Left Ventricular Assistance Without Thoracotomy: Mediastinal and Transseptal Approaches to the Left Heart

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Two methods to cannulate the left atrium for initiating mechanical left ventricular circulatory assistance using a centrifugal pump were investigated in 25 sheep. A modified Dennis transatrial septal approach produced flow rates of 88.6 ± 14 mL · kg⁻¹ · min⁻¹ through 21F catheters inserted during fluoroscopy through the jugular vein. In 8 animals the septal perforation was plugged after decannulation with a modified Rashkind umbrella plug. Fibroendothelial tissue covered the plug by 4 weeks. In 7 other animals, the septal defect was not plugged. The septal defect reached pinpoint size by 2 weeks and was completely closed by 4 weeks. In 10 sheep, the left atrium was cannulated from the neck through the mediastinum. Left ventricular assistance flow averaged 71.6 ± 14 mL · kg⁻¹ · min⁻¹. Mean blood loss during 1 hour of left ventricular assistance was 47 mL. In 8 animals, the atrial perforation was plugged with a mean blood loss of 253 ± 194 mL. In 2 animals, the perforation was intentionally not plugged; mean blood loss was 700 mL. All animals survived. The modified Dennis transatrial method is recommended as a safe, expedient, cost-effective method to implement left ventricular assistance without thoracotomy. The mediastinal approach, which is technically possible in humans, is more difficult but feasible. Left ventricular assistance has been proven to be the most effective way to rest the failing, ejecting left ventricle. Implementation without thoracotomy potentially expands applications of left ventricular assistance for temporary support of patients with severe manifestations of ischemic heart disease.


Many causes of acute heart failure are reversible if the injured ventricle can be temporarily supported and adequate circulation maintained [1-9]. Although venoarterial bypass is easily and quickly implemented using peripheral cannulas [10-12], this bypass system does not adequately decompress the left heart [13, 14]. In 1960, Salisbury and associates [15] showed that left ventricular bypass was superior to venoarterial bypass for left ventricular failure. More recently, Bavaria and co-workers [16] demonstrated that venoarterial bypass actually increases wall stress in postischemic, failing hearts. In contrast, Ratcliffe and colleagues [17] have shown that left atrial to arterial bypass decreases circumferential wall stress, dramatically reduces end-systolic volume, and increases preload recruitable stroke work in the poorly contracting postischemic ventricle.

The need for thoracotomy is the primary disadvantage of temporary mechanical left ventricular circulatory assistance. In 1961, Dennis, Senning and colleagues [18, 19] blindly cannulated the left atrium in dogs and 7 patients from the jugular vein using a rigid metal cannula. Glassman and colleagues [20] revived this technique in 1975 using a long, flexible 26F catheter inserted from the femoral vein across the atrial septum in animals and 3 patients. There were no human survivors in either series.

Carlens [21] developed mediastinoscopy for staging lung carcinoma. From this approach, left atrial blood samples can be aspirated. In 1985, Seremitis [22] cannulated the left atrium of dogs from the mediastinum, and devised a double-balloon catheter to implement left heart bypass. However, he did not develop a means to decannulate, and this method has not been used clinically.

This study was designed to develop an expeditious, clinically applicable method to establish mechanical left ventricular assistance (LVA) without thoracotomy using the transseptal and mediastinal approaches.

Material and Methods

In pilot studies, techniques for cannulating the left atrium from the mediastinum and right internal jugular vein in sheep were developed (Fig 1). Human cadaver dissections were performed to confirm the feasibility of cannulating the left atrium from the mediastinum. A modified Rashkind patent ductus plug [23] was developed for closing left atrial puncture sites. Finally, animal studies were made to evaluate these cannulation and decannulation techniques and to determine maximal flow.

Twenty-five Dorsett sheep (38.0 ± 9.2 kg) were divided
into three groups. Group 1 (n = 10) animals were placed on LVA by the mediastinal approach. In group 2 (n = 8) sheep were placed on LVA by transseptal cannulation from the right jugular vein. The septum was closed with a Rashkind plug when the catheter was withdrawn. In group 3 (n = 7), the interatrial puncture site was not closed after decannulation.

All animals were premedicated with gentamycin (1.5 mg/kg intramuscularly), penicillin (600,000 U intramuscularly) and glycopyrrolate (0.4 mg intravenously). Anesthesia was induced with thiopental sodium (25 mg/kg), and the animals were intubated in the supine position. Anesthesia was maintained with isoflurane inhalation (0.8% to 1.5%) during mechanical ventilation (Drager AV; Drager, Teleford, PA). The electrocardiogram and arterial pressure were monitored (BD Electrodyne ST419; Becton-Dickson, Sharon, MA). A fluoroscope (Mobile Fluoricon; General Electric, Milwaukee, WI) was placed in a cross-table lateral position. The necks were prepared and draped using sterile technique.

**Group 1**

A mediastinoscope was inserted along the pretracheal plane to the tracheal bifurcation (Fig 1). Tilting the scope upward at the tracheal bifurcation revealed the posterior wall of the left atrium. Before proceeding, the following structures were identified: (1) the right pulmonary veins entering the left atrium, (2) the pulmonary artery closely applied to the cranial edge of the left atrium with its right branches crossing over the trachea, and (3) the more proximal impression of the aorta. Under direct vision, a 31-cm, 16-gauge needle (BD-Yale, Rutherford, NJ) with a slightly curved tip was inserted into the posterior left atrium and bright red blood was withdrawn. After lidocaine bolus (3 mg/kg) and heparin (200 U/kg) bolus injection, a J-tip wire 3 mm in diameter and 150 cm in
An introducer was advanced over the wire into the left atrium or ventricle. A 30-cm, 16F cannula (Medtronic-Biomedicus) was inserted into the right carotid artery.

Cannulas were connected to an LVA circuit consisting of 1/2-inch venous and 3/8-inch arterial polyvinyl tubing and a centrifugal flow pump (Medtronic-Biomedicus) with a built-in precalibrated electromagnetic flowmeter. The system was primed with 400 mL of hetastarch (Hespan; DuPont Pharmaceuticals, Wilmington, DE). Left ventricular assist was begun for 1 hour at the maximal flow rate attainable at less than 4,500 rpm. A long flexible suction catheter was placed in the mediastinum to monitor blood loss. Activated clotting time was maintained at greater than 350 seconds.

At the time of decannulation, heparin was fully reversed with protamine. An introducer was advanced down the venous cannula under fluoroscopy and the modified Rashkind plug was deployed immediately outside the cannula within the left atrium (Fig 2). The Rashkind plug device was custom manufactured by Medtronics Inc. When folded, this device fit in a cannula with a 20F inner diameter. Unfolded, it had a strut diameter of 1.5 cm, with a total plug diameter of 1.8 cm. Full specifications are given in Appendix 1. Withdrawal of the cannula/introducer complex left the plug across the atrial puncture site. Manual tension was maintained until a long absorbable suture attached to the device was fixed to the trachea. The flexible mediastinal catheter was left in place until bleeding ceased. After bleeding stopped, the wound was irrigated and closed in layers. The awake animal was sent to the recovery room.

Group 2

In 8 animals, a 5-cm longitudinal sterile incision was made in the right side of the neck. Through a stab in the right internal jugular vein, a J wire was advanced under fluoroscopy into the inferior vena cava. A slightly curved 31-cm, 16-gauge needle (BD-Yale) with a rubber covering sheath was advanced along the wire into the inferior vena cava. Injection of 15 mL of 50% diatrizoate meglumine (Hypaque-76; Winthrop Pharmaceuticals, New York, NY) delineated the cavitral junction and the limbs. With the tip exposed and pointing directly posterior, the needle/sheath complex was slowly withdrawn. As the needle rode over the ridge of the limbus it “dropped” posteriorly (see Fig 1). At this point it was pushed across the septum. Fifteen milliliters of contrast medium were injected to confirm entrance into the left atrium. The J wire was inserted through the needle, and the 21F venous catheter and stylet were advanced across the septum, into the atrium, and if desired, into the left ventricle. The animal was connected to the LVA circuit as for group 1. After 1 hour, the animal was decannulated with the modified Rashkind plug device deployed in the left atrium. The device stay suture was brought out through the right jugular vein and attached to the nearby strap muscles.

Group 3

Seven animals were treated identically to group 2, but the septal defect was not closed.

All animals were killed at intervals, and careful postmortem examination was performed. Attention was paid to device location and coverage, and to signs of pericardial effusion or mediastinitis. The kidneys were finely sectioned for evidence of arterial emboli.

In 5 fresh sheep hearts, the intraatrial septum was punctured with the 21F cannula and stylet. The size and shape of the resulting defect were measured.

M numbers define pressure-flow relationships of catheters that vary in size and design [24]. Low M numbers describe catheters with high flows per unit pressure difference [24]. The M numbers of 19F and 21F venous catheters (Medtronic-Biomedicus) were measured in a water bath using a centrifugal pump. Flows were manually recorded with five timed 1-L collections at 10 different pump inlet pressures ranging from 0 to -100 mm Hg.

Results

Human cadaver dissections (Fig 3) demonstrated that cannulation of the superior wall of the left atrium is feasible in the human. During mediastinoscopy, a long 18-gauge straight needle enters the left atrium when passed over the origin of the left main bronchus–tracheal junction posterior to the left pulmonary artery, which is elevated anteriorly by the dissection and mediastinoscope.

Group 1 (Mediastinal)

All 10 animals were readily cannulated without complication. The venous cannula was placed in the left atrium in 4 animals and in the left ventricle in 6. Flow summaries are shown in Table 1. In 9 animals, there was less than 30 mL blood loss during the 1 hour of LVA. The tenth animal lost 200 mL of blood but completed the hour. Eight animals were decannulated and had the atrial defect plugged. The mean blood loss with this maneuver was 253 ± 194 mL. In the 2 animals without plugs, the mean loss was 700 mL.
Flow rates during LVA are summarized in Table 1. Plugs were well situated and covered with fibrous tissue at 2 weeks and a complete fibrous coating at 3 hours to 8 weeks. Autopsies showed the plug covered with granulation tissue at 2 weeks and a complete fibrous coating at 4 weeks (Fig 4). Postmortem examination showed no evidence of tamponade, pericarditis, or endocardial or valve injury. In those animals without plugs, the defect was a pinpoint by 2 weeks and was completely healed by 4 weeks (see Fig 4). No animal had evidence of systemic emboli in kidney sections.

The animals placed on LVA by the transseptal approach had a slightly higher mean flow than the mediastinal group (88.6 ± 14 versus 71.6 ± 14 mL · kg⁻¹ · min⁻¹, p = 0.014). There was no significant difference in flow between those with catheters in the left atrium and those with catheters in the left ventricle (p = 0.194).

In five fresh cadaveric sheep hearts, the 21F catheter (7.1 mm) left a slit-like opening in the muscular septum after removal that measured 1.8 ± 0.2 × 5.2 ± 0.8 mm.

Flow characteristics of the two sample catheters are shown in Figure 5. The calculated M numbers were 2.67 and 2.81 for 21F and 19F venous cannulas, respectively.

Comment

Left ventricular assistance rests the ejecting heart. No other mechanical circulatory assist system moves blood and also reduces the work of the heart [17]. However, the need for thoracotomy has largely limited clinical applications of LVA to postcardiotomy patients and those who are bridged to transplantation by modified versions of the artificial heart. Expanded applications require a method to implement LVA expeditiously and safely without thoracotomy. The dramatic physiologic benefits of LVA in the ejecting failing heart compel greater efforts to broaden clinical use.

Zwart and associates [26] introduced transaortic LVA in 1966. The recently introduced Nimbus Hemopump (Nimbus Medical, Inc, Rancho Cordova, CA) also aspirates blood from an intraventricular catheter and ejects it into the ascending and descending aorta. The pump itself resides within the aorta and is driven by a transarterial and transcutaneous cable and external motor. This novel device may achieve wide clinical application, but currently it has several limitations. The intraaortic screw pump is pressure sensitive and flow decreases as pressure rises [27]. Cable torque and reliability are problems with the pump operating at high speeds [27, 28]. Insertion of the 7-mm-diameter pump and stiff catheter requires access to the aorta or a large artery [27–29]. Injury to the aortic valve, induction of arrhythmias, and perforation of the ventricle, particularly if a fresh infarct is present, are also important concerns.

Modernization of the Dennis technique provides a safe, expeditious means to implement LVA. We recommend the cervical approach, which permits insertion of shorter, larger-diameter catheters than the femoral approach. From the neck, the angle of entry into the left atrium is less acute and may allow better flow. The catheter can also be easily advanced into the left ventricle if desired. The catheters used in this study are substantially smaller (21F versus 26F) than those used by Glassman and co-workers [20] but still attained excellent flow without excessive pump speed (always less than 4,500 rpm). Catheter flow is influenced by the ratio of catheter to vessel diameters [30] and the flow characteristics of the catheter as indicated by the M number [24]. The cervical approach using
the Medtronic-Biomedicus catheter permits high flow and creates small interatrial punctures.

The Dennis transseptal method requires fluoroscopy, but it uses existing technology and equipment and requires less expertise than a balloon mitral valvuloplasty. The LVA system is readily available in hospitals that perform catheterizations and open heart operations, and does not require additional personnel to operate. The centrifugal pump is reliable and has low heparin requirements. The availability of a plug to close the septal perforation is a backup option for patients who do not tolerate temporary left-to-right shunts. Experience with balloon mitral valvuloplasty suggests that few patients will need plugs [31, 32].

The mediastinal approach is less attractive than the transseptal method but may occasionally be used for special circumstances. General anesthesia is required, and the operator must be thoroughly familiar with mediastinoscopy. Perhaps owing to catheter positioning, this technique achieves slightly lower flows than the transseptal method in sheep. Plugging the hole after decannulation is mandatory but not difficult.

Several exciting potential applications of LVA are introduced by the avoidance of thoracotomy. In patients with cardiogenic shock after acute myocardial infarction [6], LVA can stabilize the circulation, unload the left ventricle, and prevent ischemic damage to other organs while thrombolysis, cardiac catheterization, angioplasty, or emergency revascularization is performed [33-35]. There is evidence that LVA may actually reduce the size of the infarct [36-39], and by resting the ejecting ventricle, LVA may prevent infarct expansion or new ischemia in the distribution of a second partially obstructed coronary artery [40]. By maintaining ventricular ejection, LVA reduces the possibility of intraventricular clot. Acute infarctions cause severe dysfunction in adjacent, nonischemic myocardium [41] by a poorly understood mechanism that may be related to stretch injury and myocardial creep.

*Fig 4. (a, b) Septal puncture sites (arrows) from the right atrium at 2 and 4 weeks, respectively. (c, d) Defect with Rashkind plug in place at 2 and 4 weeks from left atrium. (FO = foramen ovale; IVC = inferior vena cava; SVC = superior vena cava.)

*Fig 5. Flow characteristics of 19F and 21F Medtronic–Biomedicus venous catheters at varying inlet pressures.*
Left ventricular assistance may accelerate recovery from both myocardial creep and reversible ischemia or stunning. Finally, by reducing ventricular end-diastolic and end-systolic volumes and regional wall stresses, LVA may favorably alter ventricular remodeling and prevent ventricular rupture and aneurysm formation after acute infarction. Although the efficacy of LVA in these latter applications remains to be demonstrated, avoidance of thoracotomy and the inherent simplicity, safety, and cost-effectiveness of the technique provide new opportunities to preserve myocardial mass and function in patients with severe manifestations of ischemic heart disease.

Supported by grant HL 36308 from the National Heart, Lung, and Blood Institute of the National Institutes of Health.

We thank Joel Perloff and Nick Gikakis for their technical expertise and help.

References


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Appendix 1

The umbrella frame is manufactured of 0.010 304v stainless steel wire. It is attached to a 130-cm No. 1 polyglactin suture (Ethicon, Somerville, NJ). This is secured with 40 polypropylene (Ethicon). The 1.2-mm-thick, 1.8-cm-diameter foam disc is composed of TDI-based polyether polyurethane slabstock foam 2.5 lb/ft³ with ILD 25 lb at 25% deflection. It is coated on its interior surface with Estane 83A polyether polyurethane (B.F. Goodrich). It differs from the Rashkind plug [23] in that it has four struts instead of three, and the foam is coated to render it impermeable for acute hemostasis in potentially coagulopathic settings. It is also attached to an absorbable traction suture to maintain positioning until healing occurs.

The introducer is designed to reach the tip of the catheter and to release the preloaded plug by advancing a wire stylet. It fits down a 19F (inner diameter) or larger catheter.