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Principles of Multiple Organ Procurement from Cadaver Donors

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The need for cadaveric organs other than kidneys for transplantation is increasing. Principles and techniques that allow their procurement without jeopardizing renal recovery are outlined. These include utilization of brain dead donors, careful donor selection, and surgery which minimizes warm ischema while avoiding iatrogenic injury. Utilizing this approach, a variety of combinations of organs have been removed and transplanted resulting in satisfactory functional results.

TRANSPLANTATION OF LIVER, PANCREAS, heart, heart/lung, and lung is becoming more frequent because of technical developments and improvement in immunosuppression. Cadaver donors are the sole source of organs for extra-renal transplantation and remain an important source of kidneys for renal transplantation. Many cadaver donors will have to provide one or several organs in addition to kidneys if the need for all these organs is to be met. It is essential that techniques be developed which ensure safe recovery of the extra-renal organs, which must function promptly for the survival of the recipient, and also achieve the same number of functioning kidneys as where kidneys alone are recovered. We have had experience with 189 donor operations where extra-renal organs were procured, including 125 combined liver and kidney donors, 50 combined heart and kidney donors, 11 combined heart, liver, kidney donors, 1 combined segmental pancreas and kidney donor, and 2 combined heart/lung and kidney donors. The functional results have been reported elsewhere.[1,2,3] The purpose of this report is to outline principles and techniques which can provide good functioning organs from a single donor.

Perioperative Management

Most of the management principles are the same for the multiple organ donor as for kidney donors alone. Maintenance of cardiovascular stability and urine output are important. Patients are considered unacceptable for heart, lung, liver, or pancreas donation who have preexisting disease, trauma to these organs, diabetes, hypertension, malignancies other than primary brain tumor, active systemic infection, or prolonged ischemia due to hypotension or asystole. There are some important differences in the perioperative management for multiple organ donors than for kidney donors alone. Brain death criteria for determination of death is essential, since the heart and visceral organs will not tolerate the warm ischemia that would occur in a nonheart-beating donor. Donors in whom the kidneys alone are to be removed can sometimes be managed without anesthesia support. Also, blood loss is usually replaced simply by crystalloid and seldom with blood. In the event of cardiovascular collapse, the aorta can be cannulated, the kidneys perfused, and the dissection quickly completed avoiding injury to the kidneys. Removal of pancreas, liver, or heart in addition to kidneys requires a meticulous dissection, ischemia is not tolerated, and the organs cannot be protected in case of early cardiac arrest or cardiovascular collapse. Therefore, it is critical to have anesthesia support for careful fluid and electrolyte replacement and monitoring of the cardiovascular status. Blood loss early in the procedure must be replaced with blood, also to maintain cardiovascular integrity. Hypothermia can lead to cardiac arrest, and is a frequent problem in these donors, so that temperature monitoring and control is essential.

Surgical

The technical details will differ, depending on the combination of organs to be removed. Curtain principles are the same regardless of which organs are removed: wide exposure, dissection of each organ to be removed up to disconnection from the circulation while the heart is still beating, placement of cannulas for *in situ* cold perfusion, orderly removal of the organs with cold perfusion pro-

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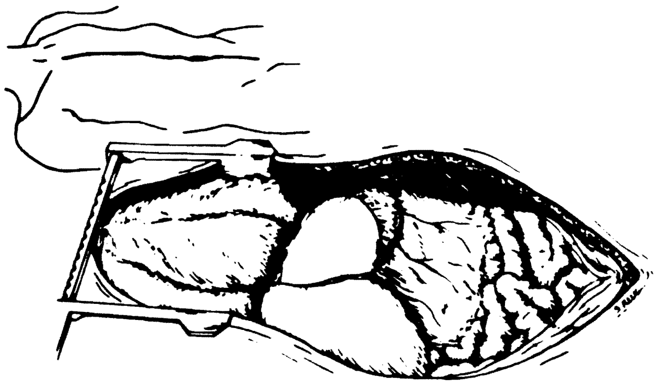
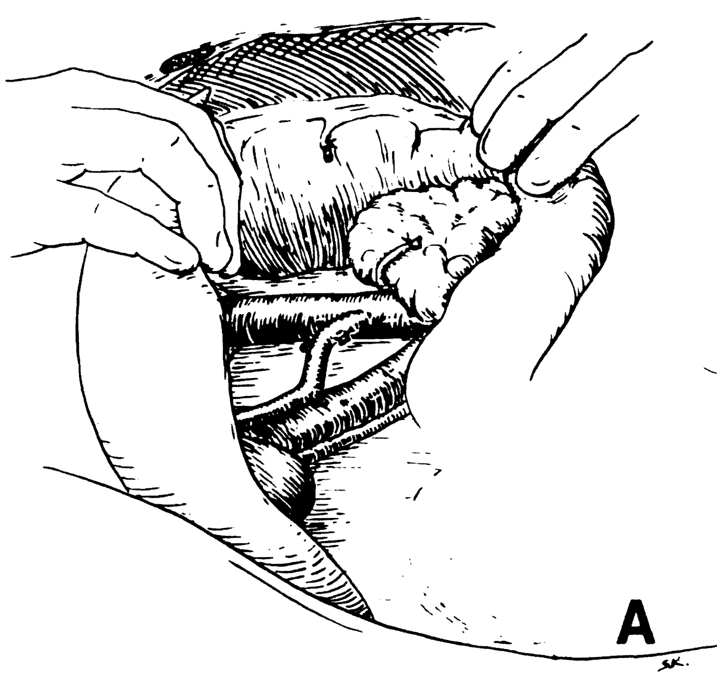
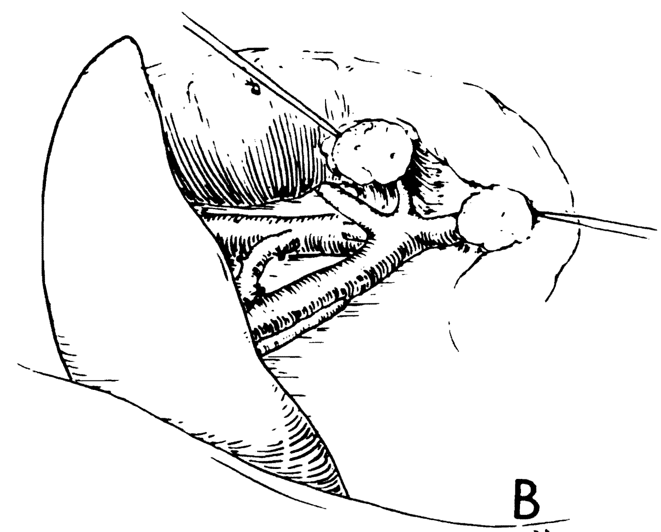


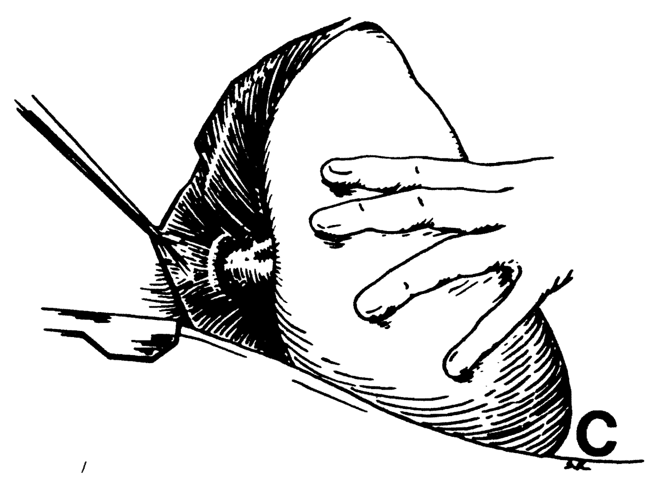
FIG. 1. Incision. Sternal notch to pubis provides adequate exposure for any combination of organs.

tection of the organs to be removed last, and removal of the heart first. The details of combined heart, liver, and kidney removal are applicable to other combinations, and are illustrated in Figures 1–6. A midline sternal splitting incision is used routinely; this provides immediate access to the heart if there is any instability. It also enables core temperature to be maintained by placing warm fluid around the heart in case of hypothermia, and is helpful, though not essential, for liver dissection and control of the upper aorta when *en bloc* kidney dissection is done.

Liver mobilization is carried out first, since this is the most meticulous dissection and attention to hemostasis is strict. If pancreas or small bowel were to be removed, their dissection likewise would proceed first. Careful inspection of the arterial anatomy is done first, any anomalous arteries must be preserved. A branch to the left lobe is sometimes seen arising from the left gastric artery and can be seen in the superior portion of the gastrohepatic ligament. A branch to the right lobe arises from the superior mesenteric artery and can be palpated in the foramen of Winslow posterior to the portal vein. This artery







FIGS. 2A–C. A, *top left*, mobilization of the liver. Meticulous dissection of the celiac axis is carried out. Gastroduodenal, splenic, gastric, and phrenic arteries are carefully ligated to avoid intimal damage. Segmental aorta above and below celiac takeoff are isolated. B, *top right*, after division of common bile duct close to the duodenum, the pancreas is divided and the branches making up the portal vein are isolated. C, *left*, suprahepatic vena cava is exposed. The phrenic veins are ligated. Important to include complete segment of vein up to the right atrium.

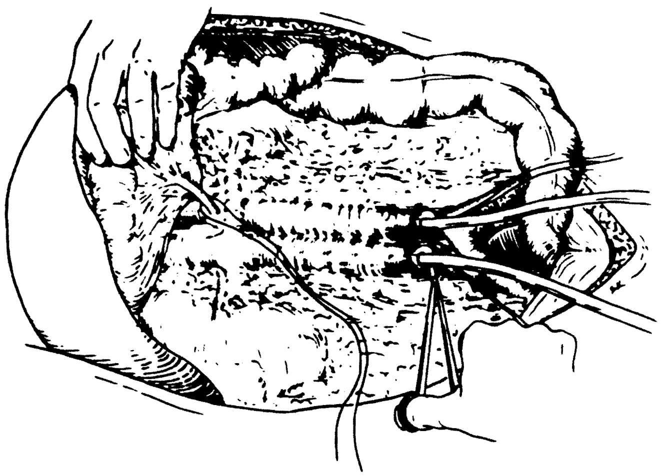


FIG. 3. Kidney Mobilization. Kidneys are mobilized. Ligature is placed around SMA but not tied. Cannulas are placed in the great vessels.

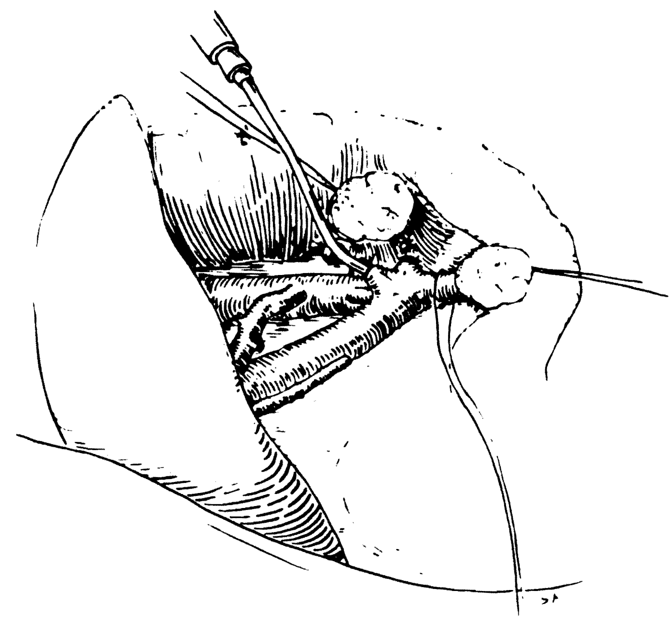


FIG. 4. Liver cannulation. Inferior mesenteric vein is ligated. Splenic vein is cannulated for liver pre-cooling.

has occasionally been the entire arterial supply to the liver. The hepatic artery is dissected to the aorta. The arcuate ligament and crura of the diaphragm are transected, exposing the origin of the celiac axis and the aorta above it. Segment of aorta below the celiac axis and above the superior mesenteric artery is also exposed. The common bile duct is exposed at its entrance to the pancreas and transected. Through a small incision in the gallbladder, the extrahepatic biliary tract is flushed with saline. The portal vein is dissected after transection of the pancreas to facilitate exposure. The inferior mesenteric and coronary veins are ligated; the splenic and superior mesenteric veins are mobilized. The triangular and coronary ligaments are cut and by retraction medially of the right lobe of the liver the right adrenal vein is ligated. The suprahepatic vena cava is isolated by incising the diaphragm and ligating the phrenic veins. The junction of the inferior vena cava and right heart is identified to provide maximal length of upper cuff of vena cava. The liver is essentially ready for removal at this point.

The kidneys are mobilized next. The cecum and right colon are elevated and the duodenum is Kocherized. The kidneys are elevated from the retroperitoneum within Gerota's fascia; the ureters are divided; ligature is placed around the superior mesenteric artery but not tied so as to continue to provide enriched portal blood flow to the liver; and the aorta and vena cava are isolated at the bifurcation. This is sufficient mobilization to allow removal after the heart and liver are removed.

Cannulas are then placed for *in situ* perfusion and precooling of the liver. First, cannulas are placed in the vena cava and aorta at their respective bifurcations and the vessels divided distally. Heparin 300 units/Kg is given to prevent clotting. Splenic vein is cannulated and portal infusion is begun slowly with ice Ringer's. The splenic vein is ligated and divided behind the cannula. The superior mesenteric vein and artery are both ligated at this point. The liver still has an intact arterial supply at this time, but core cooling occurs with the Ringer's infusion.[4] Close monitoring of temperature and blood pressure are crucial at this stage so that there is no compromise to the heart. If the liver becomes too firm, the vena cava cannula can be temporarily opened to vent the venous outflow from the liver. If the heart is not to be removed, the infusion can be carried out until the core temperature reaches 30 C, or there is any hemodynamic instability, or 1–2 l of solution have been infused. An alpha blocker is then given[5] and the aorta cross-clamped above the origin of the celiac axis. As soon as the aorta is cross-

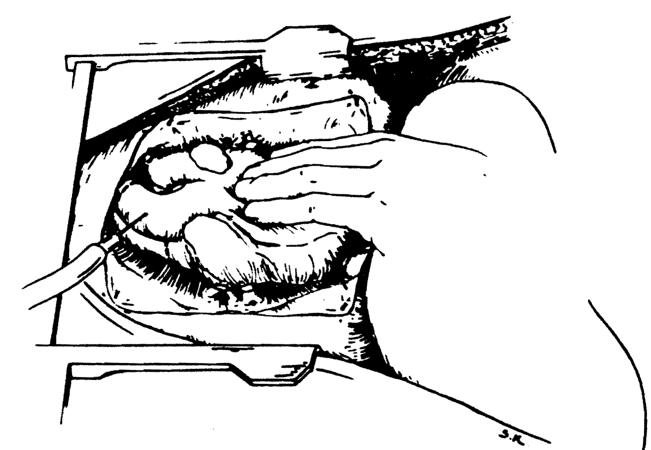
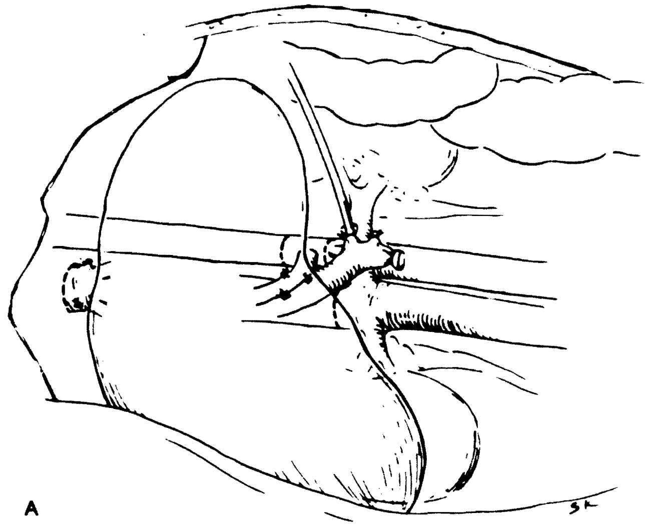
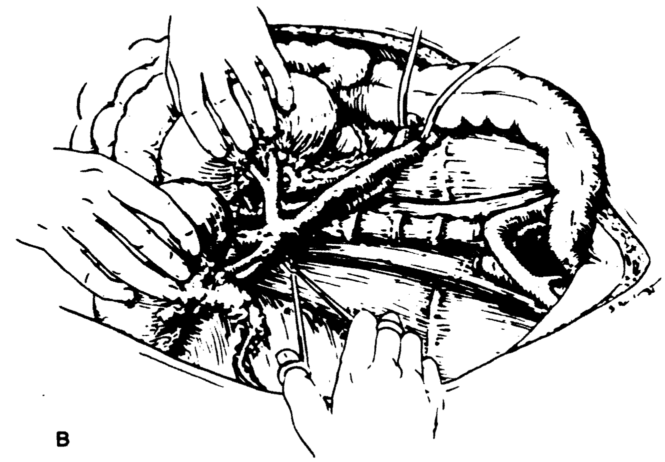


FIG. 5. Mobilization of the heart. Cannula is placed in ascending aorta. Dotted lines mark resection margins for heart removal.





FIGS. 6A and B. Completion of resection. A, *left*, liver resection is completed by dividing supra and infra hepatic vena cava and aorta cylinder above and below celiac axis. B, *right*, renal dissection is completed by dividing between great vessels and the spine.

clamped, the aortic flush is begun, immediately cooling the kidneys. Two to 300 cc of intracellular solution is run into the liver, at which time the aorta is cross-clamped again below the celiac axis. The portal flush is switched to an intracellular solution at the time of aortic cross-clamping. The sequence is slightly modified if the heart is to be included. Steps are the same until the portal infusion is begun.

When the heart is to be removed, greater care in the portal infusion stage is necessary so that no instability occurs. At this point the pericardium is opened, the superior vena cava is mobilized, and the aorta is separated from the pulmonary artery. A 14 gauge catheter is inserted into the ascending aorta and secured so that cardioplegic solution can be infused both during cardiectomy and implantation. The cavae are clamped first to facilitate partial emptying of the heart, followed closely by the aorta. Care is made to include as little as possible of the inferior vena cava since it is not needed in the cardiac operation, but is essential in the liver reimplantation. At the moment the aorta is cross-clamped, infusion of cardioplegic solution is begun, aortic flush from below is begun to complete the liver flush and begin the renal flush and cooling, and the inferior cava is divided to drain the cardioplegic solution from the coronary sinus. Experience indicates that infusion of the cardioplegic solution is facilitated by next dividing a pulmonary vein which empties the left cardiac chambers and the ascending aorta between the aortic valve and the aortic clamp. In sequence, the left interior and superior pulmonary veins, aorta, the origins of the left and right pulmonary arteries, the posterior attachment of the left atrium to the pericardium, the right-sided pulmonary veins, and superior vena cava are divided. After the heart is removed, the distal aorta and superior vena cava are stapled. Stapling of the distal aorta facilitates infusion of cardioplegic solution from preservation of the myocardium during suturing of the left and right atrial anastamoses.[6] Early in our experience, the heart was removed after the visceral organs. Several hearts were lost due to cold or vascular collapse. Because of this, we have elected to remove the heart first. This can be accomplished in less than 5 minutes from the time of aortic cross-clamping, and there have been no adverse effects on the visceral organs or kidneys.

After the heart is removed, the liver is removed by resecting a cylinder of aorta which includes the celiac axis, and dividing the lower vena cava just above the renal veins. This usually takes another 5 minutes. During this time, the kidneys are cold and flushed so that there is no warm ischemia. The kidneys can be removed individually, but our routine has been to remove them *en bloc* with aorta and vena cava. The advantages of this have been documented[7] and include: less risk of damaging arteries, especially in an unclear field as sometimes exists at this point; less dissection around the hilum to prevent arterial spasm; no possibility of twisting the kidneys around their pedicle, possibly producing intimal tears; and large cuffs of aorta and vena cava are always present for later use in recipient operation. It only remains to divide the attachments between the great vessels and the spine to complete the removal.

Separation and cleaning of the kidneys is done in a basin with ice slush. Though this is difficult at first, since landmarks are obscured, it is actually easy and safe. The left renal vein is separated from the vena cava working from the anterior surface. Then, working from the posterior surface of the aorta identified by the lumbar arteries, the number and position of the renal arteries can be identified easily. The aorta is divided diagonally so that an aortic cuff is present with both kidneys. This method is applicable, regardless of the number of renal arteries involved. Each end of the aorta can be cannulated if machine preservation is to be used, which avoids cannulation injury to the renal arteries. This step is omitted if slush preservation is used.

Discussion

Teamwork and coordination are important if these techniques are to be successful. One surgeon can do the entire operation, regardless of which organs are removed, but often the donor is identified by a local renal procurement group and heart and liver groups brought from regional centers. When several surgeons are involved, each must understand the others' goals and needs; this is often facilitated by one member of the team coordinating the center personnel with those in the donor hospital and the various surgeons involved. The only difference between multiple procurement over kidneys alone is the slightly longer operative time and slightly increased cost because of the necessity of anesthesia and blood replacement. Blood replacement has averaged 4 units in adults and 2 units in children in multiple organ procurement. Kidney wastage using these techniques and principles has been minimal. The function of hearts, livers, and kidneys procurred using these principles has been excellent.

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