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SPECIAL ISSUE ARTICLE

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Transport of extremely low birth weight neonates for persistent ductus arteriosus closure in the catheterization lab

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Objective: The objective of this article is to describe the elements involved with transporting extremely low birth weight (ELBW) infants from referring centers to our center's neonatal intensive care unit (NICU) and then from the NICU to the catheterization lab for transcatheter closure of patent ductus arteriosus (PDA).

Setting: Several referring centers are over 300 miles away. ELBW infants are transferred in to our NICU safely for the procedure and transferred back following the procedure. A multidisciplinary team approach is necessary in order to achieve a safe transport of these fragile patients.

Patients: To date, we have over 12 centers referring patients that weigh <1000 g for transcatheter PDA closure (TCPC). Three of these centers are over 300 miles away. Five other centers are between 100 and 300 miles from the hospital in which we perform TCPC.

Interventions: Fixed-wing aircrafts are necessary for long-distance transfers. Various modes of mechanical ventilators including transport oscillators are built into temperature- and humidity-controlled incubators in which these infants are transported. Ambulances are used to take the patient between the airport and the hospital. Shorter distance transports are accomplished via helicopters or ambulances. Transfer from the NICU to the catheterization lab to perform TCPC is a relatively easier endeavor.

Outcome Measures: Patients' body temperature, fluid balance, and hemodynamics have to be maintained throughout the transport and the procedure for best outcomes.

Results: There has been 100% procedural success of performing TCPC in ELBW infants with no hemodynamic compromise during transport.

Conclusions: TCPC has shown promise in improving overall patient outcomes that the potential hazards associated with complex transport measures are worth it. Successful transfer to and from referring centers and to and from the catheterization lab can be accomplished safely with increasing institutional experience.

KEYWORDS
anesthesia, cath lab, ELBW, PDA, transport

1 | INTRODUCTION

Transcatheter device closure of patent ductus arteriosus (PDA) in the catheterization lab[1-3] (Figure 1), versus bedside surgical closure of PDAs[4,5] in extremely low birth weight (ELBW) neonates is being performed with increasing frequency at our institution. However, for device closure, patients must be transported from the neonatal intensive care unit (NICU) to the catheterization lab, and back to the NICU.[6] Transport of these fragile patients poses certain challenges, and involves not only anesthesia providers, but catheterization lab, and NICU providers as well.

Before going into the details of the transport from within the hospital from the NICU to the catheterization lab, it must be emphasized that we get ELBW infants transferred from various other NICUs in the region and beyond. To date, we have referrals from 12 different NICUs for transcatheter PDA closures (TCPCs). Three such centers have transported children less than 1 kg from over 300 miles away (Figure 2), and three other centers are between 100 and 300 miles away. Therefore, when ELBW newborns could be safely transferred from such long distances, sometimes on transport oscillators, or other forms of mechanical ventilators, transferring them from the NICU to the catheterization lab for the procedure is a relatively easier task.

2 | LONG-DISTANCE TRANSFERS (>300 MILES) OF ELBW INFANTS

Long-distance consults are performed using our telemedicine service. Once it is agreed that an ELBW infant will benefit from TCPC, arrangements are made. Insurance details are first worked out. Typically, these patients are critically ill. Most require high frequency oscillator ventilation (HFOV) or other forms of mechanical ventilator support. Helicopters are not ideal for such transports. A fixed-wing aircraft in therefore preferred. The transport aircraft is staffed by a neonatology nurse practitioner/physician, a respiratory therapist, paramedics, transport specialists, and the flight crew. The transport incubators are equipped with inbuilt heating/humidifying systems. Different types of mechanical ventilators and oxygen cylinders are built into the incubator transport equipment including HFOV. The appropriate ventilator is used for transport. Facilities to have continuous hemodynamic monitoring are inbuilt. A blood gas and electrolyte analyzer is available. Provisions to provide inotropic support and blood product transfusion are possible. Resuscitation medications and equipment are onboard as well. Patients on extracorporeal membrane oxygenators or other assist devices can also be transported in this manner. However, ELBW infants are not candidates for such assist devices. Therefore, we do not have to discuss these details in this section.

These fixed-wing aircrafts fly out of and land in small regional air strips where the air traffic is not busy. The ELBW patient will have to be transferred by ambulance from the referring hospital NICU to the regional airport. The patient will then have to be moved from the ambulance to the aircraft. The aircraft can again only land in small, regional airports. Our transport ambulance is waiting to receive the patient from the aircraft to transfer to our NICU (Figure 3A). Because the runways of these smaller airfields are shorter than most airport runways, these fixed-wing aircrafts are only allowed to carry a limited load. Heavier aircrafts require longer runways which is not feasible. Therefore, the number of personnel and equipment is rationed. This is quite an undertaking. We have been successfully transporting patients for TCPC this way for the past 2 years. Typically, the procedure is performed the day after they transfer in. The patient is typically transferred back to the referring center a day after the procedure. The back transfer happens pretty much the same manner in the reverse direction.

FIGURE 1 Transcatheter PDA closure in a 900-g infant being performed in the catheterization lab using fluoroscopy and echocardiography

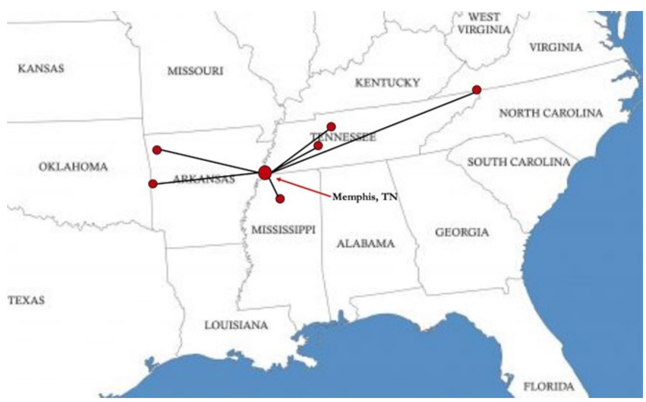

FIGURE 2 Map of the southeast United States showing the location of the centers that transfer ELBW infants over 100 miles to Memphis, TN for transcatheter PDA closure. The infant is transferred back to the referring center typically within 24-48 hours after the procedure

FIGURE 3 A, A fixed-wing aircraft that transferred a 700 g, extremely premature infant over 300 miles to a nearby air strip to LeBonheur Children's Hospital, Memphis, Tennessee, with the hospital ambulance waiting to receive the patient to be transferred to the hospital NICU. B, The relatively easy endeavor of transporting the same patient from the NICU to the catheterization lab for transcatheter PDA closure

3 | TRANSFER OF ELBW INFANTS FROM CENTERS <300 MILES

The transport ambulance is the primary transport vehicle for any child less than 1 kg within the 100 miles radius. Centers that are between 100 and 300 miles consider transport by helicopters or ambulance depending on the weather and the critical nature of the patient's clinical condition. The principles of the transfer are the same. Once the patient reaches the NICU, a multidisciplinary evaluation is performed. Planning for the transfer from the NICU to the catheterization lab for the procedure is then undertaken as detailed below.

4 | PREPARATION

Prior to transport, discussion with various team members is necessary for a safe journey to and from the lab. Conversation between the anesthesia provider(s) and the NICU team may include discussion regarding existing vascular access or difficulties with obtaining adequate access for the procedure, fluid selection, respiratory, and electrolyte or hemodynamic concerns. Information obtained from the catheterization lab team includes planned site of procedural access, and any anticipated difficulties and potential complications. The anesthesia team for these procedures at our institution is comprised of an anesthesiologist, and a certified registered nurse anesthetist. An anesthetic plan (ventilation, analgesia, anesthesia, contingencies) is formulated, and team members are in agreement prior to transport.

5 | CONSIDERATIONS

5.1 | Temperature

Due to a high surface area to body weight ratio, and low body fat percentage, ELBW neonates are at significant risk of hypothermia and its consequences (impaired wound healing, coagulopathy). To prevent heat loss during transport, our NICU neonates are transported in their Giraffe Isolette (GE Healthcare, Chicago, Illinois). Isolettes offer the ability to provide active warming and temperature monitoring. In addition, the lid can be closed completely, providing protection from a cold environment. The cumbersome nature of the isolette does add a degree of difficulty to transport.

5.2 | Ventilation

Neonates for PDA closure usually have an endotracheal tube (ETT) already in situ, but on occasion are not intubated at the time of transport. Whether to secure the airway in the NICU prior to transport, or intubate in the lab is normally decided at least 24 hours prior to the procedure, and requires a discussion among the anesthesiologist, cath lab physician, and NICU physician.

Frequently, some of these ELBW neonates require HFOV. Typically, in this scenario, we would attempt a trail of conventional mechanical ventilation a day prior to the procedure. Capillary blood gas analysis is performed prior to the trial and every half hour into the trial. If a child tolerates the trial for at least 2 hours without having a 20 torr increase in the capillary CO_2, then we would proceed with the procedure the following day, and switch the patient to a conventional mechanical ventilator a few minutes prior to the transport.

Due to their extremely small size (frequently <1000 g), this patient population is at risk of either accidental extubation or mainstemming with minute movements in or out of the ETT. Simply flexing or extending the head, as may occur when moving from the isolette to the table, can have a significant effect on the ETT position.

Pulmonary overcirculation from a PDA, in addition to an immature pulmonary system, can make ventilation of the extremely premature neonate challenging. Ventilation strategies must also take into account the effect fractional inspired oxygen concentration (FiO_2), carbon dioxide, and acidosis/alkalosis have on the shunt magnitude across the PDA, and thus the degree of pulmonary overcirculation. Our ventilation mode of choice for transport is the NeoPuff (Fisher & Paykel Healthcare, Auckland, New Zealand). The NeoPuff is easy to set up, has few moving parts, and provides simple to manageable control over FiO_2, inspiratory pressure, and positive end expiratory pressure. The anesthesia provider ventilating the patient has independent control over the respiratory rate.

6 | MONITORING AND BACKUP EQUIPMENT

All patients are transported with monitoring of oxygen saturation, blood pressure, and EKG. Backup equipment includes, but is not limited to: supplemental oxygen source, extra pulse oximiter, intubating equipment (laryngoscope blade and handle, ETTs), airway adjuncts (oral airway), and ventilating adjuncts (self-inflating ambu bag, Jackson-Reese circuit; Medline Industries, Northline, Illinois).

7 | MEDICATIONS

Secondary to an immature sympathetic system, premature neonates are at risk of bradycardia, especially in the setting of hypoxia. Even mild hypoxia can result in significant bradycardia. We therefore normally, prior to transport, pretreat these patients with atropine.

Muscle relaxants (ie, rocuronium) are routinely used to: ease ventilation, help prevent accidental extubation due to a moving patient, and provide optimum operating conditions. Benzodiazepines (midazolam) and opiods (fentanyl) are employed to achieve sedation and analgesia.

8 | ROLES DURING TRANSPORT

The provider to patient ratio is high, and has been as high as 6:1. Roles during transport include: (a) Ventilator—their ONLY responsibility is to ventilate the patient; (b) Navigator—responsible for clearing the hallway, directing, opening doors, and calling the elevators; and (c) Movers—the ones actually pushing the isolette.

9 | IN THE CATH LAB

On arrival to the catheterization lab, the next task is to transfer the patient from the isolette to the lab table while avoiding hypothermia, accidental extubation, losing any in situ vascular access or feeding tubes, and physical injury. Injury can occur as simply as when a cable or iv tubing still connected to the neonate becomes trapped and transfer of the patient continues.

Once on the table, transfer to the OR ventilator/monitors, and patient positioning/padding ensues. These tasks are performed by multiple providers on a very small child, increasing the potential for mistakes and patient harm. Once everything previously mentioned has been completed, the actual procedure can begin.

10 | POSTPROCEDURE TRANSPORT BACK TO NICU OR THE REFERRING CENTER

Do it all again in reverse!

11 | DISCUSSION

When we first started to perform TCPCs in ELBW infants at our center, there were considerations to perform this procedure at the patient's bedside in the NICU.[7,8] The perils of transporting these extremely fragile patients form the NICU to the catheterization lab was unknown. The risks associated with moving the patient out of their safe environment into hostile surroundings was unknown. With increasing experience, we figured out how to safely accomplish this task. The advantages to performing TCPC in the catheterization lab over the bedside in the NICU are multifold. The operator is more comfortable in the catheterization lab which houses multiple equipment that may aid in case a procedural complication is encountered. For example, if a device used for TCPC embolizes or causes obstruction of the pulmonary artery branch, it can be safely and easily snared and retrieved in the catheterization lab. This bail out technique may be impossible at the patient's bedside. The fluoroscopic equipment in the catheterization lab is far superior to any portable fluoroscopic system. Optimal imaging is paramount while performing TCPC. Since TCPC involves no direct visualization of the PDA, the operator is dependent on fluoroscopic and echocardiographic imaging.[9-12] All this equipment occupies a large space. The patient's room can get packed with no safe space left to monitor or resuscitate the patient if an emergency arises. For all these reasons, we believe that the catheterization lab is the best location to perform TCPC in ELBW infants. If it is possible to safely transfer these patients over long distances, the transfer to from the NICU to the catheterization lab is a relatively easy and worthwhile endeavor (Figure 3A,B).

TCPC has shown promise in improving overall patient outcomes that the potential hazards associated with complex transport measures seem to be worth it. A multidisciplinary team approach is necessary in order to achieve a safe transport of these extremely small and fragile patients. Successful transfer to and from referring centers and to and from the catheterization lab can be accomplished safely with increasing institutional experience.

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CONFLICT OF INTEREST

We have no conflicts of interest to disclose.

AUTHOR CONTRIBUTIONS

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REFERENCES

1. Abu Hazeem AA, Gillespie MJ, Thun H, et al. Percutaneous closure of patent ductus arteriosus in small infants with significant lung disease may offer faster recovery of respiratory function when compared to surgical ligation. *Catheter Cardiovasc Interv*. 2013;82(4):526-533.
2. Francis E, Singhi AK, Lakshmivenkateshaiah S, Kumar RK. Transcatheter occlusion of patent ductus arteriosus in pre-term infants. *JACC Cardiovasc Interv*. 2010;3(5):550-555.
3. Narin N, Pamukcu O, Baykan A, Sunkak S, Ulgey A, Uzum K. Percutaneous PDA closure in extremely low birth weight babies. *J Interv Cardiol*. 2016;29(6):654-660.
4. Koehne PS, Bein G, Alexi-Meskhishvili V, Weng Y, Bührer C, Obladen M. Patent ductus arteriosus in very low birthweight infants: complications of pharmacological and surgical treatment. *J Perinat Med*. 2001;29(4):327-334.
5. Mikhail M, Lee W, Toews W, et al. Surgical and medical experience with 734 premature infants with patient ductus arteriosus. *J Thorac Cardiovasc Surg*. 1982;83(3):349-357.
6. Zahn EM, Nevin P, Simmons C, Garg R. A novel technique for transcatheter patent ductus arteriosus closure in extremely preterm infants using commercially available technology. *Catheter Cardiovasc Interv*. 2015;85(2):240-248.
7. Bentham J, Meur S, Hudsmith L, Archer N, Wilson N. Echocardiographically guided catheter closure of arterial ducts in small preterm infants on the neonatal intensive care unit. *Catheter Cardiovasc Interv*. 2011;77(3):409-415.
8. Zahn EM, Peck D, Phillips A, et al. Transcatheter closure of patent ductus arteriosus in extremely premature newborns: early results and midterm follow-up. *JACC Cardiovasc Interv*. 2016;9(23):2429-2437.
9. Philip R, Rush Waller B, Agrawal V, et al. Morphologic characterization of the patent ductus arteriosus in the premature infant and the choice of transcatheter occlusion device. *Catheter Cardiovasc Interv*. 2016;87(2):310-317.
10. Sathanandam S, Justino H, Waller BR, Radtke W, Qureshi AM. Initial clinical experience with the Medtronic Micro Vascular Plug™ in transcatheter occlusion of PDAs in extremely premature infants. *Catheter Cardiovasc Interv*. 2017;89(6):1051-1058.
11. Paudel G, Philip R, Zurakowski D, et al. Echocardiographic guidance for trans-catheter device closure of patent ductus arteriosus in extremely low birth weight infants. *J Am Coll Cardiol*. 2018;71(11):A576.
12. Sathanandam S, Balduf K, Chilakala S, et al. Role of transcatheter patent ductus arteriosus closure in extremely low birth weight infants. *Catheter Cardiovasc Interv*. 2018.

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