Open technique of performing total cavopulmonary connection on cardiopulmonary bypass

Sachin Talwar, Arindam Choudhary, Niwin George, Amitabh Satsangi, Shiv Kumar Choudhary
Cardiothoracic Centre, All India Institute of Medical Sciences, New Delhi, India

ABSTRACT

A simplified technique of performing the extracardiac Fontan operation on cardiopulmonary bypass is described. The advantages of this technique are briefly discussed.

Keywords: Cardiopulmonary bypass, Fontan operation, univentricular heart

INTRODUCTION

Since its first description by Marcelleti *et al.* in 1990, the extracardiac Fontan[1] (ECF), which is a form of total cavopulmonary connection, is currently the procedure of choice for final palliation in patients with a univentricular heart because it confers many advantages over the other modifications of the traditional Fontan operation.[2-6]

ECF is commonly performed as a staged procedure after a prior bidirectional superior cavopulmonary anastomosis bidirectional Glenn (BDG) and is usually performed while the heart is kept ejecting and beating on cardiopulmonary bypass (CPB) at normothermia. Therefore, aortic cross-clamping and cardioplegic arrest are not needed, and this avoids postoperative ventricular dysfunction and improves early outcomes following the Fontan operation.

Traditionally, the ECF is performed after placing an arterial cannula in the ascending aorta and placing separate venous cannulas in the superior vena cava (SVC) and inferior vena cava (IVC). In the quest to make this operation simpler and free of potential complications, a wide variety of technical modifications[4-6] have been described. The technique described below makes this operation simpler and confers many advantages.

TECHNIQUE

Informed consent was obtained from the parents of all patients. For the description of a surgical technique, a formal ethics committee approval is not needed at our institution, provided that the patient's confidentiality is preserved.

After a usual sternotomy, the aorta is first identified. Before proceeding any further, purse-string sutures are placed on the aorta and the right atrial appendage for initiating CPB in the event of an emergency. The adhesions between the heart and the pericardium are carefully dissected to the safely permissible extent. A double arm suture of 4-0 polypropylene suture with a 1 cm × 1 cm pledget of soft Teflon (Bard Peripheral Inc., Tempe, AZ, US) is placed on the aorta, and both ends of this suture are passed through another pledget, after which the needles are cut, and both ends of this suture are passed through a snugger. When the snugger is pulled up and fixed onto the drapes

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Address for correspondence: Prof. Sachin Talwar, Department of Cardiothoracic and Vascular Surgery, All India Institute of Medical Sciences, New Delhi - 110 029, India.
E-mail: sachintalwar@hotmail.com

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opposite to the side of the previous BDG, the aorta is retracted away, and this provides excellent exposure of the BDG and the pulmonary artery (PA) on the side of the proposed anastomosis of the upper end of the extracardiac conduit [Figure 1a]. The SVC and BDG are identified. However, these are neither dissected extensively nor looped. The PA on the side on which the extracardiac conduit is to be placed is identified, but it is also not dissected. Instead, its junction with the SVC is barely identified, and its lobar branches are neither identified, dissected, nor looped. However, limited dissection is performed toward the side of the aorta, with the dissection extending just behind the aorta.

The IVC is now dissected free of the surrounding structures by sharp dissection avoiding electrocautery. It is verified that it is free from the pericardium on the right and posteriorly and from any tissue on the left and that it is free circumferentially. No purse-string sutures are placed on the IVC, and no loops/snares are passed around it.

Heparin (3–4 mg/Kg) is administered, and after achieving satisfactory activated clotted time, the aorta is cannulated as usual. An angled venous cannula (Dr. Surgical, Bhiwadi, India) that is one size larger than that appropriate for the weight of the patient is placed into the right atrium, and its angle is directed downward [Figure 1a]. Standard normothermic CPB is now established with the heart ejecting. As described above, no purse-string sutures are placed on the SVC and IVC, and no snares are passed around them. During the minimal dissection that may be needed, care is taken to stay away from the pericardial reflection close to the phrenic nerve, especially near the SVC, and the use of electrocautery is avoided.

The distance between the PA and the IVC is now measured, and an expanded polytetrafluoroethylene (e-PTFE) graft of the appropriate length and diameter to match the size of the IVC and the PA is chosen. The end to be placed on the PA is beveled. Two 5-0 polypropylene stay sutures are placed at the junction of the SVC and the PA, one on either side. A small incision is made at the SVC-PA junction, and two pump suckers are placed inside the created opening to direct the blood into the venous reservoir of the CPB circuit. This opening is now extended for 5 mm in the upward direction toward the SVC and then horizontally in the PA. The incision into the PA is extended toward its lobar branches but stops well short of them. On the side of the aorta, it extends up to slightly behind the aorta. All the time, the pump suckers are placed by the assistant into the resultant arteriotomy, and the sump suction is adjusted to keep the field as dry as possible while not increasing it beyond 300–400 ml/min to prevent hemolysis.

This is followed by suturing the upper part of the graft to the PA arteriotomy [Figure 1b]. As a first step, the suturing of the posterior rim of the e-PTFE graft to the lower edge of the PA is completed using a continuous 5-0 polypropylene suture. After the lower suture line is completed, the second assistant places two sump suckers through the graft into the arteriotomy to further improve exposure [Figure 1c]. This maneuver prevents cluttering by the suckers, facilitates exposure, and makes further suturing simpler. After the suturing is completed, both the ends of the suture are tied, the sump suckers are removed, and the graft is clamped using an angled vascular clamp [Figure 2a]. This technique of open anastomosis of the graft toward the PA end is described by us in a prior publication.[7] Following the completion of the graft–PA anastomosis, preparation is begun for the

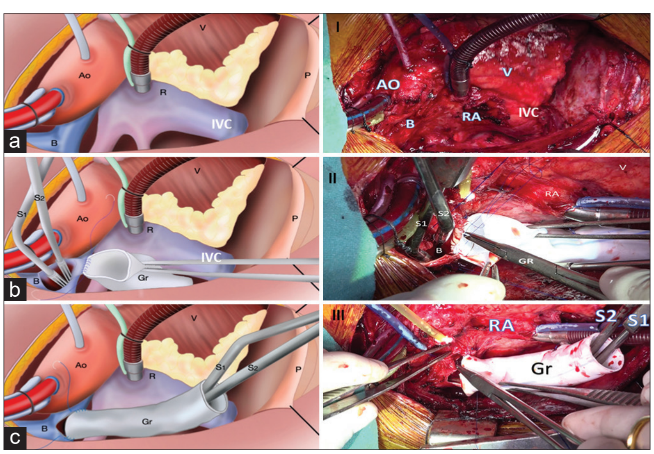

Figure 1: Setting up of cardiopulmonary bypass and its upper anastomosis to the pulmonary artery. (a-c) Line sketch with corresponding intraoperative photographs (I-III) on the right side. A: Aorta, R: Right atrium, B: Prior bidirectional Glenn, V: Right ventricle, P: Pericardium, Gr: Graft, S1 and S2: Sump suckers, IVC: Inferior vena cava

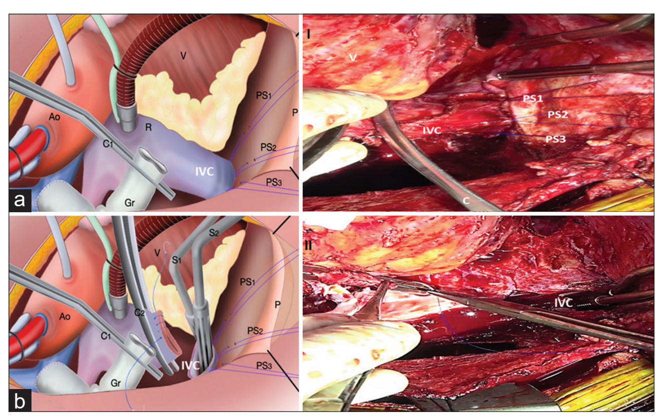

Figure 2: (a and b) Line sketch with corresponding intraoperative photographs (I and II) on the right side. Having completed the anastomosis of the upper end of the graft (Gr) to the pulmonary artery, it is clamped (C1). (a and b): PS1, PS2, PS3 are three stay sutures as described in the text. (a and b). Inferior vena cava (IVC) has been divided and sump suckers (S2, S2) are placed into it. The cardiac end of the IVC is closed after placing a clamp on it (C2). IVC: Inferior vena cava

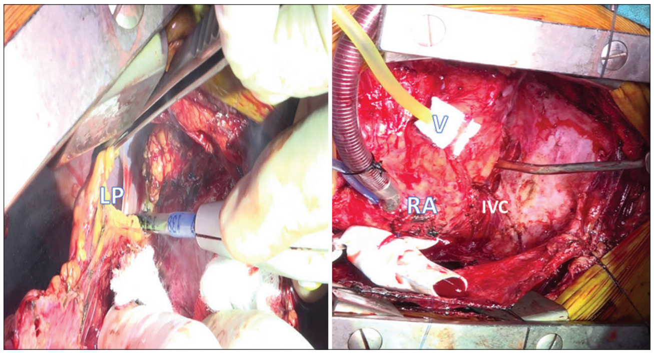

Figure 3: This intraoperative photograph shows the opening of the left pleura to displace the heart into the left pleural cavity. Note the excellent exposure of the inferior vena cava. IVC: Inferior vena cava

anastomosis of the graft to the IVC. Pleura on the opposite side of the IVC is opened widely, and the pericardium on this side is split all the way down to the phrenic nerve, taking care not to injure the nerve. A double arm suture of 4-0 polypropylene is taken; its ends are passed through a 1.5 cm × 1.5 cm felt of hard Teflon. This suture is placed on the crux of the heart; deep bites are taken, and care is taken to avoid the coronary arteries and their branches. This is followed by passing both ends of this suture through a similar pledget. Both the needles of this suture are cut, and both ends of this suture are passed through a long snugger. This snugger is now pulled up toward the 2 o'clock position opposite to the side of the IVC and is fixed to the drapes. This maneuver enables displacement of the heart into the pleural cavity, thereby improving the exposure of the IVC [Figures 2-4]. Three stay sutures [Figure 2a] are placed on the IVC, one on each angle and one in the midline. All of these are passed through the diaphragmatic surface of the pericardium, taking care not to pierce the needles through the liver underlying the diaphragm. When these sutures are pulled toward the foot end of the patient below the sternal retractor and fixed onto the surgical drapes, the opening of the transected IVC toward the diaphragm is pulled upward and becomes completely open and free of any distortion.

A Crawford clamp (Pilling, Morrisville, NC, US) is placed at the cardiac end of the IVC, and it is transected. The cardiac end of the IVC is transected close to the heart, and an adequate margin of the IVC is ensured. This ensures a safe margin for closure of the IVC end and also avoids too much traction and accidental slippage of the clamp.

As the IVC is divided, three pump suckers are selected. Two are placed into the lower end of the IVC [Figure 2b]. One sucker is intermittently placed in the IVC and into the pericardial cavity to provide excellent exposure of the IVC while preventing flooding of the field. It is crucial that the flow through suckers is maintained at a minimum for exposure and well below 300–400 ml/min to avoid hemolysis.

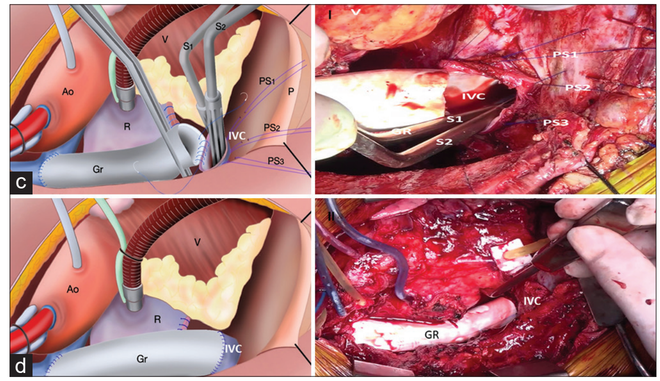

Figure 4: (c and d) A line sketch with corresponding intraoperative photographs (I and II) on the right side. After closing the cardiac end of the inferior vena cava (IVC), the anastomosis of the graft has begun, as shown in (c) on the left and panel a on the right. Note the excellent exposure to the IVC and the clear intraoperative field using sump suckers. The completed Fontan circuit is shown in panels labeled (d). IVC: Inferior vena cava

Once adequate exposure is obtained, the cardiac end of the IVC is closed in two layers, and the Crawford clamp is released. The lower end of the graft is now sutured to the transected lower end of the IVC using a continuous 5-0 polypropylene suture. Suturing is begun from the one angle of the IVC. After passing the needle of the suture inside the IVC opening, the needle exits from the IVC. It is then passed into the posterior pericardium taking bites into it, followed by passing it through the lower end of the graft [Figure 2c]. Once the other angle of the IVC is reached, the needle on the opposite end of the suture is continued anteriorly to complete the anterior suture line between the IVC and the graft.

After the suturing is completed, the graft is deaired, the clamp on the graft is removed, and the ECF procedure is completed [Figure 2d]. The suture line is checked for any bleeding, and hemostasis is achieved. The heart is located back into the pericardial cavity.

The patient is weaned off CPB with minimal inotropic support (commonly dobutamine at 5 micrograms/kg/min). Protamine is usually not administered. Postoperative care is as per standard protocol.

COMMENT

The advantages of this technique are many and are discussed as the advantages of minimal dissection, advantages of excellent exposure, and advantages of avoiding venous purse strings and avoidance of venous cannulation.

One of the major advantages of this technique is the need for minimal dissection of the SVC, IVC, and PAs. The PAs are very thin in patients with reduced pulmonary blood flow,[8] and it is possible to damage them even after utmost care has been exercised; placement of sutures to control the resultant bleeding is not desirable because of the narrowing at the site of suture placement as no distortion or narrowing of the PA is the essence of a good Fontan circuit.[9]

Another major advantage of this technique is the avoidance of any dissection in the area around the SVC. This prevents any electro-diathermy-induced injury to the phrenic nerve. It is well known that preservation of the respiratory mechanics is crucial for the optimal functioning of the Fontan circuit. Paresis or paralysis of the phrenic nerve may compromise the respiratory mechanism, which increases the risk of suboptimal function of the circuit. An impaired function of the Fontan circuit is known to prolong the duration of the pleural effusion, which further compromises the Fontan pathway.[10,11] Therefore, a situation results where concomitant occurrence of an effusion further compromises the Fontan circuit and this further increases the amount of pleural effusion and so on. The open technique that avoids dissection in the area of the phrenic nerve may, therefore, minimize these problems.

The Fontan circulation is a low-pressure circuit in contrast to the systemic arterial circuit.[9] The threshold at which optimal hemodynamic patterns result is very low. Therefore, to ensure optimal flow in the Fontan circuit, any distortion of the venous circuit must be avoided. The placement of purse-string sutures on the SVC and IVC needs to be accurate with a very low margin of error; the slightest error results in a gradient at the site of purse-string placement. This technique eliminates these.

The need to mobilize the IVC lower down toward the abdomen is avoided; this is otherwise needed when cannulation of the IVC is planned. If a purse string suture is placed lower down into the IVC and a snugger is tightened around the IVC canula, the IVC opening is puckered, once the IVC is divided, and this makes the anastomosis of the graft to the IVC technically difficult because the space is occupied by the venous cannula into the IVC. The technique of open anastomosis at either end prevents any anastomotic distortion, particularly at the lower end toward the IVC as the IVC end is open with stay sutures as described above. Any bleeding that occurs from the graft-IVC anastomosis is easier to manage with minimal distortion as the IVC dissection has been minimal without any cannula in it.

To address these issues, many groups advocate femoral vein cannulation using a long venous cannula followed by CPB for an open IVC anastomosis.[12] However, it is important that the venous system in patients undergoing the creation of the Fontan circulation be handled minimally. In some patients, femoral vein obstruction due to cannulation and its subsequent repair may occur. The incidence of peripheral thromboembolic phenomena is also higher in patients who are deeply cyanotic,[13] and peripheral venous thrombi as a result of the gradient at the peripheral venous cannulation site may extend into IVC and are not desirable.

As has been described above in the surgical technique, while performing the graft to IVC anastomosis, the posterior sutures of the anastomosis are placed into the IVC and graft along with the pericardial reflection, thus making the suture line secure and ensuring hemostasis.

In our earlier publication on the open technique of performing the superior caval end of the graft to PA anastomosis,[7] we stressed upon the advantages of the open SVC-PA anastomosis. In a subsequently undergoing study, the results of the latter technique on Doppler studies have been encouraging, and extrapolating this technique to performing the Fontan procedure on CPB, we now use only the open technique on CPB if patients do not require an intracardiac procedure.

Attempts to improve the exposure at both the SVC-PA anastomosis and the IVC end have been previously described, often using total circulatory arrest.[14] The group from Philadelphia.[15] have popularized the Fontan operation under CPB and aortic cross-clamping with total circulatory arrest in 132 out of 160 patients (83%). They have reported excellent results and stressed the importance of deep hypothermic circulatory arrest in providing excellent exposure, avoidance of any distortion, and avoiding anastomosis-related problems. However, deep hypothermia and circulatory arrest are not benign, and avoiding it may be beneficial.[16,17] In addition, deep hypothermia requires a longer CPB during cooling and rewarming. The longer CPB time may lead to more inflammation and more activation of the complement cascade[17] which may compromise pulmonary function and respiratory dynamics that may further adversely affect the Fontan circuit.[9]

We additionally believe that by not snugging the IVC and venous cannula, hepatic venous congestion may be minimized which may lead to better hepatic function. However, we do not have any data to support this observation.

At our institution, 70 patients have undergone completion of Fontan (ECF) on CPB since 2017 by a single surgical team. In patients in whom where CPB support is used, we have now transitioned to using the open technique in the last 47 (67%) patients. In the aorto-bicaval technique, the CPB time was 67.5 ± 23.2 (median 68) min. In contrast, in the open technique, it was 85.9 ± 28.3 (median 81) min, indicating acceptable prolongation of the bypass time with the open technique, and this has been gradually reducing with our increasing experience. We have not encountered any technical challenges so far using this technique. We have consistently noted that the need for the placement of sutures for hemostasis at the lower end of the anastomosis has been minimized, particularly if inadvertent IVC injury occurs in a cluttered space while performing the operation with IVC cannulation. We have not encountered any gradient at the SVC and IVC ends, and a continuous laminar flow has been observed through the graft on transesophageal echocardiography in all patients. None of the patients developed phrenic nerve palsy, and bleeding/anastomotic distortions.

One of the pitfalls of this technique is that often, extra assistance is required to prevent the obscuring of the operating field by the blood filling into it. This has to be combined with enhancing the flows on the sump suckers. In the event of prolonged CPB time and increased sump suction, hemolysis can result. We have obviated this problem by using three instead of two sump suckers and ensuring that the flow through them does not exceed 300–400 ml/min; hence, we have not observed any major hemolysis.

We conclude that this alternative technique of performing the ECF is safe and reliable and may minimize many problems that may occur with the traditional techniques of ECF. However, more comparative studies are needed to further demonstrate whether it is superior to traditional techniques. At our center, a randomized comparative study of the traditional technique of performing the completion Fontan with aorta bicaval versus the technique described above is in progress, and detailed results are awaited.

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Conflicts of interest

There are no conflicts of interest.

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