Simulation and Deliberate Practice in a Porcine Model for Congenital Heart Surgery Training

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Background. **Surgeons in training for congenital cardiac surgery face considerable challenges owing to procedure complexity, closely scrutinized outcomes, and a steep learning curve. Simulation methods have been initiated in other surgical specialties, but have yet to be established for congenital cardiac surgery trainees. The purpose of this study was to assess high-fidelity simulation as a method to train and improve skills of resident trainees learning critical components of index congenital cardiac surgical procedures.**

Methods. **Using 5 neonatal piglets over a period of 2.5 days, the following procedures were simulated: Norwood procedure, arterial switch operation, neonatal Ross procedure, tetralogy of Fallot repair, systemic to pulmonary artery shunt procedures, transmediastinal coarctation repair, atrial septal defect repair, ventricular septal defect repair, and right ventricular to pulmonary artery conduit. Anastomoses were tested with saline, all procedures were timed and video recorded, and resident trainee techniques and skills were critiqued by the instructor.**

Results. **All aspects of the procedures were simulated with minimal modifications. Anastomoses were tested, and the procedure successfully replicated without the pressures of operative time. Operative techniques involving suture placement in neonatal tissue, depth perception, and patch size estimation were corrected in real time, resulting in observed improvement of surgical skills. Video review allowed for further pedagogic value through examination and documentation of competency.**

Conclusions. **This neonatal porcine simulation model allows surgical trainees in congenital heart surgery to make and correct mistakes in a safe and controlled learning environment without compromising patient safety, thereby fostering surgeon competence and confidence.**

(Ann Thorac Surg 2017;■:■–■)

The current training paradigm in congenital heart surgery has been described as a fellowship followed by a long-term apprenticeship to become conversant with some of the more technically demanding aspects of the field. In a recent poll, graduating congenital heart surgery fellows did not feel adequately prepared to perform certain technically demanding operations as the primary surgeon [1]. The aging congenital heart surgeon population [2] combined with a cadre of young surgeons who do not feel ready to assume a fully autonomous surgical role [3] presents the possibility of an impending crisis as experienced surgeons exit the workforce without a sufficiently competent cohort to replace them.

There are numerous reasons for the recent difficulties that fellowship graduates have had in assuming an autonomous role. Increased scrutiny of outcomes from local and national organizations combined with a more educated population has made it even more important to maintain the best possible outcomes. Because outcomes in congenital heart surgery have been repeatedly demonstrated to be proportional to surgical volume [4], there is a paradox. One must have experience to obtain good outcomes. For congenital heart surgeons at the beginning of their careers, this paradox represents a significant impediment to skill development and limits the number of surgeons who feel comfortable with complex procedures.

Simulation in many medical fields has provided a method to improve technical and decision-making skills through the apprenticeship model [5, 6], but has only recently been proposed in cardiac surgery [7] and has not yet been established in congenital heart surgery. Simulation provides the opportunity to practice certain key maneuvers inherent to these procedures and allows for more efficient training of congenital heart surgery residents, as well as decreases the time necessary for trainees and mentors to feel comfortable during the training

Accepted for publication Oct 2, 2017.

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Published by Elsevier Inc.

0003-4975/$36.00
https://doi.org/10.1016/j.athoracsur.2017.10.011

process, leading to a better trained workforce. Furthermore, simulation may reduce the risks inherent in complex congenital operations while creating a better curriculum for congenital heart surgery fellows [7].

The purpose of this study is to introduce a freshly sacrificed neonatal porcine model for simulation and deliberate practice [8, 9] of congenital heart operations because the neonatal piglet's cardiovascular anatomy bears a striking resemblance to that of a neonatal human [10]. Operations amenable to simulation and deliberate practice in this model include the Norwood operation, arterial switch operation, ventricular septal defect and atrial septal defect closure, Ross operation, systemic to pulmonary artery shunt procedures, tricuspid valve repair, transmediastinal coarctectomy and extended end-to-end anastomosis, right ventricular to pulmonary artery conduit placement, tetralogy of Fallot repair, and transventricular modified Konno operation, among others. Using appropriate planning, all of these operations can be simulated in 5 neonatal piglets.

Material and Methods

All procedures were performed in the Florida Hospital Nicholson Center, Orlando, Florida, over a 2.5-day period under the supervision of veterinary professionals. The protocol was approved by the Florida Hospital Institutional Animal Care and Use Committee. Neonatal piglets weighing between 2.6 kg and 4.2 kg were humanely sacrificed immediately before the procedures. After sternotomy and sternal retraction, the pericardium was suspended. Three important exposure maneuvers were completed: (1) complete thymus resection; (2) right atrial appendage retraction; and (3) inferior pulmonary annulus retraction using pledgeted mattress sutures. The trainee was a postgraduate fourth-year cardiothoracic surgical resident with no prior congenital heart surgery experience, considerably less experienced than a congenital heart surgeon trainee. The instructor was a professor of surgery and academic congenital heart surgeon with more than 35 years of experience. An experienced scrub nurse was an integral part of the three-member operative team. All procedures were recorded using both fixed and wearable high-definition video cameras.

Piglet 1: Norwood Operation

The essential techniques of the Norwood operation were performed including neoaortic arch reconstruction, pulmonary artery and aorta amalgamation, main pulmonary artery isolation, and restrictive pulmonary artery flow performed by a right ventricular to pulmonary artery conduit (Sano shunt). Great vessel dissection, mobilization, and control were accomplished in the same way as would be in a human. The piglet has a common brachiocephalic artery and a left subclavian artery, but the remainder of anatomic landmarks are quite similar to humans. The aorta in this model was not hypoplastic, and although there was a well-formed ductus arteriosus, there was no coarctation. Consequently, this simulated Norwood operation amalgamated the normal sized aorta and pulmonary artery. To simulate regional perfusion techniques, the brachiocephalic artery was prepared for end-to-side anastomosis of a polytetrafluoroethylene graft (Fig 1).

The pulmonary artery was transected and isolated by patch arterioplasty. The descending aortic dissection was also analogous, as were the courses of the recurrent laryngeal nerve and spinal arteries. The longitudinal aortotomy was performed across the transverse arch and ascending aorta to the level of the aortic valve commissures. CardioCel (Admedus, Malaga, Australia) pericardial patch was used for neoaortic reconstruction (Fig 2). The systemic to pulmonary artery connection was performed using a Sano shunt (Fig 3).

Piglet 1: Ventricular Septal Defect/Atrial Septal Defect Closure, Tricuspid Valve Repair, and Mitral Valve Exposure

The Norwood simulation involved mostly the great vessels leaving the endocardial structures of piglet 1 to remain available for continued simulation such as closure of ventricular septal defect/atrial septal defect, tricuspid valve repair, and mitral valve exposure. A medial right atriotomy was performed as it would be in a human, recognizing delicate atrial tissue. The atrial septum was excised to create an atrial septal defect, and the resulting defect was closed using running suture technique and patch material. A ventricular septal defect was created using a coronary punch; however, the irregular muscular margins and fragile incised myocardium made closing the defect difficult. The approach was modified by closing a simulated ventricular septal defect. Doing so allowed for an appreciation of the anatomic relationships and a realistic simulation of suture placement required for effective closure. The tricuspid valve of the piglet is analogous to that of a human; however, the leaflets were quite thin, preventing primary leaflet work owing to the

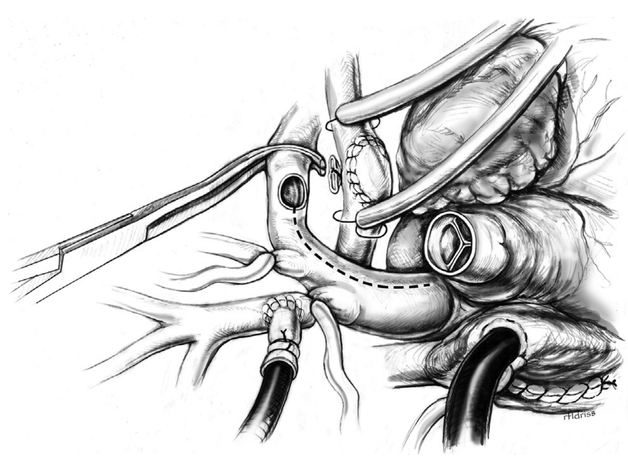

Fig 1. Neonatal piglet model simulating regional perfusion with snuggers engaged at the proximal brachiocephalic arteries and distal aortic clamp. Noted also are the transected pulmonary artery, distal pulmonary artery patch isolation, ductus arteriosus resection, and proposed (dashed line) aortic incisions for the neoaortic reconstruction.