



HRS/ISACHD/PACES scientific statement on provider and institutional best practices for comprehensive adult congenital heart disease electrophysiology programs

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ABSTRACT

The global population of adults with congenital heart disease (CHD) now exceeds that of children, reflecting decades of surgical and medical advances. As this cohort has aged, arrhythmias have emerged as a predominant cause of morbidity, hospitalization, and late mortality. Arrhythmia mechanisms in adult CHD (ACHD) arise from congenital abnormalities, surgically altered substrates, progressive hemodynamic lesions, multisystem comorbidities, and acquired cardiovascular risk factors, creating a distinct electrophysiological (EP) phenotype that diverges fundamentally from that of populations without CHD. Despite increasing complexity and demand, ACHD EP care remains fragmented, with marked variability in provider training, institutional resources, and access to specialized expertise. This joint Heart Rhythm Society/Pediatric and Congenital Electrophysiology Society/International Society for Adult Congenital Heart Disease statement defines provider- and center-level best practices for comprehensive ACHD EP programs. It establishes ACHD EP as a distinct subspecialty and proposes a competency-based framework spanning 5 domains: congenital cardiac anatomy and physiology, arrhythmia mechanisms and risk stratification, noninvasive EP assessment, procedural proficiency in ablation and device therapy, and longitudinal ACHD arrhythmia care. The statement outlines key elements of preprocedural evaluation, procedural planning, and peri- and postprocedural management and specifies institutional requirements for personnel, facilities, and infrastructure. Recognizing the paucity of validated ACHD-specific performance metrics, the document proposes candidate indicators of procedural efficacy, safety, efficiency, longitudinal outcomes, and patient-reported health status and articulates principles for credentialing and institutional accountability. These recommendations are intended as scalable standards to support regional centers of excellence and harmonized training pathways, thereby promoting safe, effective, and equitable ACHD arrhythmia care.

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ABBREVIATIONS ACC = American College of Cardiology;
ACHA = Adult Congenital Heart Association; ACHD =

adult congenital heart disease; ACLS = advanced cardiovascular life support; AHA = American Heart Association;

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AV = atrioventricular; CHD = congenital heart disease; CIED = cardiac implantable electronic device; CME = continuing medical education; CRT = cardiac resynchronization therapy; CT = computed tomography; ECG = electrocardiogram; EP = electrophysiology; HRS = Heart

Rhythm Society; IBHRE = International Board of Heart Rhythm Examiners; ICE = intracardiac echocardiography; MRI = magnetic resonance imaging; PACES = Pediatric and Congenital Electrophysiology Society; TEE = transeophageal echocardiography

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Preamble

The Heart Rhythm Society (HRS) has developed scientific and clinical documents guiding the management of cardiac arrhythmias since 1996. This HRS-led scientific statement was developed in collaboration with the International Society for Adult Congenital Heart Disease and the Pediatric and Congenital Electrophysiology Society (PACES). This statement discusses best practices for adult congenital heart disease (ACHD) electrophysiology (EP) programs.

Editorial independence

The statement is sponsored by the HRS and was developed without commercial support. All writing committee members and peer reviewers volunteered their time to the writing and reviewing efforts.

Organization of the writing committee

HRS has rigorous policies and methods to ensure that documents are developed without bias or improper influence. The HRS policy on relationships with industry and other entities can be found in [Appendix C](#) of the *HRS Code of Ethics and Professionalism* and in the *HRS Scientific Documents Meth-*

odology Manual. A comprehensive list of relationships with industry and other entities disclosed by the writing committee members is presented in [Appendix 1](#). [Appendix 2](#) is a comprehensive list of relationships with industry disclosed by the peer reviewers.

Document review and approval

This statement was approved by the writing committee and underwent internal review and approval by the HRS Scientific Documents Committee. This statement was reviewed and endorsed by the International Society for Adult Congenital Heart Disease and PACES.

Document updates

The HRS Scientific Documents Committee reviews each scientific document for currency every 2–5 years after publication.

Document rationale

Advances in pediatric cardiac surgery and medical care have transformed survival for children with congenital heart disease (CHD).¹ Adults now outnumber children with CHD,²

marking 1 of the most striking demographic shifts in modern cardiology.³ This expanding ACHD population is heterogeneous in terms of anatomy, physiology, previous interventions, comorbidities, genetic and syndromic background, and long-term outcomes. As this cohort has aged, rhythm disorders have become increasingly prevalent and have emerged as a leading cause of morbidity, hospitalization, and mortality.^{4–7} The arrhythmia burden in ACHD is unique, reflecting substrates shaped by congenital anomalies of the sinus node or atrioventricular (AV) conduction system, postoperative scars and baffles, residual or progressive hemodynamic lesions, and genetic influences. With advancing age, acquired risks such as hypertension, diabetes, smoking, and obesity further modulate arrhythmogenesis.^{8,9} The result is a dynamic arrhythmia profile that differs from that in childhood CHD and is specific to the underlying lesions, previous surgical or interventional procedures, and other mediating factors.¹⁰ Compared with those without CHD, adults with CHD typically develop arrhythmias earlier in life, have more complex arrhythmia substrates and vascular access issues, face higher complication rates with antiarrhythmic drugs and device therapy, and, in selected subgroups, benefit from a strategy of earlier interventions when performed by teams with expertise in congenital EP.^{11,12} Provider expertise should encompass the full spectrum of therapies, including pharmacology, catheter ablation using advanced non-fluoroscopic mapping systems, and the expanding array of cardiac implantable electronic devices (CIEDs).

Despite the magnitude of this challenge and the growing population, care remains fragmented across institutions and geographies, with few formal standards and substantial unmet global needs. Expertise in ACHD arrhythmia management remains limited and concentrated within highly specialized centers, creating disparities in access to care and clinical outcomes. These context-dependent features demand care models that integrate EP, hemodynamic, imaging, and surgical expertise tailored to adults with CHD. Therefore, ACHD EP has emerged as a distinct subspecialty dedicated to the prevention, detection, and management of arrhythmias rooted in congenital substrates and surgical legacies, while advancing tailored strategies for access, mapping, ablation, device implantation, and lifelong follow-up.

ACHD EP as a distinct subspecialty

Professional societies are progressively articulating guidance to standardize safe, effective arrhythmia care in adults with CHD. The 2014 PACES/HRS consensus was seminal in formally distinguishing ACHD EP as a unique discipline, recommending that invasive procedures in adults with CHD be performed by electrophysiologists with ACHD expertise in appropriately equipped laboratories, with involvement of ACHD cardiologists and anesthesiologists familiar with CHD physiology.¹³ It further advised that centers of excellence include at least 1 electrophysiologist with CHD expertise, a principle reiterated

by the 2018 American College of Cardiology (ACC)/American Heart Association (AHA) guideline¹⁴ and reinforced by the 2020 European Society of Cardiology ACHD guideline, which emphasized congenital anatomic knowledge, multidisciplinary decision making, consideration of early ablation in experienced centers, and development of organized networks for acute arrhythmia care.¹² These statements collectively established the expectation that ACHD arrhythmia care be delivered within systems possessing the requisite expertise, technology, and processes.

The emergence of ACHD EP reflects a broader historical trajectory. Traditional EP training, whether adult or pediatric, has generally provided limited preparation for the distinctive needs of patients with ACHD. Pediatric-trained electrophysiologists offer a deep understanding of CHD anatomy, physiology, and lesion-specific substrates but often have limited exposure to high-volume procedures more commonly required in adults, such as pulmonary vein isolation, ventricular tachycardia ablation, cardiac resynchronization therapy (CRT), conduction system pacing, and lead extraction.¹⁵ Conversely, adult-trained electrophysiologists may be skilled in these complex interventions but lack fundamental comprehensive training in CHD anatomy and physiological and surgical particularities and in the nuances of vascular, transbaffle, or transconduit access. Recognizing these limitations, the 2014 PACES/HRS statement delineated competencies beyond standard curricula and called for structured collaboration across adult EP, pediatric EP, and ACHD cardiology teams.¹³

Together, these developments justify ACHD EP as a distinct subspecialty. The population and substrates are unique and evolve over time, the shortcomings of applying “standard” EP training pathways are tangible, and optimal outcomes depend on multidisciplinary teams embedded in ACHD centers. However, care remains fragmented across pediatric and adult services, with wide variability in operator experience and institutional resources.¹⁵ This underscores the urgency of defining specialty standards, structured training pathways, and institutional requirements that ensure equitable access to high-quality ACHD EP care worldwide.

Scope of the document

This consensus statement is directed toward the broad community engaged in the arrhythmia care of adults with CHD, including adult and pediatric electrophysiologists, ACHD specialists, trainees, allied professionals, and policy stakeholders responsible for defining systems of care. The purpose of this document is to articulate the essential provider qualifications, institutional infrastructure, and system-level practices required to deliver safe, effective, and equitable ACHD EP care. It is not a set of clinical management guidelines. Rather, it focuses on training pathways, multidisciplinary team structures, and organizational requirements that enable consistent, high-quality management of arrhythmias in ACHD.

This statement complements and builds upon existing society documents, including the 2014 PACES/HRS consensus on arrhythmia management in ACHD,¹³ the 2013 PACES training statement for pediatric/congenital EP,¹⁶ the 2014 HRS consensus on EP laboratory standards,¹⁷ the 2018 ACC/AHA ACHD guideline (with an anticipated 2025 update),¹⁴ the 2020 European Society of Cardiology ACHD guideline,¹² Adult Congenital Heart Association (ACHA) accreditation criteria,¹⁸ the 2015 ACC/AHA/HRS advanced training statement on clinical cardiac EP (with an anticipated 2026 update),¹⁹ and ACHD training statements.²⁰ By situating these within a unified framework, the present document provides specialty-specific guidance for ACHD EP that addresses training, infrastructure, and system design across diverse health care models.

ACHD EP training pathways

The workforce caring for adults with arrhythmias with CHD is multidisciplinary and heterogeneous. Physicians may enter the field through internal medicine, pediatrics, or combined medicine/pediatrics before subspecializing in ACHD and may pursue EP training through adult or pediatric tracks. Certification in ACHD has now been standardized to a 24-month fellowship in both the United States (American Board of Internal Medicine in collaboration with the American Board of Pediatrics) and Canada (Royal College of Physicians and Surgeons of Canada). Alternative pathways combining adult cardiology with EP (eg, the 2 + 2-year model) are being piloted, and an American Board of Internal Medicine 2 + 2 pathway is also a potential avenue to enter ACHD training after 2 years of adult cardiology. Neither 2 + 2 pathway is currently available for American Board of Pediatrics diplomates, who require at least 1 additional year after a 3-year pediatric cardiology fellowship to be eligible for pediatric EP certification from the International Board of Heart Rhythm Examiners (IBHRE). Allied professionals may also obtain specialty certification (eg, from IBHRE) to support their roles in ACHD arrhythmia care. Although a few centers now offer dedicated ACHD EP fellowships, there is no “one size fits all” approach, given the multiple entry points and highly variable systems in which this population is managed.

Regardless of entry pathway, ACHD EP practitioners are expected to meet baseline qualifications. These include completion of an accredited adult or pediatric EP fellowship and certification in advanced cardiovascular life support, together with maintenance of board certification and licensure. Advanced training or certification in ACHD would further strengthen preparation, and additional IBHRE credentials (eg, certified EP specialist/certified EP specialist-pediatrics, certified cardiac device specialist) are encouraged to document advanced expertise in arrhythmia and device management. Initial training requirement recommendations for competency in ACHD EP are anticipated with the next update to the ACC/AHA/HRS advanced training statement on clinical cardiac EP. In practice, most current ACHD EP operators have acquired expertise in ACHD through clinical expo-

sure during EP training or subsequent practice rather than through formalized ACHD subspecialty training. In a recent PACES survey, 87% of respondents reported gaining ACHD EP experience during fellowship (most via pediatric EP programs), whereas 13% reported achieving competency solely through post-training clinical practice.¹⁵

There are currently no established data to define the minimum procedural volume or case mix required to achieve or maintain proficiency in ACHD EP. Moreover, even with dedicated ACHD EP training, differences in case-mix exposure between pediatric and adult EP programs make it difficult for any single operator to acquire and maintain competency across the full spectrum of ACHD EP practice.¹⁵ As a result, few operators possess all of the necessary skills, and many centers rely on collaborative models in which team members contribute complementary expertise to deliver high-quality ACHD arrhythmia care. Against this backdrop, this document emphasizes that training should be structured around a defined set of core competencies, allowing flexibility in how these are achieved across diverse entry pathways (Table 1).

Core competencies in ACHD EP

A competency-based framework is essential to ensure that clinicians are prepared to deliver safe, effective, and equitable arrhythmia care for adults with CHD. Training programs should be structured to provide consistent exposure, mentorship, and assessment across all core domains while allowing flexibility to accommodate the varied entry pathways into ACHD EP. By anchoring education in defined competencies rather than prescriptive training routes, this approach promotes a uniformly high standard of care across diverse health care systems.

After initial training, maintenance of ACHD EP proficiency requires sustained exposure to complex cases and continued involvement in multidisciplinary ACHD care. Ongoing participation in arrhythmia procedures, device management, and collaborative case review is critical to ensure that skills remain current and aligned with evolving best practices. Consistent with these priorities, accreditation frameworks and cardiovascular disease training statements are beginning to align with core competencies and proficiency standards by emphasizing operator expertise and multidisciplinary integration. For example, in the United States, the ACHA accreditation criteria specify that interventional EP procedures be performed by operators with demonstrated expertise in ACHD in collaboration with the ACHD team for periprocedural evaluation and management.¹⁸

A qualified program for ACHD EP training should be structured to ensure mastery in 5 core domains. These domains represent both the educational outcomes expected of trainees and the enduring proficiencies required of practicing ACHD electrophysiologists to deliver safe and effective care: (1) congenital cardiac anatomy; physiology, pathology, and surgical interventions; (2) arrhythmia mechanisms and substrates; (3) technical interpretation of advanced imaging

Table 1 Core competencies for ACHD electrophysiology training programs

Domain	Competency expectations
Congenital cardiac anatomy and physiology	- Fluency in anatomy, physiology, embryology, and natural history of simple, moderate, and complex CHD lesions, including conduction system variants - Understanding of postsurgical anatomy across palliative and corrective procedures - Anticipation of lesion-specific arrhythmia patterns and late sequelae, effects of growth and aging, and applications to procedural planning
Arrhythmia mechanisms and substrate interpretation	- Competence in identifying arrhythmogenic substrates (eg, scar-related reentry, dual AV nodes, and atrial switch/Fontan circuits) - Application of risk stratification approaches with recognition of their limitations in ACHD - Integration of inherited and acquired arrhythmia syndromes and evolving strategies for heart failure and structural heart disease - Knowledge of indications, risks, and benefits of electrophysiological study, ablation, and CIEDs in ACHD, including pharmacologic considerations (anticoagulants and antiarrhythmics)
Imaging integration and noninvasive interpretation	- Interpretation of 3D multimodality imaging (MRI, CT, ICE, and TEE) for procedural planning and intraprocedural guidance - Expertise in ECG and ambulatory rhythm monitoring in atypical anatomies and orientations - Device interrogation, programming, troubleshooting, and remote monitoring interpretation tailored to ACHD
Procedural and technical proficiency	- Proficiency with 3D mapping and catheter ablation in complex congenital anatomies - Mastery of techniques to access the pulmonary venous atrium, such as robotic magnetic navigation or puncture through conduits, baffles, or surgical patches when indicated - Understanding the indications, risks, and options for alternative vascular access (eg, jugular, transhepatic, and epicardial) and collaborating with multidisciplinary teams for execution when standard routes are not feasible - Implantation of CIEDs (transvenous, subcutaneous, and leadless) across varied anatomies; meaningful exposure to CRT and conduction system pacing - Experience with lead extraction, or collaboration with colleagues who have established extraction expertise - Ability to select CIED type and configuration tailored to the patient's anatomy, physiology, and arrhythmia substrate
Multidisciplinary integration and longitudinal care	- Ability to participate effectively in multidisciplinary ACHD care models, including arrhythmia conferences, surgical planning, and hybrid interventions - Skill in collaborating with congenital surgeons (including familiarity with intraoperative and hybrid electrophysiology procedures), imaging specialists, heart failure teams, anesthesiologists, and allied professionals - Competence in managing outpatient ACHD arrhythmia and device clinics with structured follow-up and remote monitoring - Commitment to continuous medical education (maintenance of certification, ACHD electrophysiology-focused CME, and society participation)

3D = 3-dimensional; ACHD = adult congenital heart disease; AV = atrioventricular; CHD = congenital heart disease; CIED = cardiac implantable electronic device; CME = continuing medical education; CRT = cardiac resynchronization therapy; CT = computed tomography; ECG = electrocardiogram; ICE = intracardiac echocardiography; MRI = magnetic resonance imaging; TEE = transesophageal echocardiography.

and device telemetry; (4) procedural and technical proficiency; and (5) longitudinal care and interdisciplinary collaboration.

Core knowledge of CHD

Trainees in ACHD EP should achieve fluency in the anatomy, physiology, embryologic development, and natural history of simple, moderate, and complex CHD lesions, including surgical variants and conduction system anomalies. They should understand lesion-specific arrhythmia patterns, anticipate late sequelae, and apply this knowledge to risk stratification, procedural planning, and longitudinal care.

EP-specific risk stratification and substrate interpretation

Trainees should develop competence in identifying arrhythmogenic substrates across ACHD populations, including

reentrant circuits related to surgical scars or conduits. They should be able to apply established risk stratification models, recognize their limitations, and integrate knowledge of inherited and acquired arrhythmia syndromes and evolving strategies for heart failure management and structural heart disease. Knowledge of the specific benefits, risks, and limitations of pharmacologic, device-based, and ablative therapies in ACHD is expected.

Imaging integration and interpretation of noninvasive studies

Modern ACHD EP proficiencies include the ability to incorporate 3-dimensional (3D) multimodal imaging (magnetic resonance imaging, computed tomography scan, intracardiac echocardiography, and standard or 3D transesophageal echocardiography) for preprocedural planning and

periprocedural navigation. They should also develop expertise in interpreting electrocardiograms and ambulatory monitoring in patients with atypical anatomy and chamber orientation. Competence in device interrogation and remote monitoring interpretation is expected.

Procedural expertise in complex EP and device interventions

Candidates must develop technical facility in catheter ablation within complex congenital anatomies, including the use of 3D mapping, application of transeptal techniques to surgical baffles or conduits, and understanding of ablation energy modalities. Proficiency in alternative vascular access, CIED implantation (transvenous, subcutaneous, and leadless), and meaningful exposure to CRT, conduction system pacing, and lead extraction is expected. Programs should ensure direct access to hybrid procedures and congenital surgical support where needed.

Multidisciplinary ACHD integration and longitudinal care

ACHD EP specialists must be embedded in multidisciplinary care models, with ongoing and active participation in ACHD surgical planning, arrhythmia case conferences, and ambulatory care and device clinics, in collaboration with CHD surgeons, ACHD providers, interventional/structural cardiologists, heart failure specialists, and imaging experts. Training should also include collaboration with congenital cardiac surgeons during intraoperative arrhythmia and device procedures.

Procedural considerations in ACHD EP

The inherent complexity of ACHD EP procedures demands careful planning, substantial center resources, multidisciplinary input, experienced staff, and shared decision making.²¹ Anatomic and physiological heterogeneity, compounded by rising comorbidities in the aging ACHD population, necessitate coordinated expertise and robust ancillary support. Detailed planning and regular multidisciplinary discussion are recommended for ACHD EP procedures. Key elements include careful review of anatomy and surgical history, assessment of comorbidities, planning of the procedural strategy, coordination of the EP laboratory team, and perioperative care (Table 2).

Preprocedural planning

Medical history and surgical records

A comprehensive review of surgical history, previous operative notes, and electrocardiographic documentation is essential before undertaking complex procedures. Ensuring timely access to these records is critical for procedural preparation. Adults with CHD may present with arrhythmias unique to congenital anatomy and surgical interventions, such as biatrial reentry after atrial switch or Björk-Fontan procedures, reentrant tachycardia related to twin AV nodes, or scar-related ventricular tachycardia in repaired tetralogy of Fallot

or Ebstein anomaly.^{22–25} In addition, they commonly develop substrates seen in the general population, including AV nodal reentrant tachycardia, typical atrial flutter, right ventricular outflow tract ventricular tachycardia, accessory pathway-mediated tachycardias, and atrial fibrillation, which are frequently rendered more challenging by complex anatomy and previous surgical or catheter-based interventions.

Cross-sectional, multiplane, and 3D imaging

Advanced imaging provides crucial preprocedural information on anatomy, chamber size, the course and caliber of vascular pathways, and relationships between structures. These modalities are particularly valuable in planning complex interventions such as baffle or conduit puncture after the Fontan operation, assessing the feasibility of cannulating the coronary sinus in congenitally corrected transposition of the great arteries, ruling out thrombus, and assessing preprocedural risk in tetralogy of Fallot.^{26–28} In addition, imaging may be augmented by emerging technologies including 3D printing, virtual reality, and computational modeling in ACHD.²⁹ Specialized centers should maintain ready access to high-quality imaging resources to support optimal procedural workflow.

Multidisciplinary discussion

Preprocedural review by an ACHD-focused team is recommended to anticipate challenges and optimize outcomes, with recognition that the composition of such teams and the structure of collaboration vary across institutions and clinical contexts. Surgical and anesthesiology input may not be required in every case but should be readily available when dictated by patient characteristics or procedural complexity. Expertise from advanced imaging, interventional cardiology, or other disciplines may also be integrated as appropriate.

Perioperative management

Anesthetic risk assessment

Patients with complex ACHD should be managed by anesthesiologists experienced in CHD.¹⁴ Risk assessment must consider acquired comorbidities (eg, metabolic syndrome, obesity, coronary atherosclerosis, and obstructive sleep apnea), lesion-specific factors (eg, shunts, heart failure, and pulmonary circulatory characteristics), and noncardiac conditions (eg, hepatic or renal impairment).^{30–32} Syndromic features may carry orofacial abnormalities that further increase anesthetic risk.³³

EP laboratory staff

In addition to anesthesiologists with CHD expertise, nursing staff should be familiar with unique aspects of ACHD physiology, including appropriate blood pressure monitoring (eg, previous subclavian shunts), oxygen saturation assessment, resuscitation strategies (eg, avoidance of positive pressure ventilation in single ventricle physiology and defibrillation pad placement with abnormal situs), and

Table 2 Key considerations for ACHD electrophysiology procedures

Phase of care	Considerations
Preprocedural planning	• Comprehensive review of surgical and procedural records • Acquisition and interpretation of advanced imaging (CT, MRI, and echocardiography) • Anticipation of vascular and cardiac access challenges, including congenital inferior vena cava interruption, venous occlusion, transbaffle or transconduit puncture, transhepatic access, or coronary sinus anomalies • Assessment of conduction system location and risks of AV block, sinus node dysfunction, and intra-atrial conduction block • Evaluation of thromboembolic and bleeding risk (eg, uninterrupted anticoagulation, heparinization strategies, high-risk access such as transconduit or transhepatic, cyanosis and secondary erythrocytosis mitigation strategies) • Anticipated hemodynamic monitoring requirements (noninvasive, urinary catheter, intra-arterial, or central venous monitoring) • Consideration of anesthesia needs (duration, ventilation control, paralysis) • Anticipated procedural outcomes, including implications for future interventions
Multidisciplinary discussion	• Determination of need for surgical backup and availability of intra-/periprocedural imaging support • Type of procedure under consideration (ablation, device implantation, lead extraction, and hybrid procedure) • Possibility of combining procedures • Patient comorbidities and overall procedural risk profile • Optimal procedural location (adult vs pediatric hospital setting) • Involvement of ancillary services and adequacy of institutional resources (equipment, operator skill, and anesthesia expertise)
Procedural workflow	• Establishment of a baseline procedural plan, including staff roles and expectations • Preprocedure TEE, CT, or MRI as indicated (assessment for intracardiac thrombus, function, shunts/fenestrations, and image integration for 3D mapping), with intraprocedural imaging support (eg, ICE) when appropriate • Anticoagulation and monitoring strategy • Definition of procedural endpoints and contingency strategies • Planning of alternate access strategies if required
Postprocedural assessment	• Anticipation of vascular hemostasis needs • Hemodynamic status and recovery profile • Postprocedural imaging when clinically indicated, with attention to complications relevant to ACHD such as vascular injury, iatrogenic/residual shunts, and pericardial effusion • Postprocedural management, including medications and device programming • Determination of postprocedure level of care (ward vs step-down vs intensive care)

3D = 3-dimensional; ACHD = adult congenital heart disease; AV = atrioventricular; CT = computed tomography; ICE = intracardiac echocardiography; MRI = magnetic resonance imaging; TEE = transesophageal echocardiography.

prevention of paradoxical embolism (eg, air filters for residual cardiac shunts or cyanotic lesions). At times, complementary skill sets may be required by additional providers such as ACHD cardiologists with imaging expertise.

Procedural workflow

Team discussions should cover anesthesia, procedural strategy, CIED programming needs during ablation procedures, fluid management, and anticipated challenges. Given the elevated thromboembolic risk in many adults with CHD,³⁴ uninterrupted anticoagulation is often pursued.³⁵ Baseline transesophageal echocardiography or cardiac computed tomography imaging may be performed before intracardiac catheter placement. For catheter ablation procedures, full therapeutic anticoagulation, typically targeting an activated clotting time of 300–350 seconds, is recommended when ablating within the pulmonary venous atrium or in the presence of an intracardiac shunt. Given that many adults with CHD possess congenital or acquired venous abnormalities, alternate routes of access may be required (eg, superior vena caval,

transhepatic, or remote magnetic navigation).³⁶ Baseline hemodynamic assessment with monitoring of ventricular filling pressure, volume status, and laboratory indices of acidosis is useful during protracted cases or with fragile circulatory physiology. Collaboration with interventional colleagues may also be necessary, for example, to perform baffle stenting before CIED lead placement or to coordinate timing and assessment in relation to transcatheter pulmonary valve replacement. Clear communication between the electrophysiologist, the anesthesia team, and the circulating staff is imperative to preemptively identify clinical deterioration.

Institutional and center-level requirements

High-quality management of arrhythmias in adults with CHD requires care in institutions with the personnel, facilities, and infrastructure necessary to address complex anatomy, physiology, and procedural risk. The accreditation framework by the ACHA outlines foundational expectations, including continuous access to electrophysiologists with ACHD expertise.¹⁸ General principles regarding laboratory processes,

Table 3 Institutional requirements for ACHD arrhythmia management

Domain	Essential elements
Personnel	• Electrophysiologists with expertise in ACHD • Multidisciplinary ACHD physician team including ACHD providers, CHD surgeons, imaging experts, interventional cardiologists, heart failure specialists, anesthesiologists, and critical care specialists with ACHD expertise • Dedicated nursing, technical, and allied professionals with experience in CHD care • Dedicated staff for care transition and longitudinal coordination • Personnel for CIED/device management and follow-up
Electrophysiology laboratory qualifications	• Advanced 3D electroanatomic mapping platforms • Multiple ablation energy sources (eg, radiofrequency, cryothermal) • Multimodality imaging capability (ICE, TEE, and fluoroscopy, with integration of cardiac CT/MRI) • Nontransfemoral access capability (eg, transhepatic, transjugular, and epicardial) • Expertise and equipment for transbaffle puncture or robotic magnetic navigation and closure of access sites • Capability for CIED implantation and extraction, with immediate access to high-risk surgical backup
Clinic infrastructure	• Regularly scheduled ACHD arrhythmia outpatient clinics • Dedicated CIED follow-up program with remote monitoring • Multidisciplinary ACHD patient care coordination conferences at regular intervals • Access to financial services, psychosocial support, and structured care transition services

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safety, and personnel were previously outlined in the 2014 HRS consensus statement on EP laboratory standards.¹⁷ The current statement expands on those principles by defining essential center-level requirements specific to ACHD (Table 3). These requirements extend beyond individual operator expertise to encompass specialized personnel, comprehensive facilities, and integrated outpatient services.

Alignment with these standards provides a framework to promote safe and effective ACHD arrhythmia care.

Personnel

Institutions should ensure the availability of electrophysiologists with demonstrated ACHD expertise, supported by allied professionals and nursing staff experienced in CHD

Table 4 Suggested minimum annual case volumes for comprehensive ACHD electrophysiology programs*

Procedure type	Suggested minimum annual case volume	Rationale and notes
Catheter ablation of atrial arrhythmias (eg, intra-atrial reentrant tachycardia, focal atrial tachycardia, and atrial fibrillation)	≥25	Ensures sufficient exposure to atrial arrhythmia substrates, which are highly prevalent in ACHD; recurrence and complication rates emphasize the need for institutional expertise
Catheter ablation of ventricular arrhythmias (eg, ventricular tachycardia and premature ventricular complexes)	≥10	Low frequency but high complexity/risk; supported by volume–outcome data in ventricular tachycardia ablation
Specialized access to the pulmonary venous atrium (eg, transbaffle or transconduit puncture, robotic magnetic navigation)	≥5	Specialized skill set; requires imaging support and complication management; may involve the combined expertise of ACHD interventional and electrophysiology providers
Cardiac implantable electronic device implantation (all types)	≥25	Includes transvenous, subcutaneous, and leadless systems; case mix should reflect ACHD complexity
Cardiac resynchronization therapy and conduction system pacing	≥10	Requires institutional experience in advanced device therapy and careful patient selection in ACHD
Lead extraction	≥5	High-risk procedure that mandates institutional expertise, specialized equipment, and surgical backup

ACHD = adult congenital heart disease.

*These volumes, which apply specifically to procedures performed in adults with congenital heart disease, represent consensus-based suggestions extrapolated from adult electrophysiology literature on volume–outcome relationships and adapted to the unique complexity of ACHD. They have not been validated specifically for ACHD electrophysiology. Categories are nonexclusive and may be achieved simultaneously. Importantly, the thresholds in this table pertain only to procedures performed in ACHD and are not intended to replace overall maintenance of competency requirements (all patients, with or without ACHD), such as the Heart Rhythm Society's recommendation that individual lead extractors perform removal of ≥20 leads per year to maintain competency.

Table 5 Candidate procedure-related performance metrics for ACHD electrophysiology

Domain	Candidate metrics
Acute procedural efficacy	Ablation procedures • Arrhythmia termination • Noninducibility • Bidirectional block across ablation lines CIED procedures • Successful lead delivery to the intended location • Acceptable lead parameters and function • Achievement of conduction system pacing (when attempted)
Procedural efficiency	• Total procedure duration • Fluoroscopy time • Radiation dose • Contrast volume
Safety and complications	• Vascular injury • Cardiac perforation • Thrombotic or thromboembolic event • Pneumothorax • Device malfunction • Lead dislodgement • Infection • Bleeding complication (eg, hematoma, retroperitoneal, hemothorax, gastrointestinal, and cerebral) • Injury to the sinus node or conduction system • Phrenic nerve injury • Unplanned escalation of care (eg, intensive care unit transfer) • Death
Postprocedure outcomes	Short term • Postprocedure length of stay • Readmission or emergency department visit within 30 d • All-cause mortality within 90 d Longer term • Arrhythmia recurrence after ablation (eg, at 6–12 mo) • Device performance and lead integrity over time • Late procedure-related complications (eg, thromboembolism, effusion, infection)

ACHD = adult congenital heart disease; CIED = cardiac implantable electronic device.

care. Ready access to subspecialty input from multidisciplinary ACHD teams, congenital cardiac surgery, cardiac anesthesia, advanced imaging, heart failure, and critical care is necessary. Dedicated device clinic staff familiar with the unique needs of patients with ACHD is also required.

Facilities and equipment

Centers performing ACHD EP must have access to the facilities and expertise required to accommodate complex anat-

omy, including options for alternative vascular access (eg, transjugular, transhepatic, and epicardial), multimodal imaging integration, and 3D mapping. Centers should ensure the availability of multiple ablation energy sources (eg, radiofrequency, cryothermal, and pulsed field ablation) to allow selection of the modality most appropriate for the underlying arrhythmia.^{37,38} Emerging technologies are expected to broaden the therapeutic armamentarium as evidence and experience accumulate. Centers must maintain expertise in accessing the pulmonary venous atrium, such as by baffle or conduit puncture or robotic magnetic navigation.^{26,39} Interventional ACHD support is critical when vascular intervention, postprocedural shunt closure, or hybrid strategies are required, and immediate access to congenital surgical backup must be ensured. The laboratory or hybrid surgical-catheterization suite should also be capable of performing the full spectrum of CIED procedures relevant to ACHD, including CRT, conduction system pacing, leadless pacing, subcutaneous defibrillators, and lead extraction. Postprocedural care requires the availability of intensive care units with specific expertise in ACHD.

Clinic infrastructure

Outpatient services should include a dedicated ACHD arrhythmia clinic and device follow-up staffed by clinicians familiar with CHD. As noted, regular multidisciplinary conferences are recommended to coordinate longitudinal management and procedural planning.

Quality of care and performance metrics

The success of a comprehensive ACHD EP program depends not only on procedural expertise but also on a sustained focus on quality of care, patient-centered outcomes, and systematic performance evaluation. Because of the heterogeneity of congenital anatomy, previous surgical interventions, and comorbidities, quality metrics tailored specifically to ACHD are needed to guide benchmarking, inform quality improvement initiatives, and ensure delivery of high-quality arrhythmia care.

Although observational studies suggest that adults with CHD followed at specialized ACHD centers experience improved outcomes, including survival,⁴⁰ validated quality indicators specific to ACHD EP have not yet been established. Existing data from ablation and device studies demonstrate good acute success but variable recurrence rates and complication profiles across arrhythmia mechanisms and substrates,^{41–44} highlighting that outcomes and complications in ACHD must be interpreted in the context of CHD complexity, individual risk profile, and lesion-specific features, factors not adequately captured by conventional EP benchmarks. In this regard, the concept of minimum annual center ACHD procedure volume has been raised as a potential quality measure to support the maintenance of expertise (Table 4). These thresholds are intended for centers rather than for individual operators, with the aim of fostering environments capable of training electrophysiologists

Table 6 Candidate domains for credentialing and institutional accountability in ACHD EP programs

Domain	Candidate expectations	Rationale
Evaluation process	• Programs assess internal expertise and resources. • ACHD EP care provided by board-certified pediatric or adult cardiologists with advanced EP fellowship training including ACHD exposure • IBHRE certification is encouraged. • Programs define the level of procedural complexity (basic, intermediate, advanced) that they are equipped to perform. • Programs integrate ongoing CME, institutional support for professional development, and regular case reviews (eg, morbidity and mortality rounds). • Collaboration with high-volume ACHD EP centers is encouraged.	Ensures transparency about local capabilities and fosters appropriate case selection Promotes maintenance of competency and dissemination of best practices
Institutional responsibility	• Programs maintain an internal registry of ACHD EP procedures, outcomes, and adverse events. • An ACHD EP leader is identified to oversee quality improvement. • Multidisciplinary meetings for case discussion are held regularly.	
Accountability	• Providers maintain board certification, licensure, ACLS certification, and continuing medical education. • Providers contribute to broader ACHD accreditation processes. • EP, cardiology, surgical, anesthesia, nursing, and allied professionals participate actively in program development and review. • Outcomes are reported regularly within the team.	Ensures professional standards and integration with institutional accreditation
Institutional accountability	• Programs align with the mission of the institution to support ACHD care, education, and research. • Accreditation and accountability processes strengthen program identity and commitment to quality.	Reinforces the long-term sustainability of ACHD EP programs

ACHD = adult congenital heart disease; ACLS = advanced cardiovascular life support; CME = continuing medical education; EP = electrophysiology; IBHRE = International Board of Heart Rhythm Examiners.

specifically in ACHD. They should be regarded as aspirational benchmarks, acknowledging both the relative rarity of certain procedures in this population and the inherent year-to-year variability that arises from small case numbers in a rapidly evolving field. Patient-reported outcomes, including symptom burden and quality of life, have been shown in large international ACHD cohorts to provide important context and may represent a valuable complement to procedural endpoints.^{45–47}

Future quality frameworks will likely need to span multiple domains and encompass procedural outcomes, longer-term clinical results, patient-reported measures, and process indicators (Table 5). Candidate measures at the operator and program level include procedural volumes, acute procedural success, and complication rates. Longitudinal measures, including arrhythmia recurrence, device performance, and late procedure-related complications, represent critical dimensions of care that warrant systematic consideration as quality in-

dicators. Similarly, integration of patient-reported outcomes and process indicators, such as timely access to ACHD EP consultation and intervention, regular multidisciplinary case review, and structured feedback, may contribute to a more comprehensive assessment.

Participation in registries and national audits provides an important foundation for quality measurement. The National Cardiovascular Data Registry – Improving Pediatric and Adult Congenital Treatment Registry and the UK National Congenital Heart Disease Audit demonstrate the feasibility of large-scale data collection in CHD cardiology and offer models for developing ACHD EP-specific metrics.⁴⁸ Building on these platforms, initiatives such as the Improving Pediatric and Adult Congenital Treatments – Electrophysiology module and the Multicenter Pediatric and Adult Congenital EP Quality Registry are beginning to capture arrhythmia- and device-related outcomes in CHD populations, providing the first specialty-specific frameworks for benchmarking EP

procedures in CHD.⁴⁹ In parallel, PACES has advanced consensus statements and collaborative registries that lay the groundwork for standardized ACHD EP quality metrics.^{13,15} Where feasible, complementary internal quality reviews involving institutional leadership, multidisciplinary teams, and quality administration may further enhance local performance assessment and provide opportunities for discussion of cases and complications.

Credentialing and institutional accountability

Accreditation standards in North America and Europe currently require that ACHD centers include at least 1 EP specialist with expertise in ACHD as part of their multidisciplinary team.^{12,14} However, there is no accreditation pathway specific to ACHD EP training, nor is there an external body responsible for institutional oversight in this field. In the absence of formal structures, programs must rely on internal consensus standards, self-assessment, and alignment with broader ACHD accreditation frameworks to promote quality.¹³ Consensus principles, presented in Table 6, can help guide credentialing and institutional accountability for ACHD EP programs. These principles should be viewed as candidate expectations rather than prescriptive requirements, reflecting the current evidence gap. They emphasize appropriate expertise, multidisciplinary collaboration, continuous improvement, transparent reporting, and institutional commitment. In the absence of formal accreditation, programs are encouraged to integrate ACHD EP quality initiatives within existing institutional or multidisciplinary review frameworks.

Future directions

The field of ACHD EP is at a pivotal stage, requiring deliberate system design and investment to meet the needs of a rapidly growing and aging population. Establishment of regional ACHD EP centers of excellence with adequate volume, resources, and multidisciplinary expertise is essential to ensure consistent, high-quality care. Where procedural volume or expertise is insufficient, structured referral networks and collaborative partnerships between regional centers and community institutions should be developed to ensure equitable access. The writing group also recognizes that the resources, infrastructure, and workforce required to implement these recommendations may not be uniformly available across all health systems. Accordingly, the standards outlined in this document are intended as aspirational goals that can be adapted pragmatically to local contexts, promoting incremental progress toward comprehensive ACHD EP care worldwide.

Integration of ACHD EP into national cardiovascular strategies is urgently needed to align workforce planning, quality initiatives, and resource allocation. Dedicated funding for ACHD EP-specific research and innovation will be critical to generate outcome data, refine procedural strategies, and validate quality metrics that are currently lacking. Clinically, the next decade must reinforce multidisciplinary, competency-based care models and promote pragmatic adoption of

consensus recommendations across diverse health care settings. Sustained progress will require alignment among the relevant professional societies and partner organizations to establish shared standards, harmonize training pathways, and foster global collaboration. By articulating these priorities, this document provides a roadmap for advancing ACHD EP as a recognized subspecialty and for ensuring that adults with CHD worldwide have access to safe, effective, and equitable arrhythmia care.

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