A transapical-to-aorta double lumen cannula-based neonate left ventricular assist device efficiently unloads the left ventricle in neonate lambs

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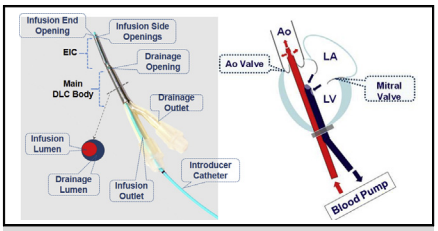
ABSTRACT

Objective: We are developing a transapical-to-aorta double lumen cannula (TAA DLC) for a less-invasive/more dependable neonatal left ventricular assist device.

Methods: The 18-Fr TAA DLC prototypes were bench tested and evaluated for 6 hours in neonate lambs (n = 6, 7.7-10 kg). The cardiac apex was exposed through a left anterolateral thoracotomy through the sixth intercostal space. The TAA DLC was inserted through a mattress stitch on apex, passing LV-aortic valve, into the ascending aorta with insertion/deployment guided by pressure waveform. The DLC was connected to blood pump. Cardiac output and aortic root blood flow were measured with perivascular flow sensors. Activated clotting time was maintained at 180-250 seconds.

Results: The DLC pumped up to 1.8 L/min flow against 63 mm Hg drainage pressure and 145 mm Hg infusion pressure in bench testing. In all lambs, the DLC was inserted/deployed properly within 1 minute on the first attempt. Pumping flow was maintained at 1.2-1.3 L/min. Systolic arterial pressure decreased and diastolic arterial pressure/mean arterial pressure increased, indicating decreased afterload and increased perfusion pressure. Left ventricular end-diastolic pressure decreased from 13 ± 1 mm Hg to 6 ± 2 mm Hg, indicating decreased preload. Aortic root backward flow was 2.4% ± 0.6% without DLC and 3.5% ± 0.8% of cardiac output with DLC, indicating no significant DLC-induced aortic valve regurgitation. After 6 hours, free hemoglobin was <5 mg/dL with hemoglobin/platelets unchanged. No significant thrombus was found in pumps/DLCs. No trauma was found in LV, aortic valve, and aorta.

Conclusions: Our TAA DLC-based neonate left ventricular assist device efficiently unloaded the LV in lambs. (J Thorac Cardiovasc Surg 2016;■:1-8)



Transapical-to-aorta double lumen cannula inserted from apex into left ventricle-aorta for a less-invasive and more reliable left ventricular assist device.

Central Message

A transapical-to-aorta double lumen cannula-based neonate left ventricular assist device is easily implanted and efficiently unloads the left ventricle in neonate lambs.

Perspective

Pediatric pump installation in neonates is challenging. Our transapical-to-aorta double lumen cannula for less-invasive/more dependable neonatal left ventricular assist device is inserted from apex though left ventricle (LV)-aortic valve into the ascending aorta. Coupled with a blood pump, the double lumen cannula withdraws blood from the LV and delivers blood into the aorta, unloading the LV. This transapical-to-aorta double lumen cannula-based neonate left ventricular assist device efficiently unloaded the LV in neonate lambs.

CONG

Left ventricular assist devices (LVADs) have been applied successfully in adult patients with heart failure. However, the application of LVAD in neonates is limited by the very few choices of LVADs specific for the neonate patient.

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Abbreviations and Acronyms

ABP = arterial blood pressure
CO = cardiac output
DLC = double lumen cannula
ECMO = extracorporeal membrane oxygenation
EIC = extension infusion cannula
LVAD = left ventricular assist device
LV = left ventricle
mABP = mean arterial blood pressure
PA = pulmonary artery
TAA = transapical to aorta
VA = venoarterial
VAD = ventricular assist device

Venoarterial extracorporeal membrane oxygenation (VA ECMO) is the most common technology for mechanical circulatory support in neonates, providing biventricular support and total gas exchange.[1] However, VA ECMO (1) is complicated and bulky, requiring high-level anticoagulation; (2) requires continuous sedation or even paralysis with intubation/mechanical ventilation; and (3) occasionally does not fully unload the left ventricle (LV). By contrast, a LVAD circuit lacks a gas exchanger, reduces trauma to blood elements, and decreases the need for anticoagulation. The EXCOR (Berlin Heart GmbH, Berlin, Germany) is the only ventricular assist device (VAD) approved by the Food and Drug Administration available for neonates on the market.[2-5]

Several new pediatric VAD pumps designed for infants and neonates are under development (Jarvik child/infant VAD, PediPump, and PediaFlow).[6-9] Although these pumps are very small, it is still challenging to implant them into the small neonate body.[10-12] The neonate's mediastinal cavity is very small and easily leads to conduit kinking/heart compression, which may prevent chest closure. The neonate's open chest requires continuous sedation/anesthesia and is associated with a greater incidence of bleeding/infection, which makes extubation, mobilization, and oral feeding impossible. Furthermore, LVAD implantation in neonates requires sternotomy and cardiopulmonary bypass, which is very invasive. A less-invasive neonate LVAD is needed to avoid sternotomy and cardiopulmonary bypass, allowing chest closure/extubation, eliminating deep sedation requirement, and enabling oral feeding.

Our approach to the development of a neonate LVAD is to use a DLC for 1-site transapical-to-aorta (TAA) cannulation. This double lumen cannula (DLC)-based LVAD will withdraw blood from the LV and deliver it to the aorta, unloading the LV. Compared with the aforementioned implantable LVADs, our DLC-based neonate LVAD omits the outlet graft. This DLC is also much smaller than a traditional LVAD inlet cannula, distinguishing our system by its easy/less-invasive installation and theoretically reliable performance. In this study, we developed a TAA DLC and tested the prototype in neonate lamb. Our result shows easy, less-invasive implantation, reliable 6 hours in vivo performance, and minimal blood trauma.

METHODS AND MATERIALS

Design and Fabrication

The TAA DLC consisted of a main DLC body and an extension infusion cannula (EIC, Figure 1, *A*). The round-shaped membrane infusion lumen was internally tangent to outer wall of main DLC body, with one end connected to EIC and the other end connected to the infusion connector. The drainage lumen was the crescent-shaped space between the infusion lumen and the outer wall of main DLC body. The drainage opening was located at the junction between the main DLC body and the EIC. When the TAA DLC was deployed properly, the EIC end was in the ascending aorta for blood delivery and the drainage end opening was in LV for blood drainage, thereby unloading LV (Figure 1, *B*). Side openings were designed in the EIC to guarantee coronary perfusion (Figure 1, *A*).

The size of the main DLC body was 18 Fr and the EIC was 13 Fr. The whole DLC was made by one-piece molding. The DLC body outer wall and the EIC was polyurethane copolymer with flat, stainless-steel wire reinforcement to prevent kinking and drainage lumen collapse. The introducer was a single-lumen PVC catheter (450 mm length and 3 mm OD), fitting DLC infusion lumen with very smooth transition on the EIC end opening. The introducer catheter tip pressure can be measured continuously through the catheter lumen opening on the tip. This pressure waveform helped to identify the introducer catheter tip location for accurate catheter insertion and deployment, preventing catheter misplacement into the left atrium and subsequent left atrium penetration. The introducer catheter tip was made blunt to avoid heart injury.

Bench Test of TAA DLC Prototype

A bench test was performed for TAA DLC performance. The mock circuit included a CentriMag pump (Thoratec, Pleasanton, Calif), 18-Fr TAA DLC prototype, and Tygon connection tubing (US Plastic Corp, Lima, Ohio). A room temperature 37% glycerin solution was used in the circuit to mimic blood viscosity. The DLC outlet and inlet pressures were measured with a hemodynamic monitor (MP-50; Philips Medical Systems, Boeblingen, Germany). Circuit flow was measured with an ultrasonic tubing flow meter (HT110; Transonic, Ithaca, NY). A pressure-flow curve was generated to characterize DLC performance.

In Vivo Neonate Lamb Evaluation

Neonate lamb preparation. All studies in animals were approved by the University of Kentucky Institutional Animal Care and Use Committee and were conducted in accordance with the Principles of Laboratory Animal Care (National Society of Medical Research) and the "Guide for the Care and Use of Laboratory Animals" (National Institutes of Health publication no. 86-23, revised 1996).

The TAA DLC prototype-based LVAD system was tested in 6 cross-breed neonate lambs (7.7-10 kg, 13-20 days). These neonate lambs were not yet weaned and relied exclusively on mother's milk feeding. After morning feeding, the neonate lamb was immediately transferred from sheep farm to our laboratory for TAA DLC-based LVAD investigation.

Anesthesia and instrumentation. After anesthesia induction with ketamine (7 mg/kg) and diazepam (0.5 mg/kg), all sheep were intubated and connected to the anesthesia machine (Narkomed 2B; DRAGER, Telford, Penn). Anesthesia was maintained with 1% to 3% isoflurane, titrating a normal range of heart rate and arterial blood