anglo-Australian connections, HOC (later also called **Marshall's solution**) became very popular in the UK for kidney preservation [23,24]. Less well known was a modification of C2 and EC called **phosphate-buffered sucrose (PBS) solution** which contained the larger and more effective saccharide sucrose as impermeant instead of glucose [25].

A breakthrough in CS preservation was the development of the **University of Wisconsin (UW) solution** by Belzer and Southard in the late 1980s. Following a systematic approach by adding and leaving out certain components, the most effective impermeants (raffinose, lactobionate), colloid (hydroxyethyl starch) and buffer (phosphate) were tested in a series of tissue-assay, small and large animal experiments [26,27,28]. In addition, for the first time, the importance of antioxidants was recognized, by adding glutathione to the UW solution.

The UW solution has been tested in the experimental setting for all organs including heart and lung but has predominantly found its place as the most effective preservation solution for intra-abdominal organs (kidney, liver, pancreas, intestine) [29].

UW solution was tested in a number of clinical trials and found to be superior, which ended the EC era in preservation.

Not long after the introduction of UW solution, another solution was presented by the German physiologist Bretschneider in Goettingen [30]. The **histidine–tryptophane–ketoglutarate (HTK) solution** was originally developed for induction of cardioplegia during open-heart surgery. Early experimental animal work by Hoelscher et al. in Munich and Gubernatis et al. in Hannover showed that HTK could also be used for other organs, such as preservation of kidney and liver [31,32]. An important explanation by Bretschneider of why his solution was effective is its buffering capacity.

The beneficial effect of HTK can only be reached when a large volume is flushed through the organs via the aorta (10–15 L).

Using less than 10 L of HTK due to financial considerations might compromise the effect and render the organs open to more injury and less protection.

HTK was compared in the clinical setting of kidney transplantation with EC and UW and found to be superior to EC and equivalent to UW when preservation times were not extended.

HTK is nowadays used by many transplant centres for abdominal organ preservation, including liver and pancreas [33,34].

With an increase in DCD procedures, the initial approach was to use the femoral double-balloon triple-lumen (DBTL) catheter to flush the kidneys with large volumes of preservation solution. As the standard volume of 4–5 L UW solution was in the same price range as 10–15 L HTK solution, some centres switched to using HTK for DCD, assuming that this would be better for the organs. Since then we have started to accept not only kidneys but also livers and pancreata from controlled DCD donors and therefore the DBTL catheter is not used any more for this type of DCD. With a standard laparotomy and thoracotomy, the abdominal and thoracic aorta can easily be cannulated and standard volumes of UW solution with additional back-table flush suffice.

The important question, however, has remained whether conventional CS solutions are effective enough in high risk donors with prolonged warm ischemia time followed by cold preservation. In light of an increasing number of publications describing ischemic cholangiopathy in the liver or pancreatitis after pancreas transplantation, this might not be the case and therefore it urges us to evaluate how adequate both UW and HTK solutions are when used under these circumstances.

Machine perfusion revisited: a renaissance in preservation?

Due to the higher numbers of older, more marginal and DCD donor organs that have been transplanted in recent years, a significant increase in absence of

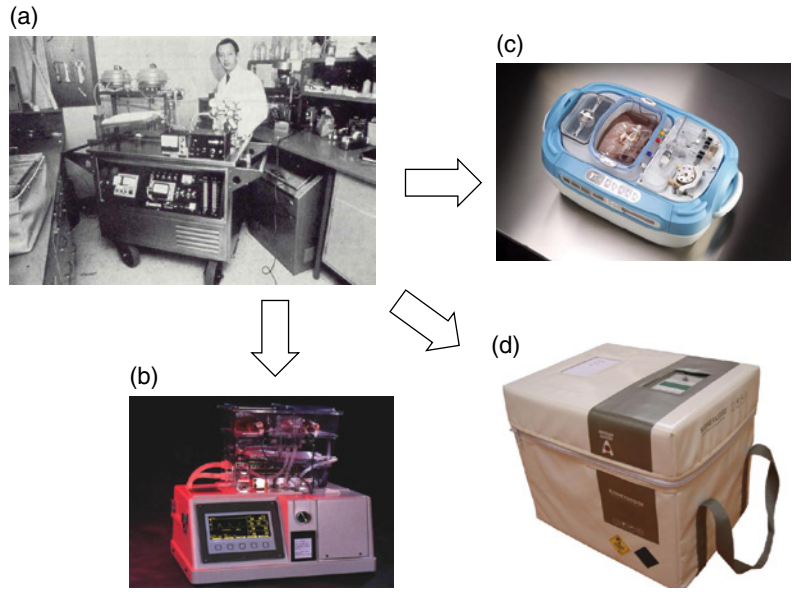

Figure 2.5 Consecutive generations of machine preservation devices for kidneys: the original 'Belzer machine' in 1967 (a); the modified 'table' model by Waters (b); the portable roller pump LifePort by Organ Recovery Systems (c); the miniturized oxygenated device Kidney Assist by Organ Assist (d).

immediate function and often reduction in graft survival has been observed. In kidney transplantation using DCD donor organs, the DGF rate was found to be as high as 70–80%, with a PNF rate sometimes in excess of 10%. In the past decade it has been shown that in experimental kidney studies, machine perfusion (HMP) preservation provided a better function and survival compared to simple CS, particularly for high risk donor kidneys. Single centre clinical studies suggested similar results but often were either retrospective analyses or underpowered trials and therefore were not conclusive. In their excellent meta-analysis, Wight et al. [35] showed that HMP was able to reduce the DGF rate by approximately 20%, begging the question why there is such a persistent reluctance to revert to using machine preservation on a larger scale?

When we go back to the 1970s, the reason why pulsatile HMP did not become popular was not due to the fact that the method was inferior, but because the technique of submerging organs in a cold preservation solution was simpler than using the large Belzer machine. Furthermore, static cold preservation appeared to be sufficient to sustain function after transplantation. Since then technology has advanced and smaller devices have been developed (albeit the modified Belzer and Waters machines remained rather solid table models which were not really transportable) (Figure 2.5).

In those centres, predominantly in the US, that continued to use MP, donor kidneys were retrieved in or out of State, shipped to the recipient centre using simple CS, and attached to the machine to be pumped for a certain number of hours until operation theatre capacity allowed starting the transplant procedure. In the 1990s, for the first time a miniaturized HMP device became clinically available using roller pump technology that was transportable – the LifePort machine by Organ Recovery Systems.

At that point in time, a consortium led by the transplant centres Groningen, Leuven and Essen was established in collaboration with Eurotransplant and initiated three randomized controlled trials in kidney preservation and transplantation comparing continuous MP versus simple CS preservation. The studies were sufficiently powered and included post-transplant function and survival up to 3 years. The trials demonstrated a significantly better outcome with MP than SCS, with a reduction in DGF and an improvement in graft survival in the overall group of all types of donors above 16 years of age [36], a reduction of

DGF in DCD III donors [37] and an impressive improvement in graft survival in ECD donors [38,39]. In the design of the trials, the original concept voiced by Belzer (the application of the optimal preservation method and solution as soon as possible after retrieval) had been followed. Thus, in all studies, kidneys were immediately attached to the HMP device and pumped until the moment of transplantation. The European MP trial also allowed us to study a number of other risk factors, such as the relevance of renal resistance (RR) during perfusion and some biomarkers of injury that were analysed in the perfusate [40]. RR was clearly associated with a higher chance of DGF; however, no statistically reliable cutoff point could be calculated despite sufficient numbers. A number of injury markers including LDH (lactic dehydrogenase), AST (aspartate aminotransferase), GST (glutathione s-transferase), NAG (N-acetyl-beta-D-glucosaminidase), AAP (alanine-aminopeptidase) and H-FABP (heart fatty acid-binding protein) were analysed in the perfusate at different time points, to assess predictability of DGF and PNF. Only GST and H-FABP showed significance and predicted DGF but not PNF due to a too small number of PNF kidneys in the trial [41]. The conclusion was that although both RR and the two biomarkers are associated with an increased chance of DGF, the discard of kidneys based on these indicators is not justified [40,41].

HMP for kidneys has been re-established and currently, in a number of countries, health authorities are considering nationwide introduction of HMP, at least for DCD and ECD with reimbursement.

The fact that HMP demonstrated a significant short-term and long-term cost-effectiveness over CS has certainly propelled this policy [42].

Whilst HMP for kidneys has been more or less used in clinical practice for quite some time, it took approximately 30 years from the first experimental attempts showing a beneficial effect of HMP in liver transplantation by Pienaar and D'Alessandro at the University of Wisconsin [43] to the first clinical series published by Guerrera at Columbia University, NY, in 2011 [44]. One of the Achilles' heels and major complications in liver transplantation is ischemic cholangiopathy causing significant morbidity and often requiring retransplantation [45]. Pulsatile perfusion of the hepatic artery and continuous low pressure perfusion of the portal vein have been found to reduce injury and provide adequate recovery of function after transplantation. Data from the Groningen group revealed that under cold conditions arterial pressure had to be kept at a moderate level of 30–40 mmHg to prevent endothelial injury related to shear stress. The addition of oxygen appears to be beneficial as functional parameters upon reperfusion are better and bile volume is larger than without oxygen [46,47,48].

The greatest challenge in liver transplantation is, however, to evaluate whether controlled and uncontrolled DCD donor livers are better preserved using HMP versus simple CS, or in fact (a short period of) normothermic reperfusion after retrieval is required to predict transplantability, reduce PNF and prevent ischemic cholangiopathy. Using a prototype of the Groningen Machine Perfusion System, in close collaboration between the Barcelona and Groningen groups, a series of experiments was performed testing simple CS versus HMP after 45, 60 and 90 minutes of cardiac arrest and warm ischemia, followed by liver transplantation in the pig model. With extended warm ischemia times of 90 minutes simulating prolonged DCD III and DCD II donation, simple CS failed and HMP was only able to allow function and survival of a small percentage of grafts. In the next series, 1 hour of normothermic resuscitation with pig blood followed by cold preservation was tested and compared with continuous normothermic machine preservation (NMP) of the liver prior to transplantation. Only 1 hour of normothermic reconditioning resulted in adequate function and 83% survival, whilst with NMP from donation until implantation excellent function and 100% survival was observed [49,50].

In parallel to these experiments, the Oxford group with Friend and Coussios developed an NMP device for the liver that is able to preserve pig livers for 20 hours and achieve successful transplantation despite 40 minutes' warm ischemia time prior to retrieval. These findings suggest that high risk donor livers require a period of normothermic reperfusion to monitor and recondition the graft-to-be prior to transplantation [51,52,53].

In this regard it is not entirely clear yet whether *in situ* normothermic regional perfusion (NRP) of abdominal organs using extracorporeal membranous oxygenation (Figure 2.6) alone is sufficient to make high risk donor kidneys and livers better transplantable,

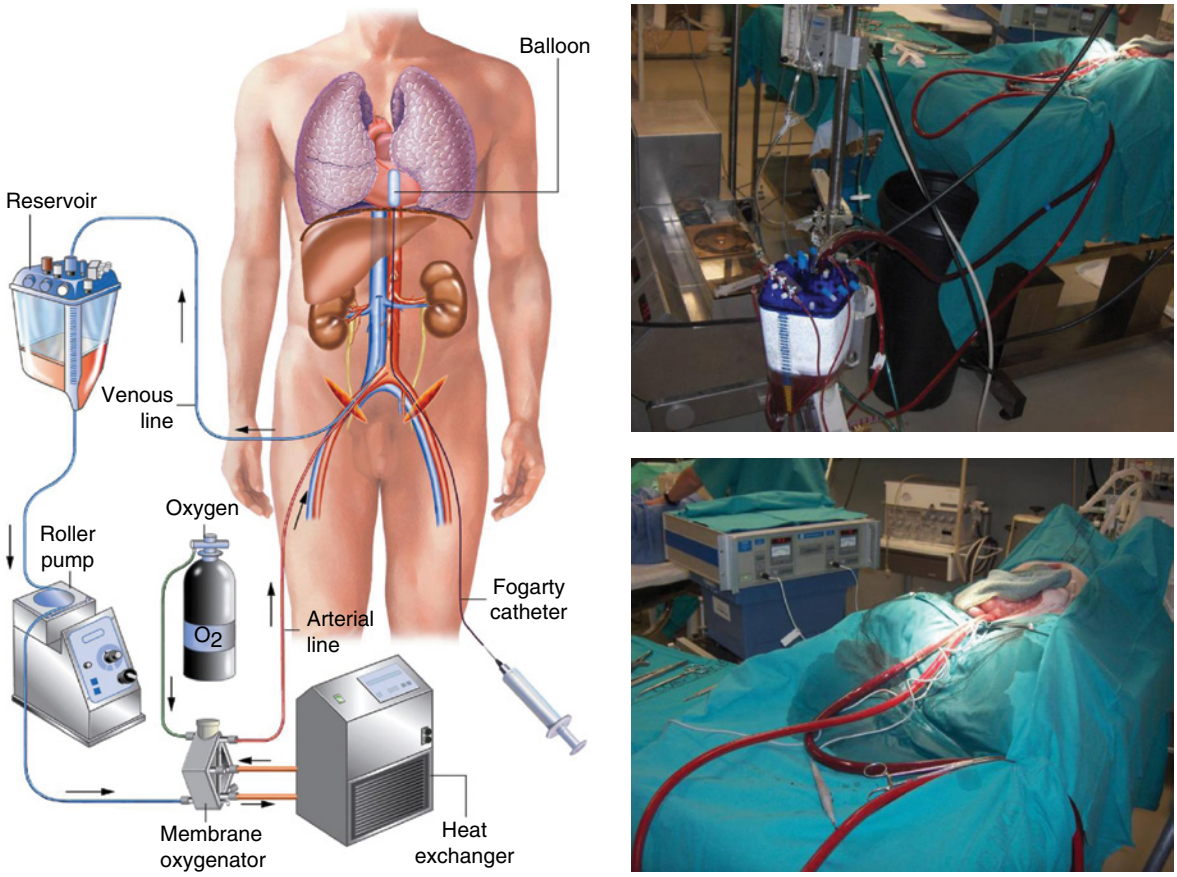

Figure 2.6 Following cardiocirculatory arrest in DCD donors, *in situ* normothermic machine perfusion (NMP) with an extracorporeal membraneous oxygenation (NRP) device is used to perfuse and resuscitate abdominal donor organs prior to preservation and transplantation.

or that additional hypothermic or even normothermic continuous MP are required to improve outcome after transplantation.

Practical consequences to consider during retrieval

To date, the majority of retrieval teams use one preservation solution (in the majority of cases either UW or HTK solution) during multiorgan donor procedures that include kidney, liver and pancreas, irrespective of whether it concerns a DBD or DCD III donor. Most teams will perform a median laparotomy and thoracotomy which gives better access to liver and pancreas, even when no thoracic organs are procured. The abdominal aorta just cranial to its bifurcation can be secured, cannulated and flushed following administration of heparin (and streptokinase in DCD). The temperature of abdominal organs is cooled down with an intravascular flush and equilibration of tissues with preservation solution as well as due to immediate surface cooling of the abdominal cavity using ice-slush and/or cold saline. It has been shown that a volume of 4–5 L UW solution via the aorta with a proximal clamp placed on the subdiaphragmatic aorta is enough to rapidly cool the organs, flush out (most of) the blood and diffuse the tissues with the effective agents in the solution. As different solutions include a variety of components and chemical agents based on physiological rules, mixing solutions is not advocated since interaction in the tissue between components and effect on the preserved organ has never been examined. An additional *in situ* or bench flush with 1 L UW through the

portal vein will perfuse the liver even better and get rid of remaining blood. Especially in DCD III donors, often both kidneys appear not well perfused and rather bluish in colour. This is due to underperfusion of both kidneys as initially most of the flush-out volume will shunt to the liver as it has a large vascular bed with a low resistance. In these instances, it is important to also perform an adequate back-table flush of the kidneys with approximately 250 mL UW solution. In many cases, the kidneys will then become pale and appear homogenously perfused. Due to the anatomical configuration of the tissues, the pancreas and the intestine are prone to oedema and should not be 'over-perfused'. Therefore, additional back-table flushes for these organs are normally not necessary.

In cases where HTK solution is used, the volumes required are much larger (between 10 and 15 L). This is important to note, as with lower volumes (5–8 L) this solution will not achieve an optimal result and not effectively preserve abdominal organs. When other simple CS solutions are used – such as Celsior or IGL-1 – the same volumes as with UW solution are needed [54,55,56,57].

For kidney retrieval only, predominantly in the UK, Marshall's solution is used as flush-out as well as preservation solution using simple SCS. No clinical trial has been performed to evaluate this solution and compare it to UW and HTK solutions. A recent review comparing different simple CS solutions for kidneys was published by O'Callaghan et al. [58], while the same authors are currently analysing the use of Marshall's solution in the UK using NHSBT data.

Following flush-out and retrieval, the donor organs have to be carefully inspected. Adherent fat has to be removed from kidneys to be able to assess the quality of perfusion of the kidney and rule out a malignant tumour. The kidney should be pale and homogenously perfused. If a lower or upper pole remains hemorrhagic it is likely that there is an additional polar artery that has not been flushed well or has been injured or cut. Additional perfusion using a small cannula can improve the condition of the kidney. Identification of the number of arteries (using the aortic lumen as a reference for the number of orifices) with and without patch as well as number of veins is important for the receiving surgeon. If any (vascular) injury is present this should be noted on the forms. The repair of the lesion should be performed by the transplant surgeon as he will have to take the recipient anatomy into account. Abnormalities found when liver and pancreas are retrieved should be communicated as quickly as possible to allow time for the recipient centre to adjust or abandon the transplant procedure.

Packaging of donor organs

The packaging of donor organs is an essential routine that is important to ensure quality and safety. In most countries or organ sharing systems for abdominal organs, three size-adjusted bags are used. In the innermost bag the organ is submerged in sufficient preservation solution that should be the same type of solution that was used for the flush-out. In the second bag cold saline is used which will be a buffer to keep the inner bag cold and prevent any contact with the melting ice in the container. The last and third bag (sometimes slightly larger) is dry and includes both inner and second bag. It guarantees better sterility when unpacked at time of transplantation as a theatre nurse can open and fold it, allowing the surgeon to take out the two inner sterile bags. Taking out the air prior to tying the bags is important to obtain optimal cooling. The bags with the organ are then stored and kept cold on melting ice in a closed container. In contrast to the common practice in the US and the European continent, in the UK the liver is placed in a plastic bowl submerged in approximately 2 L of preservation solution. The air has to be sucked out of the two bags that surround the bowl. The bagged bowl is then placed on melting ice in a container.

The pancreas and liver are accompanied by additional vessels, predominantly the right and left donor iliac arteries and veins, to allow reconstruction at time of transplantation. These vessels have to be packed separately and are to be submerged in preservation solution and not in saline.

Additional splenic and lymphatic tissue is packed separately using saline.

A brief outlook on future practice

Due to the use of more high risk donors, it is likely that current practice in organ preservation will change. Whilst in standard criteria donors, simple CS preservation might prevail, in DCD and ECD our practice will switch to MP. HMP will be used for DCD III and ECD to reduce DGF and improve survival in

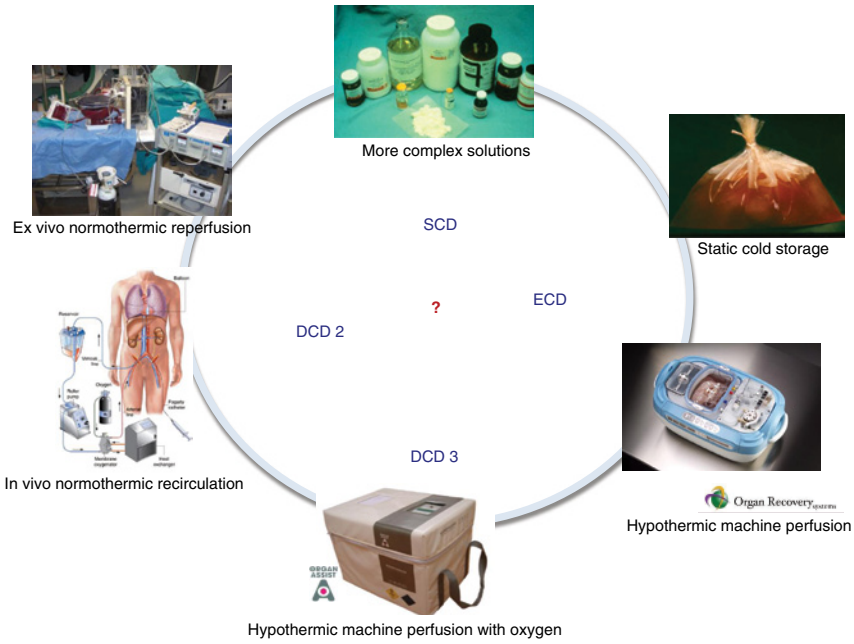

Figure 2.7 Sufficiently powered randomized controlled trials will evaluate optimal strategies for preservation, monitoring and reconditioning of donor organs prior to transplantation.

kidneys. Under certain circumstances, in controlled DCD III and certainly in uncontrolled DCD donors, *in situ* normothermic perfusion using NRP technology will be tried out for the liver, followed by CS, HMP or even NMP. These new strategies for liver and kidney will affect our current retrieval routine and manpower planning. New protocols have to be introduced and criteria discussed within the existing organ sharing communities. Retrieval teams have to be trained to use the new techniques and novel devices. Additional devices and disposables will generate cost and although in many instances the use of these devices can be cost-effective, making untransplantable organs transplantable, funding and reimbursement policies will have to be revised in collaboration with healthcare authorities (Figure 2.7).

It is important to realize that we are on the verge of an exciting period during which we will learn how we can better monitor, match and condition donor organs, improving outcome after transplantation. Collaboration of all professionals in the field of donation and transplantation is a must, in order to advance our knowledge and make high quality transplantation sustainable in the future.

Summary box

Preservation strategies should maintain viability and allow rapid restoration of function:

- Hypothermia, prevention of acidosis and oedema and neutralization of ROS are the main principles of organ preservation
- Ten percent of the normal metabolic rate is maintained at 10°C
- To provide an effective preservation, the solution has to contain macromolecular agents or impermeants, an adequate pH-buffer, a balanced electrolyte composition of Na and K and antioxidants
- University of Wisconsin (UW) solution is the most commonly used preservation solution
- Less than 10 L of HTK compromises the clinical outcome
- Machine perfusion provides a better outcome than static cold perfusion in kidney transplantation
- *In situ* normothermic regional perfusion is showing promising results for organ reconditioning in liver transplantation
- *Ex situ* warm perfusion liver machines are undergoing clinical trials
- Organs should be packed in three adequately sized bags

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3 Management of the Brainstem Dead Organ Donor

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Physiological changes occurring soon after the development of brain death can, if untreated, lead to rapid deterioration and cardiac arrest even if ventilation is continued [1,2]. There are variations in timing and rapidity of change, but there are predictable derangements which can be moderated or reversed [3].

Even if early deterioration is not apparent, brainstem death triggers complex systemic changes which require continued treatment to prevent organ damage and loss [4,5,6].

Effective organ donor management (ODM) can reduce the number of donors lost before a retrieval operation, maintain or improve organ function and allow unhurried and planned organ retrieval [7,8,9,10,11,12].

Ensuring that all organs possible can be transplanted with acceptable results mandates very active care of the donor from the time of brainstem death to retrieval and preservation of organs. There should be no conflict of priorities between abdominal organ and other retrieval teams, as evidence is accumulating that good ODM should benefit all organs [7,8,13].

Physiological changes associated with brainstem death

Brainstem death is preceded by a period of rising intracranial pressure. As intracranial pressure rises there is a compensatory arterial hypertension to attempt to restore blood flow to the medulla – the Cushing reflex. This results in stimulation of the arterial baroreceptors and a vagally mediated bradycardia. Following brainstem death, there is a period of marked sympathetic stimulation with intense vasoconstriction and tachycardia ('catecholamine storm'). The levels of catecholamines are raised enormously, particularly in cases of rapid intracranial pressure (ICP) rise. This storm is followed by loss of vascular tone and hypotension. If respiration is not controlled then apnoea, hypoxia and cardiac arrest will occur.

All of these changes will be considerably modified by treatments which may be in place at the time of brainstem death. These treatments are usually aimed at maintaining cerebral perfusion pressures in the face of raised intracranial pressure, relative dehydration and vasoconstriction. Clearly these may have considerable effects on subsequent ODM.

The physiological changes that occur around the time of brain death are caused by the body attempting to restore blood flow to the brain.

Organ damage

Organ damage is caused by:

- Direct organ damage at the time of brainstem death
- Systemic changes triggered by brainstem death
- Failure to adequately implement critical care techniques in ODM aimed at moderating the changes that will result in organ damage.

Abdominal Organ Retrieval and Transplantation Bench Surgery, First Edition. Edited by Gabriel C. Oniscu, John L. Forsythe and John Fung.

Direct damage to organs at the time of brainstem death occurs because of cardiovascular changes. Catecholamine levels are dramatically elevated, and raised systemic vascular resistance and vasoconstriction leads to central redistribution of blood volume. Left- and right-sided vascular pressures rise and the increased afterload may lead to acute cardiac damage in donors. Acute pulmonary oedema may develop because of raised hydrostatic pressure and increased capillary permeability [5,6,14,15].

These changes may be rapid and severe but are often of relatively short duration.

The 'catecholamine storm' is followed by myocardial injury, vasodilation and hypotension, which, if not actively managed, lead to hypoperfusion of all organs including heart. The uncontrolled vasodilation accelerates heat loss and hypothermia.

Brainstem death is also associated with an active inflammatory response, with elevated levels of pro-inflammatory cytokines and upregulation of receptors in target organs. Although this may be due to associated trauma or critical illness, brainstem death itself may trigger this response. The inflammatory response is maintained or amplified by the physiological changes related to brainstem death [16,17,18].

This affects all organs and is associated with measurable organ damage in the donor, and subsequent poor function and increased risk of graft loss in recipients.

Endocrine changes are variable. Posterior pituitary function is commonly lost, leading to central diabetes insipidus, but anterior pituitary function may be preserved or only partially lost. Reduced levels of thyroid hormones may contribute in some donors to deterioration in cardiac function and general organ perfusion. Insulin levels fall, and hyperglycemia may be further adversely affected by steroid administration.

Failure to actively support, restore physiology and maintain stability in the donor is associated with high rates of donor loss from cardiac arrest, fewer transplantable organs and impaired functionality after transplantation. ODM is a complex intervention aimed at maximising the number and functionality of organs transplanted from donors. The individual components of organ donor management have been developed following consideration of experimental and clinical observations.

Achieving and maintaining stability in the donor allows an unhurried approach to organ retrieval. Organs that originally appear unusable may improve function during donor management and become transplantable. Although the duration of brainstem death has been seen as an adverse factor for the outcome of transplanted organs [19], there is evidence that a period of good donor management can moderate this effect and, indeed, lead to improved outcomes [10,20,21].

If untreated, the physiological changes that occur following brainstem death will result in cardiopulmonary arrest and organ loss.

Clinical management and use of guidelines

Early guidelines

From the early days of transplantation from brainstem dead heart-beating donors, it was realised that failure to achieve reasonably 'normal' values of physiology led to donor deterioration and cardiac arrest. Goals for therapy within the normal range were therefore set and standard critical care techniques applied in order to achieve these.

An early, easily remembered series of goals was the 'rule of 100' [22]:

- systolic blood pressure > 100 mmHg
- urine output > 100 mL/h
- PaO_2 > 100 mmHg
- hemoglobin concentration > 100 g/L.

An example of a modern set of physiological goals can be found from the Canadian Council for Donation and Transplantation [23] and include:

- Systolic blood pressure > 100 mmHg and/or MAP > 70 mmHg
- Systolic blood pressure < 160 mmHg and/or MAP < 90 mmHg
- CVP 6–10 mmHg
- Temperature 36–37.5°C
- Urine output > 60 mL/hr
- SVO_2 > 60%

Standardization and wider application

Goals such as the 'rule of 100' were widely adopted and guidelines with suggested treatments to achieve these were advocated. The wider transplant community

in the US stimulated the introduction of the first United Network for Organ Sharing (UNOS) Critical Pathway, which provided both goals and suggested therapies to achieve them.

A pilot study showed increases in the number of organs retrieved and transplanted, but these were not statistically significant. The use of a standardised pathway was, however, seen as advantageous, particularly for smaller hospitals where donation was a rare event.

Subsequent modification of the pathway following a consensus conference and addition of a package of therapies termed 'hormonal resuscitation' was associated with significantly increased chances of organs being transplanted from donors, but there was also an increase in intensity of ODM over this period [24]. Introduction of good standard ODM is frequently associated with increased numbers of organs and transplants, although this is usually in reference to historic controls. When actively delivered by dedicated staff the results can be dramatic [7,8,12].

Effective ODM can result in increased numbers of organs transplanted.

A practical approach to brainstem dead donor management

The approach described is generated from experience managing brainstem dead organ donors and review of international guidelines. It is assumed that brainstem death has been correctly diagnosed and documented. There may be variation from local protocols and guidelines, but the overall principles are likely to be robust and applicable. Evidence from randomized controlled trials in ODM is limited, but with increased standardization of the basic management it is likely to accumulate [25]. References include detailed suggested guidelines from a number of sources.

Initial assessment and management

Effective ODM mandates critical care skills from nursing and medical staff, and should be delivered in an environment which supports this. This is likely to be an Intensive Care Unit (ICU) or similar area. Family members are often present at the bedside, and experienced staff, who can empathically communicate with them in these difficult circumstances, are necessary.

Admission and management of a brainstem dead donor in the ICU may be unusual in smaller hospitals [26]. Clarity of communication with critical care staff and emphasising to them the advantages to recipients of optimal ODM is essential. Staff in these units will generally welcome the use of guidelines and the opportunity to discuss ODM with retrieving units.

Rapid review of patient records and clinical details of the time prior to brainstem death is necessary. Particular attention is paid to fluid balance, cardiovascular status and evidence of adequate end-organ function as to whether urgent treatment is required. Recent investigations should be available or repeated to enhance useful discussions with retrieval teams. Prior goals aimed at maximising cerebral perfusion pressure can almost always be rapidly modified – often allowing for reduction in vasopressor support. Current therapies should be reviewed and unnecessary drugs and therapies stopped.

Donor methylprednisolone administration in an attempt to reduce inflammation has been shown to be beneficial in randomised studies for lung and liver transplant and is commonly given as soon as a plan for donation is confirmed [11,27,28].

Many potential donors will already have comprehensive monitoring, but there should be no hesitation in ensuring that invasive cardiovascular monitoring at a minimum is instituted, given the potential benefits (Table 3.1).

Effective ODM programmes will also usually include some form of cardiac output monitoring. Good results have been obtained with all the standard technologies.

Loss of hypothalamic function of temperature control, and peripheral vasodilatation associated with cardiovascular changes, promotes heat loss that results in hypothermia, which occurs almost invariably. This could be further exacerbated by a failure to reduce heat loss or infusion of large volume of cool fluids. Hypothermia affects cardiovascular and hemostatic function and increases susceptibility to sepsis. The core temperature must be monitored and active techniques such as forced air warming to maintain normal body temperature prior to the retrieval operation are recommended.

Table 3.1 Benefits of hemodynamic monitoring.

Intra-arterial monitoring	Central venous monitoring	Cardiac output monitoring
Regular blood sampling	Administration of drugs	Allows fluid resuscitation to be goal directed to stroke volume
Rapid assessment of effect of intravenous fluid bolus	Right atrial pressure monitoring	Allows changes in cardiac output with inotropes to be measured
Beat to beat control of vasoactive drug administration	Estimation of the adequacy of oxygen delivery (via central venous oxygen saturations measurement)	Many techniques now minimally invasive

Summary box for initial assessment and management

- Manage patient in a critical care area
- Review records, notes and charts
- Alter physiological goals to more 'normal' values
- Use established ODM goals
- Ensure invasive monitoring
- Avoid hypothermia: warming techniques
- Methylprednisolone 15 mg/kg

Respiratory management

Effective ODM can produce many more lungs for transplantation [29]. Key techniques include avoiding lung damage due to excessive volume or pressure, repeated expansion and collapse of lung units, as well as avoiding excessive fluid administration. The patient should be nursed with the head of bed elevated to limit pulmonary aspiration and the endotracheal tube cuff can be inflated to a higher pressure than routine to ensure a good seal.

Continued modern critical care ventilator techniques with tidal volumes of 6–8 mL/kg and inspiratory pressures limited to < 30 cm H_2O are advocated. Older guidelines specified high tidal volumes of the order of 10–15 mL/kg of predicted body weight. Lower tidal volumes should be aimed for, with regular recruitment manoeuvres to open and retain collapsed lung, improve oxygenation and reduce inspired oxygen requirements. Recruitment manoeuvres are particularly important following apnoea testing, endotracheal suction or disconnection from the ventilator [4,5,30].

Methylprednisolone administration is associated with reduced lung water accumulation and increased numbers of transplantable lungs, as well as potential beneficial effects for other organs.

Limiting excessive fluid administration as part of active ODM to help with thoracic organ retrieval does not adversely affect abdominal organ retrieval or function [8,13] .

Summary box for respiratory management

- Nurse patient 30 degrees head up
- Limit tidal volume to 6–8 mL/kg predicted body weight.
- Limit ventilatory plateau pressure to < 30 cm H_2O
- Avoid hyperoxia
- Conservative fluid strategy

Cardiovascular management

Treatment of the rapid and dramatic changes around the time of brainstem death is challenging, and if attempted only short-acting drugs should be used due to the dynamic nature of the circulatory changes. If these strategies are effective they may allow more hearts to be retrieved [31].

Following this, a consistent syndrome with marked vasodilation and relative hypovolemia develops. This may be worsened by fluid losses from all sources, such as the common development of central diabetes insipidus.

Failure to rapidly achieve cardiovascular stability will lead to rapid deterioration and cardiac arrest. Rapid restoration of effective circulating volume

without overload is an essential first priority. Serum electrolytes, previous and current losses, may help with choice and volume of fluid, but initially a crystalloid such as Ringer's lactate or 0.9% saline is usually suitable. If further fluid is required, a balanced crystalloid may be preferred to 0.9% saline to avoid hyperchloremia, or a colloid may be used. Large volumes of some older starch solutions have been associated with delayed kidney graft function. If vascular tone is impaired, simultaneous restoration of this with vasopressor support will be helpful.

It can be very difficult to get a balance between adequate intravascular volume and avoiding excessive extravascular lung water.

There is evidence that if donors are 'fluid responsive' and become more stable after intravenous bolus fluids, blood cytokine levels fall. Adequate restoration of intravascular volume is associated with more transplantable organs and better function on implantation [32].

Vasoconstriction and restoration of vascular tone may be achieved by infusion of catecholamines such as norepinephrine or dopamine. If intravascular volume is reliably replenished, catecholamine dosage can often be reduced. Although many ODM programmes use catecholamines liberally, high doses of catecholamines are associated with poor function in transplanted hearts. Vascular tone can be restored and the dosage of catecholamines reduced by the use of vasopressin.

Vasopressin is a component of 'hormonal resuscitation' packages.

Guidance of cardiovascular management, particularly if thoracic organ donation is planned, is considerably aided by cardiac output monitoring. The choice of technique will be dictated by local expertise and equipment. Pulmonary artery catheters are frequently used by cardiothoracic donor teams, but are now not widely used in general ICU. Less invasive cardiac output monitoring techniques, now commonly used in general intensive care, include oesophageal Doppler monitoring and strategies based around analysis of the arterial waveform.

Echocardiography is useful to delineate any structural contraindications to heart retrieval (ventricular hypertrophy or valvular lesion). Heart donation is not precluded by a single investigation showing poor function as this may improve with ODM and further re-evaluation may be indicated.

Summary box for cardiovascular management

Hypotension, systolic pressure variation with ventilation, metabolic acidosis, hyperlactemia and low CVP can all be markers of ineffective circulating volume.

- Rapid bolus of a warm balanced crystalloid or 0.9% sodium chloride are usual first-line fluids.
- If repeated boluses, consider need for colloid or blood.
- If vascular tone is inadequate, consider a catecholamine or vasopressin infusion.
- Cardiac output monitoring may aid cardiovascular management.
- Poor cardiac performance may respond to hormonal resuscitation or require inotropes.

Hormonal changes

Posterior pituitary function is commonly lost, whilst anterior function is variably affected. Central diabetes insipidus frequently develops and may require treatment with desmopressin (DDAVP) or vasopressin, as discussed in the sections on cardiovascular and fluid management.

Animal studies have also shown marked changes in thyroid hormones after brain death, with improved cardiac function when these are given as part of an active ODM programme. When 'hormonal resuscitation' including T3 or T4, vasopressin and methylprednsiolone was introduced into clinical practice, it was associated with significantly more transplantable organs being retrieved. As active ODM has become more common, the additional benefits of thyroid supplementation in particular have been questioned, as randomised studies have shown little beneficial effect. Many guidelines now only recommend the use of thyroid hormones if cardiac function is poor, although there is little risk in administration.

Hormonal therapy often includes methylprednisolone, thyroid hormones, vasopressin/DDAVP and insulin.

Due to a combination of low insulin levels, critical illness and steroid administration, glucose levels are often high.

An intravenous infusion of a short-acting insulin should be used to maintain normoglycemia.

Fluid and electrolyte management

Close general ICU management of fluids and electrolytes should continue. Established enteral feeding can continue. There may be specific problems relating to the frequent development of central diabetes insipidus, which should be suspected if the patient develops polyuria with rising plasma sodium. This should be treated promptly with DDAVP. Vasopressin has less potent renal effects, but may adequately treat diabetes insipidus if being administered as part of cardiovascular management or 'hormonal resuscitation'. Hypotonic intravenous fluid may be required to restore normal sodium levels. Hypernatremia has been associated with poor organ function after transplantation, but it may in fact be a marker of poor overall ODM.

Blood and coagulation

Coagulopathy may be related to donor pathology or release of activating substances from necrotic brain. Treatment is required if there is active bleeding, and should be considered before a retrieval procedure. Point-of-care coagulation testing including thromboelastography may aid treatment decisions.

Transfusion should be considered if necessary as for any ICU patient. Suitable crossmatched blood should be available promptly for a donor operation if required.

Physiological support in the operating theatre

A multiorgan donation operation generally involves a laparotomy extended by sternotomy, even if thoracic organs are not to be retrieved. As with any major body cavity surgery there is potential for significant blood loss and hypothermia. Marked cardiovascular instability can occur during organ retrieval and vasoactive drug infusions are likely to be in progress. The goals of perioperative ODM should be to maintain stability in the operating theatre to allow unhurried removal of optimized organs.

ODM must be continued during transfer to, and in, the operating theatre by an appropriately experienced anesthetist.

The procedure should be treated in similar fashion to any major operating procedure. Surgical safety checks (appropriately modified) should be carried out. Team introductions may be particularly important as this is likely to be an unusual procedure in many hospitals, and there may be multiple operating teams. It will be useful to liaise closely with the anesthesia/critical care support team to describe phases of the procedure and likely effects.

Early communication of difficulty between the anesthetic and surgical team may reduce the need for accelerated or 'crash' retrievals.

Arterial monitoring is ideally in the upper limbs to prevent loss of monitoring when the distal aorta is ligated, whilst large bore reliable venous access should be placed in the right arm or central veins (not femoral). Intraoperative active warming should be continued, as the duration of retrieval is unknown. Intravenous fluids should be warmed and blood and blood products should be available rapidly if required.

Ensure adequate muscle relaxation as reflex movements can occur spontaneously.

Cardiovascular changes mediated by spinal reflexes may be induced by surgical stimulus and may require to be treated with vasoactive drugs. Since brainstem death has occurred the administration of anesthesia is unnecessary. Some retrieval teams administer volatile anesthetic drugs during retrieval for the control of hypertension and as they may have beneficial preconditioning effects on retrieved organs, although there is no evidence for this.

Coordination of drug administration, particularly heparin, is important. Retrieval teams should be skilled in abdominal and thoracic perfusion techniques.

Summary box for intraoperative support

- Experienced anesthesia support in the operating theatre is essential.
- Perform a preoperative surgical safety check.
- Continue intraoperative ODM.
- Good communication between teams is vital.

Implementation and outcomes

The increasing demand for organs has led to the development of campaigns and strategies, targeted at producing change across multiple systems, to improve transplant outcomes. These include:

- increasing public awareness and registrations as donors
- early identification and notification of potential donors in all areas
- timely diagnosis of brain death
- effective ODM
- retrieval of organs and preservation.

These strategies have proved effective when compared with historic controls. More evidence-based guidelines for donor management have the potential to deliver further improvements (Table 3.2).

Table 3.2 Summary of physiological changes occurring around brainstem death, with suggested intervention.

Physiological change	Example intervention
Arterial hypertension, cathecholamine storm	Sodium nitroprusside, esmolol
Vasodilatation following catecholamine storm	Blood pressure support with noradrenaline or vasopressin External warming device
Myocardial depression following catecholamine storm	Cardiac output monitoring Inotropic drug such as adrenaline or dobutamine
Cessation of respiration	Lung protective ventilation, keeping inspiratory plateau pressure < 30 cm H_2O
Loss of posterior pituitary function	Vasopressin infusion for hypotension DDAVP if central diabetes insipidus develops
Loss of anterior pituitary function	Intravenous levothyroxine and methylprednisolone

Future research and development of guidelines

Current guidelines have been effective to some extent, but determining the effectiveness of individual components is challenging. These studies are difficult to carry out and donor numbers are not high, but have recently validated improvements in outcome where a lung protective ventilation strategy is used or fluid responsive donors are adequately resuscitated.

The ethical and practical challenges of conducting such research are significant, but the potential for improvement in outcomes for recipients remains high.

Key practical points

- Manage donors in a critical care environment in collaboration with intensivist colleagues.
- Use lung protective ventilation.
- Fluid balance can be challenging and may be best guided by cardiac output monitoring.
- Hormonal resuscitation as per local protocols.
- Good perioperative communication during retrieval procedures is vital.
- Active organ donor management to achieve physiological goals consistently produces more transplantable organs of a higher quality and standard.

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4 Multiorgan Retrieval

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Introduction

The organization of organ retrieval services varies widely. In some parts of the world the retrieval is an intrinsic component of the transplantation service and the same teams perform the organ recovery and implantation. In many countries, however, there has been a gradual move to dissociate the retrieval from implantation, in order to facilitate timely access to the donor and avoid unnecessary delays and excessive travel. Organ procurement organizations work in close relationship with dedicated retrieval teams in well-defined geographical areas to facilitate the logistics of the donation process. A self-sufficient multiorgan retrieval team working to a clear protocol and in close cooperation with a network of donor coordinators ensures optimal donor management and organ recovery.

A similar level of standardization would be beneficial for the technical aspects of the retrieval as it would increase the utilization of organs, particularly when shared on a wider geographical area. There are several aspects (such as sequence of organ retrieval, type and volume of cold perfusion) that are dealt with differently by the retrieval teams. There is, however, a growing body of evidence that may help even out some of these practice variations in the future.

Retrieval team

It is a prerequisite that the retrieval team is fully conversant with the legal setting applicable to the country in which the retrieval is about to take place.

The structure of the retrieval team includes:

- Lead abdominal surgeon (fully trained in all aspects of abdominal retrieval)
- Assistant surgeon
- Theatre nurse
- Theatre practitioner (responsible for perfusion)

There is evidence that the addition of a transplant anesthetist to the team improves the quality of donor management and renders the team self-sufficient, with faster access to theatre, particularly in smaller hospitals.

Retrieval logistics

Once a donor has been identified, the donor coordinator should liaise with the retrieval team coordinator to mobilize the team. In many situations, the abdominal multiorgan team is attached to a liver transplant centre, and therefore the logistics of team mobilization are handled by a liver donor coordinator.

The local coordinator is responsible for:

- Arranging transport to and from the donor hospital
- Relaying donor details to the retrieving team
- Informing all team members of departure time, transport modality, destination and type of retrieval.

Organ procurement travel is associated with significant risks [1]. It is therefore the responsibility of the local team and the national transplant organizations to ensure that safe and standardized travel arrangements (by road or by air) as well as adequate standards for life insurance for the retrieval personnel are in place [2].

Best travel and insurance practices should be in place for the retrieval team, given the high risk of organ procurement travel.

Abdominal Organ Retrieval and Transplantation Bench Surgery, First Edition. Edited by Gabriel C. Oniscu, John L. Forsythe and John Fung.

Pre-retrieval checks

On arrival at the donor hospital, the team should go directly to the operating theatre, introduce themselves to the local team and familiarize themselves with the theatre setup. The team should be aware that, to some extent, they all act as ambassadors for transplantation and should act accordingly in the donor hospital. The lead surgeon should liaise with the donor coordinator and ensure that all the necessary paperwork and relevant donor data are available for review.

When the patient comes to theatre, the donor surgeon should check:

- Donor identity
- Donor case notes for relevant history
- Brainstem death tests documentation
- Consent for donation and for specific organs to be retrieved
- Blood group (there should be clear documentation)
- Donor data including hematology and biochemistry tests, virology results, and the amount of inotropic and ventilatory support.

Patients' notes should be carefully reviewed for the relevant history and to confirm the accuracy of the donor data on the retrieval forms.

Once the preoperative checks are completed, the lead surgeon should organize a short team brief and discuss the operative approach and the roles for each team member.

If a thoracic team is present, a common approach (in particular with regards to the sequence of incisions, vena cava drainage and sequence of organ removal) is agreed to ensure a smooth process, once the retrieval is underway.

It is good clinical practice to adopt a surgical safety checklist system, where all the information pertaining to the donor, consent, virology and organs to be retrieved are reviewed, prior to starting the procedure (Figure 4.1).

Most anesthetists in the donor hospitals are unfamiliar with the donor management and the retrieval operation. Therefore the lead donor surgeon should discuss the strategies to ensure hemodynamic stability (fluid and inotropic support) and the interactions between the surgical teams and the anesthetic team at various points during the retrieval procedure.

As part of preoperative management, antibiotics can be administered to the donor. In our practice we use:

- 1–2 g benzylpenicillin
- 4 g cefotaxime
- 160 mg gentamicin

Prolonged hypotension is detrimental to organ quality. Should this occur the team must be prepared to proceed with a crash retrieval (rapid cannulation and cold perfusion) to ensure a successful retrieval of all intended organs.

The lead donor surgeon is also responsible for communicating all relevant findings to all surgeons that have accepted the organs for transplantation.

Multiorgan retrieval technique in DBD donors

A video for multiorgan retrieval in DBD donors can be found on the companion website: www.wiley.com/go/oniscu/abdominal

Technical variations

Several techniques for organ retrieval have been described. Although the principles are similar, there are a few notable differences.

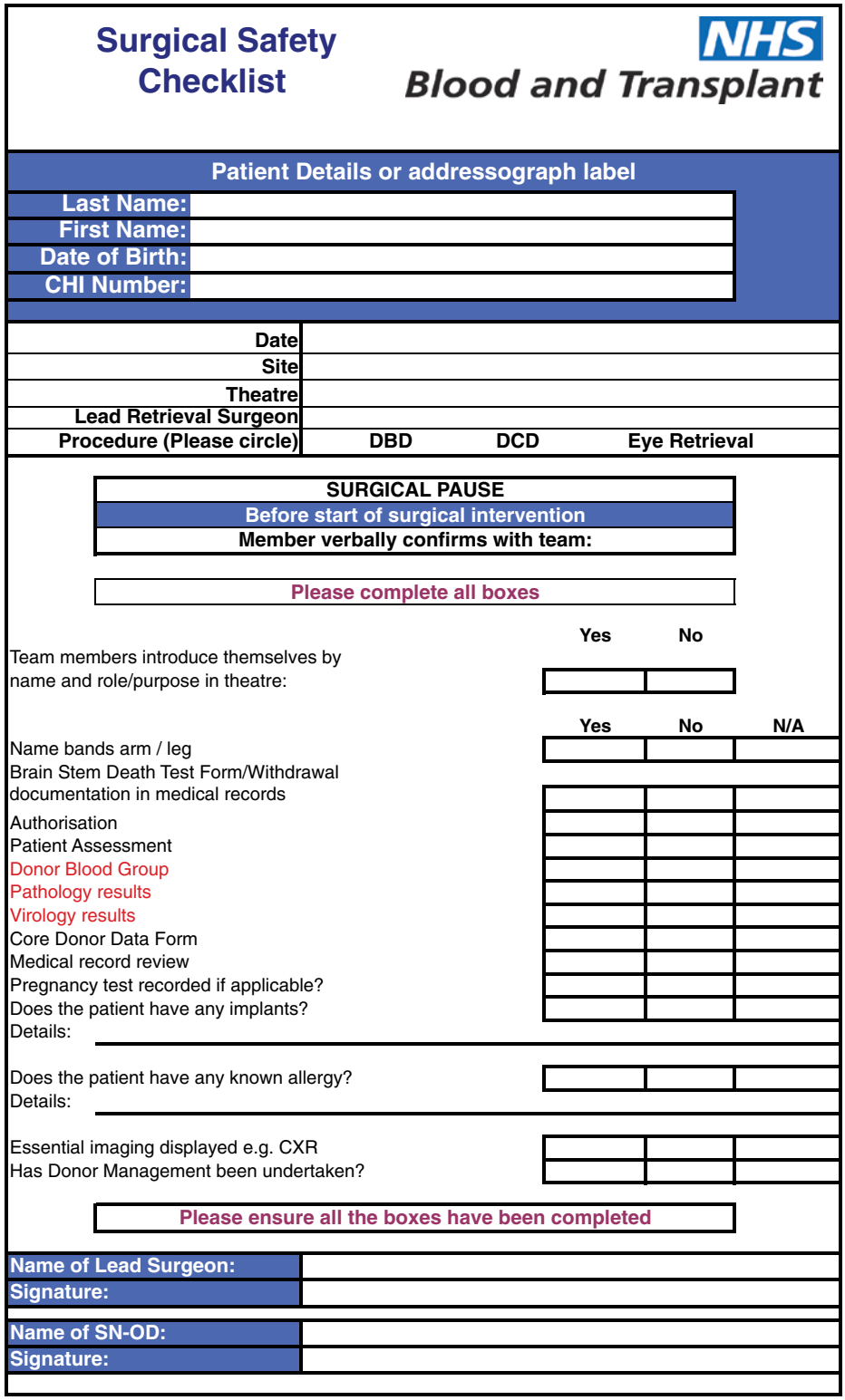
Warm vs. cold dissection

A retrieval procedure involves two phases: abdominal organ dissection before aortic cannulation (warm phase) and further dissection and organ removal post circulatory arrest and cold perfusion (cold phase). In the early years of transplantation, dissection and identification of the anatomy in the warm phase was the norm. Despite a more tedious dissection process [3], this allowed for a shorter cold phase, potentially reducing the risk of organ re-warming. However, damage of the arterial supply during warm phase dissection could compromise the organs and potentially render them untransplantable.

The introduction of a rapid technique (*in situ* perfusion followed by cold phase dissection) [4] led to shorter operating times and appeared to be associated with a lower incidence of organ damage and better organ function.

Cold phase dissection is associated with faster retrieval times and better organ function.

However, correct identification of vascular anatomy in cold phase requires a higher level of experience.



Surgical Safety Checklist

NHS Blood and Transplant

Patient Details or addressograph label

Last Name:	
First Name:	
Date of Birth:	
CHI Number:	

Date			
Site			
Theatre			
Lead Retrieval Surgeon			
Procedure (Please circle)	DBD	DCD	Eye Retrieval

SURGICAL PAUSE

Before start of surgical intervention

Member verbally confirms with team:

Please complete all boxes

	Yes	No	N/A
Team members introduce themselves by name and role/purpose in theatre:			
Name bands arm / leg			
Brain Stem Death Test Form/Withdrawal documentation in medical records			
Authorisation			
Patient Assessment			
Donor Blood Group			
Pathology results			
Virology results			
Core Donor Data Form			
Medical record review			
Pregnancy test recorded if applicable?			
Does the patient have any implants?			
Details:			
Does the patient have any known allergy?			
Details:			
Essential imaging displayed e.g. CXR			
Has Donor Management been undertaken?			

Please ensure all the boxes have been completed

Name of Lead Surgeon:	
Signature:	
Name of SN-OD:	
Signature:	

Figure 4.1 Surgical safety checklist. (SN-OD-Specialist Nurse in Organ Donation).

Therefore the retrieval surgeon must strive for a balanced approach according to his/her level of expertise and ability to deal with these critical complications.

The balance between the amount of warm phase and cold phase dissection is determined by the surgeon's level of expertise and donor hemodynamic stability.

Single vs. dual perfusion

There is a reasonable amount of evidence indicating that in the setting of multiorgan DBD retrieval, aortic only perfusion provides comparable if not better outcome for the liver graft [5], with significant advantages for the quality of the pancreas [6] and intestinal grafts, when compared with dual aortic and portal perfusion. However, dual perfusion remains the standard in the setting of DCD donors, in order to provide a rapid cooling of the liver and minimize the risk of primary nonfunction.

Single aortic perfusion is the standard for multiorgan DBD retrievals.

In situ vs. *ex situ* liver split

The techniques of liver splitting are discussed in other chapters, but it is important to highlight that each technique has its pros and cons and a uniform approach is yet to be established. There have been concerns regarding the quality of other organs retrieved when an ***in situ*** split is performed. However, data from centres that practise this approach routinely have failed to demonstrate an inferior outcome [7]. Irrespective of the approach, the splitting of suitable livers should be strongly encouraged.

Separate vs. *en bloc* liver–pancreas removal

Traditionally, organs are removed individually in a certain order (thoracic organs, liver, pancreas, kidneys). A prolonged time to remove the organs after cold perfusion increases the risk of rewarming [8] and could lead to organ dysfunction post transplantation. Furthermore, there is evidence that intra-abdominal temperature does not drop as rapidly as previously thought, despite intravascular as well as topical cooling. Therefore, an *en bloc* technique has been advocated. This reduces the dissection and removal time, is associated with fewer procurement related injuries and may be associated with a better initial organ function [9].

En bloc organ removal is associated with fewer injuries and leads to better function in a multiorgan retrieval setting (liver/pancreas/small bowel).

Retrieval technique

Irrespective of these differences, the technique employed must ensure a rapid and successful removal of organs with a minimal risk of damage. Most abdominal multiorgan retrievals include liver, pancreas and kidneys. The retrieval technique presented in this chapter is one of the many options available for this setting. Paediatric retrievals and multivisceral retrieval including small bowel are discussed in the relevant chapters.

Incision

Once the preoperative checks are completed, the operating field is prepared and draped from the suprasternal notch to the pubis. A midline incision from the xiphisternum to the pubis symphysis is then made (Figure 4.2).

The falciform and the round ligaments are divided (Figure 4.3), an abdominal retractor is placed and a thorough laparotomy is performed to identify any pathology.

Abdominal organs assessment

The laparotomy should be carried out in a structured fashion, examining the right and left lobes of the liver, the stomach and duodenum, followed by the small bowel, colon and rectum. Particular attention should be paid to the pelvic organs in female donors. The pancreas is briefly inspected, by dividing the gastrocolic ligament. It is rather difficult to inspect the kidneys at this stage, but they should be palpated for any gross pathology and carefully inspected on the bench, once they are removed.

Any abnormal finding should be documented and the appropriate microbiological samples taken in case ascites or peritonitis are present. Any lesions should be biopsied. The availability of on-call pathology services varies and appropriate arrangements must be in place in the transplant centre should none be available in the donor hospital. In general, the biopsy is examined in the centre that has accepted the liver and the results are communicated to all other recipient centres.

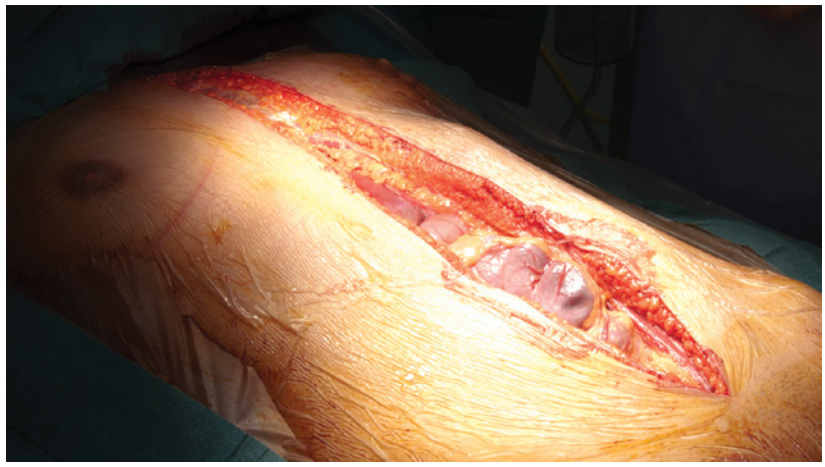


Figure 4.2 Midline incision.

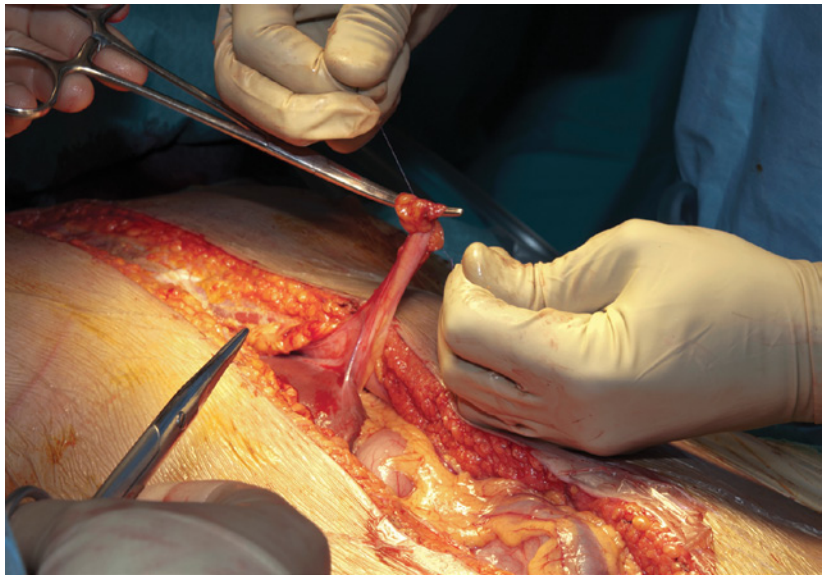


Figure 4.3 Ligation of the falciform ligament.

Sternotomy and initial thoracic exposure

Once the laparotomy is completed, the falciform ligament is fully divided and a muslin pack is placed over the liver to protect it during sternotomy.

The pretracheal fascia and the suprasternal ligament are incised, taking care to avoid the suprasternal veins. Using blunt finger dissection and a supra- and infrasternal approach, a tunnel is created behind the sternum, in the anterior mediastinum (Figure 4.4).

Using a powered saw, a median sternotomy is undertaken (Figure 4.5). It is critical that the ventilator is disconnected prior to sternotomy, to allow the collapse of the lungs and avoid any potential iatrogenic injuries. Once the sternotomy is completed, the ventilator is reconnected and lungs are reinflated.

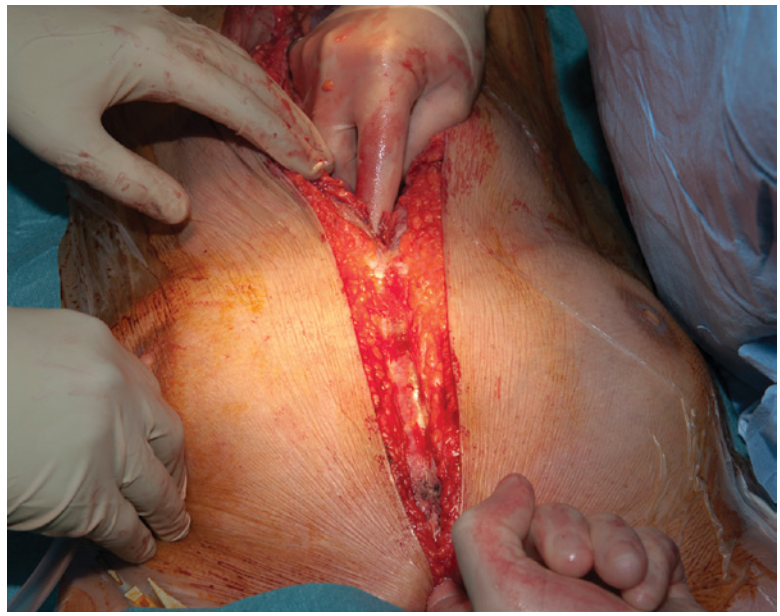


Figure 4.4 Creation of a retro-sternal tunnel.

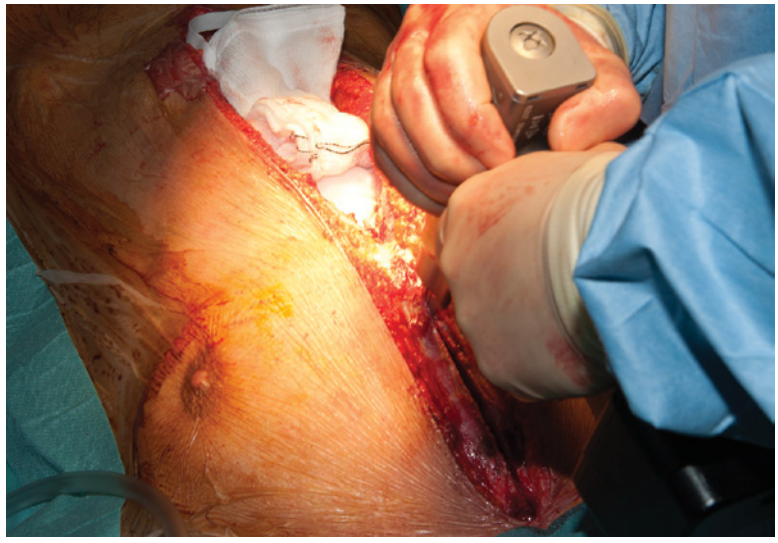
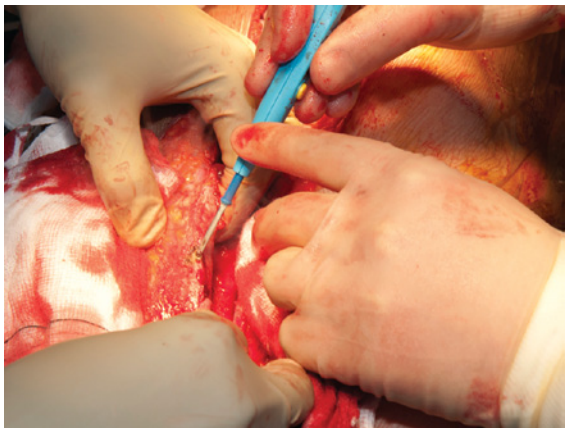


Figure 4.5 Median sternotomy with a power saw.

When a power saw is not available, a long forceps is introduced immediately behind the posterior aspect of the sternum to avoid pericardial injuries. A Gigli saw is inserted and passed under the sternum. Following the temporary disconnection of the ventilator, sternotomy is performed.

When using a Gigli saw, lower the height of the table to facilitate the sawing movements. Keep your arms wide apart when using the saw. Prevent the uncontrolled release of the saw on completion of sternotomy by holding an instrument across the incision.



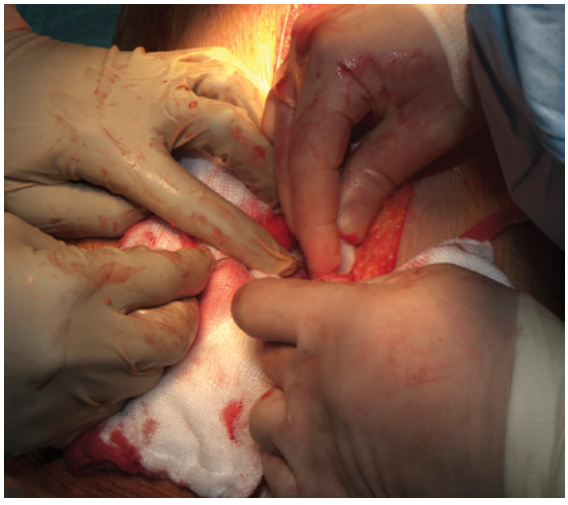


Figure 4.6 Sternal edges hemostasis is secured using bone wax and diathermy.

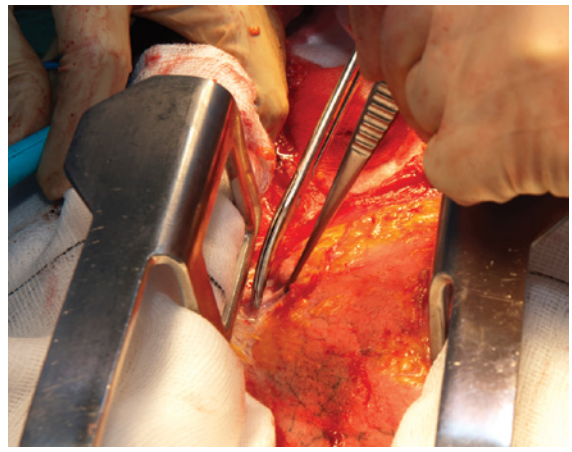


Figure 4.7 Pleurae are opened and the lungs are exposed.

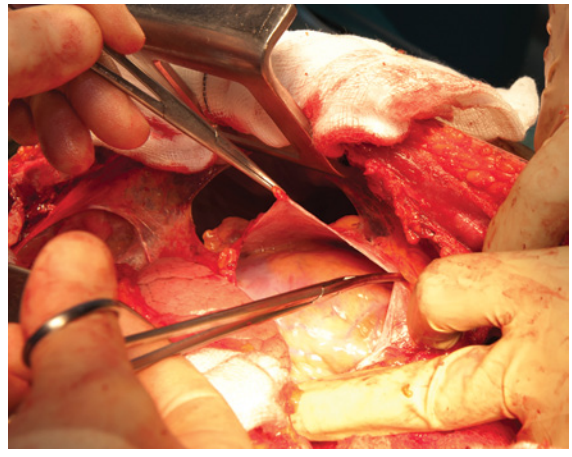


Figure 4.8 The pericardium is opened.

Once the sternotomy is completed, the pleural edges should be gently mobilized using blunt dissection, to allow the placement of a retractor. Hemostasis from the sternal edges is achieved using bone wax and diathermy (Figure 4.6).

A Finochietto retractor is placed in the wound and gradually opened. The pleurae are opened and the lungs are exposed (Figure 4.7).

The pericardium is opened using scissors rather than diathermy and the heart is protected with a moist swab. The anterior aspect of the diaphragm can be incised to facilitate further opening of the retractor (Figure 4.8).

Visceral mobilization and vascular exposure

A swab is placed under the left lateral segment of the liver to protect the viscera, and the left triangular ligament is divided close to the liver (Figure 4.9), to avoid damaging the left hepatic and phrenic veins. The liver can now be fully inspected for the presence of aberrant anatomy, palpating the right side of the hepato-duodenal ligament for the presence of an aberrant right hepatic artery (ARHA) and lifting the left lateral segment to inspect the lesser sac for the presence of an aberrant left hepatic artery

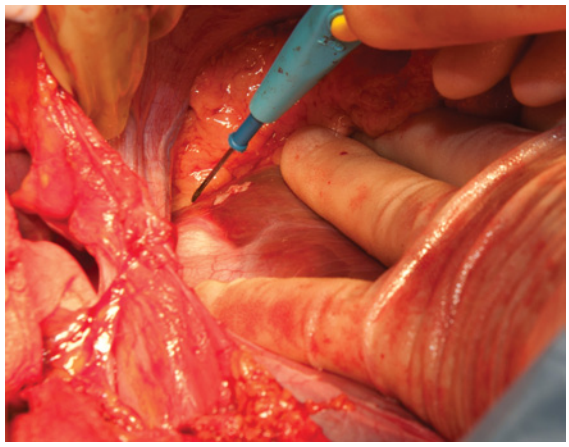


Figure 4.9 Division of the left triangular ligament.

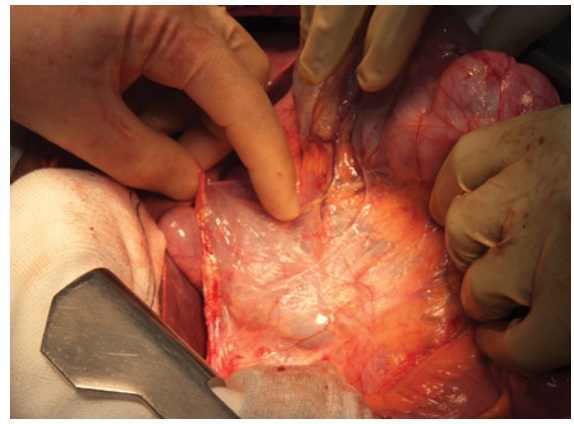


Figure 4.11 Mobilization of the right colon and exposure of the right kidney.

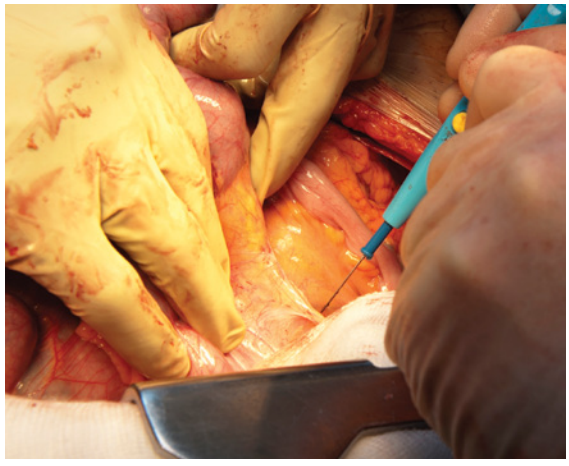


Figure 4.10 Cephalad retraction of the small bowel and mobilization of the mesentery.

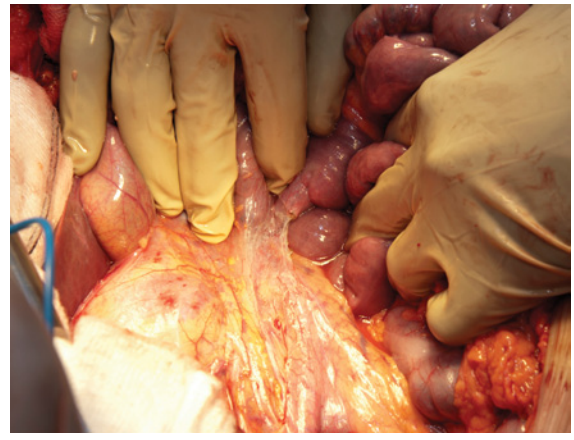


Figure 4.12 Completed Cattel-Brasch maneuver.

(ALHA). The lesser sac is opened, preserving any aberrant artery.

The entire small bowel and the caecum are retracted by the assistant in a cephalad direction (Figure 4.10). This allows exposure of the white line of Told, which marks the correct plane of dissection. In obese patients this line of dissection may be harder to find, but time should be taken to identify the correct plane as this facilitates exposure of the great vessels.

The colon and small bowel are mobilized (Figure 4.11), taking care to avoid damaging the right ureter and the gonadal vessels. Dissection is carried towards the hepatic flexure, which is mobilized together with the duodenum and the pancreatic head, to expose the infrahepatic vena cava.

This right medial visceral rotation (Cattel-Brasch maneuver) (Figure 4.12) exposes the inferior vena cava (IVC), aorta, right kidney and the ureter as well as the left renal vein. The viscera are mobilized until the origin of the superior mesenteric artery (SMA) can

be identified by palpation (above the level where the left renal vein crosses the aorta).

The SMA can be dissected and encircled at the level of its aortic origin. This is a useful maneuver, particularly if an ARHA is identified during the latter stages of the dissection. This will facilitate and guide the vascular division in the cold phase. The SMA is surrounded by a fair amount of lymphatic tissue, which must be divided so the artery can be carefully identified and encircled.

At this point, it is useful to divide the peritoneal attachments to the inferior aspect of the right lobe of the liver, to prevent any capsular tears due to excessive traction by an over-zealous assistant.

The peri-aortic lymphatic tissue is divided and the aorta and the common iliac arteries are exposed. The distal aorta is dissected circumferentially above the level of the bifurcation, taking care to avoid damaging the lumbar arteries. Two heavy ties/tapes are placed loosely around the aorta (Figure 4.13).

If a lower polar kidney artery arises from the distal aorta or the common iliac artery, cannulation can be undertaken via the controlateral common iliac artery, which is isolated at this stage.

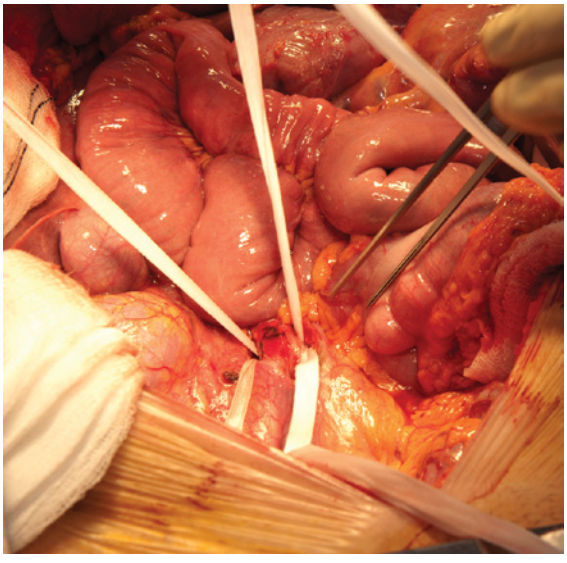


Figure 4.13 Distal aorta is dissected and two ties are placed around it.

In most cases, venous venting takes place in the chest, as it does not compromise thoracic organ retrieval. However, the abdominal IVC can also be used for venting, and in this case it should be dissected and controlled above the iliac bifurcation, in a similar manner to the aorta.

Vascular control is a crucial step and can be performed earlier in the procedure, immediately after the laparotomy and before the sternotomy. This enables quick access to cold perfusion, particularly if sternotomy is fraught with difficulties (previous surgery) or the donor becomes unstable after the chest is opened.

Porta hepatis dissection

The liver is retracted and the hepatoduodenal ligament is exposed. The peritoneum is incised about 0.5 cm above the upper border of the duodenum and dissection is carried in a transverse manner from lateral to medial. Multiple small veins are encountered at this level and should be ligated and divided.

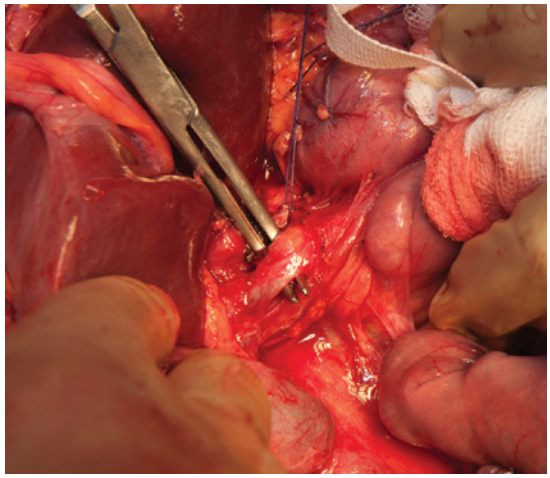
The common bile duct is encircled, ligated and divided above the duodenum (Figure 4.14).

Do not dissect the common bile duct higher, to avoid injuries to the portal vein or aberrant right hepatic artery.

The gallbladder is opened and flushed with warm saline until the effluent from the divided end of the common bile duct is clear (Figure 4.15). Bile is toxic and should be washed away assiduously.

Once the bile duct is divided, dissection in the porta hepatis is resumed from the medial side identifying the common hepatic artery (CHA). Dissection is then carried towards the right to identify the gastroduodenal artery (GDA). The GDA is dissected towards the pancreas. A 5 mm stump of GDA must be preserved on the hepatic artery to allow for reconstruction options in case aberrant vasculature is present.

The CHA is then dissected towards the celiac axis, staying above the upper border of the pancreas, which



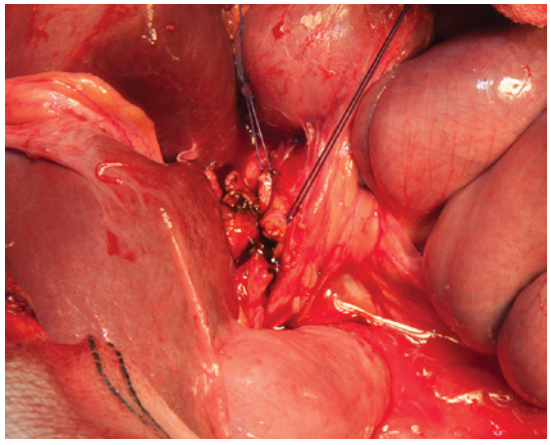


Figure 4.14 Dissection and division of the common bile duct.

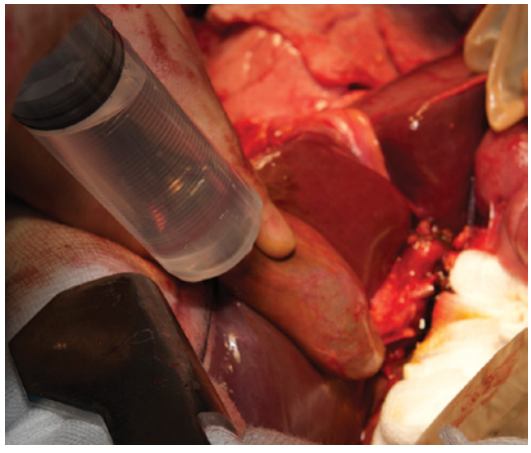
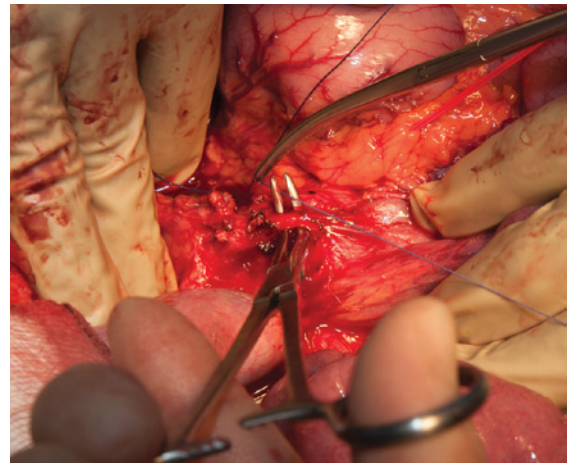


Figure 4.15 Gallbladder is flushed.



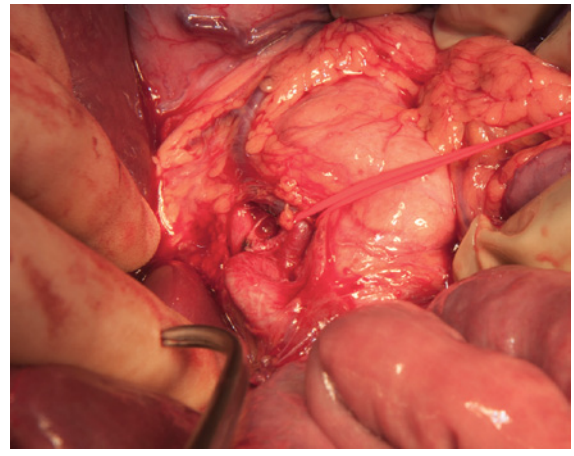


Figure 4.16 The GDA and splenic arteries are identified.

is gently retracted by the assistant. The origin of the splenic artery is identified and dissected for 5 mm, without straying into the pancreas and preserving any dorsal pancreatic artery, which seldom may arise at this level (Figure 4.16).

The gastroduodenal and splenic arteries could be loosely encircled with vascular sloops to facilitate identification in the cold phase, but care must be taken to ensure that the sloops do not compromise the blood flow.

The presence of aberrant hepatic vasculature must be ascertained during porta hepatis dissection. Several

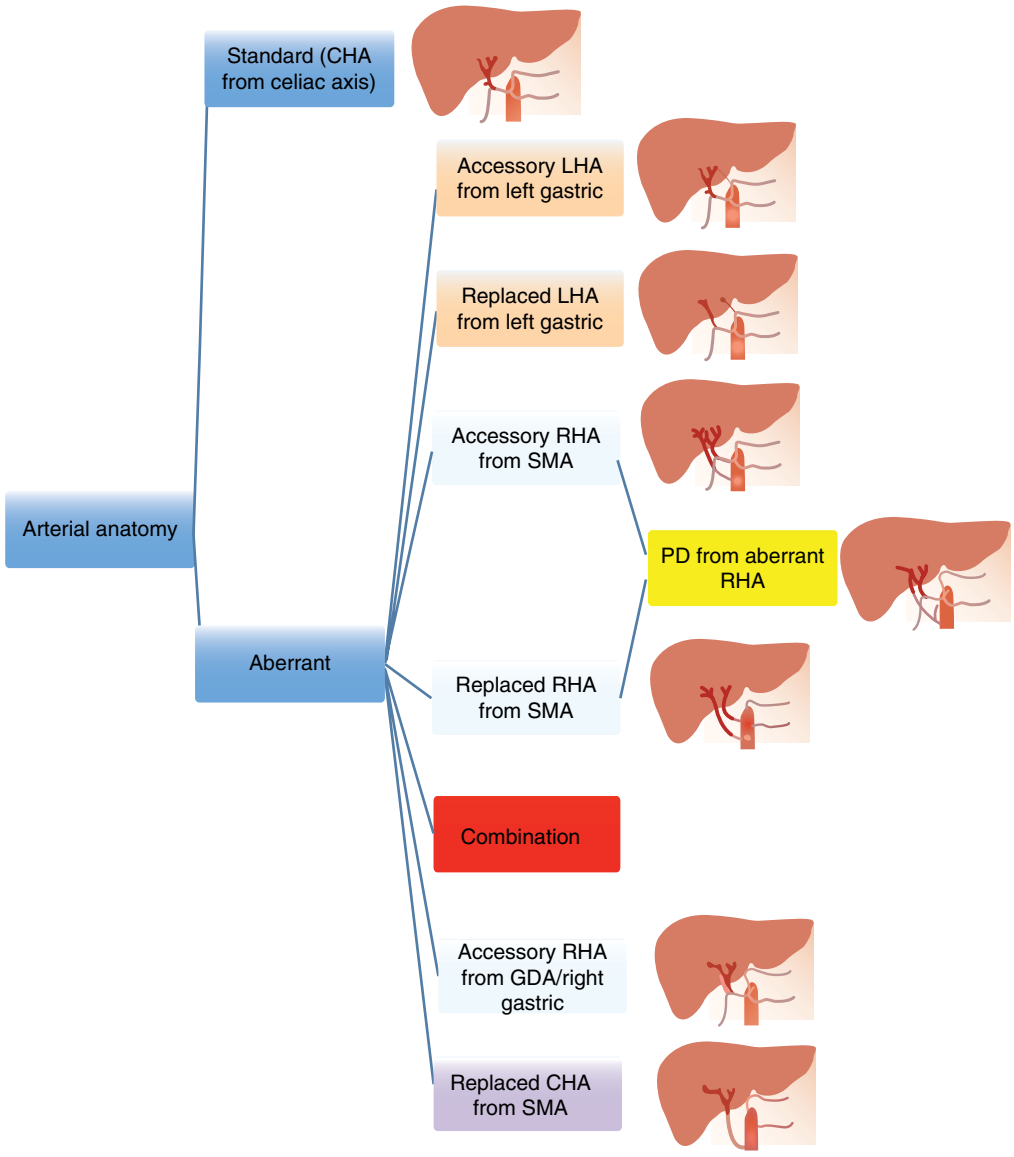


Figure 4.17 Hepatic artery variations.

variations have been described (Figure 4.17). An ARHA will be encountered on the posterolateral aspect of the portal vein. The presence of a completely replaced hepatic artery from the SMA should be suspected if the portal vein (rather than CHA and GDA) is encountered first during the dissection of the porta hepatis following the bile duct division. The presence of an accessory/replaced left hepatic artery should have already been determined when the lesser sac was opened.

Pancreas assessment and dissection

The lesser sac is entered dividing the gastroepiploic vessels. The gastric antrum is isolated and a vascular sloop can be placed around it to mark the site of proximal gastrointestinal (GI) tract transection for the removal of the pancreas (Figure 4.18).

The greater curvature of the stomach is mobilized for a suitable length to facilitate a detailed inspection and palpation of the entire pancreatic gland. The proximal

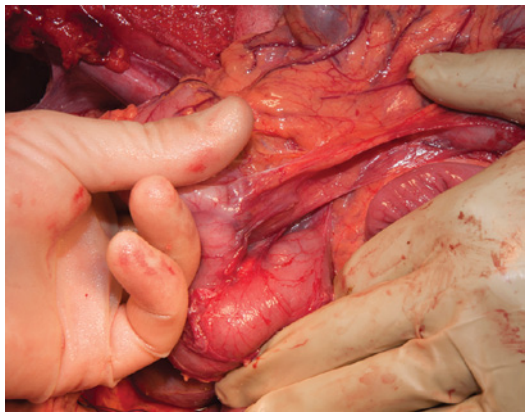
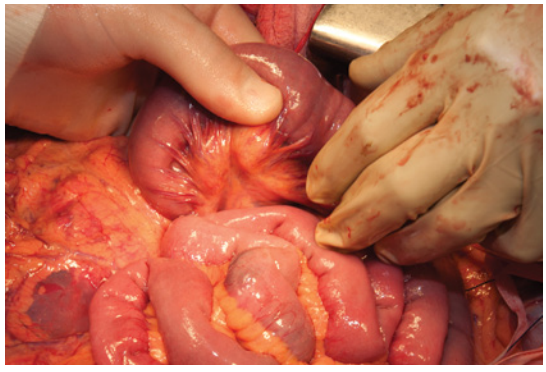


Figure 4.18 Identification of proximal GI transection site.



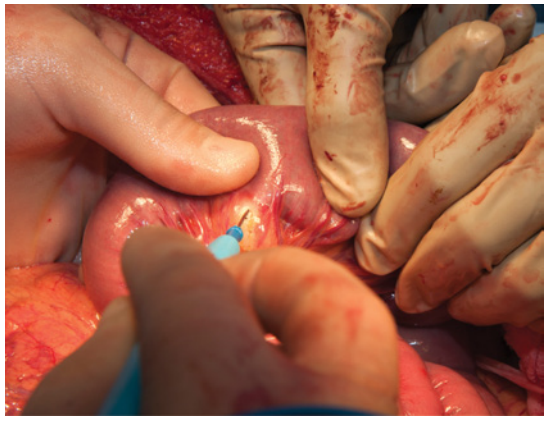


Figure 4.19 Identification of jejunal transection site.

jejunum is then inspected and a vascular sloop can be placed to mark the distal site of transection (Figure 4.19).

Further dissection and mobilization of the pancreas is not needed at this stage. The descending colon is mobilized along the Told line, to expose the left kidney and allow placement of ice for topical cooling.

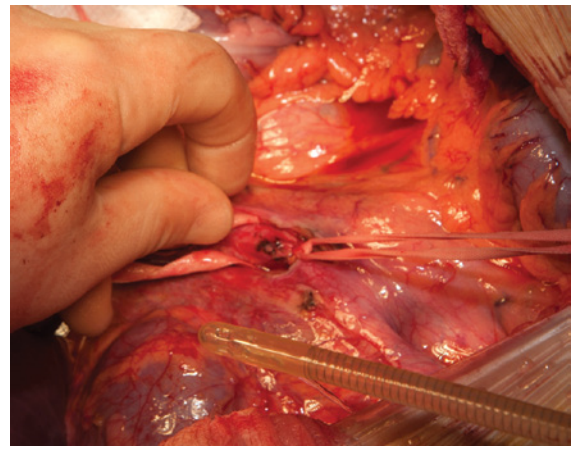


Figure 4.20 Ligation of the distal aorta.

Supraceliac aorta preparation

The left lateral segment is retracted laterally and the supraceliac aorta is palpated through the lesser sac. The diaphragmatic crura is incised vertically over the aorta, using diathermy. Using forceps the divided crura is retracted and the aorta is dissected for a suitable length to allow placement of a clamp. There is no need to dissect the aorta circumferentially, but the dissection of the lateral aortic walls should be taken all the way to the spine to allow accurate clamping.

Take care to avoid injuries to the oesophagus, IVC and lumbar arteries during this step.

Vascular cannulation and cross-clamping

Having completed all these steps, after discussion with the cardiothoracic team, 30,000 units of heparin (300 units/kg) are administered intravenously. After 5 minutes, the small bowel is retracted cephalad and the distal aorta is exposed. The previously placed distal umbilical tape is ligated at the level of the aortic bifurcation (Figure 4.20).

The proximal tape is lifted to allow the surgeon to pinch and control the aorta. This maneuver must be gentle, particularly when the aorta is atheromatous. A small incision is made and an appropriately sized cannula (usually a 22 Fr) is inserted in the aorta

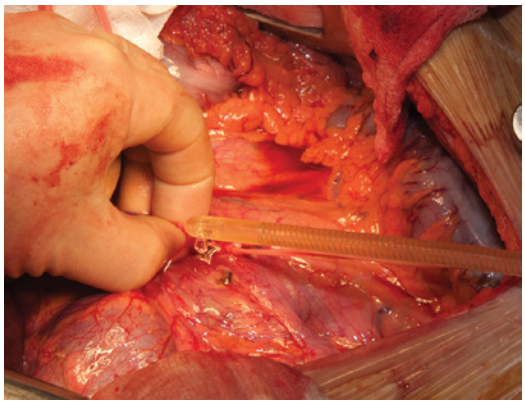


Figure 4.21 Aortic incision and cannula insertion.

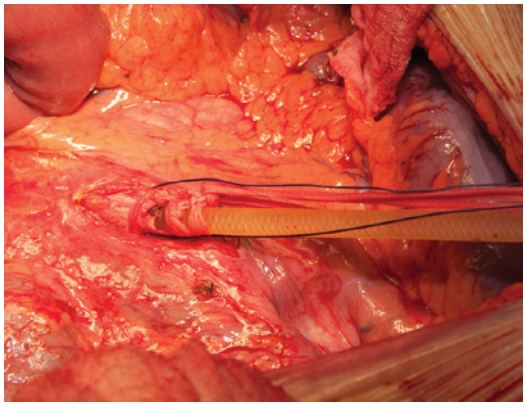


Figure 4.22 Cannula firmly secured in place.

(Figure 4.21). The cannula should be primed and bubbles removed from the circuit prior to insertion.

The surgeon holds the aorta and the cannula to prevent displacement and significant blood loss, whilst the assistant secures the cannula in place, tying the tape. The proximal end of the cannula should be 2–3 cm above the arteriotomy, and the surgeon must ensure that the tip is well below the origin of the renal arteries. Once the adequate position of the cannula tip is confirmed, the tape is looped and tied around the cannula again to prevent inadvertent displacement (Figure 4.22).

- Rehearse surgeons and assistant's roles for this step prior to making an aortotomy, to ensure an effortless aortic cannulation.
- Ensure proximal tip of cannula is below the level of renal arteries.

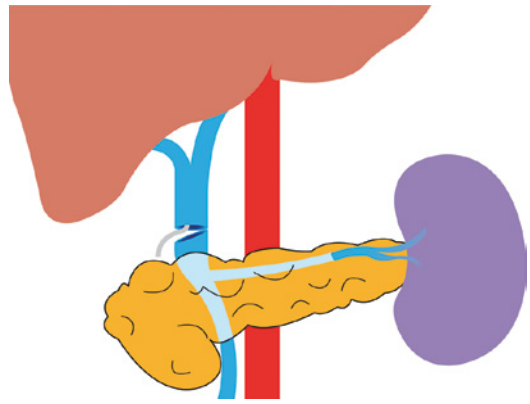


Figure 4.23 Portal vein cannulation in the porta hepatis.

Although aortic perfusion alone is the current standard for multiorgan DBD donors, portal perfusion may be used for marginal liver donors or if the liver is considered for *ex situ* split.

Portal vein cannulation can be achieved via several approaches:

- **Inferior mesenteric vein (IMV) cannulation**. The transverse colon is lifted and the IMV is exposed to the left of the ligament of Treitz. The peritoneum is incised and the vein is dissected for a few centimeters. Cannulation at this level, however, could be difficult given the size of the vein. Furthermore, the cannula can inadvertently be positioned in the splenic vein. Therefore the cannula should be manipulated until the position of the tip is confirmed in the portal vein at the level of the porta hepatis.
- **Superior mesenteric vein (SMV) cannulation**. The transverse colon is lifted whilst the small bowel mesentery is pulled down. The peritoneum over the junction between the transverse mesocolon and small bowel mesentery is incised. The SMA is palpated and the SMV is dissected to the right of the artery. This approach could be difficult if there is a large amount of mesenteric fat.
- **Portal vein cannulation** (Figure 4.23). This approach is superior to the other two methods as it avoids pancreatic congestion. The portal vein is identified in the porta hepatis and is dissected circumferentially approximately 1 cm above the upper border of the pancreas. A tie is placed around the vein and secures the cannula that is inserted towards the liver. As soon as perfusion is started, the portal vein must be completely divided, to allow unrestricted venous outflow from the pancreas and to avoid venous congestion.

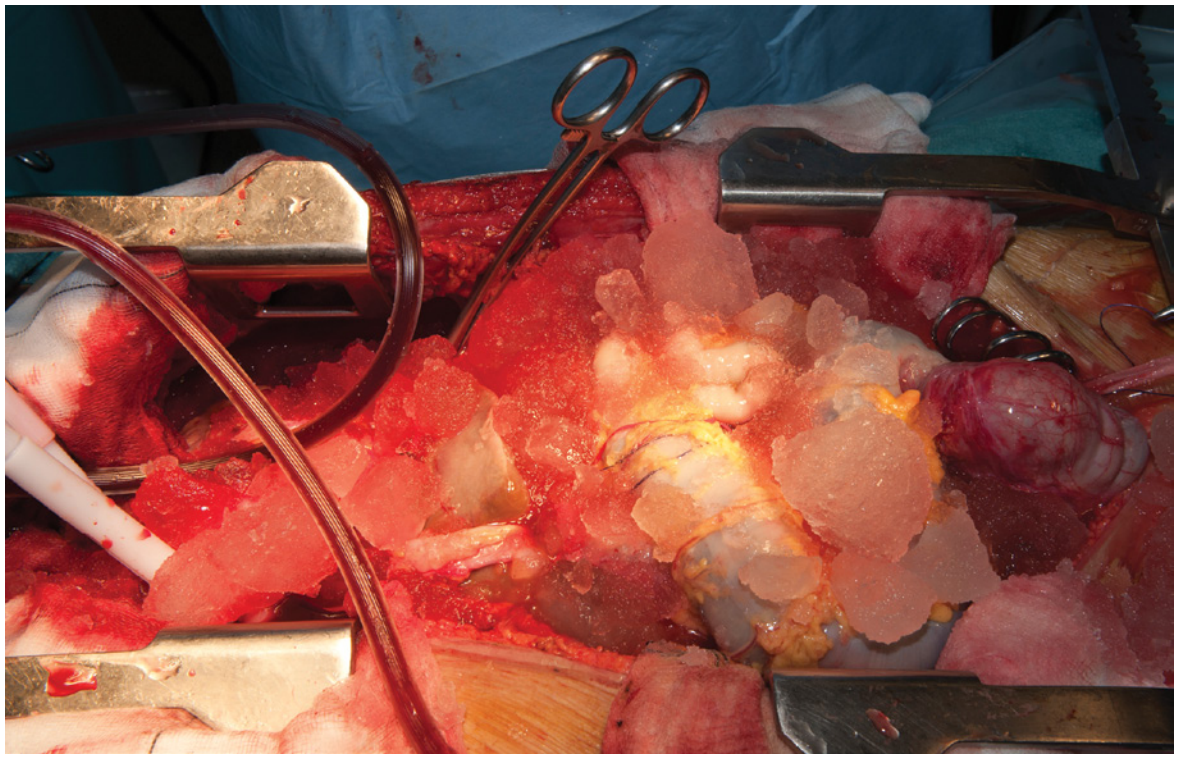


Figure 4.24 *In situ* cooling.

Once the aortic cannulation is completed, the abdominal viscera are returned to the anatomical position to avoid arterial occlusion or spasm and ensure uniform cold perfusion. To this extent, if vascular loops have been placed around the GDA and splenic arteries, ensure they are loose and not compromising the flow.

After consultation with the cardiac team, the cross-clamp time is agreed.

Check that ice and perfusion fluid are ready and that two functioning suction devices are available, prior to cross-clamping.

The left lateral segment is retracted to the right with the left hand and a long vascular clamp is positioned around the previously dissected supraceliac aorta, with the tip against the spine, to provide complete aortic occlusion.

The aorta is cross-clamped and the time is noted. The supraceliac aorta should be clamped even if the cardiac team clamp the thoracic aorta. The heart is lifted and the cavoatrial junction is incised sharply and exsanguination commenced. At the same time aortic perfusion is commenced.

- Pull the liver downwards to ensure an adequate length of suprahepatic IVC and to avoid damaging the hepatic veins when dividing the IVC.
- Do not start the aortic perfusion before the IVC is divided.

Slush ice is placed around the liver, in the lesser sac, around the kidneys and around the mesenteric root (Figure 4.24). A sucker is placed at the level of the suprahepatic vena cava to keep the thoracic field clean. Some slush ice should also be placed in the right chest, above the diaphragm to ensure uniform cooling of the liver and avoid rewarming due to the blood draining in the right chest.

The organs must be constantly assessed and the caval effluent examined to ensure adequate perfusion. The operating theatre practitioner must inform the surgeons if there are any problems with the perfusion circuit and the flow. If problems are detected, inspect the aorta and ensure the cannula is in the correct position, is not tied too tightly and there are no kinks in the circuit.

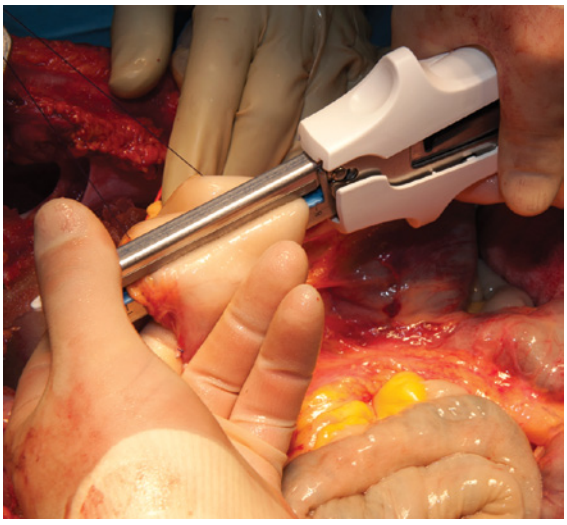


Figure 4.25 The gastric antrum is stapled.

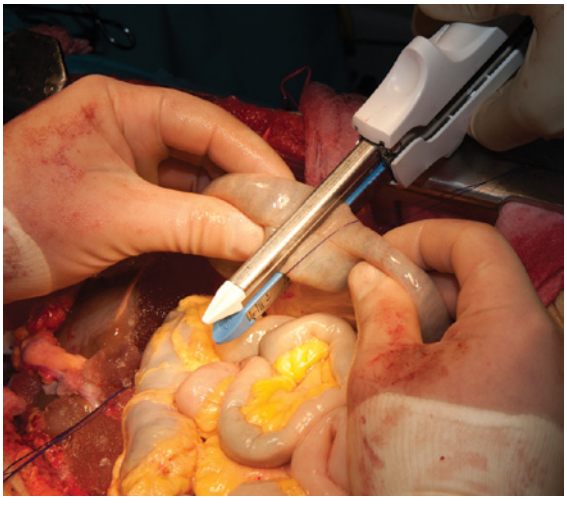


Figure 4.26 Jejunum is stapled.

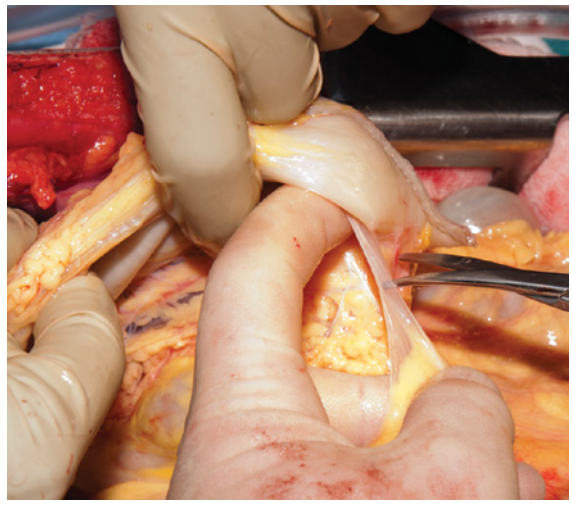


Figure 4.27 Mobilization of the stomach.

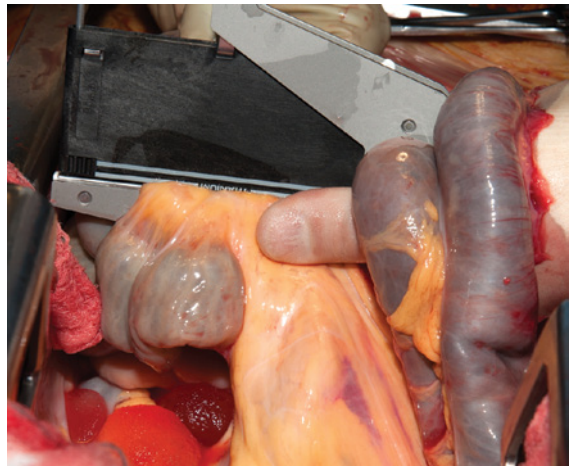


Figure 4.28 Small bowel mesentery is stapled.

Cold phase dissection

Once the thoracic organs are removed, the abdominal organs are recovered.

En bloc liver–pancreas removal

The best way to remove the liver and the pancreas is *en bloc*. Whilst waiting for the thoracic team to complete their part of the retrieval, the gastric antrum (Figure 4.25) and the jejunum (Figure 4.26) are divided with a linear stapler (e.g. GIA 75) at the previously marked sites.

Once thoracic organs are removed, the stomach is fully mobilized along the lesser and greater curvature and the short gastric vessels are divided (Figure 4.27). The fully dissected stomach is then retracted into the chest to expose the pancreas and the supraceliac aorta.

The transverse colon and the splenic flexure mobilization is then completed and once the aortic perfusion is near the end, the small bowel mesentery is stapled (Figure 4.28). The staple line must be well

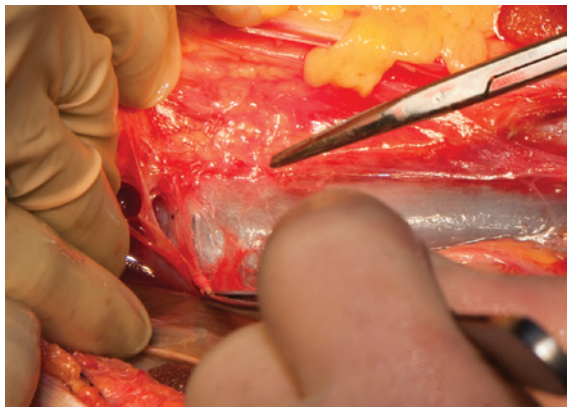


Figure 4.29 Dissection of the IVC and identification of the left renal vein origin.

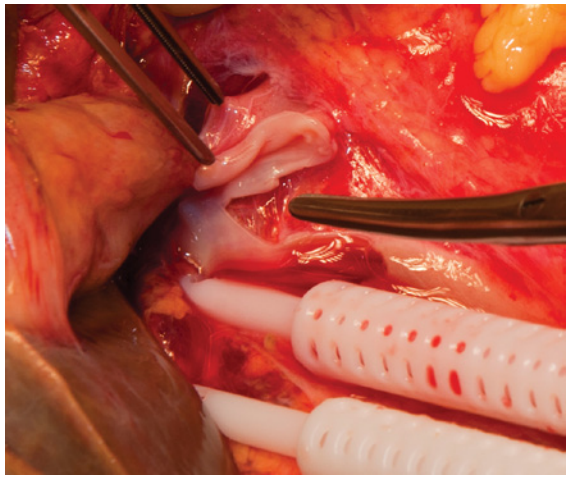


Figure 4.30 Left renal vein is divided.

clear of the uncinate process to avoid damaging the pancreas and its blood supply. The small bowel and the colon are then retracted towards the patient's left iliac fossa.

This exposes the entire retroperitoneum. The IVC is dissected and divided above the origin of the renal veins (Figure 4.29).

At this point, the left renal vein is divided flush with the IVC (Figure 4.30) (although traditionally a small cuff was taken with the vein) and dissected to the left side of the aorta to avoid injuries when the aorta is divided.

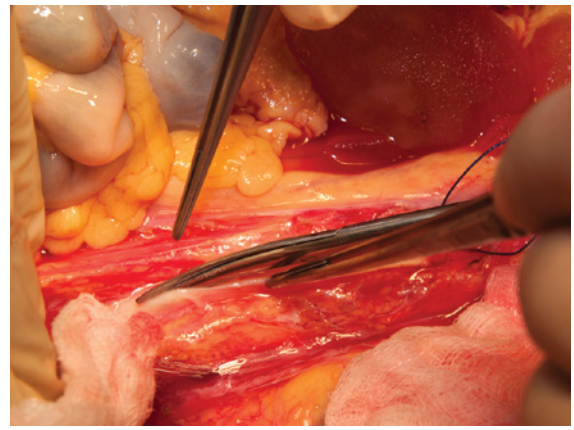


Figure 4.31 Incision of the anterior aortic wall.

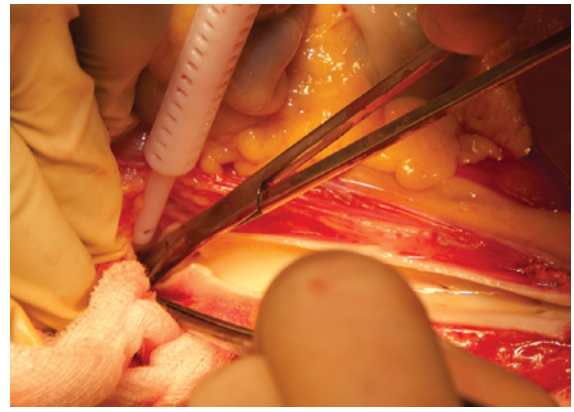


Figure 4.32 Oblique incision of the aorta above the origin of the renal arteries.

The aortic cannula is removed and the anterior wall of the aorta is incised up to the origin of the SMA (which was identified +/– slung during the warm phase dissection) (Figure 4.31).

The origin of the renal arteries is very close to the origin of the SMA and care must be taken during this step to avoid vascular injuries.

Once the renal arteries have been identified, an oblique incision is made towards the posterior aortic wall, to include the SMA on the aortic patch and separate it from the renal arteries (Figure 4.32).

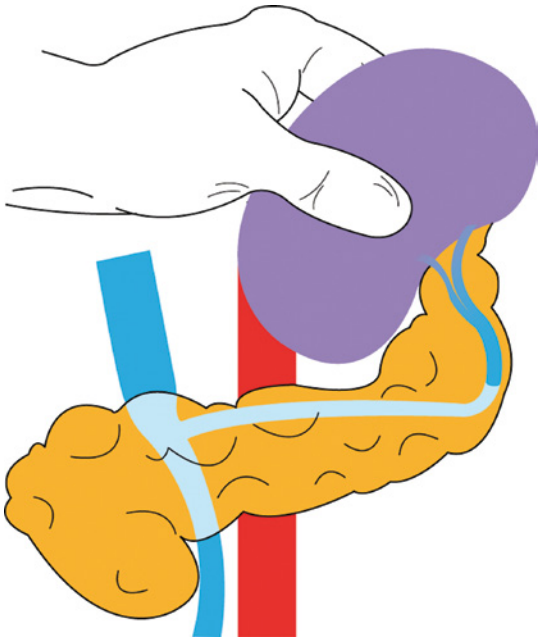


Figure 4.33 Mobilization of the pancreatic tail.

At this point, the tail of the pancreas is mobilized, using the spleen as a handle (Figure 4.33). The lienorenal ligament is divided and dissection is carried out approximately 1 cm away from the upper and inferior borders of the pancreas to avoid capsular of vascular injuries. The left adrenal gland may be encountered, and in thin patients the kidney can be injured if dissection is not carried out under vision at all times.

The pancreas is mobilized until the left lateral aspect of the aorta and the level of aortic transection for SMA/renal arteries separation is identified. The posterior wall of the aorta is then dissected in a cephalad direction (Figure 4.34).

At this point, the inferior aspect of the liver–pancreas block is completely separated and attention is turned towards the supraceliac dissection. The left diaphragm is divided to facilitate access to the aorta, which is divided below the previously placed cross-clamp. The dissection of the posterior wall of the aorta is then completed, creating an aortic tube with the celiac axis and SMA.

The suprahepatic IVC is completely divided and the surgeon should place a finger in the suprahepatic IVC to guide the next steps of the dissection (Figure 4.35).

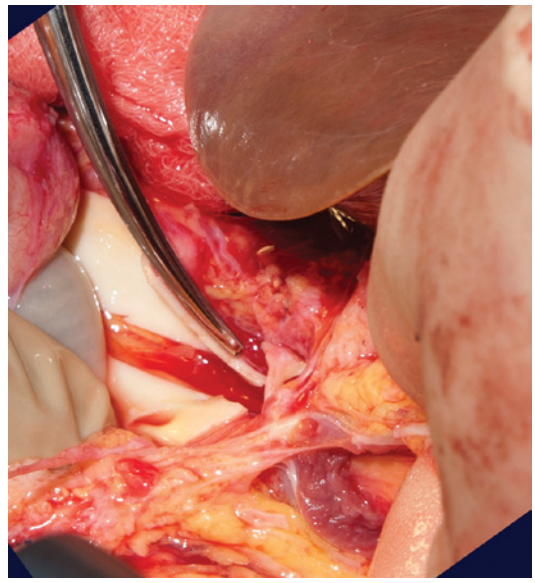


Figure 4.34 Cephalad dissection of the posterior aortic wall.

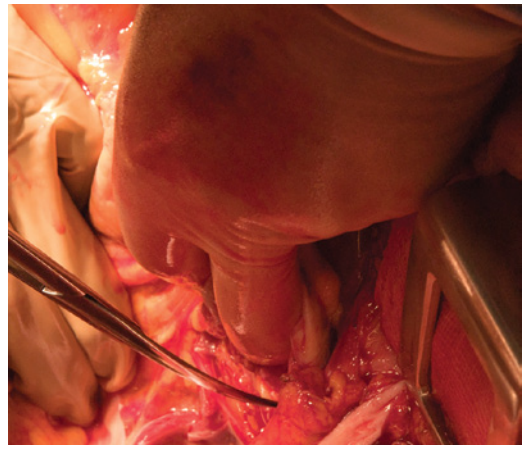


Figure 4.35 Division of the diaphragm behind the suprahepatic IVC.

The diaphragmatic dissection is carried towards the right, at the back of the IVC. The assistant retracts the liver to facilitate the division of the right diaphragm (Figure 4.36). Gentle traction is required at this stage to avoid capsular damage.

The right lobe is then separated from the right kidney (which is retracted downwards by the assistant), the optimal dissection plane being through the adrenal gland (Figure 4.37).

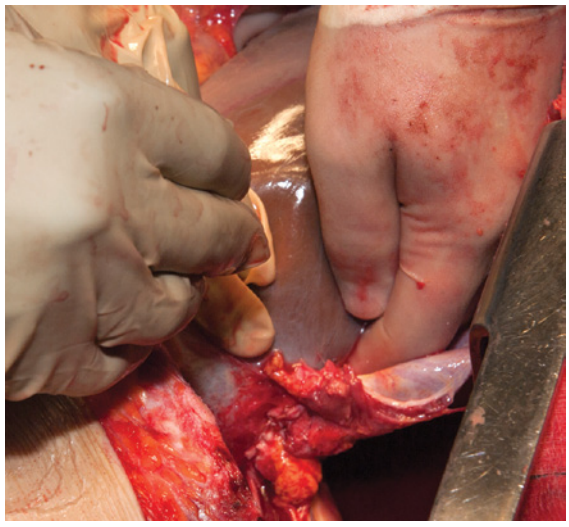


Figure 4.36 The assistant takes over the right lobe retraction to facilitate mobilization.

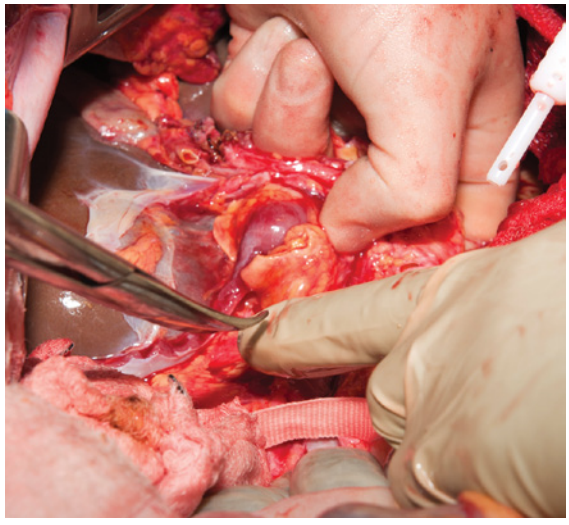


Figure 4.37 Right lobe dissection and division of right adrenal gland.

The liver–pancreas block is removed, dividing any remaining posterior attachments, and is placed in cold U.W. solution on the bench (Figure 4.38).

Separate liver and pancreas retrieval

The liver and the pancreas can also be removed separately. In this case, the first step of dissection is the *in situ* separation of the liver from the pancreas. The GDA and splenic arteries have been identified

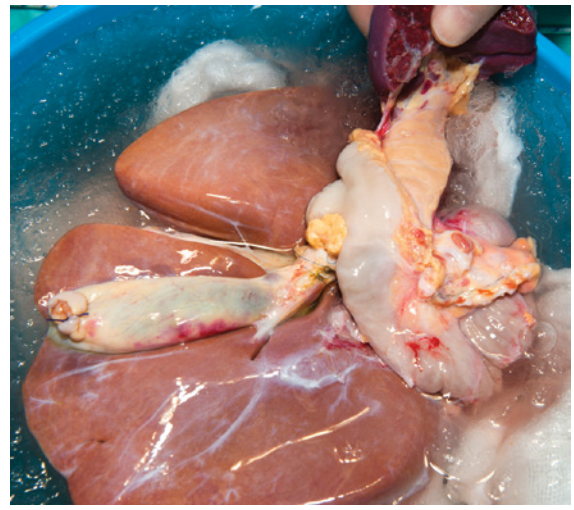


Figure 4.38 Liver–pancreas block on the bench.

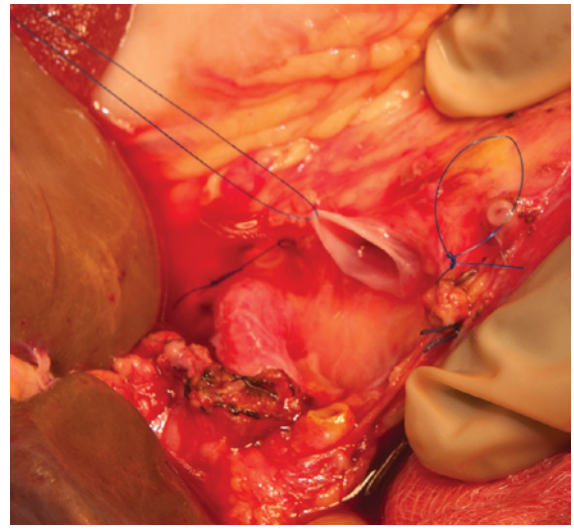


Figure 4.39 GDA and portal vein are divided and pancreatic ends are marked.

during the warm phase dissection. The assistant retracts the liver to expose the porta hepatis, and the GDA is divided, leaving a 5mm stump on the hepatic artery. The pancreatic side of the GDA is marked with a fine suture and left open. The portal vein is now exposed and is divided about 10 mm above the upper border of the pancreas, marking the pancreatic end of the vein (Figure 4.39). The tissue behind the portal vein is carefully dissected to exclude the presence of an ARHA.

The CHA is dissected towards the celiac axis and the splenic artery is divided, leaving a 5mm length with the hepatic artery, whilst the pancreatic end is marked for easier identification during bench surgery (Figure 4.40).

The left gastric artery is divided, or dissected from the lesser curvature of the stomach in the presence of an ALHA (Figure 4.41).

The dissection is then carried out vertically down towards the aorta, on the left side of the celiac axis. There is a large amount of lymphatic tissue, which must be divided to expose the celiac origin. An aortic patch is created, taking care to avoid the SMA, which sometimes arises quite close to the celiac axis origin.

In most cases, an ARHA arises from the SMA, close to its aortic origin, and can be identified in the warm phase, particularly if the SMA is dissected and placed on a sloop. In this case, the SMA should be divided above the ARHA origin towards the pancreas, allowing an aortic patch with the SMA and the celiac axis for the liver graft. A detailed algorithm for dealing with aberrant hepatic arteries is presented in Chapter 6 (Figure 6.16).

The diaphragm and the suprahepatic IVC are divided and the liver is mobilized as previously described. At this point, the infrahepatic IVC is divided. The liver is removed, having divided the posterior retroperitoneal attachments.

Place a finger in the suprahepatic IVC and lift the liver and its vascular structures with the left hand to facilitate retrohepatic dissection.

The pancreas is removed next following the steps described above. The gastric antrum, jejunum and small bowel mesentery are stapled. The aorta is divided above the renal arteries and the tail of the pancreas is mobilized medially. With a finger in the aorta and the tail rotated medially, the posterior wall of the aorta is dissected, dividing the remaining retroperitoneal attachments. The pancreas is then transferred to bench in cold U.W. solution.

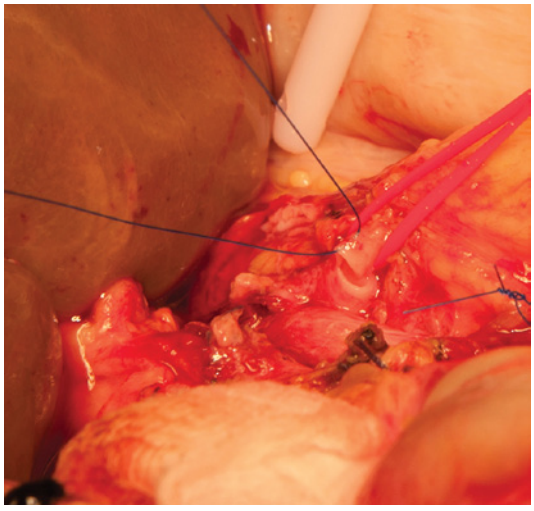


Figure 4.40 Splenic artery is divided and marked.

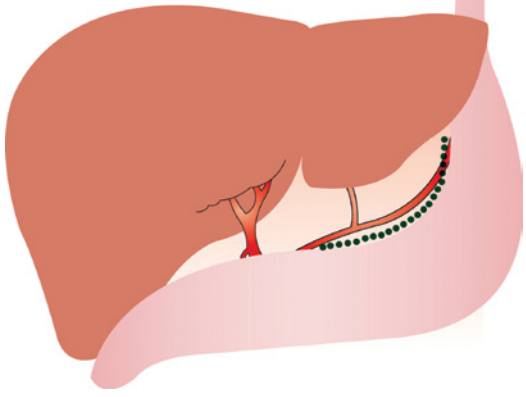


Figure 4.41 Line of dissection to preserve an ALHA.

Kidney removal

Kidneys can be removed separately or *en bloc*. Our practice is to remove the kidneys separately.

Having removed the liver–pancreas block, the aorta is divided above the distal tie and the posterior wall is incised between the lumbar arteries (Figure 4.42). Care must be taken during this step, to avoid damaging

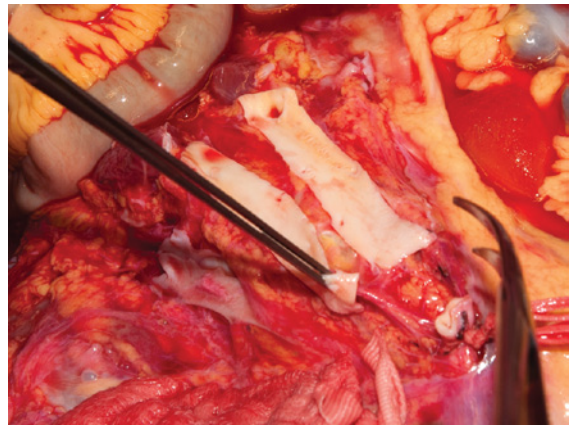


Figure 4.42 Posterior wall of the aorta is divided.

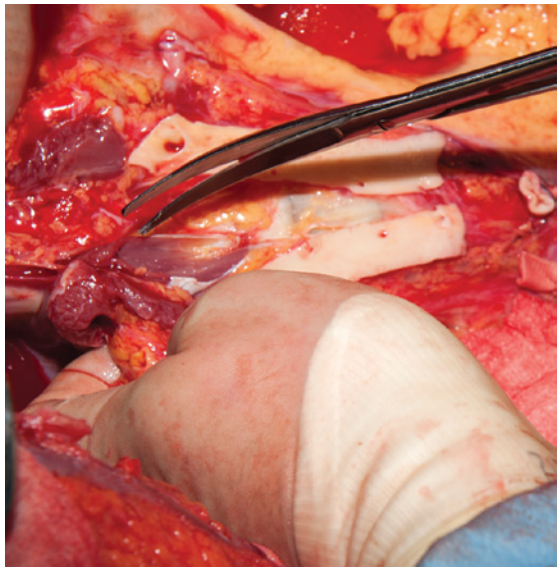


Figure 4.43 Vascular separation and dissection of the upper pole of the right kidney.

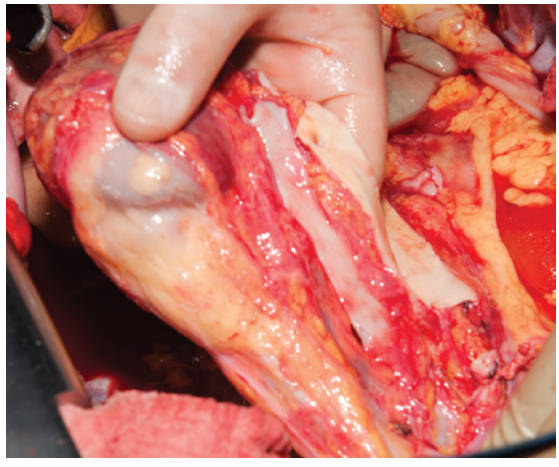


Figure 4.44 Right kidney dissected towards the pelvis.

a potential retro-aortic left renal vein. The vascular pedicles of the two kidneys are now completely separated (Figure 4.43).

The posterior aspect of the right kidney is mobilized medially and, taking care to avoid damaging the vascular patches, dissection is carried out on the paraspinal muscle, completely detaching the kidney and leaving only the ureter connected (Figure 4.44).

The ureter is dissected with enough periureteric tissue to preserve vascularity and it is divided as far down as possible (below the level of the pelvic brim)

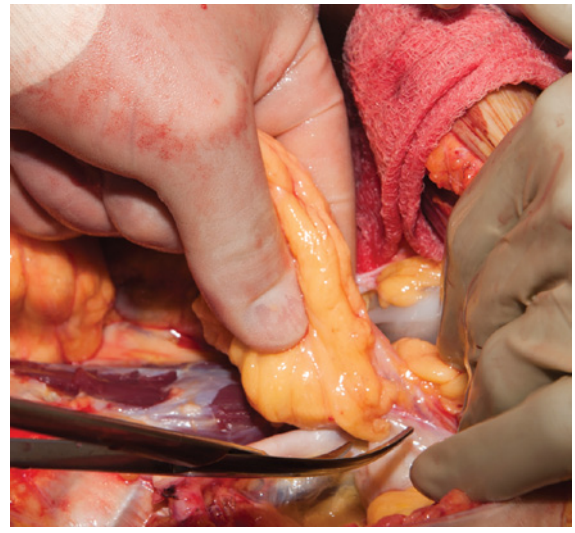


Figure 4.45 Division of the ureter.

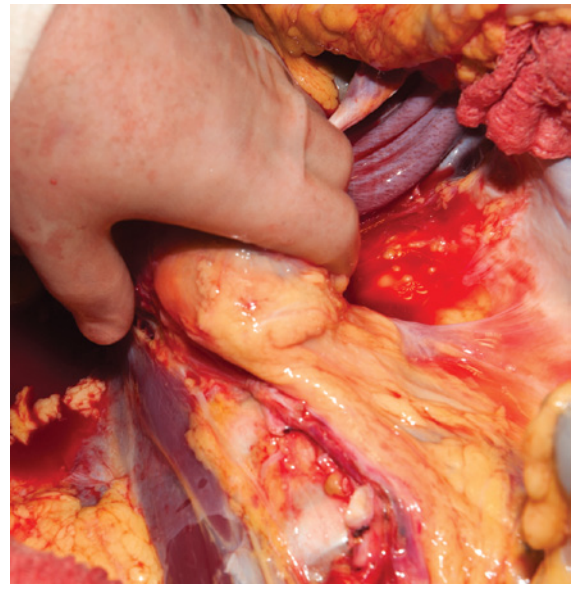


Figure 4.46 Mobilization of the posterior aspect of the left kidney and ureter.

(Figure 4.45). The left kidney is dissected in a similar manner (Figure 4.46).

Both kidneys are placed on the bench in two separate cold U.W. containing dishes. The side of the kidney (left or right) should be marked in some way to avoid a mix up prior to transfer to the transport boxes or perfusion machines.

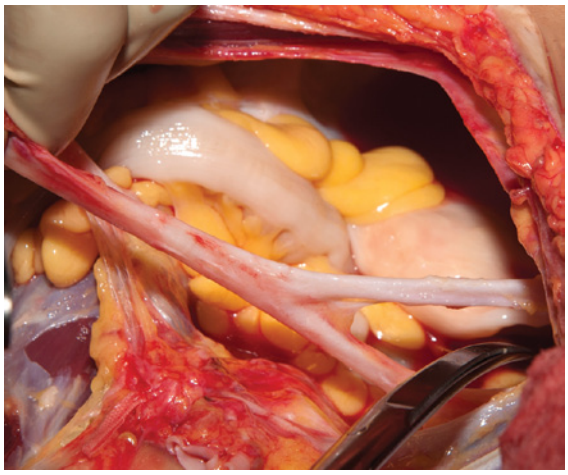


Figure 4.47 Dissection of right external and internal iliac arteries.

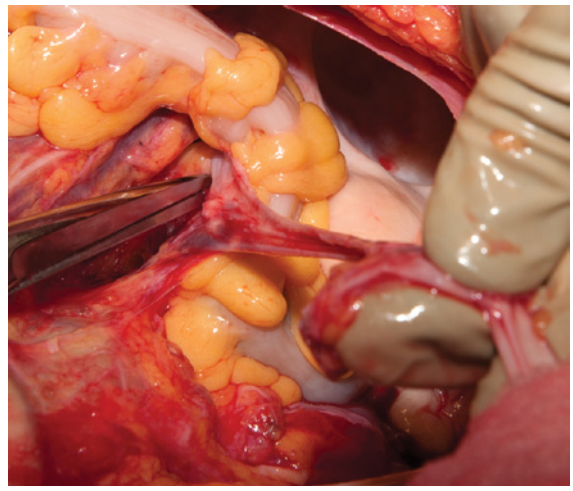


Figure 4.48 Dissection of left internal and external iliac veins.

Additional vessels and tissue

Additional vessels are required for pancreas and potentially for liver transplantation and therefore the iliac vessels are retrieved. The iliac arteries are dissected *en bloc*, including good lengths of both internal and external iliac arteries and taking care to avoid cuts or traction injuries during the process (Figure 4.47). Sometimes this part of the procedure is delegated to the junior surgeon, while the lead surgeon attends to the organs prior to packing. The junior surgeons must be instructed on the importance of careful vascular retrieval and meticulous technique.

The iliac veins are also dissected *en bloc* with similar attention to detail (Figure 4.48) and separated on the bench.

If the iliac vessels are not suitable, other vessels such as the carotid artery with its bifucation, SMA and the first mesenteric branches, or the innominate vessels should be retrieved.

Several lymph nodes should be dissected from the mesentery as they are required for tissue typing and must be shared between all retrieved organs together with samples of spleen (Figure 4.49).

Closure

When the procedure is completed, the operating field must be completely dried and the fluid aspirated. The wound is closed with a herringbone stitch achieving a good cosmetic result (Figure 4.50).

Perfusion fluids

The team must have large volumes of perfusion fluid and frozen saline to ensure optimal *in situ* cooling, bench perfusion and adequate packing of the retrieved organs. As an indication, 10 L of University of Wisconsin (UW) solution and 10 × 1 L bags of frozen saline are required for an abdominal multiorgan retrieval.

In situ perfusion

There are substantial practice variations with regards to the choice of perfusion fluid and the route of administration (portal and aortic vs. aortic only). Current evidence seems to suggest that for multiorgan retrievals, aortic only perfusion with UW solution is the best choice, providing a better outcome for the multivisceral and liver grafts [5,6]. Around 4 L of UW are used during a liver–pancreas–kidney retrieval. The initial 3 L are perfused under pressure, with the remaining litre perfused slowly, to preserve the cold intravascular environment during the cold dissection phase. However, these volumes (Table 4.1) must be regarded as indicative, and intraoperative evaluation of the venous effluent aspect will guide the actual usage.

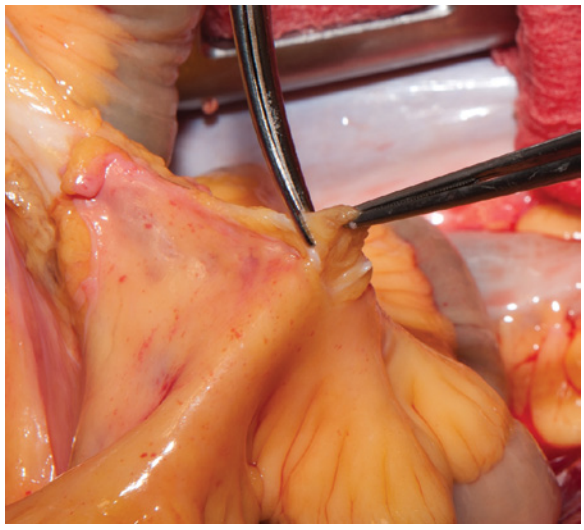


Figure 4.49 Lymph node dissection.

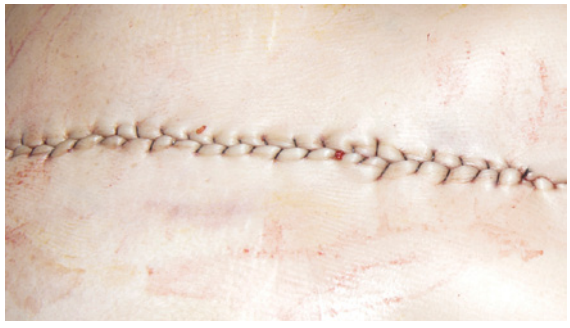


Figure 4.50 Abdominal wound closure.

Table 4.1 Indicative volumes for *in situ* perfusion (§ denotes unpressurized perfusion).

	Aortic	Portal
In situ	UW 3–4 L	(UW)§ (1–2 L)

It is universally agreed that aortic perfusion should be pressurized in order to achieve reasonable end-organ perfusion. Evidence suggests that pressurized perfusion is associated with less ischemic type biliary complications in the liver and fewer primary nonfunction events [10,11]. On the contrary, pressurized portal perfusion has a detrimental effect [12]

Table 4.2 Indicative volumes for bench perfusion (§ denotes pressurized perfusion).

	Liver				
	Aortic§	portal	Bile duct	Pancreas	Kidney
Volume perfusate	300 mL	1000 mL	200–300 mL	200–300 mL	200 mL

and therefore if portal perfusion is utilized, it should be under gravity. Low pressure perfusion (80–100 mg Hg) is favoured by some centres, although higher pressures (< 150 mm Hg) can be achieved with a pump pressure system.

Pressurised aortic perfusion (< 150 mmHg) provides a better outcome for the retrieved organs.

Bench perfusion

Once all organs are placed on the bench, additional perfusion must be undertaken (Table 4.2). This is particularly important for the liver, where portal perfusion takes place on the bench (rather than *in situ*). [Table 4.2]

Bile duct perfusion on the bench must ensure that the effluent is clear of bile.

The pancreas must be gently perfused (unpressurized) via the splenic artery and SMA to confirm the presence of cross-circulation and the patency of portal system and to ensure no damage has occurred when the small bowel mesentery has been stapled.

The kidneys are also flushed to confirm that the renal vein effluent is clear of any residual blood.

Bench surgery

The purpose of additional bench surgery is to separate the liver–pancreas block if the organs have been retrieved together, to check the quality of perfusion and to inspect the organs for damage and any other unsuspected lesions.

Separation of the liver–pancreas block

The liver–pancreas block is placed in cold UW solution in the anatomical position (Figure 4.51). The dissection is facilitated by the identification of GDA and splenic arteries in the warm phase.

The celiac axis is dissected from the aortic patch and the splenic (Figure 4.52) and the GDA (Figure 4.53) are identified in this order. Both arteries are divided and marked as described, preserving an adequate stump with the hepatic arterial tree.

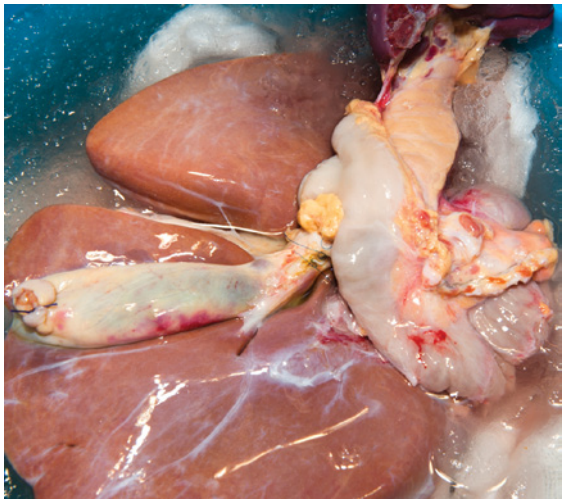


Figure 4.51 Liver–pancreas block in anatomical position on the bench.

The portal vein is then dissected and particular attention must be paid when exposing the right side of the vein, to ensure that no aberrant artery is present. The portal vein is then divided (Figure 4.54), sharing its length between the liver and the pancreas, and the remainder of the periportal tissues are divided to complete the separation.

Once separated, the liver and the pancreas are perfused individually as described. The organs are inspected and any damage must be adequately documented. If identified, any significant injuries that would require reconstruction must be communicated to the implanting team.

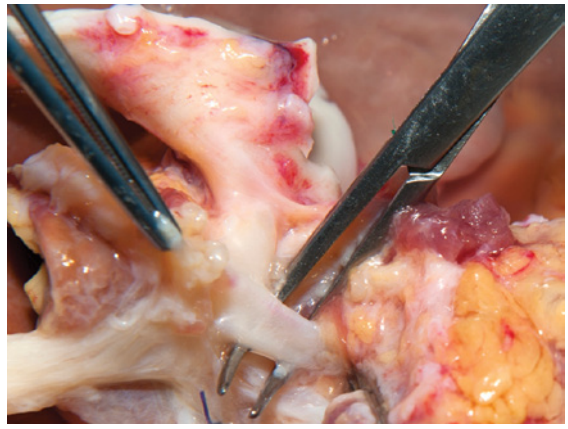


Figure 4.52 Identification of splenic artery.

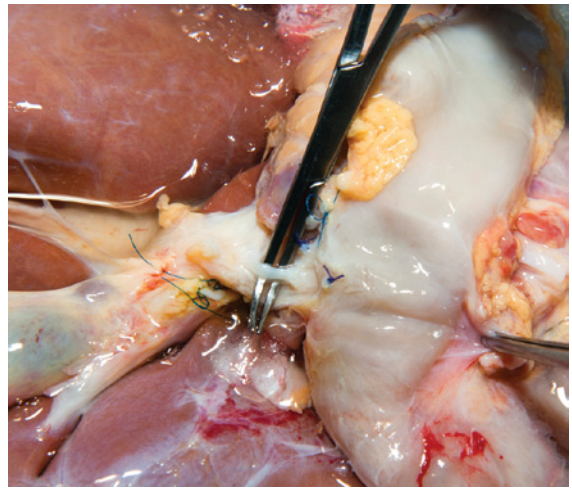


Figure 4.53 Identification of GDA.

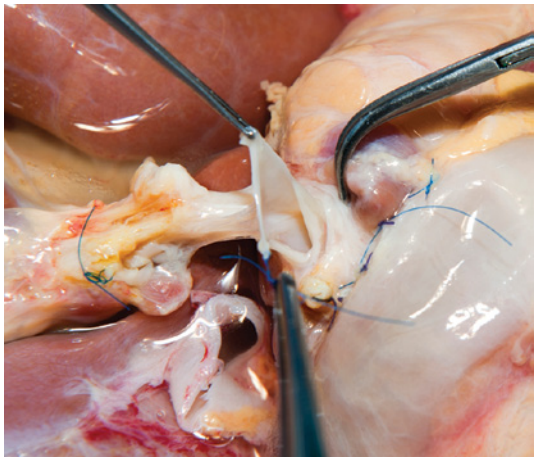


Figure 4.54 Portal vein is divided.

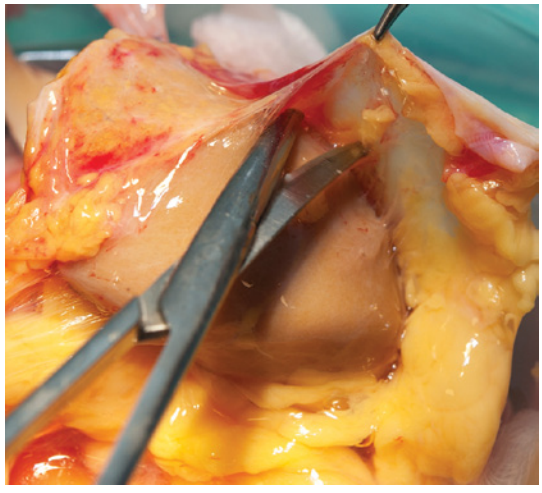


Figure 4.55 Exposure of the kidney on the bench.

Kidney bench surgery

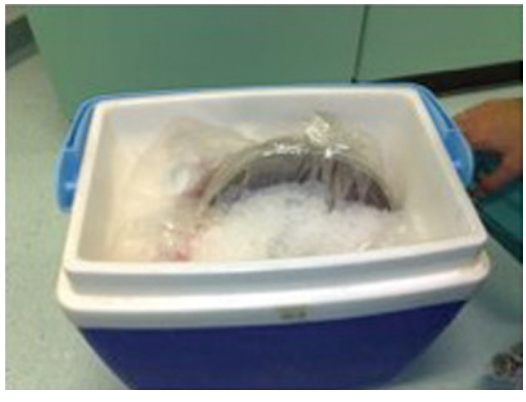
Each kidney is assessed and the perirenal fat should be partly incised to inspect the quality of perfusion throughout the kidney and to check for the presence of renal lesions (Figure 4.55). Excess perirenal fat should be removed as it creates an insulation layer that prevents adequate cooling of the kidney in the transport box and renders subsequent bench surgery at the recipient center more difficult. Preparation of kidney for implantation is not required at this stage.

Sometimes renal fat can be very adherent – in that case it should not be removed, as in the pressure of the retrieval, theatre damage may be caused. However, a message should be passed to the recipient team warning them of the problem.

Packing of organs

Liver

The liver is placed in an appropriately sized sterile bag (e.g. 3 M Steri-drape isolation bag 50 × 50 cm) and submerged in UW. The bag is vacuumed, ligated and placed in a suitable bowl. The bowl is then placed in two additional vacuumed bags surrounded by slush ice prior to being placed in the transport box. The transport box must be large enough to accommodate the bowl in a horizontal position and completely submerged in ice.



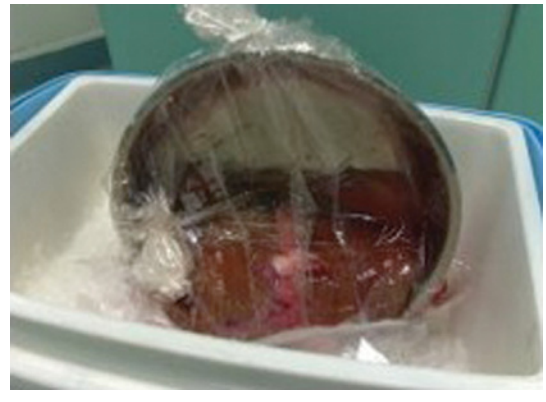


Figure 4.56 Inappropriate packing of the liver.

Pancreas

The pancreas is placed in a sterile bag (e.g. Aldon intestinal bags 33×25 cm) and submerged in UW. The air is evacuated by squeezing the bag or using a sucker and the bag is ligated. A second bag is used, placing some slush ice to provide a constant cold surrounding to the first bag. The pancreas is then placed in a transport box surrounded by ice.

Kidneys

Each kidney is packed individually, in a similar manner to the pancreas.

Additional samples

The iliac vessels are separated, and a pair of artery and vein is packed in containers with UW and sent with the liver and the pancreas respectively.

Saline filled pots with six to seven lymph nodes and 1–2 cm^2 spleen sample as well as blood samples accompany each organ in the transport boxes.

Paperwork and documentation

The lead surgeon has the responsibility to ensure that the operation record and all the relevant documentation that accompanies the organs are completed accurately. Some of the tasks may be delegated, but proper sign off remains the duty of the lead surgeon.

The following is an indicative list of the paperwork required, although requirements may vary:

- **Organ specific form** required by the procurement organization, detailing retrieval times and place, organs removed, individual organ appearance and injuries, quality of perfusion, etc. A copy of this form will accompany each organ to the destination center.
- **Retrieval team information form**, which is required for audit purposes.
- **Operation note**, which must be written by the lead surgeon in the donor's case notes. This should document type of incision, findings at laparotomy, organs removed, additional vessels and tissue recovered, and details of closure.

Summary box

- Ensure appropriate level of training for the retrieval team to enable a successful multiorgan retrieval.
- Safe travel arrangements must be in place.
- All paperwork and patient data must be carefully reviewed prior to starting the procedure.
- Establish adequate communication and relationship with local hospital team and cardiothoracic team.
- Carry out a full laparotomy prior to any dissection.
- Ensure early aortic control to enable rapid aortic cannulation if required.
- Single aortic perfusion is the standard for multiorgan DBD retrieval.
- Use aortic perfusion under pressure < 150 mmHg.
- Ensure adequate intravascular and *in situ* cooling of all abdominal organs.
- Cold phase dissection is better, but balance the amount of warm/cold dissection according to individual level of experience.
- Liver and pancreas are best removed *en bloc*.
- Do not compromise the retrieval of individual organs because of complex arterial anatomy.
- Ensure further bench perfusion of all retrieved organs.
- Pack all organs adequately including the mandatory additional tissue and blood samples.
- Inform the implanting surgeons of any unusual anatomy and/or organ damage.
- Ensure proper documentation of the retrieval operation in the case notes.
- Completion of the relevant paperwork is the responsibility of the lead surgeon.

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5 Kidney Retrieval and Bench Surgery

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General principles and logistics

Nowadays it is rare that the surgeon starts out with the intention of retrieving only kidneys from a deceased donor. This may come about because of donor or family consent/authorization, or it may rarely be the case that donor contraindications are such that only the kidneys can be retrieved. In these circumstances, the general principles and logistics of organ donation are much the same as described in Chapter 1 and Chapter 4. In this chapter special considerations regarding the kidneys will be set out. Many of these pertain to multiorgan retrieval as well as kidney-only donation.

Access

The old surgical advice that 'good access is vital' can be applied with extra emphasis to organ retrieval. In most types of surgery, slight damage to the organ being removed is not a major problem. In organ donation and transplantation such damage may cause the organ to be untransplantable (in about 1% of cases) [1] with significant implications for the donor family and the intended recipient. In kidney only donation, it is feasible to perform the operation through a full-length abdominal midline incision. However, this relies upon there being a good level of assistance and good retraction systems available. If there are extra difficulties, then the surgeon should be aware of the potential to improve access either by extending the incision into the chest or by using a transverse extension (Figure 5.1). This can be particularly valuable in patients where obesity or previous surgery are a problem.

Anatomical variations

Surgeons removing kidneys for transplantation should be aware of the common anatomical variations. Most important are the arterial variations (Figure 5.2) with the possibility that a lower pole vessel could be coming off the aorta much lower down than the main renal artery. It is probably best that the surgeon operates **expecting** anatomical abnormalities, so that a diagnosis of normal anatomy is a diagnosis of exclusion. This ensures that the surgeon is on guard for dealing with any problems.

Common anatomical variations which should be 'expected' are:

- **Absent kidney or kidney in an unusual position, e.g. pelvic kidney**. Such a finding should give heightened expectation of other anatomical abnormality.
- **Multiple veins** (Figure 5.3). This is not such a difficult problem as multiple arteries, but should still be dealt with properly (see section **Vein**).
- **Multiple arteries** – around 20% of the population have two arteries or more to one kidney [2]. The aim should be to remove all the arteries intact with a cuff of aortic tissue and preferably all arteries on the same aortic patch.
- **Bifid urinary system/double ureter** – it is amazing how frequently the gonadal vein can look like a double ureter, but the retrieval surgeon should always be aware of the possibility of this true abnormality. Both ureters should be removed with a good length with sufficient accompanying tissue to preserve blood supply.

Awareness of common injuries

Common injuries for the kidney at retrieval are listed below. An awareness of the types of injuries that

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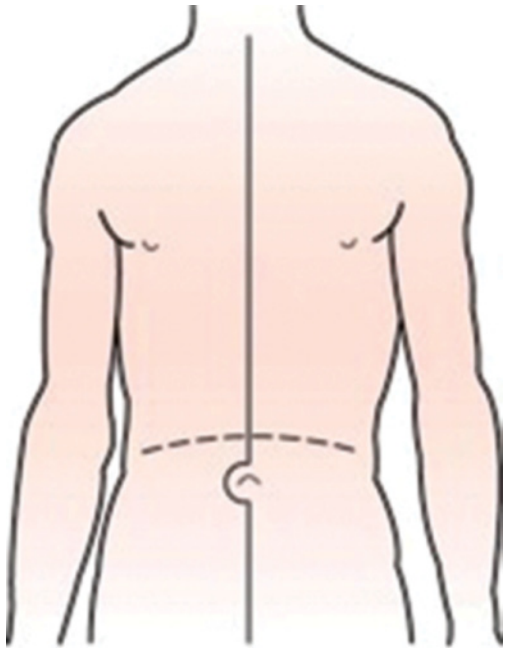

Figure 5.1 Access options for kidney retrieval.

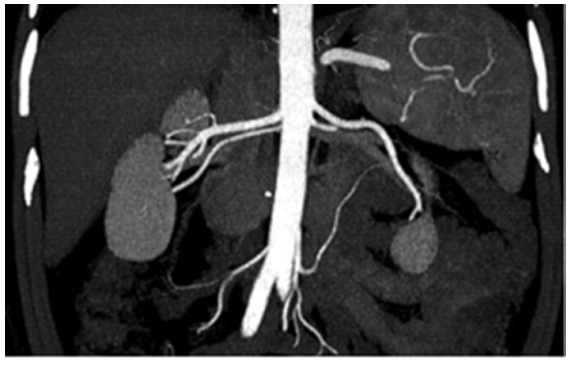

Figure 5.2 CT appearance of multiple bilateral renal arteries.

occur and at what point they happen during the operation will help the surgeon avoid perpetrating such injuries. That said, every experienced transplant surgeon has caused damage at some time during a retrieval. Detection of the degree of damage and good communication with the recipient surgeon are vital to overcome any difficulty and make sure that the recipient does not suffer in any way [3].

Atheroma

Organ donation figures over recent years have demonstrated significant increase in donor age in many

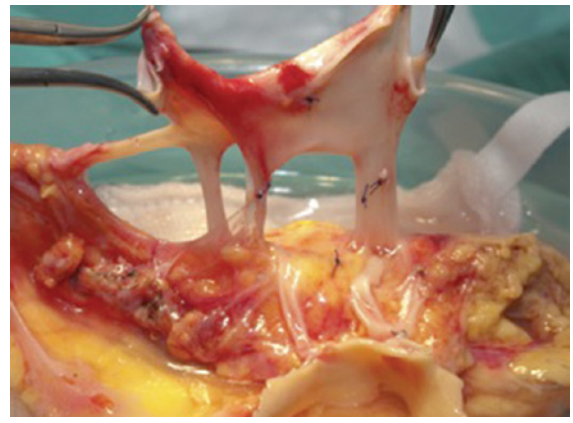

Figure 5.3 Multiple renal veins in a retrieved kidney.

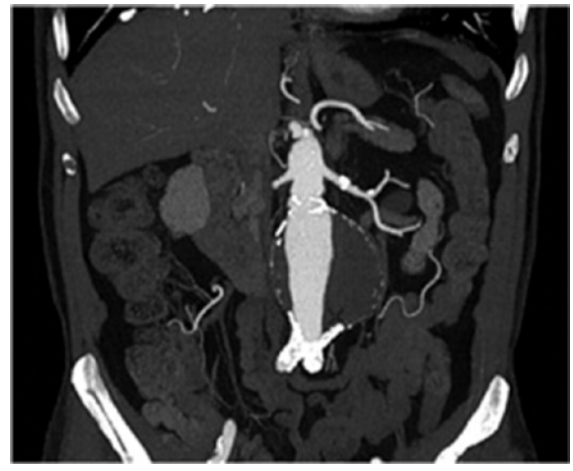

Figure 5.4 Abdominal aortic aneurysm appearance on CT scanning.

countries. This results in the retrieval surgeon having to operate on patients with a greater degree of atheroma, which can be a problem for the following reasons:

- **Aneurysm of the aorta**. Prior to death the presence of an aortic aneurysm may be undiagnosed and only found during the initial laparotomy at retrieval (Figure 5.4).

The retrieval surgeon must be very careful indeed during placement of the aortic perfusion cannula. This should be done away from the site of aneurysm and with all due care to make sure that the cannula is placed within the true lumen of the main vessel, either aorta or iliac system. Perfusion at pressure through aneurysmal tissue can cause disruption of the material

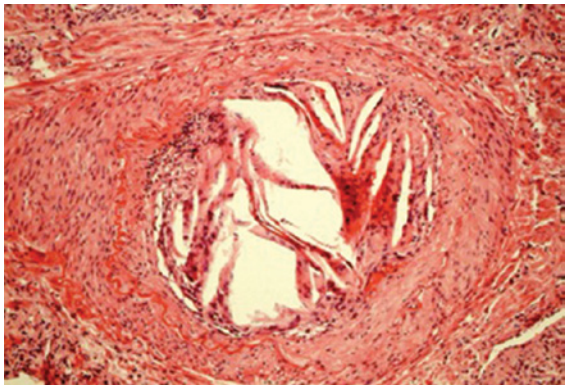

Figure 5.5 Cholesterol emboli in the renal artery from a donor with an abdominal aortic aneurysm. (Image courtesy of Professor Chris Watson, Cambridge)

within the aneurysm sac and lead to cholesterol embolization (Figure 5.5), which may affect future function within the intended recipient.

Antegrade cannulation of the descending aorta is a useful technique in the presence of an infrarenal aortic aneurysm.

• **Difficult placement of the aortic cannula**. It is quite frequent, nowadays, to find that the aorta is atheromatous and quite hard. This can make the placement of the aortic catheter difficult – tying this in place and making the whole system watertight poses a challenge when the aorta is calcified. Careful choice of the placement site of the catheter is vital and good briefing of the assistant prior to making the incision in the aorta is very important to correctly place the catheter and ensure good perfusion.

The surgeon must discuss with the assistant the details of their roles during aortic cannulation to ensure correct and secure placement of the cannula.

• **Renal ostial stenosis**. With increasing atheroma in the older donor cohort it is quite common to find an ostial stenosis of the renal artery. In itself this is not a problem, but if there is some bench perfusion performed at the end of the retrieval operation it is vital to ensure that any person carrying this out (either the retrieval surgeon or someone delegated to do so) is very careful indeed in cannulating the renal artery to avoid intimal damage. It is also important that the presence of an ostial stenosis is highlighted to the recipient surgeon, allowing that individual to make the choice whether to remove the aortic patch (this would be our preference) or not.

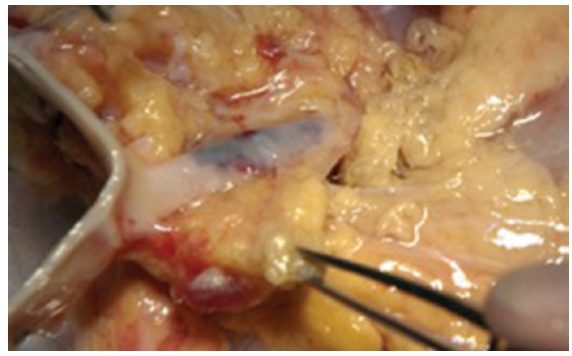

Figure 5.6 Renal artery intimal dissection.

In the presence of aortic atheroma and ostial stenosis, ensure gentle cannulation of the renal artery on the bench to avoid intimal damage.

Avulsion

The retrieval operation is a complex and stressful procedure since it is often carried out away from the base hospital in the small hours of the morning. The temptation to carry out the operation quickly can mean that the surgeon pulls inadvertently on organs or vessels and this problem can be transmitted to an eager assistant as well. An intimal tear because of avulsion injury is very difficult for the recipient surgeon to diagnose and can be catastrophic. Likewise in patients in whom there is greater atheroma the vessels are more fragile and intimal flaps or adventitial tears can easily occur (Figure 5.6). Once again awareness of this possibility encourages more gentle handling of the organs and their vessels.

Procedure

Although some surgeons prefer to remove the kidneys and the attached aorta and vena cava plus ureters '*en bloc*' it is our practice to dissect the renal arteries and veins at the great vessels and then remove each kidney separately. This procedure will be described.

Following completion of perfusion, and with the continued avoidance of any rewarming of the kidneys, it is important to ensure that the aorta and the inferior

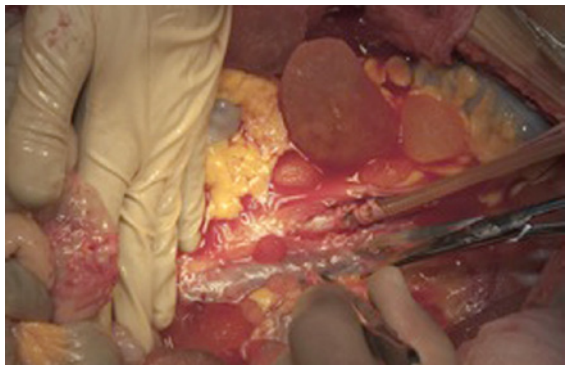

Figure 5.7 Exposure of the IVC and aorta.

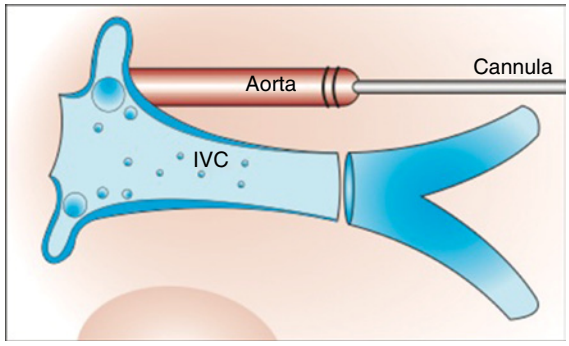

Figure 5.8 The IVC is opened in the midline.

vena cava (IVC) are exposed to the levels of the left renal vein (Figure 5.7).

The IVC is incised in the midline anteriorly (Figure 5.8).

This allows inspection of the inside of the IVC so that any orifice which 'has the potential for' being a renal vein can be identified. It is then very unlikely that a renal vein will be removed from an IVC patch. The IVC patch for the right kidney can now be dissected away, with great care being taken as the posterior wall of the IVC is excised to avoid any damage to the renal artery which is lying just behind this structure.

This is the most likely time that a right renal artery will be accidentally removed from the patch of aorta.

The renal vein is then reflected towards the right kidney a centimeter or so, so that it can be removed from the area of concentration for this particular part of the operation. The patch of IVC and any orifices for the left renal vein are now dealt with in a similar fashion, reflecting them over towards the left kidney.

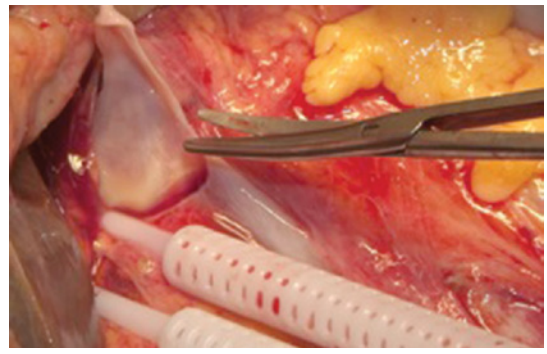

Figure 5.9 Division of the left renal vein flush with the IVC.

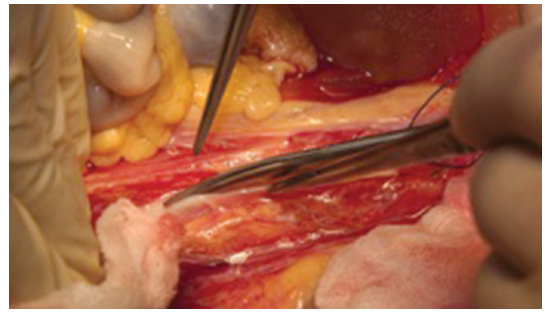

Figure 5.10 Midline anterior incision of the aorta.

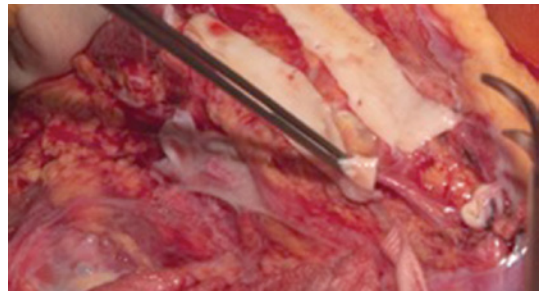

Figure 5.11 Complete separation of the right and left side of the aorta.

Some surgeons prefer to remove the IVC with the right renal vein to give the implanting surgeons the option of renal vein extension in difficult recipients. In this case, the left renal vein is divided flush with the IVC (Figure 5.9).

The aorta and the renal arteries should now be partly visible. A similar maneuver is carried out on the aorta. A midline incision is made anteriorly and inspection of the interior surface of the aorta allows any orifices associated with renal vessels to be fully identified (Figures 5.10 and 5.11).

An aortic patch, including all such orifices that 'have the potential for being' renal arteries, is then fashioned.

It is our practice to then remove the right kidney from above downwards. The area of incision into the fat surrounding the kidney which has been made to allow the kidneys to be cooled properly (see Chapter 4) is developed further and the kidney plus a significant amount of surrounding fat and tissue is removed completely. In the upper part of the excision this often entails going through the adrenal gland (Figure 5.12).

The kidney is fully mobilized with great care allowing for the previously selected and identified vessels to be included in the excision (Figure 5.13).

Working down the body, the only structure that should be now attached is the ureter and this, plus all of the surrounding tissues of the ureter, are removed down to a level of transection just below the pelvic brim. This procedure is then repeated on the left side (Figures 5.14, 5.15, 5.16) with the only difference being that the gonadal vein is normally attached to the renal vein on this side rather than to the IVC.

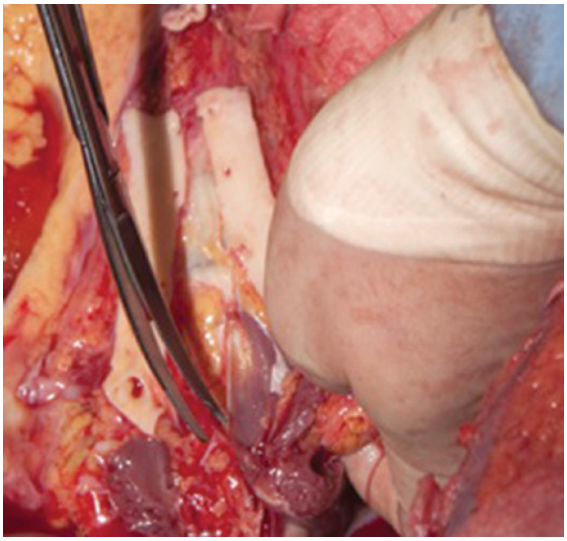

Figure 5.12 Dissection of the upper pole of the right kidney.

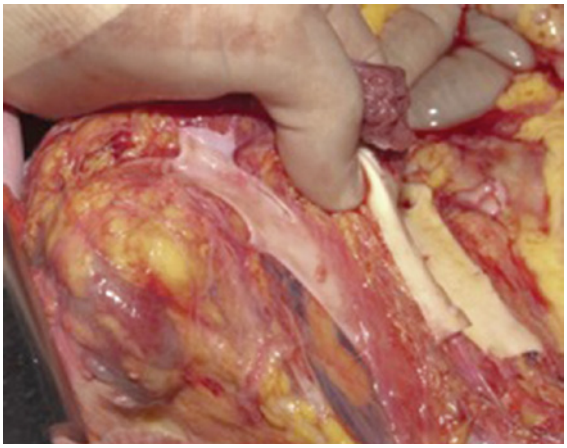

Figure 5.13 Dissection of the right kidney.

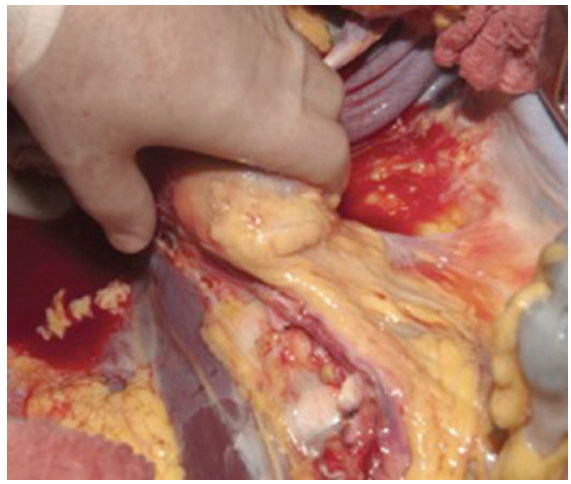

Figure 5.14 Mobilization of the posterior aspect of the left kidney.

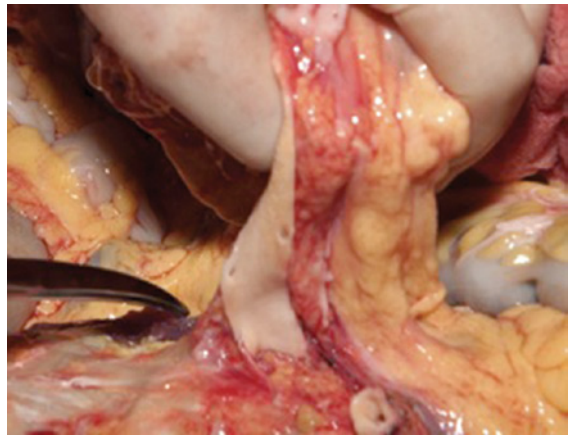

Figure 5.15 Mobilization of the medial aspect of the left kidney.

Immediately on removal the kidney is placed into slush ice for bench inspection check and careful preservation (Figure 5.17).

As has been stressed elsewhere, following removal of tissue for histocompatibility testing purposes, the abdomen should be closed carefully with a reasonable cosmetic and watertight incision acknowledging that the family may wish to view the body of their loved one some time after the retrieval procedure is finished.

Immediate bench check

As soon as all organs have been removed and are safely placed in slushed ice and preservation solution, each kidney should be examined. Once again the anatomy of the kidney should be checked (Figure 5.18).

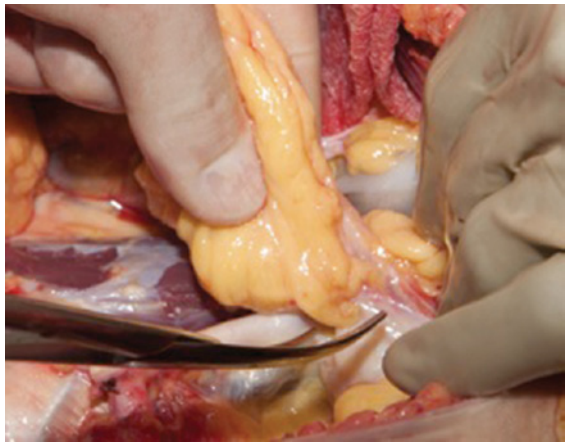

Figure 5.16 The ureter is divided at the pelvic brim.

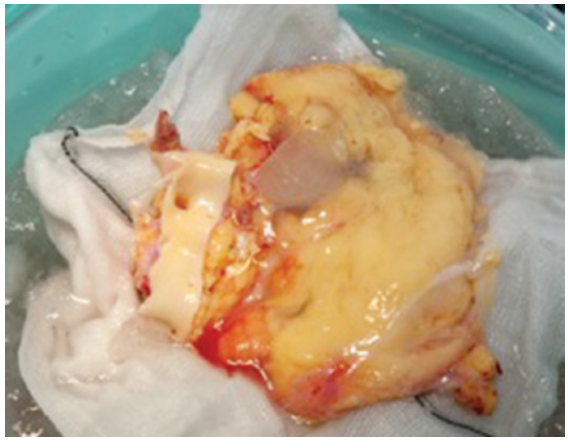

Figure 5.17 The kidney is placed in slushed ice.

There should not be excessive dissection into the renal hilum. This is a job for a recipient surgeon, carried out in a quieter theater setting with proper instrumentation and lights. Such a situation does not usually exist in the donor theater.

However, the retrieval surgeon should remove enough fat from the kidney to check how well the kidney has perfused (Figure 5.19).

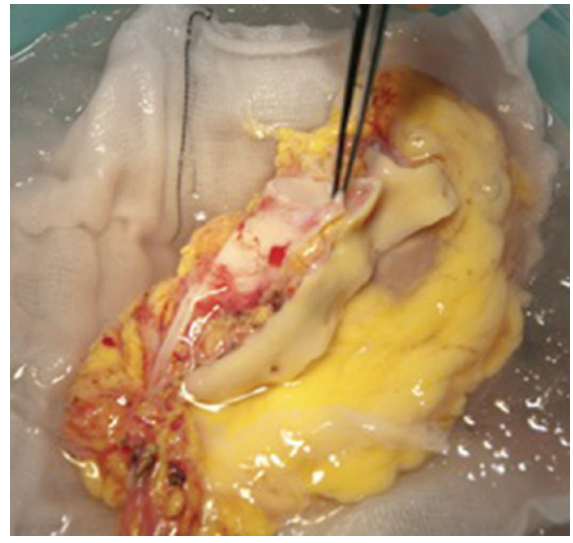

Figure 5.18 Inspection of the kidney on the bench.

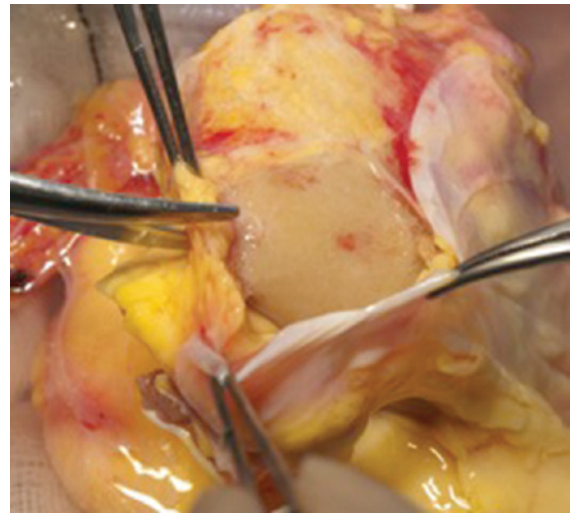

Figure 5.19 Perirenal fat is partially removed to check the quality of kidney perfusion.

Any problems should be communicated to the recipient surgeon. In addition, the kidney should be checked for any obvious major abnormality. Large cysts or any other problems should be documented and, obviously, any unusual lesion which may represent a benign or malignant tumour should be examined in detail. Any uncertainty as to the diagnosis should be followed by biopsy and expert pathological opinion.

It is good practice at this stage to carefully cannulate one or more renal arteries using a cannula which is smooth and unlikely to damage the renal arterial intima. Approximately 100 mL of fluid should be infused and the effluent from the renal vein should be checked to ensure that it is clear. The kidney can then be preserved either in cold storage or by machine perfusion.

Special considerations with kidney retrieval

Removal of peri-renal fat

It is noted above that some of the fat should be removed from around the kidney. Particularly in middle-aged or older men who are smokers the fat can be peculiarly adherent to the renal capsule. If the overzealous retrieval surgeon tried to remove too much fat in a hurry, the common result is to find that the plane of dissection has been taken into the subcapsular plane, which, in itself, is likely to produce more bleeding at the time of recipient perfusion and risks further damage to the parenchyma.

In these circumstances it is suggested that a number of small areas of fat are removed from three zones of the kidney to check perfusion but that proper removal of the fat is left to the recipient surgeon. Communication regarding this issue should be carried out with the recipient surgeon.

Rewarming

Even in specialist text on the subject of renal retrieval, some forget to mention the damage that occurs by rewarming. During multiorgan retrieval when there are difficulties removing the other organs (cardiothoracic or hepatic) or if there is some other distraction in the donor theater, it is very easy to forget that the kidneys will tend to rewarm unless this issue is addressed. The retrieval surgeon should continually 'fuss' about making sure that there is plenty of cold fluid and slushed ice around the kidneys whilst they remain in the body. If the anatomy at the time of removal of the kidneys is difficult the surgeon should not speed up but rather slow down to make sure that no damage occurs and, at the same time, ensure that the kidneys are repacked with ice and cold fluid. Rewarming is an unseen form of accidental damage but it is probably more pernicious than direct damage to a vessel.

The donor surgeon should ensure that the kidneys are surrounded by cold solution and ice throughout the retrieval, until removal, to avoid rewarming.

Most common forms of damage following kidney retrieval

Polar artery cut/patch removed from artery of an aortic patch

This may either be recognized by the retrieval surgeon or go unrecognized and only be picked up on the bench by the recipient surgeon. By following the procedure outlined above it is more likely that the former should happen than the latter.

Upper polar vessel

On occasions an upper polar vessel supplies a very small amount of parenchymal tissue and it is possible to sacrifice such a vessel without long-term damage to kidney function. However, this is a decision for the recipient surgeon, and if identified by the retrieval surgeon the aim should be to preserve as much length as possible on the upper polar artery.

Lower polar vessel

Given that the lower polar vessel usually supplies a small artery (often situated around two-thirds of its length to the kidney) to the ureter, this lower pole vessel should be preserved in all circumstances. The ideal situation is that both arteries remain on a single aortic patch.

If any polar artery has been separated inadvertently, the retrieval surgeon should not attempt rejoining of the patch but rather identify the damage and communicate this to the recipient surgeon.

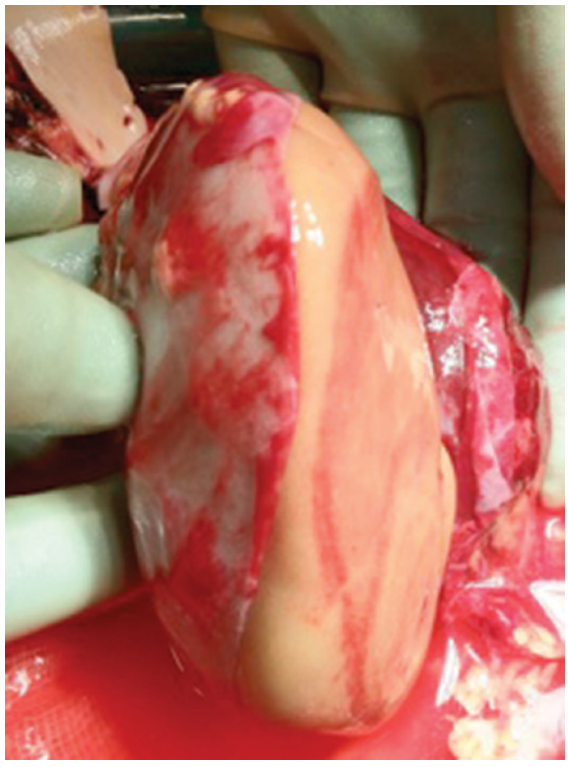

Figure 5.20 Complete capsular detachment from the kidney ('degloving').

Capsular damage

Most commonly capsular damage is simply a small tear to the capsule where the retrieval surgeon has got into the wrong plane of dissection around the kidney. Because there are small vessels which run between the capsule and the renal parenchyma, the danger is that a severe capsular tear (Figure 5.20) will produce a significant amount of bleeding (which manifests as a substantial ooze from the parenchymal tissue at the time of reperfusion).

Avoidance of capsular damage is relatively easy if the retrieval surgeon stays in the correct plane inside Gerota's fascia, avoids heavy handling of the kidney and is aware of the variant of adherent fat to the capsule as described above.

Rewarming of kidney

See notes in the section **Special considerations with kidney retrieval**.

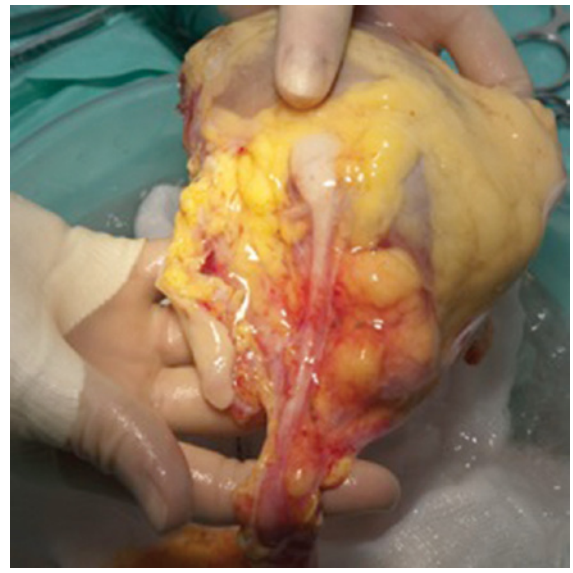

Figure 5.21 The ureter with a good amount of tissue surrounding it.

Ureter cut short or 'skinned'

As described, the ureter should be transected at a level just below the pelvic brim. This would normally give plenty of ureter for reanastomosis.

At the early part of the retrieval when the colon is being reflected (on either the right or the left side) it is possible to get into the wrong plane and cut the ureter at this point. In fact the planes of dissection here are fairly straightforward and there should really be no difficulty except in cases where previous surgery has occurred and adhesions blur tissue planes.

In order to preserve the blood supply to the ureter, it is important to take a good amount of tissue around this structure.

Those who are inexperienced can end up dissecting only the ureter itself and not including small vessels which run alongside. This should be avoided. In thin patients or children there may not appear to be very much tissue around the ureter itself. In these circumstances the small vessels mentioned lie very close to the ureter and in fact the ureter is not 'skinned'. However, this normal variant should not be an excuse in the vast majority of cases where a sizeable amount of tissue must accompany the ureter right to the level of transection (Figure 5.21).

Bench surgery for the kidney

A video for the kidney bench surgery procedure can be found on the companion website: www.wiley.com/go/oniscu/abdominal

Around the same time as the recipient leaves the ward for the operating theater, bench dissection of the kidney should commence. This gives an adequate time for this important procedure. Good preparation will ensure an adequate length of vessels with good hemostasis at the time of clamp release. Bad preparation can result in a difficult anastomosis and release of clamps may induce significant blood loss.

The kidney should be kept cold throughout the bench preparation [4]. Initially the kidney should be placed in the anatomical position with the side of the kidney (left or right) being labelled properly. Stay sutures (or if there is large excess of major vessels available, fine clips) are applied first to the IVC causing a gentle stretch on the renal vein. This can be then dissected free of extra tissue and any tributaries coming from extraneous areas (adrenal, gonadal veins, etc.) can be ligated and divided (Figures 5.22–5.24).

The overzealous bench surgeon usually ends up taking the dissection too far into the hilum of the kidney. This is not necessary.

There needs to be a balance between good mobility of the vein, allowing a relatively easy anastomosis, and getting too close into the hilum of the kidney and thus risking damage to vascular structures at this level, which is much more difficult to repair.

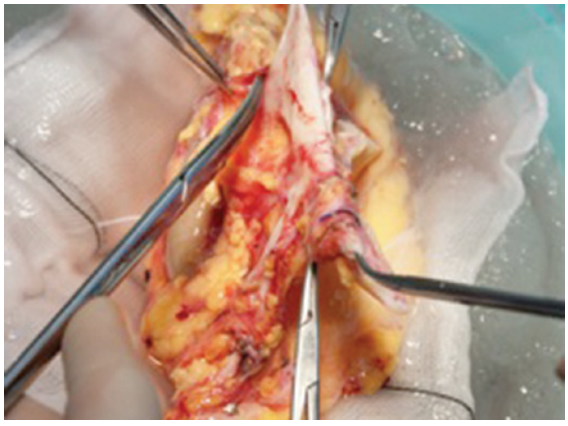

Figure 5.22 Dissection of the renal veins.

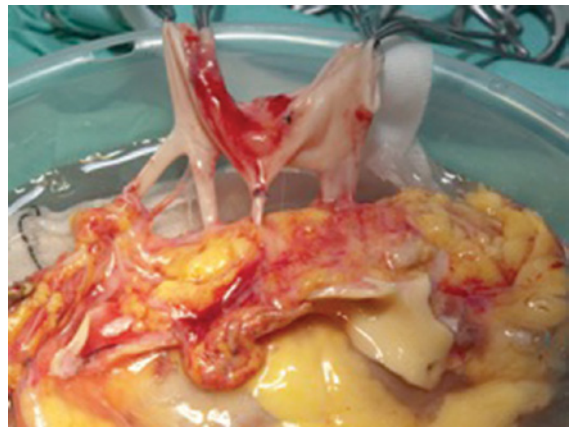

Figure 5.23 Multiple renal veins.

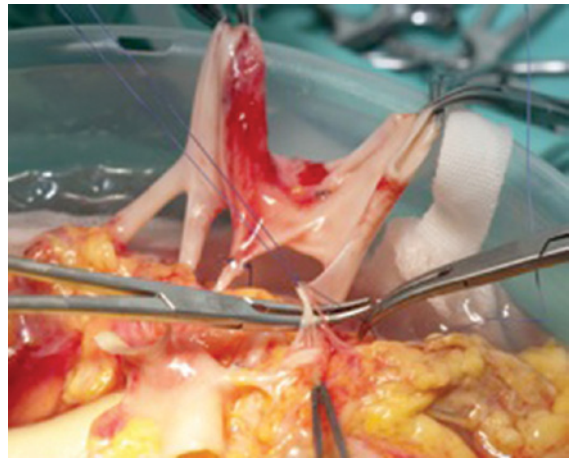

Figure 5.24 Ligation of small venous tributaries.

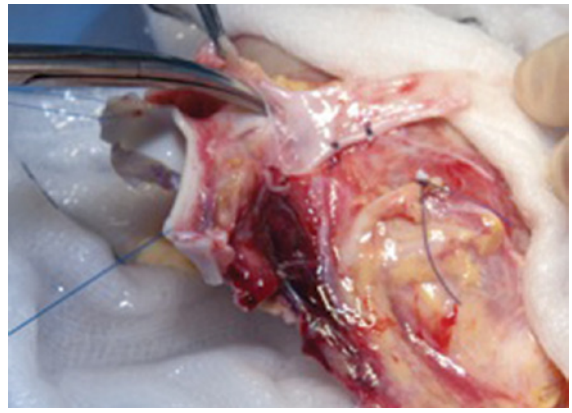

Figure 5.25 Dissection of the renal artery.

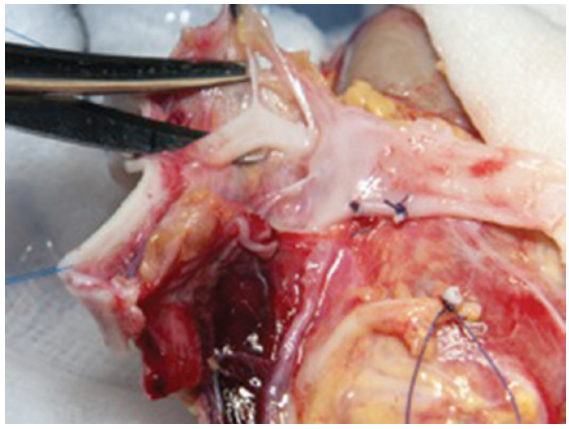

Figure 5.26 Adrenal vessels can be ligated.

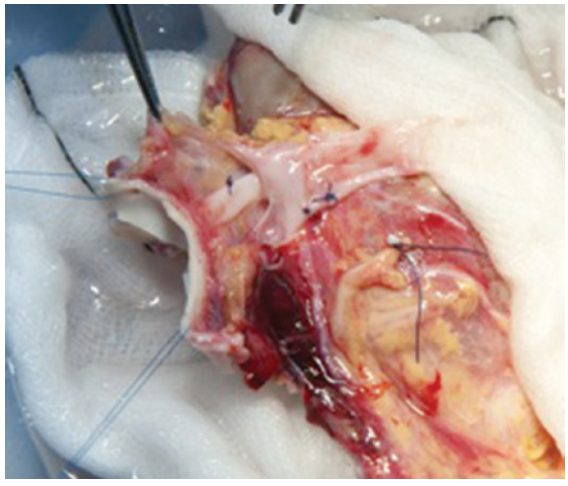

Figure 5.27 Adequate dissection of the renal artery.

The renal vein is now folded over the kidney and the artery dissected out from any adherent fat (Figure 5.25).

Any branches from the artery should be followed very carefully and only tied off if it is proven beyond doubt that they do not pass to the renal parenchyma. In truth there are very few branches of the renal artery that are not directed towards the kidney itself. The adrenal vessels are an obvious exception (Figure 5.26).

Again the artery should not be followed too deeply into the renal hilum (Figure 5.27).

Once all of these vital elements of the kidney have been identified and dissected out, the fat that has been

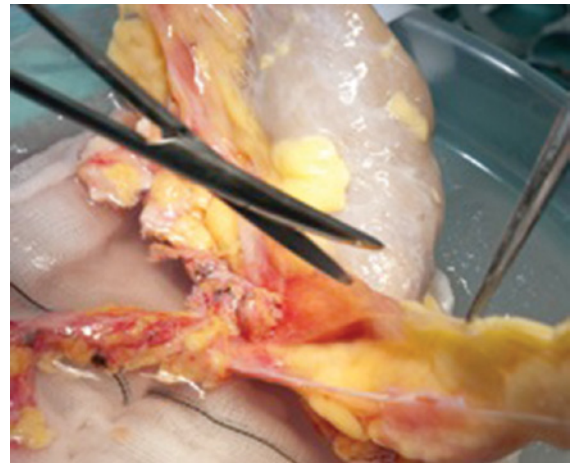

Figure 5.28 Removal of perirenal fat.

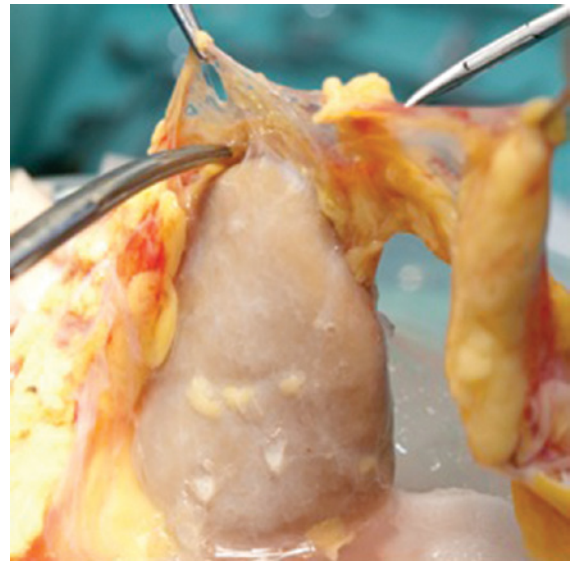

Figure 5.29 Removal of the adrenal gland and upper pole perinephric fat.

left around the kidney at the time of retrieval can be removed (Figure 5.28).

The adrenal gland has often been taken together with the kidney at the time of organ procurement – this should be removed with the perinephric fat and any vasculature not already dealt with should be ligated and divided (Figure 5.29).

It is rare to need to do anything further on the bench with the ureter. This should be checked to make sure that the ureter is intact with good vascular supply

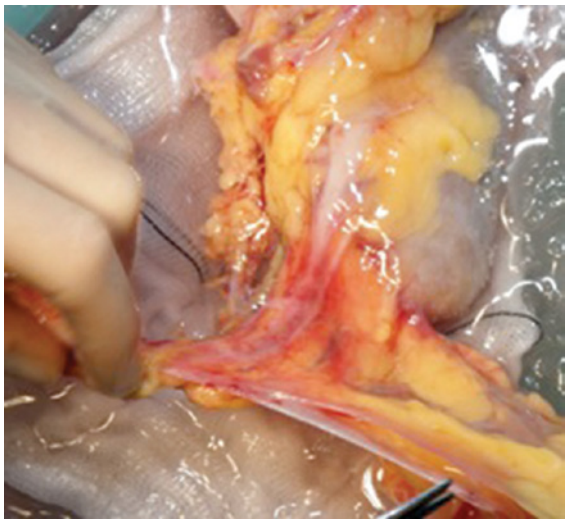

Figure 5.30 The ureter is checked and periureteric tissue preserved.

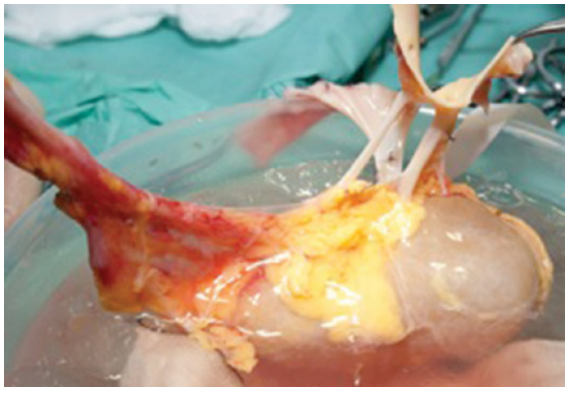

Figure 5.31 Final inspection of the kidney.

from the tissue included in the excision. A check should always be made to ensure that there is no double ureter (Figures 5.30 and 5. 31).

Dealing with common bench surgery problems

Capsule

As described in the section **Most common forms of damage following kidney retrieval**, there may be some damage to the capsule of the kidney. On most occasions this is simply an incision into the capsule which has partly been removed from the parenchyma underneath. If the area of parenchyma denuded is small, then simply some attention to the hemostasis of this area either with diathermy, tissue glue or some other hemostat and then careful resuturing of the capsule is likely to be very successful.

If the damage is over a greater area (on one occasion we have had the experience of total 'degloving' of the kidney from its capsule) we would advocate not replacing the capsule over the kidney until the time of reperfusion. At this stage it is then possible to do some direct diathermy to the most severe areas of bleeding (if available, the use of argon beam diathermy is advantageous) and other measures including direct pressure with or without hemostatic material. At the conclusion of these hemostatic maneuvers, the capsule can then be sutured back over the parenchyma if required.

Vein

Short vein

Rarely the retrieving surgeon may have inadvertently divided the vein quite close to the renal hilum. If the removed portion of the renal vein and IVC are still available the surgeon can make a choice as to whether to repair the cut/complete excision of the vein or to attempt reimplantation with no venous graft. With the advent of live donor nephrectomy by laparoscopic method and the resulting relatively short length of renal vein at times, recipient surgeons have become more adept at dealing with a short renal vein. Grafts may be considered, if available. An alteration of technique in the recipient might also be contemplated with maximization of the external iliac vein by division of the internal iliac vein which allows the external iliac vein to become more superficial with appropriate maneuvering. Early identification of a short renal vein and contemplation of these options (and recruitment of experienced advice and support) is helpful in managing the problem.

Multiple veins

In general terms, multiple renal veins may be dealt with by using the largest vein and ligating smaller veins (Figure 5.32).

There appears to be no untoward effect on the kidney function because of internal collaterals at parenchymal level. However, it is not uncommon to find two renal

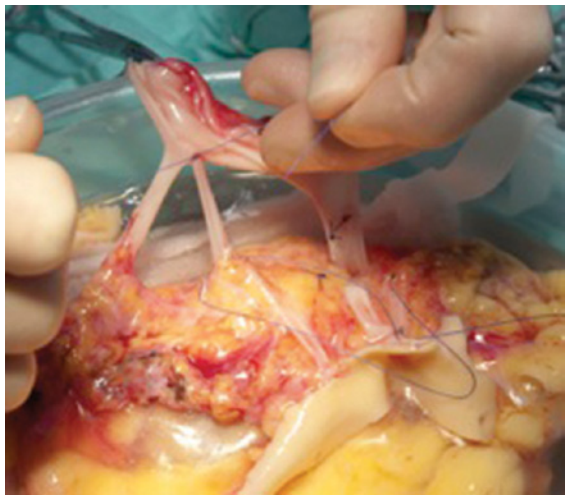

Figure 5.32 Smaller renal veins can be ligated.

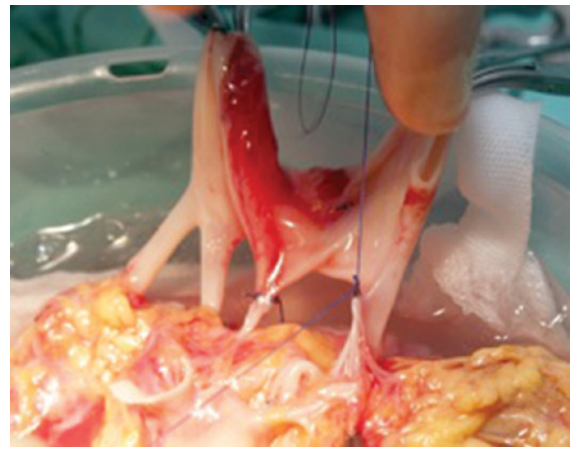

Figure 5.33 Ligation of multiple small veins.

veins of roughly the same size. If these are received on a single IVC patch the surgeon has two options: either anastomosis of the whole patch to the recipient vein or shortening of the patch and preserving only one vein, if the whole length is considered too long for that particular recipient.

In general terms it is not advisable to perform multiple venous anastomoses as access to the extreme ends of these anastomoses can be difficult causing either obstruction or bleeding at the time of clamp release.

Very rarely a network of veins is found running over the renal hilum and rejoining to form multiple veins which then eventually empty into the IVC. This network of veins can be dealt with by tying off the small tributaries which result from the network (Figure 5.33) and then treating the resultant one or two larger veins in the manner described above.

Artery

Upper polar

In general it is best to preserve all arterial supply to the kidney. In a small percentage of cases the upper polar vessel is so small that the parenchyma that it supplies is a similar size. Sacrifice of this vessel is possible without damage to the outcome and indeed attempting to revascularize this tiny vessel may prejudice good blood supply to the main artery for no huge benefit. This is a judgment call for the recipient surgeon based on the size of the upper polar vessel (and its comparative size with the 'main' renal artery). If it is decided that the upper polar vessel should be reconstructed then similar techniques to those described for the lower polar vessels should be used.

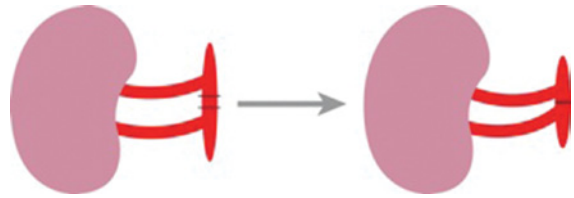

Figure 5.34 Shortening of the arterial patch.

Double artery with an accessory lower pole vessel

This can be dealt with as follows:

- **If both vessels are on a single patch** then can be used in its entirety.
- **If the patch is particularly long** or if the recipient has relatively small vessels (a slim woman or a child) one may not wish to use a whole long patch and this can be shortened, as illustrated in Figure 5.34. When anastomosing a patch which has been shortened, particular attention should be paid to needle placement around the area of the suture line in the patch.
- **If the accessory vessel has been removed from the patch** it may be preferable to anastomose the accessory vessel end to side to the main renal

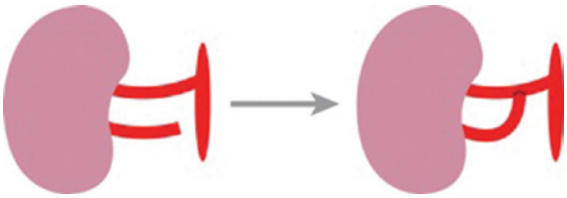

Figure 5.35 Reconstruction of polar artery.

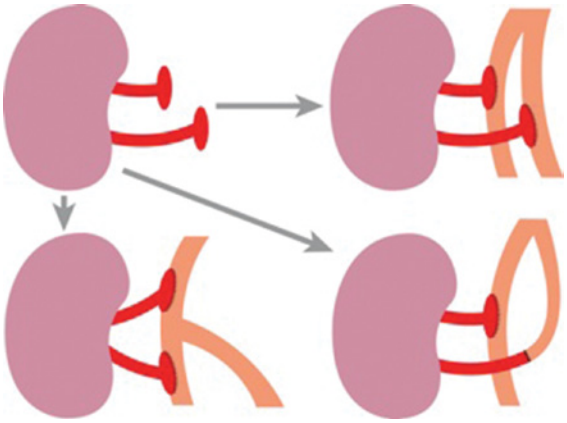

Figure 5.36 Implantation options for two separate arteries.

artery (Figure 5.35). The difficulty of this anastomosis is often underestimated. Sometimes it is applied too much at right angles to the main renal artery, with the resulting flow not optimal and the smaller vessel suffers. Consideration should be given to performing this anastomosis, if chosen, over a soft 'stent' such as a very fine umbilical catheter. As in all the maneuvers described in this section, optical magnification is recommended for the recipient surgeon. Finally, the surgeon should have in mind the position of the kidney and how the new arrangement of vessels will lie when the kidney is placed in the recipient.

- **Use of two recipient vessels**. Various possibilities are available (Figure 5.36).

  i. Use of the external iliac artery and the internal iliac artery – this would be recommended in situations where there are two renal arteries, both much the same size. This solution has the disadvantage of the need for two separate anastomoses (compared with a single patch) but the position of the kidney is often very satisfactory in this option.

  ii. Common iliac artery and external iliac artery – this is similar to option (i).

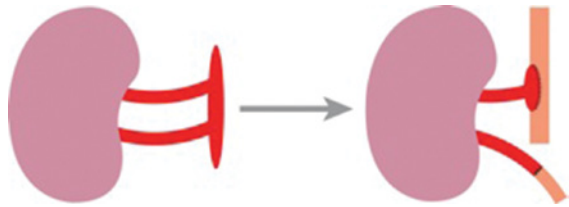

Figure 5.37 Reconstruction option using inferior epigastric artery.

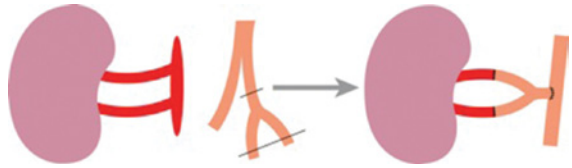

Figure 5.38 Reconstruction option using recipient internal iliac artery.

  iii. External iliac artery/internal iliac artery plus inferior epigastric artery – during bench surgery it may be possible to predict that the recipient inferior epigastric artery might be suitable for use if an accessory lower pole vessel is detected (Figure 5.37). The chosen recipient for this option probably requires to be a younger patient with relatively little chance of severe atheroma since the inferior epigastric vessel tends to be affected early in this disease process. Even if the inferior epigastric vessel is satisfactory, it can often undergo spasm and the precise positioning of the vessel is also critical. We have seen this technique used very successfully on a number of occasions, but there is little doubt that this procedure comes under the category of 'easier to draw than to do'!

  iv. Excision of the recipient bifurcation of the internal iliac artery and bench reconstruction (Figure 5.38). The main trunk of the internal iliac artery and the two primary divisions of this artery are dissected out in the recipient and excised. The resultant arterial graft is then reversed and the primary divisions are anastomosed to the two renal arteries from the donor. This produces a single trunk, which can be anastomosed to the artery of choice in a recipient.

More than two arteries

In the situation of more than two renal arteries, a combination of the techniques described above can be employed.

Ureter

A short ureter

It is rare for a deceased donor kidney but the retrieval surgeon may have transected the ureter short. The important point for bench surgery is to identify this problem early. This then allows careful placement of the kidney in the recipient, making the distance as short as possible between the transplant kidney and the bladder. Alternatively, if the ureter is cut extremely short, alternatives such as anastomosis with the recipient ureter may need to be contemplated. In that case it is ideal, if possible, to have consent from the patient for this procedure preoperatively and the effect on the native kidney on that side predicted and managed. In addition, a longer ureteric stent would be required.

'Skinning' of the ureter

Essentially this should be treated as if this were a short ureter. The positioning of the kidney should be as close to the bladder as possible with the possibility of keeping the ureter as short as feasible with a no tension anastomosis to the bladder. If necessary the bladder can be dissected free from surrounding structures slightly so it can be mobilized towards the transplant kidney.

Double ureter

The recipient surgeon has two choices. Either each ureter can be anastomosed separately with an anastomosis that is exactly the same as if there had been a single ureter. Different points on the bladder are chosen for each anastomosis. Or the ureters can be anastomosed together after spatulation and anastomosed to a single cystotomy. In either case it is recommended that two ureteric stents are employed. It is our preference to use the former technique rather than the latter.

Pre-implantation biopsy

This is practiced routinely by many units and is used for later comparison with postimplantation biopsies for 'marginal kidneys' in most transplant units. The inexperienced surgeon who performs a kidney transplant biopsy on the bench can make two reasonably common errors. The first is to direct the biopsy relatively deep into the kidney because the biopsy needle is introduced partly across the cortex and the 'core' is then taken as medulla only. This has risks and is a much less useful biopsy for pathological judgment since the cortex is the area of interest for the specialist pathologist.

The risk that this entails is that a deep biopsy may damage some larger vessels with the second complication of bleeding or the less common complication of arterio-urinary tract fistula. The ideal biopsy should be either a core biopsy taken tangentially towards one end of the kidney or a wedge biopsy using a sharp blade, which can be sutured.

Donation after cardiac death and kidney retrieval

Retrieval of kidneys after cardiac death should follow the same principles outlined throughout this chapter. As detailed in other chapters, the team should be prepared and ready prior to the patient coming into theater.

Quick (but not hasty) access to the abdominal cavity with establishment of the aortic perfusion as rapidly as possible is the most important step [5]. The placement of the cannula should be checked to ensure it is well below the presumed level of the renal arteries.

There is high risk of ureteric injuries when exposing the aortic bifurcation.

In addition, aortic perfusion without allowing the effluent out of the venous system is very deleterious and the kidney is not exempt from this. In the context of DCD retrieval, one must also underline the worry about rewarming of the kidneys [6]. Once adequate aortic perfusion and venous drainage are established, the abdominal cavity should be cooled with ice and the kidneys removed as quickly as possible, following the technique outlined above. Some surgeons prefer to remove the kidneys *en bloc* to minimize the risk of rewarming due to prolonged dissection time in removing kidneys individually.

Once the kidneys have been placed on ice on the bench, examination of the parenchyma to check perfusion is a very important step, as it allows a preliminary assessment of the kidneys and in particular if they are transplantable. Additional bench perfusion at this stage improves the overall quality of the perfusion, prior to cold or machine perfusion storage.

Summary box

- The retrieving surgeon should be familiar with the common anatomical variations.
- Awareness of common injuries and at what point they happen helps avoiding perpetrating these injuries.
- Gentle handling of the kidneys avoids traction/avulsion injuries.
- Incision of the middle of the IVC and aorta allows identifications of all arterial and venous renal ostia.
- An aortic patch including all potential renal arteries should be fashioned.
- The ureter should be dissected with sufficient periureteric tissue.
- Inspect the quality of the kidney perfusion on the bench and remove excessive fat, prior to storing the kidney.
- Do not attempt vascular reconstruction at the donor hospital.
- Report all injuries to the implanting team.
- Overzealous bench dissection into the hilum of the kidney is unnecessary.
- Multiple renal veins may be dealt with by using the largest vein and ligating smaller veins
- The surgeon must be familiar with the various techniques for arterial reconstruction in case of multiple renal arteries.
- The choice of arterial reconstruction depends on donor as well as recipient factors.
- The ideal bench biopsy is a wedge biopsy.
- DCD kidneys are increasingly more common.
- A slick surgical technique with rapid aortic perfusion and quick kidney extraction are important in the DCD retrieval.

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6 Liver Retrieval and Bench Surgery

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Liver retrieval

Donor information

Prior to starting the retrieval procedure, the donor surgeon is responsible for checking all the relevant donor information. This should include:

- Donor identity
- Brainstem death tests
- Consent for donation
- Blood group
- Donor data form including the liver function tests, the amount of inotropic support, virology results and the circumstances of death.

If the donor requires significant amounts of inotropic support, the retrieval surgeon must be prepared to proceed with a crash retrieval, in case of sudden hemodynamic instability, to ensure that organs are adequately perfused.

Liver assessment

Following the initial steps described in Chapter 4, inspection and assessment of the liver are essential to ensure that the organ can be utilized. At the end of the assessment, the retrieval surgeon should be able to answer the following questions:

- Is the liver usable?
- How marginal is the graft?
- Is the liver suitable for the chosen recipient?

These are essential information for the team that has provisionally accepted the graft, and therefore close communication with the implanting team is important, particularly if the graft is marginal. The evaluation of the liver includes:

- an assessment of the aspect of the liver and in particular the sharpness of the edges
- an estimation of the consistency (i.e. whether the liver is soft or hard and indurated)
- a description of the colour (indicating the degree of steatosis)
- an estimation of the size.

Aspect of the edges

A normal-looking liver has sharp edges (Figure 6.1).

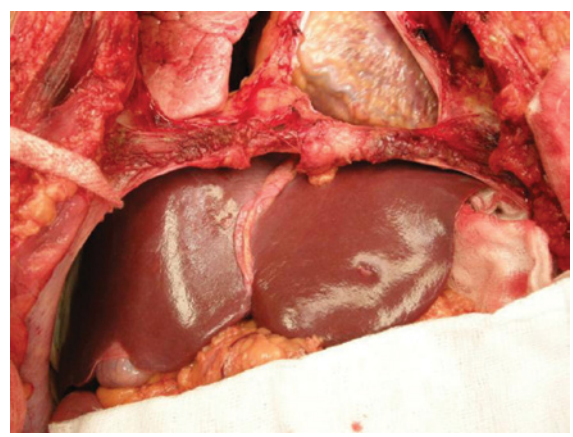


Figure 6.1 Normal-looking liver.

Abdominal Organ Retrieval and Transplantation Bench Surgery, First Edition. Edited by Gabriel C. Oniscu, John L. Forsythe and John Fung.

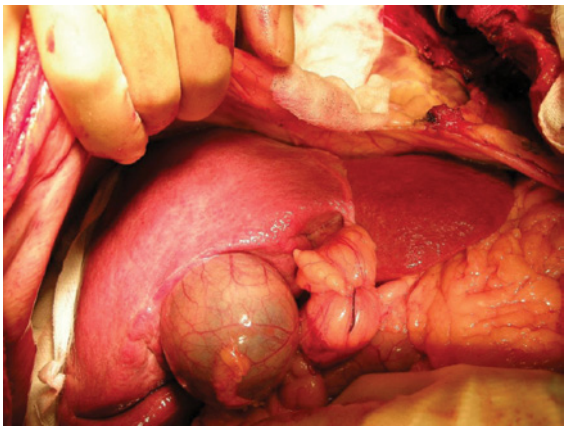


Figure 6.2 Moderately steatotic liver.

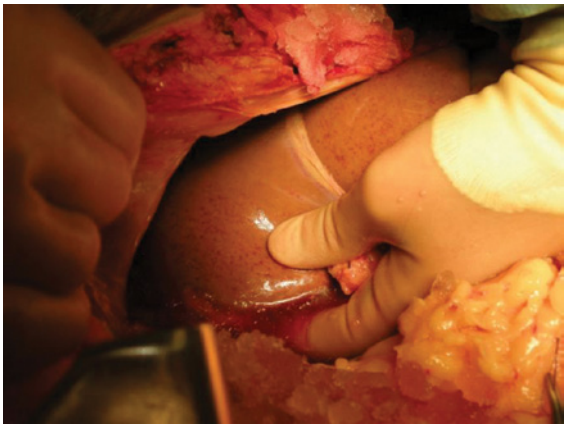


Figure 6.3 Severely steatotic liver.

However, it is increasingly more common that steatotic grafts are retrieved. These grafts will have blunted edges (Figure 6.2), progressing to round edges both in the right and left lobe in severely steatotic livers (Figure 6.3).

Colour

A healthy looking liver has a brown colour, whilst with increasing steatosis the colour shifts towards pale yellow in the severely steatotic graft.

The actual degree of steatosis is quantified by a liver biopsy, but this is rarely available during the retrieval process. Most commonly, if there are concerns about the quality of the liver, a biopsy should be carried out during the bench surgery procedure at the recipient center. The degree of steatosis (microvesicular or macrovesicular) is classified into three groups:

- < 30% (mild)
- 40–60% (moderate)
- > 60% (severe).

More than 60% macrovesicular steatosis is associated with a high risk of graft failure [1,2,3].

Consistency

The liver is soft and has a slightly spongy consistency. A marginal liver graft that has suffered as a consequence of brainstem death and perhaps increased inotropic support has a hard and indurated consistency.

The consistency of the graft corroborated with its colour and overall aspect allows the retrieving surgeon to classify the graft into normal-looking mildly steatotic, moderately steatotic and severely steatotic. This classification, although subjective, will help the implanting team to decide if the graft is suitable for the chosen recipient.

A donor risk index (DRI) based on type of graft, length of cold ischemic time, cause of death, donor race and height and type of donor has been devised. An increased DRI correlates with a poorer outcome following transplantation [4].

A summary of the assessment (Figure 6.4) allows a final correlation between the risks associated with the quality of the graft and the recipient risks.

Technical aspects of liver retrieval

The organ retrieval procedure is described in detail in Chapter 4. This section will focus on the liver-specific steps of the process. Following the assessment, the round ligament and the falciform ligament are divided. The chest is opened and, during this step, the anterior surface of the liver is protected with a muslin pack to avoid iatrogenic injuries. The adhesions to the liver, in particular to the right lobe, must be divided at this stage to avoid damage during mobilization of the liver during the cold phase.

The left triangular ligament is divided to allow exposure of the hepatogastric ligament and the

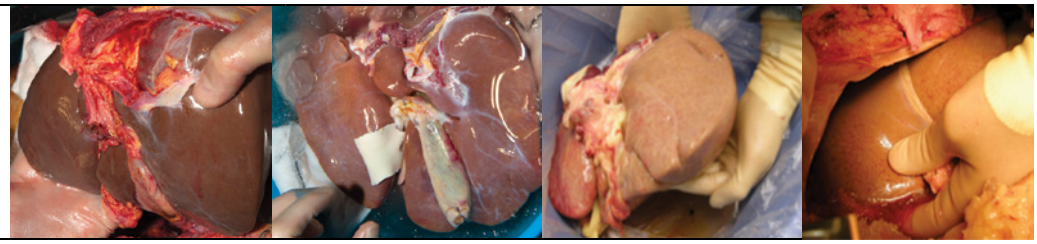
	Normal graft	Mild steatosis	Moderate steatosis	Severe steatosis
Colour				
Margins	Sharp	Sharp / mild blunting	Blunting right lobe / left lobe	Blunt
Consistency	Soft	Slightly indurated	Heavy	Heavy
Appearance				

Figure 6.4 Summary of the liver assessment.

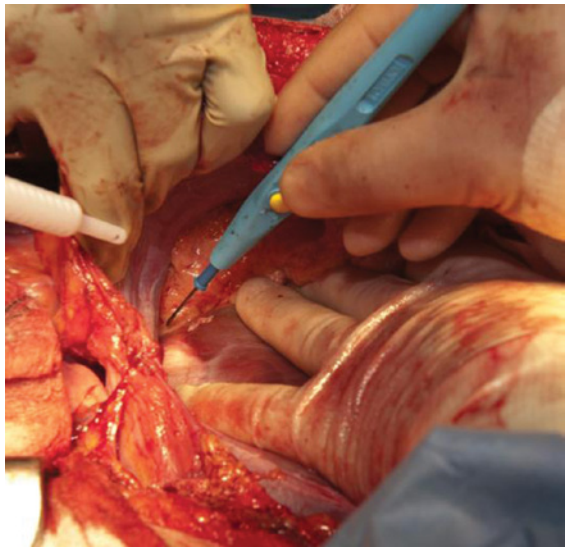


Figure 6.5 Division of the left triangular ligament.

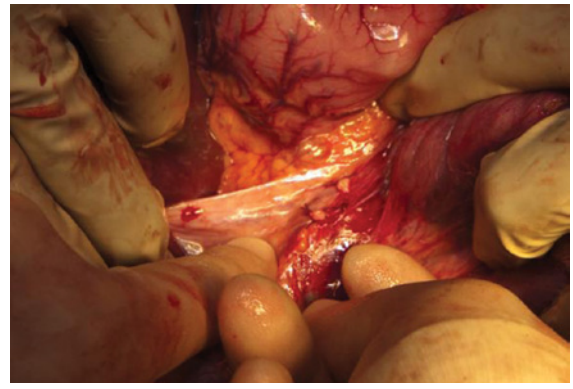


Figure 6.6 Palpation for the presence of accessory right hepatic artery.

lesser sac to check for the presence of aberrant arterial anatomy and to inspect the pancreas (Figure 6.5).

At this point, the surgeon must check for the presence of accessory/replaced left hepatic artery in the hepatogastric ligament and the presence of an accessory right hepatic artery in the porta hepatis.

The presence of an aberrant right hepatic artery (ARHA) will be suggested by the palpation of arterial pulsations to the right/behind the portal vein (Figure 6.6).

The common bile duct is dissected and divided above the duodenum, ligating the distal end. The

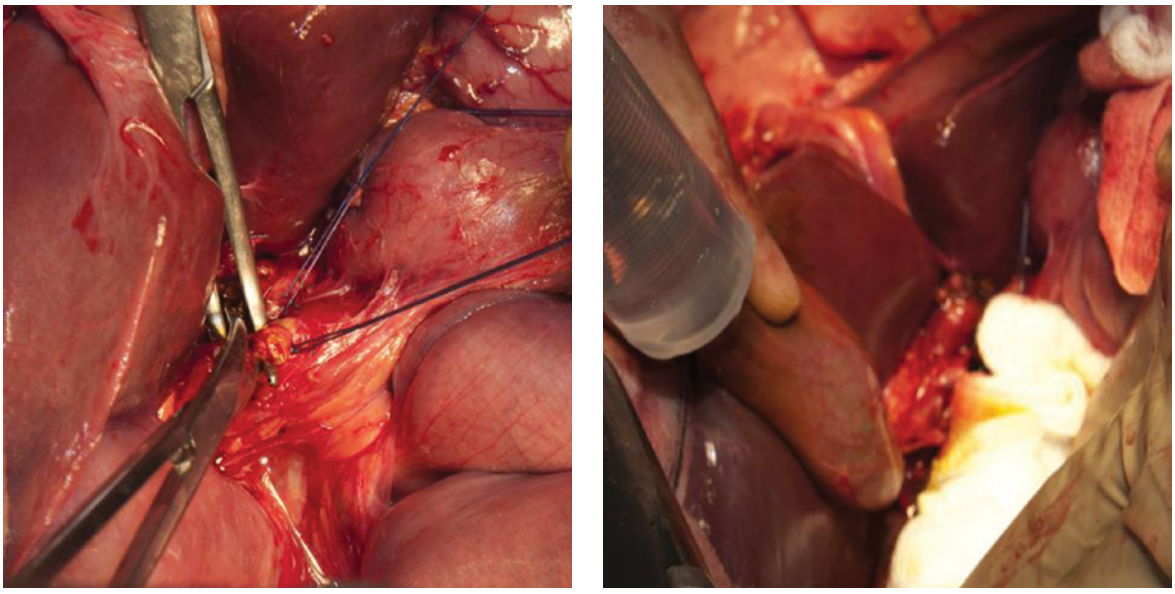


Figure 6.7 Division of the common bile duct and gallbladder washout.

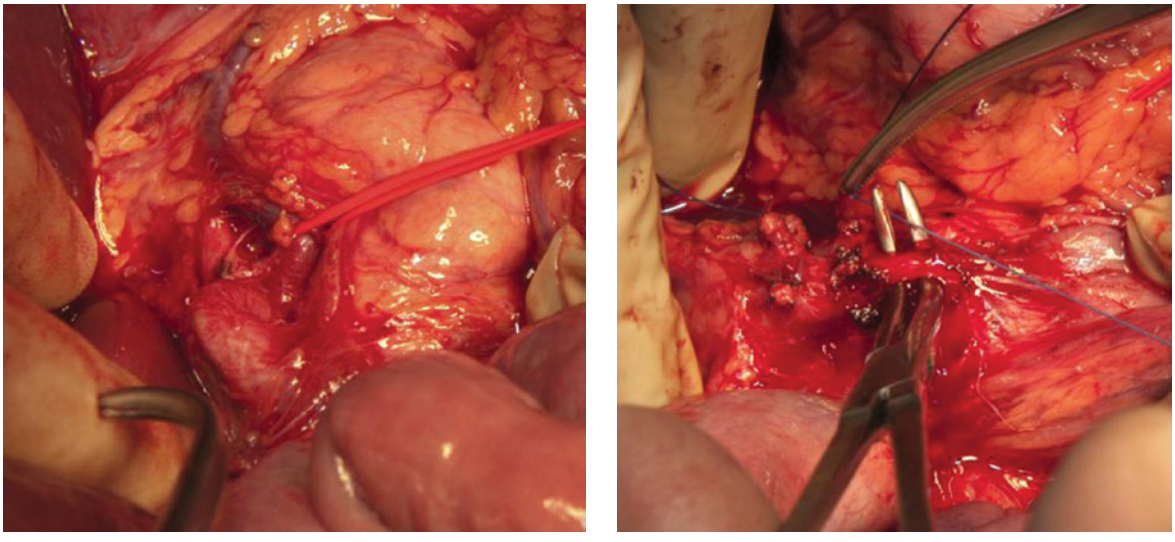


Figure 6.8 Identification of splenic and gastroduodenal arteries.

gallbladder is opened and flushed until clear fluid drains from the cut end of the bile duct (Figure 6.7).

The amount of hilar dissection in the warm phase, varies from a no-touch technique [5] to complete dissection of the entire hepatic arterial tree [6]. To avoid damaging the vascular structures and jeopardizing the perfusion of the liver, there should be minimal hilar dissection. The surgeon should identify/sling the gastroduodenal artery (GDA) and then identify/sling the splenic artery, to facilitate the cold phase dissection, particularly when pancreas retrieval takes place (Figure 6.8).

Extensive warm phase dissection of the porta hepatis should be avoided to minimize the risk of injuries [7].

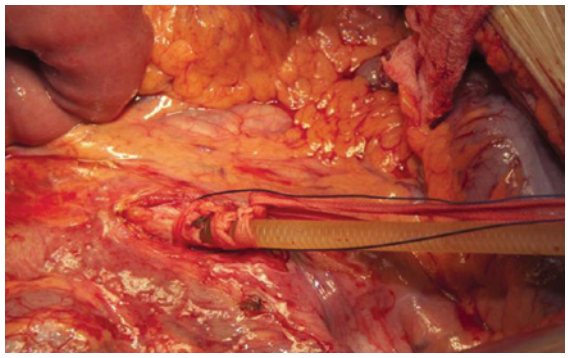


Figure 6.9 Aortic cannulation.

Figure 6.10 Topical ice cooling of the abdominal cavity.

The infrarenal aorta is cannulated in preparation for cold perfusion (Figure 6.9). In the setting of a multiorgan retrieval, aortic perfusion only is preferred as it provides a better function for other organs retrieved without a detrimental effect on the liver function [8,9]. If the pancreas or the small bowel are not retrieved, some surgeons prefer to use dual liver perfusion with a second cannula inserted to perfuse the portal system, although there is no clear benefit for the graft function post-transplantation [10].

Evidence suggests that single aortic perfusion is superior to dual aortic and portal perfusion [8,9].

Cross-clamping is coordinated with the cardiothoracic team and the venous drainage is most commonly achieved by venting the suprahepatic inferior vena cava (IVC). However, some cardiothoracic teams prefer to vent in the abdomen, via the infrarenal IVC. The choice of drainage should be discussed and agreed between the abdominal and thoracic teams, but in general, suprahepatic IVC venting is preferable, as it provides a better outflow for the liver perfusate.

Pull the liver down when dividing the suprahepatic IVC to ensure an adequate length of IVC with the liver (the cardiothoracic team does not require a long suprahepatic IVC for heart transplantation).

As soon as the venous drainage is established and the cold perfusion is started, the entire abdominal cavity is packed with slush ice to allow rapid *in situ* cooling of organs (Figure 6.10). Topical cooling of the liver should include placement of ice-cold solution above the diaphragm in the costodiaphragmatic angle.

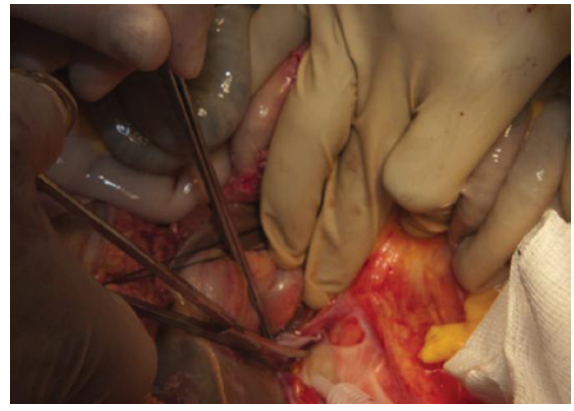


Figure 6.11 Division of the infrahepatic IVC.

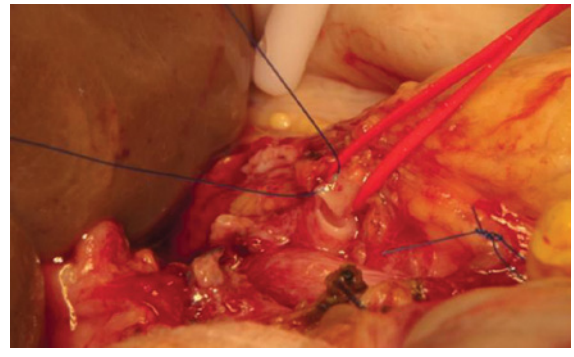


Figure 6.12 Division of gastroduodenal artery.

Following the retrieval of the thoracic organs, the liver is the first abdominal organ to be retrieved. The infrahepatic IVC is divided above the renal vein orifices (Figure 6.11).

The hilar cold dissection commences by dividing the previously slinged GDA (Figure 6.12). The pancreatic

end is marked with a Prolene suture for identification during pancreatic bench surgery.

The portal vein is divided, sharing the length between the liver and the pancreas (Figure 6.13). Usually about 1 cm of supraduodenal portal vein is sufficient for pancreatic transplantation.

The common hepatic artery is dissected towards the celiac axis. The origin of the splenic artery is identified and divided, providing a 5 mm stump, which could be used for hepatic arterial reconstruction if needed.

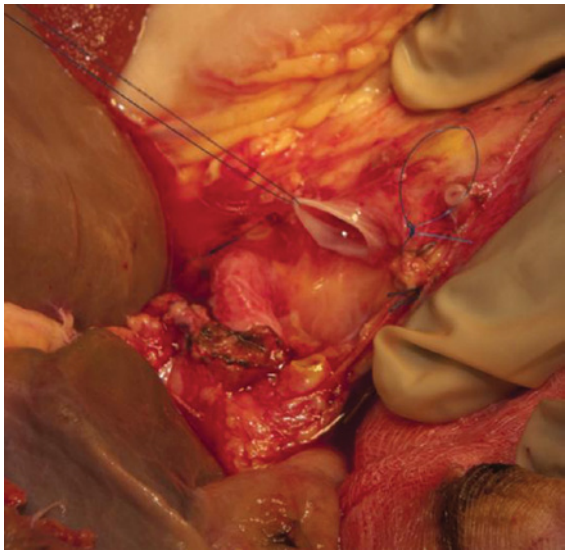


Figure 6.13 Division of the portal vein.

The distal end of the splenic artery is also marked with a suture for identification during pancreatic bench surgery.

The celiac axis is dissected from the surrounding lymphatic tissue with a patch of aorta.

The diaphragm is then divided around the suprahepatic cava, starting on the left side of the IVC, continuing posteriorly and completing the division by taking a patch of the right hemidiaphragm around the right lobe of the liver (Figure 6.14).

Do not mobilize the right lobe of the liver as for a hepatectomy.

A skilled assistant is essential during this part of the procedure to ensure that no right lobe traction injuries occur.

Insert a finger in the suprahepatic IVC to guide the dissection of the diaphragm and assist in the mobilization of the right lobe of the liver.

The right lobe is separated from the right adrenal gland and the right kidney, the retroperitoneal tissue at the back of the IVC and aorta is divided and the liver is removed and placed on ice (Figure 6.15).

The technique of *en bloc* liver and pancreas retrieval is preferred by many centers and is described in detail in Chapter 4. The main technical differences are:

- No cold phase dissection of the porta hepatis.
- Gastric antrum, proximal jejunum and small bowel mesentery are stapled.

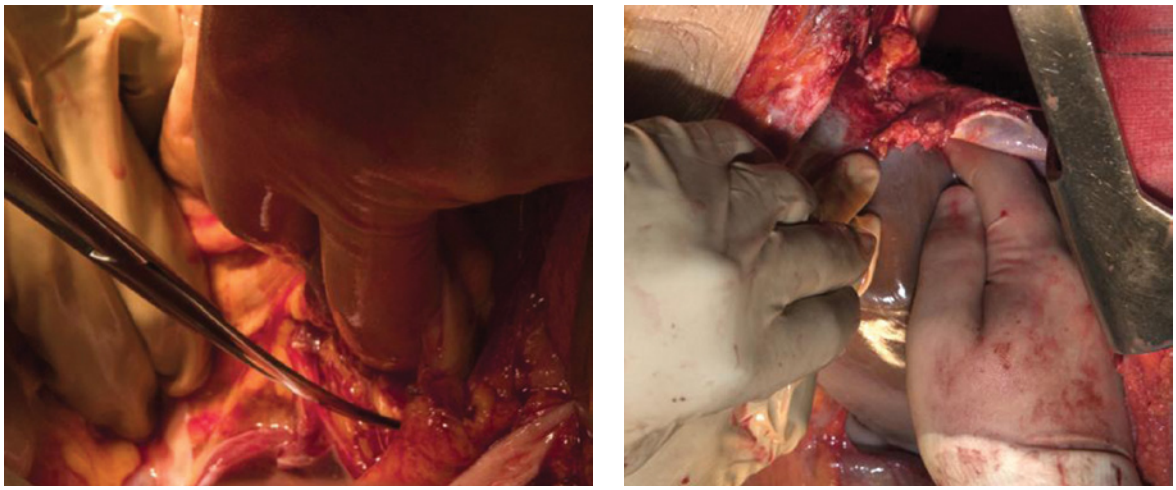


Figure 6.14 Division of the diaphragm around the suprahepatic IVC and right lobe of the liver.

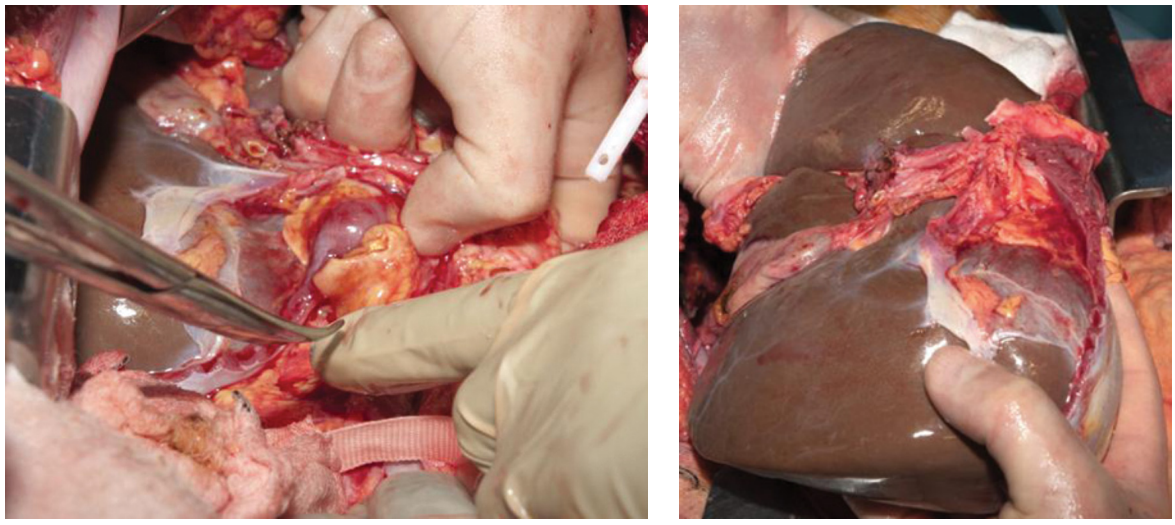


Figure 6.15 Separation from adrenal gland and division of retroperitoneal attachments followed by liver removal.

- The aorta is divided at the origin of the superior mesenteric artery (SMA), protecting the origins of renal arteries.
- Mobilization of the tail of the pancreas and spleen.
- The supraceliac aorta is divided to enable the retrieval of an aortic tube containing the origin of the celiac axis and SMA.
- Bench surgery separation of the liver and pancreas with division of the GDA, portal vein and splenic artery.

Choice of perfusion fluid

There is no uniform practice regarding the type of fluid used for *in situ* perfusion. Some centers prefer Marshall's solution for the aortic perfusion and University of Wisconsin (UW) for the portal perfusion. In case of aortic-only perfusion retrieval, UW is preferable, although some centers use initially a litre of Marshall's solution (to flush all potential clots) followed by UW perfusion.

There is some evidence suggesting that UW solution provides better *in situ* cooling and maintains the lower temperature for longer compared with other solutions.

The perfusion should continue until the effluent is clear. This is usually achieved after 3–4 L of perfusion.

Most centers run the perfusion fluid at an average pressure of 80–100 mmHg, but higher pressures (< 150 mmHg) could be used when aortic-only perfusion is utilized. There is some indication that higher perfusion pressure is associated with better short-term graft function and better recipient and graft survival [11]. Portal perfusion is usually carried out without pressure.

Bench perfusion

Once the liver is placed on ice, further perfusion of the graft is carried out, particularly if aortic-only perfusion has been used *in situ*.

Portal perfusion is critical and around 0.5–1 L of UW is required to ensure clear effluent from the IVC. The perfusion of the common bile duct is another essential component of the bench preparation, as stagnant bile can be toxic to the bile duct during cold storage and may contribute to postreperfusion bile duct damage. Further arterial perfusion on the bench is also recommended. Bench arterial and bile duct perfusion is performed under pressure and there is evidence that this reduces the incidence of ischemic cholangiopathy and provides better graft function [12]. There is, however, no evidence to support high-pressure portal perfusion on the bench [13].

Indicative perfusate volumes *in situ* and *ex situ* are given in Table 6.1.

Packing

The liver is totally submerged in cold UW and packed in a sterile bag (such as 3 M Steri-drape isolation bag), which is placed on top of slush ice solution in a suitable sized bowl. The bowl is packed in a second sterile and vacuumed bag and should be placed horizontally in a transport box, completely surrounded by ice. The transport box should also contain a set of iliac vessels, spleen, lymph nodes and blood samples and be accompanied by the relevant documentation. Figure 6.16 shows how not to pack a liver.

Table 6.1 Volumes of *in situ* and *ex situ* perfusion volumes.

	Aortic	Portal	Bile duct
In situ	UW/(Marshall's)* 3–4 L	(UW)* (1–2 L)*	Saline flush 30–60 mL (via gallbladder)
Ex situ	UW 0.2–0.5 L	UW 0.5–1 L	UW 0.25 L

()*denotes preference for dual perfusion.

Variant arterial anatomy scenarios and solutions

It is always safe to assume that there is aberrant arterial anatomy (Figure 6.17). The retrieval strategy should be adapted according to several factors:

- a pancreas retrieval takes place
- the presence of aberrant arterial anatomy which could impact on the pancreas retrieval
- the need for long vessels due to recipient factors (e.g. recipient portal vein thrombosis).

If an accessory or a replaced left hepatic artery is encountered, the cold phase dissection should be modified accordingly. The dissection line should stay on the lesser curvature of the stomach, to preserve the left gastric artery with all its branches (including the abherrant left hepatic artery (ALHA)) on the aortic patch.

A practical algorithm for dealing with the right hepatic arterial anatomy variations is given in Figure 6.18. It is extremely uncommon to abandon the pancreas retrieval due to arterial variations. In most cases the ARHA can be divided above the pancreas, as it requires reconstruction and this is most commonly carried out on the GDA. In the unusual situation that the pancreas retrieval cannot take place, this decision must be taken after consultation with the liver and the pancreas surgeons from the centers that have provisionally accepted the organs.

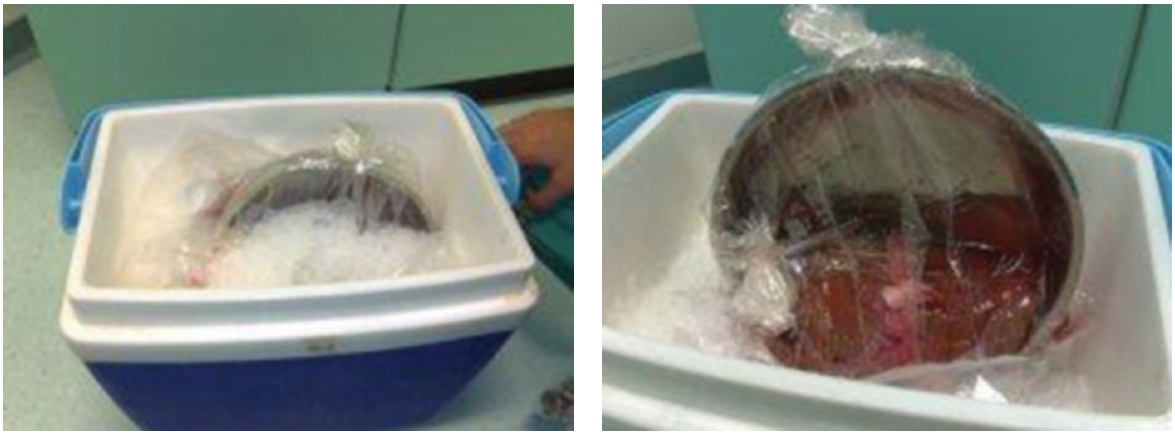


Figure 6.16 How not to pack a liver.

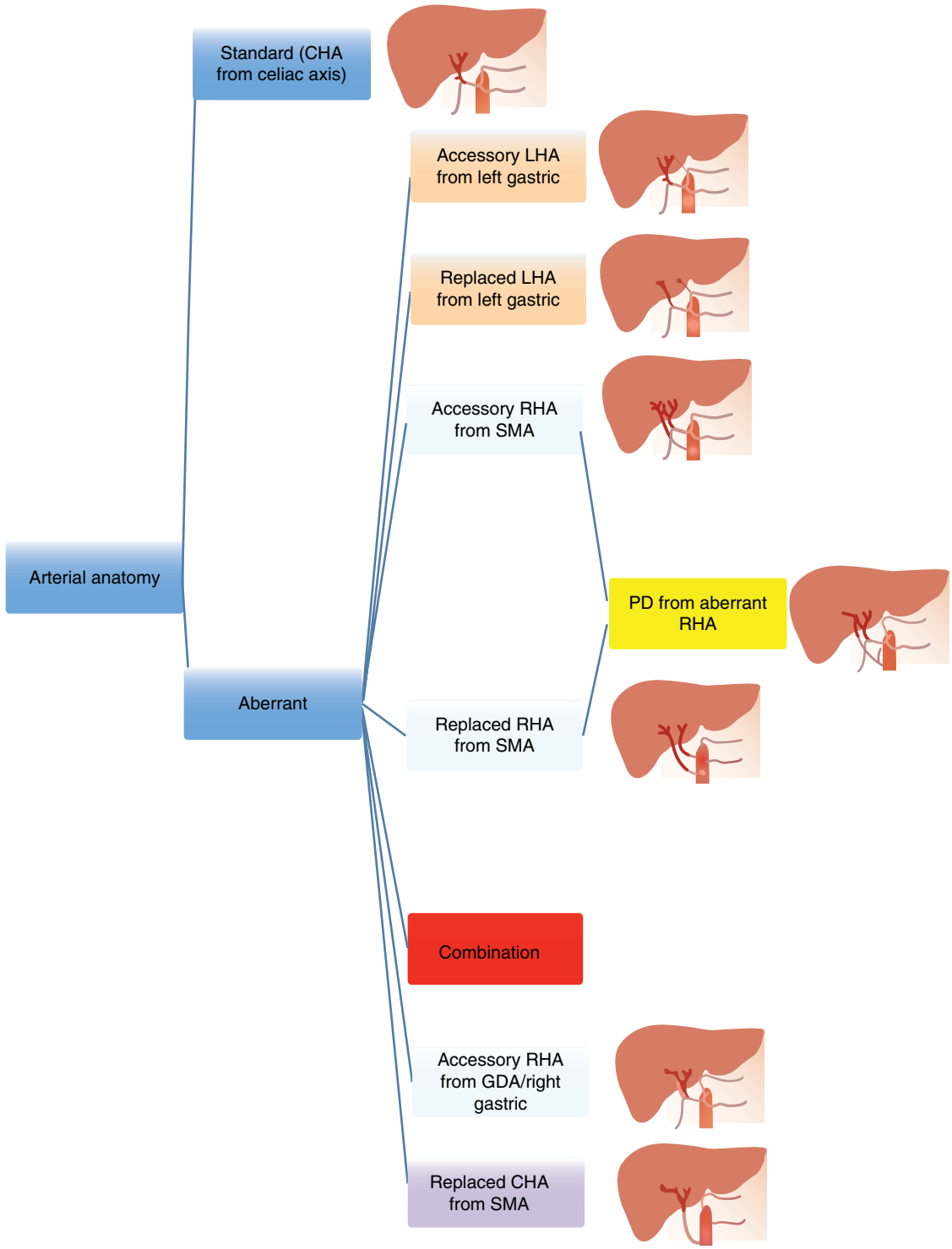


Figure 6.17 Hepatic arterial anatomy variations.

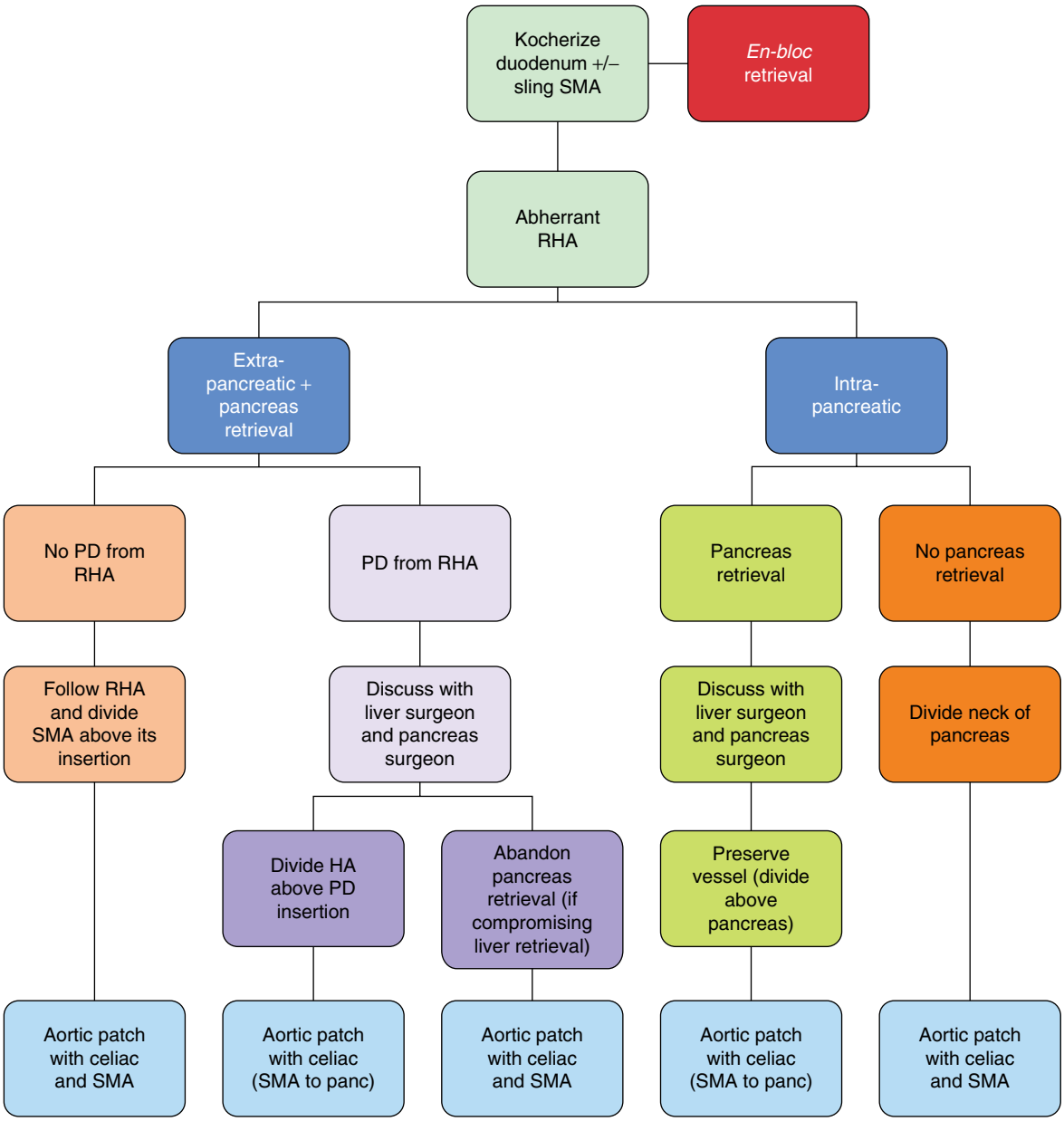


Figure 6.18 Practical algorithm for dealing with right hepatic arterial anatomy variations.

Bench surgery

A video for the liver bench surgery procedure can be found on the companion website: www.wiley.com/go/oniscu/abdominal

Donor information

The retrieval team should have discussed the quality and the anatomy of the liver graft with the implanting surgeon.

On receipt of the graft, the paperwork should be checked. Particular attention should be paid to

Figure 6.19 Set-up for liver bench surgery.

the retrieval information, noting the cross-clamp time, the amount of perfusion fluid used and the quality of the perfusion, the anatomy of the graft and the appearance of the graft (whether steatotic or not). Any reported damaged should also be noted.

The recipient surgeon should also check the blood group of the donor and the donor core data form to verify the virology, the liver function tests as well as the use of inotropic support or any prolonged periods of hypotension. All this information would give some indication about the expected performance of the graft.

Set-up for bench surgery

Bench surgery can be a complex procedure, particularly if it involves splitting the liver or major vascular reconstruction.

The bench should be set up to include a standard surgical tray (scissors, forceps, blade, clamps, perfusion cannulas, needle holders) (Figure 6.19). Additional microsurgical instruments may be required. A suitable sized bowl for the preparation of the liver is required to ensure that the graft is kept in sterile slush ice and UW at 4 °C for the duration of the procedure, to avoid rewarming.

A perfusion-giving set with cold UW should be set up to perfuse the liver and also to check the integrity of the portal vein and arterial tree, once the graft has been prepared for implantation.

Liver assessment

A full assessment of the graft should be undertaken during bench surgery. This should be correlated with the information from the retrieval paperwork and the donor core data form.

The assessment should include four components:

1 Aspect (edges)
2 Consistency
3 Colour (degree of steatosis)
4 Weight.

This assessment allows the surgeon to make a final decision whether the liver is usable and in particular if it is suitable for the chosen recipient.

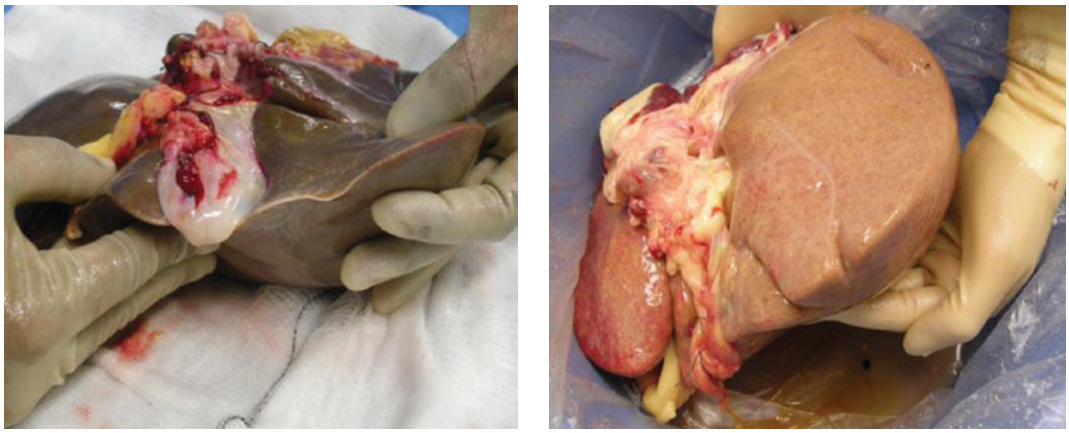


Figure 6.20 Comparative appearance of a normal and steatotic liver graft.

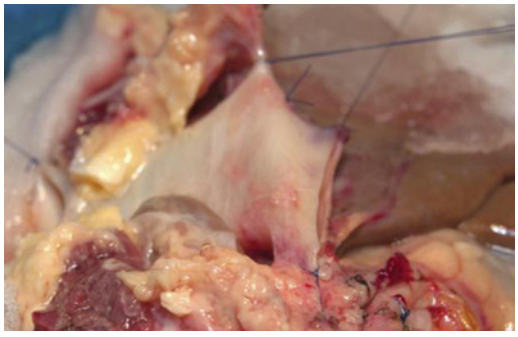


Figure 6.21 Ligation of the adrenal vein.

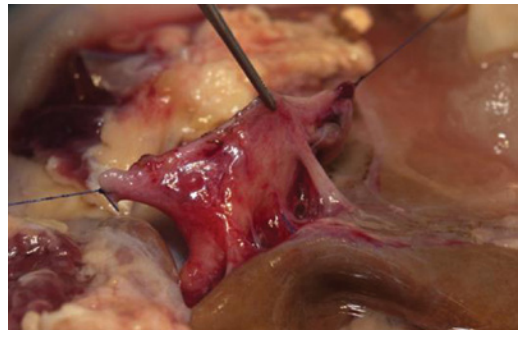


Figure 6.22 Ligation of short hepatic veins.

A normal, healthy liver has sharp edges, whilst the presence of blunted and rounded margins indicates that the liver is steatotic (Figure 6.20).

The aspect of the liver edges is corroborated with the consistency of the liver and the colour (Figure 6.4). The liver should be soft and have a light brown colour, whilst the presence of a firm, heavy indurated and yellow colour liver raises concerns regarding the quality of the graft.

Preparation for implantation

The preparation of the liver involves removal of the excess tissue and dissection and preparation of the vena cava, the portal vein and the arterial tree.

Dissection of the vena cava

Stay sutures are placed in the corners of the supra- and infrahepatic cava, to assist the exposure.

The infrahepatic cava is prepared first, ligating and dividing the right adrenal vein (Figure 6.21).

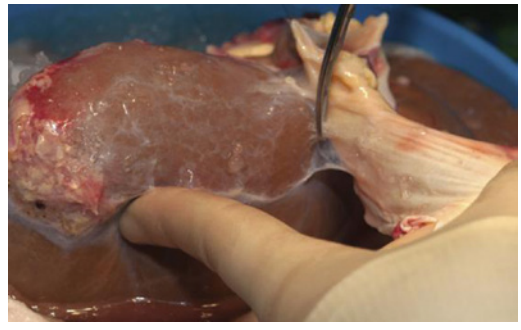


Figure 6.23 Dissection of the diaphragm.

If a side-to-side cavocavostomy implantation is planned, the short hepatic veins that are too close to the cut edge of the cava can be divided at this stage, to facilitate the closure of the infrahepatic caval end (Figure 6.22).

The diaphragm is completely dissected off the liver, freeing the suprahepatic end of the cava (Figure 6.23).

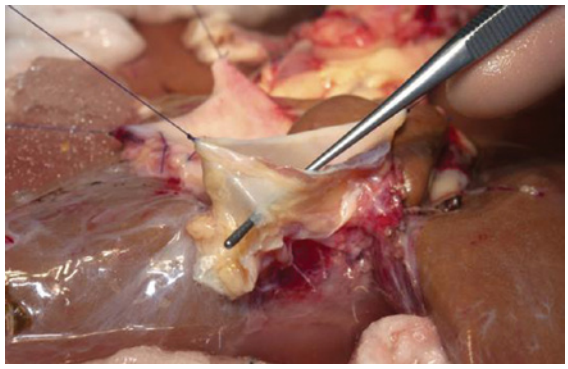


Figure 6.24 Identification of the phrenic veins.

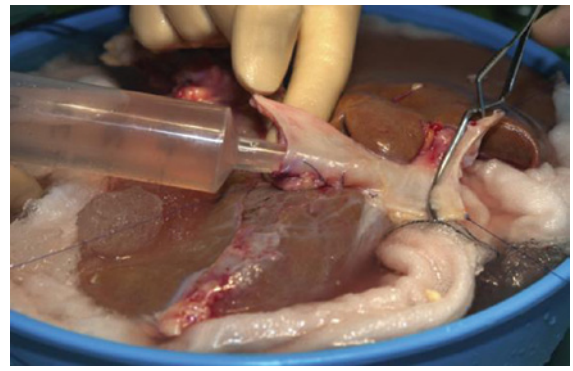


Figure 6.25 Caval flush.

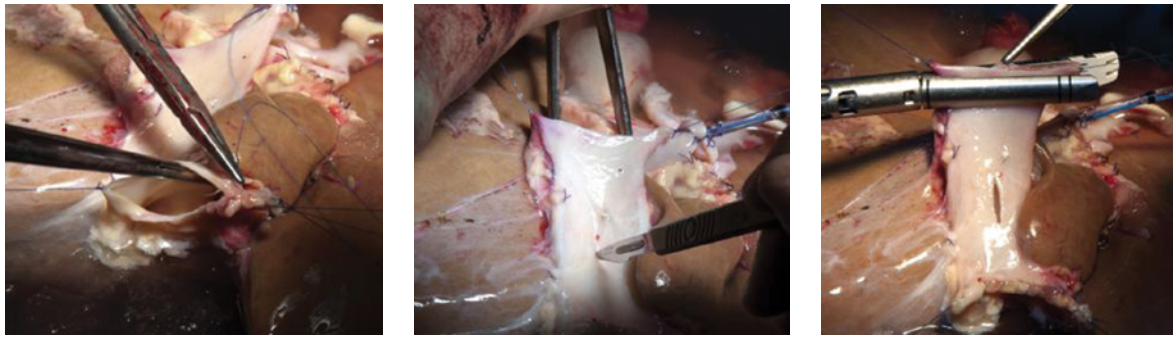


Figure 6.26 Closure of caval ends and posterior cavotomy for side-to-side cavocavostomy implantation.

This allows the identification of the left and right phrenic veins, which should be ligated/sutured to avoid bleeding at reperfusion (Figure 6.24).

Once the cava is prepared, its integrity is checked with a probe and/or flushing cold fluid under pressure (Figure 6.25).

At this point, further preparation of the cava depends on the type of implantation.

- **Classical transplant (caval replacement)** – no further dissection is required and both ends of the cava are left open.
- **Piggyback on the hepatic veins** – no further dissection of the cava is required and both ends of the vena cava are left open.
- **Side-to-side cavocavostomy** – the caudate lobe should be mobilized to allow adequate exposure of the retrohepatic cava. Some surgeons elect to complete the preparation of the donor cava for implantation at this stage. This involves making a small incision in the posterior caval wall (which will be extended to match the recipient cavotomy at the time of implantation) and closing both ends of the cava (suture or staple) (Figure 6.26).

When closing the suprahepatic end of the cava, ensure that the hepatic veins outflow is not compromised by the suture/staple line.

The cavotomy should be overlying the orifices of the right hepatic vein (RHV), middle hepatic vein (MHV) and left hepatic vein (LHV) to ensure optimal venous drainage.

Dissection of the portal vein

An adequate length of portal vein is dissected. This is particularly important when the pancreas has been retrieved and the length of hepatic portal vein is short. The vein should be dissected posteriorly (as it is the

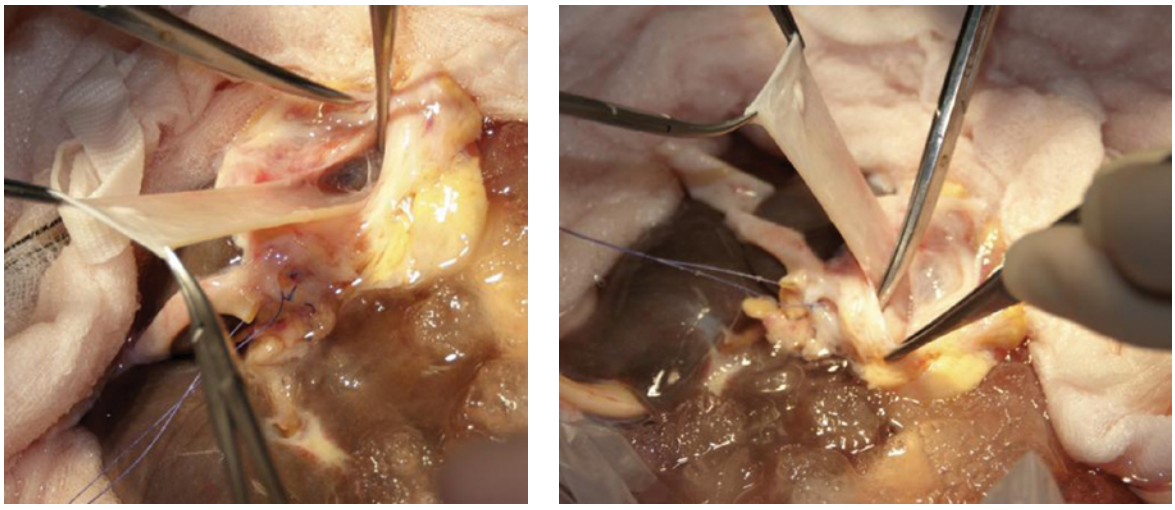


Figure 6.27 Portal vein dissection.

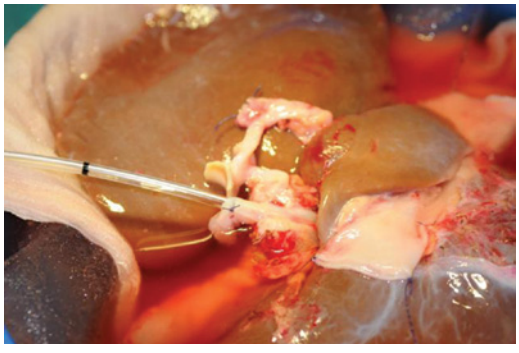


Figure 6.28 Cannulation of the portal vein.

safest place to avoid damage) to the level of portal bifurcation (Figure 6.27).

The vein is then dissected circumferentially, separating it from the surrounding loose areolar tissue. Small venous tributaries can be ligated.

Once the vein has been dissected, a cannula is placed in the portal vein to facilitate flushing the graft before reperfusion (Figure 6.28).

There is some evidence suggesting that a blood flush of the liver prior to reperfusion leads to a better initial graft function.

Dissection of the arterial tree

The arterial anatomy should have been documented by the retrieval surgeon. However, it is not uncommon to identify missed injures at the time of bench surgery.

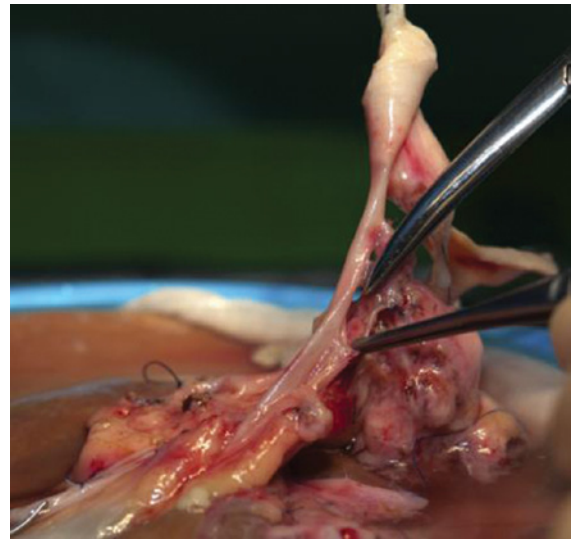


Figure 6.29 Dissection of the arterial tree.

Be aware of missed injuries to the arterial tree.

The arterial preparation depends on whether the liver is retrieved on its own or *en bloc* with the pancreas. In case of liver-only retrieval, bench preparation of the arterial tree starts with the identification of the splenic artery and the GDA stumps.

The artery is then dissected from the aortic patch towards the liver (Figure 6.29).

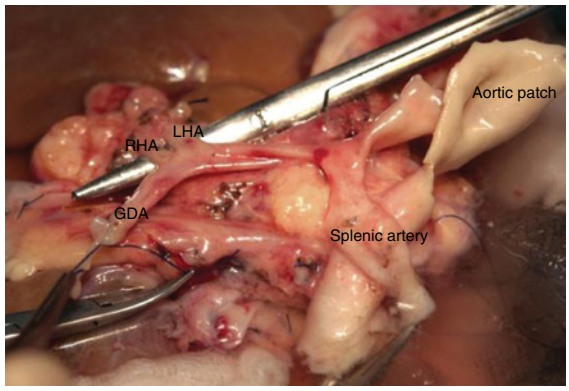


Figure 6.30 Completed arterial dissection.

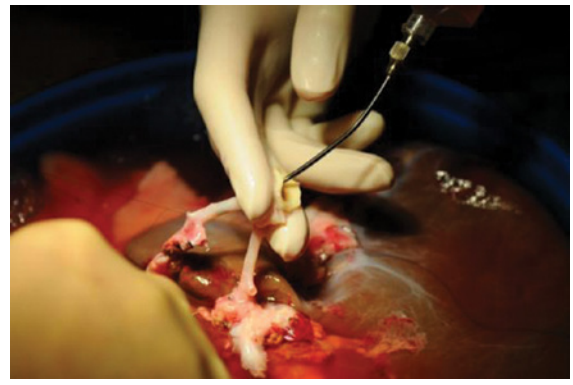


Figure 6.31 Arterial tree flush.

The dissection identifies the stump of the splenic artery, left gastric artery and GDA. Dissection is carried towards the hilum, up to the level of the hepatic artery bifurcation, to confirm the presence of standard and intact arterial anatomy.

Do not dissect between the artery and the common bile duct, as there is a significant risk of compromising the blood supply to the bile duct.

Once the hepatic arterial tree has been dissected (Figure 6.30) the integrity of the vessels is checked with cold perfusion. Any leaking points should be sutured with 6/0–8/0 Prolene (Figure 6.31). It is common to leave the GDA stump open to vent the arterial tree following arterial revascularization.

If the liver is retrieved together with the pancreas, arterial preparation must ensure preservation of the arterial supply to both organs.

The liver and the pancreas are placed in anatomical position and, following the division of the portal vein, the celiac axis is dissected along the border of the pancreas, where the splenic artery is identified and divided. Dissection is carried out proximally and the GDA is identified and divided. Once the pancreas is separated, the proximal part of the hepatic arterial tree dissection is similar to the one described above (Figure 6.32).

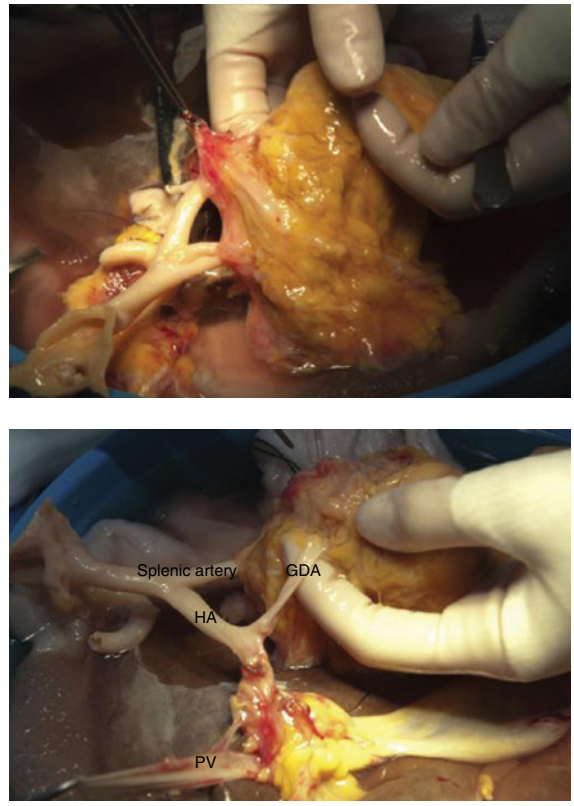


Figure 6.32 Arterial tree bench dissection for *en bloc* liver-pancreas retrieval.

Abherrant arterial anatomy and reconstruction options

Several arterial anatomical variations have been described and are illustrated in Figure 6.17.

The ALHA should be carefully dissected and all extrahepatic branches ligated to minimize bleeding at reperfusion. The left gastric artery is preserved with the celiac axis which will be anastomosed with the recipient artery.

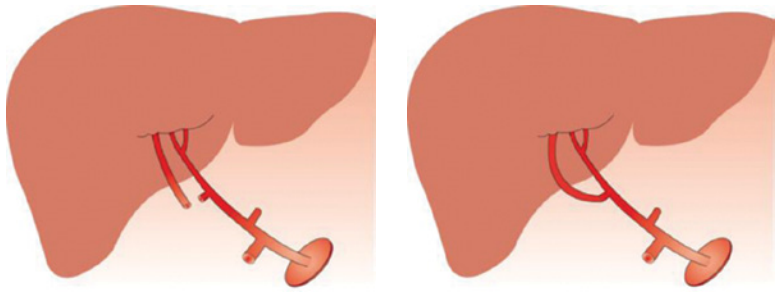


Figure 6.33

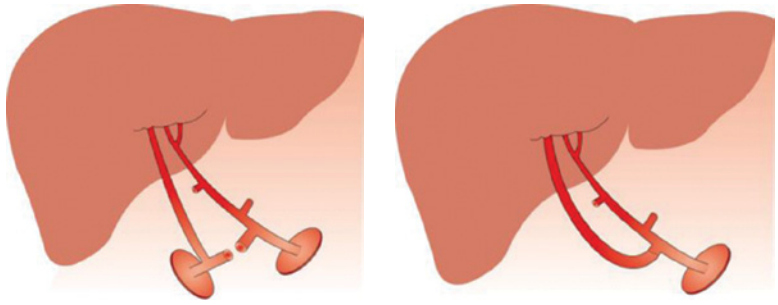


Figure 6.34

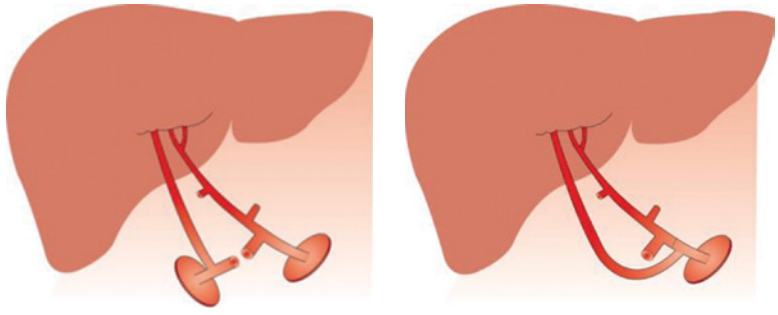


Figure 6.35

The ARHA will require reconstruction if the pancreas has been retrieved and the donor had anatomical variations, such as the ones described above. Most commonly, the reconstruction involves implantation of the ARHA onto the donor GDA stump. The bench surgeon should also be aware of the recipient hepatic arterial anatomy and in particular of the presence of aberrant/accessory vessels that could be used for a second arterial anastomosis with the donor ARHA. Most surgeons, however, prefer to reconstruct the ARHA during bench surgery.

The most frequent reconstruction options for the ARHA are:

- **ARHA to the donor GDA (most common)** (Figure 6.33.)
- **ARHA to the donor splenic artery** (Figure 6.34).

The choice between these two options is dictated by the calibre and length of the vessels and the final layout of the reconstructed arterial tree, which should avoid vessel rotation/kinking.

- **SMA to celiac axis using donor SMA for anastomosis with the recipient artery** (Figure 6.35). This option is possible if the SMA and celiac axis have been retrieved on a single aortic patch or separately.
- **SMA to splenic artery using donor celiac axis for anastomosis with the recipient artery** (Figure 6.36).

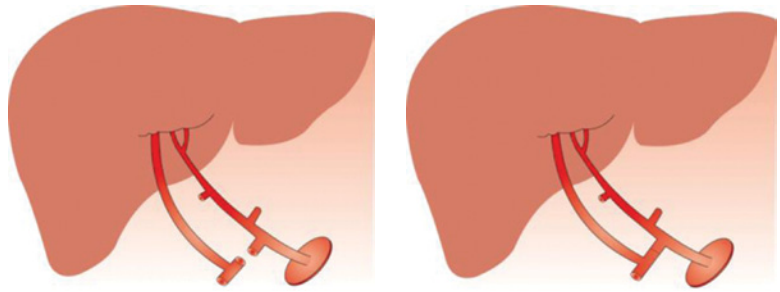


Figure 6.36

• **Separate arterial anastomoses** (if recipient ARHA present).

• **Two separate arterial anastomoses on the right and left recipient hepatic arteries** (less frequent).

Most arterial injures occur during the cold phase of the dissection and involve an unsuspected ARHA and occasionally an ALHA. In this scenario, the reconstruction of the right hepatic artery follows the same steps illustrated above.

If an ALHA has been damaged, it should be repaired/reconstructed if there is no demonstrable left hepatic artery in the porta hepatis (i.e. this is a replaced left hepatic artery). If the presence of a proper left hepatic artery is confirmed and the accessory vessel is small, it could be ligated.

Bile duct

No dissection of the bile duct is carried out during bench surgery and the gallbladder is not removed.

Summary box

- Check paperwork and retrieval information.
- Maintain liver at 4°C throughout the bench procedure.
- Check liver for injuries, size and degree of steatosis.
- Dissect vena cava and suture/ligate phrenic and adrenal veins.
- Dissect portal vein for an adequate length.
- Dissect hepatic artery, checking for aberrant or missed arteries.
- Reconstruct right hepatic artery if required.
- Check the integrity of all vessels.
- Pack liver in ice box if recipient hepatectomy not completed.

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7 Deceased Cardiac Donor Liver Retrieval

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Introduction

Successful transplantation of abdominal organs and lungs from donors after circulatory death (DCD) has become an accepted practice. The recovery of extra renal organs has become possible over the years, as the retrieval procedure has been standardized to rapidly induce hypothermia in the donor. The published techniques of deceased cardiac donor hepatectomy share analogous components [1,2]. There has been great caution in using DCD livers for transplantation and the selection process is of vital importance to avoid the main problems associated with the additional damage of donor warm ischemia time (DWIT), including primary nonfunction (PNF), delayed graft function and ischemic-type biliary strictures (ITBS).

According to the setting in which cardiac death occurs, DCDs are divided into two main categories: controlled and uncontrolled (Table 7.1). The retrieval procedure differs according to the DCD category.

Controlled DCD

Controlled DCDs suffer from terminal illness, usually a catastrophic neurological injury, without the possibility of meaningful recovery. Controlled DCDs experience cardiocirculatory arrest following planned withdrawal of life support, either in intensive care or in the operating room. The organs suffer less ischemic injury and are associated with better outcome after transplantation compared with organs from uncontrolled DCD. Maastricht category III donors, awaiting cardiac arrest after withdrawal of life support, are by far the majority of the controlled DCD group, but there are a few cases of category IV brain dead donors (DBD) where the family does not wish for the retrieval to go ahead unless after cardiocirculatory arrest.

Preparations prior to withdrawal of treatment

The surgical team should arrive at the donor hospital with plenty of time ahead of the planned withdrawal time, to enable a review of the donor details, history,

Table 7.1 Maastricht classification of deceased cardiac donors.

Category	Alternative categorization	Status of potential donor	Hospital department
I	Uncontrolled	Dead upon arrival	Accident and Emergency
II	Uncontrolled	Resuscitation attempted without success	Accident and Emergency
III	Controlled	Awaiting cardiac arrest	Intensive Care
IV	Controlled	Cardiac arrest while brain dead	Intensive Care

Abdominal Organ Retrieval and Transplantation Bench Surgery, First Edition. Edited by Gabriel C. Oniscu, John L. Forsythe and John Fung.

consent and all other donor documentation. This will also allow the team to make the necessary preparations for the hypothermic flush and infusion of preservation fluids. The preparation steps are now explained.

Setting up perfusion set

A giving set tubing is connected to an 18-French catheter (i.e. William Harvey Arterial Perfusion cannulae) or any appropriately sized catheter for aortic cannulation. The bubble trap is passed to the perfusionist and is primed with a low viscosity solution for aortic perfusion, i.e. Marshall's solution. The first liter of Marshall's solution infused contains 20,000 units of heparin. Usually four 1L IV bags of Marshall's solution are used. IV fluid pressure bags are used to apply pressure only to the aortic perfusion fluids, as described in previous chapters.

Similarly, a giving set tubing is connected to a 16-French catheter for portal cannulation, which is primed with University of Wisconsin solution (UW). The first liter of UW contains 20,000 units of heparin.

The portal infusion fluid may include the following drugs:

- *Benzylpenicillin* (1.2 mega units reconstituted in 20 mL of saline) 400 mg in each bag, i.e. 4 mL (omit if the donor is allergic to penicillin)
- *Dexamethasone* (16 mg, usually 4 mg/mL – 4 mL in each bag)
- *Actrapid insulin* (40 IU in each bag – 0.4 mL)

Both tubings are clamped with Kelly clamps for flush control on the surgical field.

Bench set up

The bench should be set up to receive the liver. A separate bowl is filled with 2 L of sterile crushed ice and 1 L of UW for topical cooling.

A double-balloon triple-lumen (DBTL) catheter is prepared as an alternative method to cannulate the aorta. The DBTL is used in case of history of previous thoracic surgery, anticipating a prolonged sternotomy or in rare cases where the family does not wish for the thorax to be accessed.

Operative table set up

The scrub nurse should set up the instrument tray in the order required for a rapid laparotomy and aortic cannulation, to minimize the time taken from cardiac arrest to cold perfusion (knife, scissors, abdominal retractor, aortic cannula, Lahey forceps and cannula ties, automated sternal saw, partially opened Finochetto sternal retactor, long Roberts forceps).

Team briefing

The surgeon should discuss with the rest of the team the steps of the retrieval process and any potential deviations from a standard DCD retrieval due to specific donor issues (e.g. aortic aneurysm, previous thoracic surgery).

If a thoracic team is present, the abdominal team should discuss the steps of the retrieval process and agree a common strategy to ensure that all organs are retrieved in a rapid and safe fashion.

- Brief team about the steps of the procedure.
- Check donor paperwork.
- Setup the bench and the perfusion kits.
- Do not:
  - visit intensive therapy unit (ITU)/place of treatment withdrawal
  - interfere with confirmation of death
  - interfere with patient care.

Withdrawal of treatment and definition of ischemic times

The attending physician, usually an intensivist, disconnects the ventilator and extubates the patient and withdraws all inotropic medication.

Medications, such as vasodilators or heparin, can be administered premortem in some countries but not in the UK. In the case of category IV donors, however, as they have been certified brain dead, heparin and vasodilators can and should be given prior to cardiac arrest to improve perfusion of the organs. Needless to say, in this particular situation, there is also no need to recertify death or wait for 5 minutes. Pain relief can be given according to local protocols.

The transplant coordinator attends the withdrawal process with the family and records blood pressure and pulse oxymeter oxygen saturations every 5 minutes.

The attending physician certifies the death of the patient after observing a period of 5 minutes from cardiocirculatory standstill, after which the donor is transported rapidly to the operating theater. Blood is drawn for final serology and chemistry profiles.

Donor warm ischemia time (DWIT) is defined in different ways across the world.

In the UK, the start of DWIT is defined from the advent of hypotension (systolic blood pressure less than 50 mmHg) or hypoxia (saturation less than 70%), to better reflect effective hypoperfusion of the liver, to the initiation of cold perfusion. A Consensus Conference in the US defined DWIT as the interval of time between withdrawal of treatment and initiation of cold perfusion. The latest American Society of Transplant Surgeons practice guidelines for DCD distinguish between the following:

- total DWIT from withdrawal of treatment to initiation of cold perfusion
- true DWIT from mean arterial pressure 60 mmHg to cold perfusion.

True DWIT is similar to the DWIT definition in the UK and other European centers, and its upper acceptable limit, for safe utilization of DCD livers, is set to 30 minutes [3].

Cold ischemia time (CIT) extends from the initiation of cold preservation of the liver to reperfusion after implantation in the recipient.

For DCD, liver transplantation CIT should be shorter than 8 hours.

When the CIT exceeds 8 hours or 12 hours, the incidence of liver graft failure within 60 days of transplantation has been shown to increase to 30% and 58%, respectively. The DCD retrieval pathway is illustrated in Figure 7.1.

- Withdrawal times
  - Liver 60 minutes
  - Pancreas 60 minutes
  - Kidney 2 hours (up to 4 hours in some centers)
- Donor warm ischemia times
  - Liver 30 minutes
  - Pancreas 30 minutes
  - Kidneys 60 minutes

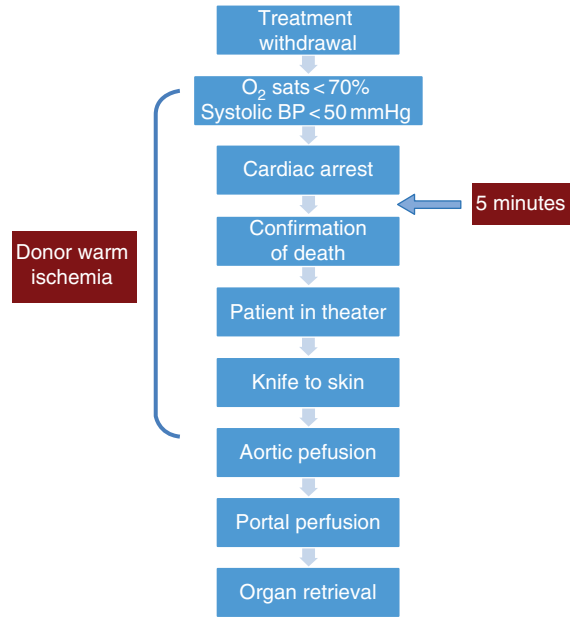

Figure 7.1 DCD retrieval pathway.

Retrieval procedure technique

The donor is placed in a supine position and the skin is quickly prepped with antiseptic solution and draped typically with a large single-use light drape to save time. A clear sterile adherent drape (Steri-Drape™) is placed over the abdomen and chest to ensure sterility and to secure the drapes.

The standard retrieval procedure derives from the super rapid technique, originally described by Casavilla et al. [4]. The procedure begins with a midline laparotomy that extends from the sternal notch to the pubis. The incision is made with a scalpel, as there is no need for diathermy in the absence of circulation. Rapid access to the peritoneal cavity is aided by lifting the abdominal wall. This also minimizes the risk of intra-abdominal organ injury during this step. The abdomen is kept open using a large self-retainer retractor that has been prepared half open for speed of insertion.

Following an incision of the peritoneal duplicature of the distal ileum and cecum, the small bowel is reflected superiorly, exposing only the area of the

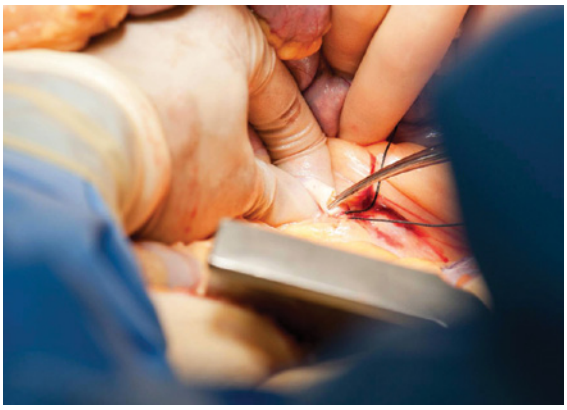

Figure 7.2 Aorta is controlled and incised.

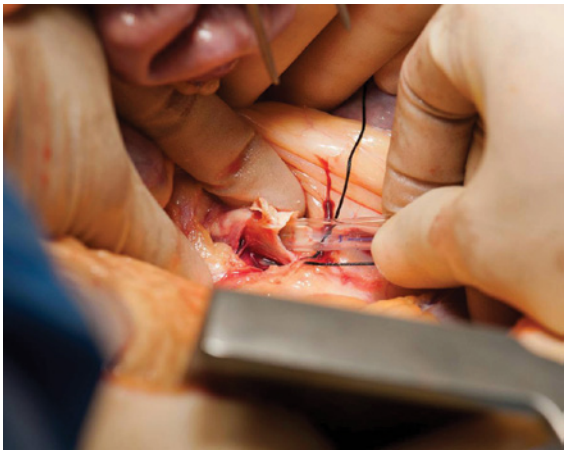

Figure 7.3 Aortic cannulation.

aorto-iliac bifurcation enough to rapidly identify and cannulate the distal aorta (Figures 7.2 and 7.3).

The easiest way to identify the aorta is at the level of the sacral promontorium.

Once the aorta is cannulated, cold perfusion begins immediately by gravity with low viscosity preservation solution (i.e. Marshall's solution) containing 20,000 units of heparin. The cannula should be secured in place to avoid displacement.

The inferior vena cava (IVC) can be vented in the abdomen or in the chest. The latter is preferable and can be done by opening the diaphragm or with a thoracotomy. Venous venting should be concomitant with the start of the aortic perfusion, to avoid congestion of the abdominal organs.

Copious saline ice slush is placed in the abdomen (paracolic gutters, lesser sac and over the liver) and chest for topical cooling of the organs.

The thoracic cavity is entered via a sternotomy using a Gigli or automated sternal saw. The sternum and ribs are kept apart with a Finocchetto retractor, offered half open for speed, the pericardium incised and the right atrium partially divided to improve venous venting. Both pleurae are opened so that the right atrium drains into the large pleural cavities where two pool suction tubes are placed to collect the effluent blood/perfusion solution.

The left lung is lifted, exposing the descending thoracic aorta, which is clamped using a long Roberts forceps.

Now that the perfusion fluid will not be wasted in the chest, a 200 mmHg pressure will be applied with the pressure bag to Marshall solution to improve perfusion pressure in the aorta. Perfusion of the aorta by gravity flow of UW or histidine–tryptophan–ketoglutarate (HTK) solutions only achieves suboptimal pressures in the hepatic artery of 19 mmHg and 16 mmHg, respectively [5].

In DCD liver retrievals, dual perfusion is advisable as the aorta often contains clots that may embolize into the vasculature of the abdominal organs.

The portal vein is cannulated via the superior mesenteric vein (SMV) and perfused with 1 L of UW also containing 20,000 units of heparin. The SMV is exposed at the root of the mesentery for cannulation below the head of the pancreas, in the groove between the transverse mesocolon and the mesentery of the first loop of the small bowel. Inferior mesenteric vein (IMV) cannulation should be avoided, as it is small calibre, provides a slow perfusion and could lead to edema of the pancreas.

In the case of concomitant pancreatic retrieval, the portal vein needs to be directly isolated after division of the common bile duct (CBD) and cannulated approximately 1 cm from the edge of the duodenum. The portal vein should be divided to ensure free drainage and to avoid congestion of the pancreas.

The fundus of the gallbladder is secured with a Kelly clamp and a 2 cm incision is made with scissors. The gallbladder content is aspirated and the lumen flushed with copious cold normal saline using a bladder syringe. The divided graft's CBD is also directly lengthily flushed with cold saline using a 10mL syringe with a heparin needle.

The subsequent steps of the procedure are no different from the cold phase dissection used for a rapid retrieval technique in unstable DBD donors.

Liver, pancreas and kidney

The liver is retrieved first, followed by the pancreas and the kidneys. Some teams advocate the retrieval of liver and pancreas *en bloc* and subsequent separation of the two organs on the bench, though there is no clear advantage for this.

Twenty thousand units of heparin must be added to the first liter of UW for the portal vein and the first liter of UW for the aorta. The latter does not require any drugs added to the solution.

Usually the flow of UW in the portal vein is slowed down after 800 mL to complete 1 L of UW portal perfusion *in situ*.

Usually pressure is stopped after the second bag of fluid is through the aorta and subsequent perfusion is by gravity, to allow cold perfusion of the aorta throughout the entire procedure, until organs are removed. However, these steps must be confirmed with the retrieving surgeon.

Liver and lungs

Several techniques have been described for retrieving lungs in suitable DCD. The implications are important and, generally, given the greater tolerance of lungs to warm ischemia, the thoracic team will allow the liver team to cannulate the abdominal aorta and the portal system whilst reintubating the donor and inflating the lungs.

Given the greater tolerance of the lungs to the effect of ischemia, the general agreement is that the abdominal organs (liver and pancreas) should be retrieved before the lungs are removed, to minimize the ischemic time. The lungs can then be retrieved at the same time as the abdominal surgeons proceed with the kidney retrieval.

Modifications to the super rapid technique procedure

A modification of this technique entails starting with a quick thoracotomy and venting the right atrium to reduce congestion of the abdominal IVC and of the liver in particular. This step may delay aortic cannulation by 2–3 minutes. A laparotomy follows with aortic or iliac cannulation and aortic perfusion. After a first rapid cold flush, the supradiaphragmatic aorta is clamped and pressure perfusion begins.

This modified technique of early sternotomy has two advantages:

1 It circumvents aggravating congestion of the liver and abdominal organs, yet avoiding venting the IVC in the abdomen and keeping the cavity clean from the warm venous effluent blood.

2 The access to and prompt clamping of the descending thoracic aorta allows for more immediate pressure perfusion of the abdominal organs without wasting the cold perfusion in the chest.

In summary, the modifications of the retrieval procedure reduce liver congestion, improve organ perfusion and facilitate surgical dissection, thus further reducing DWIT.

Other minor changes to the Casavilla technique have been described which use different techniques of securing the aorta, aimed at speeding aortic cannulation.

DCD retrieval steps include:

- thoracolaparotomy
- cannulate aorta and start cold perfusion
- vent IVC (in the abdomen or chest)
- clamp the supradiaphragmatic aorta
- topical cooling
- portal cannulation and perfusion
- bile flush.
- Cold phase dissection

Normothermic regional perfusion (NRP)

Normothermic regional perfusion (NRP), also known as normothermic extracorporeal membrane oxygenation (NECMO), is a new and novel technique of

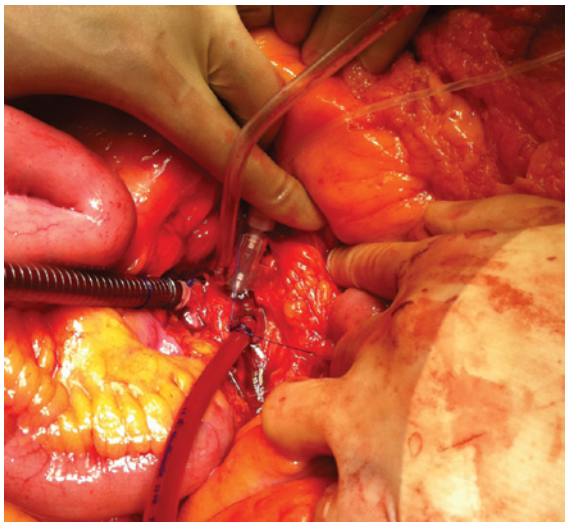

Figure 7.4 Aortic and IVC cannulas in position for NRP in standard DCD.

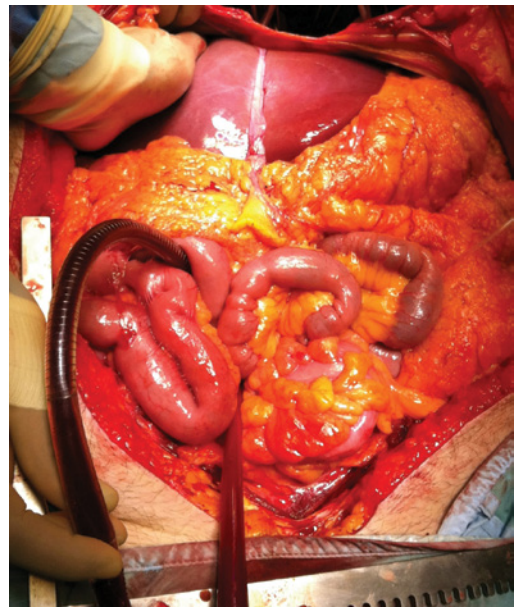

Figure 7.5 Intraoperative appearance of NRP-perfused abdominal organs.

improving the quality of grafts and expanding the donor pool from DCDs. It acts as a bridge between asystole and successful procurement as it enables the rehabilitation of marginal DCDs and permits organ assessment under nonischemic conditions, by creating a regional abdominal warm perfusion circuit. NRP also helps recover ischemically damaged livers from uncontrolled DCDs, thus enabling transplantation with acceptable survival. NRP support may contribute towards an increased donor pool and preliminary results for category III DCD appear promising, with more liver grafts from marginal controlled DCD offered for transplantation.

NRP has already shown great potential to improve results in uncontrolled liver donors and may also become, in the near future, the standard of preservation for controlled donors [6].

The concept is that of restoring regional circulation of oxygenated blood in the donor after certification of death. This has been done by premortem cannulation under local anesthesia of the femoral vein and artery of the prospective DCD at the University of Michigan where this practice is allowed together with systemic heparinization. The contralateral femoral artery is also cannulated with a balloon catheter that is positioned in the thoracic aorta to prevent recirculation of the heart and brain. After certification of death, NRP is started for a period of 90–120 minutes with the following settings:

- 100% oxygen at 4 L/minute
- flow rate adjusted to $PaCo_2$ 30–50 mm Hg
- sodium bicarbonate to maintain pH 7.1
- heparin to maintain clotting time for more than 500 seconds.

This protocol can be adapted to the traditional DCD, with postmortem cannulation of the aorta and abdominal IVC immediately after laparotomy (Figures 7.4 and 7.5).

After NRP is completed, the surgical team proceeds with a thoracolaparotomy and cold perfusion of the abdominal organs as for the usual cold rapid retrieval.

Establishing an NRP-supported DCD program is a complex undertaking. Tailoring such a program to make provisions for current legislation and ethical guidelines would be necessary and intricate. If successful, an NRP-supported DCD program would offer substantial benefits by improving graft quality and contributing to meeting donor organ needs. Moreover, it has the potential to transform traditional thinking

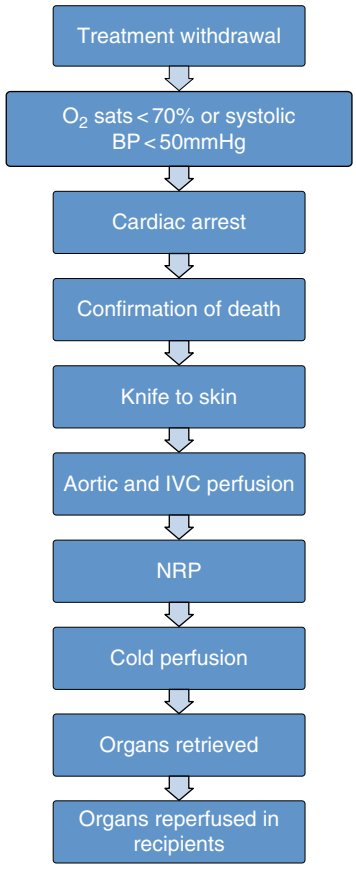

Figure 7.6 NRP DCD retrieval pathway.

on organ procurement methods. Ultimately, this will be determined by public and professional acceptance and patient need. The NRP DCD retrieval pathway is illustrated in Figure 7.6.

Bench perfusion and packing

Bench arterial perfusion with pressure has shown to be effective in preventing ischemic-type biliary strictures and is an essential part of the procurement of a DCD liver. The volume of UW to obtain a clear perfusate should not exceed 400 mL in the hepatic artery and 600 mL in the portal vein. The recommended perfusion pressure in the coeliac artery for the *ex situ* perfusion should be 80–120 mmHg. The CBD is flushed with a heparin needle syringe several times with UW aspirated from the bowl, to minimize the risk of ischemic bile duct injury and postoperative intrahepatic biliary strictures.

Uncontrolled DCD

Uncontrolled DCDs are more likely to be trauma victims, younger and healthier individuals, yet the use of these grafts is still limited. Death often occurs after prolonged periods of resuscitation maneuvers, leading to substantial injury from warm ischemia, the real extent of which is difficult to assess.

Maastricht DCD categories I and II have been revisited mostly in Spain, where withdrawal of life support and controlled donation are not yet fully supported for medicolegal reasons.

As donation interventions need to be initiated quickly, the surrogate decision makers are unlikely to be immediately available to provide consent.

Retrieval procedure technique

The organization required to cope with an uncontrolled DCD program is unique and needs a dedicated on-call team 24 hours a day. In Madrid, for example, special ambulances, staffed with a physician and nurse trained in critical care, are equipped to provide intensive medical care to seriously ill patients.

When a potential category I or II donor suffers cardiac arrest and all resuscitation attempts fail, cardiopulmonary resuscitation (CPR) is suspended for a 5-minute interval, after which death is declared. CPR is resumed manually or by means of a mechanical compression device, either in the mobile ICU unit or in the emergency room after death is certified. Automatic mechanical devices (piston, load distributing band, vest CPR and Lund University cardiac arrest system) provide high quality chest compressions, which are more effective than manual CPR in maintaining organ perfusion [7]. Cold perfusion fluids failed to provide viable uncontrolled DCD livers for transplantation, and have been replaced by NRP circuits. Monitoring of blood parameters and bypass flow are maintained until cold preservation is established at retrieval [8].

The procurement follows and is divided into three phases:

Phase 1: Dissection phase while on NRP

Phase 2: Discontinuation of CPR/NRP

Phase 3: Organ perfusion with cold preservation solution using standard retrieval techniques.

Mechanical ventilation, external massage and NRP in uncontrolled DCD are means to maintain organ viability until permission can be obtained from the family to proceed to donation. NRP, by providing prolonged organ preservation, grants more time to locate the next of kin, allowing the family the opportunity to decide on organ donation.

Preservation solutions

Effective washout of the DCD liver microvasculature during retrieval is essential for optimal preservation. If the blood remnants in the liver are not completely washed out of the microcirculation, perfusion of the biliary tree and graft viability may be compromised.

There is not enough evidence that a room temperature preflush with a fibrinolytic drug is of benefit in terms of graft function and survival. If one of the multiorgan teams wishes to use a warm preflush it should be discussed well in advance and in detail with the other teams as it can significantly delay cold perfusion and prolong DWIT.

A better approach to administer fibrinolysis is described by the Cleveland group and is done when the liver is removed from the icebox and prepared for implantation. This entails injecting room-temperature recombinant tissue plasminogen activator (rTPA) (0.5 mg/100 g of graft) in the hepatic artery. If post-reperfusion bleeding is anticipated, a lower dose of rTPA (0.2–0.4 mg/100 g of graft) should be used. Both normal saline and blood flush are performed in the recipient to limit the systemic effects of rTPA [9].

DCD livers should be transplanted with CIT of less than 8 hours; therefore most of the current crystalloid-based, low-viscosity preservation solutions should be suitable, including Euro-Collins, Marshall, HTK and Celsior solution. HTK has recently gained popularity as a washout and preservation solution for DCD livers.

Advantages of HTK compared to UW include lower viscosity, faster cooling rates, a low potassium content that avoids the need for the portal flush prior to reperfusion and inferior cost. An analysis of the United Network for Organ Sharing (UNOS) database, comparing 575 liver grafts UW-preserved and 254 HTK-preserved, however, showed that HTK was independently associated with a 44% increased risk of graft loss compared to UW [10].

HTK preservation is associated with a higher risk of graft failure compared with UW preservation.

As *in situ* aortic perfusion has been shown to be inadequate in delivering physiological pressures in the hepatic artery, high-pressure *in situ* and *ex situ* perfusion has been suggested as a technique to improve perfusion of the hepatic arterial tree, therefore more effectively flushing the microcirculation of the bile ducts, aiming at reducing biliary complications.

Although machine perfusion of the liver with cold preservation solutions may have theoretical advantages, it has not reached widespread clinical use as with kidney transplantation. Guarrera first demonstrated the safety and reliability of hypothermic machine perfusion (HMP) with a pilot case-controlled series of 20 adults transplanted with HMP-preserved livers at the Columbia University Medical Center [11].

Assessment of DCD liver grafts

Assessment of the suitability of a DCD for liver donation remains difficult and somehow subjective to the experience of retrieving and implanting surgeons. Several parameters to identify the best DCD liver have been reported [12,13].

Ideal DCD liver parameters include:

- age less than 50 years
- DWIT less than 2 minutes
- CIT less than 8 hours
- minimal steatosis

Transplants of these ideal DCD liver grafts achieve similar results to that of recipients of standard DBD livers.

The DCD liver seems to be more edematous than the standard DBD liver graft and the verdict of suitability of a DCD liver for transplantation is still generally made on gross appearance, ease of perfusion, degree of steatosis and thorough evaluation of donor characteristics.

Liver biopsy is of limited value and a comparison of postreperfusion biopsies of DCD and DBD livers performed by a blinded pathologist showed no differences between the two types of grafts. Other markers, including glutathione S-transferase and xanthine oxidase, have not proved to be reliable indicators of DCD liver graft quality. The relevance of hepatocyte viability with trypan blue exclusion technique was also assessed in choosing DCD liver grafts for transplantation, though it was not valuable in terms of graft selection [14].

Extracorporeal liver machine perfusion (hypothermic or normothermic) is a promising tool that may soon contribute to improved safety and outcomes of DCD liver grafts. The development of effective new means to preserve, resuscitate and assess controlled and uncontrolled DCD grafts may, in the future, see these donors challenge or surpass cadaveric heart-beating and living donation as a source of livers for transplantation.

Summary box

- Brief team about the steps of the procedure.
- Check donor paperwork.
- Set up the bench and the perfusion kits prior to starting the procedure.
- Be aware of organ-specific withdrawal and donor warm ischemic times.
- A modified super-rapid retrieval technique improves organ perfusion and facilitates a faster organ recovery, reducing the warm ischemic time.
- Dual aortic and portal perfusion is employed in DCD.
- The benefit of systemic fibrinolysis is yet unclear.
- HTK preservation is widely used but appears to be associated with a higher risk of graft failure compared with UW.
- Assessment of DCD livers is difficult and subject to surgeons' experience.
- Bench arterial perfusion (pressurized) is effective in reducing the incidence of ischemic biliary strictures.
- DCD livers should be transplanted with a CIT of less than 8 hours.
- Uncontrolled DCDs (Maastricht category I and II) have the largest potential for expansion in the future.
- Uncontrolled DCD organ retrieval requires a specific organizational and retrieval process.
- Normothermic regional perfusion is a new technique, which may improve the quality of organs recovered from DCD and contribute to an increased donor pool.

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8 *In situ* Liver Splitting

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Introduction

Split liver transplantation (SLT) is a well-established technique for addressing the organ shortage by creating two functional grafts from a whole deceased donor liver. Since the inception of SLT, the vast majority of suitable organs have been shared between a pediatric and an adult recipient [1]. SLT has a great impact on decreasing waiting times and reducing mortality rates in pediatric patients [2, 3]. Since the early 2000s, small series of SLT for two adults have been reported and its feasibility is now broadly recognized [4,5,6]. However, it is still challenging to adapt SLT as a routine procedure because of technical and logistical issues, especially where MELD-based national allocation systems rule organ distribution [7].

Originally, SLT was started with *ex situ* splitting on the bench following a conventional whole liver procurement. Disadvantages of this technique include long cold ischemia time due to complex bench preparation and potential profuse bleeding after graft reperfusion [8]. Although implementation of *in situ* splitting has overcome these issues, it imposes a longer procurement time that requires more logistical coordination with the thoracic and other abdominal teams [8].

Donor and recipient evaluation

A careful donor and recipient selection is essential for the success of SLT [9]. Donors should be less than 50 years old and have normal liver function test. Since splitting *per se* is a known factor to compromise donor quality, any additional negative factors are discouraged [10]. High body mass index (BMI), history of heavy alcohol use and low platelet counts on admission are important pieces of information to rule out the probability of steatosis and fibrosis. Hypernatremia and inotropic support can be a negative factor, but the decision to proceed with splitting needs to be taken in combination with other factors (e.g. estimated cold ischemia time, length of ICU stay of the donor, MELD score, the degree of portal hypertension and recipient functional status).

Donor criteria for splitting:

- Age less than 50 years old.
- Normal liver function tests (can be up to 2–3 times normal).
- Short ITU stay (less than 5 days).
- Estimated cold ischemia time (less than 8 hours).
- High sodium and inotropic support are important but not absolute contraindications.

Evaluation by the donor surgeon with a direct visualization is of the highest importance. The consistency and colour of the liver need to be examined to assess the quality of the liver. If the appearance of the liver is not normal, liver biopsy is indicated. Pathological changes such as macrosteatosis, inflammation, fibrosis and cholestasis are contraindications for splitting.

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Contraindications for splitting after direct visualization and biopsy

- Fatty liver: macrosteatosis (more than 10%).
- Inflamation.
- Fibrosis.
- Cholestasis.

Once the decision to proceed is made, the recovering team must coordinate with the recipient surgeon to minimize cold ischemia time.

Graft size is an important issue. Splitting at the falciform ligament yields a left lateral segment graft (S2–3) and a right trisegment graft (S1+S4–8) (line A in Figure 8.1). The left lateral segment graft is generally suitable for pediatric recipients. When a small baby is the recipient, the graft to recipient weight ratio (GRWR) should not exceed 5%. If this is the case, the partial graft has to be further reduced to avoid problems with abdominal closure and subsequent vascular complications. In splitting for two adult patients, the liver is divided into a right lobe (60–70% of the liver) and a left lobe (30–40% of the liver) (line B).

In living donor liver transplantation, the minimal amount of hepatocyte mass to meet the recipient's metabolic demand is considered as GRWR 0.6–0.8%, but the minimal GRWR in SLT remains unclear. Given the negative factors in SLT such as longer cold ischemia time and donor's hemodynamic instability associated with brain death, the GRWR should be at least greater than 0.8% and ideally greater than 1.0% [11].

In recipient selection, small adults with minimal portal hypertension are good candidates for the left lobe graft. The selection for the right lobe graft can be more liberal, but those with severe portal hypertension should be avoided when the estimated GRWR is less than 1.0% [11]. The indication to use the right trisegment graft is the same as for the whole liver graft.

As long as both grafts have a complete set of vessels and biliary drainage, anatomical variations are not considered to be a contraindication to splitting. In most cases, the vena cava and common bile duct remain with the right-sided graft (adult vena cava does not fit pediatric recipients). In left/right splitting, the middle hepatic vein is preserved in the left lobe graft. In the right lobe graft, large drainage veins of the anterior segment should be reconstructed to prevent graft congestion. The celiac trunk and the main portal vein can be preserved with either graft, but the decision generally depends on who the primary recipient is for the whole graft. The decision also depends on the recipient's size and anatomy (e.g. the presence of portal vein thrombosis).

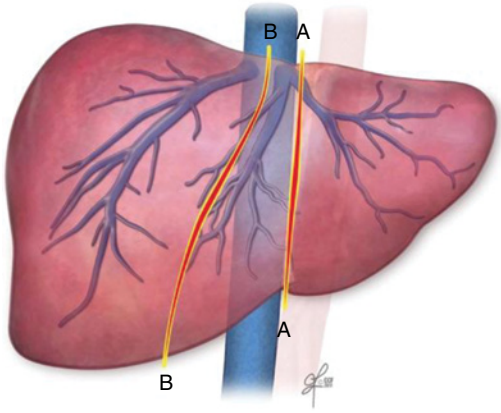

Figure 8.1 Liver splitting options.

Summary box for donor and recipient evaluation

- Consider the following donor factors prior to splitting: age, BMI, history of alcohol intake, platelet count on admission, length of ICU stay, hypernatremia, inotropic support, estimated cold ischemic time.
- Recipient factors to be considered for selection: MELD score, degree of portal hypertension, functional status.
- GRWR should be at least greater than 0.8% and ideally greater than 1.0% when splitting for two adults.
- Small adults with minimal portal hypertension are good candidates for a left lobe graft.
- GRWR should not exceed 5% for small babies.
- Indications for a trisegment graft are the same as for whole graft.

Surgical techniques

Left (S1–4) and right (S5–8) lobe grafts

Laparotomy and mobilization of the liver

A midline incision is made from the upper edge of the sternum to the pubis. The round ligament is tied and divided. After the falciform ligament is taken down with electrocautery, sternotomy is performed. A Balfour retractor is applied to expose the entire

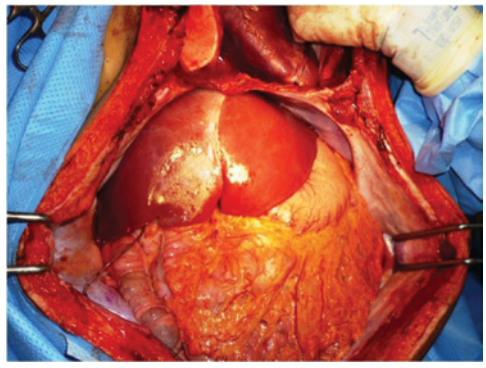

Figure 8.2 Liver assessment.

abdominal cavity. The liver is assessed to ensure that it can be used for splitting (Figure 8.2).

If the appearance of the liver is not normal, a liver biopsy should be performed or splitting can be aborted at this point. An estimated weight of the left and right lobe should be notified to the recipient surgeon.

The left lateral segment is mobilized by taking down the left triangular ligament, coronary ligament and gastrohepatic ligament. If there is an accessory left hepatic artery, it must be preserved. If there is a decent sized vein in the gastrohepatic ligament, the left accessory artery is likely to exist even if pulse is not felt on it.

The base of the left and middle hepatic veins is dissected and exposed (Figure 8.3).

The right triangular and coronary ligaments are taken down.

The assistant gently holds the right lobe up to better expose the lateral aspect. Great attention is necessary in order not to tear the capsule of the liver (Figure 8.4).

The hepatorenal ligament and bare area of the liver are dissected until the retrohepatic vena cava appears. The hepatocaval ligament does not need to be divided, unless the vena cava remains with the left lobe graft.

Hilar dissection

The gallbladder is removed. A cholangiogram is performed through the cystic duct to rule out any anatomical variants making splitting unfeasible. If a cholangiogram is not available in the donor hospital, the distal common bile duct can be transected to probe the bile duct.

The hepatic hilum is examined manually to delineate the anatomy of the arterial blood supply. The right replaced hepatic artery usually runs posterior to the portal vein.

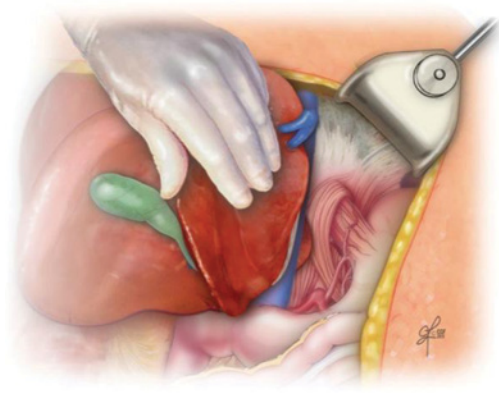

Figure 8.3 Exposure of middle and right hepatic veins.

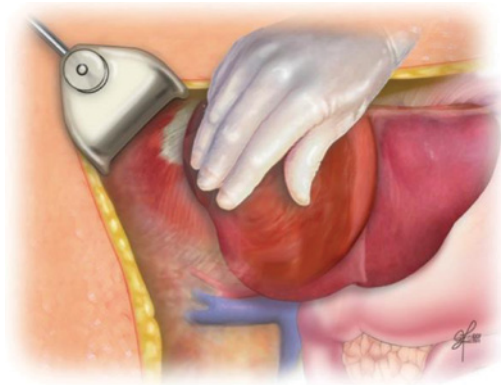

Figure 8.4 Mobilisation of the right lobe.

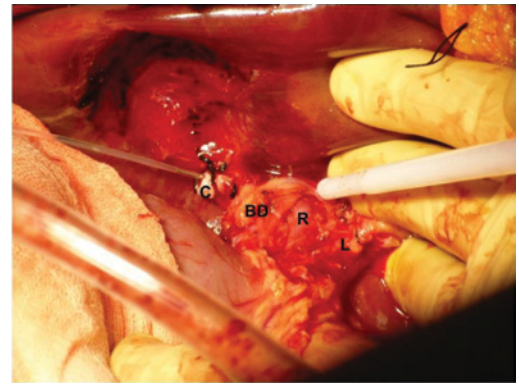

Figure 8.5 Hepatic artery dissection. (BD, bile duct; C, cystic duct; L, left hepatic artery; R, right hepatic artery)

The bifurcation of the hepatic artery is identified and dissected (Figure 8.5).

When performing a right hepatectomy in living donors, dissection of the hepatic hilum must be

started on the right side of the bile duct and the arterial bifurcation is left untouched to ensure blood supply to the common bile duct. In split liver procurement, however, arterial dissection is performed at the bifurcation.

The right aspect of the hepatic hilum is dissected for the purpose of isolating the main portal vein and identifying a replaced right hepatic artery. However, since this dissection can be safely done on the bench, this step does not need to be completed before cross-clamping. The short hepatic veins of the left lobe are divided to detach the left caudate lobe from the vena cava. However, this step also can be easily and safely done on the bench.

Portal vein dissection and ligation of the left lobe short hepatic veins can safely be done on the bench.

Preparation for liver hanging maneuver

The goal of the hanging maneuver is to isolate liver parenchyma from the vena cava and hepatic hilum on the transection line. The groove between the right and middle hepatic veins is dissected and exposed. The space between the liver and retrohepatic vena cava is tunneled downward from this groove (Figure 8.6).

By holding the right lobe up, a Kelly clamp is horizontally introduced toward the groove along the anterior surface of the infrahepatic vena cava to complete tunneling. After 4–5 cm of gentle blind dissection, the clamp appears between the right and middle hepatic veins (Figure 8.7).

An umbilical tape is grabbed by the clamp and passed through this tunnel (Figures 8.8, 8.9 and 8.10).

A few branches of short hepatic veins can be divided before tunneling to prevent bleeding, but branches greater than 5 mm have to be preserved for better venous drainage of the right lobe.

An angled clamp is introduced into the liver parenchyma from point A (0.5 cm above the bifurcation of the hepatic hilum) and passed behind the hepatic hilum. The tip of the clamp appears at point B (0.5 cm below the bifurcation) and the umbilical tape is pulled back through liver parenchyma (Figure 8.11).

There are no major vessels or bile ducts in this area of liver parenchyma where the clamp

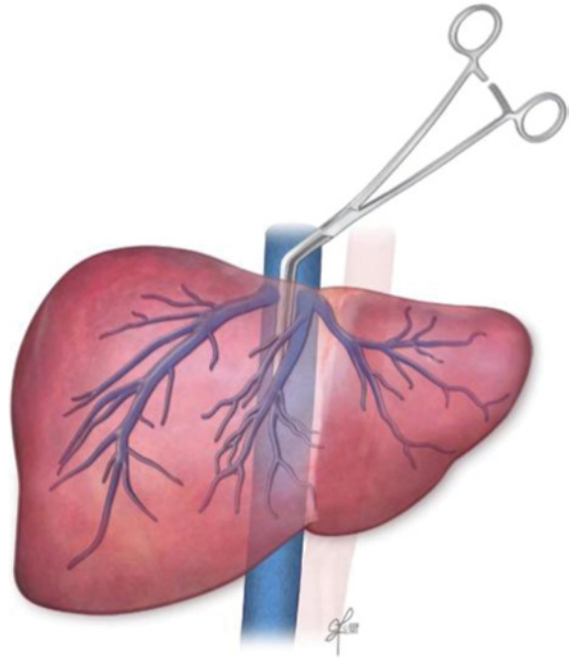

Figure 8.6 The precaval plane is developed.

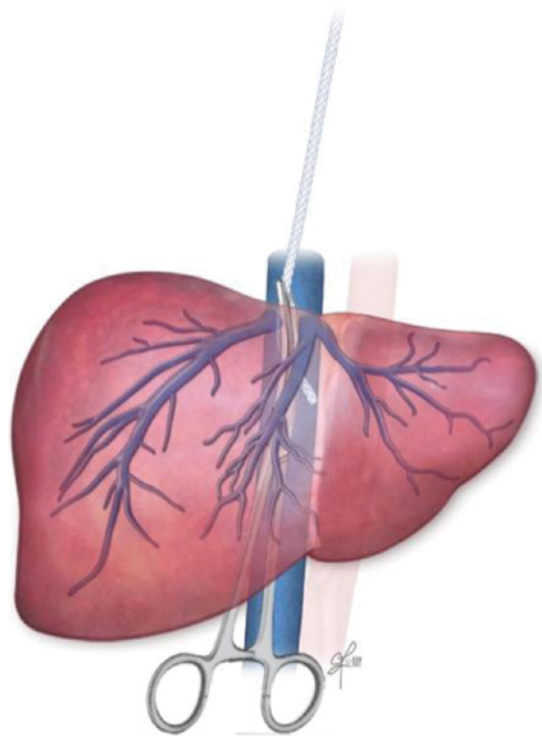

Figure 8.7 The retrohepatic, precaval plane fully developed.

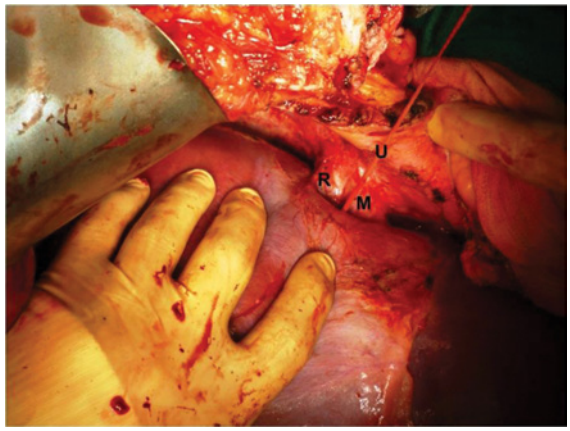

Figure 8.8 Position of the umbilical tape in relation to the hepatic veins. (IVC, infrahepatic vena cava; M, middle hepatic vein; R, right hepatic vein; U, umbilical tape)

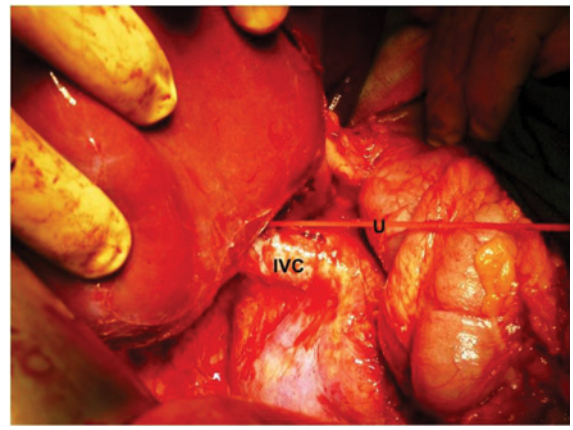

Figure 8.10 Position of the umbilical tape in relation to the infrahepatic IVC. (IVC, infrahepatic vena cava; U, umbilical tape)

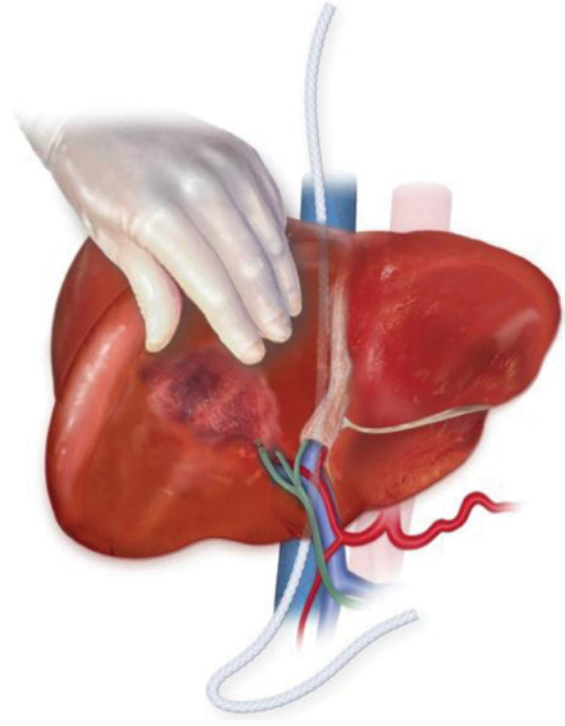

Figure 8.9 Umbilical tape in position behind the liver.

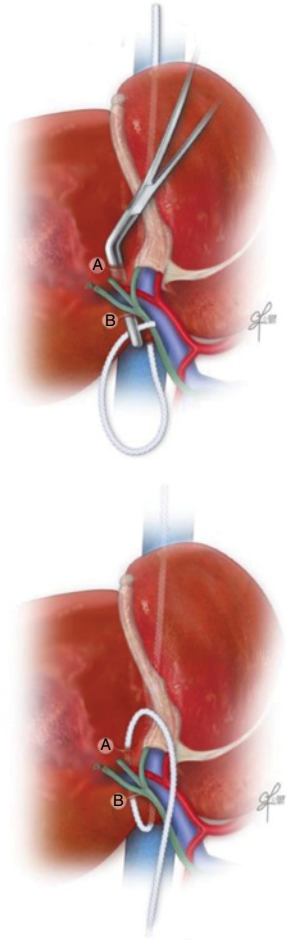

Figure 8.11 Umbilical tape is placed in front of the hilar structures.

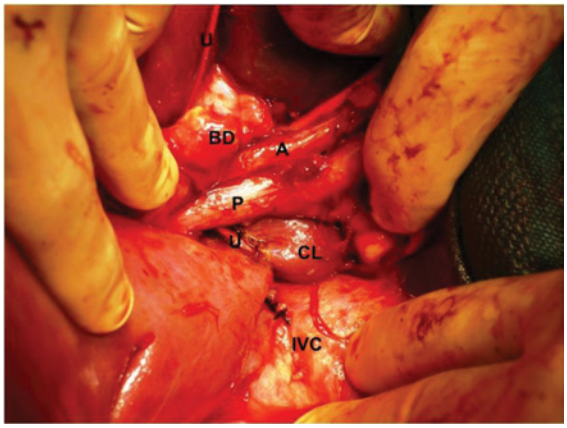

Figure 8.12 Intraoperative view of the umbilical tape in relation to the hilar structures. (A, hepatic artery; BD, bile duct; CL, caudate lobe; IVC, infrahepatic vena cava; P, portal vein; U, umbilical tape)

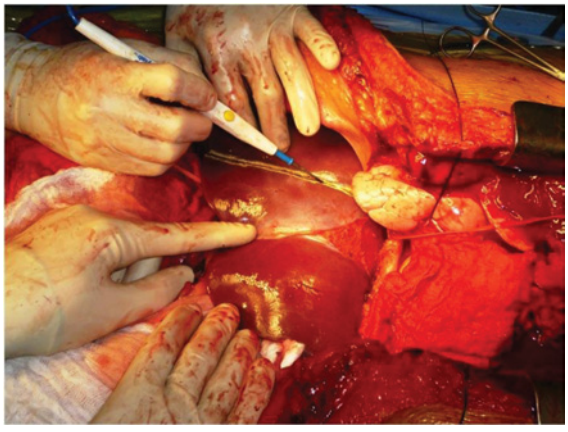

Figure 8.13 Superficial marking of the transection line.

passes through. Only minor bleeding may occur in this step (Figure 8.12).

If a clamp is introduced along the cephalad margin of the bifurcation, a tip of the clamp may migrate into the hilar structures, resulting in serious bleeding or bile leakage.

An angled clamp should pass through liver parenchyma, not along the cephalad margin of the liver hilum, to avoid serious injury to the hilar structures.

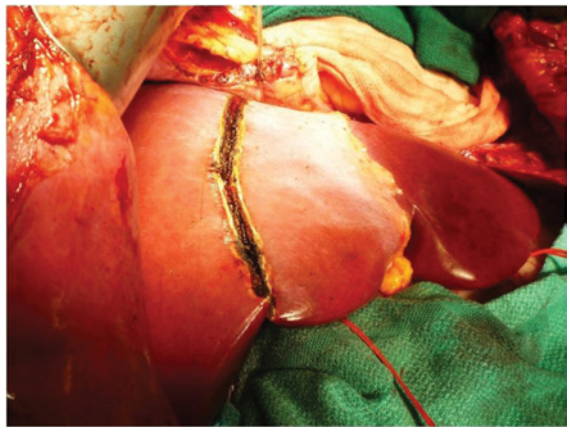

Figure 8.14 Superficial parenchymal transection on the anterior surface of the liver.

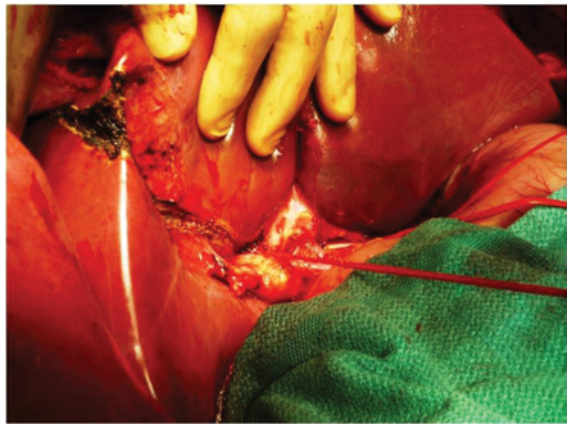

Figure 8.15 Superficial parenchymal transection on the inferior surface of the liver.

Parenchymal transection

The liver is rotated toward the left and sponges are placed in the right subphrenic space. A transection line is marked by an electrocautery along the Cantlie line (Figure 8.13).

This line can be deepened to 0.5–1 cm since there are no important vascular structures present (Figures 8.14 and 8.15).

Because the transection line in right and left splitting is detemined based on the anatomy of the middle hepatic vein, it is not neccesary to confirm the demarcation line by a temporary hemihepatic inflow occlusion.

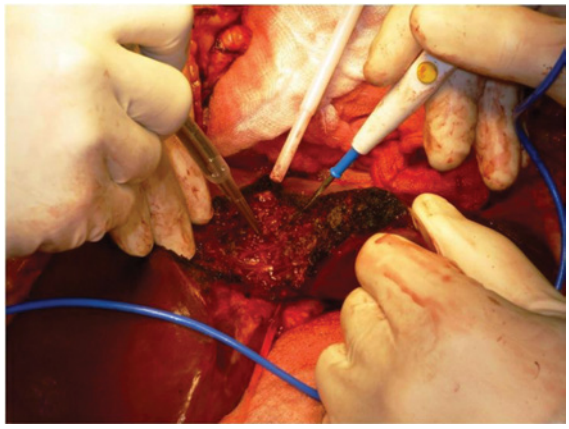

Figure 8.16 Parenchymal transection technique.

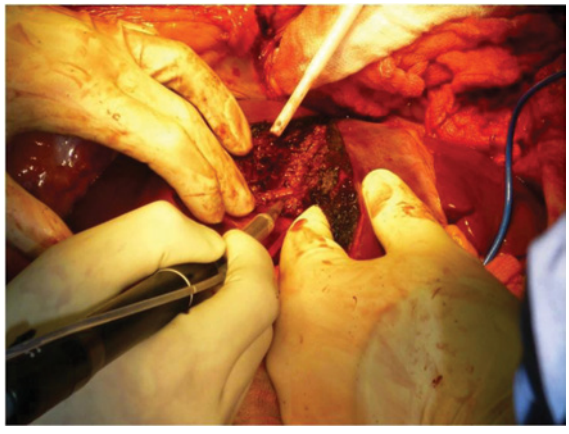

Figure 8.17 Ligation of segment 5 vein.

Parenchymal transection can be carried out by any available methods in the donor hospital (clamp-crushing technique, CUSA, LigaSure, Water-jet, etc.) (Figure 8.16). The Pringle maneuver is usually unnecessary.

If major bleeding occurs during transection and the donor becomes unstable, do not hesitate to stop splitting and proceed to cross-clamping in coordination with the thoracic team.

The intraparenchymal vessels are generally easy to identify. Small vessels (less than 1 mm) can be cauterized. Bigger vessels are tied or clipped, depending on their size. The middle hepatic vein remains with the left lobe graft.

A tributary of the middle hepatic vein is identified and followed until the segment 5 vein (V5) is identified (Figure 8.17). The V5 is tied on the middle hepatic vein and clipped toward the right lobe.

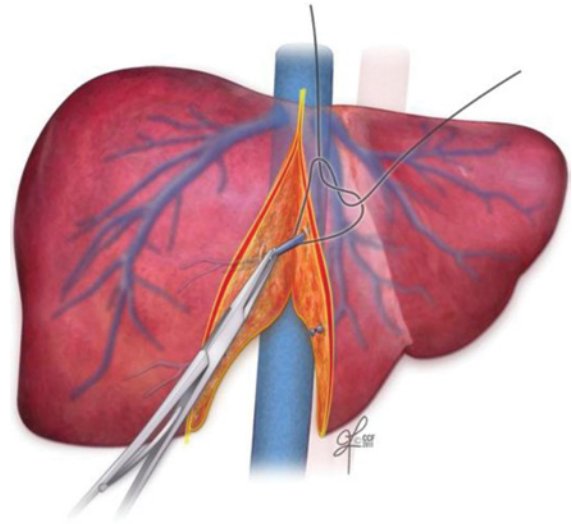

Figure 8.18 Ligation of segment 8 vein.

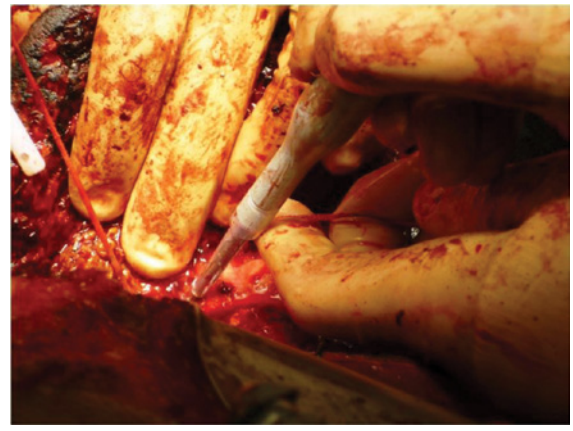

Figure 8.19 Hanging maneuver to assist parenchymal transection.

The segment 8 vein (V8) is also divided in the same manner (Figure 8.18).

To prevent bleeding from small branches of the middle hepatic vein, the transection line stays on the right side of the middle hepatic vein to leave a layer of parenchymal tissue over the middle hepatic vein.

During parenchymal transection, both ends of the umbilical tape are pulled to give upward traction (Figure 8.19).

This facilitates the exposure and hemostasis by elevating the liver away from the vena cava. Once the V5 is identified, subsequent parenchymal transection is performed to keep the cutting surface vertical toward the umbilical tape. When a large inferior right hepatic vein is encountered, it must be preserved.

The liver is completely separated into the right and left lobes and the anterior aspect of the retrohepatic vena cava is exposed (Figure 8.20).

At this moment, the graft is ready for cross-clamping. After coordinating with the thoracic team, 30,000 units of heparin are administered intravenously. After 3 minutes of heparin infusion, the distal aorta at the level of the bifurcation is tied and a cannula is placed into the infrarenal aorta. The supraceliac aorta is cross-clamped and cold perfusion is started.

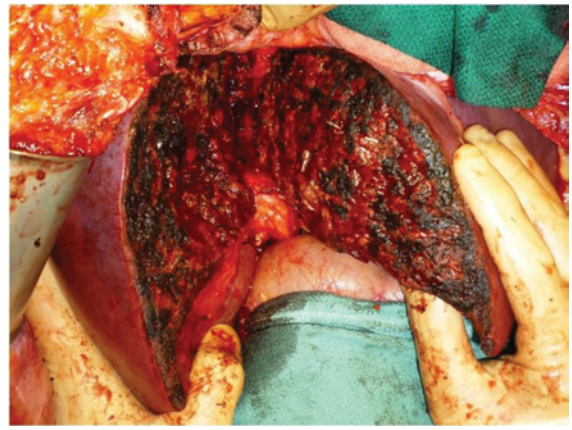

Figure 8.20 Completed parenchymal transection.

As soon as cold perfusion is started, remove the clips on V5 and V8 to ensure adequate perfusion and avoid congestion of the anterior segment.

The liver is subsequently taken out using a standard cold dissection technique (Figure 8.21).

The donor surgeon must retrieve both iliac arteries and veins of good length and quality. If iliac artery and vein grafts need to be shared with pancreas and intestine teams, extra grafts must be taken (e.g. carotid artery, subclavian artery and vein, femoral artery and vein, internal jugular vein and innominate vein).

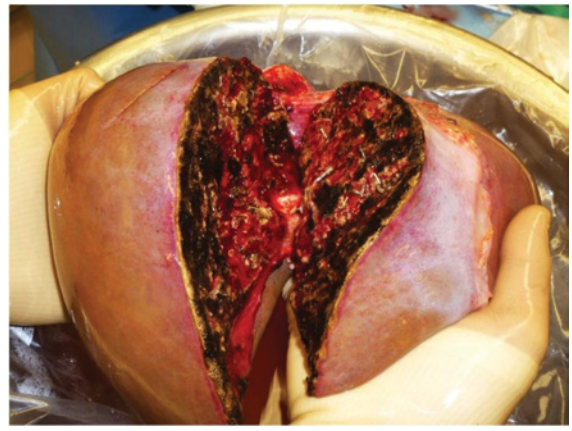

Figure 8.21 Split liver graft appearance on the bench.

Bench preparation to separate into the left and right lobe

The liver is placed in a basin to perfuse it through the main portal vein. After making sure the liver is immersed in the cold preservation solution, stay sutures are placed on upper and lower edges of the vena cava. The adrenal vein and phrenic veins are tied (Figure 8.22).

The common channel of the left and middle hepatic veins is transected with a vena cava patch (Figures 8.23 and 8.24).

This technique ensures a good outflow of the left lobe without the need for a venoplasty, which commonly needs to be done in living donor liver transplantation (Figure 8.25) [12]. The defect on the vena cava provides perfect venous drainage from the V5 and V8 (refer to section **Reconstruction of tributaries of the middle hepatic vein**).

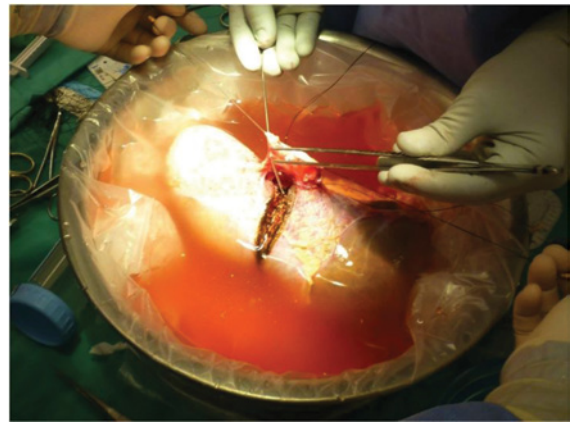

Figure 8.22 Ligation of venous tributaries to the IVC.

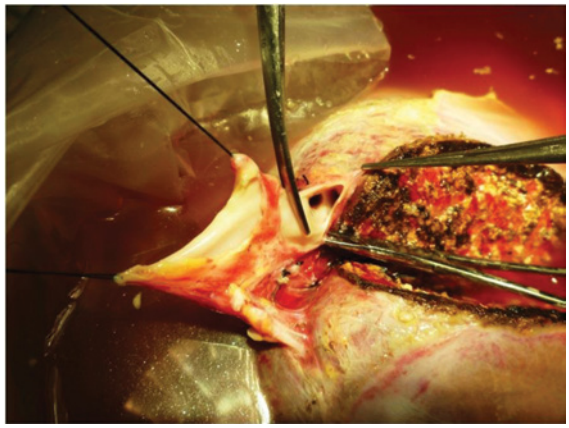

Figure 8.23 Detachment of the middle and left hepatic vein from the cava.

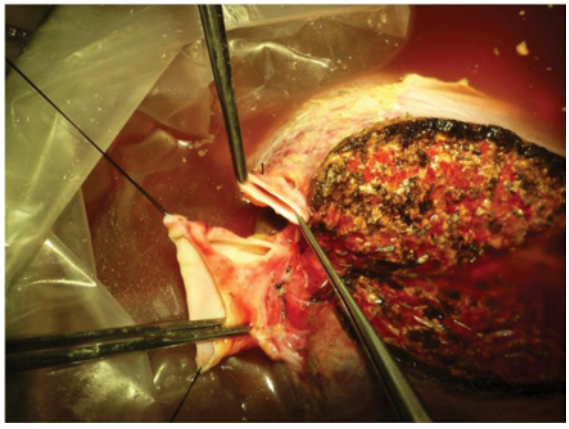

Figure 8.24 Completed transection of the venous outflow of the left graft.

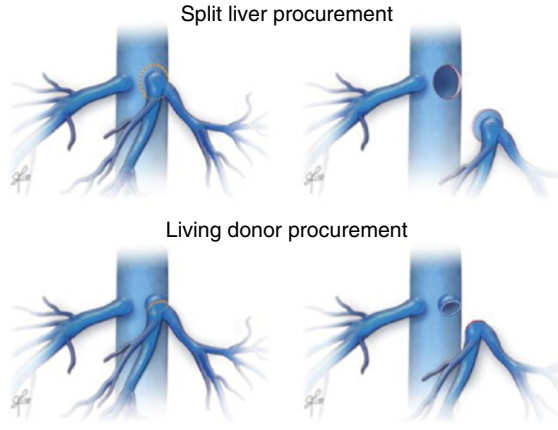

Figure 8.25 Comparison of split and living donor MHV/LHV procurement.

Undivided short hepatic veins of the left lobe are divided to detach the left caudate lobe from the vena cava. The main portal vein is dissected all the way to its bifurcation if it was not done *in situ*.

The left branch of the portal vein is dissected and transected 2–3 mm from the bifurcation (Figure 8.26). The caudate branch of the left portal vein usually needs to be tied and divided.

The stump on the main portal vein is closed transversely with 6–0 prolene running suture (Figure 8.27).

Do not close the stump longitudinally, because the risk of stenosis is high.

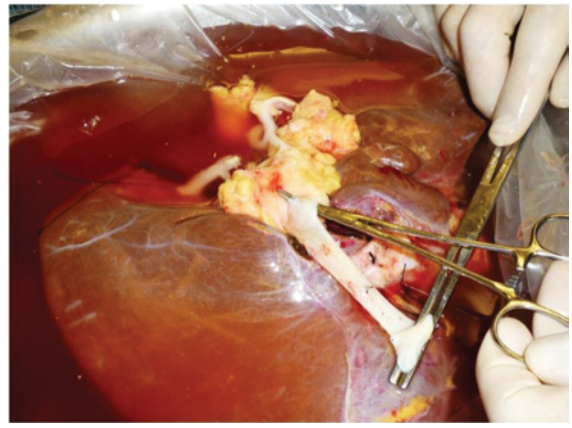

Figure 8.26 Transection of the left portal vein.

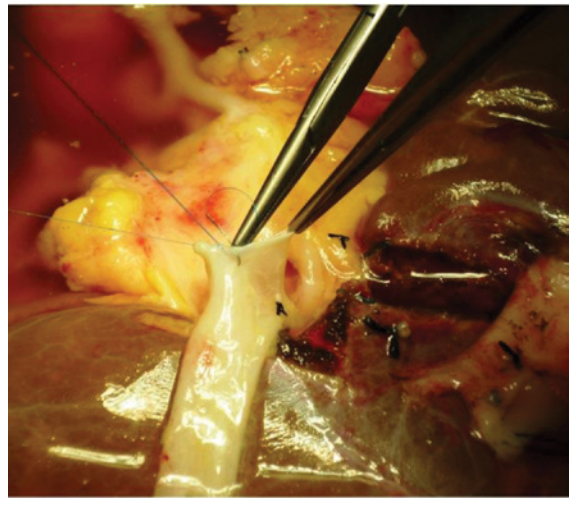

Figure 8.27 Transverse closure of the defect in the main portal vein.

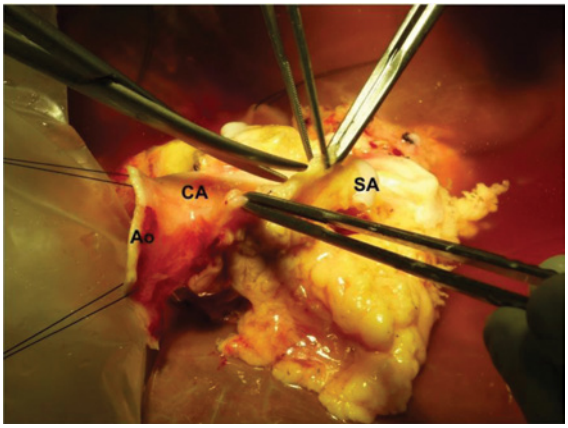

Figure 8.28 Arterial dissection. (Ao, aortic patch; CA, celiac artery; SA, splenic artery)

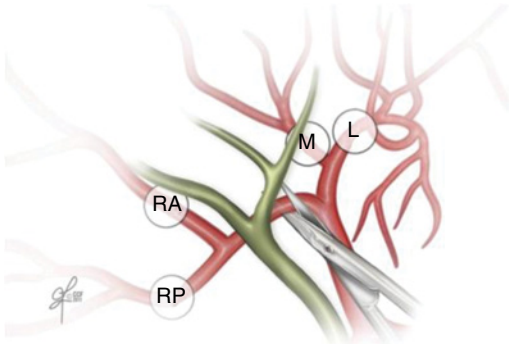

Figure 8.29 Division of the right hepatic artery. (L, left hepatic artery; M, middle hepatic artery; RA, anterior branch of right hepatic artery; RP, posterior branch of right hepatic artery)

The arterial component is dissected up to 1 cm distal to the takeoff of the splenic artery (Figure 8.28).

The arterial bifurcation is isolated and confirmed. The proper hepatic artery and the right and left hepatic arteries do not need to be skeletonized unnecessarily.

The right hepatic artery is transected distal to the bifurcation (Figure 8.29).

Great attention must be paid not to transect the artery too close to the main hepatic artery. When the middle hepatic artery is arising from the right hepatic artery, the right hepatic artery is transected distal to the middle hepatic artery (Figure 8.30).

Regardless of the anatomy of the middle hepatic artery, the right hepatic artery should be transected on the left side of the common hepatic duct to ensure its arterial blood supply.

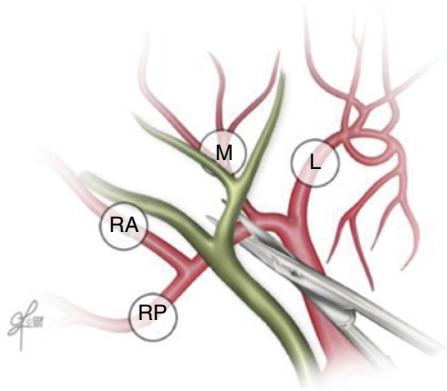

Figure 8.30 Correct plane of transection for the right hepatic artery. (L, left hepatic artery; M, middle hepatic artery; RA, anterior branch of right hepatic artery; RP, posterior branch of right hepatic artery)

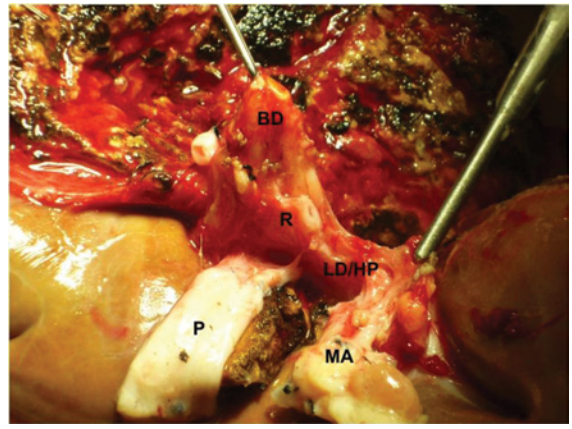

Figure 8.31 Intraoperative view of the completed vascular transection. (BD, bile duct; LD/HP, left hepatic duct and hilar plate; MA, main hepatic artery; P, portal vein; R, right hepatic artery)

At this moment, only the hepatic duct and hilar plate are intact at the hilum (Figure 8.31).

The bile duct is probed again to confirm the location of the biliary bifurcation (Figure 8.32).

The left hepatic duct with the hilar plate is transected at 0.5 cm from the bifurcation (Figure 8.33).

The proximal stump of the left hepatic duct is closed with 6-0 prolene running suture. Preservation solution is injected into the distal left hepatic duct to check for leakage from the hilar plate and the cut surface. Any leakages must be sutured.

Now, the left lobe is ready for implantation (Figure 8.34).

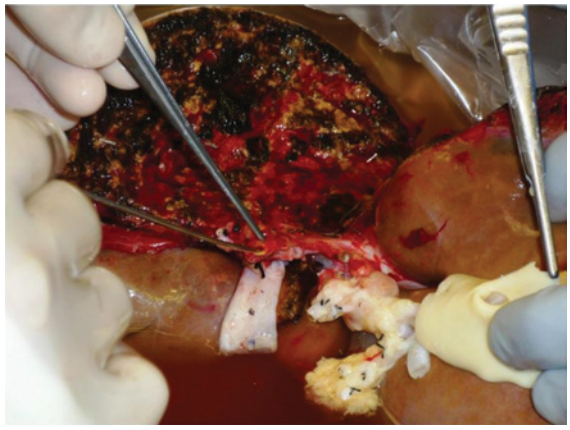

Figure 8.32 Identification of hilar biliary anatomy.

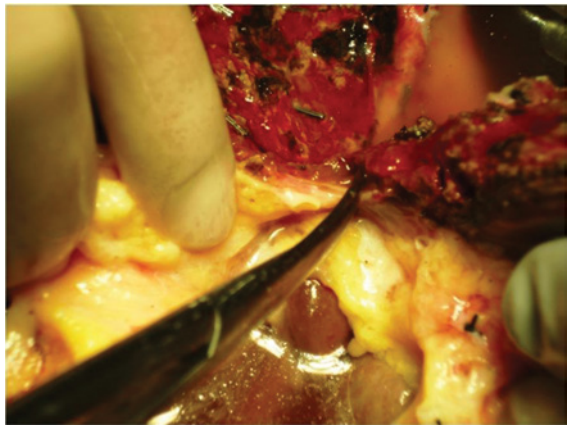

Figure 8.33 Left hepatic duct transection.

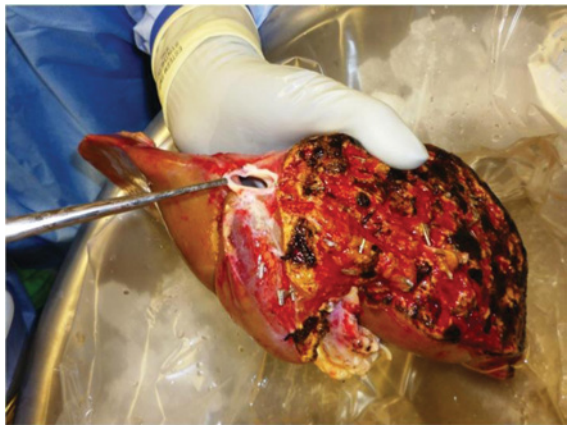

Figure 8.34 Final appearance of the left lobe graft.

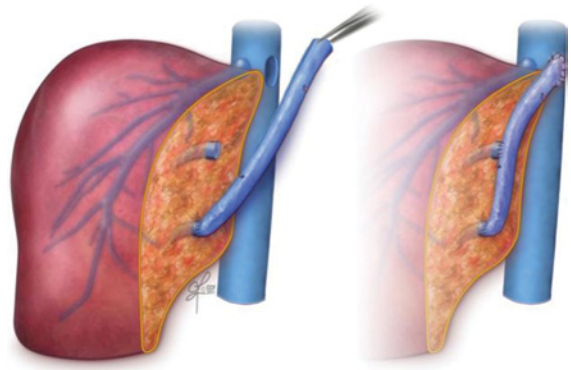

Figure 8.35 Reconstructive option for V5 and V8.

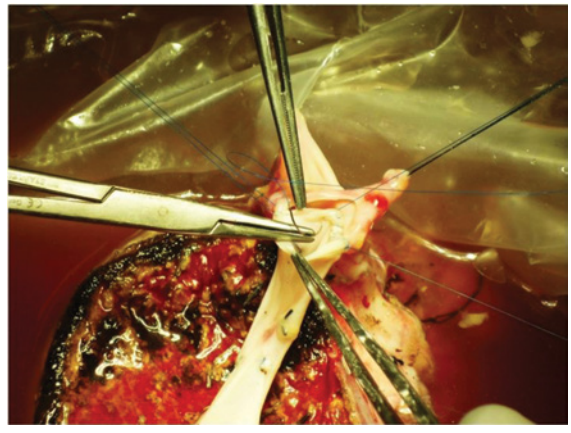

Figure 8.36 The iliac graft is anastomosed to the MHV/LHV caval origin.

Reconstruction of tributaries of the middle hepatic vein

A donor iliac vein graft is prepared for the reconstruction of the V5 and V8. If venous valves are identified in its lumen, these should be removed.

The proximal end is directly anastomosed to the defect on the vena cava where the left and middle hepatic veins were located (Figure 8.35).

An end-to-side or end-to-end anastomosis using 6–0 prolene running suture is performed for the V5. Subsequently, the V8 is reconstructed in an end-to-side fashion using 6–0 prolene running suture.

Lastly, an end-to-side anastomosis between the proximal end of the iliac vein graft and the defect on the vena cava is performed using 5–0 prolene running suture (Figure 8.36).

Preservation solution is injected into the common bile duct to check for leakage. Any leakages must be sutured. Now, the right lobe graft is ready for implantation (Figure 8.37).

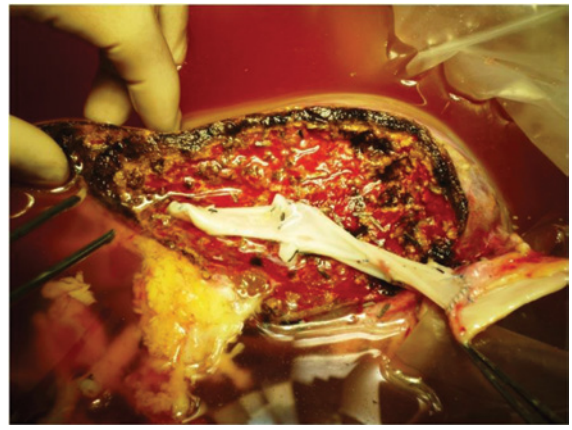

Figure 8.37 Final appearance of the right lobe graft.

Left lateral segment (S2+3) and right trisegment (S1, S4–8) grafts *in situ* splitting

After midline sternotomy and laparotomy, the liver is assessed. The left lateral segment is mobilized in the same manner as left/right splitting (Figure 9.3). Great attention has to be paid to the left accessory hepatic artery in the gastrohepatic ligament. If it exists, it must be preserved. After dividing the Arantius ligament, better approach to the left hepatic vein is achieved. The left hepatic vein does not need to be encircled.

The hepatic hilum is examined manually to delineate the anatomy of the arterial blood supply. The bifurcation of the hepatic artery is identified and dissected. The left branch of the portal vein is identified posterior to the left hepatic artery. Because the dissection of artery and portal vein can be safely done on the bench, only minimal dissection needs to be done *in situ*.

On the surface of the liver, a transection line is marked by an electrocautery on the right side of the falciform ligament. Parenchymal transection can be carried out by any available method in the donor hospital (clamp-crushing method, CUSA, LigaSure, Water-jet, etc.). The Glissonian triads to the medial segment are tied and divided.

After dividing the inflows, the medial segment becomes ischemic (Figure 8.38). However, this does not affect the outcomes of using the right trisegment graft, and the medial segment does not need to be resected.

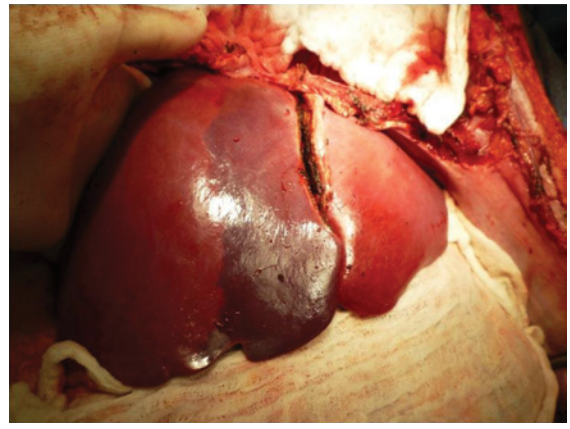

Figure 8.38 Ischemic appearance of segment 4.

Vessels are cauterized, tied or clipped, depending on their size. Usually, inflow occlusion (the Pringle maneuver) is not necessary during parenchymal transection.

The liver parenchyma is completely separated into the left lateral segment and right trisegment grafts (Figure 8.39).

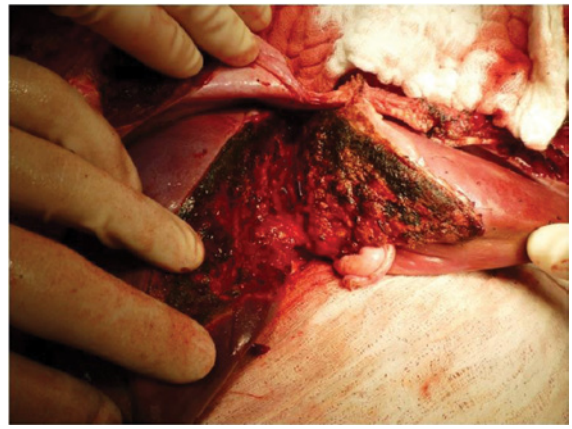

Figure 8.39 Completed parenchymal transection.

After cross-clamping, the liver is taken out of the donor using a standard cold dissection (Figure 8.40).

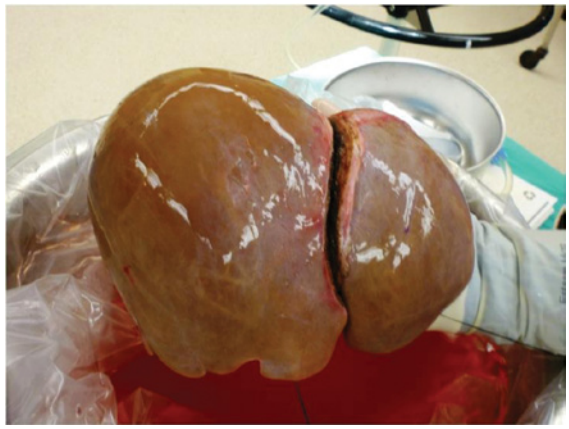

Figure 8.40 Bench appearance of the split liver (left lateral and trisegment grafts).

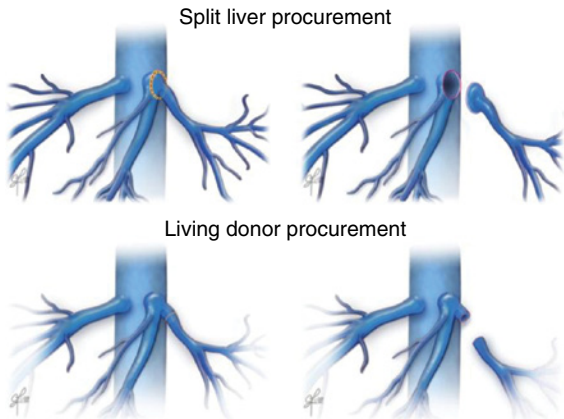

Figure 8.41 Comparison of split and living donor LHV procurement.

Bench preparation to separate into the left lateral segment and right trisegment grafts

After the standard preparation of the vena cava, the left hepatic vein is transected with a vena cava patch to give sufficient length of a venous cuff to the left lateral segment graft.

This technique makes venous anastomosis during implantation less challenging than living donor liver transplantation (Figure 8.41).

This technique does not compromise the outflow of the middle hepatic vein in the right trisegment graft. A piece of donor iliac vein graft is used to patch up the defect on the vena cava where the left hepatic vein

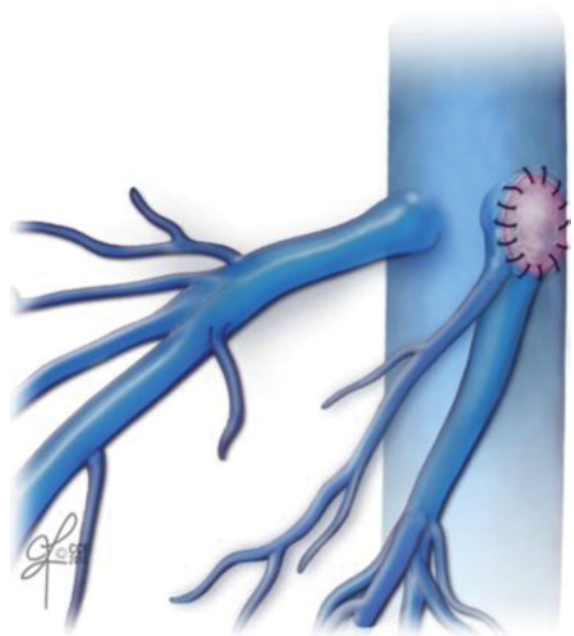

Figure 8.42 Patch closure of the LHV defect.

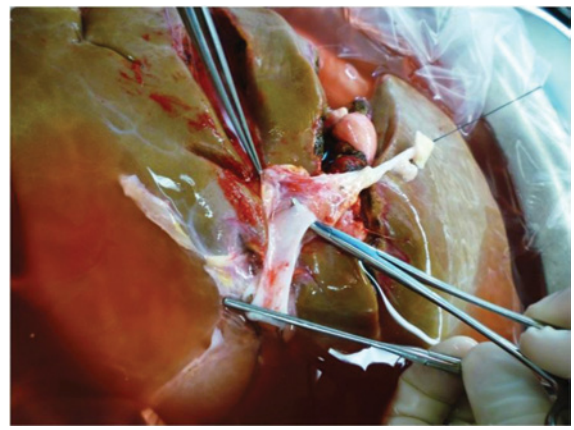

Figure 8.43 Division of the left portal vein in a left lateral split.

was located. Because a caval patch was taken with the left hepatic vein, a primary closure of the defect can cause an outflow problem of the middle hepatic vein (Figure 8.42).

The caudate branch of the portal vein is tied and divided. The left branch of the portal vein is isolated and transected 2–3 mm from the bifurcation (Figure 8.43).

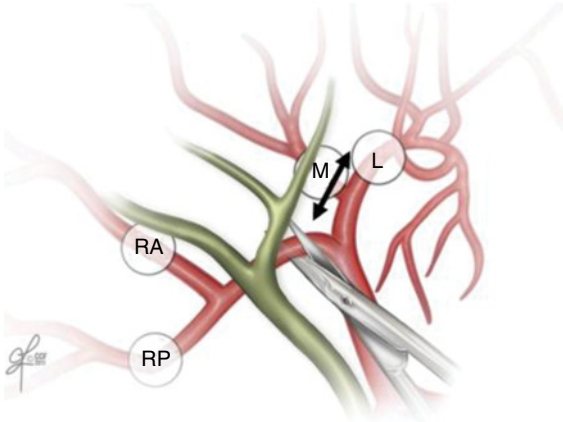

Figure 8.44 Arterial transection options for left lateral splitting. (L, left hepatic artery; M, middle hepatic artery; RA, anterior branch of right hepatic artery; RP, posterior branch of right hepatic artery)

The stump on the main portal vein is closed transversely with 6-0 prolene running suture (as previously described in Figure 8.27).

The right hepatic artery is transected distal to the bifurcation (Figure 8.29). The middle hepatic artery remains with the right trisegment graft to preserve arterial supply to the medial segment. However, the middle hepatic artery can be sacrificed if it arises from the left hepatic artery (Figure 8.44).

At this moment, only the hepatic duct and hilar plate are intact at the hilum. The biliary system is probed to confirm the anatomy. The left hepatic duct and hilar plate are transected on the line of parenchymal transection. Preservation solution is injected into the distal left hepatic duct to check for leakage. Any leakages must be sutured. Now, the left lateral segment graft is ready for implantation.

The proximal stump of the left hepatic duct is closed with 6–0 prolene running suture. Preservation solution is injected into the common bile duct to check for leakage. Any leakages must be sutured. Now, the right trisegment graft is ready for implantation.

Summary box

- All donors who fulfill the criteria should be considered for splitting.
- Discuss the splitting plans with the thoracic and the other abdominal teams.
- *In situ* liver splitting is logistically demanding but minimizes the cold ischemia time for both grafts.
- Liver splitting for two adults is technically more challenging but feasible.
- Do not hesitate to cross-clamp if the donor becomes unstable during the splitting procedure.
- Donor and recipient selection is a critical part of ensuring a successful outcome.

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9 *Ex situ* Liver Splitting

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Introduction

The development of split liver transplantation started with the left lateral *ex situ* split procedure, creating a left lateral graft for a child and an extended right graft for an adult recipient, by the German surgeon Pichlmayr in 1989 [1]. Since then, the feasibility of the *ex situ* technique and its safe application has been shown in several series [2]. Rogiers introduced a technical modification by performing the procedure *in situ* in 1995 [3,4]. Nowadays, the decision whether to perform the split procedure *in situ* or *ex situ* is often a logistical question, since the results do not differ significantly. However, dividing a liver graft *ex situ* offers a more flexible and practical application of liver splitting in situations where the logistical conditions for an *in situ* split are not met. Furthermore, the *ex situ* procedure allows a better use of the anatomy of the deceased donor liver. The prolonged ischemic time and the risk of premature warming of the graft remain the main challenges during the split procedure.

Performing the full split procedure by dividing a deceased donor liver along the line of Cantlie into hemilivers for transplantation of two adults marked further progress of this art [5]. Although its evolution is almost complete, this technically challenging procedure is still lacking wide application, due to the constraints of the liver allocation systems ('sickest first').

Selection of the deceased donor

The selection of the appropriate donor liver is of utmost importance. Over the years donor criteria have been established for split liver transplantation:

Donor criteria for split liver transplantation:

- Age of the donor less than 50 years.
- Hemodynamically stable.
- No or minimal inotropic support.
- Sodium less than 160 mmol/L.
- AST and ALT: less than double of normal value.
- GGT: less than double of normal value.
- BMI: < 30.
- ICU stay: less than 5 days

Several studies have shown that split liver transplantation can be safely applied in deceased donors fulfilling these criteria. However, in situations where one criterion is missing, a left lateral split can also be safely performed.

Full right–full left liver splitting should only be applied if all donor criteria are fulfilled, since both halves of the liver are resulting in a small for size situation.

The projected graft to recipient weight ratio (GRWR) should not be less than 1%. The additional damage to the liver of the deceased donor caused by the brain death situation does not allow a GRWR below 0.8. The degree of fatty change is also taken into account during splitting. In left lateral splitting the amount of fatty change should not exceed 30%, while in full right–full left split it should not be more than 15%.

Recipient selection

For safe and successful application of split liver transplantation, a careful recipient selection is crucial.

Abdominal Organ Retrieval and Transplantation Bench Surgery, First Edition. Edited by Gabriel C. Oniscu, John L. Forsythe and John Fung.

The first selection criterion is the recipient's body weight and the resulting GRWR. The commonly accepted GRWR is 1% in split liver transplantation [6], despite the published results with GRWR less than 0.8% with no inferior outcome [7,8].

Moreover, the recipient's weight is not the only factor; the general condition of the recipient and his or her constellation of risks also play a role. Split liver transplantation, especially in adults, should be performed in elective recipients and cautiously applied for high-urgent patients due to inferior results in these patients [8,9]. Transplantation of a split graft has been shown to be a negative predictor of survival in urgent patients [10,11].

Special attention must also be paid to patients with severe portal hypertension. The combination of a small for size graft and pre-existing severe portal hypertension cause injury to the graft by portal hyperperfusion [12,13], leading to a compensatory decreased arterial flow [14] and graft failure.

Therefore recipients with major portal hypertension should be excluded from transplantation with borderline-size segmental grafts.

Left lateral liver graft

The left lateral liver graft including segments II and III represents about 20–25% of the whole liver with approximately 250 cc in volume [15] and is usually allocated to a pediatric recipient. In most pediatric recipients, large for size is a more likely scenario than small for size since most of the pediatric recipients are below 25 kg of body weight. If the graft is too large for the recipient's abdominal cavity, a temporary closure of the abdomen with a silastic mesh is indicated to provide an appropriate graft perfusion. The liver graft will shrink and allows the definitive closure after 3–7 days.

In pediatric recipients, left lateral grafts derived from left lateral splitting can also be safely transplanted in high-urgency cases, since the graft size will meet the demand of these critically ill children in almost every case.

Extended right liver graft

The extended right graft resulting from left lateral splitting including segments I and IV–VIII represents about 75% of the liver volume with approximately 1100 cc. According to an average-weighing adult recipient, the extended right graft can be allocated in most situations like a whole liver organ, because this graft will provide a GRWR of more than 1%. The aspects mentioned above should be recognized, thus favouring elective recipients and avoiding high-urgent patients with history of major previous abdominal surgery, requiring a time-consuming hepatectomy, which prolongs the already extended ischemic time of the split liver graft.

Full right and full left hemiliver grafts

The donor selection criteria mentioned above are even more important in full right–full left liver splitting. The size of grafts resulting from the full split procedure also limits the pool of suitable recipients. The full right liver graft (segments V–VIII) with a weight of approximately 700–900 g is suitable for a recipient with body weight below 80 kg. The allocation of the full left lobe (segments I–IV) weighing approximately 300–600 g requires a small adult or an adolescent with less than 60 kg of body weight [16,17,18,19,20]. Usually only 20% of patients on the waiting list of a Western transplant centre are suitable for a left hemiliver.

Technique of the *ex situ* left lateral split procedure

The retrieval of the whole liver in the deceased donor can be performed in a regular fashion. The anatomy of the hilar structures, especially the presence of accessory or replaced hepatic arteries, should be ascertained and documented. After *in situ* perfusion of the deceased donor via the abdominal aorta, the liver should be additionally perfused on the bench via the portal vein stump, and the bile duct system should be flushed without any pressure, after removing the gallbladder. The liver is then stored in ice-cold preservation solution and shipped to the transplant center. The optimal temperature of 0–4°C will be reached after 1–2 hours. The total cold ischemic time, including the time of the split procedure of 1–2 hours, has to be kept as short as possible.

To prevent rewarming of the graft during the bench preparation, the graft has to be kept in cold preservation solution during the whole splitting procedure and should not be touched with warm hands by the splitting team.

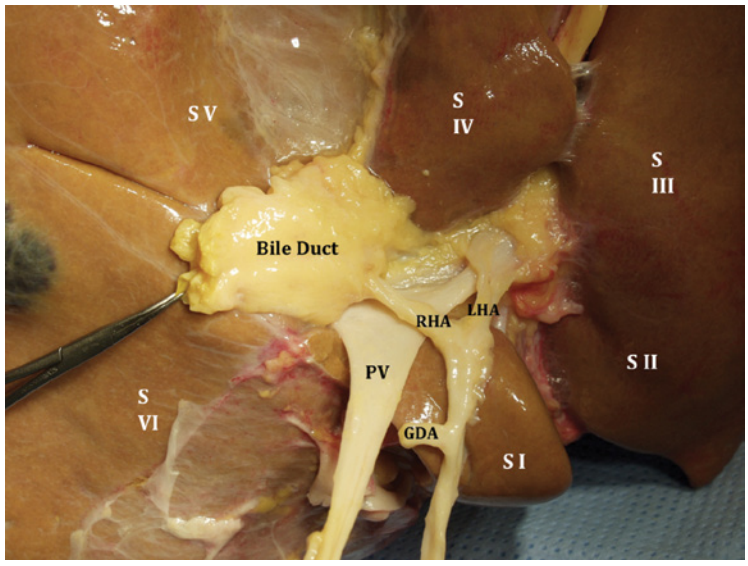

Figure 9.1 View of liver and hilum orientation, after complete benching of the liver hilum. (The view is the same for open liver surgery, thus enabling an easy view of liver anatomy. Note that the surrounding tissue of the main bile duct is kept intact to avoid compromising blood supply to the bile duct system. The portal vein and hepatic artery system are ready for transection). (GDA, gastroduodenal artery; LHA, left hepatic artery; PV, portal vein; RHA, right hepatic artery; S, segment)

The liver has to be kept in the bowl with the preservation solution in the same position and orientation during the entire splitting procedure. The view of the anatomy of the hilum during splitting should be the same as in open liver surgery since every liver surgeon is familiar with this view, thus avoiding confusion about the anatomy (Figure 9.1).

Prior to the splitting procedure, a detailed evaluation of the quality and anatomy of the whole liver must be performed.

Quality

The first inspection assesses the colour and consistency of the liver. Any significant signs of fatty change (more than 30% for left lateral split; more than 15% for full right–full left split) are an indication for biopsy, to provide histological evidence for the degree of fatty change.

Fatty change of more than 30% is a contraindication for the split procedure.

The same is true for apparent signs of fibrosis. After excluding iatrogenic or traumatic damage to the liver, the quality of the bile duct system as well as the arteries has to be evaluated. Macroscopic trauma to the whole liver should also be considered as a contraindication for splitting. In situations where arteriosclerotic plaques or dissections are detectable to the level of either left or right hepatic arteries, the split procedure should be cancelled. Obvious inflammation of the extrahepatic bile duct system is also a contraindication for splitting.

Anatomy

The anatomical evaluation starts with the weight of the whole liver. The actual weight should be compared with the calculated or estimated standard liver volume of the deceased donor. In cases of significantly higher actual liver weight compared to the standard liver volume, liver biopsy should be performed to rule out any liver disease associated with hepatomegaly (surprisingly a large liver is more dangerous than a small liver).

The relation between left and right liver lobes and the size of the left lateral lobe (segments II and III) need to be noted and taken into account to select the appropriate recipient. Both recipients should be selected according to the estimated GRWR, aiming for a GRWR above 1.

• **The anatomy of the left hepatic vein** can be explored by direct visualization through the suprahepatic opening of the caval vein. Additionally, probing

the left hepatic vein can help in identifying the tributaries within the left lateral lobe as well as significant veins (segment II or segment IV veins) crossing the proposed line of transection. Variations of the left hepatic vein are rarely a contraindication for splitting.

• **The portal vein exploration** can also be done from inside the main portal vein to exclude the rare situation of the absent main left portal vein, which is a reason to abort the splitting procedure. All other variations of the portal vein are eligible for splitting.

• **The gross exploration of the hepatic artery bifurcation** and the identification of the median hepatic artery (segment IV artery) are the final steps in the anatomical examination of the liver before starting the split procedure. Variations in the arterial anatomy have to be recognized and considered while dividing the arterial trunk. Only significant malformations (e.g. multiple small arteries supplying the liver) or arterial diseases (e.g. aneurysm) can be considered as contraindications for splitting.

• **The intrahepatic bile duct system** should be irrigated with preservation solution to wash out the toxic bile. Cholangiography on the bench is not routinely necessary if the line of parenchymal transection stays exactly at the falciform ligament and the line of transection of the left umbilical plate remains exactly behind the left main portal vein (Figure 9.2).

Contraindications for liver splitting:

- Fatty content more than 30%.
- Major trauma to the liver.
- Dissection or atherosclerotic plaques of the right or left hepatic arteries.
- Obvious inflammation of the extrahepatic bile ducts.
- Absent main left portal vein.
- Arterial disease (e.g. aneurysms).

Surgical technique of left lateral *ex situ* split

The splitting procedure starts with the division of the vessels (as opposed to the *in situ* technique). After regular benching of the whole liver, the meticulous dissection of the main hepatic artery starting from the celiac trunk follows, thus ruling out any accessory or replaced left hepatic arteries originating from the left gastric artery. In cases where a significant left hepatic artery is originating from the left gastric artery within the hepatogastric ligament, the artery to the left lateral lobe has to be dissected to a maximum of 1 cm away from its origin.

Complete dissection close to the replaced left hepatic artery up to the entrance into the liver carries an unnecessary risk of damage to the artery.

The surrounding connective tissue protects the left hepatic artery from damage and kinking. Even in a

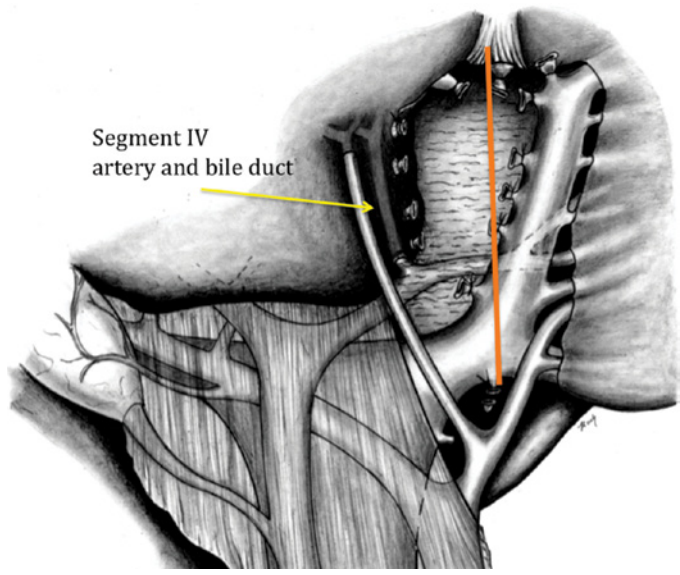

Figure 9.2 The line of transection of the umbilical plate during left lateral *ex situ* splitting is indicated by the orange line. This line of transection respects the integrity of the segment IV artery as well as the segment IV bile duct.

situation where there is a replaced left hepatic artery originating from the left gastric artery, the proper hepatic artery branches must be identified to rule out the presence of any small additional proper left hepatic artery.

The main portal vein is dissected towards the main bifurcation to confirm the presence of the left portal vein (Figure 9.3).

Dissection of the bile ducts should be avoided to minimize the risk of injury and devascularization of the extrahepatic bile ducts. The donor's main bile duct has to be cut as short as possible, just above the junction of the cystic duct with the main hepatic duct, and the cystic duct of the donor liver should be removed. After appropriate shortening of the extrahepatic bile duct system, the bile duct can be flushed again with preservation solution and the intrahepatic bile duct anatomy explored via probing of the bile ducts with a metal cannula.

Further dissection and division of the artery is performed after identifying the bifurcation of the proper hepatic artery into the left and right arteries. Then, segment IV artery has to be identified, to choose the appropriate site for the transection of the arterial trunk. The question whether to leave the main arterial trunk with the right or left graft remains controversial. However, it is acceptable to leave the main trunk with the graft for the primary recipient. If the organ is primarily allocated to an adult recipient, the main arterial trunk should stay with the right extended graft, thus minimizing the risk for the adult recipient.

The anatomy of the segment IV artery should be taken into account when dividing the arterial trunk (Figure 9.4).

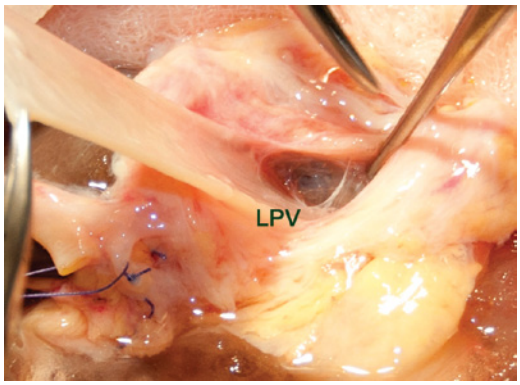

Figure 9.3 Dissection of the portal vein towards bifurcation to identify the left portal vein. (Courtesy of Mr Gabriel C. Oniscu)

If the segment IV artery arises from the right hepatic artery, the left hepatic artery can be transected at the level of its origin from the proper hepatic artery. In most cases, the segment IV artery originates from the left hepatic artery. Therefore the site of transection of the left hepatic artery has to be towards the left lateral liver, thus saving the arterial perfusion to segment IV.

Most livers have a parenchymal bridge (of variable size) between the left lateral graft and segment IV covering the left portal branch. In some patients, an accessory or replaced segment III bile duct can be found within this parenchymal bridge. In this case, the tissue has to be divided with a knife or sharp scissors to allow subsequent anastomosis of the replaced left lateral bile duct with the recipient's small bowel. In situations where a small accessory segment III bile duct is found, this has to be closed carefully, to avoid a bile leak in the recipient. After cutting the parenchymal bridge, the peritoneum covering the left main portal vein has to be opened longitudinally up to the top of the left main portal vein (Recessus of Rex). The dissection moves to the right side of the left main portal vein, thus freeing all portal branches toward segment IV arising from the left main portal vein. The portal branches toward segment IV arising from the main portal vein bifurcation can be preserved.

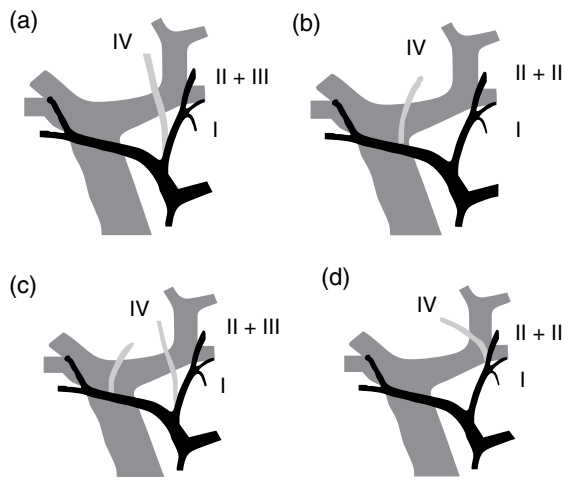

Figure 9.4 Anatomical variations of the origin of the segment IV artery (median hepatic artery). (a) Common type: the segment IV artery arises from the left hepatic artery. (b) Origin of the segment IV artery from the right hepatic artery. (c) Dual arterial blood supply of segment IV from the left and right hepatic artery. (d) Origin of the segment IV artery distal from the left hepatic artery.

At this stage, the splitting surgeon has to ensure that segment IV artery is not damaged during the dissection.

The dissection of the left main portal vein has to be continued far to the left. Segment I branches originating from the main left portal vein have to be sacrificed, while segment I portal branches originating from the main portal vein have to be preserved (Figures 9.5 and 9.6).

After the circumferential dissection of the first 10 mm of the left main portal vein has been completed, the left main portal vein can be divided from the main portal vein bifurcation (Figure 9.7).

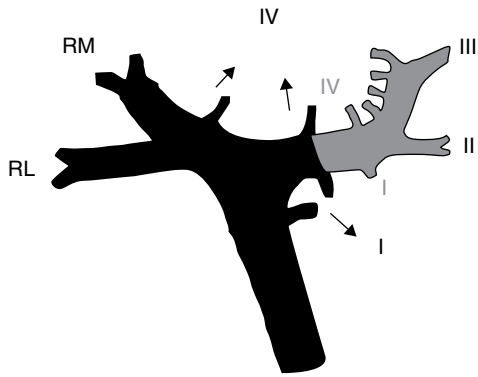

Figure 9.5 Portal perfusion of segment IV via segment I portal branches, sustained portal branches from main portal bifurcation and perfusion of portal segment IV from the right main portal vein. (I–IV, liver segments according to Couinaud; RL, right lateral sector; RM, right medial sector)

Figure 9.6 Ligations of segment I branches arising from the left portal vein with preservation of the ones from the main trunk. (Courtesy of Mr Gabriel C. Oniscu)

Further dissection of the left main portal vein is carried out close to the wall of the portal vein to avoid any damage to the umbilical plate carrying the left lateral bile duct and the surrounding vascular plexus. In a significant number of patients, the left lateral bile duct and segment IV bile duct are gleaming, making them visible during division of the umbilical plate exactly behind the left portal vein far enough to the left to avoid opening the segment IV bile duct.

The transection of the umbilical plate has to be performed with sharp scissors or a knife in one clean cut to avoid filleting the umbilical plate (Figure 9.8).

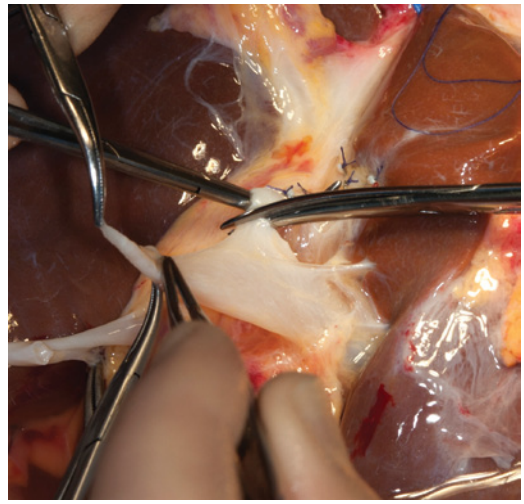

Figure 9.7 Left main portal vein is divided. (Courtesy of Mr Gabriel C. Oniscu)

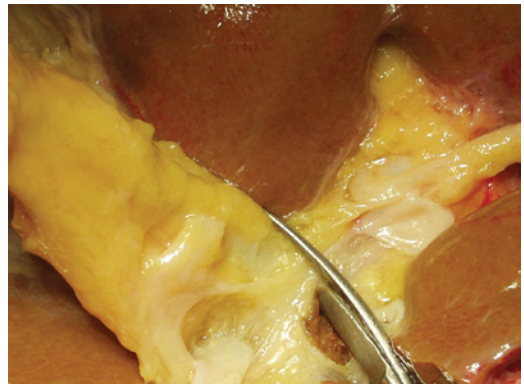

Figure 9.8 Sharp transection of the umbilical plate.

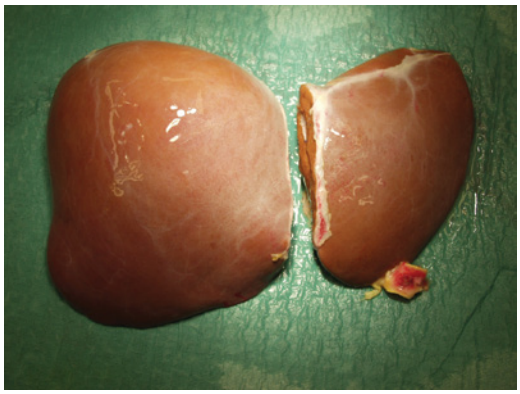

Figure 9.9 Transection line of the parenchyma next to the falciform ligament. The image illustrates the situation after complete left lateral *ex situ* split using the sharp knife technique.

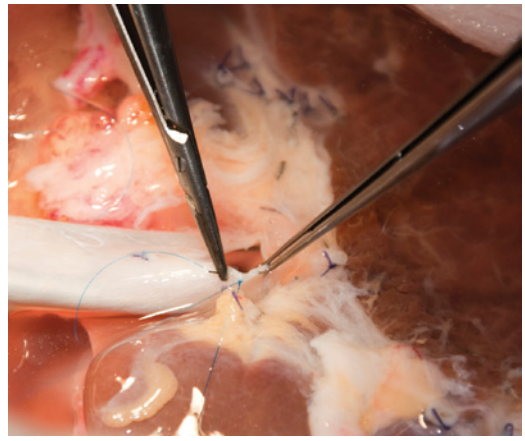

Figure 9.10 Transverse closure of the portal vein. (Courtesy of Mr Gabriel C. Oniscu)

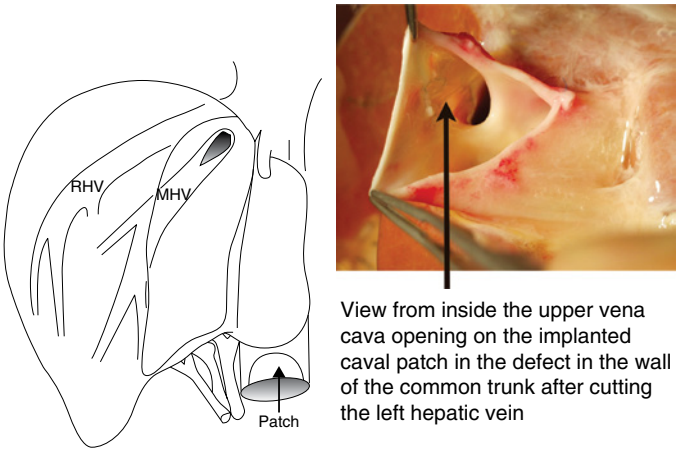

Figure 9.11 Closure of the left hepatic vein origin using a small caval patch from the lower end of the vena cava.

After completing the hilar transection, attention moves to the left hepatic vein. The left hepatic vein is cut with scissors at the level of the parenchyma, since the left hepatic vein can never be too short for implantation. The shorter the left hepatic vein stump, the lower the risk of kinking and twisting of the vein after anastomosis in the recipient.

The parenchymal transection is then carried out using the sharp knife technique, with the transection line following the right border of the falciform ligament (Figure 9.9) in the direction of the arantius sulcus and the transection line of the umbilical plate.

The goal is to cut the liver in a single even plane, thus allowing precise hemostasis by suturing every visible vessel opening, which can be performed simultaneously by two surgical teams, one for each graft [2].

The benching of the right extended lobe after removing the left lateral lobe starts with the transverse closure of the left portal vein stump (Figure 9.10).

Care has to be taken during this step to avoid closure of the small portal segment I and segment IV branches originating from the main portal bifurcation.

The stump of the left hepatic artery can be closed by either ligature or oversewing. The vena cava, including the right and middle hepatic veins, remains with the right extended graft, and the defect in the wall of the extrahepatic part of the common trunk can also be closed by transverse suture or using a patch reconstruction with a small caval wall strip from the infrahepatic cava (Figure 9.11).

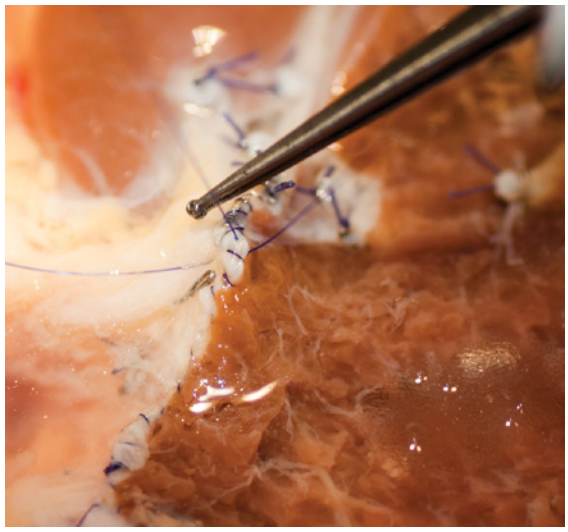

Figure 9.12 Closure of the umbilical plate. (Courtesy of Mr Gabriel C. Oniscu)

To avoid bile leakage, the entire stump of the umbilical plate of the right extended lobe has to be oversewn using a 6/0 polydioxanone (PDS) suture, starting from segment I up to the end of the umbilical plate at segment IV (Figure 9.12).

Continuous suturing stitches should be placed superficially to avoid closure of the segment I bile duct and segment IV artery as well as the segment IV bile duct.

After the suturing of the hilar plate is completed, the main bile duct has to be flushed with preservation solution to exclude any leakage on the umbilical plate.

Surgical steps for left lateral splitting

- Maintain liver in anatomical position throughout procedure.
- Assess liver quality.
- Assess anatomy (left hepatic vein, left portal vein, hepatic artery, bile duct).
- Divide parenchymal bridge between left lateral segment and segment IV.
- Dissect hepatic artery, identify segment IV artery and choose site of left hepatic artery transection.
- Dissect portal vein, ligate segment I and segment IV branches from left portal vein and transect left portal vein.
- Shorten extrahepatic biliary tree, probe bile ducts and transect sharply the mbilical plate, behind left portal vein.
- Divide left hepatic vein.
- Carry out sharp transection of liver parenchyma.
- Suture cut surface vessels.
- Close left portal vein stump, left hepatic artery stump and left hepatic vein defect.
- Oversaw umbilical plate of right extended graft.

Technique of the *ex situ* full left–full right split procedure

The initial steps – benching of the whole liver, exploration of the anatomy and the assessment of quality of the liver – do not differ from those described above for left lateral splitting.

The hilar dissection and transection is less demanding compared to the left lateral *ex situ* spitting, while the parenchymal transection is significantly more challenging in full right–full left splitting.

Only perfect donor livers with a short cold ischemic time should be considered for full right–full left splitting.

Hilar dissection

Hilar dissection starts with the identification and preparation of the hepatic artery bifurcation and segment IV artery as previously described for left lateral splitting. The site of transection of the arterial trunk depends on the origin of segment IV artery, aiming to preserve the segment IV artery and leaving the main arterial trunk with the left hemiliver in most cases.

The portal vein is dissected down to the main bifurcation and the main portal vein also stays with the left hemiliver to preserve segment I branches originating from the main portal vein.

The exploration of the bile duct system is crucial in full right–full left splitting.

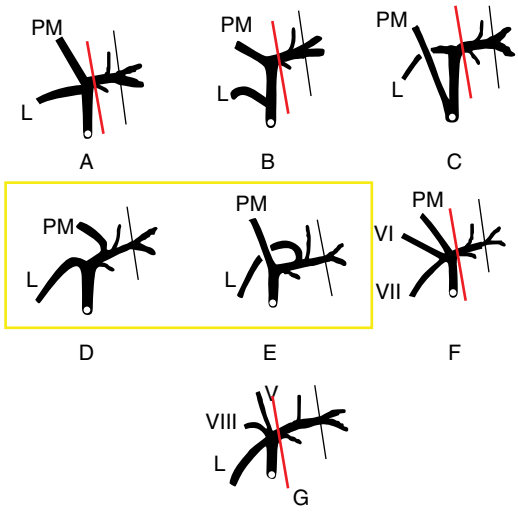

Figure 9.13 Sharing of the bile ducts in full right–full left splitting according to several bile duct variants. The red line indicates the site of transection of the bile duct in full right–full left splitting. The gray line indicates the potential line of transection of the umbilical plate in the case of left lateral split. The two variants within the yellow rectangle are reasons to abort the full right–full left split procedure and alternatively performing a left lateral split.

A detailed exploration of the intra- and extrahepatic bile duct anatomy is required, by probing all segmental bile ducts with a small metal probe. However, cholangiography on the bench is preferred if available, to visualize the detailed anatomy of the donor bile duct system. Several bile duct variations carry significant risk for biliary complications. Figure 9.13 illustrates the bile duct variations in which a full right–full left split procedure should be aborted and switched to a left lateral split if possible.

If the bile duct anatomy is suitable for full right–full left splitting, dividing the bile duct results in leaving the main bile duct with the right liver lobe due to more frequent biliary variants of the right hemiliver. The site of transection of the main left bile duct should allow preserving a stump of the left main bile duct of 2 mm, thus enabling safe closure of the bile duct stump (Figure 9.14).

At the same time, the site of transection should respect the confluence of segment IV and left lateral bile ducts to avoid having two bile duct stumps at the left hilar plate. In situations where segment I bile duct

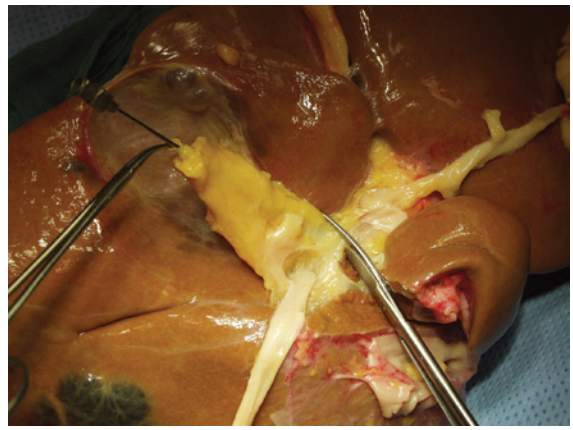

Figure 9.14 Site and technique of transection of the left main bile duct in full right–full left splitting. (The metal probe is passed through the common bile duct into the right main bile duct, thus preserving the main bile duct bifurcation)

is separate from the main left bile duct, the stump of segment I bile duct will require a separate anastomosis in the recipient. In cases where there is a very tiny segment I bile duct, resection of segment I is preferred.

Achieving optimal venous outflow for both grafts is a challenge, since the middle hepatic vein is draining both hemilivers. By leaving the middle hepatic vein with the left lobe as described for the *in situ* technique, the right median sector of the right hemiliver is predisposed to develop venous congestion [21], because these segments (V and VIII) are mainly drained by the middle hepatic vein.

Therefore, *ex situ* split has the advantage of superior access to the complete anatomy to create an optimal venous outflow in both grafts, which can be achieved by splitting the vena cava [22] and the middle hepatic vein [16,23].

The dorsal and ventral wall of the vena cava are divided in the midline, acquiring two hemicaval patches [22] before starting the parenchymal transection (Figure 9.15).

The parenchymal dissection is performed using the sharp knife technique, as described by Daniel Azoulay, along the line of Cantlie to achieve a plain cut surface. If the middle hepatic vein is not split, the cut line is on the right to the middle hepatic vein, thus leaving the

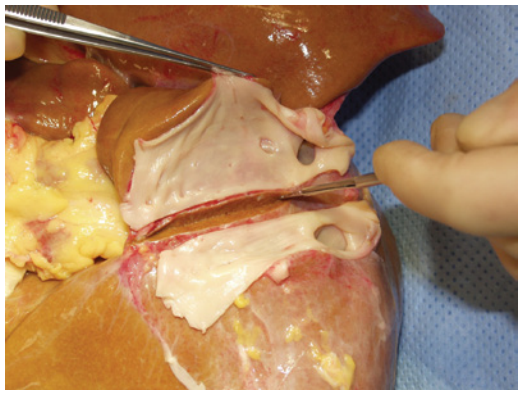

Figure 9.15 Technique of splitting the vena cava in full right–full left splitting. The line of transection is exactly on the midline, resulting in two hemicaval patches. The bridge between segment I and IX is cut initially with the knife.

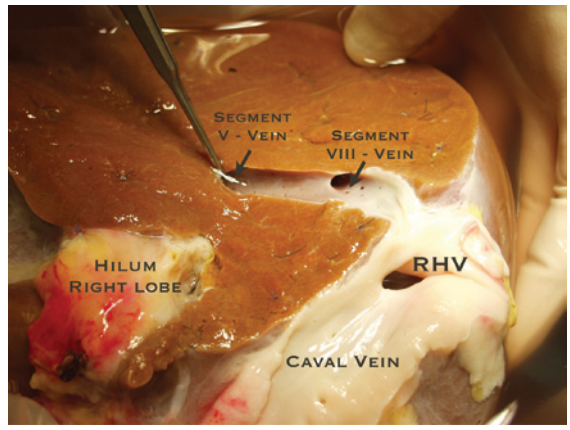

Figure 9.17 The right liver after splitting the middle hepatic vein. (Note the multiple small veins draining into the right half of the middle hepatic vein additional to the large segment V and VIII veins)

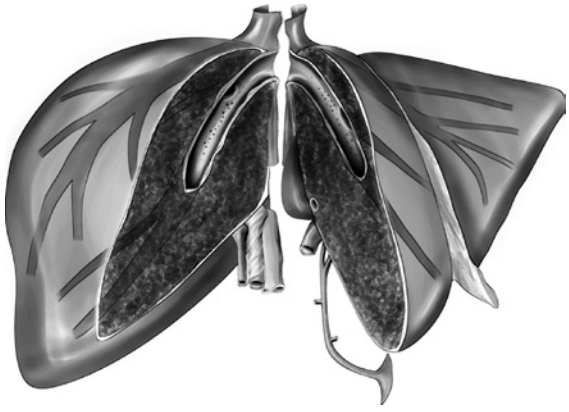

Figure 9.16 Splitting through the middle hepatic vein before reconstruction.

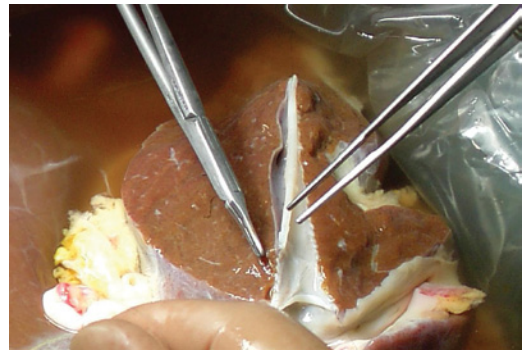

Figure 9.18 Reconstruction of the left half of the middle hepatic vein on the left hemiliver using half the iliac vein from the same deceased donor.

middle hepatic vein with the left hemiliver. However, the technique of splitting the middle hepatic vein is preferable to make maximum use of the anatomy of the donor liver.

In the early application of splitting the middle hepatic vein, the vein was cut in the middle over the entire length, including the conjunction with the vena cava [23] (Figures 9.16 and 9.17).

Both halves are reconstructed with donor iliac vein patches (Figure 9.18).

The benching procedure is completed by oversewing the vessel openings on the cut surface as described for the *ex situ* left lateral split and closing the stumps of the portal vein as well as the hepatic artery stump.

Outcome of split liver recipients

Split liver transplantation represents an efficient use of the scarce resource of deceased donor organs, enabling two transplants by dividing one liver. Although this option has gained acceptance, particularly in child/adult split liver transplantation, it still represents only 4% of the total number of liver transplants in the US [24] and 2% in Europe [25].

Outcome of extended right liver grafts

Split liver transplantation was originally performed by splitting a liver for a child and an adult in order to decrease mortality on the pediatric waiting list, due to rare size-matched grafts for children. Despite excellent results in pediatric recipients, the outcome for the adult recipient transplanted with the extended right liver lobe was questioned for a long time. Recently there have been several reports of favourable survival of these recipients compared to whole organ recipients. The 1-year survival rates reported throughout the last decade have ranged from 74 to 100% [4,10,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43] (Table 9.1).

The reported overall complication rate is high, with 23–45% in the mentioned studies, with an accumulation of biliary and vascular complications. Consensus is growing to restrict the application of extended right split liver transplantation in non-urgent patients, due to the inferior outcome of high-urgent patients after implantation of an extended right graft [9,44]. However, under optimal conditions with careful donor and recipient selection, the implantation of right extended grafts causes no harm at all to the adult recipient and should be supported further.

Outcome of full right–full left split liver transplantation

The overall experience in full split liver transplantation is lacking, due to the challenging nature of the surgical technique and the resulting relatively small grafts. The application of full right–full left split liver transplantation requires careful donor and recipient selection to provide acceptable results. Hence, the number of cases reported from the few centers performing this technique is low but, nevertheless, with encouraging 1-year patient survival rates of 67–94% and graft survival of 63–90% [7,8,16,45,46,47,48] (Table 9.2).

In our experience with the transplantation of 16 full right and 19 full left liver lobes, we achieved actual patient survival of 87.5% and 89.5% and actual graft

Table 9.1 One-year survival rates with extended right split liver transplantation (HAT, hepatic artery thrombosis).

Author	City	Year	Number	One-year patient survival	One-year graft survival	Biliary complications (%)	Vascular complications (%)
Rogiers [4]	Hamburg	1996	7	100 (6 months)	100 (6 months)	0	NA
Goss [42]	Los Angeles	1997	14	86	93	7.1	0
Rela [37]	London	1998	22	95	95	13.6	NA
Ghobrial [10]	Los Angeles	2000	55	80	NA	NA	NA
Porta [29]	Milano	2000	49	77	67	NA	NA
Reyes [43]	Pittsburgh	2000	16	74	60	6.6	10
Maggi [40]	Milano	2001	16	86	80		
Sauer [39]	Berlin	2001	18	90	90		
Kilic [41]	Houston	2002	8	100	100	0	25
Nashan [38]	Hannover	2002	78	80			
Margarit [30]	Barcelona	2003	12	84	NA	33	8
Moreno [31]	Madrid	2003	13	77	68	5.5	11
Yersiz [15]	Los Angeles	2003	71	78	69	10	7
Baccarani [34]	Udine	2005	14	83	73	21	7 (HAT)
Sampietro [35]	Brussels	2005	36	78	78	35.1	15.2
Spada [28]	Palermo	2005	15	93	93	27	13.3
Washburn [32]	Texas	2005	65	87	85	9	9
Cardillo [27]	Milano	2006	154	79 (3 years overall)	72 (3 years overall)		
Cintorino [33]	Palermo	2006	17	88	88	23	0
Corno [36]	Bergamo	2006	32	22 adults: 100; 10 children: 90	22 adults: 100; 10 children: 79	34	0
Wilms [26]	Hamburg	2006	70	86	77	11.4	2.8

Table 9.2 Results of full right–full left liver transplantation (FL, full left; FR, full right).

Author	City	Year	Number		One-year patient survival (%)		One-year graft survival (%)		Biliary complications (%)		Vascular complications (%)	
			FR	FL	FR	FL	FR	FL	FR	FL	FR	FL
Adorno [45]	Genova	2001	4	4	75	75	50	75	0		25	25
Azoulay [8][8]	Paris	2001	17	17	74	88	74	75	17.6	23.5	11.7	11.7
Colledan [48]	Bergamo	2001	4	4	75	100	50	75	0	75	25	25
Humar [7]	Minnesota	2001	6	6	83.3		83.3		16.6	16.6	0	16.6
Giacomoni [46]	Milano	2005	9		67		67		33		11	
Broering [16]	Hamburg	2005	16	19	87.5	89.5	75	84	37.5	21	0	
Adham [47]	Lyon	2007	15		94		93		20		26.6	

survival of 75% and 84%, respectively [16]. There was no significant difference compared with the whole organ transplants performed during the same period.

The Paul Brousse group reported a series of 17 right and 17 left hemiliver transplants with a 1-year recipient survival of 74% in the full-right group and 88% in the full-left group, and a respective graft survival of 74% and 75% [8], likewise comparable to their results of whole organ transplantation. The first North American experience was reported by Humar et al. after six full split procedures with a patient and graft survival of 83% at a mean followup of 9 months [7]. Most of the published series reported high morbidity rates, with biliary complications occurring most frequently (12–22%). The majority of biliary complications in our experience are noted from the resection plane, particularly in the right hemiliver group, implicating the impact of the complex biliary anatomy on the outcome for the right liver lobe. Interestingly, the Paul Brousse group reported a higher incidence of biliary complications in the left graft. However, improving visualization of the biliary system remains one of the future challenges in full split liver transplantation, besides optimal donor and recipient matching.

Summary box

- The graft to recipient weight ratio (GRWR) should be 1%.
- Fatty change of more than 30% is a contraindication for splitting.
- Split liver transplantation (in adults) should be performed only in elective recipients.
- Avoid graft rewarming during the splitting procedure by using a 'no-touch' technique and replacing the cold fluid to keep the temperature at 4°C.
- Prior to splitting, a detailed evaluation of liver quality and anatomy should be performed.
- There are very few anatomical contraindications to left lateral splitting.
- Dissection of the bile ducts should be avoided to minimize the risk of devascularization and injury.
- A cholangiogram is not required for left lateral splitting but is essential for a full-left–full-right split.
- The adult and pediatric teams should agree the destination of the main arterial trunk (i.e. right or left graft).
- The level of arterial division is dictated by the anatomy of the arterial supply to segment IV (which should be preserved).
- Portal inflow to segment I is preserved via the branches from the main portal vein.
- The umbilical plate is transected with a knife or sharp scissors and must be sutured to avoid bile leaks.
- Parenchymal transection is carried out to the right of the falciform ligament in left lateral splitting.
- Only perfect donors with short cold ischemic time should be considered for a full left–full right split.
- Parenchymal transection is challenging in full right–full left split.
- The middle hepatic vein is reconstructed on both grafts in full right–full left split using the donor iliac vein.
- Split liver procedures allow for an efficient use of donor livers, achieving excellent outcomes.

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10 Pancreas Retrieval and Bench Surgery

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Background

Transplantation of the pancreas is the only curative treatment for patients with insulin-dependent diabetes mellitus. Since the first such procedure in 1966, approximately 30,000 pancreas transplants have been performed. This number should be seen in the context of the high prevalence of diabetes. It is estimated that about 4% of the UK population has diabetes, of which about 10% have type 1 diabetes; pancreas transplantation is appropriate to a small subset of these patients that develop severe and specific complications of diabetes. It is only in recent years that patient and graft survival rates following solid pancreas transplantation have exceeded 90% and 80%, respectively, with a very high incidence of technical graft failure that precluded better results for many years. Even in the current era, as many as 25% of pancreas transplant recipients need further surgery after transplantation to deal with complications. Pancreas-specific risks are commonly related to the exocrine secretion of this gland, reperfusion pancreatitis and the actions of amylase-rich secretions causing severe local and systemic inflammation. Advances in surgical technique, immunosuppressive therapy and perioperative treatment have enabled the current, improved success rates of pancreas transplantation.

In the context of increased usage of marginal donor organs, the quality of organ procurement techniques, preservation and bench preparation of the graft are paramount to success.

Organ procurement

Donor selection

Donor selection for pancreas transplantation is more restrictive than for kidney or liver transplantation (Table 10.1); the ideal pancreas donor is a brain-dead donor, less than 45 years old, with a body mass index (BMI) of less than 27, a short intensive care unit (ICU) stay and who is hemodynamically stable.

Table 10.1 Pancreas donor criteria.

Ideal pancreas donor	
Young age	8–45 years
Normal body habitus	BMI 20–27
ICU stay	Short period of ICU stay
Cause of death	Brainstem death following head injury
Hemodynamic stability	Minimal use of inotropes
Acceptable donor criteria	
Age	8–60 years
BMI	< 30 kg/m^2

However, increasing demand and changes in the demographics of donor population have led to increasingly less ideal organs being retrieved and transplanted.

Donor organs outside standard criteria have a high risk of postoperative complications.

Abdominal Organ Retrieval and Transplantation Bench Surgery, First Edition. Edited by Gabriel C. Oniscu, John L. Forsythe and John Fung.

Medical background

As described in other chapters, prior to organ retrieval, the surgeon in charge (either for all or individual organs) has the responsibility to:

- check the patient's identity;
- check the notes for confirmation of brainstem death, lack of objection to donation, blood group and assessment of risk factors, along with the general suitability of the donor;
- communicate with other members of the retrieval team (anesthetists, theater staff, other retrieval teams) the specific requirements of the individual donor and agree on the process.

Of special interest for pancreas retrieval are the following aspects:

1 Acute medical history:

- cause of death;
- abdominal trauma;
- time in ICU;
- hemodynamic stability;
- inotropic support;
- blood test results (lipase, amylase, bilirubin, liver function tests, glucose);
- insulin dependence.

Acute insulin dependence in the brain-dead patient or ICU patients is frequently observed and is rarely an obstacle to pancreas donation.

2 Medical background:

- history of (acute) pancreatitis;
- alcohol consumption;
- smoking history.

3 Tissue typing

Tissue typing should ideally be available by the time the retrieval procedure starts in order to minimize the cold ischemia time.

Pancreas transplantation (with or without kidney) requires a negative crossmatch. Serum of the recipient and a tissue-preparation of the donor (from blood, lymph nodes or spleen) are analyzed for this assay. A positive crossmatch implies that the serum of the recipient contains antibodies that recognize the donor tissue; a transplant cannot go ahead in this situation.

Donor procedure

Most pancreases are retrieved as part of a multiorgan donor procedure. Injury to the pancreas during the donor operation can cause postoperative complications and lead directly to graft failure; therefore the operative technique for pancreas retrieval is critical for a successful transplant. The retrieving surgeon must be fully aware of the potential injuries that can occur during retrieval. Some of the injuries that can render the pancreas unsuitable for transplantation include:

- capsule damage;
- laceration of the pancreatic parenchyma;
- intraparenchymal hematoma;
- vascular injury.

The pancreatic head and duodenal segment in particular are at risk of ischemia if the proximal branches of the inferior pancreaticoduodenal artery (an early branch of the superior mesenteric) are injured or divided.

The pancreas is usually retrieved together with the spleen and removed from the donor following the retrieval of the thoracic organs and the liver. An alternative approach is to remove the liver and pancreas *en bloc* and separate the organs on the bench. This technique has the advantage of faster organ removal and shorter warm ischemic time, but the dissection, especially the bench separation, is technically more challenging.

Adequate flushing of the pancreas is of great importance to the postoperative function. Therefore the cannulation technique, and in particular the placement of any portal cannula, is critical. If dual perfusion is required (as is stipulated in some deceased cardiac donor liver retrieval protocols), the cannula should ideally be placed directly in the suprapancreatic portal vein following the commencement of aortic perfusion, rather than in the superior mesenteric vein (SMV) or inferior mesenteric vein (IMV) before aortic perfusion, in order to avoid obstruction of the venous outflow and congestion of the pancreas. The proximal portal vein is left open to allow free drainage of the pancreatic venous effluent.

Ensure adequate pancreas venous outflow if aortic and portal liver perfusion is used.

Preparatory steps

At laparotomy, the pancreas cannot be readily inspected, but it is helpful to obtain a preliminary view at an early stage (Figure 10.1).

Abnormalities including fatty infiltration or fibrosis cannot be detected before retrieval surgery; this highlights the importance of an experienced and skilled surgical team for evaluation as well as retrieval of the organ. Difficulty in quantifying 'donor quality' may be a significant factor in the high rate of discarded organs in pancreas transplantation.

As described in other chapters, mobilization of the right colon allows good access to the right iliac artery or distal aorta for cannulation. Mobilization should include the hepatic flexure and dissection of any adhesions to the liver and gallbladder.

A Kocher maneuver is then performed (Figure 10.2).

This gives access to:

- the origin of the superior mesenteric artery (SMA) (Figure 10.3). It is important at this stage to check for an accessory/replaced right hepatic artery – this is most easily identified posterior to the common bile duct (Figure 10.4).
- the head of the pancreas – allowing for a gentle palpation and inspection of the gland.

In order to inspect the body of the pancreas, the gastrocolic ligament can now be divided and the lesser sac opened. Dissection is performed close to the greater curvature of the stomach. Holding the colon distally, the pancreas can now easily be inspected for size, texture and evidence of fatty infiltration. If this reveals gross abnormalities, then the organ can sometimes be discarded at this early stage; however, in most cases this decision should not be made until after pancreatectomy.

The decision to discard the pancreas should usually be taken only after full examination on the bench and after discussion with the recipient team.

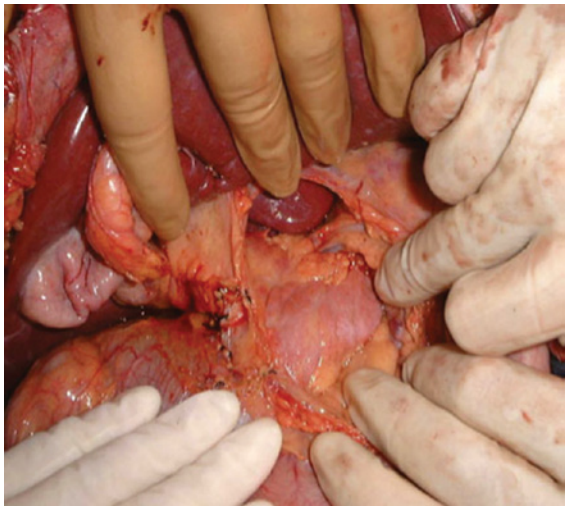


Figure 10.1 Inspection of the pancreas in the lesser sac.

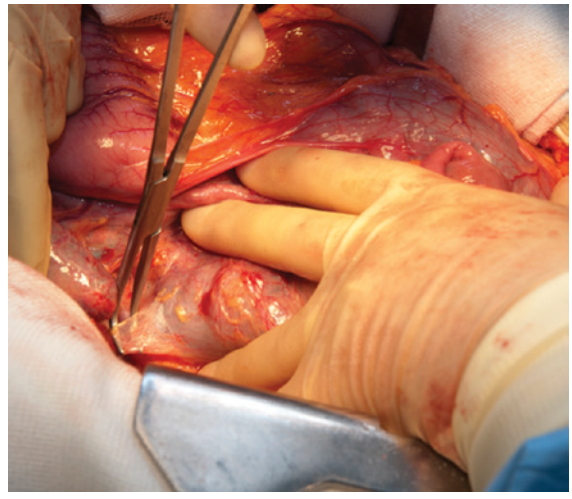


Figure 10.2 The duodenum is mobilized (Kocher maneuver).

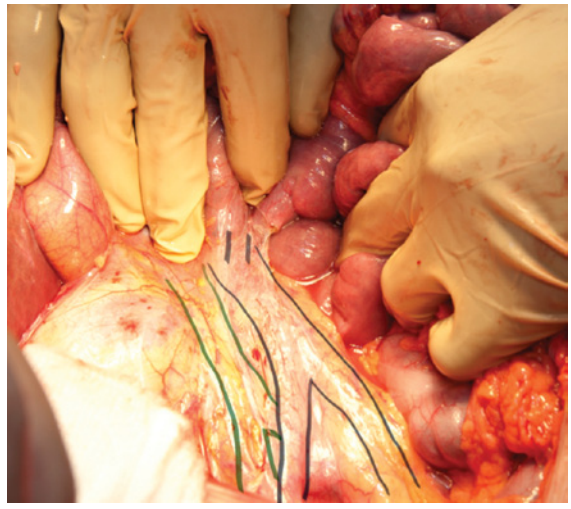


Figure 10.3 Exposure of origin of the SMA and inferior vena cava (IVC).

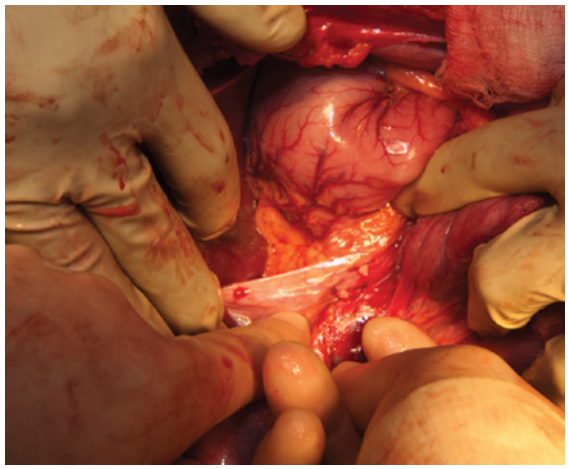


Figure 10.4 Location of the accessory right hepatic artery.

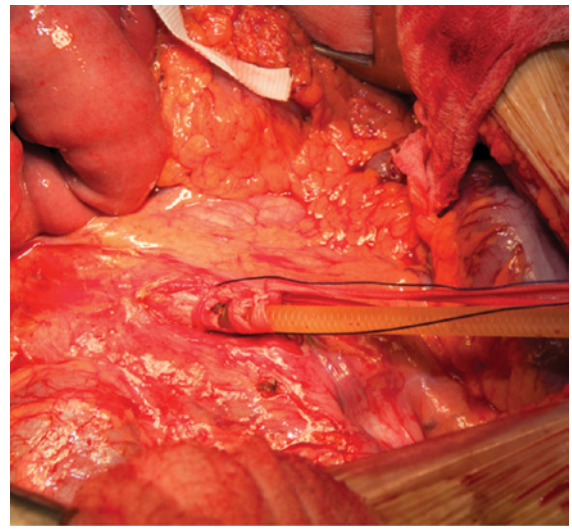


Figure 10.5 Cannulation of distal aorta.

Portal dissection

Portal dissection should be carried out with great care. If branches of the celiac trunk/common hepatic artery are dissected before perfusion, the use of slings or ties should be minimized as these can cause traction injury or interfere with the flushing of the pancreas. A 2/0 or 3/0 tie attached to an artery forceps can easily be snagged during the perfusion phase when the tie (and clip) is likely to be obscured by fluid/loops of intestine/swabs. At this stage, an accessory right hepatic artery should be sought and identified (Figure 10.4).

Cannulation

In situ aortic perfusion (Figure 10.5) is the gold standard for pancreas retrieval.

Some centers prefer dual aortic and portal perfusion, primarily to shorten the cooling time of the liver. There is, however, no experimental evidence to suggest that this is superior to *in situ* aortic-only perfusion followed by portal perfusion on the bench. In situations where dual perfusion is contemplated – such as donation after circulatory death donors (DCD), then (as described above) special care must be taken not to cause pancreatic outflow obstruction. The outflow can be secured by insertion of the portal vein cannula above the pancreas and complete transection of the portal vein following the insertion of the cannula.

Duodenal rinse

Some centers apply a duodenal rinse prior to cross-clamping, in order to prevent bacterial translocation through the enteric wall. For this, 500–1000 mL of diluted aqueous povidone solution, sometimes with an antifungal agent, is administered into the stomach via a nasogastric tube. However, this is not universal practice and there is little evidence for or against it.

Perfusion

Cold perfusion of all abdominal organs is best applied by single aortic pressure perfusion. There is little consensus regarding the optimal volume with respect to the pancreas, but 4–5 L of University of Wisconsin solution (UW) or about twice this volume of histidine–tryptophan–ketoglutarate (HTK) solution is appropriate in most donations. Low-volume perfusion protocols for pancreas retrieval remain theoretical and, in any event, the perfusion requirements are dictated by other retrieved organs (liver and kidneys).

Pancreatectomy

The pancreas is usually retrieved after the thoracic organs and the liver have been removed. During hepatectomy the celiac trunk is dissected as far as its origin from the aorta. The splenic artery arising from the celiac trunk should be divided close to its origin; a 5 mm of stump will suffice for any reconstructive surgery needed for the liver. The splenic artery on the pancreas side is marked with a fine suture (e.g. 6/0 prolene) as it may retract into the pancreatic tissue. Similarly, the gastroduodenal artery (GDA) is marked on the pancreas side following its

transection (Figure 10.6). The GDA should not be tied, as it occasionally needs to be used for reconstruction in order to improve the vascular supply to the pancreatic head.

When the liver is removed, it is important to preserve a 10 mm length of portal vein with the pancreas (Figure 10.7). The full length of portal vein is almost never needed with the liver and complete excision of the portal vein to the level of the splenic/superior mesenteric confluence can make implantation of the pancreas very difficult.

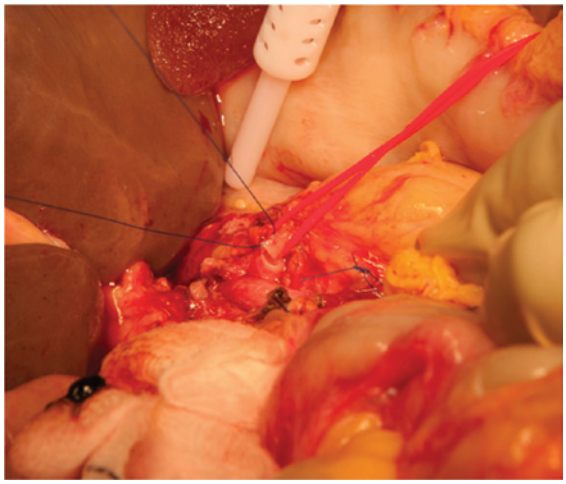


Figure 10.6 The GDA and splenic artery are marked with prolene sutures.

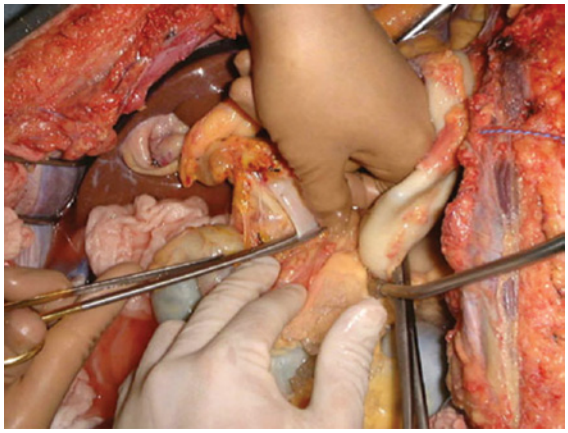


Figure 10.7 An adequate length of portal vein should be preserved with the pancreas.

Following hepatectomy, the SMA should be excised at the level of the aorta.

An aortic patch is not critical for the pancreas transplant, but if one is fashioned, care must be taken not to injure the origin of the right and left renal arteries, which are very close to the SMA.

If not done at an earlier stage, the colon should now be completely mobilized. The colon mesentery can be transected close to the bowel.

The stomach is mobilized completely along the greater curvature up to the level of the diaphragm. Attention should be paid to avoiding any damage to the pancreatic tail during this step.

Thereafter the stomach is transected below the pylorus using a linear stapling device and the stomach can be placed in the thoracic cavity (Figure 10.8).

The distal duodenum is mobilized by dividing the ligament of Treitz and transected using a refill for the linear stapler (Figure 10.9).

The root of the mesentery is then transected using a linear stapler (Figure 10.10).

The root of the mesentery must be stapled well clear of the uncinate process of the pancreas to avoid any damage to the inferior pancreaticoduodenal artery by dividing the mesenteric vessels too short.

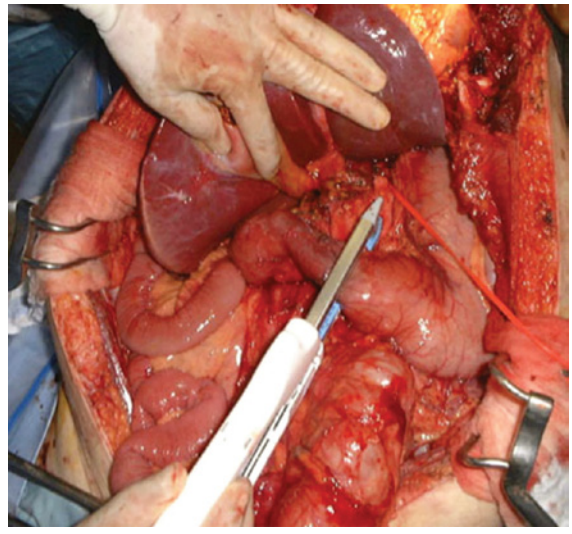


Figure 10.8 Transection of the stomach.

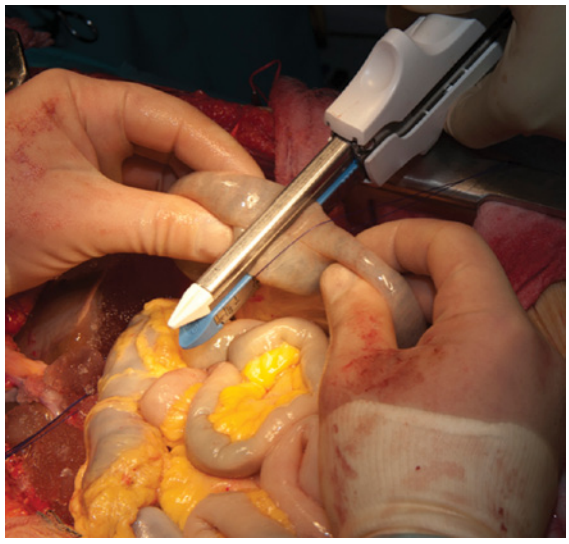


Figure 10.9 Division of the duodenum.

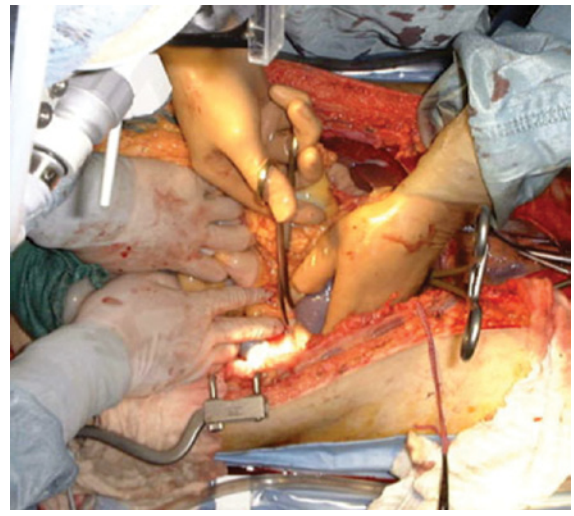


Figure 10.11 Mobilization of the tail of the pancreas using the spleen as a handle.

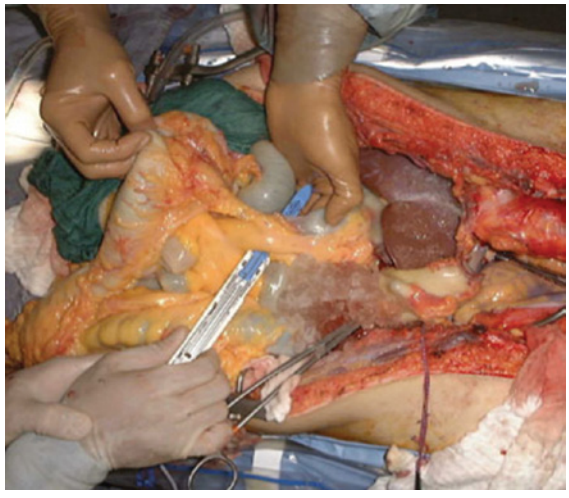


Figure 10.10 Transection of the small bowel mesentery.

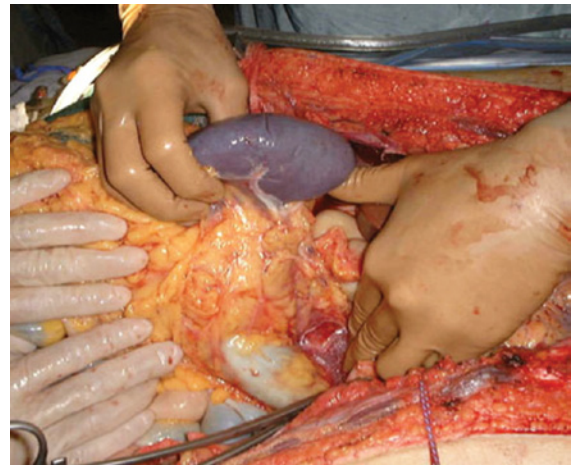


Figure 10.12 Tail of the pancreas fully mobilized.

At this point, the pancreas is only fixed by its retroperitoneal adhesions. The final dissection starts by mobilization of the spleen, which can then be used as a handle to lift the pancreas cranially and anteriorly to dissect the retropancreatic space (Figures 10.11 and 10.12).

Packing

Bench preparation of the pancreas at the donor center is limited to inspection of the organ for major lesions (see above) and an assessment of vessel length. Any additional dissection and preparation should be performed by the implanting team.

There is no need for additional bench perfusion of the pancreas, prior to packing.

The organ is placed in a sterile bag filled with approximately 1 L of preservation solution (UW), which is then placed in an additional one or two sterile bags for transport.

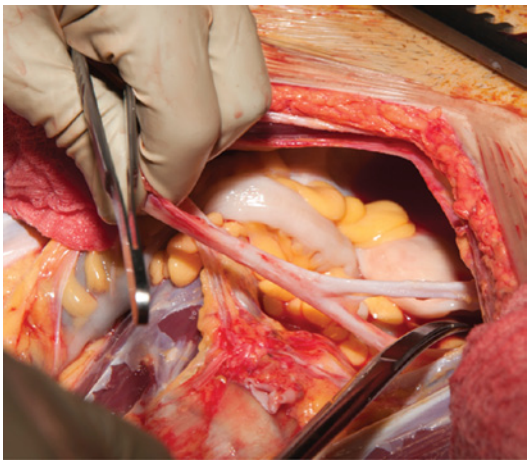


Figure 10.13 Retrieval of additional blood vessels.

Additional blood vessels

Vascular reconstruction is essential for pancreas transplantation and usually requires the bifurcation of the donor common iliac artery (including a short length of internal and external iliac artery) (Figure 10.13). It is also advisable to retrieve a length of iliac vein, although this is not commonly required for reconstruction. If the iliac artery is not suitable, then an alternative bifurcation (brachiocephalic trunk) should be procured.

It is essential to retrieve adequate donor vessels to enable pancreas transplantation.

Organ preservation

Static cold storage is the universal method for pancreas preservation. Several studies have addressed the question of optimal preservation solution. Whereas in many trials no significant difference was seen, some have demonstrated a higher incidence of acute rejection, graft pancreatitis and decreased rates of insulin independence when HTK was used [1]. Adverse effects of HTK, when compared with UW preservation, were also reported from an analysis of the United Network for Organ Sharing (UNOS) database, especially in cases of long cold ischemic times (more than12 hours) [2]. Machine preservation for pancreas transplantation has not been introduced in the clinical practice so far.

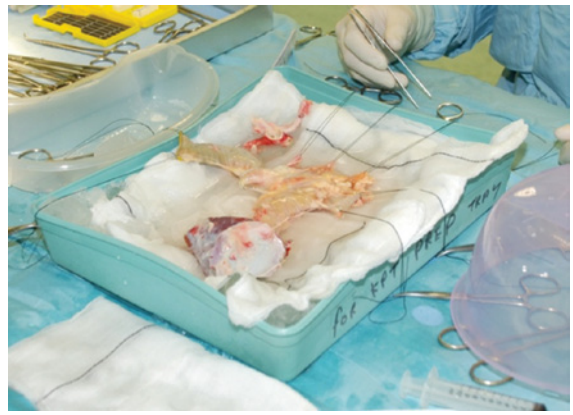


Figure 10.14 Bench surgery preparation.

Bench surgery

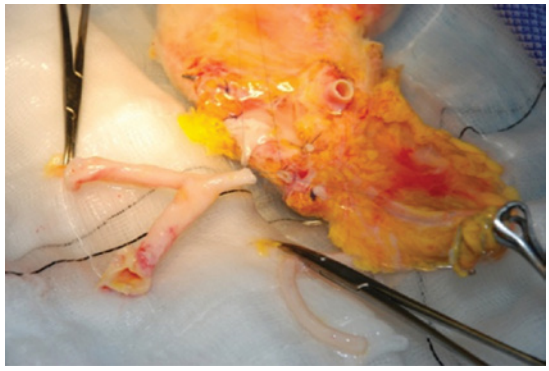
A video for the pancreas bench surgery procedure can be found on the companion website: www.wiley.com/go/oniscu/abdominal

When the donor organs arrive, time is paramount as every additional hour of cold ischemia time diminishes the medium-term survival of the graft. The logistics of retrieval, admitting and preparing the patient for surgery, crossmatch and the bench preparation of the organ mean that it is rarely possible to achieve cold ischemia times of less than 8 hours, and more commonly, ischemia times are 10–12 hours. The immediate consequence of increasing preservation time is increased ischemia-reperfusion and reperfusion pancreatitis (although this is also affected by other pre-retrieval factors). In terms of acceptable preservation time limits, it is reasonable to regard the pancreas as having similar characteristics to the liver.

In pancreas transplantation, meticulous preparation of the organ before implantation is of fundamental importance (Figure 10.14). This is a substantial procedure, with several components.

Reconstruction of arterial supply

The standard pancreas graft on arrival at the recipient center comprises the whole organ, a segment of the duodenum (closed at both ends with linear staple lines) and the spleen. Arterial inflow to the pancreas is supplied by the splenic artery originating from the celiac trunk and the first branches of the SMA arising directly from the aorta. The celiac trunk is generally used with the



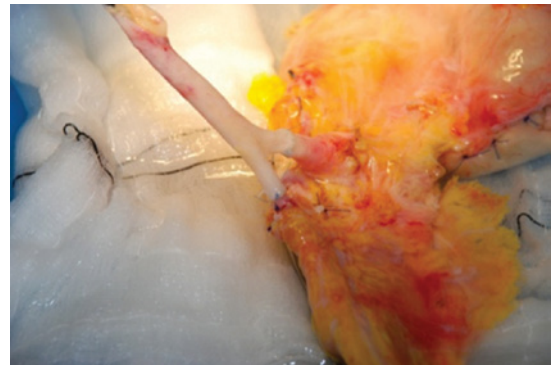


Figure 10.15 Arterial reconstruction using an iliac 'Y' graft.

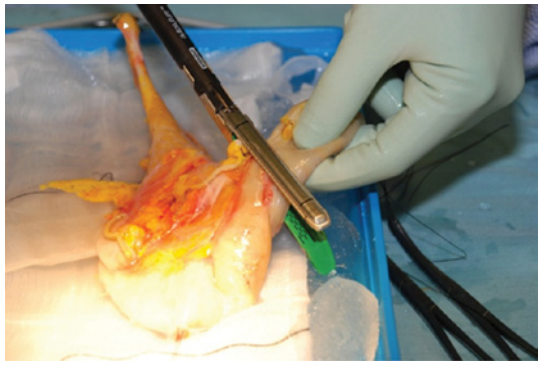


Figure 10.16 Preparation of the duodenum.

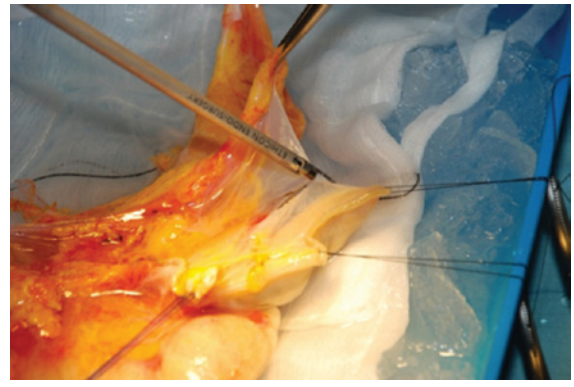
liver graft which leaves a short splenic artery stump with the pancreas. For reconstruction of the splenic artery and SMA, a Y-shaped artery graft is normally used, most commonly the donor iliac bifurcation (Figure 10.15). The GDA is occasionally important to improve perfusion of the pancreatic head and duodenum, but in most cases there is adequate collateral circulation and the GDA can be ligated without problems.

Preparation of the duodenum

The duodenum is stapled and transected at both ends during the retrieval procedure. In order to ensure that the transplanted duodenum has an adequate blood supply, both ends are partially mobilized and restapled to enable this segment to be shortened. These staple lines are inverted using an interrupted or running prolene sutures (Figure 10.16).

Peripancreatic tissue

The pancreas is embedded to a varying degree with peripancreatic connective (fatty) tissue. This tissue



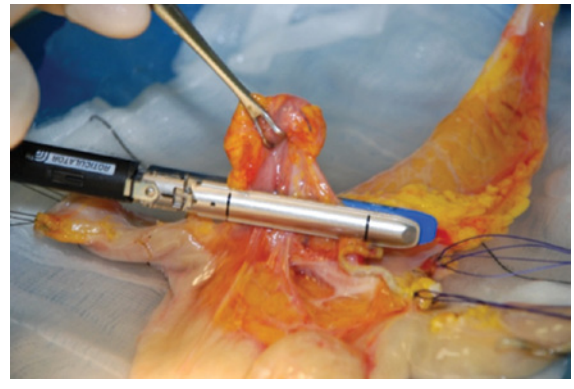


Figure 10.17 Removal of the excess peripancreatic tissue.

should be removed during bench preparation of the organ (Figure 10.17).

Larger vessels (including the IMV) are ligated. Use of harmonic scalpel may help to seal this well-vascularized tissue and reduce bleeding after reperfusion. The spleen is removed from the tail of the pancreas by meticulous dissection and ligation of all vessels.

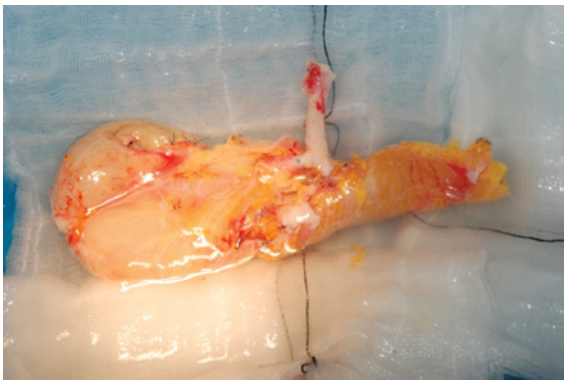


Figure 10.18 The pancreatic graft is ready for implantation.

Root of the mesentery

The root of the mesentery including the infra-pancreatic part of the SMA and SMV are normally transected using a linear stapler device during the donor operation. As noted above, it is important that this staple line is not too close to the uncinate process as it is easy to retract the origin of the inferior pancreaticoduodenal artery into the staple line. This staple line is reinforced with a running prolene suture during bench preparation – this is particularly important when the initial staple line is from a GIA stapler (which is not hemostatic).

The bench procedure is of considerable importance to the success of pancreas transplantation. Technical complications in the early postoperative period could be reduced by meticulous surgical technique in this part of the operation (Figure 10.18).

Meticulous bench preparation prevents significant post-reperfusion bleeding and reduces the incidence of early technical complications.

Islet transplantation

Although the spectrum of ideal donors is not the same for islet donors as for solid organ donors, there is considerable overlap and there is much debate as to how the critical supply of donor organs should be allocated to patients awaiting islet as well as solid organ transplants [3]. An equitable allocation system must incorporate many factors – for example, the isolation of the islets from young donors (less than 18 years) is less successful, whereas these are usually excellent whole pancreas donors. Conversely, donor body mass may be a less severe detrimental factor in islet transplantation compared to solid organ.

The retrieval operation should be carried out in exactly the same way as described above. In order to allow good tissue penetration of the collagenase used to break down the structure of the gland to allow separation of the islets, it is important that the structural integrity of the organ is maintained. Lacerations to the parenchyma or other injuries can lead to leakage and poor tissue penetration.

Summary box

- Donor selection for pancreas transplantation is more restrictive compared with kidney or liver transplantation.
- Acute insulin dependence in donation after brain death (DBD) in the intensive therapy unit (ITU), or a raised amylase pre-retrieval, are rarely obstacles to donation.
- *En bloc* liver and pancreas retrieval allows for a faster organ removal, but bench surgery separation is technically more challenging.
- Adequate pancreas venous outflow must be ensured if aortic and portal perfusion are used.
- Early inspection of the pancreas is beneficial.
- Duodenal rinse is not universally practiced.
- All arteries must be marked with prolene sutures.
- An aortic patch with the SMA is not essential, but care must be taken to avoid injuries to the renal arteries when dividing the SMA.
- Preserve 10 mm portal vein with the pancreas.
- The small bowel mesentery must be stapled away from the uncinate process.
- There is no need for additional bench perfusion of the pancreas prior to packing.
- Retrieval of additional vessels is essential to enable pancreas transplantation.
- An iliac artery conduit is used for vascular reconstruction.
- Meticulous bench surgery reduces the risk of early postoperative complications.
- Organs retrieved for islet transplantation require the same level of integrity as whole pancreas transplantation.

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2 Stewart ZA, Cameron AM, Singer AL, et al. Histidine–tryptophan–ketoglutarate (HTK) is associated with reduced graft survival in pancreas transplantation. *Am J Transplant* 2009; 9(1):217–21.

3 Berney T, Johnson PR. Donor pancreata: evolving approaches to organ allocation for whole pancreas versus islet transplantation. *Transplantation* 2010; 90(3):238–43.

11 Intestinal Retrieval and Bench Surgery

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Introduction

The purpose of this chapter is to outline the basic steps in the procurement of isolated intestinal allografts (ISO-INT), liver–intestinal allografts (LIV-INT) and multivisceral allografts (MVT). These operations represent three distinct procurement and transplant procedures. Whilst there are some common aspects to all three procedures, other technical issues require separate descriptions. For the purpose of this chapter, each will be discussed separately, whilst the common techniques will be reviewed only once. Variations on the procurement will also be addressed and are illustrated by a step by step pictorial accompanied by the necessary text. There are several other texts on the subject which the reader may find helpful [1,2,3,4,5,6,7,8] .

Intestine donor selection

Selection of ISO-INT, LIV-INT and MVT donors is not standardized and can vary from center to center. The criteria mentioned herein are meant to be general guidelines rather than absolute policies.

Donor selection rests on the following major issues:

- **Donor ABO blood group**

The vast majority of donors are identically matched for ABO blood groups. ABO-compatible donors (e.g. O donor to A recipient) have been used with variable outcomes. ABO-incompatible (B donor to A recipient) grafts are not used.

- **Donor age**

Strict age limits have not been established. Donors at the extremes of age raise most controversy. Neonatal or premature donors have not been routinely used mainly due to technical reasons, given the small size of the vasculature. For liver-inclusive grafts, the use of donors from this age group can be higher risk. However, the longest surviving ISO-INT recipient received an allograft from an anencephalic neonate [1]. Similarly, the upper age limit for the intestine donor has not been established. Due to the fact that deceased donors far outnumber ISO-INT candidates, donors older than 50 years of age tend to be avoided. There are no specific data to support this practice. However, for liver-inclusive grafts, the donor to candidate mismatch is not favorable and therefore there is a need to consider donors older than 50 years of age.

- **Donor weight**

The donor to recipient weight ratio (DRWR) or size matching is critical to outcome. Most intestine recipients have undergone prior intestinal resections and have contracted abdominal domains. Therefore intestine donors of equal size or greater tend to be associated with recipient abdominal wall defects and morbidity. As a consequence, most centers strive for a DRWR of less than 1.

- **Hemodynamics and pressors**

The intestine is exquisitely sensitive to ischemia and low flow states. Therefore intestine donors with

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prolonged downtime, CPR and high pressor requirements potentially have sustained ischemic injury to the graft. Again, due to the favorable number of cadaveric donors available, hemodynamically unstable donors or those with high pressor requirements or prolonged downtime/CPR are usually avoided. This practice is not necessarily used for liver-inclusive donors, again due to organ shortage in this recipient population [2].

Intestine donor preparation

Preparation for procurement of the ISO-INT, LIV-INT or MVT is similar to that for other solid organs. Prior to starting the operation, the donor medical chart should be thoroughly reviewed by the procuring team. The ABO blood group should be verified, as should the donor identity. Most national organ banks assign a donor number to each deceased donor and this number should be confirmed.

A discussion between the liver, pancreas, intestine and kidney teams should take place regarding the sharing of vasculature and which organ will take priority in the instance of aberrant vascular anatomy.

Isolated intestine grafts (ISO-INT)

Procurement

Step 1 – incision and exposure

The ISO-INT, LIV-INT and MVT donor is approached identically to the other multiorgan donors.

A midline incision from the sternal notch to the pubic symphysis is carried out. The sternum is divided using standard techniques and the abdominal fascia is divided carefully so as to avoid injury to the abdominal viscera. Appropriate retractors are placed for exposure. In our experience, large Balfour retractors provide sufficient exposure (Figure 11.1).

Step 2 – inspection of the abdominal viscera

After opening, a thorough inspection of all abdominal and thoracic organs is required to rule out other pathology such as abscesses and malignancies. Suspicious lesions should be biopsied. Additionally, other pathology such as hepatic cirrhosis and pancreatitis may influence the decision to accept the intestine graft.

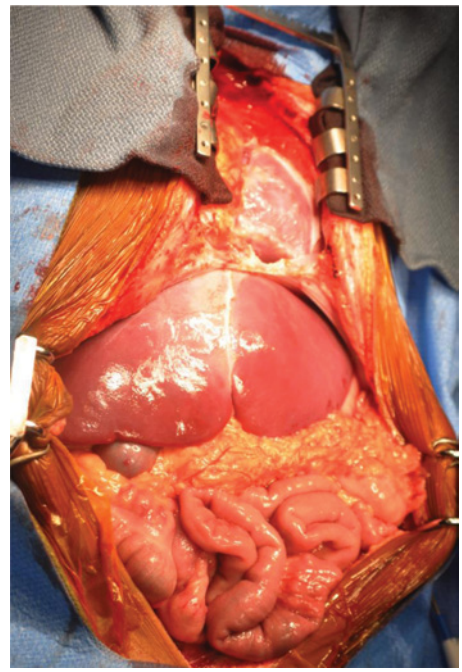

Figure 11.1 General appearance after applying a retractor.

The entire jejunoileum from the ligament of Treitz to the ileocecal valve should be carefully inspected. The appearance of the intestinal wall should be assessed. Problem lesions such as mural hematomas, ecchymosis and peticheal hemorrhage should be assessed. The perfusion of the intestinal wall should also be assessed. Congestion and pallor are concerning appearances. Examination for peristalsis is also critical. Next, the mesentery is inspected and the vascular arcade is carefully assessed for visible arterial pulsation as well as venous congestion. Particular attention should be paid to the terminal ileum, as this is many times a watershed region for vascular issues. The mesenteric lymph nodes should be inspected. Enlarged or abnormal lymph nodes should be biopsied.

Intraoperative assessment of the intestine includes:

- quality of perfusion;
- presence of peristalsis;
- presence of mural lesions;
- evaluation of vascular arcade;
- evaluation of the mesenteric lymph nodes.

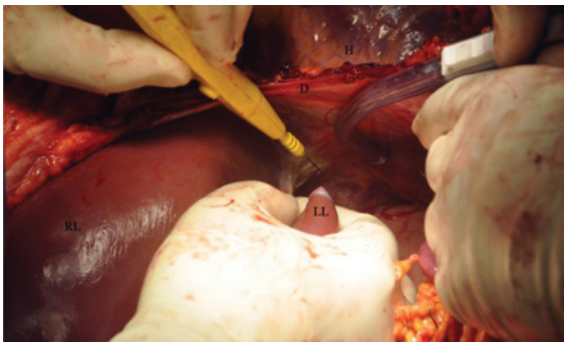

Figure 11.2 Lateral segment mobilization. (D, diaphragm; H, heart; LL, left lateral segment; RL, right lobe)

Step 3 – warm dissection

The first two steps of warm dissection are universal to all organ procurement and are necessary to obtain vascular control in preparation for cross-clamp and perfusion. It is essential that these are performed first in case of donor hemodynamic instability.

The left lateral segment of the liver is mobilized (Figure 11.2).

The gastrohepatic ligament is opened after inspection for a replaced/accessory left hepatic artery (LHA) (Figure 11.3).

The diaphragmatic crura is incised and the supraceliac intra-abdominal aorta is mobilized and encircled with umbilical tape (Figure 11.4).

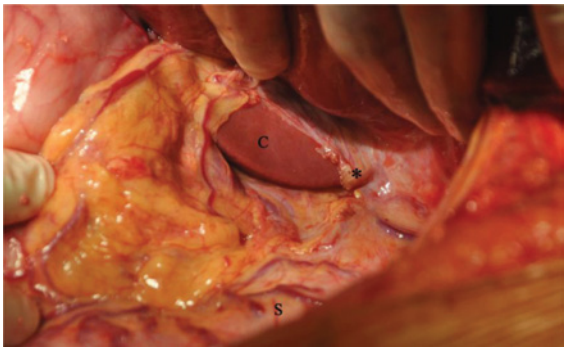

Figure 11.3 Complete mobilization of the left lateral segment of the liver. (C, caudate; S, stomach; *, location of replaced LHA)

This step is performed easiest with the sternum opened and a retractor in position. Difficulty should lead to deferring the encirclement of the aorta until just before cross-clamp to avoid catastrophic aortic injury.

A medial visceral rotation of the abdominal viscera is performed to expose the retroperitoneum (Figure 11.5).

Starting with the cecum, the colon and jejunoileum are mobilized off the retroperitoneal structures. Mobilization will include the duodenum in a

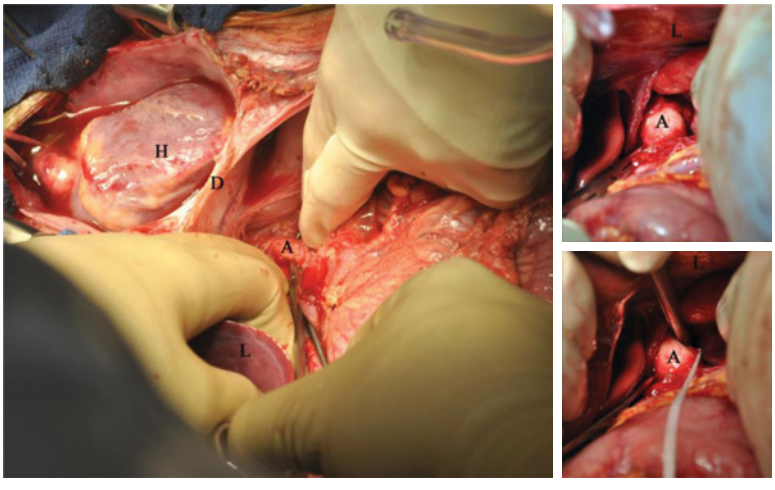

Figure 11.4 Encircling the supraceliac aorta. (A, supraceliac aorta; D, diaphragm; H, heart; L, lateral segment)

Kocher-type maneuver. The full mobilization will end at the root of the mesentery and superior mesenteric artery (SMA).

The exposure will unveil the aorta and iliac arteries, inferior vena cava (IVC), bilateral kidneys, ureters and the renal veins.

Next, the infrarenal aorta is encircled and controlled with umbilical tape (Figure 11.6). With these maneuvers complete, urgent vascular control and cannulation can occur, should it become necessary.

As an alternative technique, especially for pediatric donors, the iliac artery can be cannulated. To prepare for this variation, both the distal aorta and bilateral iliac arteries must be dissected and controlled (Figure 11.7).

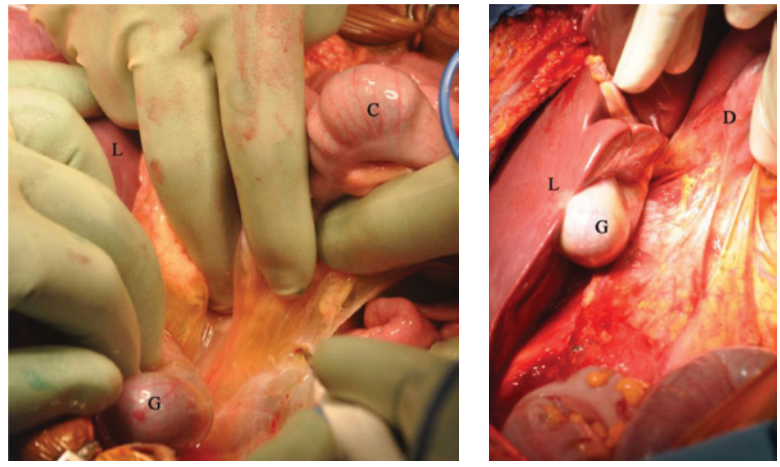

Figure 11.5 Medial visceral rotation. (C, colon; D, duodenum; G, gallbladder; L, liver)

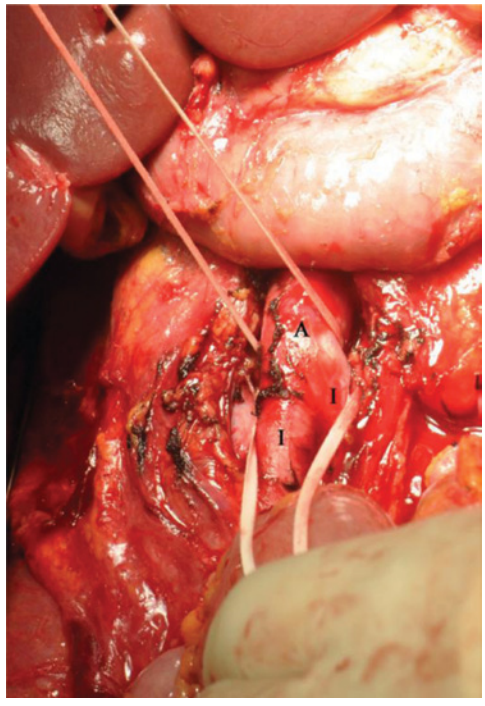

Figure 11.6 Encircling the aorta. (A, aorta; I, iliac artery)

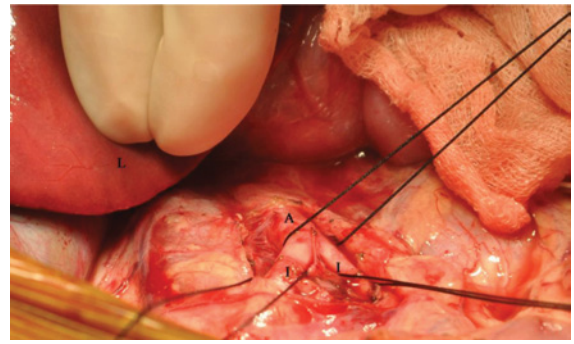

Figure 11.7 Encircling bifurcation of the aorta. (A, aorta; I, iliac artery; L, liver)

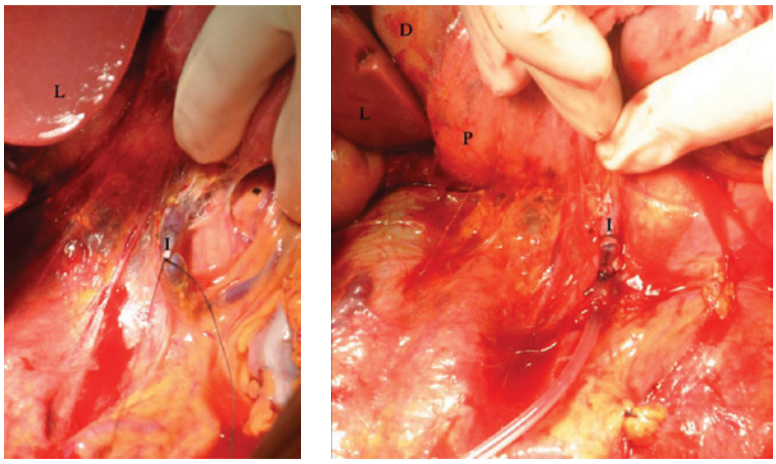

Figure 11.8 IMV cannulation. (D, duodenum; I, inferior mesenteric vein; L, liver; P, pancreas)

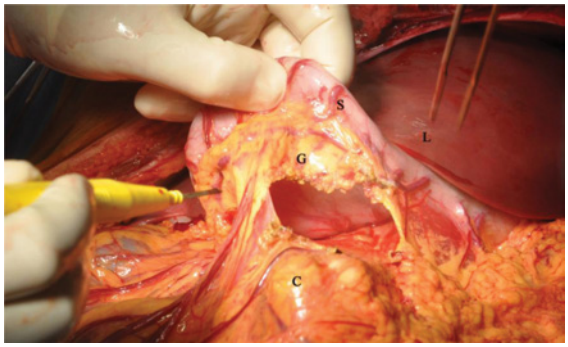

Figure 11.9 Dividing the gastrocolic ligament. (C, colon; G, gastrocolic ligament; L, liver; S, stomach)

Some teams elect to cannulate the inferior mesenteric vein (IMV) to facilitate perfusion of the grafts. The IMV can safely be cannulated at this juncture for later perfusion. This does not interfere with intestinal procurement (Figure 11.8).

Step 4 – distal GI tract

Further warm dissection is related to the colon. The gastrocolic ligament should be divided (Figure 11.9). A near total colectomy is performed starting at the ileocecal valve. Care is taken to preserve the ileocolic artery perfusion to the terminal ileum.

The mesentery underlying the ileum is freed and the terminal ileum is divided using a stapling device (Figure 11.10).

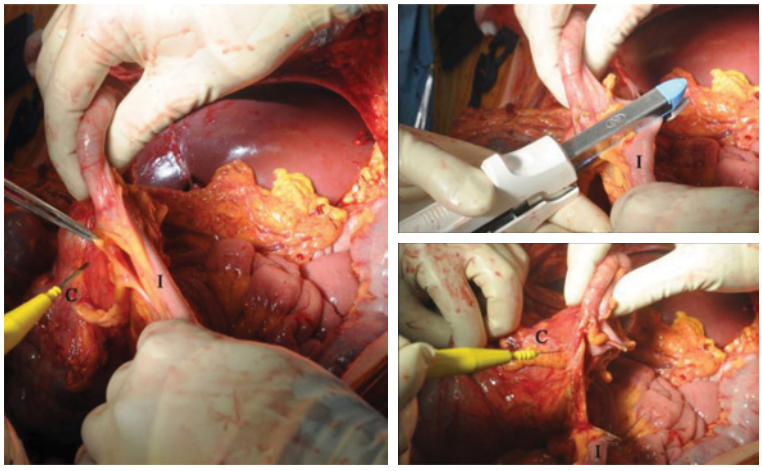

Figure 11.10 Dividing the terminal ileum. (C, colon; I, ileum)

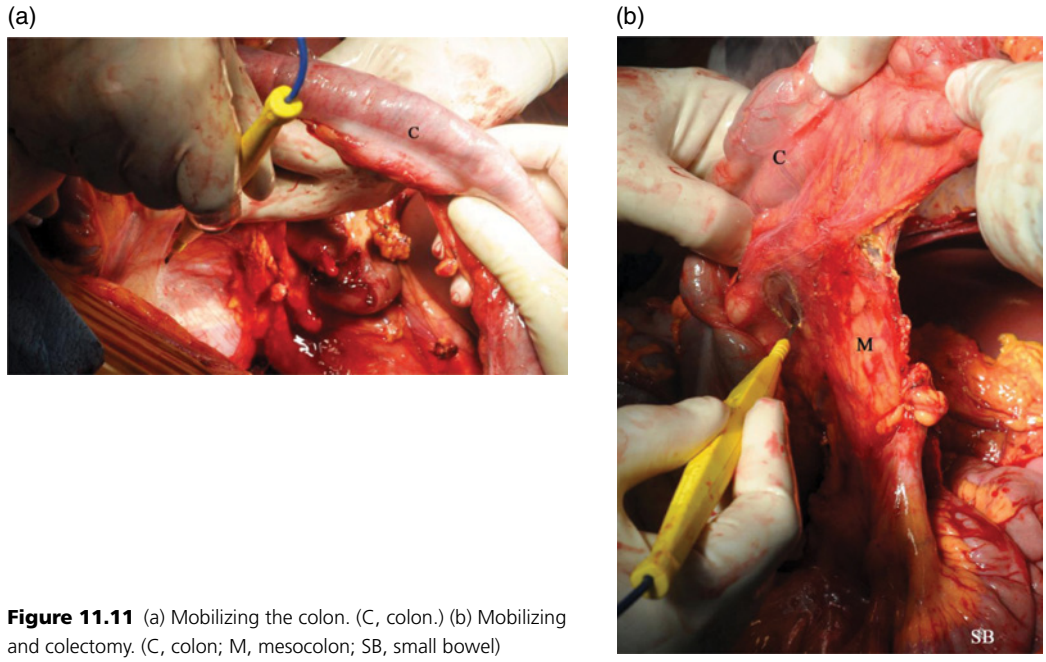

Figure 11.11 (a) Mobilizing the colon. (C, colon.) (b) Mobilizing and colectomy. (C, colon; M, mesocolon; SB, small bowel)

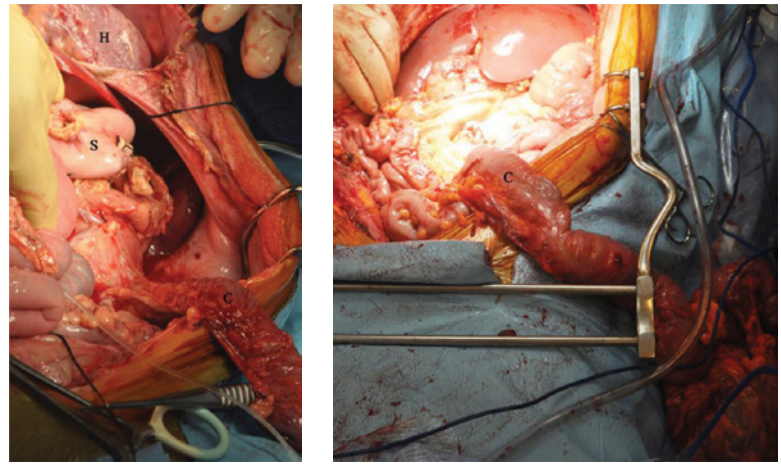

Figure 11.12 Near total colectomy with the colon retracted out. (C, colon; H, heart; S, stomach)

Next, the mesentery underlying the cecum, right and transverse colon is serially clamped and divided (Figure 11.11 a and b). Manual ligation and division is commonly performed but stapling devices can be used for such dissection.

Once this is complete, the dissected colon can be retracted off the operative field to the donor's left side (Figure 11.12).

Inclusion of all or part of the colon may be performed with any type of intestinal transplant. This modification requires the colon to be surgically divided at the desired level – usually midtransverse beyond the middle colic vessels or distal descending colon. The gastrocolic ligament is completely divided. The included colon is mobilized from its retroperitoneal position. The mesentery is not divided but instead retained for transplantation (Figure 11.13).

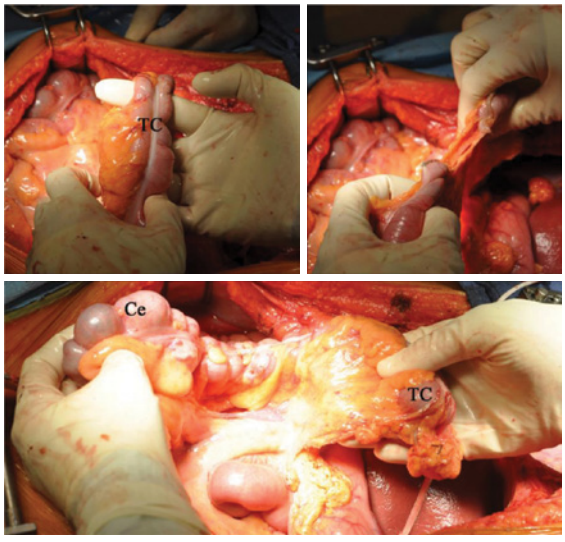

Figure 11.13 Dividing the midtransverse colon. (Ce, cecum; TC, transverse colon)

Step 5 – proximal GI tract

The proximal jejunum should be mobilized at the ligament of Treitz and divided using a stapling device. Then the mesentery should be ligated and divided down to the duodenum and pancreas (Figure 11.14). Inspect the divided jejunum on the ISO-INT side to ensure adequate vascular perfusion.

Step 6 – vascular control

The SMA should also be exposed at this time. Re-approaching the root of the mesentery, the SMA can be easily palpated above the left renal vein.

The lymphatic and nerve tissue should be divided and the SMA encircled (Figure 11.15).

Dissection to the base of the aorta will help identify the renal arteries. Dissection for 2–3 cm distal on the SMA will help to identify the takeoff of an aberrant replaced/accessory right hepatic artery (ARHA).

The presence of a replaced/accessory right hepatic artery does not necessarily preclude the procurement of the ISO-INT graft.

If the replaced/accessory RHA is of sufficient size, then it can be divided after its takeoff from the SMA and reconstructed on the liver side. If the accessory RHA is too small, then it may be sacrificed altogether as it may not have a significant contribution to the perfusion to the right lobe of the liver. If the accessory vessel has to be preserved in continuity with the SMA,

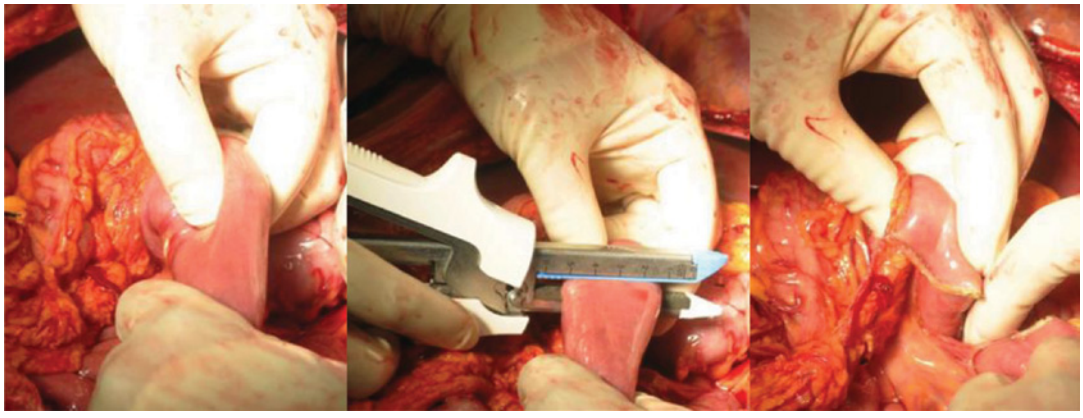

Figure 11.14 Jejunum dissected and divided.

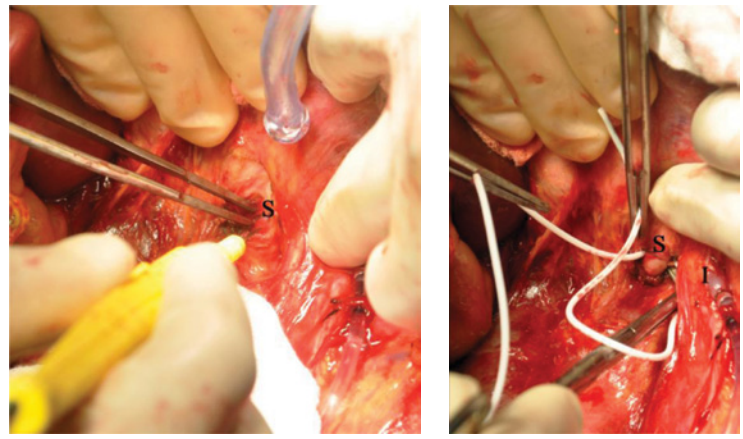

Figure 11.15 Encircling the SMA. (I, inferior mesenteric vein; S, superior mesenteric vein)

due to the liver surgeon's preference, then the SMA can be divided beyond the takeoff of the replaced RHA.

It is important to discuss such options with the pancreas and liver procurement teams prior to starting the donor procedure.

Step 7 – cannulation, cross-clamp and perfusion

This step should take place after all surgical teams have completed their warm dissection. Strict coordination with all other donor teams is required. The decision regarding where to vent the IVC blood and perfusate should be discussed prior to starting the procurement. Options include venting in the chest through the supradiaphragmatic IVC or in the abdomen through the infrarenal IVC. In the latter instance, placement of an IVC cannula is preferable. The decision as to which preservation solution is to be used should also be discussed prior to starting. Additionally, the decision as to the volume of preservation solution should be made ahead of time. Fifty to 100 cc/kg of standard preservation solution is typical.

Strict coordination is also required prior to cross-clamp regarding the intravenous infusion of medications such as heparin, lasix and mannitol.

- Heparin is an essential part of ISO-INT procurement.
- Administer at least 5 minutes prior to cross-clamp.
- Thirty thousand units is typically given to adults.
- Give 100 cc/kg to pediatric donors.

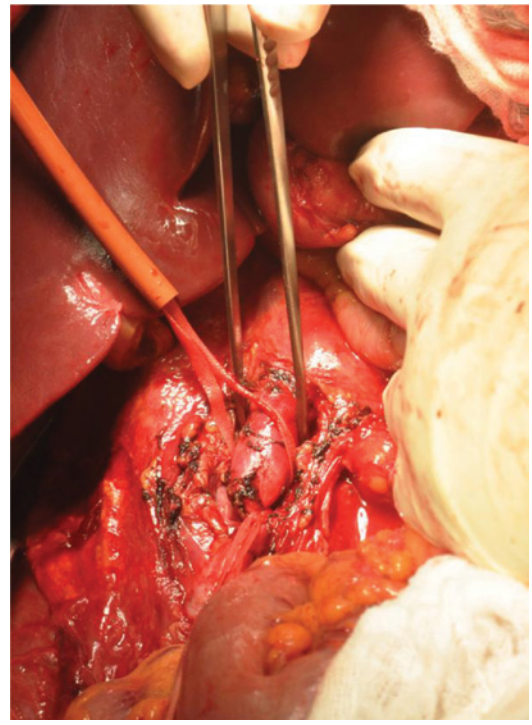

Figure 11.16 Cannulating the infrarenal aorta.

Once all teams are prepared, cannulation is undertaken. The distal aorta above the iliac artery bifurcation is ligated.

A proximal umbilical tape is placed around the aorta (Figure 11.16).

The proximal aorta is controlled. An arteriotomy is created (Figure 11.17) and the aorta cannulated (Figure 11.18). The cannula should be advanced to a level just below the takeoff of the renal arteries and is secured in position with the umbilical tape.

As an alternative technique, the cannula can be placed into the aorta via the iliac artery. With the dissection complete, as shown in Figure 11.7, both distal iliac arteries are ligated and the proximal aorta controlled (Figure 11.19). Then an arteriotomy is created in one iliac artery using an 11-blade scalpel and the artery is cannulated and controlled as above (Figure 11.20).

Once all teams have cannulated, the donor is exsanguinated by incision of the supradiaphragmatic IVC with drainage in the right chest (Figure 11.21).

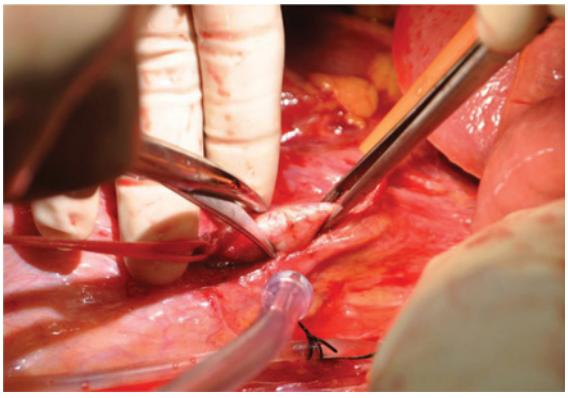

Figure 11.17 Aortic arteriotomy.

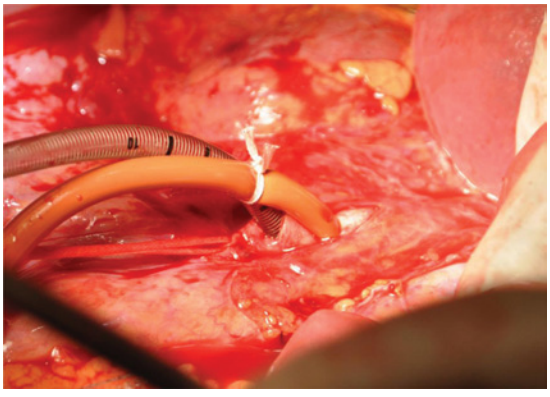

Figure 11.18 The cannula is secured in position with umbilical tape.

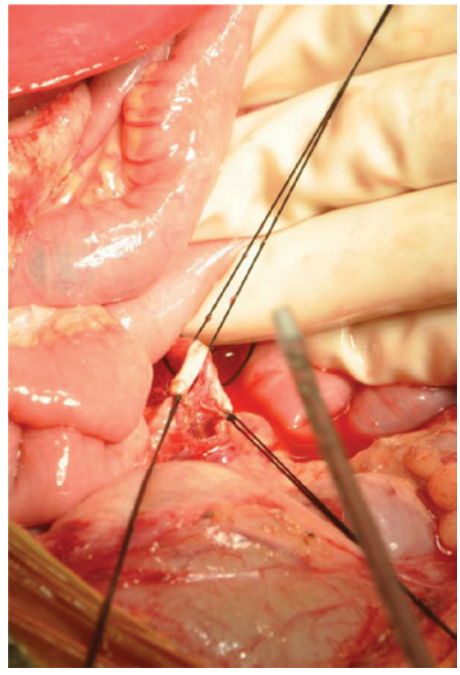

Figure 11.19 Cannulating the common iliac.

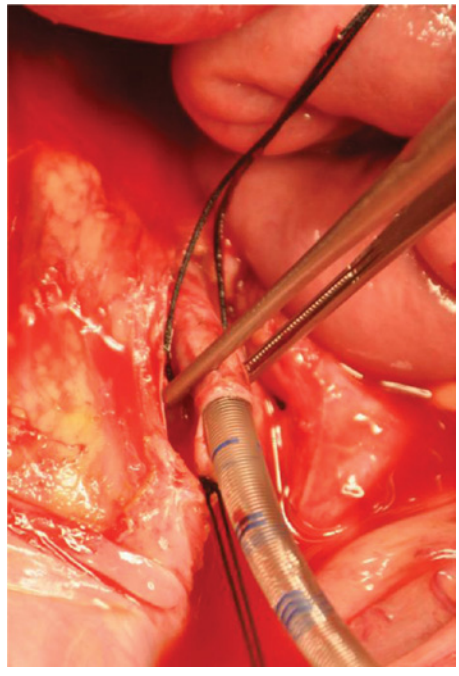

Figure 11.20 Cannulated common iliac artery.

As noted above, this maneuver can also be accomplished at the level of the infrarenal IVC with a cannula in position.

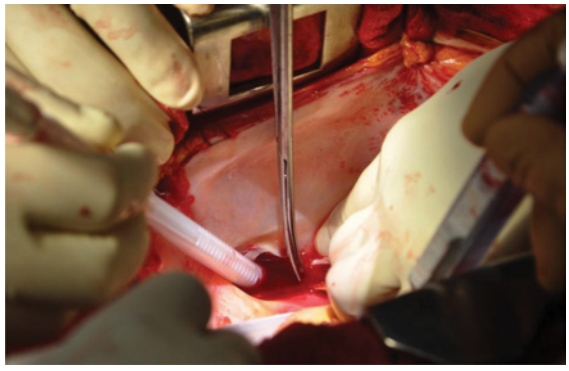

Figure 11.21 Venous effluent at the vena cava (thoracic).

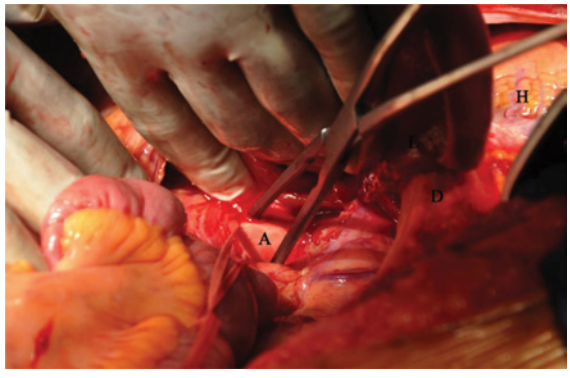

Figure 11.22 Applying the supraceliac clamp. (A, aorta; D, diaphragm; H, heart; L, left lobe of liver)

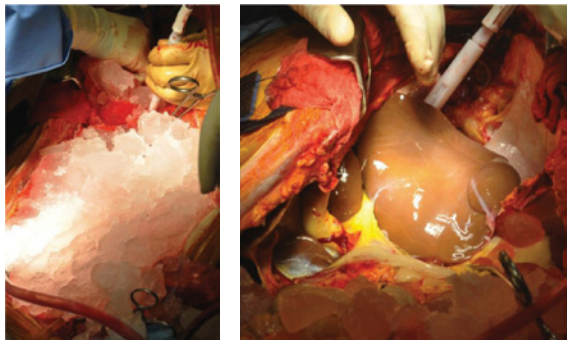

Figure 11.23 Preservation solution perfusion and organ inspection.

Immediately and using the umbilical tape placed around the supraceliac aorta, a straight vascular clamp is placed (Figure 11.22).

Then, via the cannula, preservation solution is infused into the infrarenal aorta.

Ice slush is placed topically on all abdominal viscera. Perfusion of the preservation solution then proceeds until the venous effluent clears of blood. Intermittent inspection of the viscera is required to ensure proper flushing (Figure 11.23).

Once full perfusion and core cooling is accomplished, the organs are removed in an orderly fashion, starting with the thoracic organs and proceeding with the liver, pancreas, intestine and kidneys.

Step 8 – cold dissection and organ removal

Alternative 1 – no pancreas procurement

In cases where pancreas procurement does not occur, longer mesenteric vessel lengths can be obtained. Dissection has already taken place in the foregut region, as at this stage the isolated liver graft has been removed. The entire graft save the root of the mesentery has been mobilized during the warm dissection describe above.

The portal vein is dissected first and is retained at the level determined by the liver procurement. The vein is dissected out of the head of the pancreas back to the root of the mesentery (Figure 11.24).

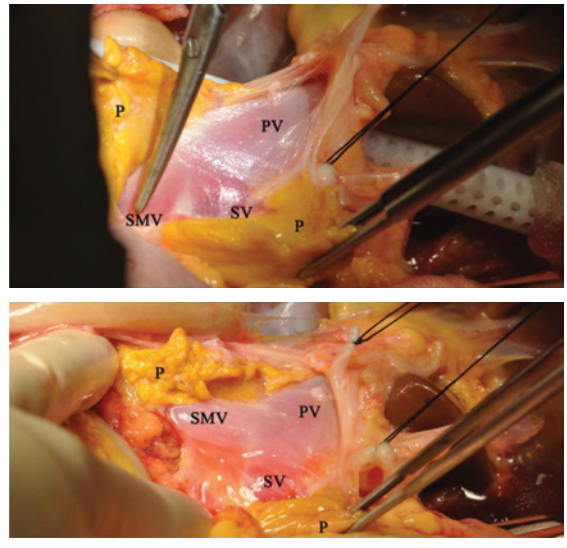

Figure 11.24 Dissecting the portal vein. (P, divided pancreas; PV, portal vein; SMV, superior mesenteric vein; SV, splenic vein)

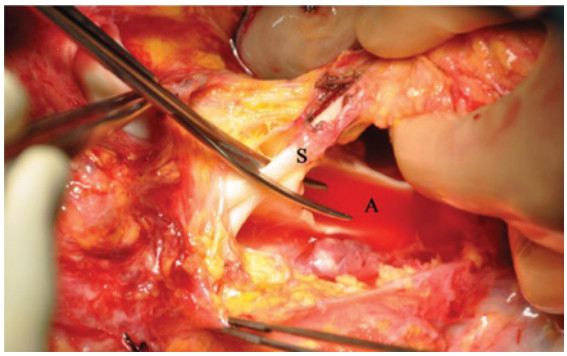

Figure 11.25 Transection of the aorta at the base of the SMA. (A, aorta; S, superior mesenteric artery)

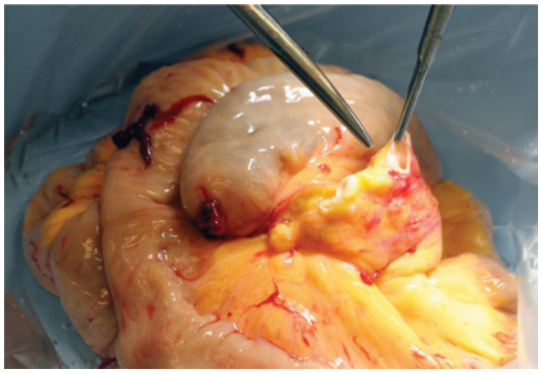

Figure 11.26 Intestinal graft.

Next, the aortic origin of the SMA is identified at the level of previous dissection.

The aorta is transected at the base of the SMA, leaving an aortic cuff on the vessel (Figure 11.25).

Take care to avoid injury to the renal arteries and leave enough aorta for ample cuffs on the renal arteries.

The dissection is carried in the plane between the two vessels out of the retroperitoneum, completely mobilizing the ISO-INT graft with vascular cuffs. The graft is then passed to the bench and placed in appropriate sterile bags, tagged and stored in ice (Figure 11.26).

Alternative 2 – aberrant RHA anatomy

If there is a replaced RHA retained with the liver segment, then the dissection is essentially the same as described above, except that the SMA is transected just distal to the takeoff of the replaced/accessory RHA, as illustrated in Chapter 6.

Alternative 3 – pancreas procurement

In cases where the whole pancreas is procured, then the extra length of portal vein and superior mesenteric vein (SMV) cannot be obtained. In this instance, the cold dissection will be restricted to the root of the mesentery. As per standard practice, a TA stapler is applied on the pancreas side of the root of the mesentery and fired (Figure 11.27).

The ISO-INT side is sharply transected using a scalpel blade. This will result in short segments of SMA and SMV, which will then require vascular extension grafts on bench reconstruction.

Bench reconstruction

ISO-INT bench reconstruction centers on the vascular component.

- When the entire SMA and SMV are retained with the graft, these vessels only require dissection from surrounding connective tissue to provide adequate cuffs for surgical implantation.
- If the vessels are transected at the root of the mesentery to allow simultaneous procurement of the whole pancreas, then only short cuffs of the SMA and SMV exist. These vessels should be identified and freed from surrounding connective tissue for a short distance. Donor vascular conduits should be prepared and sutured in an end-to-end manner to the SMA and SMV using a fine polypropylene suture. These extension conduits will then provide adequate length to perform the anastomoses in the recipient. After completion, the jejuno-ileum is wrapped in a towel to aid with implantation in the recipient.

Liver–intestine grafts (LIV-INT)

Procurement

Procurement of LIV-INT follows the initial four steps described for ISO-INT procurement:

Step 1 –incision and exposure
Step 2 –inspection of the abdominal viscera
Step 3 –warm dissection
Step 4 –distal GI tract

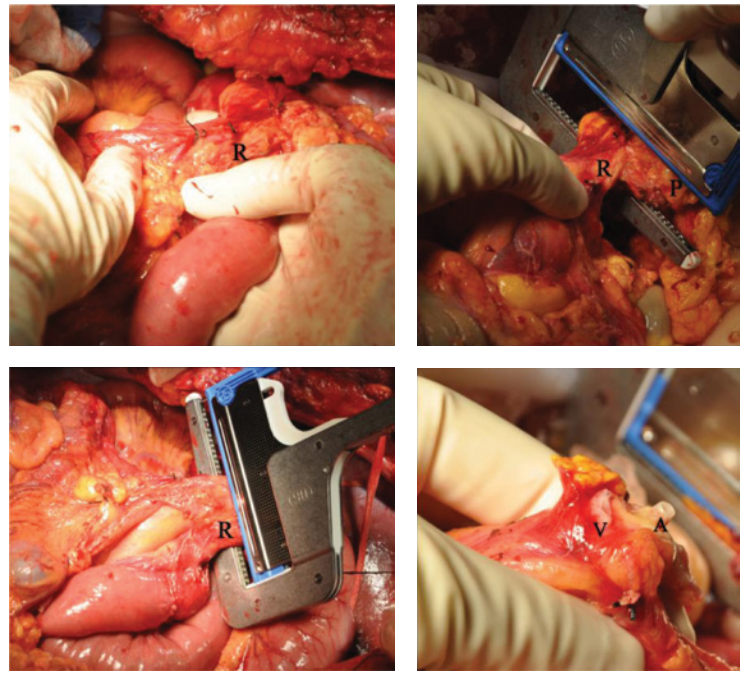

Figure 11.27 Dividing the root of the mesentery with a TA stapler. (A, superior mesenteric artery; P pancreas; R, root of mesentery; V, superior mesenteric vein)

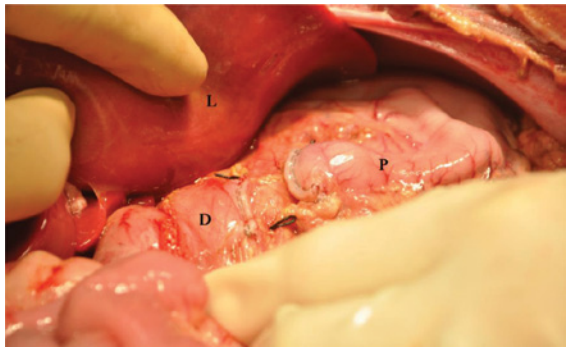

Figure 11.28 Divided duodenum with stapling device. (D, duodenum; L, liver; P, pylorus)

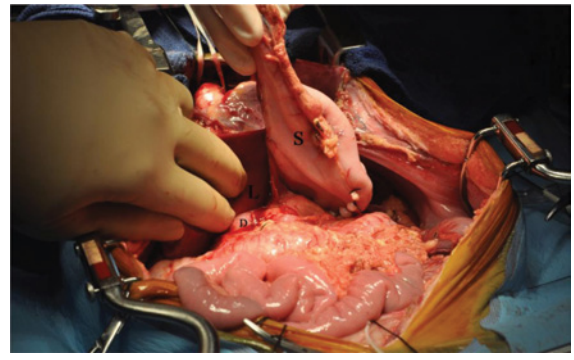

Figure 11.29 The stomach is fully mobilized. (D, duodenum; S, stomach)

Step 5 – proximal GI tract

Further warm dissection required for LIV-INT relates to the stomach. The duodenum is divided using a surgical stapling device just beyond the pylorus (Figure 11.28).

The lesser curve of the stomach is dissected, taking care to spare the left gastric arterial branch to the liver if present (replaced/accessory LHA). The greater curvature of the stomach is dissected next, ligating the short gastric vessels to completely separate the spleen from the stomach. The gastrocolic ligament and splenocolic ligaments have been divided in the earlier warm dissection described above. The stomach is now fully mobilized and retracted to the donor's left side (Figure 11.29).

The spleen and the pancreas are then mobilized medially from the retroperitoneum, until the aorta is exposed.

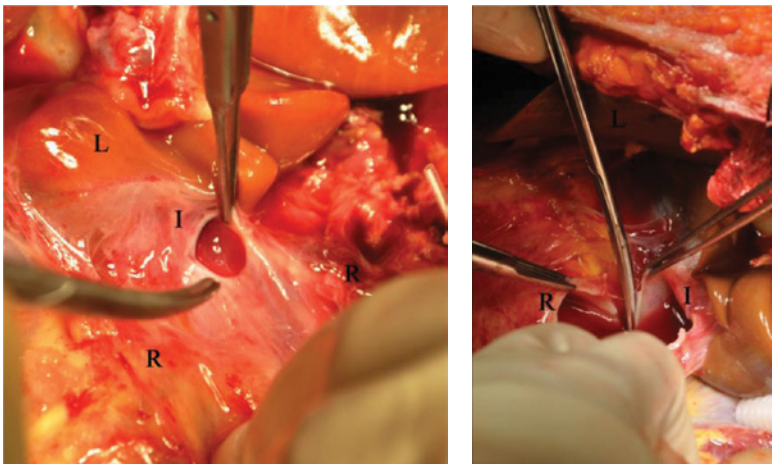

Figure 11.30 Transecting the IVC. (I, inferior vena cava; L, liver; R, renal vein)

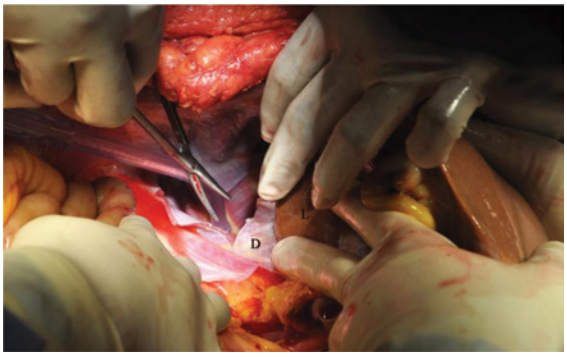

Figure 11.31 Remainder of retroperitoneal tissue is divided. (D, duodenum; L, liver graft)

Step 6 – vascular control

Essentially, proximal vascular control has already been obtained on the supraceliac aorta, and distal vascular control has been obtained on the infrarenal aorta, as described in step 3 for ISO-INT.

Step 7 – cannulation, cross-clamp and perfusion

This step is identical as for ISO-INT procurement.

Step 8 – cold dissection and organ removal

LIV-INT procurement is in reality an *en bloc* liver, duodenum, pancreas, spleen and jejunoileum procurement. This is due to modifications that have occurred with the recipient operation leading to the retention of the pancreaticoduodenal complex. The cold dissection is approached from the liver first. The diaphragm is sharply divided over the esophagus and medial to the suprahepatic IVC. The diaphragm is then divided to the right of the IVC. The liver can be retracted cephalad and placed in ice.

Next, hilar dissection is not required and should be avoided. Instead, the supraceliac aorta is identified and dissected. The entire thoracic and supraceliac aorta should be dissected free and retained with the graft.

The celiac trunk and SMA are identified. The aorta is identified below the SMA and transected. Based on the location of the renal arteries, the aorta is transected completely at this level, leaving cuffs for the renal arteries.

The entire aorta is then mobilized free. Next, the viscera are retracted cephalad.

The IVC is identified and dissected. Based on the locations of the renal veins, the IVC is transected, leaving adequate venous cuff for the renal veins (Figure 11.30).

Then, the retroperitoneal tissue between the liver and adrenal gland is divided while retracting the right kidney inferiorly. The remainder of the retroperitoneal tissue is divided while retracting the entire graft out of the retroperitoneum (Figure 11.31).

Care is taken to avoid injury to the IVC and aorta. The complex is then placed in sterile bags and in ice storage for transportation and bench reconstruction.

Bench reconstruction

The *en bloc* graft is removed from ice storage and oriented on the bench. The preparation starts with the right lobe of the liver.

• The diaphragmatic attachments are taken down from lateral to medial.
• The suprahepatic IVC is identified and dissected free.
• The retrohepatic and infrahepatic IVC are likewise dissected.
• The adrenal vein branch is ligated.
• Depending on whether the graft is to be implanted in the recipient using the piggyback technique or not, the infrahepatic IVC is either ligated or left open for anastomosis. Then the aorta is approached. The entire aortic segment is freed from connective tissue. The posterior lumbar branches are all ligated.
• The aorta below the SMA is next addressed. If an adequate cuff of aorta exists below the SMA, this can be directly closed using polypropylene. If not, an aortic patch should be placed to close this orifice. A segment of donor iliac artery or thoracic aorta can be fashioned into a size-matched patch. This can be sutured directly over the orifice using polypropylene monofilament suture.
• Next, the jejuno-ileum is oriented and wrapped in a towel to aid with implantation in the recipient.

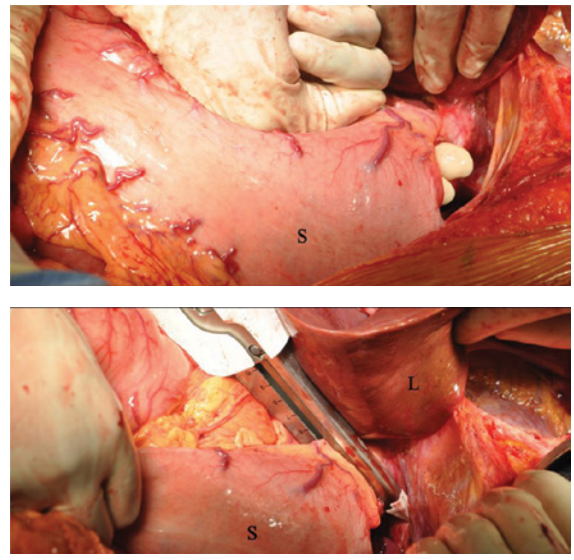

Figure 11.32 Mobilizing and dividing the stomach. (L, lateral segment liver; S, stomach)

Multivisceral grafts (MVT)

Procurement

The initial four steps of MVT procurement are as illustrated above:
Step 1 –incision and exposure
Step 2 –inspection of the abdominal viscera
Step 3 –warm dissection
Step 4 –distal GI tract

Step 5 – proximal GI tract

This step may be identical to that described above for LIV-INT procurement. However, in some MVT, the stomach is retained. Therefore, the duodenum is not divided as above. Instead, the proximal stomach is divided at the gastroesophageal junction using a surgical stapling device (Figure 11.32).

Dissection on the greater and lesser curvature of the stomach is avoided to preserve gastric blood supply.

Part of or the entire colon may also be retained. After division of the proximal stomach/esophagus, the stomach, spleen and pancreas are mobilized medially from the retroperitoneum until the aorta is reached and exposed.

Step 6 – vascular control

Proximal vascular control has already been obtained on the supraceliac aorta, whilst distal vascular control has been obtained on the infrarenal aorta (see ISO-INT step 3).

Step 7 – cannulation, cross-clamp and perfusion

This step is identical as for ISO-INT procurement.

Step 8 – cold dissection and organ removal

Much of MVT cold dissection is identical to that of the LIV-INT dissection described previously. An important difference relates to the retention of the stomach with the allograft. In this instance, the stomach, previously divided at the gastroesophageal junction, is retracted inferiorly to allow the aortic dissection, as described for LIV-INT.

Bench reconstruction

Preparation of MVT, regardless of whether the stomach is retained or not, does not differ substantially from LIV-INT bench preparation.

Summary box

- Intestine transplantation is ABO matched.
- Donors more than 50 years of age are usually avoided.
- DRWR is usually less than 1.
- Hemodynamic instability or high pressor requirement in the donor are usually avoided for isolated intestine transplantation.
- Discuss sharing of vasculature in case of aberrant anatomy.
- Discuss choice of perfusion fluid with other teams involved.
- Administer 50–100 cc/kg of perfusate.
- Give heparin (30,000 units for adults and 100 cc/kg for pediatric donors).
- Avoid renal artery injuries when dividing the SMA origin.
- Do not dissect the hepatoduodenal ligament for liver–intestinal or multivisceral retrievals.
- Preserve stomach vascular supply in multivisceral retrievals.
- Bench surgery is essentially vascular preparation (and liver preparation in multivisceral allografts).

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12 Pediatric Age-Specific Aspects of Retrieval and Bench Surgery

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Introduction

Although the general considerations (donor selection, logistical aspects and surgical techniques) presented in the other chapters of this book do apply to pediatric organ transplantation, there are several age-specific aspects particular to selection of donors, procurement and preparation of organs for transplantation in small-weight recipients. These also apply when selecting young-age donors and procurement/preparation of organs for transplantation in small recipients.

In this chapter, these specific aspects will be addressed as a complement to the other chapters.

Donor selection for pediatric solid organ transplantation

General criteria

The 'optimal donor' is usually defined based on three major criteria: age, hemodynamic characteristics and systemic risk (malignancies and infections).

The ideal donor age range considered for pediatric transplantation is from 1 to 50 years of age, but this could be easily extended at both ends of the spectrum (from 6 months of age up to 55–60 years old) when other donor characteristics are excellent.

The hemodynamic assessment includes many aspects, identified from the past medical history of the donor or from events occurring during the terminal hospital admission:

- chronic arterial hypertension treated or not with vasoactive drugs;
- severe hypotension or cardiac arrest in recent history or at/after brain death;
- the amount of inotropic support in the last 3 days.

Other donor parameters that are related to, or may suggest, tissue ischemic damage and hypoperfusion (such as urine output, creatinine level and liver tests profile) may be taken into account.

When it comes to assessing small donors, less than 5 years of age, the normal range value of arterial blood pressure according to age must be taken into account (Table 12.1) [1,2].

Table 12.1 Mean values of blood arterial pressure (systolic/diastolic) according to age.

Age	Blood pressure (mmHg)
Premature	75/45
0–3 months	70/50
3–6 months	80/60
6–12 months	90/65
1–3 years	100/65
3–6 years	100/70
6–12 years	110/75
>12 years	120/80

Assessment of risk of malignancy and infection transmission, and contraindications to organ utilization

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follow the same criteria as for adult transplantation. In the younger donor age group, meningitis is specifically a more frequent cause of brain death when compared to the adult donor population. The use of grafts from donors with bacterial meningitis for liver transplantation is accepted when both donor and recipient are well managed (appropriate antibiotics for a period of several days and careful observation to detect any unusual signs or atypical sepsis in the postoperative period) [3].

Meningitis is a more frequent cause of brain death in pediatric recipients. Organ donation is acceptable if donor and recipient are treated with appropriate antibiotics.

The duration of the donor's stay in the intensive care unit (ICU) is an important parameter of the 'quality' of the donor, based on the fact that a prolonged stay is associated with a higher risk of tissue/organ ischemic damage, colonization by resistant bacteria and subclinical infection, and metabolic or catabolic injuries. It is usually considered that donor condition remains optimal if the stay in ICU is less than 5 days, with all other parameters within normal range.

Donor to recipient weight ratio

In conventional adult solid organ transplantation or when utilizing full-size donor organs in pediatric patients, the donor and recipient should be of similar size to ensure an appropriate match between the organ and the implantation site (donor to recipient weight ratio (DRWR) = 1/1). Moderate variation of the 1/1 DRWR is acceptable (by about +/– 25%), whilst more experienced teams would accept larger mismatches (up to +/– 50%) for abdominal organ transplantation.

Higher DRWR ratios can be considered deliberately in the following circumstances:

- some types of organs may be accommodated in the recipient with greater flexibility, as is the case for kidneys and isolated intestinal grafts (DRWR up to 2/1);
- the recipient's particular condition (such as hepatomegaly or ascites) allows a larger organ to fit *in situ* (DRWR up to 2/1);
- the surgeon plans to use a reduced-size graft (using the reduction or splitting technique, or procurement of partial grafts from living donors) with DRWR from 2/1 to variable figures depending on the organ type – up to 20/1 for liver grafts [4,5].

The donor to recipient weight ratio (DRWR) = 1 (+/– 0.25) if full-size grafts are used. Higher rates can be considered in certain situations (up to 1.5 or 2 maximum).

Donor to recipient age ratio

The utilization of organs from older donors is frequent, including for transplantation in young infants, but in general the accepted age range is 1 to 50 years of age.

When considering much younger donors, there are some concerns about functional (metabolic) immaturity (for example, for livers from donors less than 6 months of age) as well as a higher risk of vascular thrombosis after transplantation. In kidney transplantation, donor age under 5 years old is associated with a significantly lower graft survival and a higher rate of thrombosis [6]. However, excellent survival is obtained when these pediatric kidneys are transplanted *en bloc* rather than as solitary organs.

There are some concerns regarding the functional maturity of the donor organ and a higher risk of vascular thrombosis in young pediatric donors.

The mortality associated with the presence of genetic abnormalities and with inborn errors of metabolism is higher in the Neonatal Intensive Care Unit (NICU) population than in older children. This calls for special consideration of the appropriateness of transplanting an organ carrying cells with known gene mutations or aneuploidies, as well as an organ from a patient in an early stage of a metabolic disorder [7].

The utilization of older donors (more than 50 to 55 years old) for transplantation in children and infants may raise concerns about organ quality and lifespan in the recipients. Despite the ethical debates on the topic, on a practical note the utilization of such organs is very much center-specific, some being more restrictive than others. A reasonable position might be to allow a wider age range for urgent patients and emergencies and a narrower range for elective cases.

The utilization of donor organs at the extremes of ages should take into account specific donor age-related risks as well as recipient factors.

Organ-specific donor criteria

Liver grafts

Ideally, the liver function tests (transaminases, gamma GT and bilirubin) should be normal, but organs with levels less than twice-normal values are sometimes considered. In certain cases (e.g. after anoxia, hypotensive episodes and cardiac arrest), higher values that follow a trend to normalization are acceptable. However, rising values with increasing gamma GT should not be utilized for elective transplants, when reduction or split procedures are necessary, due to the risk of cumulative damage.

Organs with deteriorating liver function tests (more than twice normal values and increasing) should not be utilized for reduction or split procedures.

A normal ultrasound aspect, with absent or minimal steatosis, is recommended, but it is very unlikely that a predonation ultrasound can be easily obtained.

Donors with trauma of the liver or benign malformation/tumor/cyst (such as benign cyst, small hemangioma) are acceptable if the damage or the lesion is localized within the portion of the liver that can be removed (reduction of the liver) [8].

Liver trauma and the presence of benign tumors/cysts are not a contraindication to transplantation if the site can be removed by organ reduction.

The liver graft should be thoroughly evaluated at procurement. The assessment of colour, consistency, volume and the aspect of the liver edges will allow confirmation of the quality of the organ. In case of moderate steatosis, a biopsy can be performed to confirm whether the graft can be used. In general, livers with steatosis up to 30% are routinely used as full-size organs, and other procedures (such as splitting) should be considered with care when significant steatosis (more than 10%) is present.

Depending on the team's expertise, large donors may be accepted for transplantation of partial liver grafts into young infants using the appropriate techniques (split or reduction). Nowadays, the split technique and living donation allow the routine transplantation of left lateral segments (LLS) from adult donors in children with a weight varying between 5 and 30 kg. Further reduction of the LLS segment allows the use of adult-size donors for transplantation in recipients less than 5 kg and neonates [4,9,10]. Equally, retaining segment 4 with the LLS allows transplantation of larger children.

Splitting techniques differ between teams, but there are two major standardized procedures [11,12,13,14] (see section **Split liver**): a 'suprahilar' (transumbilical scissure) and a 'transhilar' route. The latter technique allows the left portal vein to be kept less exposed and also single bile duct drainage in most cases. Basically, the splitting technique is similar to that used for procuring LLS grafts from a living donor. Splitting can be performed *ex situ* during bench surgery, or *in situ* during the procurement operation [15]. The *in situ* split procedure has the advantage of shortening the cold ischemia time of both right and left split grafts but requires a good hemodynamic stability of the donor during the procedure. Furthermore, it can take up to a few additional hours at the donor site, making the entire donor operation more demanding for the local hospital.

Although splitting is the preferred option, reduction of a liver graft can still be appropriate in specific circumstances:

- The liver is not optimal for splitting: focal damage or pathology in resected parenchyma, hepatic steatosis.
- The whole liver graft is too large to fit in the recipient's abdomen and the LLS graft would provide an insufficient parenchymal mass for the recipient (DRWR 1.5–3).
- The donor is rather small and the splitting procedure would increase the risk of compromising the vascular system, either by extensive dissection and skeletonization or in the case of multiple arteries of very small diameter.

- Liver function tests should be normal or less than twice normal values.
- Deteriorating liver function tests should preclude the use of a liver for splitting.
- Steatosis more than 10% is a relative contraindication for splitting.
- LLS can be used for recipients between 5 and 30 kg.
- Liver reduction has limited indications.

Intestinal grafts

The intestine is most susceptible to hypoperfusion induced by hypovolemia, hypotension or cardiac arrest in the donor, all leading to ischemic damage. Therefore, selection of the donor is a critical step, with selection criteria more strict than usually considered

for other organs. In the absence of specific biological data to evaluate the donor intestine, selecting donors with the best profile is necessary; this includes perfect hemodynamic stability and low inotropic support, without history of cardiac arrest.

Specific information must be obtained from the donor history and clinical condition. Procurement would be contraindicated if there are signs suggesting active or chronic digestive pathology or splanchnic hypoperfusion (food allergies, chronic or acute recent diarrhea, melena). Family history inquiry will be useful to exclude donors at risk (Crohn's disease, familial polyposis).

The recipient status and the type of transplantation affect the acceptable range of donors and DRWR. Typically, very small candidates for transplantation need in fact a combined liver and intestine transplant, and have a very small abdominal cavity because of previous intestinal resection (short gut). When transplanting organs in these small-weight infants, only small-weight donors with a 1/1 ratio (or even lower) DRWR can be used. However, a ratio of 1/3 (maximum 1/4) can be reached when the combined graft is reduced.

Inclusion of the colon in the graft depends on several factors, from recipient disease and anatomical status, to the space available in the abdomen to fit the graft and the size of the donor.

- Intestinal donor major requirements: hemodynamic stability, low inotropic support and no cardiac arrest.
- Active or chronic digestive pathology contraindicates intestinal donation.
- A family history of bowel disease or food allergy should be sought.
- DRWR varies between 1/1 and 1/4.

Kidney grafts

Donor selection follows the general principles set out for adult kidney transplantation. These include the possible acceptance of kidneys with mild dysfunction (creatinine more than twice normal value) after a biopsy has been performed and it shows reversible damage.

Kidney grafts are nowadays allocated on the basis of HLA matching and other specific priorities and therefore in most cases the DRWR is not relevant. Only for a few recipients of small weight will their size require special attention to donor selection. In fact, using a larger donor has the advantage of giving a larger parenchymal mass to the recipient. Attention to the size-match should be given when the DRWR is more than 3, which is the recommended upper limit.

Kidney grafts procured from small donors, less than 3 years of age (or less than 12 kg), carry a risk of vascular thrombosis higher then normal and should be considered carefully. Kidneys from these donors can be used *en bloc* in a single larger recipient, with the vena cava and aorta of the donor used for anastomosis into the recipient.

Small donor kidneys should be considered for *en bloc* transplantation, whilst DRWR ratios more than 3 should be avoided.

Relevant aspects for organ procurement and techniques

General aspects

In standard conditions, the organ procurement technique used in small-weight donors is the same as that used for adult donors, with some specific aspects:

- The 'no-touch' *en bloc* technique is preferred for preparation during the warm phase, minimizing dissection and surgical trauma before perfusion. The younger the donor, the lesser the dissection, in order to reduce ischemic vascular injuries [16,17,18,19].
- The *in situ* split liver technique needs prolonged preparation and extensive dissection. To respect the other principle, it should only be performed with expert teams and in donors with excellent condition and good hemodynamic stability.
- Perfusion and cooling of the abdominal organs is done *en bloc* (single preservation fluid and perfusion for liver, intestine, pancreas and kidney) and through aortic flush only (portal cannulation/perfusion is not necessary) [20,21,22,23,24,25].
- Organ perfusion is adapted to the age and weight of the donor:
  - heparin 300 units/kg for children less than 40 kg;
  - perfusion solution: the volume is reduced according to weight: For example, for Custodiol solution the volumes are:
    1 L for donors less than 10 kg
    2 L for donors 10–20 kg
    3 L for donors 20–40 kg.

No-touch *en bloc* retrieval technique and single aortic perfusion are preferred for pediatric donors.

Technical aspects

Whole liver *en bloc* retrieval

Figures 12.1–12.9 show the standard surgical preparation for multiorgan procurement.

Step 1: rapid preparation of the abdomen before perfusion

In all cases (even if thoracic organs are not procured) a xyphopubic midline incision and sternotomy are performed, to obtain a wide opening of the upper abdomen and easy access. To avoid creating excessive tension on the diaphragm, a generous incision of the anterior diaphragmatic insertions to the ribs is helpful (Figure 12.1).

Abdominal organ evaluation is completed with the assessment of arterial supply variations (i.e. accessory hepatic arterial anatomy).

Cecum and right colon mobilization with section of the root of the mesentery (Figure 12.2) and a

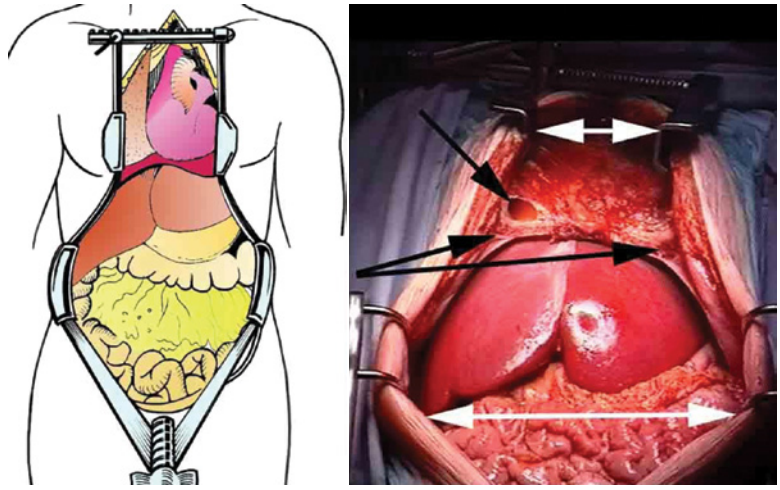


Figure 12.1 Xyphopubic midline incision and sternotomy. (Reproduced from [23] Standardised quick en bloc technique for procurement of cadaveric liver grafts for paediatric liver transplantation" Jde Ville de Goyet, R Reding, V Hausleithner, J Lerut, JB Otte. Transpl Int 8; 280–285, 1995, with permission from Springer.)

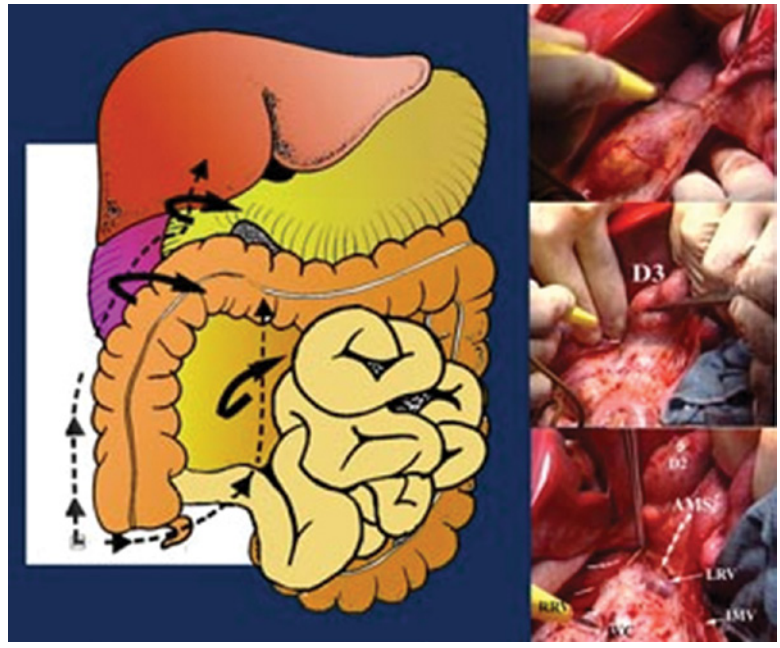


Figure 12.2 Mobilization of the cecum and right colon, section of the root of the mesentery, followed by a complete Kocher maneuver to expose the anterior aspect of the IVC, LRV and origin of the SMA. (AMS, superior mesenteric artery; D2, 2nd part of duodenum; D3, 3rd part of duodenum; IMV, inferior mesenteric vein; IVC, inferior vena cava; LRV, left renal vein; RRV, right renal vein). (Reproduced from [23] Standardised quick en bloc technique for procurement of cadaveric liver grafts for paediatric liver transplantation" Jde Ville de Goyet, R Reding, V Hausleithner, J Lerut, JB Otte. Transpl Int 8; 280–285, 1995, with permission from Springer.)

complete Kocher maneuver exposes the anterior aspect of the inferior vena cava (IVC), left renal vein (LRV) and origin of the superior mesenteric artery (SMA) (Figure 12.2).

The anterior aspect of the aorta is dissected from the level of the LRV to the aorto-iliac bifurcation, dividing the inferior mesenteric artery (optional).

The IVC is dissected from the aorto-iliac bifurcation to the origin of the renal veins (Figure 12.3).

The distal aorta and the IVC are prepared for clamping just above the level of the aorto-iliac bifurcation.

The supraceliac aorta is encircled with a tie, in preparation for clamping (Figure 12.4).

The gallbladder and biliary tree are washed with saline lavage. Then, after systemic heparinization (10,000 IU), the cannula is inserted in the lower abdominal aorta, and the supraceliac aorta is clamped (usually by simply tying the previously placed tie).

The abdominal organs are perfused using aortic perfusion only.

A generous topical ice-cold saline irrigation of the abdomen and right pleura is done to complement the cooling of the abdominal organs (Figure 12.5).

Step 2: no-touch technique for procurement after organ perfusion

1 Separation of vessels:
- The proximal aorta is transected above the clamp.
- The anterior and right lateral aspects of the abdominal aorta above the LRV are freed from the surrounding celiac plexus and lymphatics in order

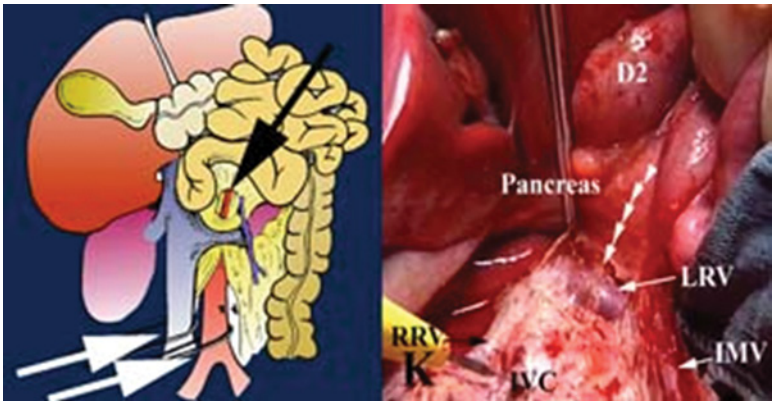


Figure 12.3 Dissection of the aorta and the IVC from the origin of the left and right renal veins (LRV, RRV) down to their bifurcation and preparation for insertion of the cannula. (Reproduced from [23] Standardised quick en bloc technique for procurement of cadaveric liver grafts for paediatric liver transplantation" Jde Ville de Goyet, R Reding, V Hausleithner, J Lerut, JB Otte. Transpl Int 8; 280–285, 1995, with permission from Springer.)

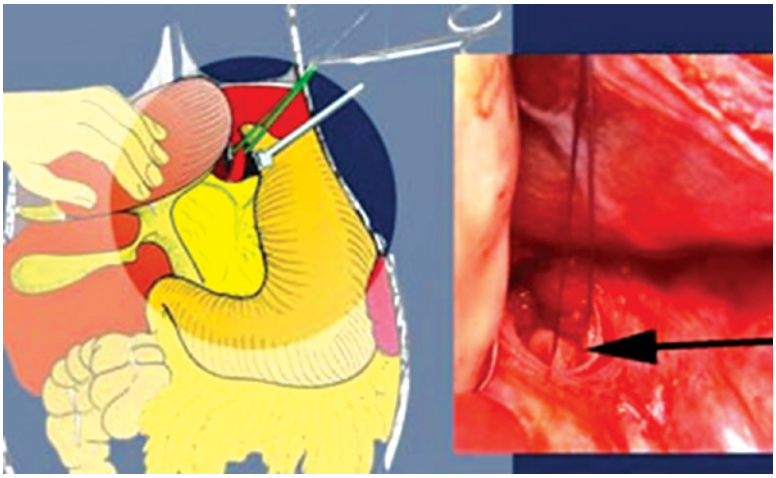


Figure 12.4 Preparation of the celiac portion of the abdominal aorta, set on a loop for further clamping. (Reproduced from [23] Standardised quick en bloc technique for procurement of cadaveric liver grafts for paediatric liver transplantation" Jde Ville de Goyet, R Reding, V Hausleithner, J Lerut, JB Otte. Transpl Int 8; 280–285, 1995, with permission from Springer.)

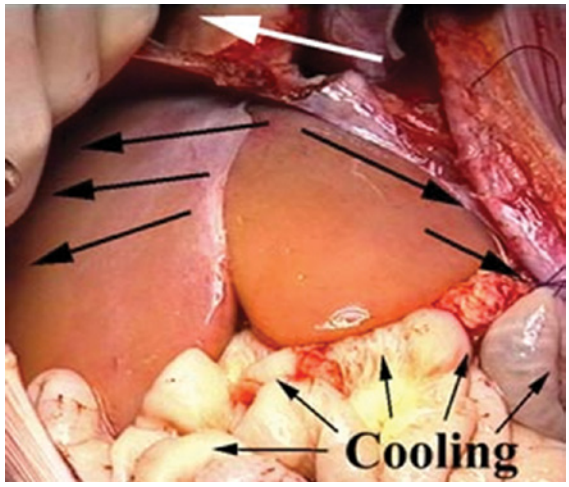


Figure 12.5 After clamping the aorta and the start of organ perfusion, generous topical ice-cold saline irrigation of the abdomen and right pleura.

Figure 12.7 The pylorus and the first portion of the duodenum are freed from attachments and the head of the pancreas is transected all the way through, along the duodenum, to the mesenteric vessels.

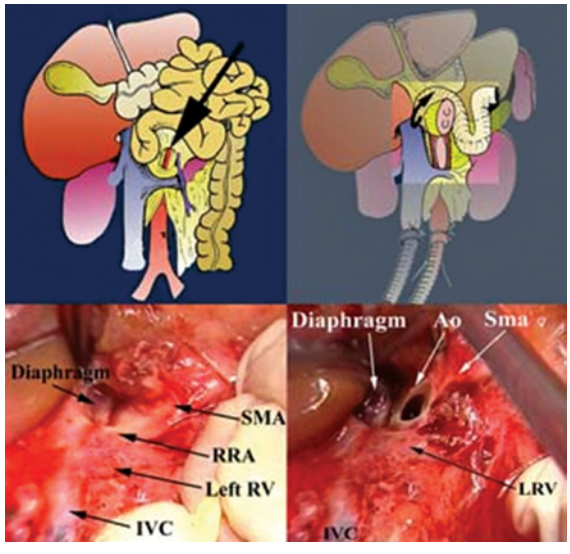


Figure 12.6 The anterior and right lateral aspects of the celiac aorta (Ao) are freed from nerves and lymphatics in order to expose the celiac aorta and the origin of the SMA. The aorta is then opened and the celiac aortic patch is procured under direct vision. (RRA, right renal artery)

to expose the aorta and the origin of the SMA (Figure 12.6).

The anterior aspect of the aorta is opened on the midline up to the SMA/aorta junction. Through the incision, the internal aspect of the aorta can then be checked to localize the ostia of the renal arteries. This allows a safe resection of an aortic patch including the SMA and celiac axis (CA) ostia without compromising the retention of patches for the renal arteries.

The left side of the celiac plexus and all lymphatics on the left of the aorta are then divided to free the aortic patch. When this maneuver is done as a first step, it allows the anterior mobilization of the duodenum and the pancreas and facilitates the subsequent steps (Figure 12.7).

Mobilization of the pylorus and duodenum: this frees the pancreas edge and allows its transection within the head at some distance from the hepatic artery and portal vein. The transection is conducted the whole way through the head of the pancreas, freeing the duodenum completely from the

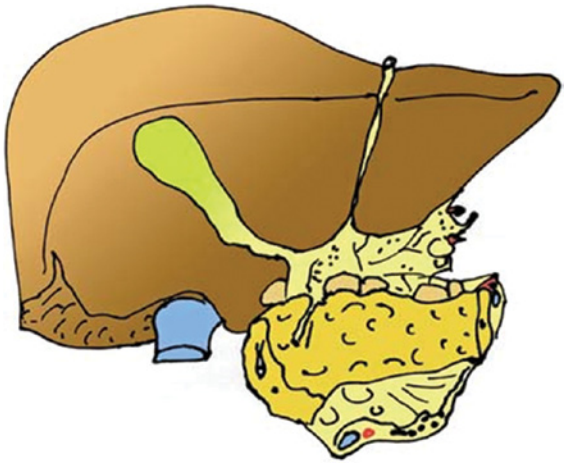


Figure 12.8 The pancreas is then further mobilized by dividing the superior mesenteric vessels, followed by freeing of the body and tail of the pancreas at its lower margin.

pancreas, to the mesenteric vessels (Figures 12.7 and 12.8).

2 The mesenteric vessels and the root of the mesentery below the pancreas are divided from right to left, to reach the ligament of Treitz; the transection line should be well below the pancreas, into the mesentery, in order to include around 3–5 cm of the SMA in the graft (Figure 12.9).

3 Transection of the body/tail of the pancreas, or division at the splenic hilum, followed by division of the remaining retropancreatic attachments, completely frees the aortic patch with the CA and SMA.

4 The intrapericardic IVC is divided and removed with a cuff of diaphragm. The right diaphragm is divided around the liver, starting around the cuff of the intrapericardic IVC: the division line continues around the liver on the right and then follows its inferior aspect towards the infrahepatic IVC. The transection line cuts through the right adrenal gland, protecting the kidney. The infrahepatic IVC is divided 1 cm above the origin of the renal veins.

5 The liver is removed from the abdomen *en bloc* with the pancreas head and all vascular structures untouched (Figure 12.9). The retrieval proceeds with removing the kidneys *en bloc* (see below).

Split liver

Splitting a liver to prepare two grafts can be performed *ex situ* during bench surgery [12,13,14] or *in situ* [15].

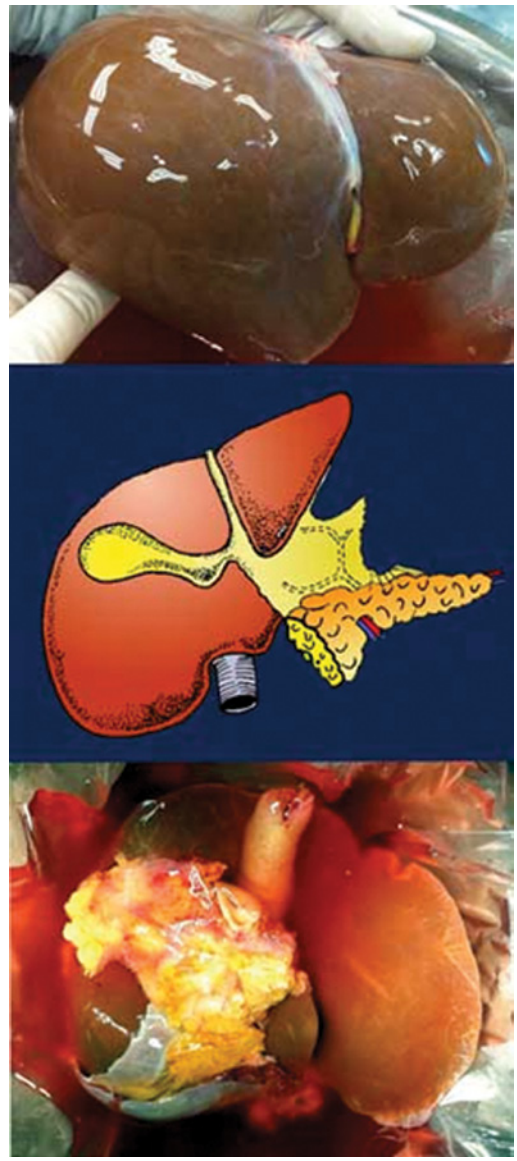


Figure 12.9 After complete mobilization of the head of the pancreas with the celiac aortic patch, the liver is procured with a large patch of diaphragm and *en bloc* with the head of the pancreas, and no dissection of the whole vascular hepatic supply.

The two main techniques for splitting are extensively described in Chapters 8 and 9:

- One consists of dividing the parenchyma exactly within the umbilical fissure ('suprahilar' approach) and dividing the umbilical plate on the dorsal aspect of the Rex recessus (distal portion of the left portal vein),

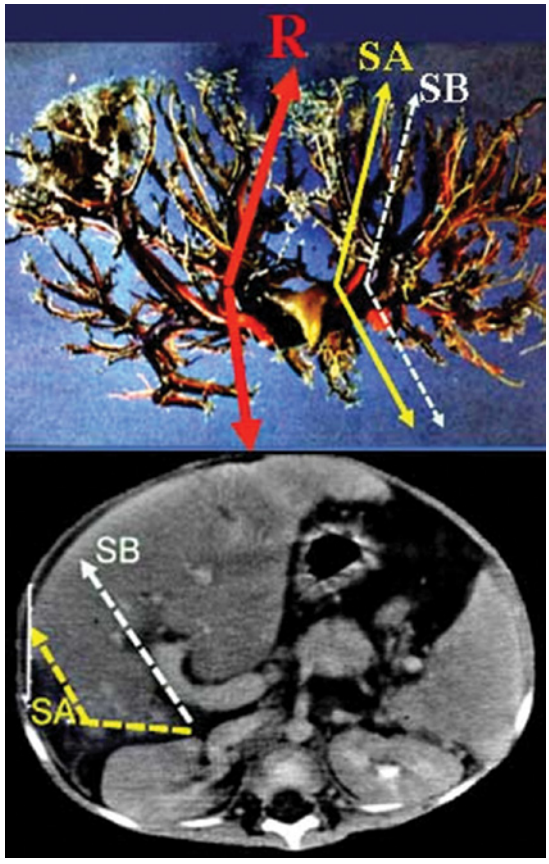


Figure 12.10 Reduction and division of the liver. The reduction is a right hepatectomy (red line). The division (splitting) can be performed by the transhilar approach (yellow line) where the left portal pedicle is transected at the hilum without dissection of the Rex recessus, or a transumbilical suprahilar approach (white dotted line) where the left portal vein is completely exposed and the biliary system divided more distally on the left (with division of more than one duct as a frequent consequence).

with the bile ducts being divided relatively proximally (high incidence of division at the segmental level with multiple ostia) [15] (Figure 12.10).

• The other technique, divides the parenchyma on the right of the umbilical scissure and approaches the left portal vein and the left bile duct slightly more to the right compared to the other technique ('transhilar' approach) [12,13,14] (Figures 12.10 and 12.11). This has the advantage of not dissecting the distal left portal vein and dividing the biliary system at the level of the common duct for segments 2, 3 and 4. In clinical practice, the latter technique helps in reducing the risk

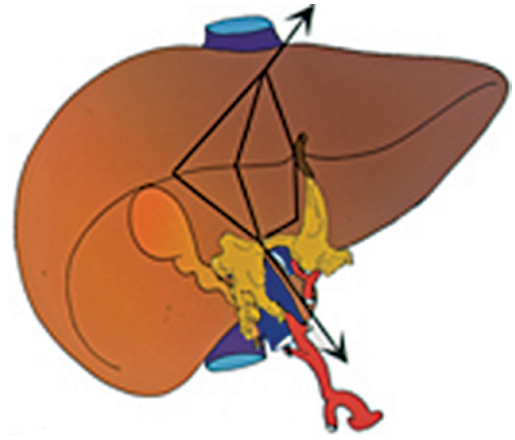


Figure 12.11 Transhilar division of the liver allows easier modulation/adjustment of the amount of parenchymal mass retained with the left split graft, by simply moving the parenchymal transection line to the right. (With kind permission from Springer Science+Business Media: Split liver transplantation: Theoretical and practical aspects, 1st edn, Techniques for ex situ cadaveric liver graft division, 2001,de Ville de Goyet J.)

of portal vein thrombosis and bile duct anastomotic problems. This technique also has the advantage of a great flexibility to include within the left graft a larger portion of segment 4, thus retaining a larger mass of parenchyma, which is useful for transplanting the left graft in larger recipients (Figure 12.11).

Liver reduction

The indications for reduction of the liver have been replaced over time by the split procedure, as it has become more accepted and successful. The major advantage is that it allows the creation of two grafts from a single donor.

However, reduction of the liver can still be appropriate in certain circumstances.

Nowadays, the following are remaining indications for liver reduction:

- When the liver is not optimal for splitting: focal damage or pathology in resected parenchyma, hepatic steatosis.
- When the liver graft is slightly too large to fit in the recipient abdomen but the LLS graft would be too small as parenchymal mass for the recipient (DRWR 1.5–3).
- When the donor is rather small and splitting increases the risk of compromising the vascular system, either by extensive dissection and skeletonization or in case of multiple arteries of very small diameter.

Reduction of the liver is usually performed during bench surgery [8,9,10,11,12], using kellyclasia, ties or bipolar coagulation (Figure 12.12). An *in situ* preparation, as in splitting, can be considered (to perform either the whole procedure or only a partial division of the parenchyma with completion on the bench).

The conventional reduction is a partial or standard right hepatectomy, possibly extended to the left or not, with the division of the right portal pedicles performed within the parenchyma or by suprahilar dissection, thereby reducing the risk of vascular or bile duct injury [8,9,10,11,12] (Figure 12.13).

With the development of pediatric transplantation and liver transplant indications arising even in neonates and small infants, came the need for ever smaller graft sizes. In the last decade, the reduction process has also been proposed as a complementary procedure to reduce the mass of the LLS (either at living or at postmortem procurement).

The graft obtained with this technique has been called by many a 'monosegmental graft'. However, the term of 'reduced LLS' should be preferred for anatomical and technical reasons (Figure 12.14). The 'reduced LLS' has been used successfully in recent years [4,9,10].

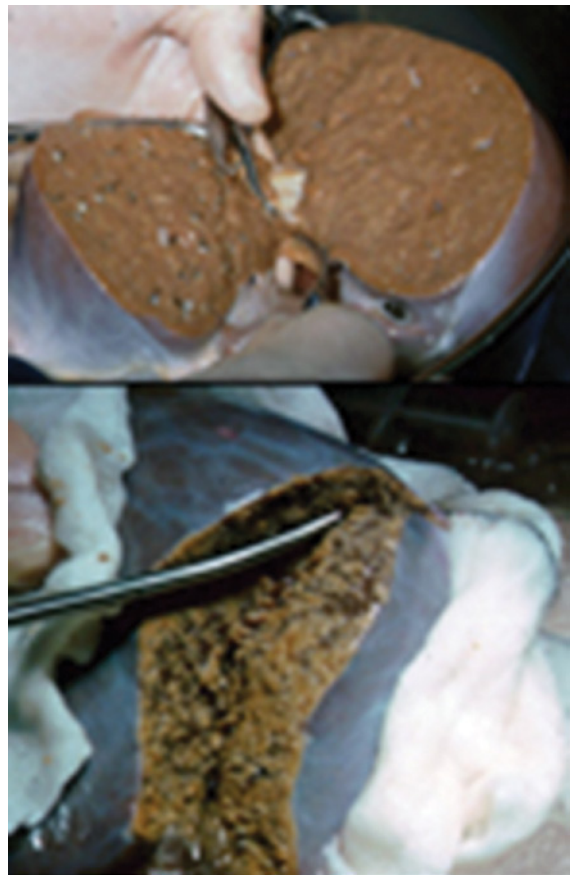


Figure 12.12 *Ex situ* reduction of the liver: hemostasis of the cut surface is achieved by meticulous division by kellyclasia or using bipolar electrocoagulation, and hemostasis by clips, ties and sutures.

En bloc intestinal procurement for isolated bowel transplant

Intestinal decontamination is recommended before and/or at procurement (transluminal gut decontamination is performed in the donor while still in ICU before the procurement procedure and then repeated in the operating room at the beginning of the procurement procedure).

Warm dissection

The warm dissection phase is similar to that for multiorgan procurement (see section **Whole liver *en bloc* retrieval** (Figure 12.15), but includes the following extra steps:

- Full mobilization of the right colon and hepatic flexure, up to the midtransverse colon, opening the great omentum cavity.
- The right and transverse colon are separated from the omentum. The transverse mesocolon is divided on the left side of the middle colic artery, down to the pancreas margin.

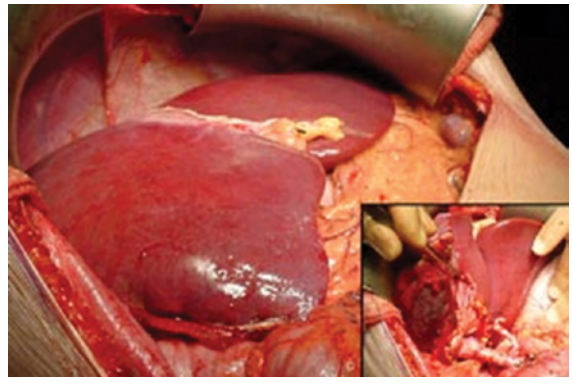


Figure 12.13 Transplantation of a reduced liver graft: only the right posterior sector has been removed to obtain a perfect match between the liver and the available abdominal space.

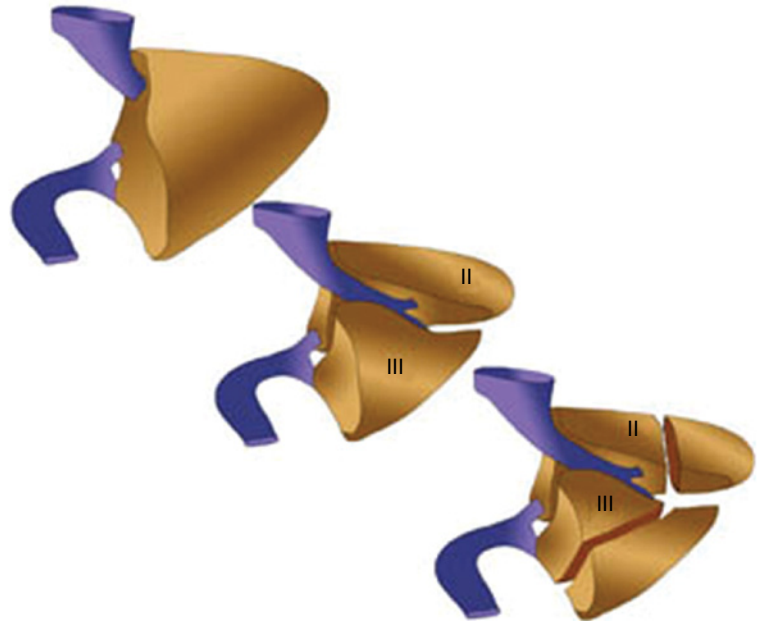


Figure 12.14 Reduced left lateral segment (LLS): the anatomy of the left liver lobe allows further reduction of the LLS, although the final graft is not a 'monosegmental graft'.

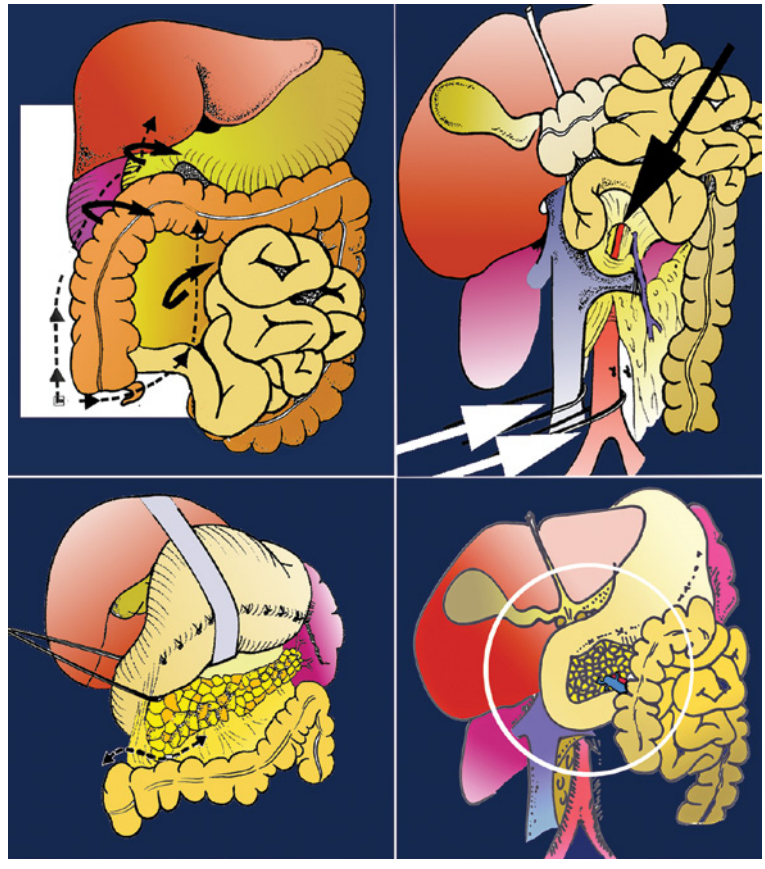


Figure 12.15 The warm dissection phase is similar to that for the multiorgan procurement *(upper quadrants)* but includes the following extra steps: -1- Full mobilisation of the right colon and hepatic flexure, up to mid transverse colon, opening the great omentum cavity (*left lower quadrant*). -2- the superior mesenteric artery and vein are identified below the pancreas (*right lower quadrant*).

• Preparation of the pylorus for further division (GIA stapler division after completion of intraoperative intestinal decontamination).

Cold dissection

1 After completion of the organ perfusion and cooling, the liver is retrieved. The procedure starts with the division of the hepatic pedicle elements:

- ◦ division of the choledocus above the duodenum;
- ◦ division of the gastroduodenal artery and procurement of the hepatic artery in continuity with the CA;
- ◦ division of the portal vein above the pancreas.

2 Once the liver has been removed, the aortic patch with the SMA is procured, as described in the section **Whole liver *en bloc* retrieval**, and the posterior aspect of the pancreas is freed from the retroperitoneal attachments.

3 The transverse colon and the pylorus are divided (GIA stapler) if not done previously.

4 The lower margin of the pancreas is freed and the pancreas tail is mobilized. The pancreas is completely freed at that point from retroperitoneal attachments and the 'pancreas–intestine' bloc with the SMA and a large aortic patch is ready for removal (Figure 12.16).

Bench surgery

Depending on the recipient's characteristics, part of the intestine may be resected, usually the donor colon. If the recipient has no colon left in place, reducing the length of the small intestine and preserving the colon may be preferred [26,27,28].

En bloc liver and intestinal procurement technique

When it comes to composite grafts and multiorgan transplantation in a single small recipient, the procurement technique may have to be tailored to specific technical needs [29].

The more common *en bloc* multiorgan graft is composed of the liver and intestine. In order to facilitate implantation in the recipient, the technique has been shifted to an *en bloc* retrieval of both organs including, without dissection, the duodenopancreas (only the head of the pancreas, or the whole pancreas) (Figure 12.17–12.19).

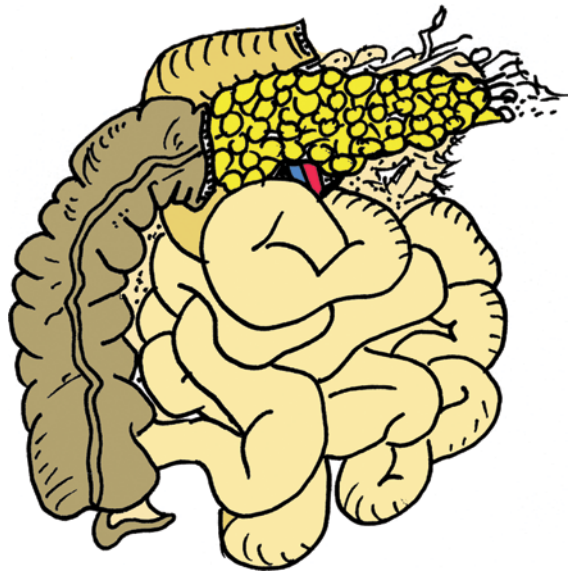


Figure 12.16 Aspect of the graft after "En bloc » procurement of an isolate Intestine. The intestine is removed en bloc with the aortic patch around the Superior Mesenteric Artery and with the duodeno-pancreas, and with the right colon. The latter can be removed during bench surgery, depending on anatomy and the needs of the recipient. The duodeno-pancreas is removed from the graft during bench surgery, freeing the main vessels with a patch of aorta and portal vein.

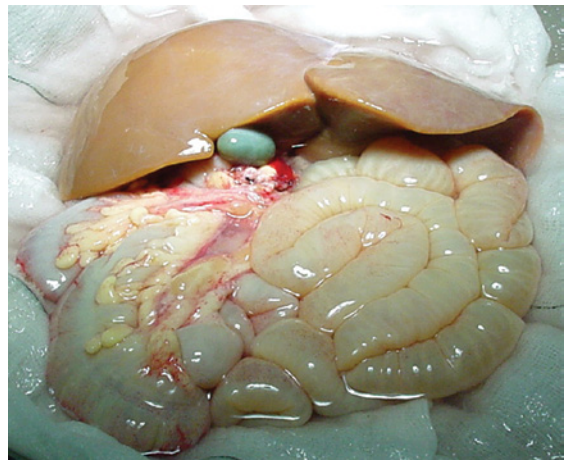


Figure 12.17 Aspect of the graft after "En bloc » procurement of a liver + Intestine graft.

The procurement is performed *en bloc* and the main steps are as follows, combining what is described in earlier sections.

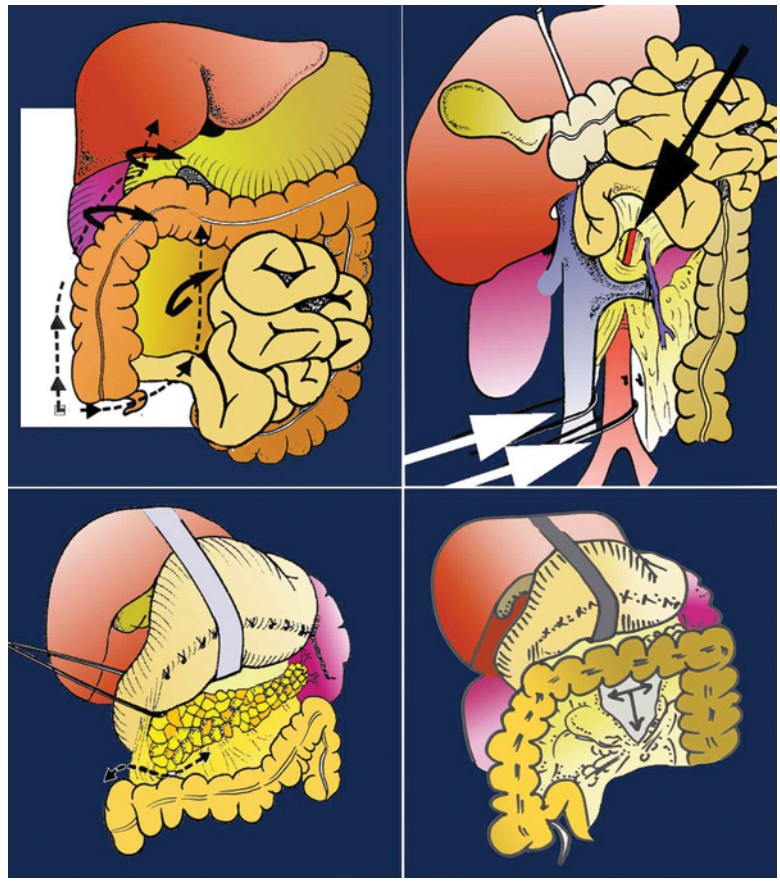


Figure 12.18 The warm dissection phase is similar to that for the multiorgan procurement (*upper quadrants*) but includes the following extra steps: -1- Full mobilisation of the right colon and hepatic flexure, up to mid transverse colon, opening the great omentum cavity (*left lower quadrant*). -2- The transverse mesocolon is divided on the left side of the middle colic artery, down to the pancreas margin (*right lower quadrant*). -3-The pylorus is then prepared and divided (GIA stapler division) after completion of intraoperative intestinal decontamination (*not shown*).

After standard preparation of the abdomen as in sections **Whole liver *en bloc* retrieval** and ***En bloc* intestinal procurement for isolated bowel transplant**, the abdominal organs are perfused and cooled down. Then the patch of the aorta including the CA and SMA is prepared as in section **Whole liver *en bloc* retrieval**.

The inferior margin of the pancreas is divided on the left side and the pancreas is procured either partially or completely.

The liver is freed from the diaphragm and the IVC is transected as usual. The liver is then removed *en bloc* with the duodenopancreas and the intestinal graft.

This *en bloc* multiorgan procurement technique allows no dissection of the hepatic pedicle and preserves a well vascularized biliary tree; in turn this allows a simplified graft implantation with a single arterial and vein anastomosis, with no biliary reconstruction [16,29] (Figure 12.18 and 12.19).

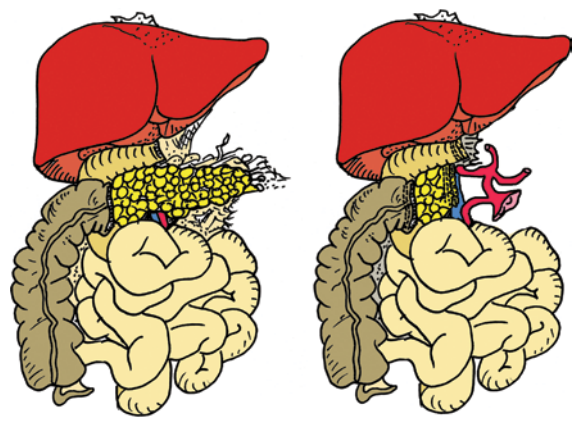


Figure 12.19 Aspect of the graft after "En bloc » procurement of a liver + Intestine graft. The liver is removed en bloc with the duodenopancreas (either in full (*right figure*) or only the cephalic portion of the pancreas (*left figure*)) and in continuity with the aortic pacth of the celiac axis and Superior Mesenteric Artery.

In order to accommodate this composite graft into small recipients and with a larger DRWR), the liver can be further reduced during bench surgery [29] (Figure 12.20).

En bloc kidney procurement

The kidneys are usually procured last, after the liver and intestinal grafts have been removed.

When procured from small donors, they are usually prepared *en bloc* and either separated from each other on the bench or used as an *en bloc* graft in a single recipient [30,31,32,33,34].

The procedure is quite simple (Figure 12.21):

- The two ureters are identified, divided as low as possible and then dissected in a retrograde mode, from pelvis to kidney with their surrounding tissue, to avoid devascularization.
- Both kidneys are then freed posteriorly from all retroperitoneal attachments: the dissection generously retains all surrounding tissue around the kidney,

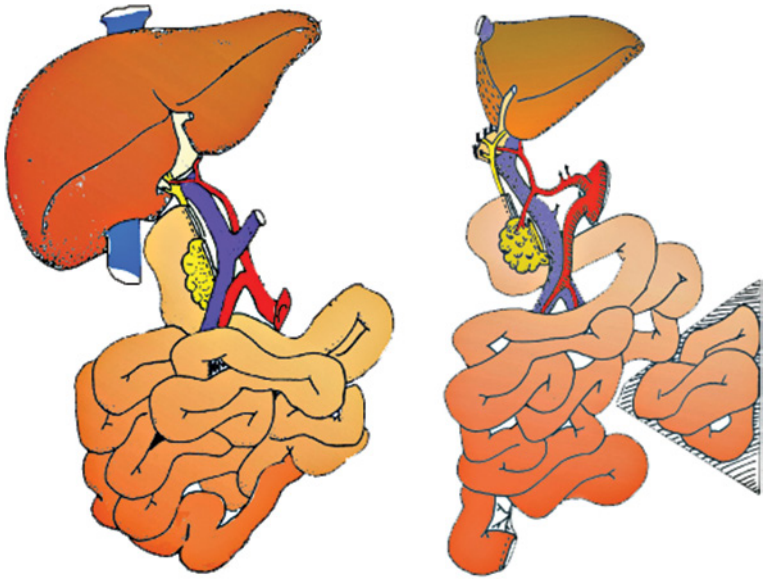


Figure 12.20 "En bloc » liver + Intestine graft : the liver and the intestine can be further reduced in size during bench surgery, by rigth hepatectomy +/- partial resection of the mid-intestine.

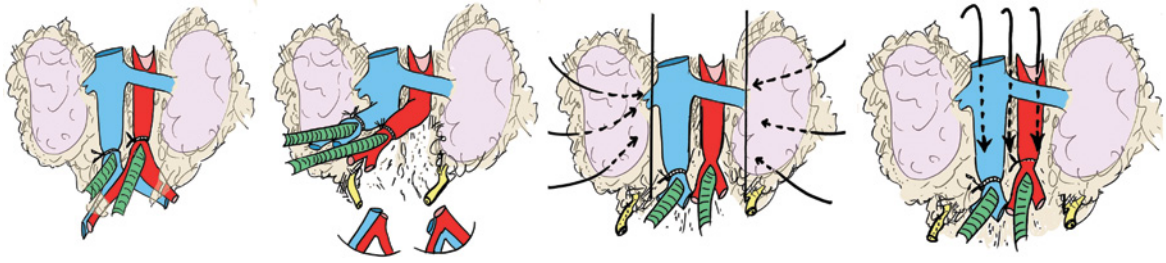


Figure 12.21 En bloc kidney procurement: the kidneys are procured en bloc and can be transplanted either en bloc or separated on the bench.

From left to right on the figure: -1- Aspect at the end of perfusion after procurement of the other abdominal organs; -2- The two ureters are identified, divided as low as possible and then dissected in a retrograde mode, from pelvis to kidney with their surrounding tissue to avoid devascularisation; -3- Both kidneys are then freed posteriorly from all retroperitoneal attachments: the dissection generously retains all surrounding tissue around the kidney, including the adrenal glands to avoid any trauma and proceeds from the lateral edge towards midline. -4- The residual segment of abdominal aorta and the infra-hepatic IVC are then pulled down en bloc with the kidneys, freeing the en bloc graft from the muscles and the fibrous fascia of the posterior wall.

including the adrenal glands to avoid any trauma, and proceeds from the lateral edge towards midline, stopping at the lateral edge of the IVC on the right side and the aorta on the left side.

- The residual segment of the abdominal aorta and the infrahepatic IVC are then pulled down *en bloc* with the kidneys, and the bloc is freed from the muscles and the fibrous fascia of the posterior wall.
- The two kidneys are separated from each other on the bench. Generally, renal veins are separated in order to leave the IVC with the right renal vein (that is shorter in length), to give an opportunity to lengthen the renal vein if necessary. The aorta is opened longitudinally along its anterior aspect and the ostia of the renal arteries (+/– accessory arteries) are checked before dividing the posterior wall; further dissection of the arteries then follows down to the kidney hilum.

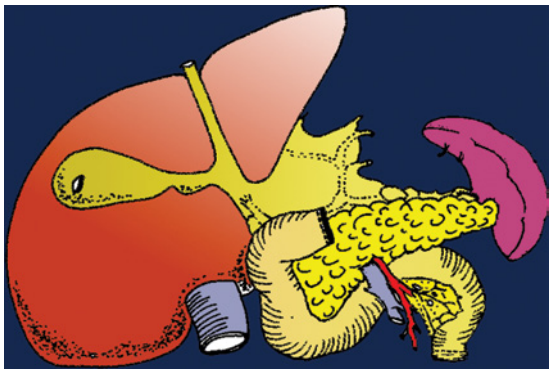


Figure 12.22 "En bloc » procurement of a Liver + full Duodeno-pancreas graft.

En bloc liver and pancreas procurement

It is unusual that the pancreas is procured from small donors for transplantation purpose. The technique for procuring it from older children is identical to that for adults and is described in Chapter 10 (Figure 12.22).

If the pancreas is procured from a small donor, the concept of 'no-touch' *en bloc* technique is again preferred and the pancreas is procured *en bloc* with the liver [35,36,37,38] (Figure 12.22).

The procurement procedure is rather simple and proceeds as described in the section **Whole liver en bloc retrieval**, adding a generous mobilization of the transverse colon with resection of the great omentum (Figure 12.22), and preparation of the first jejunal loop and the pylorus for further GIA stapler transection after the organs have been perfused (Figure 12.22). The two organs are then separated from each other on the bench using a similar preparation as described below (see the section **Liver**).

Relevant aspects for bench procedures

Kidneys

Preparation of the kidney is usually done at the recipient center and is performed in a similar way independent of donor age, as described in Chapter 5.

In the case of *en bloc* procurement, the two kidneys must be separated from each other in order to be sent to different centers (Figure 12.23). The latter division must be kept simple, leaving as much

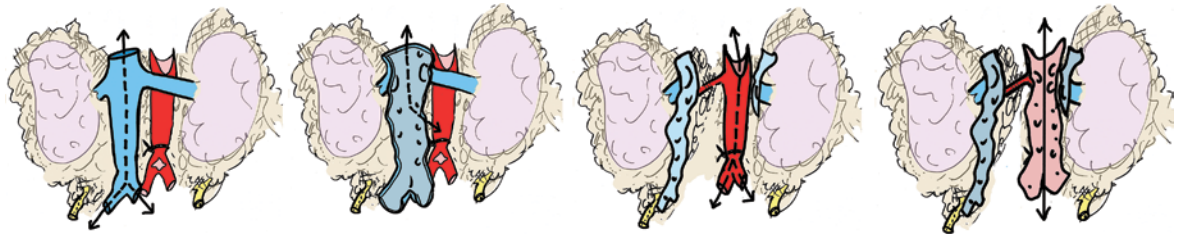


Figure 12.23 Separation of the two kidneys on the bench in case of en bloc procurement: the division is kept simple, leaving as much tissue with and around the kidneys as possible.

From left to right on the figure: -1- division of the anterior aspect of the vena cava along the midline; -2- division of the posterior wall of the vena cava, retaining a larger flap on the right side after careful identification of the main renal veins; -3- The anterior aspect of the aorta is divided along the midline, checking for the ostia of renal and possibly polar arteries; -4-The aortic division is completed by dividing its posterior wall, along the midline.

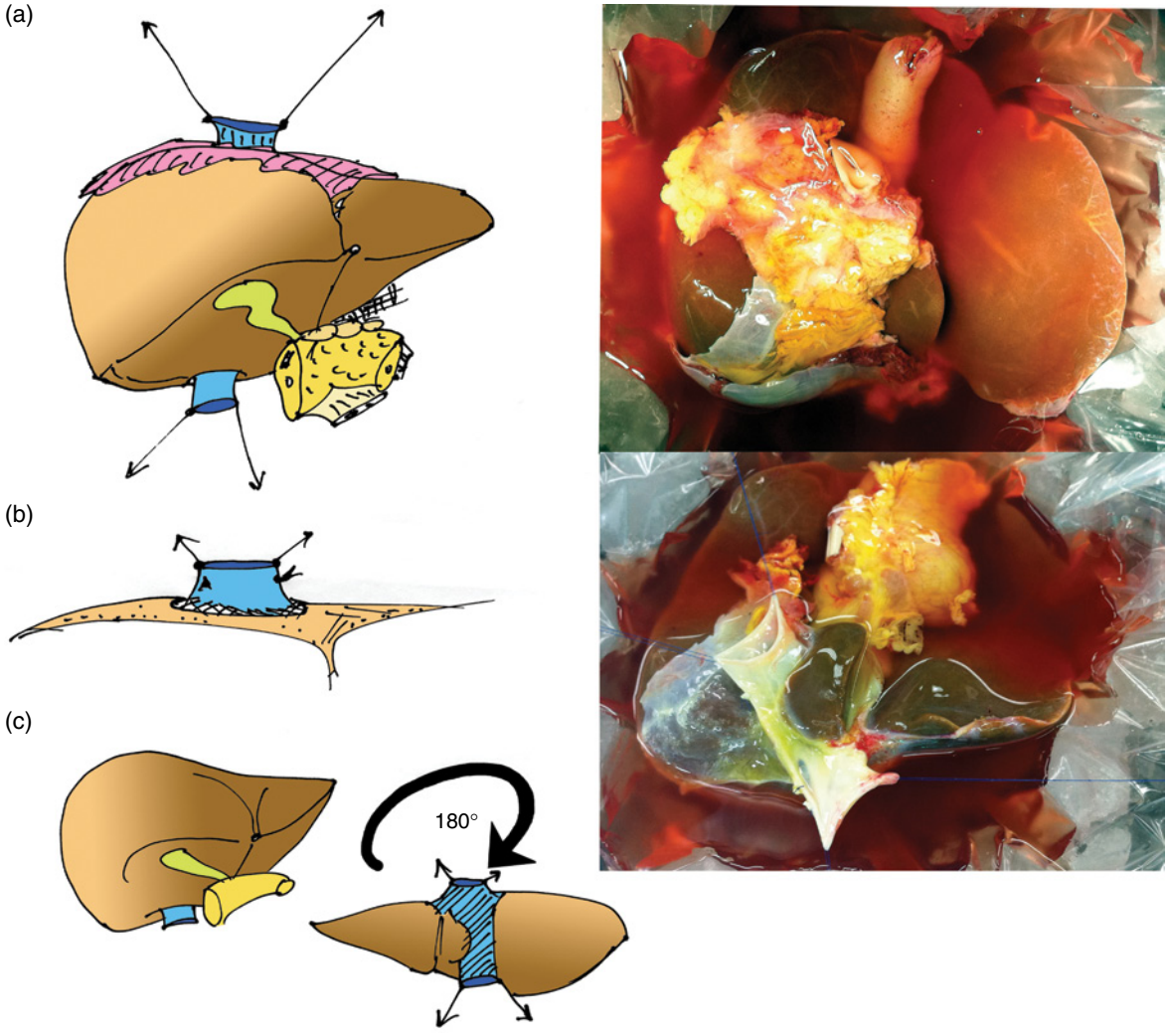


Figure 12.24 Preparation of the vena cava.

tissue with and around the kidneys as possible and leaving the final preparation to the recipient surgeon. Basically it consists of dividing the bloc along the midline and giving a large aortic and caval patch to both grafts:

- Preferably, the LRV should be divided at its origin on the IVC, leaving the IVC with the right renal vein.
- The anterior aspect of the aorta is divided along the midline, checking for the ostia of renal and possibly polar arteries.
- The aortic division is completed by dividing its posterior wall along the midline.

Liver

During bench surgery at the recipient center, the transplant team performs an additional assessment and preparation of the liver graft. This standard work includes assessing the liver parenchyma, the vascular trunks and patches and flushing the bile ducts. This standard preparation is described in Chapter 6.

When the liver is procured with the rapid *en bloc* technique (*en bloc* with the pancreas), the bench preparation of the liver is slightly more demanding in that the whole arterial and venous tract is untouched and unprepared. The preparation of the

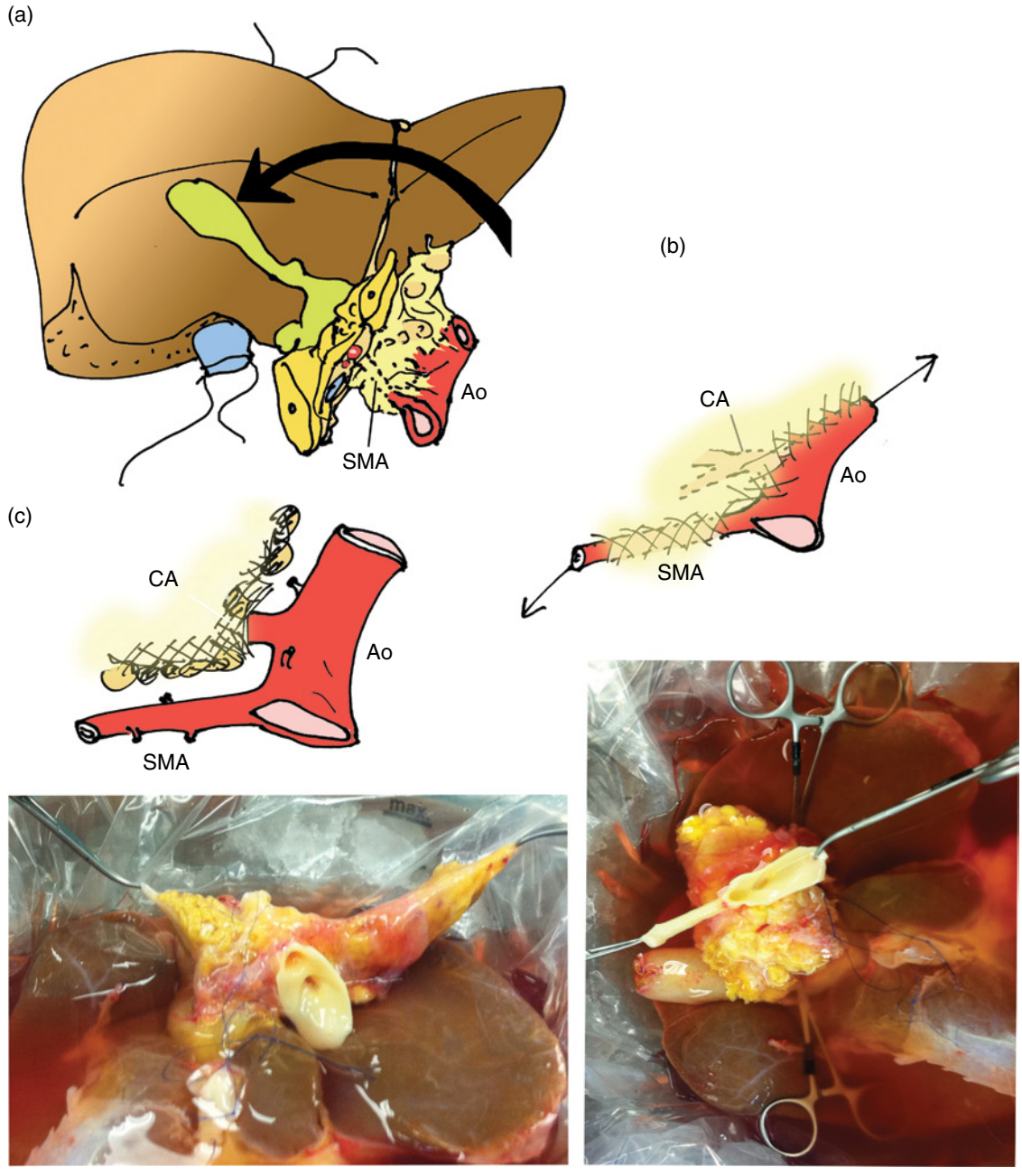


Figure 12.25 Preparation of the Aortic patch and main arterial trunks: Celiac axis and superior mesenteric artery.

organ is longer and requires a delicate and scrupulous dissection to avoid damage to the vascular elements, as in the absence of pulsatile blood flow, these structures are not so easily identifiable.

The dissection of the *en bloc* liver–pancreas can proceed in a few safe steps as illustrated in Figures 12.24–12.31 (see the legends of the figures for description of the consecutive steps).

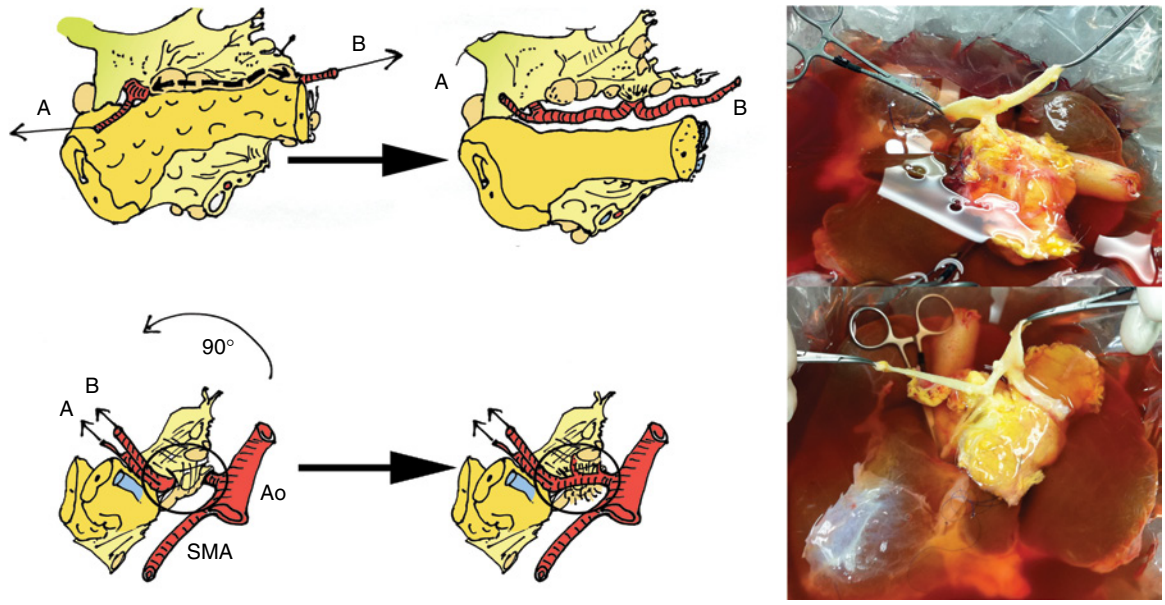


Figure 12.26 Identification of the hepatic arterial supply by dissection of the elements of the celiac trunk. The dissection proceeds along the margin of the pancreas.

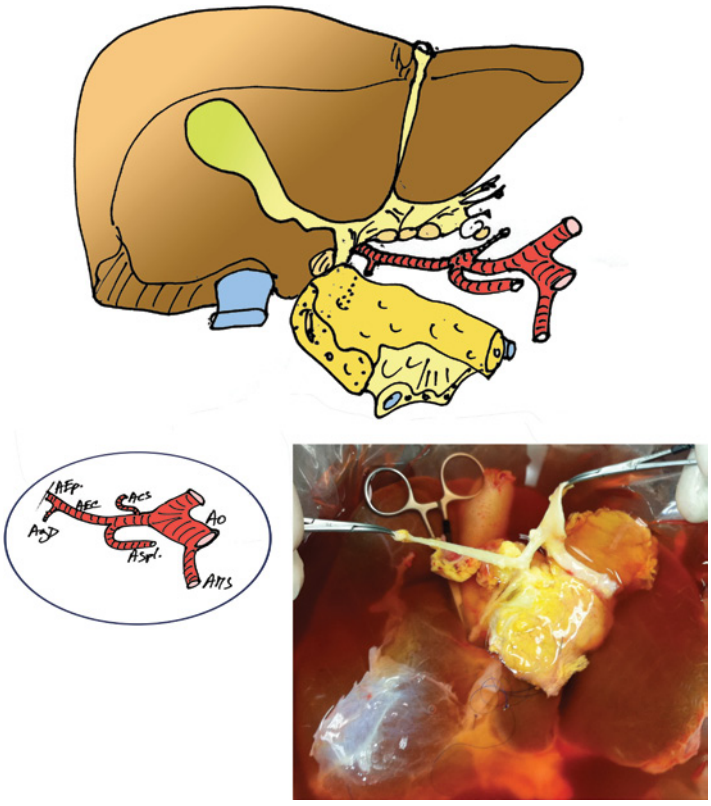


Figure 12.27 Division of the gastro-duodenal artery and end of dissection of the arterial hepatic supply in the absence of accessory arteries.

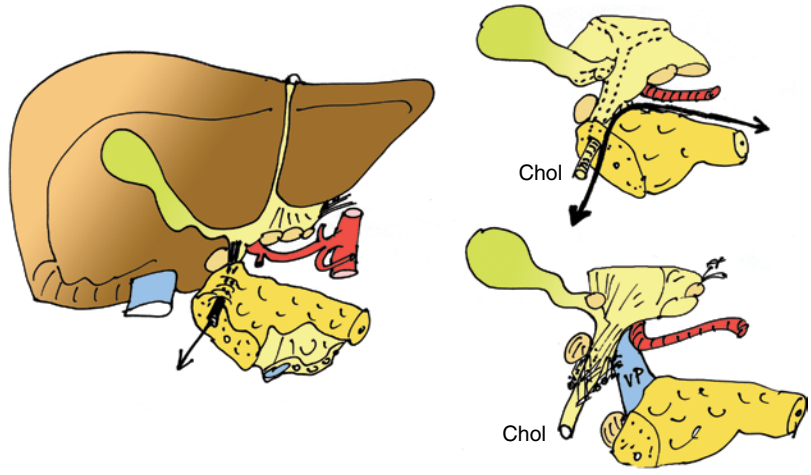
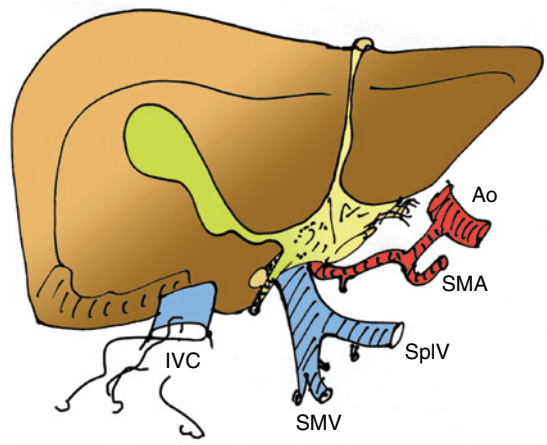


Figure 12.28 Dissection of the common bile duct and the portal vein (into the division in splenic and mesenteric veins). After dissection of the portal vein and the splenomesenteric junction, the pancreas is removed and the liver graft is ready for transplantation.



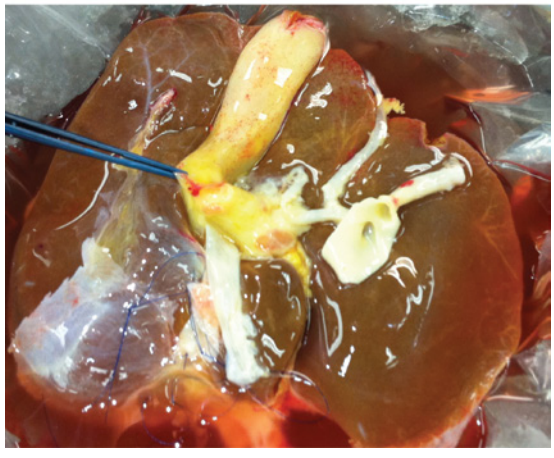


Figure 12.29 Aspect of the liver graft at the end of bench surgery.

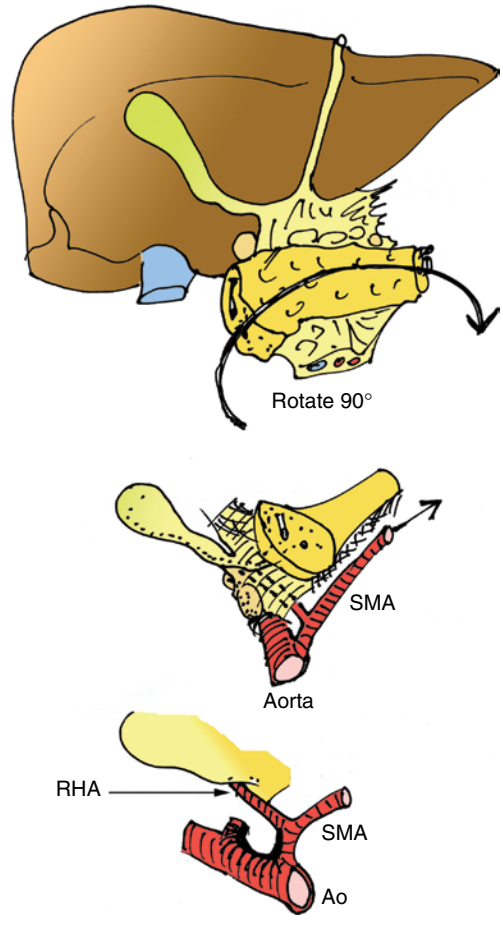


Figure 12.30 Identification and preparation of a right accessory artery from the superior mesenteric artery. The dissection proceeds along the posterior margin of the pancreas.

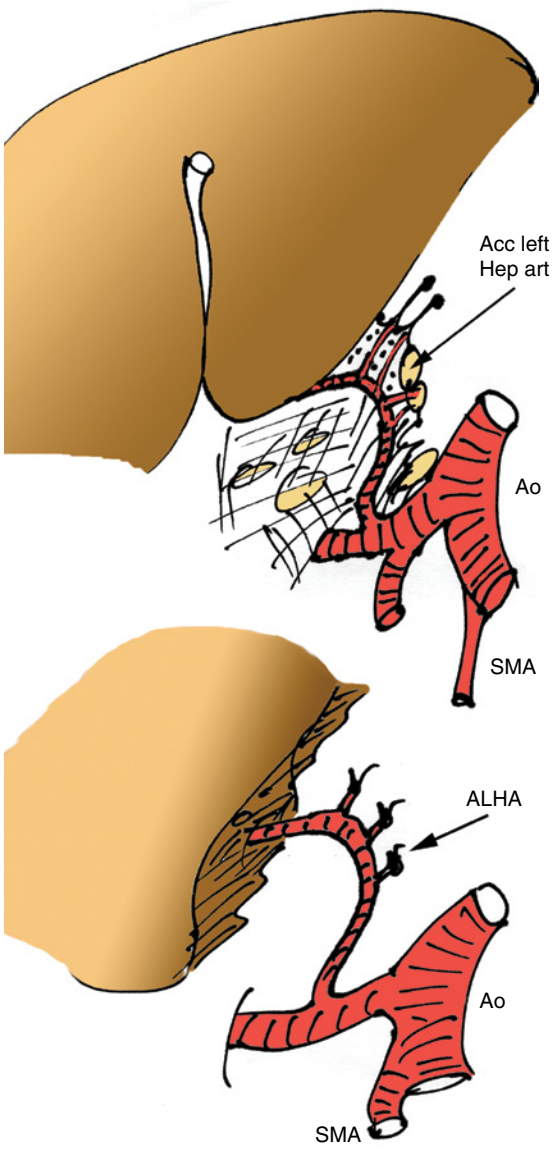


Figure 12.31 The presence of an accessory left hepatic artery arising from the coronary artery is dealt with by meticulous dissection and hemostasis along the small gastric curvature.

Division of a liver graft, either *in situ* or *ex situ*, usually ends with a graft ready to be implanted in most cases. The transplant team has little to do and often only a simple inspection is made to check the anatomical characteristics before starting the transplant operation.

Vascular reconstruction may be necessary when variant arterial anatomy is found, when vascular supply must be shared (split liver, combined multiorgan procurement) or when damage to the vascular trunks has been made inadvertently at procurement or during bench surgery. In all these situations, it is recommended to perform the vascular reconstruction *ex situ* during the bench surgery to keep the reperfusion time and the lukewarm ischemic time when the liver graft is within the abdomen as short as possible [39,40]. The use of microscope or magnification glasses and microsurgical techniques has become standard in the last decade (Figures 12.32 and 12.33).

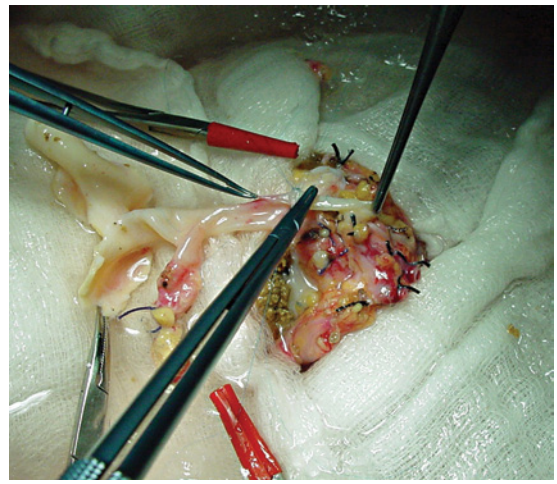


Figure 12.32 *Ex situ* hepatic arterial reconstruction using microsurgical techniques.

Reduction of the liver is in most cases performed during bench surgery, but is nowadays rarely done: as mentioned earlier, it consists simply of a right standard hepatectomy (Figures 12.12 and 12.13).

Summary box

- The optimal donor is defined based on age, hemodynamic characteristics and systemic risk.
- The utilization of donor organs at the extremes of ages should take into account specific donor age-related risks as well as recipient factors.
- Donor to recipient weight ratio (DRWR) = 1(+/– 0.25) if full size grafts are used. Higher rates can be considered in certain situations.
- Deteriorating liver function tests or steatosis more than 10% preclude the use of a liver for splitting.

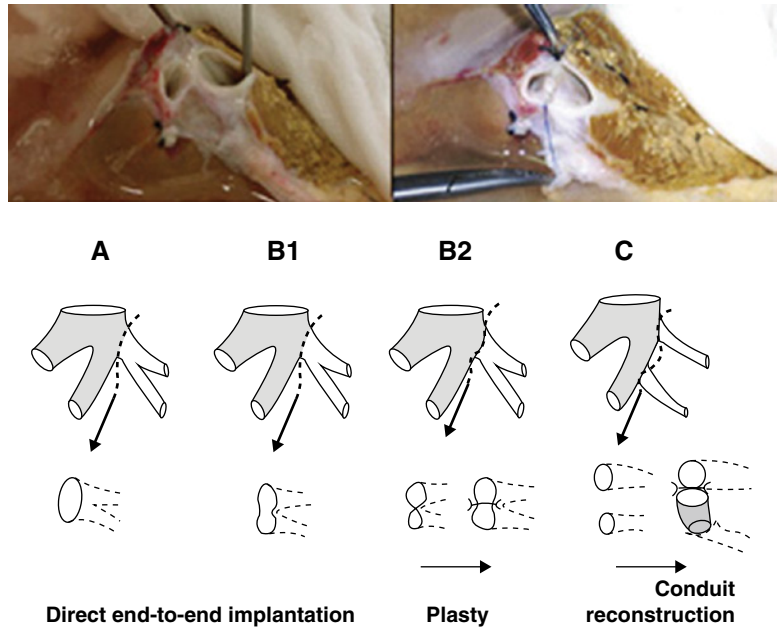


Figure 12.33 Ex situ preparation of an adequate venous patch for the implantation of a left split graft onto the recipient vena cava. Anatomical variations can be diagnosed at procurement and can be managed with adequate reconstructions. (Reproduced from [39] Hepatic vein reconstruction in ex situ split liver transplantation. Nouajim H, Gunson B, Mirza DM, Mayer AD, de Ville de Goyet J. Transplantation 2002; 74: 1018–1021 with permission from Wolters Kluwer Health.)

- Liver splitting can be performed *in situ* or during bench surgery and using a 'suprahilar' or 'transhilar' approach.
- LLS can be used for recipients between 5 and 30 kg, depending on volume/weight of the graft.
- Liver reduction has nowadays limited indications.
- Intestinal donor requirements include hemodynamic stability, low inotropic support and no cardiac arrest.
- Small donor kidneys should be considered for *en bloc* transplantation.
- 'No-touch' technique and aortic-only perfusion is preferred for preparation during the warm phase.
- When the liver is procured *en bloc* with the pancreas, the bench preparation of the liver is more demanding.
- The more common *en bloc* multiorgan graft is composed of the liver and intestine.

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