Extracorporeal Circulation in Liver Transplantation

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Abstract

Extracorporeal circulation has recently expanded outside the realm of the traditional cardiac procedures. Extracorporeal circulation and cardiopulmonary bypass has expanded to include: left and right heart long and short term support, systemic and regional hyperthermic perfusion for cancer therapy, systemic rewarming for hypothermia victims due to exposure, repair of aortic tears and aneurysms, support for respiratory failure, and more recently involvement in support of the surgical process for liver transplantation.

The first orthotopic liver graft was performed by Starzl and colleagues in 1963 at The University of Colorado at Denver. Then in 1982 Starzl began utilizing veno-veno extracorporeal circulation. Veno-arterial bypass has also been utilized in other centers.

Presently, the use of extracorporeal circulation in liver transplantation is being implemented in an increasing number of centers. There have been a wide range of benefits with the use of extracorporeal circulation in liver transplantation. These benefits are the control of the systemic and perihepatic circulation, greater control of volume status through efficient rapid infusion systems and decreased morbidity and mortality. The increased confidence gained by the use of extracorporeal circulation, enables patients to be referred for transplant surgery at an earlier stage, with a more reasonable prospect for a successful surgery.

Introduction

The first orthotopic liver graft was performed by Starzl and colleagues in 1963 at The University of Colorado at Denver. In the time between 1963 to 1980, liver transplantation did not gain acceptance or become established as a therapeutic procedure because the dangers of the surgical procedure appeared to be prohibitive. Cirrhotic patients tended to be referred for surgery in a terminal state with liver failure, portal hypertension, deranged electrolyte balance, renal failure, and toxic myocarditis manifested by hypotension.

In review the liver has a very significant and wide range of functions. These functions include: 1) removes glucose from which it synthesizes glycogen, which it stores; 2) deaminizes amino acids turned into urea; 3) produces proteins such as albumen, prothrombin component and fibrinogen; 4) secretes bile; 5) synthesizes fibrinogen and prothrombin, blood constituents essential for clotting; 6) source of RBCs in the fetus; 7) filters out bacteria; 8) storage for vitamins; 9) regulates blood volume; and 10) important in lipid metabolism.

It was only after a long period of experimentation that extracorporeal circulation for liver transplantation was introduced, in 1982, at Presbyterian University Hospital, Pittsburgh, Pennsylvania. The initial technique was the use of a veno-arterial system. The extracorporeal circuit consisted of a roller pump, cardiotomy reservoir, arterial blood filter, reservoir bag, and heat exchanger. The technique required total systemic heparinization (200Μ/kg).

Pooled blood was returned to the circuit, through suction pump to the cardiotomy reservoir. When extracorporeal circulation was terminated, protamine was given to reverse the heparin. The results obtained included: elimination of pooling, reduction of hypertension in the venous beds, and the preload to the heart remained essentially unchanged. However useful extracorporeal circulation was in the early cases, the advantages were grossly outweighed by the inability to establish normal clotting times which resulted
in unmanagable coagulopathies. Three of the nine patients transplanted using heparinized bypass died in the operating room and only two survived beyond ninety days. Based on these results heparinized bypass was discontinued for use in liver transplantation.

More recently veno-venous bypass was introduced using a Bio-Medicus vortex pump, heparin bonded tubing and heparin bonded cannula. This simple yet effective extracorporeal circuit did not require systemic heparinization. The circuit had all of the circulatory support advantages of the prior veno-arterial circuit; however, it did not require the systemic heparinization. The use of a bypass circuit, and the success rate of liver transplantation using bypass drastically increased.

There are many complications with patients referred for liver transplantation. These complications have directed us to the indications for use of an extracorporeal circuit in orthotopic liver grafting.

The use of heparinless extracorporeal circulation, in most instances, adds a degree of control during the transplant procedure and helps to minimize the complications. These complications during orthotopic liver grafting include:

1) Asystolic pressure below 100 mmHg before induction of anesthesia is serious, and often is an indicator of high morbidity or mortality.

2) Large volumes of cold acidic bank blood, with high serum citrate and potassium levels, impairs myocardial contractility and may cause cardiac arrest.

3) Major ionic fluxes may occur during other stages of the operation. Potassium and hydrogen ions may leak from the liver cells and pass through the still open hepatic veins into the systemic circulation during removal of the patient’s diseased liver.

4) A rapid reduction of venous return to the heart, by more than 50%, may result from clamping the suprahepatic inferior vena cava. This may lead to severe hypotension; additionally, vital organ perfusion is impaired.

5) The cooled donor liver loses the ability to retain intra-cellular potassium and there is a flux of potassium and hydrogen ions into the hepatic vascular tree.

6) The solution used to preserve the liver has a high potassium content.

7) When the portal-venous anastomosis is opened there is a further flow of stagnant potassium rich blood from the splanich circulation. Serum potassium always increases at this time, and this has often resulted in sudden falls in arterial pressure sometime proceeding to asystolic arrest.

The use of extracorporeal circulation achieves a higher degree of control of the above mentioned complications.

The responsibilities of the perfusionist are expanding with the increasing use of extracorporeal circulation in non-traditional, or in other than cardiac procedures. A recent challenge was presented to me and fellow perfusionists in regard to this expanding role: to develop, for the liver transplantation program, an extracorporeal circuit, a rapid infusion device and an autologous blood recovery system. After an extensive literature search, clinical case observations, animal experimentations, and numerous consultations with perfusionists experienced in liver transplantation. A group of systems has been developed for the evolving liver transplant program.

**Extracorporeal Circuit**

The heparin bonded extracorporeal circuit was developed with simplicity and safety in mind.

The circuit used is a custom device, called the Griffith TDMAC Heparinized Veno-Venous Shunt. This circuit is manufactured by Argyle, a division of Sherwood Medical Products.

This circuit consists of one-nine foot long by \( \frac{3}{8} \) section of heparin bonded tubing, with one-7mm gott shunt, and one-9mm gott shunt "Y"ed together at one end, a 7mm gott shunt is attached to the other end. This circuit is completely bonded together (Figure 1).

A Bio-Medicus pump is then placed in the approximate middle of the circuit. A \( \frac{3}{8} \)" disposable flow probe connector is placed approximately 6" distal to the biopump. One \( \frac{3}{8} \)" leur lock connector is placed distal to

![Figure 1](image)

The solution used to preserve the liver has a high potassium content.
the disposable flow connector. The purpose of the leurol lock connector is for the monitoring of line resistance. A standard male to male 4 foot high pressure line is connected to the leurol lock connector and then to a standard sterile pressure monitoring system. This line resistance monitoring will aid the perfusionist when using the resistant dependent pump. The purpose of the pigtail is for priming of the circuit. A standard three-way stopcock is connected to the pigtail. An infusion line is then connected to the stopcock and then to the priming solution. The circuit is then primed (Figure 2).

The extracorporeal circuit would not require the use of any type of systemic or circuit prime heparin. The ability to, and the advantages of, using a Bio-Medicus vortex pump without heparinization has been documented by Dixon and Magovern.2

The 7mm and 9mm gott shunts are cannulated in the portal vein and infra-hepatic inferior vena cava respectively. The 7mm and 9mm limbs represent the inflow segment of the system to the Bio-Medicus pump. The 7mm gott shunt which represents the outflow of the system is then cannulated into the auxiliary vein.

**Rapid Infusion Devices**

Traditionally during liver transplantation surgery, blood loss was great. Blood loss was surpassing the ability of the anesthesia team to maintain the volume replacement. Hypovolemic conditions then progresses, causing hypotension; as a consequence, there was poor perfusion of vital organs.

The rapid infusion device is a circuit which enables the liver transplant team to infuse large amounts of volume to the patient, over a short period of time. The infusion of volume usually occurs through an 8 French angiocath which is placed in the jugular or subclavian vein.

The volume which is infused through the rapid infusion device is usually a combination of packed red blood cells, fresh frozen plasma, and crystalloid solution (this will vary from institution to institution). The large volume infusion over a short period of time helps to maintain normal hemodynamic, and volume status. Volume is usually infused prior to initiation of extracorporeal circulation, during recipient hepatectomy, additionally, extra-volume is infused during and near termination of extracorporeal circulation.

The rapid infusion system (Figure 3) consists of a large filtered reservoir (cardiotomy reservoir), in which all of the volume to be transfused is introduced. Standard 3/8" (ID) extracorporeal tubing is connected to a bio-pump. Distal to the pump, the circuit tubing is connected to a small volume heat exchanger, and through tubing size is reduced to 1/4" ID. A 1/4" temperature probe is placed in line distal to the heat exchanger; additionally, a pediatric arterial filter is installed. Attached to the purge port of the filter, is a three-way stopcock. There are two lines connected to this stopcock. One line is connected to a sterile pressure monitoring system, for monitoring line resistance. The second line is a standard purge line with a one way valve. The purge line via a stopcock is connected to the vented cardiotomy reservoir. The purge line serves three functions; a continuous purge/vent line for the filter while infusing volume to the patient; a recirculation line when clamped distal to the filter (this recirculation helps maintain the perfusate at a normothermic temperature); and a source for a fresh blood sample which can be drawn for electrolyte levels and additional lab testing.

**Autologous Blood Recovery System**

As mentioned earlier, the probability of blood loss during liver transplantation surgery is great. An autologous blood recovery system, to return the patient's own blood loss helps to further reduce the possibility of a hypovolemic condition, and helps reduce the chance of homologous blood transfusions, and transfusion reactions, and probably reduced overall cost.

There are several types of autologous blood recovery systems available today. The autologous blood recovery system which Hemonetics has developed has a history of performing well. The Cell Saver 4 system has the ability to collect, hemoconcentrate, and wash the patient's blood loss in three minutes. This autologous blood is then available to be reinfused to

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Figure 2
the patient through the rapid infusion device, or through a transfusion bag. This extremely short blood processing time, and its ability to process large amounts of blood, makes this system ideal in liver transplantation surgery.

**Conclusion**

To summarize:

1) Extracorporeal circulation enables the surgical team to achieve a higher degree of control of possible high levels of potassium.

2) Blood loss is reduced by recirculation of blood aspirated from the hepatic fossa and surgical site. This helps avoid massive transfusion of banked blood.

3) Bypass maintains an adequate aortic pressure, preserving vital organ perfusion and reducing the strain on the myocardium.

4) The infra-hepatic inferior vena-cava below the liver is decompressed, preventing accumulation of potassium during the period when the cava is clamped.

5) There is a greater control of volume status through efficient rapid infusion systems.

6) Subsequently, there is a decrease in morbidity and mortality. These aforementioned advantages allow patients to be referred for surgery at an earlier stage in their disease process, and with a more reasonable prospect for a successful surgery.

This success can be shared by perfusionists who are interested and willing to apply their experience and knowledge to an area which was previously considered outside their purview. From these opportunities, the perfusion profession will expand, to become a stronger and more versatile force in the health care industry.

The perfusionist's role within the health care community is very specialized—one of traditionally working only with the open heart team, operating the heart-lung machine. From this highly specialized training, other specialties have developed which are applications or require the perfusionists, experience and knowledge. One of these areas is the surgical process of liver transplantation. The desire and ability to per-
form liver transplantation is increasing with the increased number of trained surgeons and the decrease in morbidity and mortality. This decrease in morbidity and mortality can be directly attributed to the use of extracorporeal circulation, rapid infusion devices and autologous blood recovery systems, and perfusionists' willingness to apply themselves.

References


Question from the Audience

Question—Robert Emerson: On your rapid infusion device, I noticed that you said you used a pediatric filter. Have you had any trouble with massive amounts of infused bank blood clotting off?

Answer: At the present we haven't. Something I think everyone should be aware of—we have used the rapid infusion device now clinically in four cases, and to date I have no problems with that at all.