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CLINICAL RESEARCH

Position paper concerning the competence, performance and environment required for the practice of ablation in children and in congenital heart disease

Position commune du Groupe de Rythmologie et de Stimulation Cardiaque de la SFC et du Groupe Affilié de Cardiopédiatrie de la SFC concernant les conditions requises pour les ablations pédiatriques et des patients adultes avec cardiopathie congénitale

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Abbreviations: 3D, three-dimensional; ALARA, as low as reasonably achievable; ASD, atrial septal defect; DIU, Diplôme Inter-Universitaire; EHRA, European Heart Rhythm Association; GUCHD, grown-up congenital heart disease.

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Summary The population of patients with congenital heart disease (CHD) is continuously increasing, and a significant proportion of these patients will experience arrhythmias because of the underlying congenital heart defect itself or as a consequence of interventional or surgical treatment. Arrhythmias are a leading cause of mortality, morbidity and impaired quality of life in adults with CHD. Arrhythmias may also occur in children with or without CHD. In light of the unique issues, challenges and considerations involved in managing arrhythmias in this

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growing, ageing and heterogeneous patient population and in children, it appears both timely and essential to critically appraise and synthesize optimal treatment strategies. The introduction of catheter ablation techniques has greatly improved the treatment of cardiac arrhythmias. However, catheter ablation in adults or children with CHD and in children without CHD is more technically demanding, potentially causing various complications, and thus requires a high level of expertise to maximize success rates and minimize complication rates. As French recommendations regarding required technical competence and equipment are lacking in this situation, the Working Group of Pacing and Electrophysiology of the French Society of Cardiology and the Affiliate Group of Paediatric and Adult Congenital Cardiology have decided to produce a common position paper compiled from expert opinions from cardiac electrophysiology and paediatric cardiology. The paper details the features of an interventional cardiac electrophysiology centre that are required for ablation procedures in adults with CHD and in children, the importance of being able to diagnose, monitor and manage complications associated with ablations in these patients and the supplemental hospital-based resources required, such as anaesthesia, surgical back-up, intensive care, haemodynamic assistance and imaging. Lastly, the need for quality evaluations and French registries of ablations in these populations is discussed. The purpose of this consensus statement is therefore to define optimal conditions for the delivery of invasive care regarding ablation of arrhythmias in adults with CHD and in children, and to provide expert and — when possible — evidence-based recommendations on best practice for catheter-based ablation procedures in these specific populations.

MOTS CLÉS
Procédures d'ablation ;
Cardiopathie congénitale ;
Cardiologie pédiatrique

Résumé La population de patients avec cardiopathie congénitale (CHD) est en perpétuelle augmentation, et une proportion significative d'entre eux vont présenter des arythmies du fait de la cardiopathie congénitale elle-même, ou comme conséquence des traitements interventionnels ou chirurgicaux. Les arythmies sont une cause majeure de mortalité, de morbidité et réduisent la qualité de vie des adultes avec cardiopathie congénitale. Les arythmies peuvent survenir aussi chez les enfants, avec ou sans cardiopathie congénitale. Au vu des problèmes, défis et considérations spécifiques impliqués dans la prise en charge des arythmies dans cette population croissante, vieillissante et hétérogène et chez les enfants, il apparaît essentiel et opportun de revoir d'un oeil critique et de synthétiser les stratégies de traitement optimal. L'introduction de l'ablation par cathéter a largement amélioré le traitement des arythmies cardiaques. Cependant, l'ablation chez les enfants et adultes avec cardiopathie congénitale est techniquement plus complexe, génératrice de complications potentielles variées, et donc requiert un haut niveau d'expertise pour optimiser le taux de succès et réduire le risque de complications. Comme des recommandations françaises concernant les compétences techniques et les équipements manquent en ce domaine, le Groupe de Travail de Rythmologie et Stimulation Cardiaque de la Société Française de Cardiologie et le Groupe affilié de Cardiologie Pédiatrique et Congénitale ont décidé de produire un document commun, compilant les opinions d'experts en élecrophysiologie cardiaque et en cardio-pédiatrie. Ce document détaille les caractéristiques requises pour un centre d'électrophysiologie pour pratiquer des ablations chez des adultes avec cardiopathie congénitale et chez des enfants, et insiste sur l'importance de pouvoir diagnostiquer, surveiller et traiter les complications inhérentes a ces gestes chez ces patients, ainsi que les ressources hospitalières supplémentaires requises, concernant notamment l'anesthésie, le recours à la chirurgie en urgence, les soins intensifs, l'assistance hémodynamique et l'imagerie. Enfin, le besoin d'évaluation de la qualité des soins et de registres nationaux d'ablation dans ces populations est évoqué. Le propos de cet article de consensus est donc de définir les conditions optimales de la délivrance de gestes thérapeutiques invasifs en matière d'ablation chez les adultes avec cardiopathie congénitale et chez les enfants, et de fournir des recommandations d'expert, et basées sur des preuves quand cela est possible, sur les meilleures pratiques pour l'ablation par cathéter dans ces populations.

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Background

As a result of improvements in surgical and interventional cardiac procedures, the majority of children with congenital heart defects can now be expected to reach adulthood. Hence, adults with congenital heart disease (CHD) constitute an ever-growing population. The medical community will encounter an increasing challenge, because most individuals with complex congenital heart defects usually become young adults nowadays. These patients, particularly the adults with moderate or highly complex CHD, can be very difficult to manage, and should be treated in a few expert and specialized ''grown-up congenital heart disease'' (GUCHD) units, concentrating resources, patients, funding and professional experience.

Over the last 20 years, remarkable progress has been made in the management of patients with arrhythmias, including advances in pharmacological treatment, catheter ablation and device therapy. Although percutaneous ablation of cardiac arrhythmias has improved dramatically, becoming the standard therapy in many situations, ablation in the paediatric population and in adults with CHD remains challenging, because of the inherent characteristics of these populations and the complexity of distorted/restricted anatomy and arrhythmia mechanisms [1—5]. For radiofrequency or cryoablation in these populations, decision making requires a deep understanding of the individual's pathological anatomy and physiology, as well as detailed knowledge of the natural history and long-term prognosis. Indeed, in many cases, the principles of anatomy and arrhythmia management in adult patients cannot be applied directly to paediatric patients or to adult patients with CHD [2,6—9].

Radiofrequency and cryoablation, targeting common atrial flutter, atrial tachycardia or fibrillation, atrioventricular node reentrant tachycardia, accessory pathways and ventricular arrhythmias in these populations, are currently achieving acceptable long-term success and complication rates when performed by experienced teams involved in paediatric or congenital electrophysiology [3,10], within a devoted environment. However, although techniques and indications have evolved, and considerable progress has been achieved in the percutaneous treatment of cardiac arrhythmias, ablation in these populations still requires specific knowledge and expertise. Ablation in adults or children with congenital cardiac defects, whether repaired or not, can be a very technically demanding procedure, where expertise and skill are essential to achieve high success rates and minimize complication rates. Adequate operator experience is required, along with a solid knowledge of paediatric cardiology or congenital heart defects and a dedicated environment, with sufficient staff and hospital-based facilities. Furthermore, delivery of care must provide the highest rates of procedural and long-term success, together with the lowest rates of complications, to a relatively limited population. Indeed, arrhythmias occurring in adults with CHD, even if common in this setting, do not currently represent a very important patient population, although the number of patients requiring treatment is growing because of progress in medical management. Ablation procedures in paediatric patients without heart disease are also rather uncommon situations, at least in France [1,10]. For these reasons, a great proportion of arrhythmias must be managed in high-volume specialized centres.

Ablation in patients with various congenital heart defects is currently performed in several centres in France, and a more limited number of centres are performing ablation in young children. Although specific recommendations regarding the required technical competence and skills of physicians, training, qualifications, technical equipment and dedicated environment for ablations in adults with CHD and in children have been proposed by both North American groups (Pediatric and Congenital Electrophysiology Society [PACES]/Heart Rhythm Society [HRS] Expert Group) [11] and European groups (European Heart Rhythm Association [EHRA]/European Society of Cardiology [ESC]/Association for European Paediatric and Congenital Cardiology [AEPC]) [2,12], no specific recommendations are currently available for France. Thus, the Working Group of Pacing and Electrophysiology and the Affiliate Group of Paediatric and Adult Congenital Cardiology of the French Society of Cardiology feel that it is now necessary to define guidelines for interventional cardiac electrophysiological procedures and organization of care for adults with CHD and for children.

The aims of this position paper are to define the criteria that guarantee the quality of physician training and experience and patient care for ablation procedures in adults with congenital cardiac defects and in children (with or without CHD), in terms of volume, institutional environment, medical and paramedical staff, technical equipment and instrumentation. The paper also aims to describe the conditions required to apply these methods correctly and to reach their objectives while ensuring patient safety. Finally, the objective of this document is to serve as a reference for practice and statutory considerations in the future.

Definition of ablation procedures in adults with CHD and in children

Adults with CHD can be defined as adults carrying any cardiac defect, from simple to complex, either surgically or percutaneously corrected or not, which was present at birth, in the form of any alteration in anatomy, septation or connections of the cardiac chambers and great vessels. A list of the various cardiac defects that may be encountered is provided below.

Ablation procedures in adults with CHD include ablation of common atrial flutter, accessory pathways and atrioventricular node reentrant tachycardia, as well as right atrial tachycardia, any atrial arrhythmia for which the target is located in the left atrium (atrial fibrillation or left atrial tachycardia) and any ventricular arrhythmia (either ventricular tachycardia or premature ventricular contractions).

Ablation procedures in children, with or without a cardiac defect, refer to procedures in patients aged < 18 years; they can be divided arbitrarily into ablation in young children (weighing < 40 kg) and older children. Invasive techniques are possible even in very small children, but with several limiting factors that may have implications for ablation procedures in infants, and avoidance — if possible — is prudent in the first 2 years of life [2]. As for adults, the procedures may include ablation of common atrial flutter, accessory

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pathways and atrioventricular node reentrant tachycardia, as well as right or left atrial tachycardia or any ventricular arrhythmia (either ventricular tachycardia or premature ventricular contractions) with or without concomitant structural heart disease or CHD.

Expected types of CHD population

The three expected types of CHD populations listed below are taken from the Bethesda classification [13,14].

''Simple'' CHD

Simple CHD includes isolated small atrial septal defect (ASD) or ventricular septal defect, repaired atrial or ventricular defects without sequalae, isolated aortic or mitral valve stenosis or regurgitation and minor or repaired ductus arteriosus.

CHD of ''moderate'' complexity

CHD of moderate complexity includes aortic-left ventricular fistulas, anomalous pulmonary venous drainage, atrioventricular septal defects, coarctation of the aorta, Ebstein's anomaly, unrepaired significant ductus arteriosus, severe pulmonary valve stenosis or regurgitation, sinus of Valsalva fistula/aneurysm, sinus venosus ASD, right ventricular outflow obstruction of significance, Tetralogy of Fallot, sub- or supravalvular aortic stenosis and ventricular septal defect with other congenital abnormalities.

''Severe'' CHD of great complexity

Severe CHD of great complexity includes any conduit, any cyanotic congenital defects, double-outlet ventricle, Einsenmenger syndrome and pulmonary vascular obstructive disease, previous Fontan procedure or cavopulmonary bypass, single ventricle (double inlet or outlet, common or primitive), any transposition of the great arteries, pulmonary, mitral or tricuspid atresia, truncus arteriosus/hemitruncus and any other abnormalities of atrioventricular or ventriculoarterial connection.

Expected types of ablation procedure

The four expected types of ablation procedure are:
- typical atrial flutter, right or left focal atrial tachycardia, right or left atrial macroreentry;
- atrial fibrillation;
- atrioventricular node reentrant tachycardia, accessory pathways, junctional ectopic tachycardia;
- ventricular premature beats, ventricular tachycardia.

Required features of an interventional cardiac electrophysiology centre for ablation procedures in adults with CHD and in children

Integrated management

The 32nd Bethesda Conference report called attention to the need for healthcare professionals, patients and their families and regulatory agencies to develop a strategic plan to improve access and delivery of care to adults with CHD [15]. Recognition and management of arrhythmias is an integral part of such specialized care [16—19]. Accordingly, coordinating care across medical subspecialties and developing training programmes dedicated to adults with CHD arrhythmias are key factors allowing access and delivery of high-quality care. Healthcare needs, especially for adults with moderate and complex CHD, should be coordinated by dedicated adult CHD centres [20—22]. The availability of integrated care for adults with CHD or young children with arrhythmias is highly recommended. Integrated care requires the cooperation of cardiologists, paediatricians, cardiac surgeons, electrophysiologists, dedicated heart failure and intensive care units, stroke specialists and patients, encompassing a wide range of therapeutic indications, lifestyle interventions, CHD treatments and arrhythmia-specific therapy (Table 1).

Table 1 Staff requirements of a specialized congenital heart centre.

Paediatric cardiologist or adult cardiologist with congenital certification
Congenital imaging specialist (echocardiography, CMR, CT)
Congenital invasive cardiologist
CHD surgeon
Anaesthesiologist with CHD experience and expertise
Invasive electrophysiologist with adult CHD experience
Psychologist
Social worker

CHD: congenital heart disease; CMR: cardiac magnetic resonance; CT: computed tomography.

Type and level of activity

An inverse correlation between the number of complex ablation procedures performed at an electrophysiology centre and the rate of complications has been confirmed by many studies [23—26], including in children [27,28]. Although not reported formally as yet in the field of invasive electrophysiology, this is highly probably true for patients with GUCHD, also because referral to specialized adult CHD care has been shown to be independently associated with a significant reduction in mortality, particularly for patients with moderate or severe CHD [29]. Thus, centres performing interventional electrophysiological procedures, including ablations in adults with CHD and in children, must maintain a minimum level of activity to ensure appropriate quality of care.

Because of the paucity of affected patients, and because of the lack of French recommendations, national registries and databases, it is probably unreasonable to set a minimal threshold for yearly ablation procedures in adults with CHD or in children per centre. Therefore, regarding the specificity of some of these patients and the complexity of their management, most procedures — and especially the complex ones — should be performed in centres specialized in both paediatric patients (with or without CHD) and

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adults with CHD. These centres should not only provide a specialized electrophysiology team, but also an appropriate environment for managing some potentially complex cases.

However, to ensure sufficient expertise and accreditation, the centre should have a minimal yearly activity in ''standard'' ablations (common atrial flutter or reciprocating supraventricular tachycardia $\geq$ 100) and ''complex'' ablations (left atrial tachycardia/fibrillation $\geq$ 100; ventricular arrhythmias $\geq$ 30) [30] in patients with and without structural heart disease. Although some simple ablation of atrial or supraventricular tachycardia in patients with simple GUCHD (i.e. right atrial tachycardia or common flutter after surgical closure of isolated ostium secundum ASD) may be performed in centres commonly certified for standard ablation, a consultation with an adult CHD specialist should be sought before invasive electrophysiological interventions [11,20—22]. Any other ablation in patients with ''simple'' or ''moderate'' cardiac defects should be performed by centres commonly certified for complex ablations [30], while even more complex ablations (either supraventricular or ventricular) in ''complex'' cardiac defects (i.e. univentricular hearts or atrial switch for transposition of the great vessels) should be optimally managed by specialized centres involved in the management and surgery of these specific populations (Table 2). Moreover, although a minimal number of ablation procedures cannot be formally fixed, centres willing to perform ablations in adults with CHD and in children should manage a significant population of adults with CHD and children in order to achieve a reasonable number of procedures per year.

For young children (weighing < 40 kg) with or without congenital defects, centres should have recognized expertise [2], and should consistently perform several cases a year over a sufficient time period. For ablation in older children without CHD, especially teenagers, sufficient expertise and activity in ablation of standard supraventricular tachycardia in adults is required (see above), although it is reasonable to allow such procedures to be performed in centres commonly certified for complex ablations [30] (see Table 2).

Finally, in particular cases of highly specialized centres managing only adults with CHD and children, but lacking activity in ablation in adults without CHD (as required above), the presence of physician(s) who otherwise have solid experience in complex ablation procedures (as described previously [30]) may be an acceptable possibility.

Centres that do not achieve and maintain these activity levels and environments should be questioned about their ability and legitimacy to continue performing ablation procedures in adults with CHD and in children if a sufficient increase is not expected soon, despite the growing patient population.

Each centre should accommodate a sufficiently large local population to reach these thresholds, and the existence of several centres with inadequate referral in the same geographical area should be avoided. In a situation where several centres in the same geographical area would not each have a sufficient number of patients, gathering of the activities at one site is strongly recommended.

As interventional electrophysiological therapy in adults with CHD and in children may involve pacemaker or defibrillator implantation/control and resynchronization therapy, centres performing ablations in patients with GUCHD and in children should also be experienced in these techniques and especially in these populations. It seems reasonable, therefore, to state that centres performing these types of ablations should also implant a sufficient number of such devices ($\geq$ 300—350 devices per year, including a significant number in adults with CHD or in children, according to the population involved).

Medical staff

Invasive electrophysiological procedures in adult CHD or paediatric settings should be performed by electrophysiologists with expertise in adult CHD or children, and within an environment suitable for CHD or paediatric patient care. In the absence of formally trained adult CHD and paediatric electrophysiologists, close collaborations between adult electrophysiologists and paediatric cardiologists or adult CHD specialists may be required to deliver high-quality care to adults with CHD and arrhythmias. The medical staff requirements of a specialized congenital heart centre for performing ablation in adults with complex congenital cardiac defects or in young children have been listed in Table 1.

As for complex ablation procedures [30], electrophysiological physicians willing to perform ablation in adults with CHD or in children should have completed specialist cardiology training (cardiovascular Diplôme d'Études Spécialisées [DES]) or have an equivalent accepted foreign certification. Ideally, they should also have passed the theoretical and practical examinations in cardiac arrhythmias and pacing set by the Inter-University Board of Cardiac Electrophysiology and Pacing (Diplôme Inter-Universitaire [DIU] de Rythmologie et Stimulation Cardiaque) or have an equivalent certification (for instance, EHRA certification).

To perform such procedures as a principal operator, the French Working Group of Pacing and Electrophysiology feel that it is further recommended to have fulfilled the remaining conditions required for performing complex ablations [30]: to have gone through an international or national fellowship (for instance, EHRA fellowship), i.e. to have $\geq$ 1 year of specific full-time practical training in interventional electrophysiology in a teaching centre, and to have acted as a principal operator in a sufficient number of complex ablation procedures in recent years.

Furthermore, with the exception of the oldest children and simple adult CHD (Table 2), experience and knowledge in paediatric cardiology and CHD are also mandatory and, ideally, electrophysiologists involved in such procedures are encouraged to pass the theoretical and practical examinations set by the Inter-University Board of Paediatric and Congenital Heart Disease (DIU de Cardiologie Pédiatrique et Congénitale) or have an equivalent foreign certification. At least, coordinated discussion and planning of the case with a CHD specialist on site or from a specialized centre is mandatory. Adequate experience in pacemaker or implantable cardioverter defibrillator implantation or programming in children is also mandatory.

We recommend that at least two trained electrophysiological operators are present locally, although both are not necessarily required in the electrophysiological laboratory for part or all of the procedure duration.

For ablation of arrhythmogenic substrates located in the left cardiac chambers in patients without cardiac

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Table 2 Recommendations regarding centre competencies: required expertise levels for each situation.

Type of ablation/population	Required competencies
Supraventricular tachycardia, WPW syndrome, common atrial flutter in healthy children weighing > 40 kg	Centres commonly certified for complex ablations [30], with paediatric environment
Any ablation in children weighing < 40 kg	Specialized congenital heart centres
Atrial or supraventricular ablation in simple adult CHD (Bethesda classification) (i.e. ostium secundum ASD) [13]	Centres commonly certified for standard ablations [30]
Atrial, supraventricular or ventricular ablation in moderate adult CHD or ventricular ablation in simple adult CHD (Bethesda classification) [13]	Centres commonly certified for complex ablations [30], with dedicated congenital environment
Any ablation in complex GUCHD (Bethesda classification) [13]	Specialized congenital heart centres

ASD: atrial septal defect; CHD: congenital heart disease; GUCHD: grown-up congenital heart disease; WPW: Wolff-Parkinson-White.

discordance, physicians should be specifically trained in transseptal and retrograde transaortic accesses. It should be pointed out that vascular and transseptal accesses may be especially difficult in patients with operated CHD, thus highlighting the potential utility of vascular ultrasound or transoesophageal/intracardiac echocardiography, which should be available when needed. Transseptal puncture in patients with previous percutaneous ASD closure may also be difficult, and should only be performed by the most experienced operators, with the help of physicians involved in ASD closure, when needed. In patients with atrial switch or with intra- or extracardiac conduits, transseptal puncture through conduits or baffles may be needed, and physicians should be ready to perform these accesses. Occasionally, percutaneous transhepatic access may be necessary when no other access to the systemic atrium is available [31], and physicians should be ready to perform this technique under fluoroscopic and ultrasound guidance. In these situations and in all complex cases, patients must be referred to a specialized congenital heart centre with an adapted environment.

Particular knowledge of CHD or collaboration with cardiopaediatricians is mandatory for carrying out ablation procedures in adults with CHD or in children, which may include multidisciplinary decisions with the assistance of experts in congenital disease and imaging at any time, and with surgical/intensive care departments experienced in the management of adults with CHD or children, and adapted to the relevant population.

Specific training in the use of radiation in children or in adults exposed to increasing amounts of low-dose ionizing radiation is mandatory in any situation [2]. The clinical application of the 'Justification' and 'Optimization' principles of ALARA (as low as reasonably achievable) must be applied in this specific population of children and adults with CHD (see below).

Paramedical staff

The requirements regarding the attendance and training of nursing staff for ablation procedures involving adults with CHD are the same as those applicable to diagnostic electrophysiological procedures or complex ablation procedures [30,32], together with special experience for complication management. As with other ablation procedures, nurses involved in ablation are encouraged to register with the Inter-University Board of Cardiac Electrophysiology and Pacing for Allied Professionals (Diplôme Universitaire de Rythmologie Interventionnelle pour le Personnel Paramedical) or have an equivalent foreign certification. Nevertheless, even for performing simple ablation in children, experience in paediatric management, in terms of nursing, anaesthesia or sedation, is mandatory for paramedical staff.

According to the legislation defining the technical conditions applicable to interventional cardiac procedures [32], at least two trained paramedical assistants, including at least one nurse, should be present during the procedure. For procedures in children, two nurses are mandatory.

Facilities and technical equipment

The electrophysiological equipment requirements are the same as those described for standard or complex catheter ablation, with an electrophysiological recorder system including $\geq$ 12 surface electrocardiogram leads, a sufficient number of intracardiac channels and invasive pressure-recording channels. The electrophysiology laboratory and postprocedure recovery unit should be suitable for the care of adults with CHD or children. Hospitalization units must be adapted to the age of the patient.

Three-dimensional (3D) electroanatomical navigation systems should be available in the electrophysiological laboratory, even in centres wiling to perform simple right atrial tachycardia ablations after ASD closure. Experience in manoeuvring and using the 3D mapping system is required for physicians, but they can receive help from specialized technicians from the manufacturers or trained paramedical staff. Even in centres that mainly use cryoablation for accessory pathways, AV node reentrant tachycardia or atrial fibrillation, solid experience in radiofrequency and 3D mapping systems is mandatory. In addition, the staff must have a thorough knowledge of ablation energy delivery systems — either radiofrequency or cryoablation — while dedicated catheters must be available in sufficient numbers, types and sizes to complete any procedure, especially in young children [2]. Remote magnetic navigation may be of additional

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value in patients with complex CHD [33], although this is rarely available in most centres.

Fluoroscopy equipment must offer the possibility of multiple views, with sufficient imaging quality and maximal radiation dose reduction (ALARA), without compromising safety and procedure outcome [13], allowing pulsed fluoroscopy, lower frame rate, collimators, limiting magnification, stored angiography and single-plane imaging. Contrast injectors and image/movie storage capacities should be available. Dose reduction should be maximal for children, concomitant with the use of non-fluoroscopic techniques when possible and suitable [2], and avoiding pre-procedural imaging using radiation. Only modern fluoroscopy systems with the lowest available radiation doses should be used in children.

The application of the ALARA principle, aiming to reduce ionizing radiation for patients, physicians and staff to the lowest levels, is mandatory in adults with CHD and in children. Nonetheless, young patients — and particularly children — are more sensitive to ionizing radiation, and a longer life expectancy increases the risk of lifetime radiation-induced cancer in this population. Adults with CHD are likely to undergo several fluoroscopy-guided cardiac haemodynamic/electrophysiological procedures or computed tomography scans during their follow-up, leading to an accumulation of radiological exposure and a higher potential for long-term radiation-induced cancer. Systematic dose reporting and long-term monitoring are therefore mandatory in this population.

Electroanatomical mapping (3D systems) allows a reduction of catheter ablation fluoroscopy time in adults with CHD and in children. Regarding the above-mentioned data, the Working Group strongly recommends the use of electroanatomical mapping for complex ablation procedures in adult CHD and paediatric populations [2].

Readily accessible comprehensive logs/files of all ablation procedures must be kept. Continuous evaluation of the results should be part of the learning process in centres performing complex ablations. Ideally, such centres should have academic counterparts and activity.

Complications and their management

Complications that may occur during or after ablation procedures in patients with GUCHD or in children are the same as for other procedures, and may include pericardial effusion/tamponade, stroke, transient ischaemic attack, pulmonary vein stenosis, atrial oesophageal fistulae, phrenic nerve palsy, air embolism, valve damage, catheter entrapment, inappropriate sinus tachycardia, atrioventricular block, gastric hypomotility, perioesophageal vagal nerve injury, acute coronary artery occlusion/stenosis, venous thrombosis and pulmonary embolism, radiation exposure hazard and local complications at vascular access [34]. Centres performing such ablations should be able to diagnose, monitor and manage these complications according to current guidelines [34], with special attention paid to recognizing evocative symptoms during or after the first weeks following the procedure [34]. Specific complications related to patients with GUCHD may also include worsening of cyanosis after transbaffle/conduit puncture or pulmonary hypertension, sometimes requiring specific management and close follow-up [3].

Supplemental hospital-based resources

Anaesthesia

Invasive electrophysiological interventions in adults with moderate or complex CHD that require conscious sedation or general anaesthesia should be performed in collaboration with an anaesthesiologist familiar with adult CHD or paediatric patients [11,35].

General anaesthesia is mandatory for performing ablation in children [36], and even if not systematically required, general anaesthesia or deep sedation may also be used for interventional electrophysiological procedures in adults with CHD because of pain, stress, haemodynamic impairment, risk of movement (leading to shifts in the 3D maps), discomfort or long duration of procedure.

The choice of anaesthesia in these situations should be determined by institutional preference and the patient's suitability for conscious sedation [34]. Although we feel that general anaesthesia can be proposed in complex atrial ablation procedures when needed, it probably should not be performed for reciprocating supraventricular tachycardia, idiopathic ventricular arrhythmias or premature ventricular beats when possible, where lack of sedation may facilitate determination of procedure endpoints and long-term success rates [37]. General anaesthesia may also increase morbidity and mortality during ablation of ventricular tachycardia, and should be carefully discussed in patients with severely compromised left ventricular function, because this can result in acute haemodynamic compromise during the ablation procedure; its use needs to be carefully considered in these patients [37]. In case of a procedure performed under conscious sedation, the presence of an ''on demand'' anaesthesiologist in the hospital is mandatory in order to perform deep sedation/anaesthesia as soon as needed or in the event of a complication. For anaesthesiologists involved in ablation procedures in adults with CHD or in children, special knowledge and training in CHD and paediatric cardiology are mandatory, adapted to the relevant population. Ideally, they should also have passed the theoretical and practical examinations in Anaesthesia and Reanimation in Congenital Heart Disease set by the Inter-University Board of Resuscitation of Congenital Heart Disease (DIU de Réanimation Chirurgicale des Cardiopathies Congénitales).

Surgical back-up

As major complications may occur during or after cardiac ablation, sometimes requiring urgent cardiothoracic or vascular surgery, surgical coverage must be available immediately if needed. The risk of tamponade requires the ability to proceed with percutaneous pericardial drainage at any time during or after the procedure. The electrophysiological physician should therefore be familiar with this technique. Furthermore, surgical pericardial drainage by a surgeon [30] with knowledge of congenital cardiac surgery or children on stand-by in the medical centre should be available at any time during and after the procedure. In

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centres without on-site cardiac surgeons, procedures should be restricted to patients without open-heart surgery history, for whom urgent pericardiectomy could be challenging. Special knowledge of paediatric heart surgery or CHD surgery is mandatory, and needs to be adapted to the population in question.

Intensive care

A cardiac intensive care/resuscitation unit in the vicinity of the interventional electrophysiological laboratory is essential for monitoring patients after complicated procedures, if required. Physicians should be experienced in the management of CHD, adapted to the relevant population. Resuscitation equipment and physicians devoted to adults with CHD and to children of any age should be available at all times. Help from an electrophysiological physician should be also available whenever needed.

For children aged < 15 years, a paediatric environment is mandatory (hospitalization, intensive care and monitoring).

Haemodynamic assistance

For performing complex ablations in very sick patients (i.e. VT ablations in moderate or complex CHD), centres and teams must be familiar with haemodynamic assist device implantation (e.g. extracorporeal membrane oxygenation [ECMO] or Impella™ [Abiomed Inc., Danvers, MA, USA]) [30], either as planned haemodynamic support before the ablation [38] or as an emergency salvation procedure because of refractory arrhythmias, cardiogenic shock or electromechanical dissociation related to the procedure [39]. Even if there are no similar data available for children or patients with GUCHD, is seems reasonable to extend these recommendations to the CHD and paediatric populations.

A neurological emergency department and adequate neurological imaging should be available at any time for the management of stroke or cerebral haemorrhage occurring during or after the ablation procedure, with the availability of any required therapy (e.g. percutaneous vascular desobstruction). If there is no on-site stroke centre, protocols — planned in collaboration with the stroke centre — should be in place.

Imaging and image integration

Cardiac imaging has become mandatory before, during and after ablation procedures. Increased use of imaging to provide preinterventional information not only potentially reduces fluoroscopy time, but also increases safety and ablation success rates, even if preprocedural imaging using radiation-based techniques should be avoided when possible in children. Fluoroscopy is still necessary during most ablation procedures, but fluoroscopy time and radiation dose should be minimized as much as possible, especially in children, while maintaining reliability and navigation safety (see above). Thus, the use of non-fluoroscopic navigational mapping systems to guide the ablation procedure is strongly recommended [2], and is even mandatory in centres performing ablations in adults with CHD and in children. However, electrophysiological physicians should be able to perform some of these procedures using fluoroscopy only (e.g. accessory pathways or AV node reentrant tachycardia), as non-fluoroscopic systems are currently not formally required for this, are probably useless and are not cost-effective.

Transthoracic echocardiography should be available at any time to monitor complications, such as tamponade. Transoesophageal echocardiography is mandatory before ablations of left atrial arrhythmias to rule out a left atrial thrombus [33]. Transoesophageal echocardiography should therefore be available before — or at the beginning of — each procedure in centres that perform such ablations in the oldest children or in adults with CHD, with specific operator experience in CHD.

The use of cardiac computed tomography and magnetic resonance imaging for delineating anatomy, scars, fibrosis or complications has increased dramatically in recent years [40]. According to the current consensus statement [41], a computed tomography scan may replace magnetic resonance imaging in some patients with pacemakers/implantable cardioverter defibrillators that are not compatible with magnetic resonance imaging [40]. Recent technical innovations have substantially reduced radiation exposure during computed tomography scans [40]. The use of these imaging techniques should therefore be encouraged when needed, and they should be available at any centre dealing with ablations in patients with congenital heart defects. Finally, coronary angiography must be available at any time in the electrophysiological laboratory when there is a suspicion of coronary artery complications, especially for accessory pathway and ventricular arrhythmia ablation.

Table 3 Summary of the resources needed in centres willing to perform ablation in patients with grown-up congenital heart disease or in children.

Paediatric cardiologist or adult cardiologist with congenital certification
Congenital imaging specialist (echocardiography, CMR, CT)
Congenital invasive cardiologist
CHD surgeon
Anaesthesiologist with CHD experience and expertise
Invasive electrophysiologist with adult CHD experience
Experience in pacemaker or defibrillator implantation/control and resynchronization therapy in both adult CHD and paediatric populations
Paramedical staff with experience in electrophysiological procedures or complex ablation procedures, and paediatric management
Electrophysiological laboratory and postprocedure recovery/hospitalization units suitable for adults with CHD or children
Three-dimensional electroanatomical navigation systems and dedicated catheters for paediatric use available in the electrophysiological laboratory
Fluoroscopy equipment with sufficient imaging quality and maximal radiation dose reduction

CHD: congenital heart disease; CMR: cardiac magnetic resonance; CT: computed tomography.

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A summary of the resources needed in the centres willing to perform ablation in patients with GUCHD or in children is shown in Table 3.

Quality evaluations and national registries

Scientific advances and technological improvements in paediatric and congenital electrophysiological interventions come with associated responsibilities to ensure that these costly therapies result in high-quality care and low complication rates. National registries should be developed in the field of such ablations to allow quality evaluations [42,43]. Use of electronic medical records and participation in electrophysiological national registries are thus strongly encouraged, and may become mandatory. The development of quality controls in electrophysiology may be done by experts under the academic supervision of the French Working Group of Pacing and Electrophysiology and the Affiliate Group of Paediatric and Adult Congenital Cardiology of the French Society of Cardiology.

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Disclosure of interest

The authors declare that they have no competing interest.

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