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Surgical Techniques of Multiorgan Procurement from a Deceased Donor

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Abstract

Solid organ transplantation is now the standard treatment for many types of diseases and using a standard surgical technique for organ procurement from the deceased donors is an important step in preventing complications after such complicated procedures. In most centers, retrieval of heart, lungs, liver, kidneys, small bowel, pancreas and other organs is done at the same time by different surgeons under supervision by a team leader who is most familiar with at least basic steps of surgical technique of procurement of all the solid organs. Each transplant surgeon, regardless of his or her sub-specialty, has to know how to prepare and dissect the delicate anatomical structures which are in common between the two adjacent organs for example portal vein (liver-pancreas), superior mesenteric vein (pancreas-small bowel), abdominal inferior vena cava (liver-kidneys), supra-diaphragmatic inferior vena cava (liver-heart) and pulmonary artery-veins (heart-lungs). This needs a multidisciplinary approach by the most experienced members of the transplant team to decrease the warm ischemic time of the organs without any harm to them by better coordination between all the surgeons. In this, chapter we briefly describe the multiorgan retrieval procedure in a deceased donor, and we hope that following these instructions results in better quality of the procured organs without jeopardizing their vital anatomical structures.

Keywords: organ transplantation, multiorgan procurement, deceased donor, surgery, technique

1. Introduction

Organ transplantation from deceased donor is the standard technique for treatment of so many diseases which is totally incurable without such complicated surgeries. A deceased donor has multiple solid organs that may be used for transplantation and multidisciplinary approach and delicate coordination between different medical and surgical teams is needed to ensure that these organs are fully functional after retrieval. Heart, lungs, liver, kidneys, pancreas and small bowel are among the most important organs that should be harvested at the same time from one donor and each surgeon who is in charge of such a complicated surgery should be familiar with at least basic techniques of other organs retrieval to prevent any harm to sensitive anatomic components of each organ especially those which are in common between two nearby organs, for example portal vein and celiac trunk (liver and pancreas), abdominal inferior vena cava (liver and kidneys), superior

mesenteric artery and vein (pancreas and small intestine), supra-diaphragmatic inferior vena cava (heart and liver), pulmonary artery and veins (heart and lungs). Chairman of the team should be the most expert surgeon who has the longest experience with all aspects of multiorgan procurement surgery. In this chapter we will discuss the basic aspects of surgical techniques which every transplant surgeon has to know about such an important procedure.

2. Brief history of multiorgan donation

The era of organ transplantation was started successful kidney transplantation in the early 1950s. First organ donation from non-heart-beating donors was associated with successful liver transplantation by Thomas Starzl in 1963 [1]. First rare heart-beating donors without any hope of survival (not living donors) were those who underwent cardiac bypass but not able to detach from the heart-lung machine whose kidneys were used for transplantation before death in 1962 [2]. Next successful transplantation from heart-beating donors were done in 1964 in Sweden and in 1966 in United States from patients with irreversible brain damage under mechanical ventilation [2]. The term “cerebral death” was supposed by Swedish neurosurgeons in 1965 [3]. First series of successful liver transplantations from such “brain death” donors was done by Thomas Starzl in 1967–1968 and Professor Barnard do the first successful heart transplant in the same year from another brain-dead person [2]. At that time Barnard waited for cardiac asystole to prevent any negative debate for “brain death concept” in the community [4]. In the next decade many authorities in all the pioneer countries in transplantation made every effort to legally confirm the brain death patients as a potential donor and at last in 1971 the “Uniform Anatomical Gift Act” in Kansas was approved by the governor as a basis for globalization of legally “brain death concept” [5]. Development of multiple transplant teams in next decade resulted in first multiorgan retrieval procedures from the same donor in the 1980s [6, 7]. First heart-lung transplant was done in 1982 and first long term survived lung transplant alone was done in 1987 [8]. In the same era till the 1990s, successful combined transplantation such as liver combined with small bowel and other more complex multivisceral transplantation was developed by Thomas Starzl and his former fellow Andreas Tzakis [9]. Thanks to all the pioneers’ efforts, now we have a near standard technique for multiorgan procurement from all stable brain-dead donors. Only the availability of all the team members and also the suitability of all the organs and suitable recipients are among the remaining obstacle such a complex procedure and multiorgan donation at the same time is a rule in most experienced transplant centers.

3. Donor management

Ideally, every deceased donor should be completely stable before and during transfer to the operating theater. Central venous pressure should be maintained between 10 and 12 mmHg for better function of abdominal organs but for lung retrieval this pressure should be maintained around 8 mmHg [10]. Systolic blood pressure maintenance over 100 mmHg and mean arterial pressure over 60 mmHg by using inotropes and crystalloid infusion is critical. Dopamine, dobutamine, vasopressin and nor-adrenaline may be used but when heart is being used for transplantation dosage of nor-adrenaline over 0.05 microgram/kg/min may reduce cardiac contractility after transplantation and should be avoided [11]. In such cases insertion of Swan-Ganz catheter is mandatory.

Every effort should be done to maintain $\text{PaO}_2 > 100$ mmHg, $\text{SpO}_2 > 95\%$, PaCO_2 between 35 and 40 mmHg and pH between 7.35 and 7.45 by using lung protective strategy including avoidance of excessive intravenous fluids, minimal tidal volume (8–12/minute) and lowest FiO_2 [12].

For hormonal management, intravenous infusion of 1000 mg (15 mg/kg) methylprednisolone succinate, insulin (target glucose level of 80–150 mg/dl), vasopressin 0.5–4 U/h or intranasal desmopressin (1–2 puff every 6 hours) and thyroxine replacement (4 mcg/h) is the standard of treatment to reduce the systemic inflammatory response in these patients and maintaining the hemodynamic stability of them [10].

Urine output is better maintained between 100 and 300 ml/hour to prevent hypo or hypernatremia. Potassium (K^+) replacement should be started when serum potassium level is reduced (target K^+ level 3.5–4.5 meq/l). Lactated ringer's solution or half saline solution is the best available fluid for these patients and using colloids such as albumin should be avoided [13].

Body temperature should be maintained over 35.8°C [13] for better cardiac function and prevention of coagulation cascade and hypoxic tissue damage. To reduce cardiac arrhythmias maintaining normal body temperature, hemodynamics, electrolyte, hemoglobin levels over 10 g/dl and minimal use of vasopressors is essential. Calcium, phosphorus and magnesium also should be maintained at physiologic level to prevent cardiac arrhythmias during the surgery [14].

4. Key controversies in the result of multiorgan procurement

We have many unresolved issues about multiorgan procurement surgery that needs more time to answer by the researchers. As the same with other works which are done by a team, expertise of each of the team member and their coordination with other members have a great effect on the final result of the operation. Undoubtedly, multiorgan retrieval may compromise the function of each organ and will be associated with a higher incidence of delicate anatomical structures damage. It may be better to perform all the dissections without any compromise in the circulation of any other organs. Many researchers show that this concern is not completely definite. Even some authors in their prospective and retrospective studies show that multiorgan harvesting may improve each separate organ function [10]. The main factor that affects the final result is the stability of the patient during the operation and the expertise of who is in charge of the whole operation [15]. One study shows that renal anatomical damage is more common when the operation is done by renal team only and if the operation is done by the liver team with experience of more than 50 procurement per year, the final anatomical (artery, vein ureter or capsular) damage will be significantly reduced [16]. In unstable patients, it is the duty of the team leader to determine which organ is more important and is the first priority. Usually in urgent situations, this is the “liver”, because liver transplantation has the only way to cure the hepatic failure without any other treatment option in these patients with an acceptable success rate.

Another concern is that should dissection be done in warm or cold condition and en-bloc or separate organ retrieval is different? In fact, although theoretically the anatomical damage may be reduced if all the delicate dissections are performed in the donor before clamping of the aorta and all the organs retrieved separately, but most studies show that en-bloc retrieval and continuing the dissections after whole body cooling and whole blood evacuation have better results [10]. The rationale for this concept is that complete dissection especially in inexperienced hands is extremely time consuming and may result in end organ ischemia by inducing vasospasm. Using rapid technique is more acceptable for operating room personnel and

other members of the team, and this technique that one was used only for unstable donors is now the routine in most transplant centers [10].

Although most centers are reluctant to change their previous successful policies and it is a routine to perform double cannulation (aortic and portal) for dual perfusion of the liver, but nowadays with increased use of the pancreas and small bowel for transplantation, double perfusion may be replaced by the single aortic perfusion as a rule for most deceased donors [10]. With the advent of machine perfusion which used only one system for ex situ perfusion, there is increasingly more doubt about need for double perfusion and most studies shows that arterial perfusion is more important in saving the organ function especially the biliary system [17].

5. Type, volume, and pressure of preservation solution

Historically, blood is the first perfusate that was used for organ preservation [18]. After that, Alexis Carrel reported the first non-blood solution named Tyrode's solution which can preserve cat thyroid tissue viable for 3–21 days [18]. In 1960s hypothermia added to blood or serum for better survival of kidney grafts. Since then, static cold storage (STS) by perfusion of the organs by cold (0–4°C) solutions was accepted as the gold standard for organ preservation till now [18]. Collin's solution (invented in 1969) and then Euro-Collin's (1980) were the standard solution for organ preservation for next two decades and at last University of Wisconsin (UW) solution was invented by Belzer in 1985 [19]. This solution is low Na^+ , high K^+ solution like intracellular fluid (ICF) which was the gold standard for organ preservation for at least 2 decades.

Histidine-tryptophan-ketoglutarate (HTK) (low Na^+ , high K^+ with cardioplegic effects) and Celsior (high Na^+ , low K^+) solutions are next preservative fluids which was initially used only for heart transplantation in 1990s which were much cheaper and very soon, UW was replaced by these solutions in all abdominal organ transplantations in some transplant centers [18]. Although, these solutions have lower cost and lower viscosities, but till now, UW is the standard solution for heart transplantation in most centers [20]. IGL-1® (Institute George Lopez-1) liquid is another low viscosity solution which reversed electrolyte concentration compared with UW (K^+ 25 meq/l, Na^+ 120 meq/l) with lower cardiac complication and some centers proved that with the use of this liquid, the results of liver and kidney transplantation will be better.

High K^+ concentration of this solution made them unsuitable for lung transplantation because of high risk of pulmonary vasoconstriction [20]. Perfadex® (a low-potassium dextran glucose solution) was invented with characteristics of extracellular fluid for this purpose in late 1980s and since then then is used as the standard preservative for lung transplantation [18].

In multiorgan procurement procedure which is a routine procedure in high volume transplant centers, each team usually used its preferred solution for individual organ transplantation. For example, cardiac and abdominal teams may choose HTK or UW solution but pulmonary team uses Perfadex®, and when a heart-lung transplantation is performed en-bloc in one person, then they should use a cardioplegic solution first and after that Perfadex® for pulmonary preservation. **Table 1** shows the characteristics of most popular different preservation solutions which are commercially available now.

Another dilemma that should be resolved is the rate and pressure of preservative solutions. Perfusion by a cold perfusate is not a physiologic process and most teams

Name of the solution	Osmolar characteristic	Major composition
Viaspan® (UW solution, University of Wisconsin solution)	Intracellular	K ⁺ 125 meq/l (prevents the K ⁺ transudation of the cells but may cause vasoconstriction) Na ⁺ + 29 meq/l Hydroxyethyl starch (HES) (reduce extravasation of the fluids but by increasing the viscosity and RBC aggregation may increase renal damage) Raffinose (prevention of cell swelling after cooling) Glutathione (reduction of oxidative effects of free oxygen radicals) Adenosine (increase ATP levels) Allopurinol (protective effect in ischemia by xanthine oxidase inhibition) Lactobionic acid (prevention of intracellular edema)
HTK®	Extracellular	K ⁺ 9 meq/l Na ⁺ 15 meq/l Histidine (precursor for energy metabolism and buffering effect) Tryptophan (cell membrane stabilization and oxygen free radicals' removal) α -ketoglutaric acid (primary substrate for anaerobic metabolism) Mannitol (prevents hypothermic cell swelling) Higher volume is needed (6–10 lit) Diastolic cardiac arrest
IGL-1®	Extracellular	Based on UW with reversed Na ⁺ /K ⁺ concentration (may reduce cardiovascular complication) K ⁺ 25 meq/l Na ⁺ 120 meq/l Polyethylene glycol (PEG-35) (instead of HES for stabilization of the lipid layer of the cell membrane) Allopurinol (protective effect in ischemia by xanthine oxidase inhibition) Adenosine (increase ATP levels) Raffinose (prevention of cell swelling after cooling) Glutathione (reduction of oxidative effects of free oxygen radicals)
Celsior®	Extracellular	K ⁺ 15 meq/l Na ⁺ 100 meq/l 320–360 mOsm/l (hypertonic) Lactobionic acid (prevention of intracellular edema) Mannitol (prevents hypothermic cell swelling) Histidine (precursor for energy metabolism and buffering effect) Glutathione (reduction of oxidative effects of free oxygen radicals) Glutamate (prevent intracellular flush of calcium)
Plegisol®	Extracellular	K ⁺ 16 meq/l Na ⁺ 110 meq/l Osmolarity of 328 mOsm/l and pH = 7.8. Ca ²⁺ (for prevention of calcium flush and sarcolemmic cracking) Phosphate buffer (counteracts the effects of metabolic acidosis). Mg ²⁺ is (myocardial stabilization by inhibition of myosin chain phosphorylation) Suitable only for cardiac transplant

Name of the solution	Osmolar characteristic	Major composition
Polysol (PS)	Extracellular	Na ⁺ 120 meq/l K ⁺ 15 meq/l Osmolarity 320 mOsm/l. Polyethylene glycol (PEG-35) (stabilization of the lipid layer of the cell membrane) Phosphate buffer (counteracts the effects of metabolic acidosis). Histidine (precursor for energy metabolism and buffering effect) HEPES (buffer of N-(2-hydroxyethyl) piperazine-N-2-ethanesulfonic acid) Glutathione (reduction of oxidative effects of free oxygen radicals) Raffinose (prevention of cell swelling after cooling) Trehalose (cytoprotective effect) Vitamins B1, B2, B3, B4, B5, B6, B7, B8, B9, B12, C, A, D2, E, and K3 21 amino acids (alanine, arginine, asparagine, cysteine, glutamine, glycine, isoleucine, leucine, lysine, methionine, ornithine, phenylalanine, proline, serine, threonine, tryptophan, tyrosine, valine)
Perfadex®	Extracellular	Na ⁺ 138 meq/lit K ⁺ 6 meq/l Osmolarity 292 mOsm/l pH 7.4) Dextran 40 (50 g/l) (maintains fluids in the endovascular space) Glucose (as a source of energy) Phosphate buffer (counteracts the effects of metabolic acidosis) Suitable only for lung preservation
ET-Kyoto	extracellular	Na ⁺ 107 mmol/l K ⁺ 42 meq/l Osmolarity 366 mOsm/l Trehalose (cytoprotective effect) Gluconate (counteract cell swelling) Hydroxyethyl starch (HES) (reduce extravasation of the fluids but by increasing the viscosity and RBC aggregation may increase renal damage) Phosphate buffer (prevents metabolic acidosis) Db-cAMP (cyclic adenosine monophosphate dibutyltin) Nitroglycerine (protect the vascular endothelial cells) N-acetylcysteine (NAC) (antioxidant effect and a free radical scavenger) Approved only for lung transplantation

Table 1.
Characteristics of different popular preservation solutions.

accepted the 80–100 cm H₂O (1 m gravity pressure) as the acceptable pressure for all organs and 150 cm H₂O for aortic infusion [10]. With the advent of machine perfusion, it is shown that target arterial flow of 0.25 mL/minute/g and target venous flow of 0.75 mL/minute/g liver tissue and mean arterial and portal venous pressure of 30–50 and 8–10 mmHg, respectively, are the acceptable rates for liver transplantation and these figures could be extrapolated to the multiple abdominal organ retrieval procedure [21]. Higher pressure for portal vein irrigation is definitively deleterious for post-transplant function of the graft. For pancreas transplantation

the machine pressure should be maintained between 50 and 70 mmHg but the maximum pressure that is acceptable during deceased donor harvesting is not well-defined, although most researchers suggest that overflow of the irrigation of the pancreas tissue is very harmful to its future function [22].

In the adults, for prevention of micro- and macrovascular thrombosis, the standard dosage of heparin is 300 IU/kg and total volume of UW solution is 2–3 liter through the aortic cannula and 1 lit through the portal vein with a flow rate of 50–100 ml/kg/min for abdominal organ transplantation and another 1 liter for back-table preparation of the liver and at least 20 ml for irrigation of the bile ducts [23]. For lower viscosity solutions such as Celsior, HTK or IGL-1®, total volume of perfusate should increase to 6 liters [23] in order to achieve better irrigation of the total blood volume of the harvested organs. For pediatric donors the dosage of heparin is 500 IU/kg and total volume of perfusate should be around 50 ml/kg [23].

6. Cooling

Peritoneal cooling technique by slush ice is a safe and accepted old method for better organ function. It is a routine in all transplant units to use a perfusion temperature of 0–4°C for flushing all the organs but it is not widely proofed that the use of topical slush ice is really beneficial [24]. One author could prove that retroperitoneal slush ice may improve renal function [25] and another one showed improved islet cell recovery from pancreas grafts by using additional slush ice around the pancreas during the organ procurement [26]. There are so many reports in the literature about successful heart and lung transplantation after using topical ice. Transporting the organs in plastic bags filled with organ preservation solution and putting them into another ice –filled bag or cool box is the standard method of transferring organs between different transplant centers. Topical slush ice should be accepted as a routine until better prospective studies show another method but in all steps of organ procurement, preservation and transferring, it is extremely necessary to prevent organs' freezing with the use of good preservative solutions and prevention of direct contact of the ice to the tissues after retrieval.

7. Surgical procedure

7.1 General principles

Thomas Starzl and his team are the pioneer of multiple organ harvesting from the deceased donor and the technique that they described has minimal change till now after more than 3 decades [27]. All the procurement procedures have some steps in common:

- i. Anesthesiologist management and use of muscle relaxant if needed
- ii. Preparation and drape
- iii. Long midline sternal and abdominal incision (with transverse extensions if needed)
- iv. Primary evaluation of all the torso organs (with frozen section evaluations when indicated)

- v. Control of the aorta for next step cannulation (abdominal; and thoracic if heart transplantation is planned)
- vi. Control of supra-celiac and supra-iliac aorta for clamping (for better irrigation of abdominal organs with lower volume of preservative solutions)
- vii. Warm dissection of all the important anatomic structures when indicated and the patient's hemodynamic is stable (for example portal vein, gastroduodenal artery, base of superior mesenteric artery and vein, renal arteries, veins and ureters, pulmonary artery and veins, bile duct, proximal and distal part of the duodenum, etc.)
- viii. Preparation of the femoral, iliac vein or inferior vena cava (between the heart and liver, superior to renal veins, near its pelvic bifurcation) for evacuation of blood at the end of operation.
- ix. Full heparinization (300/500 IU/kg)
- x. Cannulation of aorta (abdominal; and thoracic if heart transplantation is planned); and portal vein if the patient is stable (through the superior mesenteric vein; or inferior mesenteric vein if short bowel transplantation is planned or cannulation of superior mesenteric vein is impossible or difficult)
- xi. Clamping of supra-celiac, supra-iliac and thoracic aortic arc and beginning of irrigation and evacuation of blood through the previous large controlled veins and filling around of all organs with slush ice at the same time.
- xii. Removal of the organs with this order: heart, lung, liver, pancreas, small bowel, kidneys, iliac and other large vessels, tissues with potential use as grafts (pericardium, bones, cartilages, tendons, skin, cornea, ...). This order may be changed according to planned transplantations and center expertise.

7.2 Starting the operation

Table 2 shows the checklist for essential pre-requisites of the donor characteristics before starting the operation. The surgical team should confirm that all the data in this checklist is ready and acceptable before starting the operation. Usually in most transplant units, the “liver team” is in charge of the whole operation and the operation is started by the most experienced and self-sufficient surgeon in this team by a long midline incision from jugular notch to symphysis pubis in the stable patient. In unstable patients all the steps of the operation may be omitted and replaced by femoral artery and vein cannulation for cold infusion of the preservative fluid and evacuation of the blood and after that all the dissections should be done after in situ cooling and aortic cross clamping below or above the diaphragm.

The time of the starting of the incision must be fully coordinated by all the other team members, coordinators and the in-hospital and out of hospital transport system to decrease the total ischemic time to the lowest possible time. It is better not to transfer the donor to other hospitals and in most countries, it is the procurement team that should go the donor hospital and they should have all the equipment, drugs, preservative solutions, organ bags, cool-boxes and surgical instruments that is essential with themselves. The leader of the team should finally check all the pre-requisites of the organ donation operation including informed consent of donation,

Donor eligibility	
	Informed consent of donation by the next of keen
	Brain death confirmation by the authorities
Hemodynamic stability (ideal)	
	Central venous pressure 10–12 cmH ₂ O
	Systolic blood pressure maintenance >100 mmHg and mean arterial pressure >60 mmHg
	PaO ₂ > 100 mmHg, SpO ₂ > 95%, PaCO ₂ between 35 and 40 mmHg and pH between 7.35 and 7.45
Urine output between 100 and 300 ml/hour	
No electrolyte imbalance	
	Na ⁺ < 160 and K ⁺ 3.5–4.5 meq/l
	Normal Ca ²⁺ , Mg ²⁺⁺ and P
Negative viral tests	
	HBsAg, HCVAb, HIVAb, HTLV-1
No active infection	
No malignancy	
Normal organ specific function tests	
	Liver function tests, creatinine, histocompatibility tests results, echocardiography, ECG, angiography, bronchoscopy and Gram stains, chest imaging studies, insulin levels, etc.
Coordination with all the teams involved	
Readiness of all the recipients and their surgical team	
Availability of all surgical equipment needed	
Coordination with transport system	

Table 2.
Checklist for donor preparedness before starting the operation.

brain death confirmation (patient identity and certificate of death), important blood tests (especially the blood group and viral tests), previous history (especially history of untreated cancer and previous surgeries) and suitability of the donor just before the operation. Discussion of the steps of the operation with other teams will decrease potential injury to the retrievable organs.

A general physical exam is absolutely necessary because all palpable masses in the unexposed area such as breasts, genitalia, axillary and inguinal regions or any skin lesions which are suspicious for malignancies should be excised for pathologic examination.

Every surgeon has to use his or her maximum delicate surgical art to prevent any harm to any of the transplantable organs. For example, if the donor has previous midline sternotomy incision with potential adhesions of the heart, the thoracic incision should be delayed until all abdominal dissections are completed. Sternum may be incised by Gigli's saw or Stryker® sternal saw if available. After incision, complete hemostasis of all cutting surfaces is essential to prevent obscuring bleeding and suitable retractors such as large Finochietto retractors are placed for maximum exposure of the organs. All the organs should be explored for potential contraindications for donation such as congenital anomalies, malignancies or severe infective processes such as colon perforation or peritonitis.

7.3 Dissection of abdominal organs and large vessel cannulation

Every disturbing adhesion from previous surgeries should be released first to prevent jeopardizing the bowel wall. Superior mesenteric vein is dissected and controlled in the root of mesentery just to the right side of the Treitz ligament and the inferior mesenteric vein in the edge of this ligament. Cephalad retraction of the transverse mesocolon and caudal retraction of small bowel will better expose these two anatomic landmarks. After that, abdominal aorta and inferior vena cava (IVC) are fully exposed and controlled for cannulation by a complete right medial rotation of abdominal viscera from pelvic area till the infra-duodenal area superior to both renal veins. This step has to be done with caution to find all accessory renal arteries and prevent any inadvertent injury to lumbar arteries or veins which will result in uncontrollable or disturbing bleeding. If the distal aorta is not cannulable, the iliac arteries can be used instead. Inferior mesenteric artery (IMA) can be ligated and both ureters can be mobilized at this step but without any trauma to the tissues common between the ureters and genital veins.

Lesser sac is entered through the gastrohepatic ligament with caution not to injure potential left accessory hepatic artery. Left lateral segment of the liver is taken down from the diaphragm and supra-celiac aorta is exposed by blunt dissection of diaphragmatic crura and setting aside the abdominal esophagus and then controlled by an umbilical tape. If such dissections are impossible due to previous adhesions or any other reason, then thoracic aorta should be controlled in the left hemithorax just above the diaphragm and anterior to the lower thoracic vertebra.

At this stage, if “rapid flush technique” is chosen due to patient’s instability, the operation is ended by full heparinization and aortic and portal cannulation, clamping the aorta and cutting the abdominal or infra-atrial IVC for blood evacuation along with the infusion of the preservative solution and covering all the viscera by slush ice.

If the patient is stable further dissections will be done. Bile duct is transected above the duodenum and flushed with 20 ml of cold normal saline. Cholecystectomy is performed. Gastroduodenal artery is explored in upper border of pancreas. If pancreas is suitable for transplantation, duodenum is prepared just next to the pylorus and after the pancreas uncinate process, posterior to transverse colon for transection at the end of operation and superior mesenteric artery is controlled just above the renal arteries root anterior to aorta. The cardiac team is now can come into the operation field.

7.3.1 *Tips and tricks*

In patients with history of heart surgery or median sternotomy, thoracic incision should be postponed till all the abdominal dissections and cannulation of the great vessels have been finished.

In patients with history of previous abdominal operations, incision should be started as far as possible from the site of previous incision to prevent bowel perforation.

In fatty donors, it is better to perform superior or inferior mesenteric vein dissections, because after full Kocherization and right medial visceral rotation, finding the mesenteric vein will be very difficult.

If during each step of the dissections, any vascular damage is encountered, it is better to repair it with fine sutures only if the location of the damage is easily found and repairable. In other cases, no attempt should be done, because it is time consuming and may cause further damage to critical organs.

During the cannulation of the aorta, the cannula should not be advanced above the celiac artery. Clamping the supra-celiac aorta at the end of the procedure will

occlude the cannula and perfusion of the preservative solutions is stopped. All cannulas should have side holes for faster infusion of the solutions.

Unnecessary organ manipulations should be avoided to prevent vasoconstriction. In stable patients, some urologists insisted on postponing the rest of the operation when no urine is noted after ureteral transection.

7.4 Preparation of the heart

In stable donors, after the liver surgeon prepares all prerequisites in the abdomen the heart and/or lung team will welcome to the operation field. All thoracic lymphatic regions must be accurately inspected for signs of occult malignancies such as metastasis or lymphoma and if needed biopsy should be done and sent for frozen section pathologic examination. Thymus gland should be resected first and pericardium is opened longitudinally and fixed to the edges of transected sternum in both sides. Intraoperative cardiac evaluation includes inspection for: signs of previous pericarditis, hematoma or ecchymosis (resulted from previous cardiopulmonary resuscitation), any cardiac anomalies, dyskinesia, scars, contusions, calcification of ascending aorta and coronary arteries, size of the great vessels and heart chambers. At the same time, the inotrope dosage should be reduced by the anesthesiologist to ensure that cardiac contractility is good enough without need of the inotropes. If there is any sign of right heart overload immediate diuresis by furosemide and reducing the central venous pressure by avoiding any intravenous infusion of crystalloids is mandatory. All the data should transfer immediately to the recipient team so they can make decision on starting the recipient operation.

The window between ascending aorta and pulmonary trunk is opened and controlled by an umbilical tape. Superior and inferior vena cava is encircled with caution not to harm the sinoatrial region or jeopardize the pulmonary veins. For cardioplegic injection at the end of preparation a cannula should be inserted and the arc of aorta should be prepared for clamping before the origin of the innominate artery.

7.5 Preparation of the lungs

Both pleural spaces should be opened at this stage. Lungs are inspected for bullae, contusions, atelectasis, pneumonia and occult tumors. Tracheal tube is disconnected and both lungs are deflated transiently and then inflated again by a pressure of 15–30 cmH₂O to better detect the pulmonary compliance (so called “collapse test”) [28, 29]. Usually, most of the vascular dissections were done previous by the heart team including: separation of the pulmonary trunk and right pulmonary artery from posterior wall of the ascending aorta and superior vena cava, and opening the window between the lower right pulmonary vein and intrapericardial IVC (so called “oblique sinus”). The left innominate vein and artery is controlled by umbilical tape to expose the main trachea by retracting them toward the right and left, respectively. The azygous vein should be ligated at this stage to prevent rupture and bleeding. After inserting the cardioplegic cannula in the root of aorta and cannula should be inserted near the bifurcation of the pulmonary trunk for infusion of prostaglandin E1 and Perfadex for lung procurement at the end of all other organs’ retrieval.

7.6 Common steps at the end of the procedure

When all dissections were done according to patient’s stability and the retrievable organs prepared, great vessels’ cannulation is done after full heparinization. The aorta is clamped at two levels: sub- or supra- diaphragmatic and at the end of

ascending aorta. Blood evacuation is started by cutting the IVC just inferior to the right atrium or if dissections at this level is impossible, in the abdomen above the iliac vessels. Infusion of the cold preservatives (with cardioplegic effect if heart is being retrieved for transplantation) is started and supporting by the anesthesiologist is finished and the “definitive death” is announced. At the same time immersion of all the retrievable organ by slush ice should be accomplished. If lung procurement was programmed, infusion of Perfadex should be started at the same time and the pulmonary blood should be evacuated by cephalad retraction of the heart and incision of the left atrium between the two inferior pulmonary veins just below the Waterson’s groove or “sulcus terminalis”.

Infusion is continued till all the viscera are exsanguinated. Usually 2–3 lit of infusate through abdominal aorta, 1 lit through the portal vein, 1 lit for ascending aorta and 50 ml/kg of Perfadex is enough for complete blood evacuation. The superior mesenteric artery has to be ligated at this time for prevention of pancreas overperfusion which will severely affect graft function [30, 31]. If small intestinal retrieval is programmed, this step is forbidden, and portal perfusion should be omitted as well or performed through the IMV and only the aorta is perfused [30].

All the organs will be transferred after retrieval to an organ bag full of cold preservative and irrigated again if necessary. This bag should be packed and inserted to another bag filled with cold saline and again in the third bag full of slush ice and then in the cool box for transferring to the recipient ward or hospital. Sometimes especially when the transfer time is long or the donor is marginal the transplant team may decide to use cold or warm perfusion machines for better preservation of the organ.

7.7 Procurement of each organ

7.7.1 Heart and lung

Heart is easily retrieved by transecting the great vessels but this transection should be done step by step to prevent hematoma formation and injury to the vital parts especially the sinus node and pulmonary artery. When all the blood evacuated through the IVC incision, pericardium should be irrigated by cold saline at all steps to prevent warming. Cardioplegic cannula is removed. Aorta is cut just below the clamp, and SVC and IVC completely transected. The heart is gently pulled upward and inferior and superior pulmonary veins are divided one by one and at last the pulmonary trunk will be cut just at its bifurcation to remove the heart.

If the heart-lung complex is planned to be transplanted to one person, all these dissections should be avoided. The cardioplegia and pneumoplegia and prostaglandin E solutions is infused through the aortic and pulmonary artery catheters. Blood is evacuated from heart by incising the IVC and the returned blood from the lungs is evacuated through a small incision in left atrial appendages. Only the ascending aorta is transected before the innominate artery origin and the trachea is stapled after inflation of both lungs and removal of the endotracheal tube. The SVC is transected and origin of azygous vein is transligated and at last the heart -lung complex is procured by releasing their attachments to the mediastinum.

If transplantation of the lungs alone is planned, cardiac team should be left posterior wall of the left atrium intact in line with for pulmonary veins. After removing the heart, the posterior wall of left atrium and its surrounding pericardium is dissected from posterior mediastinum including the esophagus and descending and this avascular plate is continued till both lungs are released bilaterally. Small volume ventilation should be continued till all the dissections are completed and at the end and after complete inflation, the endotracheal tube is removed and trachea is stapled to extract both lungs outside the thoracic cavity.

7.7.2 *En bloc retrieval of abdominal organs*

The fastest way to retrieval of abdominal organs is en bloc resection. Sometimes the time is very important for the harvesting team for example when the organs will transfer to another city by a commercial flight. In some cases, all abdominal organs should be transplanted to one recipient, for example a recipient with cirrhosis due to complete portal and superior mesenteric vein thrombosis needs a simultaneous liver-small intestinal transplantation [32]. In such cases all abdominal organs have to be procured en bloc.

According to the organs being retrieved for multivisceral transplantation, there are several ways to do such procedure [30, 33]. After the heart and/or lung team retrieved their organs, the abdominal team can complete their operation. Amphotericin B, metronidazole and sometimes diluted povidone iodine is instilled into the duodenum by a nasoduodenal tube [31]. For better exposure and preventing of bowel content spillage, usually the stomach and colon should be resected and discarded first, by stapling the esophagogastric and gastroduodenal junction and also the ileocecal and colorectal junction and transecting their vasculature. Then the sub-diaphragmatic aorta which was previously controlled is transected. All diaphragmatic adhesions of the liver and spleen are released and the infra-atrial IVC is separated with a patch of pericardium and surrounding tissue around it. At last, all the organs including aorta, IVC, liver, pancreas, spleen and small intestine are swept up of posterior abdominal wall and lumbar vertebrae and muscles and the procurement is completed by transecting the ureters at pelvic rim and iliac vessels just before entering the femoral canal [3]. All the dissections in this step should be with extreme gentleness not to push or pull any of the vital structures.

7.7.3 *Liver*

In most centers liver and kidneys are the only organs used for transplantation especially when the donor has a high body mass index or marginal for any cause (unstable, diabetic, hypertensive, old age, etc.). For retrieval, these steps are necessary: transecting the infra-atrial IVC with a rim of pericardium and diaphragm, taking down the falciform, right and left triangular ligaments from the diaphragm, transecting the gastroduodenal (GD) and right gastric arteries and following the artery till the origin of the celiac artery by complete dissection of diaphragmatic crura.

If pancreas is not suitable for transplantation, dissection of the portal vein should be continued by transection of the pancreas neck anterior to SMV and swiping up the head of pancreas and duodenum to the right and the tail of pancreas to the left to expose the base of the SMV and SMA anterior to aorta. Then the origins of celiac and superior mesenteric arteries are separated from the aorta with a common Carrel patch. Replaced or accessory right and left hepatic arteries must not be jeopardized or pulled in any way and remained attached to their main large paternal vessel. Splenic vein and distal SMV SMA is transected at the level of uncinate process. IVC is transected above the renal veins' origin. Now after complete releasing of all inflow and outflow structures, the liver can be removed easily by final releasing it from the posterior wall and transferred to an organ bag and irrigated by another 1 lit of preservative solution without direct contact to ice.

If pancreas is transplantable all the dissections should be limited to upper border of the pancreas and portal vein and GD artery transected just above the duodenum and the SMV, SMA and splenic artery attachment to the pancreas be remained intact. Sometimes liver and pancreas will be removed in continuity and separated from each other in the time of back table preparation [30].

7.7.4 Small intestine

If gastrectomy and total colectomy were done previously with good hemostasis of the vessels, removal of the small intestine is relatively easy and straight forward. As I told before, at the start of the operation for exposure of the aorta and IVC, small intestine is gently wrapped in a lap-sponge and pull cephalad to detach all the mesentery in an avascular plain from ileum to the Treitz. At the end of operation and evacuation of all the blood by aortic and IMV irrigation, the small intestine only attached to the body superior mesenteric pedicle containing SMA and SMV. Duodenojejunal and ileojejunal junction was previously cut by staples and the whole graft can be removed only by cutting the SMA and SMV at this time. If small intestine is decided to transplant separately, it is necessary to remove it before liver and pancreas but if a multivisceral transplant is planned for the recipient, any dissection around the SMV and SMA at the root of mesentery is forbidden and IMV should be used for cannulation of the portal vein [30, 32, 33].

7.7.5 Pancreas

As I discussed previously, pancreas usually is procured along with the liver and separated from it in back table procedure. If the surgeon decided to retrieve each organ individually, then after removing the stomach by stapling of duodenum after pylorus, portal vein, GD and splenic arteries are cut at the upper border of pancreas. Another staple is used for transection of the duodenum between D2 and D3 area at the level of uncinate process, and the SMV and SMA and origin of mesentery is transected by another vascular staple. The IMV is ligated the lower border of pancreas is separated from left renal vein and the left kidney. The previously extended Kocherization is continued toward the left to separate the duodenum from the vertebra, aorta and posterior wall of the abdomen and at last the attachments of the spleen are released and procurement of the duodenum-pancreas-spleen is completed [30, 34].

7.7.6 Kidneys

Kidneys are the last organs that will be removed. They may be procured en-bloc in line with aorta and IVC when both of them are programmed to be transplanted to one person (for example from a pediatric or marginal donor for an adult recipient, or when we encounter with a horseshoe kidney with multiple renal arteries and veins) or retrieved separately. For separation, IVC is transected transversely just above the renal vein origins and then incised longitudinally to explore for possible multiple renal veins. All renal veins should be separated with a common patch of IVC. Separation of renal veins should be done with caution not to injure the renal arteries which run posterior to veins especially accessory undefined renal arteries. Ureters (sometimes double or rarely multiple) are completely separated from the surrounding tissues and transected distally in the pelvic rim, but the window tissues between kidneys and ureters and also between the ureters and gonadal veins should remain intact to prevent ischemia and future contracture or anastomotic failure. Renal arteries are exposed by longitudinal incision of the aorta to find multiple branches from inside the aorta and retrieval with a common patch. Rarely an accessory branch may originate from the iliac arteries or the other side of the aorta. It is better not to jeopardize such branches but the kidney transplant team should be capable of back-table microvascular reconstruction of several arterial branches in such cases. Left adrenal vein is ligated and transected as well.

After complete separation of all arterial and venous branches, kidneys are retrieved by medial to lateral movement by the surgeon with extreme caution not to over-retract these branches and induce intimal rupture. Also rupture of renal capsule has to be prevented by using sharp dissections specially in older marginal donors. It is better to perform these dissections outside the perirenal fatty tissues to prevent such inadvertent injuries.

8. Machine perfusion

Full discussion about the machine perfusion is beyond the scope of this chapter. Ideally all the organs retrieved should be transplanted immediately or as soon as possible in the same center of the organ procurement. But this is impossible, irrational or illegal in many situations. The donor operation can be easily done in a small rural hospital without any transplant facilities in unstable patients. In such cases transferring the organ to other hospitals is the rule. Another such circumstances is, when histocompatibility (for example for kidney and pancreas), or duration of stay in the waiting list is an important matter for decision making, and transplantation in the same center in such cases is both irrational and illegal. In marginal donors and in cases of donation after cardiac death (DCD), it is very important for the transplant surgeon to predict functionality of the organs. In all such situation, machine perfusion is the best way to know the organ function and increase the time of organ viability before final *in vivo* reperfusion.

In contrast to static cold storage (SCD) which we discussed in all sections of this chapter, dynamic perfusion techniques use a perfusate for active perfusion of the organs *in situ* (*en vivo*) or *ex situ* (*ex vivo*) [35]. For example, normothermic regional perfusion (NRP) is an *en vivo* method for reconditioning organs for DCD by restoring oxygenated blood flow to the organs before procurement. For such purpose, we need a sophisticated Extracorporeal Machine Oxygenation (ECMO) technology, which is not available in most centers. In contrast to this technique, *ex vivo* machine perfusion is used after organ recovery specially for kidneys and liver. It may be used in a hypothermic (hypothermic machine perfusion or HMP) or normothermic (normothermic machine perfusion or NMP) milieu. For kidney grafts, it is shown that HMP reduced significantly delayed graft function both after DCD and donation after brain death in marginal donors [35]. NMP is an established method for confirming the functionality of marginal liver grafts by showing the function of the graft and preventing ischemic cholangiopathy and it is shown that this method reduced the discard rate by 50% [36]. The results are promising for pancreas and small intestine as well. Machine perfusion of the heart is an essential step in all cases of DCD and for lungs it is essential for uncontrolled DCD cases [37]. In my opinion, future of organ transplantation from marginal donors is in the hand of the engineers who invents better, cheaper and more efficient and reliable machines with simpler use by transplant surgeons, but at these days use of these techniques should be limited to high income countries with an extensive network of transplantation services all around their territories.

9. Conclusion

Multiorgan procurement from the same donor is the combination of the art of cooperation between several medical team with different expertise level. If any of the team member makes any mistake during such sophisticated procedure all other

organs will be jeopardized and the life of many recipients will be in danger. It is the task of the team leader to manage such problems before they become irreversible, and this will be impossible without basic knowledge of all aspects of the other organ's retrieval by all other surgeons who is in charge of their organ.

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Conflict of interest

There is no conflict of interest to declare.

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