Journal of Cardiothoracic and Vascular Anesthesia 33 (2019) 1828–1834

Contents lists available at ScienceDirect

Journal of Cardiothoracic and Vascular Anesthesia

journal homepage: www.jcvaonline.com

Review Article

Fellowship Training in Pediatric Cardiac Anesthesia: History, Maturation, and Current Status

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Pediatric cardiac anesthesia as a discipline has evolved over the years to become a well recognized sub-specialty. Education and training in the field has also continued to change and develop. In this review, the author outline the changes in the field over the years and suggest a structure for an organized fellowship training process.

Key Words: pediatric cardiac anesthesia; fellowship; training; history; congenital heart disease

CONGENITAL HEART DISEASE (CHD) is the most frequent congenital disorder in neonates and occurs in 8 per 1000 live births. With technical advancements and medical and surgical interventions, the survival of these patients has improved substantially leading to an increase in the prevalence of all patients with CHD from neonates to adults.[1] The subspecialty of pediatric cardiac anesthesia began in concert with the early history of congenital heart surgery. Most knowledge regarding cardiopulmonary bypass (CPB) management, invasive hemodynamic monitoring, cardiovascular physiology, and pharmacology evolved through years of collaborative work between cardiac surgeons and anesthesiologists caring for children with CHD.[2] However, over the years, pediatric cardiac anesthesia experienced significant evolution and growth and now has emerged as a distinct field requiring specialized study (Fig 1).

Anesthesiologists caring for both pediatric patients and adults with CHD require a high level of expert knowledge. These practitioners need a solid foundation in congenital cardiac anatomy and pathophysiology; knowledge of standard and innovative surgical techniques; current catheter-based interventions; and the perioperative anesthetic management of neonates, infants, and children undergoing procedures with and without CPB. What is less clear is how to provide comprehensive and consistent training for those who wish to acquire this knowledge. Initially, training for pediatric cardiac anesthesiologists was not well delineated. When pediatric cardiac surgery programs first emerged, most were combined with more well-established adult cardiac programs, leading adult cardiac anesthesiologists to seek additional training in the realm of pediatric anesthesiology and CHD. Today, freestanding children's centers and university hospitals that provide high-level pediatric care have reversed this model, necessitating that pediatric anesthesiologists acquire training in the realm of cardiac anesthesia.

In this article, the authors describe the history and evolution of the subspecialty of pediatric cardiac anesthesia. The authors chronicle training in pediatric cardiac anesthesia, compare it to other disciplines, and describe the current status. They summarize the recommended milestones indicative of consultant-level knowledge in congenital cardiac anesthesia and propose an example of a 1-year training curriculum with case numbers. Lastly, the

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https://doi.org/10.1053/j.jvca.2018.08.016
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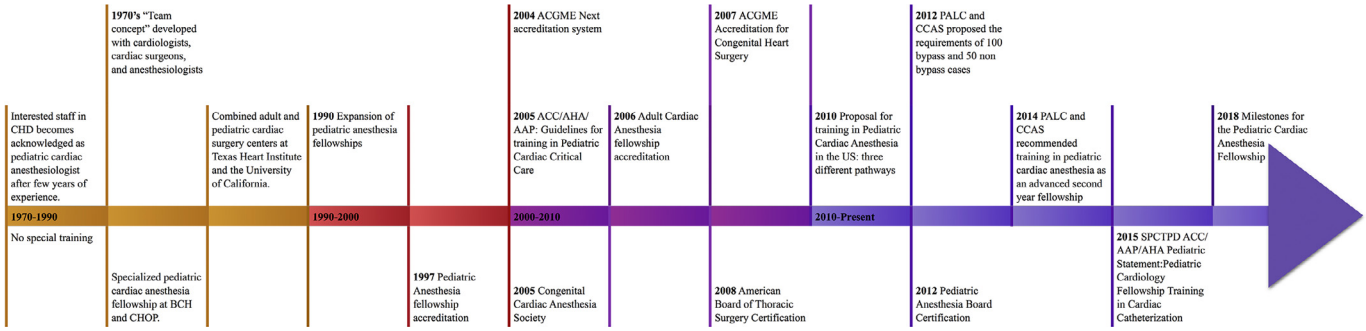

Fig 1. Timeline of major events or landmarks during the advancement of the pediatric cardiac anesthesia fellowship. CHD, congenital heart disease; BCH, Boston Children's Hospital; CHOP, Children's Hospital of Pennsylvania; ACGME, Accreditation of Graduate Medical Education; ACC, American College of Cardiology; AHA, American Heart Association; AAP, American Academy of Pediatrics; US, United States; PALC, Pediatric Anesthesia Leadership Council; CCAS, Congenital Cardiac Anesthesia Society; SPCTPD, Society of Pediatric Cardiology Training Program Directors.

authors present views on how to establish a uniform educational and training experience for individuals seeking to practice congenital cardiac anesthesia, and a proposal for future steps in the development of training and education for the specialty.

The Evolution of the CCAS and Its Educational Role

The Congenital Cardiac Anesthesia Society (CCAS) was founded on October 19, 2005, by key leaders in the field who recognized the rapid advancement of highly specialized knowledge, the substantial increase in the number of patients with congenital heart disease (CHD) presenting for surgery, and the need to provide coherent education and training.[3] Its mission statement is "to improve the perioperative care and outcomes, and facilitate technological advances in therapy for newborns, infants, children and adults with congenital heart disease requiring anesthesia." Embedded within this mission is the necessity to train anesthesiologists proficient in the management of children and adults with CHD undergoing cardiac and noncardiac procedures through consistent and standardized clinical and educational programs. From its inception, the CCAS has strived to accomplish this goal, encouraging the inclusion and participation of its membership, especially of fellows in training (Fig 2). In addition to the annual meeting, the CCAS website offers extensive educational content, including weekly questions, echocardiography tutorials, and an archive of pertinent lectures. CCAS has assembled task forces of experts to set standards for education and training and establish performance metrics within the field.

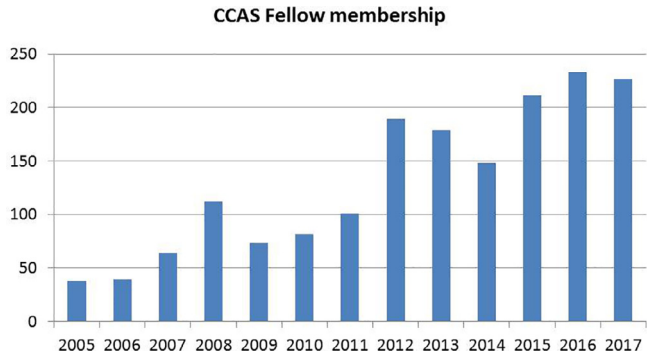

Fig 2. The number of fellows, members of the CCAS from 2005 to 2017. CCAS, Congenital Cardiac Anesthesia Society.

Despite the small number of pediatric cardiac anesthesia fellows trained in North America, the demand for specialists in the field continues to grow. In 2017, the CCAS and the Pediatric Anesthesia Leadership Council (PALC) surveyed 37 centers to determine the available fellowship training positions and number of graduating fellows. There were 24 available positions from 17 programs offering a 1-year fellowship, with 14 pediatric cardiac anesthesia fellows graduating in 2017 (Andropoulos DB, personal communication). The authors reviewed their respective centers as representatives of subspecialty training in pediatric cardiac anesthesia to identify the number of positions filled, the background and pathway of trainees, and the disposition of graduating fellows (Table 1).

Training and Education in Other Congenital Cardiac Specialties

Most congenital cardiac specialties follow a formalized postgraduate curriculum in CHD. This was influenced heavily by the historic Bristol Report, a formal assessment by the British secretary of state into the poor outcomes after complex cardiac surgery at the Bristol Royal Infirmary from 1984 to 1995. The report cited a significantly higher mortality rate in neonates and infants compared to other centers during that time.[4] An analysis into the report led to numerous recommendations, including that children must be cared for in a child-centered hospital environment by staff trained in caring for children and in facilities appropriate to their need, and that consultants in pediatric cardiac care undergo appraisal, continued professional development, and revalidation to keep their skills and knowledge competent and up to date.[5]

Training in pediatric cardiology has the longest and most well-established pathway of all pediatric cardiac specialties. For more than 25 years, the training path has required a 3-year Accreditation Council for Graduate Medical Education (ACGME) fellowship in pediatric cardiology after completion of a 3-year residency in general pediatrics. Board certification through the American Board of Pediatrics is required.[6] Recent advances in training include standardized curriculums, accreditation, and certification for competency testing in the

Table 1
Pediatric Cardiac Anesthesia Fellowship: A 5-Year Snapshot 2012 to 2017

Institution	5-Y Total Number of Fellows/Positions	Background Prior to Training	Work After Fellowship
Boston Children's Hospital	18/15	PA (11) 61% AC (5) 28% PA + PCC (2) 11%	PC ± PCC (8) 45% PA + PC (5) 27% AC + PC (5) 27%
Children's Health Care of Atlanta/Emory University	5/5	PA (5) 100%	PC (1) 20% PA + PC (3) 60% AC (1) 20%
Texas Children's Hospital	7/15	PA (5) 72% PA + PCC (2) 28%	PC ± PCC (5) 72% PA + PC (2) 28%

Abbreviations: AC, adult cardiac anesthesia; PA, pediatric anesthesia; PC, pediatric cardiac anesthesia; PCC, pediatric critical care.

subspecialties of pediatric cardiology, including electrophysiology, interventional cardiology, echocardiography, and imaging.[7] The most important components are the availability of strong mentorship and the standardization of educational curriculum and milestones as a path to competency.[8]

In 2003, the Congenital Heart Disease Committee of the European Association for Cardio-Thoracic Surgery prepared a document outlining the optimal, not minimal, structure of congenital heart surgery as a subdiscipline throughout Europe.[9] They proposed subspecialty certification through the European Board of Thoracic and Cardiovascular Surgeons with recertification every 8 years and institutional certification of hospitals offering pediatric cardiac surgical procedures through the European Cardiovascular and Thoracic Surgery Institute of Accreditation. In the United States, similar standards also were created. In 2007, congenital heart surgery became a recognized fellowship by the ACGME and, for the first time in 2008, an established subspecialty board certification through the American Board of Thoracic Surgery was offered. Eligibility for certification requires 12 consecutive months of subspecialty training in congenital heart surgery after satisfactory completion of thoracic surgery training in an ACGME-approved program. Within the training, a minimum of 75 major congenital cardiac operations, including 32 specific qualifying cases, are required. A survey review of 38 operative logs from graduates of accredited fellowship programs showed a median of 136 total cases a year with 63 qualifying cases, well above the proposed minimum.[10] The first written examination in congenital heart surgery was given in 2009 and the first oral examination in 2010.[11] Despite a robust structure, ACGME accreditation, and subspecialty board certification, 43% of graduating fellows feel their fellowship was too short. Furthermore, 40% of the fellows feel they are provided inadequate mentorship at the start of their career. Based on the survey results, the authors proposed the creation of a 1- to 2-year transitional junior faculty period with strong mentorship to follow the 1 year ACGME fellowship.[12]

Pediatric cardiac critical care is another related subspecialty going through significant evolution and change to standardize training pathways. Currently, there is significant variability worldwide in the training background of providers, potentially contributing to differences in approaches in the perioperative care and consequently the outcomes of children with CHD.[13,14] The Pediatric Cardiac Intensive Care Society is in the process of establishing specific guidelines for training and education for both physicians and advanced practice nurses, with the ambitious goal of accreditation through the ACGME and eventually a board certification process.[15]

History and Current Pathways of Pediatric Cardiac Anesthesia Training

Training in pediatric cardiac anesthesiology has developed over the past 50 years. Worldwide, several countries made efforts to understand and establish pathways for training in pediatric cardiac anesthesia. In the United States, in 1970s and 1980s, anesthesiologists interested in practicing pediatric cardiac anesthesia would spend additional months during residency or as a staff member gaining experience in anesthesia care for these patients. Only a few children's hospitals, such as Boston Children's Hospital and Children's Hospital of Philadelphia, provided an optional nonstandardized fellowship experience. Other institutions, such as Texas Heart Institute, provided a mix of adult and pediatric cardiac training. However, as congenital cardiology and cardiac surgery training continued to evolve, the need for dedicated pediatric cardiac anesthesiologists also grew, and establishing a more standardized pathway with guidelines for training became necessary.

Initially, multiple different training pathways for pediatric cardiac anesthesia emerged.[16-18] By 2010, there were 8 programs in the United States offering advanced pediatric cardiac anesthesia training with a variable duration ranging from 3 to 12 months. Other programs also offered various options, for example, a combined fellowship/staff position for 1 year. In 2010, DiNardo et al. sought to establish some degree of standardization by proposing 2 distinct training pathways: one included 9 months of core training in pediatric cardiac anesthesia after completion of a 12-month pediatric anesthesia or adult cardiothoracic anesthesia fellowship; the second included 18 months of combined training in both pediatric anesthesia and pediatric cardiac anesthesia.[16] Unlike congenital cardiac surgery, the problem with establishing training guidelines for pediatric cardiac anesthesia is that there is no evidence in the literature to support that the duration of training or number of cases affects the competency of the trainee or the clinical outcomes of patients. On the other hand, the 2003 Report of the Paediatric and Congenital Cardiac Services Review Group in Great Britain agreed that anesthetists involved in pediatric and congenital cardiac surgery should, like the surgeons and

cardiologists, set minimum standards in training and experience.[5] In 2014, as the number of programs continued to increase in the United States, PALC along with CCAS recommended a second-year advanced fellowship, consisting of 12 additional months of training in pediatric cardiac anesthesia, after successful completion of either a pediatric or adult cardiothoracic anesthesia fellowship.[19,20]

In Canada, 12 months of training is the frequently stated training period without specifications of caseload or numbers.[21] In the United Kingdom, White et al. conducted a survey aimed at defining the length of training and caseload in various pediatric cardiac anesthesia programs. Sixty-seven questionnaires were sent out with a 49% response rate.[17] The majority of anesthesiologists spent at least 2 years training with 12 months in general pediatric anesthesia, 6 months in adult cardiac anesthesia, 6 months in pediatric intensive care, and 6 months in pediatric cardiac anesthesia. However, with the current time constraint on working hours and decrease in caseloads, the authors suggested that the Royal College of Anaesthetists clearly define the requirements and standards for training in pediatric cardiac anesthesia to ensure expertise. Similarly, a working group representing the German Society of Anesthesiology and Intensive Care surveyed all pediatric cardiac centers in Germany to assess the status of training in pediatric cardiac anesthesia.[18] The authors found that the most common length of training was 12 months in 42.3% of centers with a mean of 10.8 months to achieve sufficient experience.[22] By personal communication, training in pediatric cardiac anesthesia in Italy consists of an additional 6 to 12 months of exposure to patients with CHD after the 5 years of anesthesiology residency. In the Middle East, at the American University of Beirut Medical Center, an additional 6 to 12 months of cardiac anesthesia training, including both pediatric and adult, is offered for interested residents after graduation.

Proposal for Pediatric Cardiac Anesthesia Training

Different learners with disparate knowledge or experience backgrounds progress at different rates, and the time needed by a trainee to achieve competence may vary.[23,24] Based on this concept and the ACGME Milestones model, an expert panel of the CCAS recommended 18 competency-based developmental milestones for a pediatric cardiac anesthesia fellowship.[25-27] These 18 milestones cover all 6 core competencies of the ACGME, including patient care, medical knowledge, systems-based practice, practice-based learning and improvement, professionalism, and interpersonal and communication skills with a targeted duration of 12 months (Table 2). The intent is that each program uses the described milestones to develop consistent educational objectives and a curriculum specific to its institution. In this way, trainees are exposed to a large variety of patients with CHD of all ages and attend or participate in a variety of didactic sessions, but with common objectives designed to establish expertise in pediatric cardiac anesthesiology. In addition, trainees can use the milestones as a self-directed assessment tool and to understand the expectations of the fellowship.

Clinical Experience

The primary purpose of a pediatric cardiac anesthesia fellowship is to train anesthesiologists as experts in the perioperative care of patients with both straightforward and complex forms of CHD. Although the majority of clinical experience is obtained in the operating room, other major components include the cardiac catheterization laboratory, electrophysiology laboratory, and cardiac magnetic resonance imaging. Indeed, pediatric cardiac catheterization has become a major component in the practice of pediatric cardiac anesthesia.[28-30] Fellows also can complete rotations in the cardiac intensive

Table 2
Core Competencies and Milestones for Pediatric Cardiac Anesthesia Fellowship

Patient care (4)	■ Perioperative assessment, planning, and management
	■ Technical/procedural skills
	■ Understanding cardiovascular surgical procedures
	■ Understanding cardiac catheter-based therapeutic procedures and electrophysiological studies
Medical knowledge (4)	■ Congenital and acquired cardiovascular anatomy, physiology, and pathophysiology
	■ Pharmacology
	■ Cardiopulmonary bypass, extracorporeal circulation, and circulatory assist devices principles
	■ Understanding cardiac diagnostic procedures (echocardiography, magnetic resonance imaging, cardiac catheterization, computed tomography
System-based practice (3)	■ Coordination of care
	■ Incorporation of patient safety and quality improvement into clinical practice
	■ Understanding of health care economics; cost awareness and cost-benefit analysis
Practice-based learning and improvement (2)	■ Self-directed learning and scholarly activity
	■ Education of team members and other health care providers
Professionalism (3)	■ Commitment to institution, department, and colleagues
	■ Receiving and giving feedback
	■ Responsibility to maintain personal, emotional, physical, and mental health
Interpersonal and communication skills (2)	■ Communication with patients and families
	■ Interprofessional communication and transitions of care

Adapted from Nasr VG, et al. Anesth Analg 208;126:198-207, with permission.[27]

care unit, perfusion, and echocardiography laboratory. At the completion of the program, fellows are expected to have comprehensive knowledge in congenital cardiac pathophysiology and the necessary technical skills to direct the perioperative management of infants, children, and adults with congenital and acquired heart disease undergoing cardiac and noncardiac procedures, including surgeries, imaging, and diagnostic and interventional catheterizations. Communication skills are also important to emphasize. For example, a structured handoff has been shown to improve data transfer as well as patient safety.[31,32] Ultimately, trainees are expected to become consultants in the management of children and adults with CHD having noncardiac surgery and other procedures, and to work collaboratively with other disciplines, including cardiologists, cardiac surgeons, intensivists, and radiologists, to advance the care for patients with CHD and science in the field.

Case Numbers

In 1997, the ACGME recognized pediatric anesthesiology as a 1-year fellowship, during which exposure to patients with congenital cardiac anomalies, including 15 cardiopulmonary bypass (CPB) cases and 5 non-CPB cases, is required.[33] The adult cardiothoracic anesthesia fellowship mentions a requirement in understanding (knowledge) of CHD without a specific case number requirement for CHD cases. Defining adequate experience based on case number is a difficult task. In 2012, guidelines by the PALC and CCAS suggested a minimum of 100 anesthetic procedures with the majority on CPB, 50% of cases in children less than 1 year of age and 25% in children less than 1 month of age. This experience also includes an additional 50 anesthetic cases covering diagnostic imaging, diagnostic and interventional catheterization procedures, and electrophysiology procedures. Based on a recent survey of 12-month fellows over the past few years, a suggested case number for "required" lesions or interventions is listed in Table 3. A prospective survey tracking the case numbers of pediatric cardiac anesthesia fellows, along with expert consensus, is needed to determine case numbers. In addition, some exposure to adult CHD patients is expected. Similar to training in pediatric cardiac surgery, a transitional period with strong mentorship for junior faculty may be required.

Table 3
Suggested Case Numbers for Anesthetic Management of Surgical Repairs and Diagnostic and Interventional Procedures

Surgical Cases Bypass	Case Numbers
Hypoplastic left heart syndrome	3
Transposition of great arteries	3
Total anomalous pulmonary venous return	1
Common atrioventricular canal	6
Tetralogy of Fallot	5
Ventricular/atrial septal defect	10
Bidirectional Glenn	5
Fontan	4
Left ventricular assist device	1
Right-sided valvular lesions	15
Left-sided valvular lesions	15
Heart/lung transplant	2
Interrupted aortic arch	1
Truncus arteriosus	1
Without bypass	Case Numbers
Blalock-Taussig shunt	3
Aortic coarctation	3
Patent ductus arteriosus	3
Vascular ring	2
Diagnostic and Interventional Cases (Catheterization Laboratory and Imaging)	Case Numbers
Hemodynamic catheterizations	20
Pulmonary artery dilations	7
Pulmonary vein dilations	5
Endomyocardial biopsy	5
Transcatheter valve placement	2
Device closure (atrial septal defect/ventricular septal defect/PDA)	2
Emergency cath cases (neonatal AS or PS, balloon atrial septostomy, stenting of Blalock-Taussig/Sano shunts)	3
Electrophysiology studies	10
Cardiac magnetic resonance imaging/chest tomography	2
Sedated transthoracic or transesophageal echocardiography	5
Cases with extracorporeal support (extracorporeal membrane oxygenation)	2

Abbreviations: AS, aortic stenosis; PDA, patent ductus arteriosus; PS, pulmonary stenosis.

Didactic Component

A suggested comprehensive, formal didactic program should include weekly lectures on pertinent topics in pediatric cardiology, cardiac surgery, and anesthesia. A complete list of topics to be covered has been presented previously by DiNardo et Al. (Table 4).[16] Fellows also are expected to participate in a cardiac anesthesia journal club; mortality and morbidity conferences; combined cardiac surgery, cardiology, and cardiac anesthesia conferences, during which interesting and complicated cases are discussed; and scholarly activity. The fellows are required to participate in a research or quality improvement project during their fellowship.[34] In the current era, fellows also should recognize the availability of online resources, such as the CCAS website educational content and links to additional resources and simulation programs.[35] Daily informal one-on-one teaching is an important component of all educational programs. Preoperatively, fellows are expected to evaluate fully and discuss their cases with the responsible staff member. Intraoperative teaching with case-based discussion or general didactic topics also is emphasized.

Simulation

The use of simulation-based training has become integral in many specialties. Especially in a field like pediatric cardiac care, where high-stakes events are not uncommon, simulation can be instrumental in developing skills, enhancing response rate, and facilitating appropriate care and collaboration among team members in both emergency situations and routine care.[36] Pediatric cardiac anesthesia training ideally should

Table 4
Didactics for a Pediatric Cardiac Anesthesia Fellowship

1. Embryology and morphology; nomenclature of CHD
2. Pathophysiology, pharmacology, and clinical management of patients with the full spectrum of congenital and pediatric acquired heart disease for cardiac and noncardiac
3. Pathophysiology, pharmacology, and clinical management of patients pre- and post-heart, lung, or heart-lung transplantation
4. Noninvasive cardiovascular evaluation: electrocardiography, echocardiography, computed tomography, and magnetic resonance imaging
5. Cardiac catheterization, including interventional procedures
6. Preanesthetic evaluation of patients with CHD
7. Pharmacodynamics and pharmacokinetics of medications used in the treatment of patients with congenital cardiac disorders, including anesthetics and vasoactive medications
8. Extracorporeal circulation (including cardiopulmonary bypass, low-flow cardiopulmonary bypass, deep hypothermic circulatory arrest, antegrade cerebral perfusion, and extracorporeal membrane oxygenation), management of anticoagulation while on extracorporeal circulation, and myocardial preservation
9. Circulatory assist devices
10. Pacemaker insertion and modes of action, operational characteristics of implantable cardioverter defibrillators
11. Postanesthetic critical care management of pediatric and adult CHD surgical patients, including ventilator management
12. Pain management of pediatric and adult CHD surgical patients
13. Research methodology and statistical analysis
14. Quality assurance and improvement
15. Ethical issues

Modified from DiNardo et al.[16] with permission.
Abbreviations: CHD, congenital heart disease.

include exposure to simulation-based assessment and crisis management. The reliability and efficiency of these custom-designed training scenarios and performance checklists have been shown effective in assessing progress in knowledge and skills and readiness for independent practice.[37]

The Future

The future of the specialty may drive initiatives for establishing accreditation processes for training centers through the ACGME, as well as potentially a certification process through the American Board of Anesthesiology similar to the evolution that occurred in the field of pediatric anesthesia. Should such processes occur, challenges will arise and need to be addressed. For example, attention is critical to ensure that fellows are exposed to a complete array of cases, such as ventricular assist devices or transplant, that may not be available at all centers. Training programs will have to address the concern that the case numbers for the pediatric cardiac anesthesia fellowship should not interfere with the pediatric anesthesia fellows training and clinical experience.

In conclusion, the authors reviewed the evolution of pediatric cardiac anesthesia as a subspecialty and a field of training. They examined the path that other specialties caring for patients with CHD have undertaken in the development of their training programs, and summarized the current and proposed pathways for standardization and milestones in pediatric cardiac anesthesia. Going forward, the specialty will continue to refine the expert level of knowledge required to provide outstanding anesthesia care for all patients with CHD.

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